

ROCK PHYSICS AS A TOOL FOR INTERPRETATION RISK REDUCTION AND RESERVOIR CHARACTERIZATION, TERTIARY SYSTEM, NORTH EL AMRIYA, OFFSHORE NILE DELTA, EGYPT

Presented By

Bassem Mabrouk Mohamed Ibrahim

(M.Sc. in Petroleum Geology)

A Thesis submitted for The Degree of Doctor of Philosophy of Science

Department of Geophysics, Faculty of Science, Ain Shams University

Supervisors

Prof. Dr. Said Abdel-Maaboud Aly

(Passed away in July, 2017)
Professor of Geophysics,
Geophysics Department,
Faculty of Science, Ain Shams University

Prof. Dr. Mohammed Shokry Mohammed Farag

Professor of Geophysics, Geophysics Department, Faculty of Science, Ain Shams University

Dr. Abdullah Mahmoud El-Sayed Mahmoud

Assist. Prof. of Geophysics, Geophysics Department, Faculty of Science, Ain Shams University Dr. Ali Mohammed Ali Bakr

Independent Regional Exploration Consultant



APROVAL SHEET FOR SUMISSION

Thesis Title: Rock Physics as a tool for interpretation risk reduction and reservoir characterization, Tertiary system, North El Amriya, offshore Nile Delta, Egypt.

Name of candidate: Bassem Mabrouk Mohamed Ibrahim

- **1. Prof. Dr.** Said Abdel-Maaboud Aly (Passed away in July, 2017)
- **2. Prof. Dr.** Mohammed Shokry Mohammed Farag **Signature:**
- **3. Dr.** Abdullah Mahmoud El-Sayed Mahmoud **Signature:**
- **4. Dr.** Ali Mohamed Ali Bakr **Signature:**

Prof. Dr. Sami Hamed Abd El-Nabi Chairman of Geophysics Department Faculty of Science - Ain Shams University

ACKNOWLEDGMENT

First foremost, I would like to thank Allah for all that I have been given.

There are many acknowledgments due to the fact that this thesis represents years of work which added value to my knowledge. However, I would like to start, with special thanks to a person who is not with us today, but hopefully he is in better place, within the hand of our merciful God, I would to thank **Prof. Dr. Said Abdel-Maaboud Aly**, Ex-chairman of geophysics department and the professor in the geophysics department in the faculty of science, Ain shams university, who passed away in 20th of July, 2017. Prof. Dr. Said was my primary supervisor when I started my thesis program in 2012. I can't (and I won't) forget Prof. Dr. Said's favors and his valuable and sincere advices. God forgive him and keep his soul clam in the upper paradise ISA.

The second thanks will be for one who was very patient and understandable to my job conditions and my travel period outside Egypt for several years, he was always encouraging and was source of inspiration and supported me in critical reading and reviewing and helped me so hard to bring my ideas alive on the written page. His partnership is invaluable to me. Thanks a lot **Prof. Dr. Mohammed Shokry Mohammed Farag.**

My great thanks and appreciation also for **Dr. Abdullah Mahmoud El-Sayed Mahmoud** for his support during my work in the thesis.

I'd like to express my deep thanks and sincere gratitude to my supervisor and my mentor in oil and gas industry **Dr. Ali Mohamed Ali Bakr**, for his supervision, scientific advices and valuing my work. Dr. Ali argued me into clarity on a number of issues and then wrote what I meant rather than what I said. His support and encouragement can't be forgotten.

I wish to express my sincere thanks and gratitude to my company Wintershall Dea BU Egypt for providing the opportunity to pursue my PhD degree and providing all the necessary facilities to carry out this PhD project. My deep gratitude starting from the senior vice president and managing director Eng. Sameh Sabry and my direct managers Achim Lehmann and Hesham Abu El-Saad for their support and enthusiastic encouragement which was always

gave me great eagerness and for their understanding about the thesis's work pressure.

It's worth to emphasize and show my deep thanks and appreciation to my previous Exploration managers in RWE Dea time namely; **Dr. Ali Gadallah** and **Sven Schaefer.**

Because this thesis reflects a lifetime of work, it is impossible to name and adequately express my appreciation to all the individuals who have shaped me and my ideas and values and who have energized me over the years, my great thanks to my current and ex. colleagues in Wintershall Dea BU Egypt, namely **Mahdy Mohamed, Khaled Ebied** and **Hoda Ayad**. Also great thanks to my colleague in Hamburg **Thomas Leythaeuser** for his help to get the needed approvals from Wintershall Dea board members for publishing the PhD paper.

My great appreciation and thanks to my colleagues **Dr. Shima El-Kholy** and **Islam Yehia** for their kindness, permanent support and encouragement during my work in the thesis.

My acknowledgment and salutation to Wintershall Dea partners **EGPC**, **EGAS** and **British Petroleum** (**BP**) for granting the needed approvals for the thesis study.

Any thanks words I can say can't show my gratitude towards **my mother** and my **mother in law** for their encouragement and continuous pray to accomplish this work, also my great gratefulness and thanks to **my brothers.**

My dedication to the soul of **my father** who taught me the meaning of life and to soul of my uncles (**Ibrahim**, **Ali** and **Ahmed**) and brother **Osama**.

Last but not least, Grateful and true appreciation are expressed to **my wife** "**Dalia**" and my lovely daughter "**Habiba**" for their true support, continuous help, great patience and encouragement.

LIST OF CONTENTS

Subject	Page
ACKNOWLEDGMENT	I
LIST OF CONTENTS	III
LIST OF FIGURES	IX
LIST OF TABLES	XXVII
LIST OF ABBREVIATIONS	XXVIII
LIST OF SYMBOLS	XXXII
ABSTRACT	XXXIII

Chapter. No.	<u>Subject</u>	Page
1	INTRODUCTION	1
1.1.	Introduction	2
1.2.	Highlights of the Study Area	2
1.2.1	Geographic Location	3
1.2.2	Study Area Bathymetry	3
1.3.	General Stratigraphic Framework in the Study area	4
1.4.	Exploration History of Nile Delta Province	7
1.4.1	Western sub-basin	8
1.4.1.1	Abu Qir field	8
1.4.1.2	North Abu Qir field	9
1.4.1.3	West Abu Qir Field	9
1.4.2.	Central Sub-basin	9
1.4.2.1	Abu Madi – EL QAR'A fields	9
1.4.2.2	Baltim East field	11
1.4.3	The Eastern Sub-Basin	12
1.4.3.1	Temash field	12
1.4.3.2	Akhen field	13
1.5.	Previous Work	14
1.6.	The Study Data	18
1.6.1	Well data	19
16.1.1	Well-A	19
16.1.2	Well-B	20
16.1.3	El-King-1X	20
16.1.4	Well-C	21
16.1.5	Well-D	21
16.1.6	Well-E	22

Chapter. No.	Subject	Page
16.1.7	Well-F	22
1.6.2	Seismic Data	23
1.7.	Study Motivations	24
1.8.	The Goals of The Thesis Study	25
1.9	Hardware and softwares	27
Chapter 2		
2	GEOLOGIC SETTING OF THE NILE DELTA	28
2.1	Introduction	28
2.2	Delta shapes classification	32
2.2.1	Delta Environments	36
2.2.1.1	The Delta plain	36
2.2.1.2	Delta front	36
2.2.1.3	Prodelta	37
2.3.	Nile River	37
2.4.	The Modern Delta	40
2.5.	Stratigraphic Column of the Nile Delta	41
2.5.1	Basement Rocks	41
2.5.2	Paleozoic Period	42
2.5.3	Mesozoic Period	42
2.5.3.1	Triassic	43
2.5.3.2	Jurassic	43
2.5.3.3.	Cretaceous	44
2.5.4	Cenozoic	46
2.5.4.1	Paleogene	46
2.5.4.1.1.	Paleocene	46
2.5.4.1.2.	Eocene	46
2.5.4.1.3.	Oligocene	47
2.5.4.2.	Neogene	48
2.5.4.2.1.	Miocene	49
2.5.4.2.2.	Pliocene	63
2.5.4.3	Quaternary	68
2.5.4.3.1	Pleistocene	68
2.5.4.3.2	Holocene	69
2.6	Tectonic evolution in Nile Delta	69
2.7	Nile delta structural framework	71

Chapter. No.	Subject	Page
2.8	Nile delta geologic history summary	77
2.9	Nile delta Petroleum system elements	79
2.9.1	Source rocks	79
2.9.2	Reservoir rocks	79
2.9.3	Cap rocks	81
2.9.4	Traps	81
2.9.5	Maturation	82
2.9.6	Petroleum occurrence	82
Chapter 3		
3	SEISMIC DATA INTERPRETATION	83
3.1	Introduction	83
3.2.	Seismic acquisition and processing background	85
3.2.1.	NEA-West 3D seismic survey	87
3.2.2.	NEA-West 3D reprocessing	89
3.2.3.	NEA-NA 3D seismic Survey	92
3.3.	Seismic Interpretation Workflow	93
3.3.1.	Seismic well tie	94
3.3.1.1	Log calibration – depth to time	95
3.3.1.2	The synthetic seismogram generation	97
3.3.1.3	Seismic to well tie results in the study area	106
3.3.2.	Time Interpretation	114
3.3.2.1	Manual horizon picking	116
3.3.2.2	Autotrackers	116
3.3.2.3	Contouring and Mapping	118
3.3.3	Time-depth conversion	118
3.4.	Mapping results and discussion	123
3.4.1	Structure depth maps	128
3.4.2	Mapped opportunities in the study area	130
3.4.2.1	Pliocene screening results	130
3.4.2.2	Miocene screening results	132
Chapter 4		
4	POST-STACK SEISMIC ATTRIBUTES	134
4.1	Introduction	134
4.2	Classification of seismic attributes	138

Chapter. No.	Subject	Page
4.2.1	Seismic attributes types	138
4.2.2.	Seismic attributes computation methods	139
4.2.3.	Seismic attributes categorization	140
4.3.	Seismic properties	143
4.3.2.	Phase and polarity	144
4.3.3.	Frequency	144
4.3.4.	Bandwidth	145
4.3.5.	Amplitude change	146
4.3.6.	Slope, dip, and azimuth	146
4.3.7.	Curvature	147
4.3.8.	Discontinuity	148
4.4	Seismic attribute application in the study	148
4.4.1	Seismic signal processing attributes	150
4.4.1.1	Graphic Equalizer	150
4.4.1.2	RMS Amplitude	156
4.4.2	Complex trace attributes	159
4.4.2.1	Sweetness	160
4.4.3	Structural Attributes	163
4.4.3.1	Variance	163
4.4.4	Stratigraphic Attributes	166
4.4.4.1	Relative Acoustic Impedance	166
Chapter 5		
5	SPECTRAL DECOMPOSITION	173
5.1	Introduction	173
5.2	Tuning effect	174
5.3	Spectral decomposition methods	177
5.3.1	Decomposition based on Fast Fourier transform	177
5.3.2	Decomposition based on Continuous Wavelet	
	Transform	179
5.3.3	Matching pursuit decomposition (MPD)	181
5.4	Spectral decomposition workflow	183
5.4.1	Data Conditioning	184
5.4.2	Spectral Enhancement	190
5.4.3	Standard frequency decomposition	194
5.4.4	High definition frequency decomposition	204
5.5	Conclusion	210

Chapter. No.	Subject	Page
Chapter 6		
6	ROCK PHYSICS, AMPLITUDE VERSUS	
·	OFFSET (AVO) MODELING AND ANALYSIS	212
6.1	Introduction	212
6.1.1	Compressional velocity	213
6.1.2	Shear velocity	214
6.1.3	Poisson's ratio (σ)	214
6.2.	Rock physics models templates (RPM)	214
6.2.1	Theoretical bounds	214
6.2.2	Empirical models	217
6.2.2.1	Gardner's relation	217
6.2.2.2	Wyllie's (time average) equation	218
6.2.2.3	Han's relations	219
6.2.2.4	Greenberg–Castagna relations	219
6.2.2.5.	Faust's relation	220
6.2.3	Well logs cross-plotting using Rock physics	
	templates	221
6.3.	Fluid substitution using Gassmann's equation	232
6.3.1	Mineral parameters	234
6.3.2	Fluid parameters	234
6.4.	Amplitude versus offset (AVO) modelling	239
6.4.1	The reflection coefficient	239
6.4.2	AVO modelling and half-space interface modelling	242
6.5.	Amplitude versus offset (AVO) analysis	253
6.5.1	AVO parameters estimation: intercept and gradient	253
6.5.2	AVO cross-plot analysis	254
6.5.3	AVO classes types	254
6.5.4	Porosity, lithology and compaction impact on AVO	255
6.5.5	AVO anomalies and fluid effects	256
6.5.6	AVO attributes application in hydrocarbon detection	262
6.5.6.1	Far stack and Far- versus near-stack attributes	262
6.5.6.2	AVO attributes combining intercept and gradient	264
6.5.6.3	The fluid factor	270
6.5.7	Flat-spot analysis using AVO	273

Chapter. No	. Subject	Page
Chapter 7		
7	SEISMIC INVERSION AND RESERVOIR	
	CHARACTERIZATION	277
7.1	Introduction	277
7.2	Seismic inversion theorical background	280
7.2.1	Inversion Algorithms	280
7.3.	Recursive "bandlimited" seismic inversion	283
7.4.	Sparse spike inversion	287
7.5.	Model-based inversion	291
7.5.1	Low frequency model building:	292
7.5.2	Wavelet sensitivity	293
7.5.3	Model based inversion analysis parameters	294
7.5.4	Model-based inversion application in the study	296
7.5.5	Post-stack (acoustic) inversion	296
7.5.6	Angle-limited stacks inversion	302
7.5.7	Pre-stack simultaneous inversion	305
7.6.	Coloured inversion	315
7.7.	AVO "independent" inversion	320
7.8.	Extended Elastic impedance inversion	324
7.8.1	Extend Elastic Impedance	325
7.8.2	Extend Elastic Impedance workflow	329
7.9.	Reservoir characterization workflow	338
7.10.	Quantitative interpretation impact on geologic	
	risk reduction	347
Chantar 9		
Chapter 8 8	SUMMARY AND CONCLUSIONS	351
	LIST OF REFERENCES	358
	ARABIC SUMMARY	i

LIST OF FIGURES

Figure. No.	Subject	Page
Figure 1.1	Location map of the study area.	3
Figure 1.2	Bathymetry contour map shows that the water depths of the study area ranges from 10 to 880 m. (contour interval)	
	= 20 m.).	4
Figure 1.3	Generalized-lithostratigraphic column of the Nile delta area (after EGPC,1994).	5
Figure 1.4	Interpreted seismic section showing the Tortonian	
	Qawasim Formation appears as (pockets) below the Messinian unconformity (after El-Barkooky and Helal,	
T: 1.5	2002).	6
Figure 1.5 Figure 1.6	Offshore Nile delta sub-basins. Depth-structure map of Abu Madi-El Qara fields at the top of Abu Madi level III reservoir (after Shasha et al.,	8
	1996).	10
Figure 1.7	Location of the Baltim East, South and North fields (after EGPC, 1994).	11
Figure 1.8	Location map of El Temsah wells (after EGPC, 1994).	
		13
Figure 1.9	Location map of El Temsah-Akhen fields (after, EGPC 1994).	14
Figure 1.10	Coherency horizon slice of Rosetta channel complex (above) and arbitrary seismic lines perpendicular to such channels (below) shows channel complex cutting down into the Rosetta anhydrite (bright reflectors) (after	
Figure 1.11	Wescott et al., 2000). Coherency horizon slice, showing the Abu Madi channel complex (above). Arbitrary seismic lines perpendicular to the Abu Madi channel complex (below). (Base of the	
Figure 1.12	channel complex = yellow) (after Wescatt et al., 2000.). Pre-stack modeling from well data. Synthetic CMP gathers (right) are computed from well logs for a better interpretation of seismic AVO response. (after Dalla et al., 1997).	16 17
Figure 1.13	The coverage of two 3D seismic surveys used in the	1 /
- 10010 1110	study; NEA-West and NEA-NA 3D surveys.	23

Figure 2.1	Nile Delta recent satellite image	
C	(https://www.researchgate.net).	28
Figure 2.2	Air-photo shows the main tectonic features of the Nile	
C	Delta (after Abdel Aal et. al., 2000).	29
Figure 2.3	General types of fluvial-, wave- and tide-dominated	
C	Deltas (after Dalrymple et al., 1992)	33
Figure 2.4	Modern examples of Delta systems, modified (after	
C	Fisher et al., 1969) (a-Nile Delta, b- Mississippi Delta, c-	
	Rhone Delta and d- Ganges Delta).	34
Figure 2.5	Delta triangle (Galloway, 1975) as extended by	
C	Dalrymple et al. (1992) to reflect changes in sediment	
	supply (after Reading and Collinson, 1996).	35
Figure 2.6	Nile River course from source to sea (after Hamza,	
	2001).	38
Figure 2.7	Ancient and recent geographical boundaries of both the	30
118410 2.7	direct and indirect discharging outlets of the Nile delta	
	(after Hamza, 2001).	39
Figure 2.8	Ancient shorelines of the Nile Delta (after Said, 1981).	40
Figure 2.9	Structure contour map of top Jurassic in the Nile delta	
8	(after Zaghloul et al., 1999).	44
Figure 2.10	Isopach contour map of the early Cretaceous in the Nile	
C	delta (after Zaghloul et al.,1999).	44
Figure 2.11	Structure contour map of late Cretaceous in the Nile	
_	delta (after Zaghloul et al.,1999).	45
Figure 2.12	Isopach contour map of the late Cretaceous in the Nile	
	delta (after Zaghloul et al.,1999).	46
Figure 2.13	Structure contour map of Oligocene in Nile delta (after	
	Zaghloul et al., 1999).	47
Figure 2.14	Isopach contour map of Oligocene deposits in Nile delta	
	(after Zaghloul et al.,1999).	48
Figure 2.15	Major unconformities in Nile delta during Tertiary (after	
	Harms and Wray, 1990).	50
Figure 2.16	The mid-Miocene and late Miocene (Messinian)	
	unconformities in the Nile delta region (after Harms and	
E: 0.15	Wray, 1990).	50
Figure 2.17	Early Miocene facies and thicknesses (after Harms and	
E' 0.10	Wray, 1990).	51
Figure 2.18	Structure contour map of the middle Miocene in Nile	
Ei	delta (after Zaghloul et al.,1999).	53
Figure 2.19	Isopach contour map of the middle Miocene in the Nile Delta (after Zaghloul et al., 1999).	E 1
	Dena taher Zagnioui elal. 1999).	54

Figure 2.20	Late Miocene (Messinian) facies and total late Miocene	
	thicknesses (after Harms and Wray, 1990).	56
Figure 2.21	Basal Messinian sub-crop and Messinian drainage pattern in the western Nile delta (after Barber, 1981).	57
Figure 2.22	Schematic block diagram illustrating the late Miocene	
J	(Messinian) canyon, canyon front, and turbidite	
	depositional settings of the Nile Delta area (Aal et al.,	
	2001).	58
Figure 2.23	Structure contour map on top of the late Miocene	
8*	(Messinian) in the Nile delta (after Zaghloul et al.,	
	1999).	59
Figure 2.24	Structure contour map of Kafr El-Sheikh formation	
1 18410 2.2 1	(after Zaghloul et al., 1999).	65
Figure 2.25	Structure contour map of El-Wastani formation (after	0.5
1 1guit 2.23	Zaghloul et al., 1999).	67
Figure 2.26	Main subsurface structures of the Nile Delta region (after	07
1 iguic 2.20	Sestini, 1989).	72
Figure 2.27	Messinian depositional system and structural pattern	12
1 iguic 2.27	along the Nile Delta (After Abdel Aal, et.al., 1996).	73
Figure 2.28	Schematic cross-section along Nile Delta and the	13
11guic 2.26	Mediterranean shows major petroleum plays (after	
	Dolson et al., 2001).	80
Figure 2.29	Schematic cross section illustrating the most common	80
11guic 2.27	traps and play types in the Nile Delta Basin (after	
	Vandré, 2007).	81
Figure 2.1	Relationship of seismic data acquisition and processing	01
Figure 3.1	(forward processes) with seismic interpretation (inverse	
	process) (after Herron, 2011).	84
Figure 3.2	1	04
Figure 3.2	Two "overlapped" seismic 3D surveys which used in the study; NEA-West and NEA-NA 3D surveys	86
Figure 3.3	y ·	80
rigule 3.3	Reprocessing layout of the first 3D seismic survey: NEA-West 3D.	87
Figure 2.4		
Figure 3.4	NEA-West 3D seismic processing sequence chart-part1.	90
Figure 3.5	NEA-West 3D seismic processing sequence chart-part2.	91
Figure 3.6	NEA-NA 3D seismic survey data set, part of 3D Mega	00
F: 2.7	Merge.	92
Figure 3.7	Log (depth-time) calibration: column (after Simm and	0.0
E' 2.0	Bacon, 2014).	96
Figure 3.8	Synthetic seismogram generation. Tracks show	
	time/depth scale, sonic and density log, calculated	00
	impedance, and synthetic (after Nanda, 2016).	98

Figure 3.9	Synthetic seismogram superposed on seismic section at the well location (after Bacon et al., 2007).	99
Figure 3.10	The phase spectrum related to timing relationship of various frequency components in wavelet, which in this	
	example is zero-phase (after Bacon et al., 2007).	100
Figure 3.11	Schematic illustration of least squares filtering to obtain	
8	the wavelet (after Simm and Bacon, 2014).	101
Figure 3.12	Seismic segment (T) and wavelet length (L) (after Simm	
	and Bacon, 2014).	102
Figure 3.13	Generated synthetic seismogram using statistical wavelet	
	(The blue is the synthetic while the red is the surface	
	seismic data) – Well-A.	107
Figure 3.14	Generated synthetic seismogram using statistical wavelet	
	(The blue is the synthetic while the red is the surface	
	seismic data) - Well-B.	108
Figure 3.15	Generated synthetic seismogram using statistical wavelet	
	(The blue is the synthetic while the red is the surface	
	seismic data) – Well-D.	109
Figure 3.16	Generated Synthetic Seismogram using statistical	
	wavelet (The blue is the synthetic while the red is the	
	surface seismic data) – Well-E.	110
Figure 3.17	Extracted wavelet from the 3D seismic (NEA-NA) for	
	the Well-C, showing the seismic phase is about 90°.	111
Figure 3.18	Generated synthetic seismogram using statistical wavelet	
	(The blue is the synthetic while the red is the surface	
	seismic data) - Well-C.	112
Figure 3.19	Generated synthetic seismogram using deterministic	
	wavelet (The blue is the synthetic while the red is the	
	surface seismic data) Well- C.	113
Figure 3.20	PEP (Proportion of Energy Predicted) QC slice – Well-C	114
Figure 3.21	Seismic display polarity used in this study (SEG Normal	
	polarity convention).	115
Figure 3.22	Principle of a simple horizon Auto trackers (after Bacon	
	et. al., 2007).	117
Figure 3.23	(a) A time-depth function from check-shot survey (b) an	
	average velocity-depth function calculated from original	4.00
Fi 0.04	time-depth data (after Herron, 2011).	120
Figure 3.24	a layered interval-velocity model. Interval velocities are	
	assigned to layers whose boundaries are defined by or	
	calculated from interpreted seismic horizons (after	101
F: 2.25	Herron, 2011).	121
Figure 3.25	Crossline passing through Well-D, NEA-NA 3D survey.	123

Figure 3.26	Crossline passing through Well-C, NEA-NA 3D survey	124
Figure 3.27	Composite line passing through Wells C, D and E -	
	NEA-NA 2009 PSTM.	125
Figure 3.28	Inline passing through Well-A, NEA-West- 3D survey.	126
Figure 3.29	Crossline passing through Well-B, NEA-West 3D	
	survey.	127
Figure 3.30	Structural fault model in the study area.	128
Figure 3.31	Middle Pliocene structure depth contour map.	129
Figure 3.32	Top Messinian structure depth contour map.	129
Figure 3.33	Reservoir architecture catalogue in the study area.	130
Figure 3.34	Seismic arbitrary line through Harara-1 lead.	131
Figure 3.35	Seismic arbitrary line through Harara-2 lead.	131
Figure 3.36	Seismic arbitrary line through Harara-3 lead.	132
Figure 3.37	Top Messinian 'Abu Madi' structure depth map with	
	highlighted potential leads.	133
Figure 4.1	Hidden geological features are revealed in seismic data	
	by using seismic attributes (after Barnes, 2016).	134
Figure 4.2	Time line of seismic attributes development and the	
	relation with advances in seismic exploration	
	technology, from 1960 to till now (after Barnes, 2001).	136
Figure 4.3	Seismic attributes categorization (after Barnes, 2016).	141
Figure 4.4	Phase definition and relationship with waveform $x(t)$	
	(after Barnes, 2016).	144
Figure 4.5	The standard deviation of the spectral power P(f) as	
	common measure of bandwidth fb is about the average	
	spectral frequency (fa). (after Barnes, 2016).	145
Figure 4.6	3D slope and dip are unsigned magnitudes that	
	correspond to the maximum slope or dip, in direction	
E' 4.5	defined by the azimuth (after Barnes, 2016).	146
Figure 4.7	Reflection curvature signs convention (after Barnes,	1.47
E' 40	2016).	147
Figure 4.8	Generated Seismic attributes (a) trace by trace or (b)	1.40
E' 40	using multi-traces. (after Chen and Sidney, 1997).	149
Figure 4.9	Graphic equalizer attribute sliding control parameters	151
Figure 4.10	Seismic cross-line passing through Well-C; Full stack	150
Eigung 4 1 1	seismic.	152
Figure 4.11	Seismic crossline passing through Well-C; Graphic	152
Figure 4.12	equalizer attribute.	153
Figure 4.12	Seismic arbitrary line passing through Well-C, Well-D, Well-E and the potential Messinian lead (Zwail-1); Full	
	stack seismic.	151
	Stack Scisific.	154