CHAPTER 3

METHODS OF STUDY AND TECHNICAL CONSIDERATION

3.1 Introduction.

Because the Thai-Vietnam overlapping area is a frontier area and has limited geological data, most of the geological data used in this study are derived from its adjacent areas, the northern and the southern area.

The main objective of this study is to assessment the petroleum potential of the Thai-Vietnam overlapping area. In order to achieve the objective, this thesis is divided into four studied areas. The first is general geology, such as, stratigraphy and sedimentation evolution of this overlapping area. The second describes petroleum geology and petroleum engineering system of this overlapping area. The third is the potential of the undiscovered petroleum in the overlapping area. The fourth is economic assessment of the potential discovery within overlapping area.

3.2 Methods of stratigraphic correlation and sedimentological study.

Stratigraphic correlation and sedimentological analysis in this study are derived from wire line logs data. Gamma-ray log pattern is used to identify vertical sequence and log facies because of its properties responding to clay content and grain-size profiles in clastic sequence.

Data of stratigraphic depth is obtained from the result of log interpretation of Chonchawalit [40]. Then, the figures are used for constructing and outlined the distribution and regional extent maps of each stratigraphic unit I-IV.

3.3 Methods of petroleum geochemical considerations.

Results of geochemical analysis from well Yala-2, Kraphong-1, Kraphong-3, Platong-1, Platong-5, Platong-8, Surat-1, Ranong-1, Kung-1, South Platong-1, Pakarang-1, Pladang-3, Insea 1, South Platong-2, Trat-1, Satun-1, Satun-2, Satun-3, Dara-1, Erawan 12-1, Erawan 12-7, Erawan 12-8,Erawan 12-9, Krut-1, Erawan K-1, Jakrawan-1, Jakrawan- 2, Funan-1, Baanpot-1, Baanpot B1, 17-B-1 of Unocal Thailand and JDA are as qualified as value of S1, S2, S3, TOC and QOM respectively.

The qualified value of S1, S2, S3 TOC and QOM from the study of Chonchawalit [40] are used for constructing and outlined the distribution and regional extent maps of TOC and QOM of each stratigraphic unit I-IV respectively.

S1 represents the amount of hydrocarbons pre-exiting in the rock since deposition plus those already generated in the subsurface. S2 value represents the amount of hydrocarbon being generated during pyrolytic degradation of the kerogen. S3 value represents the carbon dioxide being generated during pyrolysis. The TOC value is used to indicate organic richness of the sediment being analyzed.

(S1+S2)/TOC ratio expresses the relative quality of organic matter or QOM. The QOM is a measure of the type of organic matter and thermal maturity which high ratios indicate maturity of hydrogen-rich strata. Espitalie *et al.* [59] mentioned that a significant spread in the QOM, which can not be related to variations in the degree of organic maturation (DOM), reflects the effects of migration of hydrocarbons into or out of the strata.

In order to assess the potential of petroleum source rocks, the distribution of organic richness, type, facies and maturity have to be examined. Organic richness is best determine as the average TOC content across the thickness of a potential source horizon rather than considering organic richness as a measure of organic matter concentrate. Tertiary stratigraphic succession in the Pattani trough is subdivided into units based on the geological association and palynological assemblages. Variation within the units are also described. As a result, regional evaluation of each unit can be discussed by considering how parameter differ and by considering their combined effects on potential hydrocarbon source rocks.

3.4 Methods of petroleum resources assessment.

The undiscovered resources assessment in the Thai-Vietnam overlapping area of this study is performed using FASPU program, play analysis and analytic method. Data used in this assessment were derived from its adjacent areas; the north, the west, and the south of study area as previous mentions.

3.4.1 FASPU program

The FASPU (Fast Appraisal System for Petroleum Universal) is a prototype package of programs to assess undiscovered oil and gas resources using a play analysis approach. Play analysis is a general term for various geologic models and probabilistic methods of analyzing a geologic play for petroleum potential.

The study or assessment areas will be separated to each group which has the similar geological characteristic and the same type of play attributes. Therefore, each play will be analyzed, including hydrocarbon accumulation in form of oil, oil with dissolved gas and non-associated gas.

The three geological attributes that concern with the assessment are;

1. Play Attributes
2. Prospect Attributes
3. Hydrocarbon Volume.

The characteristic of plays and prospects is the analyzing of presence or absence of the geological properties of plays and prospects. While the hydrocarbon volume attributes is the analyzing of the hydrocarbon accumulation.

Play attributes are consist of ;

1) the existence of a hydrocarbon source
2) timing for migration from source to the reservoir
3) the effective of the migration path

4) the existence of the potential reservoir facies.

The presence of these four characteristics is due to the play favorable for containing petroleum. On the other hand, if lack of one or more of these are not favorable, that mean, every play will not has any petroleum accumulations. The judgments for probability of the presence of each attribution of the play will be done by experts with subjective judgments. The product of the probability of these four attributions is equal to the probability of this play would have the petroleum accumulation, and is called "marginal play probability".

Prospect attributes are consist of ;

1) trapping mechanism
2) effective porosity
3) hydrocarbon accumulation.

In case of play attributes are favorable and there are the presence of above three attributes, it is enough to indicated that there are petroleum accumulation in that prospect. In the same way as in play level judgment, the probability of each prospect attribute will be expected by experts with subjective judgment. The product of these prospects attributes will be equal to the probability of that prospect will contain hydrocarbon, and if play is favorable, this probability is called "conditional deposit probability".

The hydrocarbon volume attributes are consist of ;

1) area of closure
2) reservoir thickness
3) effective porosity
4) trap fill (percent)
5) depth to the reservoir
6) hydrocarbon saturation.

Hydrocarbon volume attributes jointly determine the volume of hydrocarbon accumulation within the prospect. FASPU program use the following reservoir engineering equations to calculated the in-place volumes of oil and non-associated gas, respectively:

FASPU Basic Equations.

1. Oil in place

$$\text{Oil in place} = \frac{7758 \times 1000 \times A \times F \times H \times P \times Sh}{Bo} \quad \text{(MMBBL)}$$

2. Non Associated gas in place

$$\text{Non Associated gas in place} = \frac{1537.8 \times 1000 \times A \times F \times H \times P \times Sh \times Pe}{T \times Z} \quad \text{(BCF)}$$

where

A = Area of Closure (1000 Acre)

H = Reservoir thickness (ft)

F = Trap fill (decimal fraction)

P = Effective Reservoir porosity (decimal fraction)

Sh = Hydrocarbon saturation (decimal fraction)

Pe = Original reservoir pressure (psi)

B_o = Oil formation Volume Factor (STB/BBL)

T = Reservoir Temperature (degree Rankine)

Z = Gas compressibility factor

Both equations consist of a product factors that functions of the hydrocarbon volume attributes. The attributes are treated as continuous independent random variables, with the exception of the effective porosity which displays near perfect positive correlation with hydrocarbon saturation. The probability distribution for an attribute is determined from subjective judgments made by geologist, based on geological and geophysical data, analog data and geologic extrapolations when data are unavailable. The probability distribution for each attribute is described by a complementary cumulative distribution function determined from seven estimated fractiles (100^{th}, 75^{th}, 50^{th}, 25^{th}, 5^{th} and 0^{th}). The 5^{th} fractile, for example, is an attribute value such that there is a five percent chance of at least that value. In each play analyzed the seven fractiles are estimated for all of the hydrocarbon volume attributes, except hydrocarbon saturation whose seven fractiles are one of the two possible sets of fixed values depending upon the expected reservoir lithology. Hydrocarbon type probabilities are also estimated , which are the respective probabilities of a given accumulation being either oil or non-associated gas. However, if the reservoir depth is greater than a specified depth, the accumulation always is assumed to be non-associated gas. The number of drillable prospect in the play is treated as a discrete random variables, and seven fractiles are estimated. All of the geologic data required by this program for a play are entered on an oil and gas appraisal form (Figure 3.1).

3.4.2 Play analysis

Play concept

A play is a group of prospects with geologically similar source, reservoir and trap controls of oil and gas occurrence, and thus has geographic and stratigraphic limits [60]. It is a practical, meaningful planning unit around which an integrated exploration program can be constructed. A fundamental assumption is that the geological characteristics within a play are significantly correlated but show substantially less correlation between plays. If all the regional characteristics necessary for the occurrence of trapped hydrocarbons are present in the play area, it is likely that the play will contain oil or gas accumulations. However, if one or more of these regional characteristics are missing or unfavorable, it is likely that all the prospects within the play will be dry. The ideal method of assessing the play is to aggregated all the individual prospect assessments. However, lack of time and/or data commonly dictates use of the shortcut play approach like FASPU.

Play analysis methods have usually been applied to the appraisal of relatively small areas, such as a geological trend consisting of a reef play or sand deposited in

Evaluator : ____________________ Play Name : ____________________

Date Evaluated : ________________

	Attribute	Probability of Favorable or Present	Comments
Play attributes	Hydrocarbon source		
	Timing		
	Migration		
	Potential reservoir facies		
	Marginal play probability		
Prospect attributes	Trapping mechanism		
	Effective porosity (>3%)		
	Hydrocarbon accumulation		
	Conditional deposit probability		

	Attribute								
Hydrocarbon volume parameters	Reservoir lithology	Sand							
		Carbonate							
	Hydrocarbon	Gas							
		Oil							
	Fractiles / Attributes	Probability of equal to or greater than							
		100	95	75	50	25	5	0	
	Area of closure ($\times 10^3$ Acres)								
	Reservoir thickness / vertical closure (Ft)								
	Effective porosity %								
	Trap fill (%)								
	Reservoir depth ($\times 10^3$ Ft)								
	No. of drillable prospects (a play characteristic)								
Proved reserves ($\times 10^6$ Bbl; TCF)									

Figure 3.1 Oil and Gas appraisal data form (U.S. Department of Interior, 1979)

fans along major faults. Play analysis applied to entire stratigrphic units in a large basin or province will not be consistent with the definition. It is difficult to define the probability that a play is favorable if distinctly different prospect types have been lumped together. The lognormal distribution of accumulation size, which is the model used in the FASPU program, is based on an adequate play definition.

Plays defined at early stages of exploration are often refined and split into several plays as knowledge increased with continued exploration. In addition to the use of play analysis in resources planning , it can be considered as a working hypothesis in prospect mapping and evaluation [60].

The probability of a favorable play attributes.

Assuming the play has been properly defined, the next step is to define the probability that the various play attributes are favorable or present. The parameters involved are: hydrocarbon sources, timing, migration and potential reservoir facies. For each of these four play attributes one has to assign a value between 0 (not present/not favorable) and 1.0 (certainly present/ favorable). The definition of the various attributes is;

Hydrocarbon source: The existence of a mature source rock somewhere in the study area that has generated and expelled oil or gas insufficient quantity to form at least one accumulation within the play. The source rock should contain a minimum of 0.5 percent organic matter, have source rock quality and maturity of minimum 0.6 percent (vitrinite reflectance) for oil generation and 1.2 percent (vitrinite reflectance) for gas generation.

Timing: The trapping and sealing mechanism was established before and/or simultaneously with the generation and migration of hydrocarbons.

Migration: Hydrocarbons have migrated from the source rock(s) in sufficient quantity and in the direction to form at least one accumulation somewhere in the play area.

Potential reservoir facies: Within the play area there exists a rock that may contain porosity and permeability capable of containing predicable hydrocarbons.

The probability that all the first four play attributes are simultaneously favorable or present is the product of the four separate play attributes, and is called the marginal play probability. If a discovery has been made within the play, the marginal play probability equals 1.0. However, the presence of all four play attributes is a necessary, but not sufficient, condition for the existence of oil or gas accumulations in the play.

Additional play attributes are the number of drillable prospects. The reservoir lithology (no influence on the calculations) and the hydrocarbon mix (the proportion of accumulations that may contain oil rather than non-associated gas). These attributes will be discussed in more detail below.

The probability of favorable prospect attributes.

Assuming that the conditional play probability equals 1.0, the next step is to decide on the probability that the prospect attributes are favorable or present. These prospect probability include the probability of trapping mechanism, effective porosity and hydrocarbon accumulation. The product of these three attributes is called conditional deposit probability. Given a favorable play, the presence of all three attributes is a necessary and sufficient condition for the existence of a hydrocarbon accumulation in the prospect.

In order to determinate the probability that a specific prospect attribute is favorable or present, it is necessary to define the minimum value (threshold value) for the related hydrocarbon volume parameter(s). For example, if the minimum acceptable porosity is 7 percent, the probability that the effective porosity is favorable is the probability that the effective porosity is 7 percent or higher. The minimum threshold values are selected to be less than any reasonable economic limit.

The trapping mechanism includes the probability of closure (existence of a mappable trap) and the probability of sealing, and trapping mechanism is not considered to be a play attribute. The recorded value indicates that the number of prospects having a sealed trap divided by the total number of prospects [61].

The probability that the effective porosity is equal to or larger than a minimum value (7 percent for gas and 10 percent for oil) and that the reservoir thickness is greater than the minimum value chosen for reservoir thickness determine this prospect attribute, and the risk that no reservoir rock has been deposited is taken care of by the play attribute "potential reservoir rock". It is important to avoid double-risking. In the special case of stratigraphic traps, the assessment of effective porosity is made dependent upon the occurrence of the trap. If the reservoir rock, with porosity above the threshold value, is limited to parts of assessed area, this will have consequences for the number of drillable structures.

The hydrocarbon accumulation attribute covers the probability that the traps have received at least a minimum amount of hydrocarbons (related to source rock, migration and timing) and program defines this minimum to be 1 percent of the trap capacity. In an exploration situation the well are mostly drilled outside the culmination of the trap, and a higher threshold value (e.g. 10 percent) should be considered. Assuming that the play is favorable, this attribute determiners the number of structure having received hydrocarbons divided by the total number of structures.

The product of the marginal play probability and the conditional deposit probability is called the average prospect chance (the probability of discovery). The product should not be higher than the success rates normally seen in the play or analog plays, and should be related to the probability of discovery used in standard prospect assessment in the area.

The Hydrocarbon mix.

This play characteristic describes the proportion of deposits within the play that contain oil rather than non-associated gas. Oil accumulations with gas cap and/or gas in solution is here classifieds oil. The sum the values entered for oil and gas must equal 1.0. For example, a mix of 0.3 (oil) and 0.7 (gas) indicates that 30 percent of the hydrocarbon bearing structures in the play are oil-filled.

The basis for the estimation of the hydrocarbon mix is information on sources rock quantity and quality, maturation and information from wells and seeps.

Hydrocarbon volume parameters

When the hydrocarbon volume parameters are being assessed, it is assumed that both the marginal play probability and the conditional deposit probability equal 1.0. The following parameters are included: area of closure, net reservoir thickness corrected for the geometry of the structures, effective porosity, trap fill, reservoir depth and hydrocarbon saturation. They describe the range of possibility value of the reservoir characteristics that determine the volume of hydrocarbons present in an individual accumulation within the play. Evaluation of these parameters is accomplished by recording the estimated value at seven fractiles (probability levels) ranging from 100 percent (total certainly that this estimated value will be attained) to 0 percent (total certainly that the estimated value will not be exceeded). The distribution is therefore cumulative.

An additional parameter, the number of drillable structures, is actually a play attribute, but will be discussed along with the hydrocarbon volume parameters.

The area of closure parameter estimates the possible range for the number of thousand acre within a trap above the spill point. The program uses a minimum value of 0.6 thousand acre to be used for this parameter. This minimum value is very important for the number of drillable-prospects parameter.

In areas with poor seismic coverage this parameter is difficult to determine but we can compare the study area with better known areas with similar tectonic development, such as this overlapping area and Pattani trough. In explored areas the largest traps have often been drilled.

The reservoir thickness is entered as the product of gross reservoir thickness, net to gross ratio a geometry factor. The geometry factor is a value between 0 and 1.0, and accounts for the thinning of a full hydrocarbon column at the edge. In Figure 3.2 a method for determination the geometry factor is illustrated. The definition of the net to gross value should be related to the cut off value chosen for the effective porosity. Crovelli and Balay [61] proposes 5.34 ft as a minimum value for the net reservoir thickness. But this study consider 16.7 ft as a more realistic minimum value in exploration situation. This minimum value should be considered when determination the number of drillable-prospects play attribute.

TRAP GEOMETRY MULTIPLIER

Reservoir thickness / height of closure	Dome, cone, pyramid	Anticline, prism, cylinder		Flat-top dome	Flat-top anticline		Block, vertical cylinder
L/W	1	2	10	1	2	10	
≥1.0	.34	.42	.49	.59	.68	.74	1.0
0.9	.37	.45	.54	.63	.71	.77	1.0
0.8	.41	.51	.60	.67	.74	.80	1.0
0.7	.47	.56	.65	.71	.78	.83	1.0
0.6	.53	.61	.71	.76	.81	.86	1.0
0.5	.59	.67	.76	.80	.84	.89	1.0
0.4	.66	.73	.81	.84	.88	.91	1.0
0.3	.74	.80	.86	.88	.91	.93	1.0
0.2	.83	.87	.91	.93	.95	.96	1.0
0.1	.92	.94	.96	.97	.98	.99	1.0
0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Figure 3.2 Trap geometry multiplier (After Covelli and Balay, 1986)

The effective porosity is determined by the amount of interconnected pore space in the reservoir rock. Crovelli proposes a small (cut off) value at 3 percent for this parameter. In this study would have used 8 percent for gas filled traps and 10 percent for the oil filled traps. The minimum value is incorporated into the effective porosity (prospect attribute) judgment.

The trap fill parameter estimates the possible range for trapped hydrocarbon volume as a percentage of the porous volume under the closure. The probability that this minimum value is achieved is incorporated into the determination of the hydrocarbon accumulation prospect attribute . As discussed earlier a minimum trap fill of 30 percent has been used in this study.

The reservoir depth parameter describes the possible range for the depth that must be drilled to penetrate the reservoir.

The number of drillable-prospects parameter describes the range of possible value for the number of valid targets that would be considered for drilling if the play were to be fully explored. Only prospects larger than the minimum value chosen for the area of closure parameter should be included. The distribution of the number of drillable-prospects parameter also takes into account the probability that the reservoir formation by may be absent in parts of the play area.

Seismic and geological mapping and analogy from better known areas of similar geology should be used in the evaluation of this parameter. This study uses the tectonic style of the study area and closed areas be the guide to find analog areas with a known prospect density.

Geological variables as a function of depth.

The estimation of the resources within a play requires that a number of reservoir engineering equations are included in the FASPU program. The following depth related parameters are needs as input data:

Pe : Original Reservoir Pressure (psi)

T : Reservoir Temperature (Deg Rankine)

Rs : Gas-Oil Ratio (MCF/BBL)

Bo : Oil Formation Volume Factor (No units)

Z : Gas Compressibility Factor (No units)

These variables can be modeled using one of four different mathematical functions (Zoned linear, exponential, power and logarithmic). Each of these four types of mathematical functions has two parameters A and B, except zoned linear, which has a set of A and B coefficients for each zone.

The FASPU program calculates the mean and variance of the accumulation size of oil (and gas) using the hydrocarbon volume parameters, the geological variable (functions) and a reservoir engineering equation. The accumulation of size distribution is then modeled by the lognormal probability distribution. The lognormal distribution is assumed to give a fair representation of the real accumulation distribution within a play.

Miscellaneous parameters.

The oil floor depth is the depth below which the reservoir oil has cracked into gas. By using the temperature gradient in the play area the equivalent depth can be calculated.

The oil recovery factor estimated from local data. In addition to the reservoir condition, it is very much dependent upon the recovery methods to be used. The gas recovery factor determined in the same way as the oil recovery factor.

3.4.3 Analytic Method.

The analytic method is based upon the same geologic model, same type of data, and same probability assumptions as the simulation method [61].

The analytic method was developed by the application of many laws of expectation and variance in probability theory. The analytic method systematically tracks through the geologic model, computes all of the mean and variance of the appropriate random variables, and calculates all of the probabilities of occurrence. The lognormal distribution is used as a model for various unknown distributions in order to arrive at probability fractiles. Oil, non-associated gas, dissolved gas, and gas resources are each assessed in turn. Separate methodologies have been developed for analyzing individual plays and for aggregating the plays. The basic steps of the analytic method of play analysis are simply shown in Figure 3.3 (for details see Appendix A).

3.5 Conceptual development plan.

Conceptual exploration plays type.

Prididtan [54] and Sattayarak [41] suggested that the major and significant plays type of the Thai-Vietnam overlapping area is Miocene Faulted Sandstone as evident from the existing production plays type of Bongkot field and JDA. Therefore, the conceptual exploration plan will stress on this faulted sand play type (Figure 3.4).

Conceptual platform plan and development wells located.

Platform will be located behind faulted trap structure (Figure 3.5) and conceptual development wells will also be located behind this structural closure with well spaced at approximate 1 kilometer throughout closure (Figure 3.6).

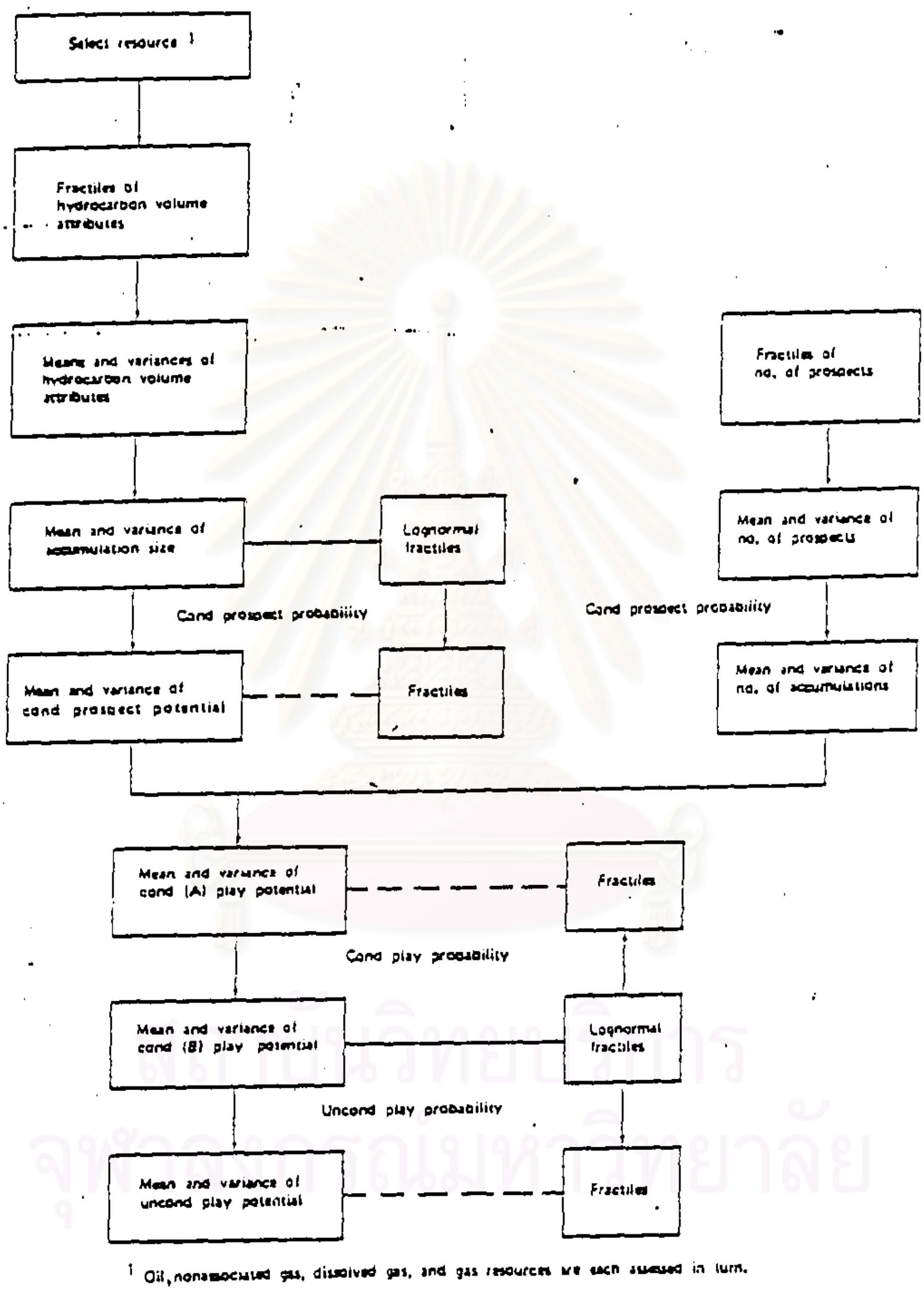

Figure 3.3 Flowchart of analytic method of play analysis (After Covelli and Baly, 1986).

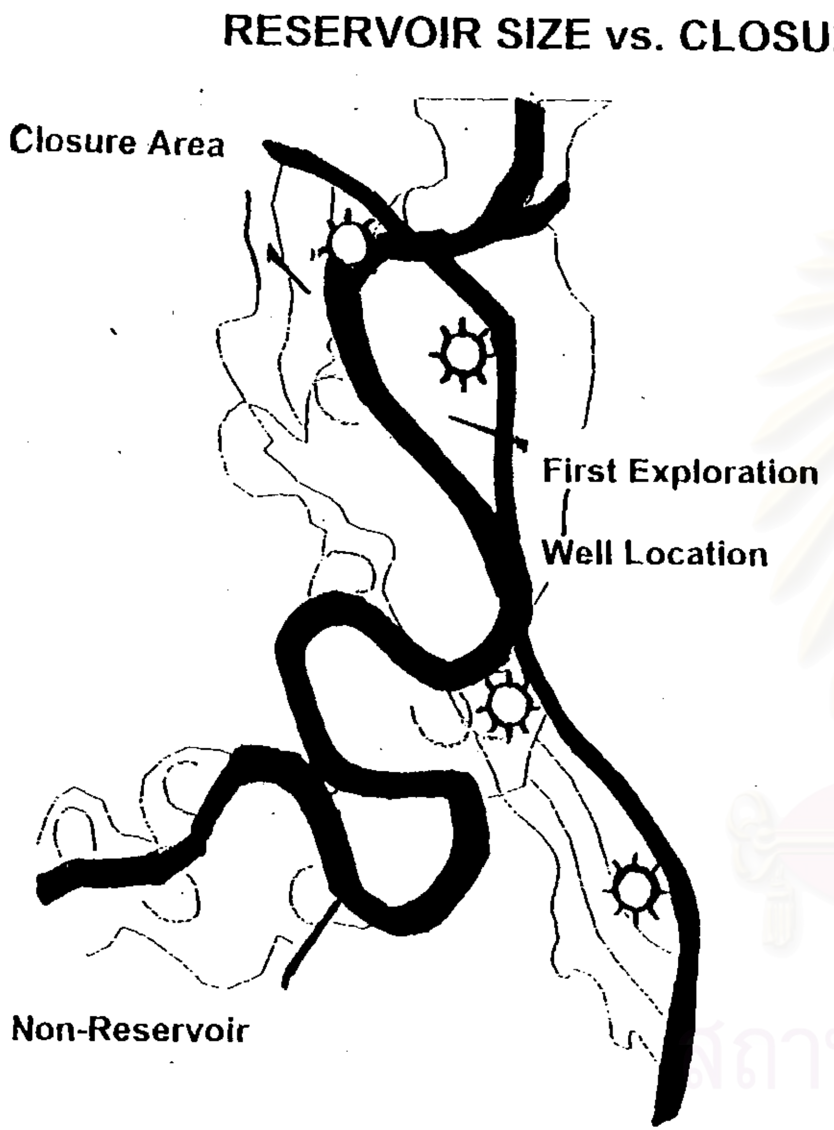

Figure 3.4 Conceptual exploration plays type (Faulted Sandstone), reservoir sizing and closure area limitation.

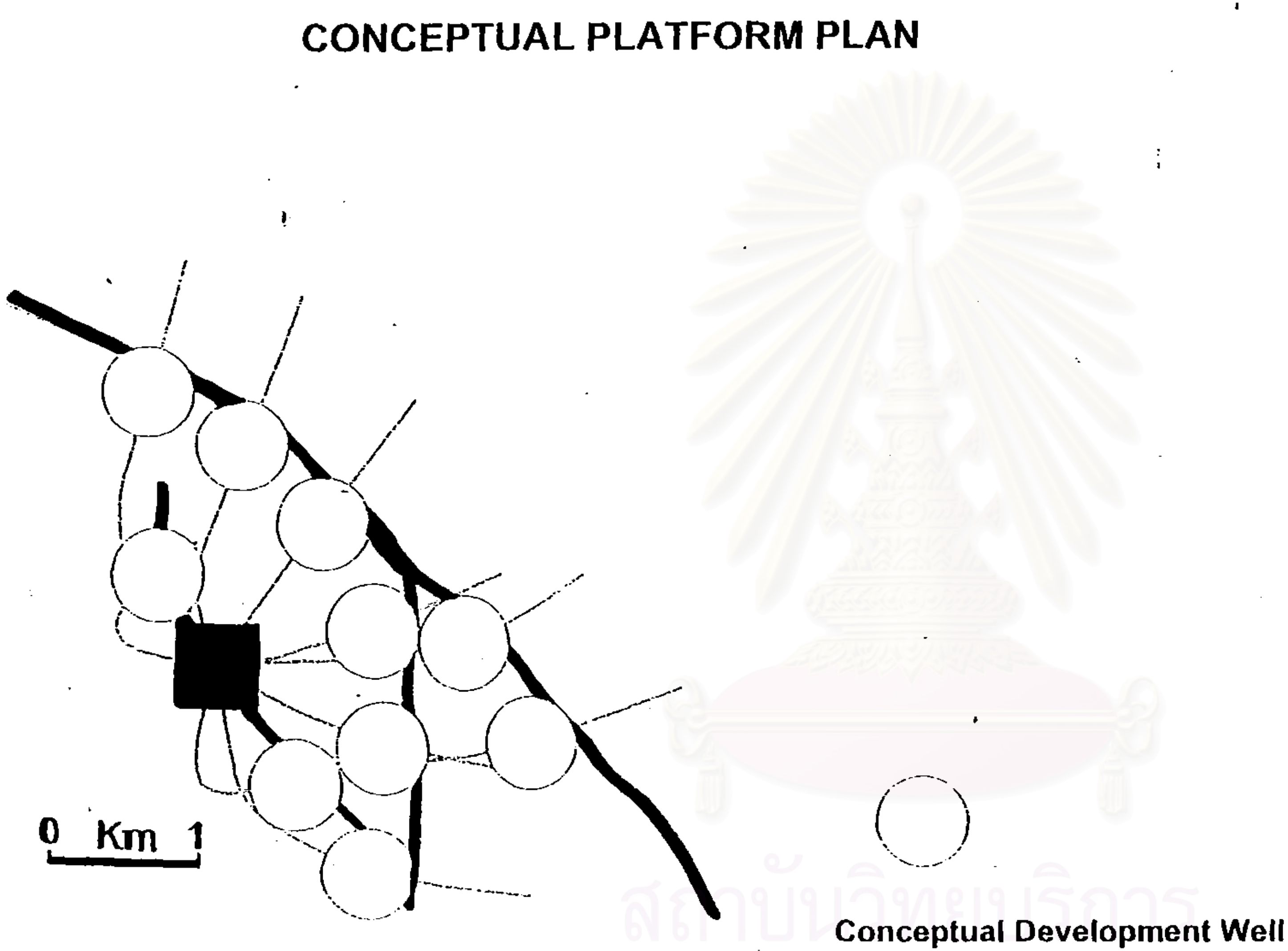

Figure 3.5 Conceptual platform planning and its location.

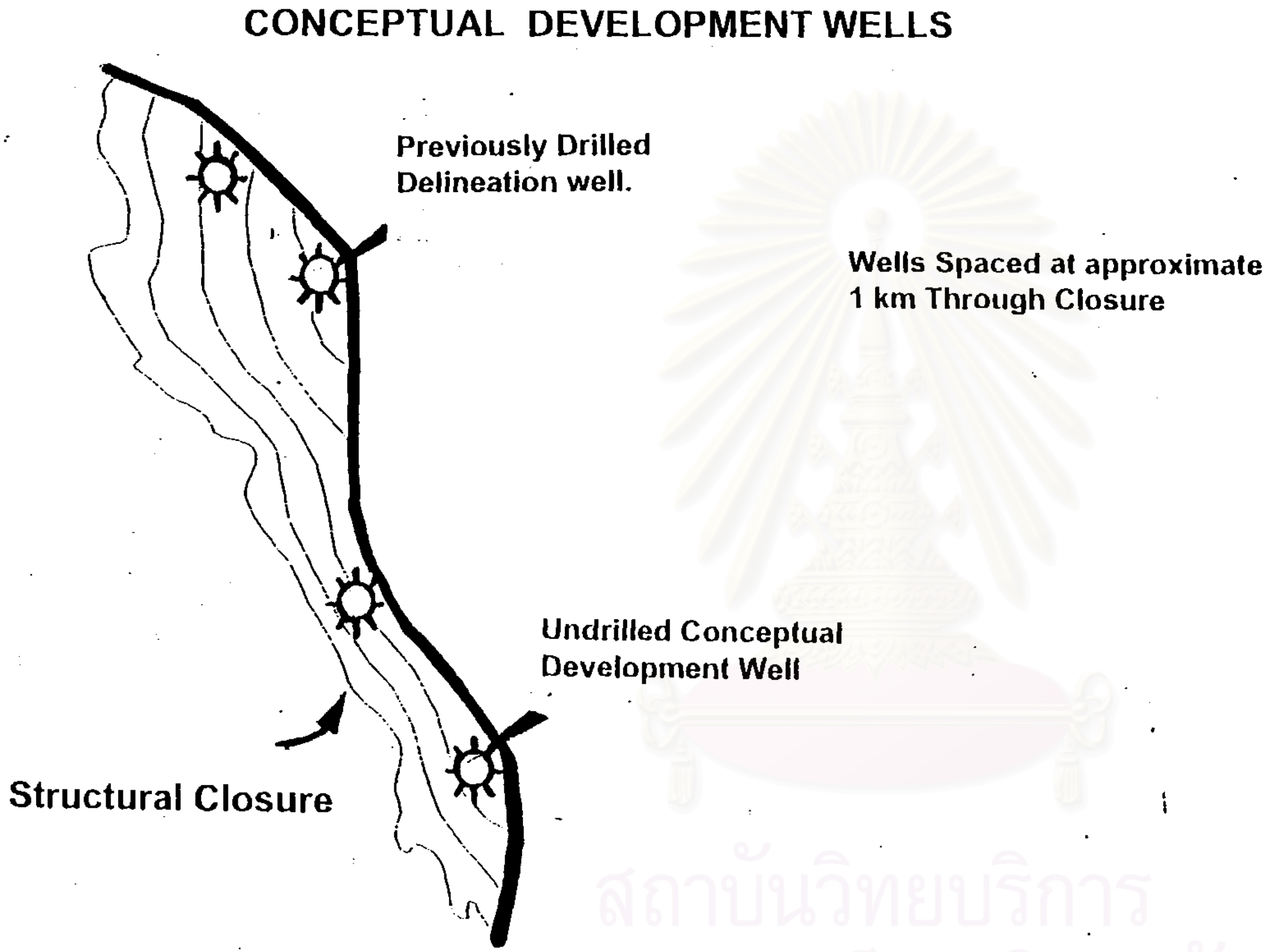

Figure 3.6 Conceptual development well located.

3.6 Petroleum economics evaluation.

Petroleum reserve from the previous step will be conducted to do economics evaluation in this section. The exploration work plan, production planning and engineering designed are also considered and designed in this step. The study for petroleum economic potential is based on Thailand III fiscal regime, recent petroleum contract used in Thailand. Thailand III fiscal regime is described in Appendix B.

Cash flow analysis using Thailand III fiscal regime is further study for its sensitivity of the investment based on following assumptions;

1. The price of gas and condensate has an escalation of 2 percent per year.
2. Increasing rate of Capital Expenditure comes from the price increasing of machinery and other equipment used in oil industry, and given to 2 percent per year.
3. Discount Rate of money which used in this study is 10, 12.5, 15, 17.5 and 20 percent respectively.
4. The first production will conduct in the sixth year of work plan.
5. Operating Cost is escalated 2 percent each year forward.

This study will not consider the Signature Bonus, Production Bonus and other Benefits to the State besides previous mentioned.