CONTENTS

Acknowledgement	c
Abstract in Thai	d
Abstract in English	f
List of Tables	j
List of Figures	k
List of Abbreviations	S
Chapter 1 Introduction	1
1.1 Data availability in study area	3
1.1.1 Seismic data	3
1.1.2 Deterministic pre-stack inversion	7
1.1.3 Well data	7
1.2 Literature review	9
1.3 Objectives of the current study	10
Chapter 2 Methodology	11
2.1 Theoretical background	11
2.1.1 Geostatistics	11
2.1.2 Bayesian inference	12
2.1.3 Geostatistical inversion algorithm	14
2.2 Geostatistical inversion workflow	17
2.2.1 Well data conditioning	17
2.2.2 Seismic-to-well tie and wavelet extraction	18
2.2.3 Building the solid model	19
2.2.4 Geostatistical model fitting	20
2.2.5 Simulation	22
2.2.6 Inversion	22

Chapter 3 Data preparation and seismic-to-well tie results	24
3.1 Well log data conditioning	24
3.2 Shear velocity prediction	27
3.3 Rock-physics analysis	31
3.4 Seismic-to-well tie and wavelet extraction	33
Chapter 4 Inversion parameters testing	39
4.1 Solid model building	40
4.2 Geostatistical model fitting	41
4.3 Simulation parameters testing	47
4.4 Inversion parameters testing	53
Chapter 5 Geostatistical inversion results	71
5.1 Geostatistical inversion results	72
5.2 Comparison of deterministic and geostatistical inversion	85
5.3 Blind well testing	93
Chapter 6 Discussions and conclusions	96
References	
TAI UNIVER	
Appendix	103
Appendix A	103
Appendix B	113
Curriculum vitae rights reserved	121

LIST OF TABLES

Table 3.1	Summary of lithology types for final discrete property set	31
Table 3.2	Summary of the correlation coefficients at each well, using	37
	the final time-depth relationships.	
Table 4.1	Stratigraphic layers that were used in the solid model building	40
	process	
Table 4.2	Simulation settings for discrete and continuous variogram	47
	tests	
Table 4.3	Summary of inversion parameter settings for variogram, PDF,	55
	input gather, and seismic S/N ratio test	
	AT UNIVERSIT	
8	้อางห่างการ์การ์การ์การ์การ์การ์การ์การ์การ์การ์	

Copyright[©] by Chiang Mai University All rights reserved

LIST OF FIGURES

Page

Figure 1.1	a) Map showing the location of Arthit Field in the Gulf of	2
	Thailand. b) AOI for 3D seismic pre-stack geostatistical inversion	
	study (red polygon) and deterministic inversion study (blue	
	polygon).	
Figure 1.2	Stratigraphic column of the North Malay Basin (PTTEP	3
	unpublished report).	
Figure 1.3	The left picture shows a regional time map across the Arthit Field,	4
	covered by 4000 km2 of 3D seismic data. The blue boundary	
	indicates the area included in seismic preconditioning and	
	deterministic inversion in 2016 (150 km2). The right picture	
	shows a detailed map of areas input to a deterministic inversion	
	study in 2016 (blue), the geostatistical inversion study area	
	considered in this thesis (red), and locations of key input wells (A	
	to E) in the area.	
Figure 1.4	Seismic arbitrary line passing through all input wells for angle	5
0	stack 1 (near), angle stack 2 (near mid), angle stack 3 (mid) and	
ĉ	angle stack 4 (far).	
Figure 1.5	Figure 1.5. a) Before Q-Wave amplitude correction. b) After Q-	6

Figure 1.5 Figure 1.5. a) Before Q-Wave amplitude correction. b) After Q-Wave amplitude correction. The application of Q-Wave reduced the effect of unwanted lateral amplitude variations caused by near-surface amplitude anomalies in this area.

k

Figure 1.6 Figure 1.6. A time misalignment correction was applied to		6
	near, mid and far angle stacks, using the near-mid angle stack as	
	a reference, resulting in improved angle-gather flatness.	
Figure 1.7	Time structural map overlaid with all input wells considered in	8
	this study.	
Figure 2.1	Variogram features, including type, range, sill, and nugget.	12
Figure 2.2	Schematic representation of how the posterior PDF is built in	13
	Markov Chain Monte Carlo (MCMC) (from MCMC, Jason	
	software manual, release 8.4).	
Figure 2.3	The PDF of each input source is shown as a circle. The target	14
	posterior pdf we are interested in is shown in black as the	
	intersection of all input PDFs.	
Figure 2.4	Simplified schematic describing the customized MCMC	16
	algorithm used for geostatistical inversion (from MCMC, Jason	
	software manual release 8.4).	
Figure 2.5	Well tie and wavelet extraction workflow.	19
Figure 2.6	Example models for stratigraphic layers (from Jason software manual).	20
Figure 2.7	Examples of a multidimensional joint distribution generated from	21
	well log data: (left) Vp-Density joint PDF (2D histogram) derived	
ລິ	from 1D sample histogram, (right) 3D joint PDF of acoustic	
CI CI	properties: Vp, Vs, and density (from Jason software training	
C	manual). By Chiang Mai University	
Figure 2.8	Exponential and Gaussian variograms (Bohling, 2007).	21
Figure 2.9	Schematic representation of the input and output data related to	23
	the geostatistical inversion process (modified from Jason workflow).	
Figure 3.1	Complete set of well log data (measured and edited) for well-A	25

and well-B.

Figure 3.2	Complete set of well log data (measured and edited) for well-C	25
	and well-D.	
Figure 3.3	Vp vs. density (ρ) cross-plot for Well-B, original logs (left) and	26
	final logs after editing (right).	
Figure 3.4	Vp vs. density (ρ) cross-plot for Well-C, original logs (left) and	26
	final logs after editing (right).	
Figure 3.5	Vp vs. Vs cross-plot for Well-B, before depth shift (left) and after	27
	depth shift (right).	
Figure 3.6	Vp vs. Vs cross-plot for Well-C, before depth shift (left) and after	27
	depth shift (right).	
Figure 3.7	Cross-plot of measured vs. predicted shear-sonic velocity for	28
	Well-B and Well-C.	
Figure 3.8	Comparison of measured shear-sonic velocity (black line) and	29
	predicted shear-sonic velocity (red line) for Well-B (left) and	
	Well-C (right).	
Figure 3.9	Predicted Vs for Well-A and cross-plot of measured Vp versus	30
	predicted Vs.	
Figure 3.10	Predicted Vs for Well-D and cross-plot of measured Vp versus	30
	predicted Vs.	
Figure 3.11	Matrix cross-plot of elastic properties, color-coded by original	32
	lithology types.	
Figure 3.12	Matrix cross-plot of elastic properties, color-coded by the final	32
C	lithology types to be considered in this study.	
Figure 3.13	Wavelet polarity convention of the seismic input data, in this case	33
A	reverse polarity ("European polarity").	
Figure 3.14	Wavelets extracted from each well, showing relatively stable	34
C	wavelets at Well-A, -B and –D, while the extracted wavelets for	
	Well-C were of poor quality.	
Figure 3.15	Multi-well wavelets for each angle stack, used as inputs to	35
0	deterministic inversions.	

Figure 3.16	Well-to-seismic tie for Well-B showing the tie at the near angle stack (0-12°).	35
Figure 3.17	Well-to-seismic tie for Well-B showing the tie at the near-mid angle stack (8-20°).	36
Figure 3.18	Well-to-seismic tie for Well-B showing the tie at the mid angle stack (16-28°).	36
Figure 3.19	Well-to-seismic tie for Well-B showing the tie at the far angle stack (24-36°).	37
Figure 3.20	Figure 3.20 The comparison between original checkshot and final time:depth relationship of Well-A, Well-B and Well-D.	38
Figure 4.1	Geostatistical inversion testing area (approximately 14 km2) covering Well-B and Well-C.	40
Figure 4.2	The solid model used for geostatistical modelling and inversion.	41
Figure 4.3	1D PDF (prior proportion) for discrete property (facies) in reservoir 1 (H30) and reservoir 2 (H37) layers.	42
Figure 4.4	A matrix cross-plot showing fitted continuous PDFs of each property in Reservoir 1 (H30). Measured data are represented by points and PDFs are represented by ellipses.	42
Figure 4.5	A matrix cross-plot showing fitted continuous PDFs of each property in Reservoir 2 (H30). Measured data are represented by points and PDFs are represented by ellipses.	43
Figure 4.6	Vertical and lateral variogram fitting for discrete properties in Reservoir 1 (H30).	44
Figure 4.7	Vertical and lateral variogram fitting of discrete properties in Reservoir 2 (H37).	44
Figure 4.8	Vertical and lateral variogram of shale continuous properties in Reservoir 1.	45
Figure 4.9	Vertical and lateral variogram of sand continuous properties in Reservoir 1.	45

n

- Figure 4.10 Vertical and lateral variogram of shale continuous properties in 46 Reservoir 2.
- Figure 4.11 Vertical and lateral variogram of sand continuous properties in 46 Reservoir 2.
- Figure 4.12 Comparison of prior and posterior proportions (1D PDF) of each 48 lithology in reservoir 1 (H30) and reservoir 2 (H37).
- Figure 4.13 Statistical comparison between prior and posterior for all 49 lithologies generated by simulation model 1 (long-range variogram).
- Figure 4.14 Statistical comparison between prior and posterior for all 50 lithologies generated by simulation model 2 (medium-range variogram).
- Figure 4.15 Statistical comparison between prior and posterior for all 51 lithologies generated by simulation model 3 (short-range variogram).
- Figure 4.16 Lithofacies section simulated from model 1 (long-range 52 variogram) passing through Well-B and -C.
- Figure 4.17 Lithofacies section simulated from model 2 (medium-range 52 variogram) passing through Well-B and -C.
- Figure 4.18 Lithofacies section simulated from model 3 (short-range 53 variogram) passing through Well-B and -C.
- Figure 4.19 Comparison of prior and posterior proportions of each lithology 56 in Reservoir 1.
- Figure 4.20 Comparison of prior and posterior proportions of each lithology 56 in Reservoir 2.
- Figure 4.21 Arbitrary sections of lithofacies (above) and P-impedance (below) 57 generated from inversion Test 2 (long-range variogram).
- Figure 4.22 Arbitrary sections of lithofacies (above) and P-impedance (below) 58 generated from inversion Test 5 (short-range variogram).
- Figure 4.23 Arbitrary sections of lithofacies (above) and P-impedance (below) 59 generated from inversion Test 9 (decreased S/N).

Figure 4.24	Arbitrary sections of lithofacies (above) and P-impedance (below)	60
	generated from inversion Test 12 (decreased prior sand proportion).	
Figure 1 25	Arbitrary sections of lithofacies (above) and P impedance (below)	61
11guie 4.25	apparented from inversion Test 16 (modified prior coal DDE)	01
F' 4.04	generated from inversion fest to (modified pror coar PDF).	60
Figure 4.26	Arbitrary sections of lithofacies (above) and P-impedance (below)	62
	generated from inversion Test 18 (modified prior sand PDF).	
Figure 4.27	Comparison of prior and posterior PDF of each lithology type	63
	generated from inversion Test 2 (long-range variogram).	
Figure 4.28	Comparison of prior and posterior PDF of each lithology type	64
	generated from inversion Test 5 (short-range variogram).	
Figure 4.29	Comparison of prior and posterior PDF of each lithology type	65
	generated from inversion Test 9 (decreased S/N).	
Figure 4.30	Comparison of prior and posterior PDF of each lithology type	66
	generated from inversion Test 12 (decreased prior sand	
	proportion).	
Figure 4.31	Comparison of prior and posterior PDF of each lithology type	67
	generated from inversion Test 16 (modified prior coal PDF).	
Figure 4.32	Comparison of prior and posterior PDF of each lithology type	68
	generated from inversion Test 18 (modified prior sand PDF).	
Figure 4.33	Synthetic and residual sections of near and near-mid angle stack	69
	generated from inversion Test 18.	
Figure 4.34	Synthetic and residual sections of mid and far angle stack	70
A	generated from inversion Test 18.	
Eigung 5 1	Constatistical inversion area accurring 85 km2 and arbitrary line	71
Figure 5.1	Geostatistical inversion area covering 85 km2 and arbitrary line	/1
	passing through four input wells.	
Figure 5.2	Geostatistical inversion results, including lithofacies, P-	74
	Impedance, Vp/Vs and density generated from inversion	

realization 3, with respective well log data superposed.

Figure 5.3	Geostatistical inversion results, including lithofacies, P-	75
	Impedance, Vp/Vs and density generated from inversion	
	realization 6, with respective well log data superposed.	
Figure 5.4	Geostatistical inversion results, including lithofacies, P-	76
	Impedance, Vp/Vs and density generated from inversion	
	realization 9, with respective well log data superposed.	
Figure 5.5	Geostatistical inversion results, including lithofacies, P-	77
	Impedance, Vp/Vs and density generated from mean of ten	
	realizations, with respective well log data superposed.	
Figure 5.6	Comparison of seismic near angle stack, synthetic and remaining	78
	residuals generated from realization 6.	
Figure 5.7	Comparison of seismic near-mid angle stack, synthetic and	78
	remaining residuals generated from realization 6	
Figure 5.8	Comparison of seismic mid angle stack, synthetic and remaining	79
	residuals generated from realization 6.	
Figure 5.9	Comparison of seismic far angle stack, synthetic and remaining	79
	residuals generated from realization 6.	
Figure 5.10	Horizon slices of seismic, probability and elastic properties (AI,	80
	Vp/Vs and density) along reservoir 1-1 (H30)	
Figure 5.11	Horizon slices of seismic, probability and elastic properties (AI,	81
	Vp/Vs and density) along reservoir 1-2 (H30)	
Figure 5.12	Horizon slices of seismic, probability and elastic properties (AI,	82
C	Vp/Vs and density) along reservoir 1-3 (H30)	
Figure 5.13	Horizon slices of seismic, probability and elastic properties (AI,	83
1	Vp/Vs and density) along reservoir 2-1 (H37)	
Figure 5.14	Horizon slices of seismic, probability and elastic properties (AI,	84
	Vp/Vs and density) along reservoir 2-2 (H37)	
Figure 5.15	Comparison of lithofacies sections from geostatistical inversion	86
	(above) and deterministic inversion (below).	
Figure 5.16	Comparison of P-Impedance sections from geostatistical	87
	inversion (above) and deterministic inversion (below).	

q

- Figure 5.17 Comparison of Vp/Vs sections from geostatistical inversion 88 (above) and deterministic inversion (below).
- Figure 5.18 Sand probability and lithofacies slices at Reservoir 1-1 layer 89 (H30) from deterministic (left) and geostatistical inversion (right).
- Figure 5.19 Sand probability and lithofacies slices at Reservoir 1-2 layer 90 (H30) from deterministic (left) and geostatistical inversion (right).
- Figure 5.20 Sand probability and lithofacies slices at Reservoir 2-1 layer 91 (H37) from deterministic (left) and geostatistical inversion (right).
- Figure 5.21Sand probability and lithofacies slices at Reservoir 2-2 layer92(H37) from deterministic (left) and geostatistical inversion (right).
- Figure 5.22 Lithofacies section overlaid with bind well. 94
- Figure 5.23 P-Impedance section overlaid with bind well. 94
- Figure 5.24 P-Impedance (AI) comparison among measured AI, inverted AI 95 from geostatistical inversion and inverted AI from deterministic inversion.



ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved

LIST OF ABBREVIATIONS

1D	One Dimensions
2D	Two Dimensions
3D	Three Dimensions
AI	Acoustic Impedance or P-Impedance
AOI	Area of Interest
AT90	Deep Resistivity
AVA	Amplitude Versus Angle
AVO	Amplitude Versus Offset
CDP	Common Depth Point
FM	Formation
GR 385	Gamma Ray
km	Kilometer
m	Meter
MCMC	Markov Chain Monte Carlo
MLR	Multi-Linear Regression
ms	Millisecond
NPHIE	Neutron Porosity
N-S	North-South
NW-SE	Northwest-Southeast
PDFCopyright	Probability Density Function
Phie	Effective Porosity
RC	Reflection Coefficient
Rho	Bulk Density
S/N	Signal to Noise Ratio
Sw	Water Saturation
T/D	Time-Depth Relationships

TWT	Two Way Travel Time
Vp	P-wave Velocity
Vp/Vs	P-wave Velocity over S-wave Velocity Ratio
Vs	S-wave Velocity
Vsh	Volume of Shale
VSP	Vertical Seismic Profile



ลิขสิทธิ์มหาวิทยาลัยเชียงใหม่ Copyright[©] by Chiang Mai University All rights reserved