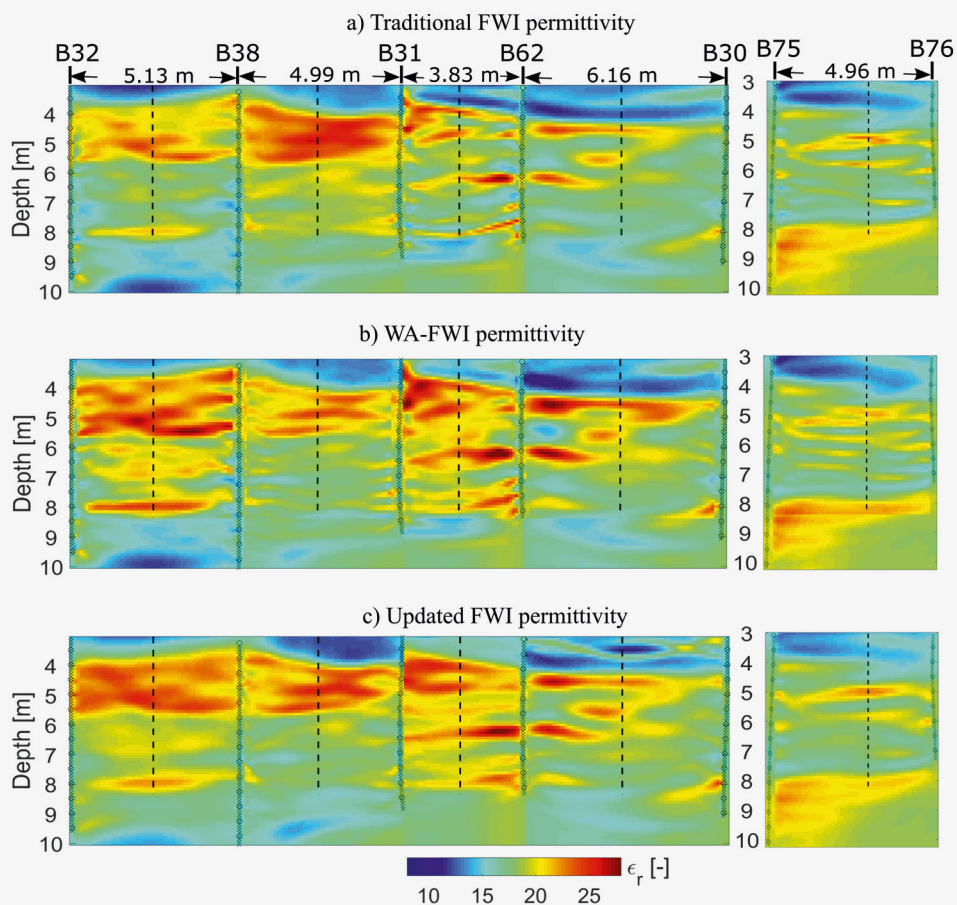




Enhanced crosshole GPR full-waveform inversion to improve aquifer characterization

Zhen Zhou

Energie & Umwelt / Energy & Environment

Band / Volume 512

ISBN 978-3-95806-500-0

Forschungszentrum Jülich GmbH
Institut für Bio- und Geowissenschaften
Agrosphäre (IBG-3)

Enhanced crosshole GPR full-waveform inversion to improve aquifer characterization

Zhen Zhou

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 512

ISSN 1866-1793

ISBN 978-3-95806-500-0

Contents

Abstract.....	I
Zusammenfassung	III
Chapter 1 Introduction.....	1
Chapter 2 Theory.....	11
2.1 MAXWELL’S EQUATIONS OF ELECTRODYNAMICS	11
2.2 RAY-BASED METHODS	13
2.3 FULL-WAVEFORM INVERSION.....	15
2.3.1 Pre-processing	15
2.3.2 Forward Problem.....	17
2.3.3 Source wavelet estimation and correction	17
2.3.4 Inversion algorithm	18
2.3.5 Implementation details.....	20
Chapter 3 3D aquifer characterization of the Hermalle-sous-Argenteau test site using crosshole GPR amplitude analysis and full-waveform inversion¹	23
3.1 FIELD SITE AND GPR MEASUREMENT SETUP	24
3.2 GPR AMPLITUDE ANALYSIS RESULTS.....	26
3.2.1 Amplitude analysis approach	26
3.2.2 Detailed analysis for crosshole plane Pz10-Pz13	27
3.2.3 Amplitude analysis for all measurement planes	30
3.3 FULL-WAVEFORM INVERSION RESULTS	32
3.3.1 Full-waveform inversion method	32
3.3.2 Short distance boreholes	32
3.3.3 Starting model test for waveguide zones	34
3.3.4 Combined FWI results of the Hermalle-sous-Argenteau.....	39
3.4 PETROPHYSICAL INTERPRETATION	45
3.5 CONCLUSIONS AND OUTLOOK	47
Chapter 4 Improvement of GPR Full-waveform inversion images using Cone Penetration Test data¹	49

4.1 UPDATING WAVELET USING AMPLIFIED FWI.....	50
4.1.1 Wavenumber filter	50
4.2 SYNTHETIC CASE STUDIES	53
4.2.1 Stochastic aquifer models	53
4.2.2 Conventional FWI	57
4.2.3 Construction of the wavenumber filter	57
4.2.4 Updating effective source wavelet and FWI	61
4.3 EXPERIMENTAL GPR DATA STUDIES.....	65
4.4 CONCLUSIONS AND OUTLOOK	74
Chapter 5 Improvement of crosshole GPR FWI results by using progressively expanded bandwidths of the data¹	75
5.1 NOVEL PEBDD FULL-WAVEFORM INVERSION SCHEME	76
5.2 SYNTHETIC CASE STUDIES	78
5.2.1 Synthetic case study I: Stochastic input models and ray-based starting models	78
5.2.2 Synthetic case study II: Permittivity starting model beyond the half-wavelength criteria.....	86
5.3 EXPERIMENTAL GPR DATA STUDIES.....	92
5.4 CONCLUSIONS.....	98
Chapter 6 Conclusions and Outlook	99
6.1 CONCLUSIONS.....	99
6.2 OUTLOOK.....	103
6.2.1 Improvement of starting models by applying ADIC	103
6.2.2 Improvement of FWI results by using staining algorithm	104
Appendix A Corrigendum to “Imaging and characterization of facies heterogeneity in an alluvial aquifer using GPR full-waveform inversion and cone penetration tests”¹	105
Appendix B Improved resolution of ground penetrating radar full-waveform inversion by using cone penetration test data: A synthetic study¹	107
B.1 INTRODUCTION	107
B.2 STOCHASTIC SIMULATION MODEL STUDY	108
B.3 FULL-WAVEFORM INVERSION RESULTS.....	110
B.4 WAVENUMBER INFORMATION IN RAY-BASED, FWI AND CPT	110

B.5 WAVENUMBER FILTER ESTIMATION USING CPT DATA.....	112
B.6 UPDATING EFFECTIVE SOURCE WAVELET BASED ON WA-FWI RESULTS.....	112
B.7 CONCLUSIONS	115
Acknowledgments	117
Bibliography.....	119
List of Figures	131
List of Tables.....	133
Curriculum Vitae.....	135

Energie & Umwelt / Energy & Environment
Band / Volume 512
ISBN 978-3-95806-500-0