

CONTENTS

DECLARATION	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
SARI	iv
LIST OF FIGURES	<u>xii</u>
LIST OF TABLES.....	<u>xviii</u>

CHAPTER I: INTRODUCTION	1
1.1. BACKGROUND OF RESEARCH	1
1.2. PROBLEM FORMULATION	2
1.3. OBJECTIVE OF RESEARCH.....	3
1.4. LIMITATION OF RESEARCH.....	3
1.5. DELIVERABLE OF RESEARCH.....	3
1.6. SCOPE OF RESEARCH.....	4
1.6.1. Research area.....	4
1.6.2. Scope of work.....	5
1.7. ADVANTAGES OF RESEARCH	5
CHAPTER II: LITERATURE REVIEW	6
2.1. REGIONAL GEOLOGY OF STUDY AREA	6
2.1.1. Geological framework overview of Cuu Long Basin...	6
2.1.2. Tectonic and geological setting of Cuu Long Basin.....	7
2.1.3. The structural geology of Cuu Long Basin	8
2.1.4. Stratigraphy and lithology of Cuu Long Basin	12
2.1.4.1 Pre – Cenozoic basement:	12
2.1.4.2 Cenozoic sediments:	12
2.1.5. The stratigraphy of Vam Co oilfield.....	14
2.1.5.1 Pre-Tertiary Basement	14

2.1.5.2	Late Oligocene Lower Tra Tan Formation/ “E” Sequence.....	14
2.1.5.3	Late Oligocene Middle Tra Tan Formation/ “D” Sequence	15
2.1.5.4	Late Oligocene Upper Tra Tan Formation/ “C” Sequence	16
2.1.5.5	Early Miocene Bach Ho Formation/ “B 1” Sequence	17
2.1.5.6	Middle Miocene Con Son Formation/ “B 2” Sequence	19
2.1.5.7	Late Miocene Dong Nai Formation/ “B 3” Sequence	19
2.1.5.8	Pliocene – Quaternary Bien Dong Formation /“A” Sequence	20
2.1.6.	Petroleum system of Vam Co oilfield.....	22
2.2.	PREVIOUS RESEARCH.....	25
2.3.	BACKGROUND THEORY.....	25
2.3.1.	Sedimentary environment, facies and stratigraphy.....	25
2.3.1.1	The meaning of sedimentary environment and sedimentary facies	25
2.3.1.2	Basic principle of sequence stratigraphy	27
2.3.1.3	Relationship between facies, environment and stratigraphy	35
2.3.2.	Some of Depositional environments.....	37
2.3.2.1	Fluvial	38
2.3.2.2	Deltas and deltaic deposits	42
2.3.2.3	Lacustrine system	45
2.3.2.4	Marine environment.....	46
2.3.3.	Basic concepts of petrophysics properties	47
2.3.3.1	Porosity	47
2.3.3.2	Permeability.....	49
2.3.3.3	The fluid saturation.....	50

2.3.3.4	Porosity-permeability relationship	51
2.3.4.	Basic principles of Well logging	55
2.3.4.1	Spontaneous Potential or Self-Potential log (SP)	55
2.3.4.2	Resistivity log	60
2.3.4.3	Gamma ray log	64
2.3.4.4	The Density log	66
2.3.4.5	The Neutron log	68
2.3.4.6	Sonic or Acoustic logs	70
2.3.4.7	Caliper logs	74
2.3.4.8	Summarize: Characteristics of wireline well logs used in the petroleum industry	74
2.3.5.	Core data and its procedures	76
2.3.6.	Facies interpretation from well logs	78
2.3.7.	Determine fluid and gas in reservoir	79
2.3.8.	Reservoir parameters calculation from well log	81
2.3.8.1	Shale volumn calculation	81
2.3.8.2	Porosity calculation	82
2.3.8.3	Water saturation calculation	84
2.3.8.4	Permeability calculation	85
2.3.8.5	Net pay determination	85
2.3.9.	Isopach map and Depth map	88
2.3.9.1	Make contour lines	88
2.3.9.2	Making a map with fault structure	90
2.3.10.	Modelling methods	93
2.4.	HYPOTHESIS	96
CHAPTER III: RESEARCH METHODOLOGY		97
3.1.	RESEARCH STAGES	97
3.1.1.	Preparation and Desk study	97

3.1.2. Data collection.....	97
3.1.3. Analysis.....	102
3.1.3.1 Facies interpretation, depositional environment and parasequence boundary	102
3.1.3.2 Log correlation	105
3.1.3.3 Petrophysics interpretation.....	105
3.1.4. Modelling.....	111
3.1.5. Finalization.....	112
3.2. WORKING TOOL.....	112
3.3. FLOW CHART OF RESEARCH.....	112
3.4. RESEARCH SCHEDULE	114
CHAPTER IV: CORE DATA DESCRIPTION.....	115
4.1. CORE SD-2X DESCRIPTION	115
4.1.1. Lithofacies Discussion	115
4.1.1.1 Core SD-2X information and summarization	115
4.1.1.2 Core SD-2X lithofacies discussion.....	116
4.1.2. Depositional Environment from Core Analysis	123
4.1.3. Core Petrophysics Properties	125
4.2. CORE SD-3X DESCRIPTION	127
4.2.1. Lithofacies Discussion	127
4.2.1.1 Core SD-3X information and summarization	127
4.2.1.2 Core SD-3X lithofacies discussion.....	127
4.2.1. Depositional environment from core analysis.....	134
4.2.2. Core petrophysics properties.....	135
4.3. SUMMARIZATION OF CORE PETROPHYSICS PROPERTIES.....	136

CHAPTER V: FACIES INTERPRETATION, DEPOSITIONAL ENVIRONMENT, SEQUENCE STRATIGRAPHY AND CORRELATION	138
5.1. FACIES INTERPRETATION, DEPOSITIONAL ENVIRONMENT AND SEQUENCE STRATIGRAPHY IN MIOCENE BACH HO FORMATION OF WELL #2X	138
5.1.1. Log Lithofacies.....	138
5.1.2. Depositional environment and sequence boundary	139
5.2. FACIES INTERPRETATION, DEPOSITIONAL ENVIRONMENT AND SEQUENCE STRATIGRAPHY IN MIOCENE BACH HO FORMATION OF WELL #3X	142
5.2.1. Log Lithofacies.....	142
5.2.2. Depositional environment and sequence boundary	143
5.3. LOG CORELATION	146
5.3.1. Lower Miocene B10 Sandstone Reservoir (Figure from 5.3 to 5.15)	147
5.3.2. Upper Oligocene C30 Sandstone Reservoir.....	156
 CHAPTER VI: PETROPHYSICS PROPERTIES	 164
6.1. INPUT DATA	164
6.2. PARAMETERS	167
6.3. EVALUATION RESULT	176
6.3.1. B10 Sandstone Reservoir	176
6.3.2. C30 Sandstone Reservoir	197
 CHAPTER VII: DISTRIBUTION OF B10 AND C30 RESERVOIRS	 201
7.1. B10 Sandstone Reservoir	201
7.2. C30 Sandstone Reservoir	208
 CHAPTER VIII: CONCLUSION AND SUGGESTION	 215
8.1. CONCLUSION.....	215

8.2. SUGGESTION	216
REFERENCES	217
APPENDICES	222

LIST OF FIGURES

Figure 1.1. The Vam Co oilfield is located in the north of Cuu Long Basin (Cuu Long JOC, 2009).....	4
Figure 2.1. Generalized map of the major Cenozoic sedimentary basins and tectonic elements of the East Vietnam Sea. (Modified from Dien, 1998, Tjia, 1998).	7
Figure 2.2. Frame of structural units in Cuu Long Basin. The Vam Co oilfield is located in the area which has thickness is around 2000 – 4000m (Nguyen Hiep <i>et al.</i> , 2007, in Huynh, 2012).....	9
Figure 2.3. Cross section of Cuu Long Basin follows the direction NW - SE (Nguyen Hiep <i>et al.</i> , 2007, in Huynh, 2012).....	11
Figure 2.4. Stratigraphic column of Cuu Long Basin (Cuu Long JOC). The red box indicate target of research.....	13
Figure 2.5. Reservoirs in the Vam Co Oilfield (Cuu Long, 2009). The red box indicate target of research.....	21
Figure 2.6. Seismic profile section along Vam Co oilfield shows the structure and faults system (Cuu Long JOC, 2009).....	24
Figure 2.7. The concept of facies and sedimentary environment (after Selley, 1985)	26
Figure 2.8. Accommodation is driven by sea level. Accommodation is "the space available for potential sediment accumulation" driven by relative sea level (Jervey, 1998). Curray, (1964), Posamentier & Allen, (1999), Coe <i>et al.</i> , (2002), and Catuneanu (2002) suggest rates of sedimentation are a co-equal control of accommodation (Kendall, 2013. After Posametier & Allen, 1999).....	28
Figure 2.9. Shifting sedimentary facies in the case of transgression (above) and regression of the sea (below) (Rygel, 2014).....	30
Figure 2.10. Stratal stacking patterns related to shore one trajectories (Kendall, 2013. After Catuneanu <i>et al.</i> , 2011).....	31
Figure 2.11. Stratal characteristics of an upward-coarsening parasequences. This type of parasequences is interpreted to form in a beach setting on a sandy, wave- or fluvial-dominated shoreline (Kendall, 2013. After Van Wagoner <i>et al.</i> , 1990).....	34

Figure 2.12. Stacking pattern (Kendall, 2013. After Van Wagoner <i>et al.</i> , 1990)	35
Figure 2.13. Schematic diagram showing the main sedimentary depositional environment (Wikipedia, 2015).	37
Figure 2.14. Principle river channel patterns (Miall, 1981)	39
Figure 2.15. Main morphological element of meandering stream (Walker and Cant, 1984).	40
Figure 2.16. The main elements on a sandy braided river. Main morphological elements include vegetable inlands, exposed sandflats covered with flow-transverse dunes, and channels with large sinuous crested and cross-channels bar (Walker and Cant, 1984)	41
Figure 2.17. Prograding delta and its sedimentary facies (Allen & Chambers, 1998)	43
Figure 2.18. Progradation facies in deltaic and non- deltaic coasts (Allen & Chambers, 1998).	44
Figure 2.19. Relative influence of fluvial process and sediment influx contrasted with marine process in development of deltas geometries (From Fisher <i>et al.</i> , 1969; original by A.J.Scott).....	45
Figure 2.20. Zonation of the ocean. Note that in the littoral zone the water is at the high tidal mark (Eugster and Kelts, 1983).....	47
Figure 2.21. Cubic packing (a), rhombohedral (b), cubic packing with two grain sizes (c), and typical sand with irregular grain shape (d) (Torsæter & Abtahi, 2003).....	48
Figure 2.22. Degree of sphericity (vertical-ward) and degree of roundness (horizontal-ward) (Powers, 1953)	52
Figure 2.23. Size of grains and pore space is different but porosity is similar.	52
Figure 2.24. A well-sorted sediment (right) and a poorly-sorted sediment (left) (Selley, 2000).....	53
Figure 2.25. Cubic configuration (48% porosity) and rhombohedral configuration (26% porosity) (Selley, 2000)	54
Figure 2.26. Block diagram of sand showing layered fabric with grain oriented parallel to current. Generally, $K_x > K_y > K_z$ (Selley, 1998).	54

Figure 2.27. Definition of Potential Cells. a) Schematic of diffusion-potential generating cell; b) Schematic of a membrane-potential generating cell. (Rider, 1996).....	56
Figure 2.28. The SP log: some typical responses. The SP log show variations in natural potentials. R_w = formation-water resistivity; R_{mf} = mud filtrate resistivity (Rider, 1996).	57
Figure 2.29. Some conditions causing aberrant SP values when the SSP is not attained (Rider, 1996).	58
Figure 2.30. The resistivity log: some typical responses. The resistivity log shows the effect of the formation and its contained fluids on the passages of an electric current (Rider, 1996).	61
Figure 2.31. (Upper) Schematic representation of invasion and resistivity profile in a water-bearing zone. (Lower)-Invasion and resistivity profile in an oil-bearing zone showing resistivity annulus (Schlumberger, 1991).	63
Figure 2.32. The Deep and Shallow logs in formations depend on drilling fluid (Thomas & Clinch, 2011).	64
Figure 2.33. Speed of cable pull affects the form of Gamma Ray line (Rider, 1996)	66
Figure 2.34. The density log: some typical responses. The density log show bulk density, *density and porosity with fresh formation-water density 1.0g/cm^3 . (Modified after Rider, 1996).	67
Figure 2.35. The neutron log: some typical response. The neutron log show hydrogen index which is converted to neutron porosity units (Rider, 1996).	69
Figure 2.36. The sonic log: some typical responses. The sonic log shows a formation's ability to transmit sound waves. It is expressed as Interval Transit Time, Δt . $*(1 \times 10^6)/\Delta t =$ sonic velocity, ft/sec (Rider, 1996).	71
Figure 2.37. The transmission of acoustic waves in borehole environments. Compressional = the first wave; shear wave = after compressional wave, present chemical characteristics of rock; mud wave = transmits in fluid; stoneley wave = the last wave (Rider, 1996)..	71
Figure 2.38. Sonic log in sand-shale sequences. (a) The sands have a lower sonic velocity (about 3385m/s) than the shales (3900m/s). (b) The reverse, where the sands have higher velocity (about 4350m/s)	

than the shales (3300m/s). Sonic velocities are therefore not diagnostic of lithology (Rider, 1996).....	73
Figure 2.39. Idealized gamma-ray log trends (after Rider, 1993).	79
Figure 2.40. Define liquid and gas by density and neutron log (Phu Quy POC, 2010)	80
Figure 2.41. Define hydrocarbon and water by Resistivity log (Phu Quy POC, 2010)	80
Figure 2.42. Shale volume from well log (Phu Quy POC, 2010).....	81
.....(2.14) (Schlumberger, 1991).....	83
Figure 2.43. Neutron – Density Crossplot (Schlumberger, 1991).....	83
Figure 2.44. Mechanical Contouring method. A – know points map; B – interpolate between know points; C – 25m contour spacing; D – 10m contour spacing (Denial & Rechard, 2002).....	89
Figure 2.45. Structure mapping (Tearpock & Bischke, 2003).	93
Figure 2.46. Example for variogram of the initial potential (line with symbols) and model (dashed curve) (Hohn, 1988)	94
Figure 2.47. Example for spherical variogram modeling (after Hohn, 1988).	95
Figure 3.1. Location of wells of Vam Co oilfield.....	101
Figure 3.2. Stacking patterns refer to the vertical and lateral arrangement of beds, bedsets, parasequences, parasequence sets, sequences, and sequence sets. These figures illustrate the basic parasequence stacking types and their use in sequence stratigraphic analysis on simulated gamma-ray logs (Culong JOC, 2009).....	104
Figure 3.3. The GR log and shale volume after split zones and interpreted ...	107
Figure 3.4. Flow chart of research	113
Figure 5.1. Core Lithofacies, Log Lithofacies, Depositional Environment and Sequence Stratigraphy analysis in Miocene Bach Ho Formation of Well #2X.....	141
Figure 5.2. Core Lithofacies, Log Lithofacies, Depositional Environment and Sequence Stratigraphy analysis in Miocene Bach Ho Formation of Well #3X.....	145
Figure 5.3. B10 Sandstone Reservoir in Wells #4P, #3X, #4X.....	147
Figure 5.4. B10 Sandstone Reservoir in Wells #6P-ST, #9I, #8I.....	148

Figure 5.5. B10 Sandstone Reservoir in Wells #2X-DEV, #1P, #7P	148
Figure 5.6. B10 Sandstone Reservoir in Wells #2X-ST, #2X-PL, #21P	149
Figure 5.7. B10 Sandstone Reservoir in Wells #18P, #6P, #12I.....	149
Figure 5.8. B10 Sandstone Reservoir in Wells #2P, #5P, #16I.....	150
Figure 5.9. B10 Sandstone Reservoir in Wells #3P, #22P, #4P-ST	150
Figure 5.10. B10 Sandstone Reservoir in Wells #4P-ST, #17P, #19P	151
Figure 5.11. B10 Sandstone Reservoir in Wells #24P, #1X, #6X.....	151
Figure 5.12. B10 Sandstone Reservoir in Wells #5X, #5X-PL, #10P	152
Figure 5.13. B10 Sandstone Reservoir in Wells #10P-ST, #10P-ST2, #14P-ST.....	152
Figure 5.14. B10 Sandstone Reservoir in Wells #20P, #21P-ST, #23P	153
Figure 5.15. B10 Sandstone Reservoir in Wells #26P, #27P, #28P	153
Figure 5.16. C30 Sandstone Reservoir in Wells #G-1X, #3X, #4X.....	156
Figure 5.17. C30 Sandstone Reservoir in Wells #1X, #4P, #2X-DEV	157
Figure 5.18. C30 Sandstone Reservoir in Wells #2X-ST, #5X, #5X-PL,	157
Figure 5.19. C30 Sandstone Reservoir in Wells #6X, #2P-ST, #3P	158
Figure 5.20. C30 Sandstone Reservoir in Wells #5P, #1P, #2P	158
Figure 5.21. C30 Sandstone Reservoir in Wells #4P-ST2, #4P-ST, #8I	159
Figure 5.22. C30 Sandstone Reservoir in Wells #5P-ST, #22P, #19P	159
Figure 5.23. C30 Sandstone Reservoir in Wells #6P, #6P-ST, #7P	160
Figure 5.24. C30 Sandstone Reservoir in Wells #21P, #9I, #18P	160
Figure 5.25. C30 Sandstone Reservoir in Wells #12I, #25P, #16I.....	161
Figure 5.26. C30 Sandstone Reservoir in Wells #16I, #24P, #17P	161
Figure 6.1. Temperature chart of Vam Co oilfield	165
Figure 6.2. Core porosity-permeability relationship of Well #3X.....	166
Figure 6.3. Porosity cross-plot of B10 reservoir, Well #3X	178
Figure 6.4. Diagram of Core porosity and Log Porosity of Well #3X	179
Figure 6.5. Diagram of Core water saturation and Log water saturation that analyzed by Indonesia equation, Archie equation and Simandoux equation.....	182

Figure 6.6. Diagram or Core permeability and Log permeability	184
Figure 6.7. B10 Sandstone reservoir evaluation result of Well #3X	185
Figure 6.8. Porosity cross-plot of B10 Sandstone Reserver, Well #2X-DEV.	186
Figure 6.9. B10 Sandstone reservoir evaluation result of Well #2X-DEV	187
Figure 6.10. B10 Sandstone reservoir evaluation result of Well #2X-ST	188
Figure 6.11. B10 Sandstone reservoir evaluation result of Well #2X-PL	189
Figure 6.12. B10 Sandstone reservoir evaluation result of Well #1X	190
Figure 6.13. B10 Sandstone reservoir evaluation result of Well #4X	191
Figure 6.14. B10 Sandstone reservoir evaluation result of Well #5X-PL	192
Figure 6.15. B10 Sandstone reservoir evaluation result of Well #6X	193
Figure 6.16. B10 Sandstone reservoir evaluation result of Well #2P.....	194
Figure 6.17. B10 Sandstone reservoir evaluation result of Well #5P.....	195
Figure 6.18. C30 Sandstone reservoir evaluation result of Well #1X	197
Figure 6.19. C30 Sandstone reservoir evaluation result of Well #2X-ST	198
Figure 6.20. C30 Sandstone reservoir evaluation result of Well #3X	198
Figure 6.21. C30 Sandstone reservoir evaluation result of Well #4X	199
Figure 6.22. C30 Sandstone reservoir evaluation result of Well #6X	199
Figure 7.1. Histogram of Isopach map of B10 Sandstone Reservoir	202
Figure 7.2. Subsurface structure map – in Depth on Top of B10 Sandstone Reservoir	203
Figure 7.3. Subsurface structure map – in Depth on Base of B10 Sandstone Reservoir	204
Figure 7.4. Subsurface structure map – in Depth on Top in 3D of B10 Sandstone Reservoir	205
Figure 7.5. Depth surface on Subsurface structure map – in Depth on Base in 3D of B10 Sandstone Reservoir	206
Figure 7.6. Isopach map of B10 Sandstone Reservoir	207
Figure 7.7. Histogram of of Isopach map of C30 Sandstone Reservoir	209
Figure 7.8. Subsurface structure map – in Depth on Top of C30 Sandstone Reservoir	210

Figure 7.9. Subsurface structure map – in Depth on Base of C30 Sandstone Reservoir	211
Figure 7.10. Subsurface structure map – in Depth on Top in 3D of C30 Sandstone Reservoir	212
Figure 7.11. Subsurface structure map – in Depth on Base in 3D of C30 Sandstone Reservoir	213
Figure 7.12. Isopach map of C30 Sandstone Reservoir	214

LIST OF TABLES

Table 2.1. The principal use of the SP log (Rider, 1996).....	56
Table 2.2. Variations in filtrate and formation-water resistivity values, as reading by resistivity tools (Rider, 1996).	64
Table 2.3. Neutron log value of some common lithologies (Rider, 1996).....	70
Table 2.4. Some diagnostic (mineral) velocities (Rider, 1996).....	72
Table 2.5. Some typical sonic matrix velocities (Rider, 1996).	72
Table 2.6. Characteristics of wireline well logs used in the petroleum industry	75
Table 2.7. General log response (Phu Quy POC, 2010)	79
Table 3.1. Summary of logging data of Vam Co oilfield.....	98
Table 3.2. Summary of core data of Vam Co oilfield.....	100
Table 3.3. Research schedule.....	114
Table 4.1. Lithofacies in Miocene Cored Interval, SD-2X (CLJOC, 2009) ...	118
Table 4.2. Core analysis final report of core SD-2X (CLJOC, 2009).....	125
Table 4.3. Lithofacies in Miocene Cored Interval, SD-3X (CLJOC, 2009) ...	130
Table 4.4. Core analysis final report of core SD-3X (CLJOC, 2009).....	135
Table 4.5. Summarise of Core data of wells 2X and 3X of Vam Co oilfield...	137
Table 5.1. Potentially Significant Surfaces in 2X Miocene Interval	142
Table 5.2. Potentially Significant Surfaces in 3X Miocene Interval	146
Table 5.3. B10 Sandstone Reservoir correlation	154
Table 5.4. C30 Sandstone Reservoir correlation	162
Table 6.1. Test temperature of Vam Co oilfield.....	164
Table 6.2. Common parameters applied for Vam Co oil field	167
Table 6.3. Parameters of well 1X.....	168
Table 6.4. Parameters of well 2X-DEV	168
Table 6.5. Parameters of well 2X-ST	169
Table 6.6. Parameters of well 3X.....	169

Table 6.7. Parameters of well 4X.....	170
Table 6.8. Parameters of well 5X-PL.....	170
Table 6.9. Parameters of well 5X.....	170
Table 6.3. Parameters of well 6X.....	171
Table 6.3. Parameters of wells from 1P to 7P	172
Table 6.11. Parameters of wells 10P to 11P	173
Table 6.12. Parameters of wells from 14P to 14P-ST.....	173
Table 6.13. Parameters of well 15P	173
Table 6.14. Parameters of wells from 17P to 28P.....	173
Table 6.15. Parameters of well 8I	174
Table 6.16. Parameters of well 9I	175
Table 6.17. Parameters of well 12I	175
Table 6.18. Parameters of well 13I	175
Table 6.19. Parameters of well 16I	176
Table 6.23. Core porosity and log porosity of Well #3X.....	176
Table 6.24. Water saturation of Well #3X from core and log data.....	180
Table 6.26. Summarization of Permeability result of B10 Sandstone reservoir	184
Table 6.25. B10 Sandstone reservoir evaluation result of Well #3X.....	185
Table 6.26. Summarization table of petrophysics properties of B10 Sandstone Reservoir, Well #2X from core and log data	186
Table 6.27. B10 Sandstone reservoir evaluation result of Well #2X-DEV	187
Table 6.28. B10 Sandstone reservoir evaluation result of Well #2X-ST	188
Table 6.29. B10 Sandstone reservoir evaluation result of Well #2X-PL.....	189
Table 6.30. B10 Sandstone reservoir evaluation result of Well #1X.....	190
Table 6.31. B10 Sandstone reservoir evaluation result of Well #4X.....	191
Table 6.32. B10 Sandstone reservoir evaluation result of Well #5X-PL.....	192
Table 6.33. B10 Sandstone reservoir evaluation result of Well #6X.....	193
Table 6.34. B10 Sandstone reservoir evaluation result of Well #2P	194
Table 6.35. B10 Sandstone reservoir evaluation result of Well #5P	195

Table 6.36. Evaluation result of B10 Sandstone Reservoir of Vam Co oilfield	196
Table 6.37. C30 Sandstone Reservoir evaluation results of Vam Co oilfield.	200