CHAPTER V

EFFECTS OF PROPERTIES OF INPUT VARIABLES ON CALCULATED OIL RESERVE

In this chapter, effects of properties of input variables on calculated oil reserve will be investigated. It is certain that uncertainty of eight input variables used in volumetric equation for oil reserve calculation causes uncertainty of calculated oil reserve. Due to the simplicity of the form of the volumetric equation, it can be seen that effects of uncertainty of the eight input variables on the uncertainty of the calculated oil reserve will depend on the magnitude and degree of uncertainty of each variable. Therefore, effects of uncertainty of the input variables will not be investigated in this study.

However, the following properties of input variables on calculated oil reserve will be investigated:

1. number of blocks used in the calculation,

2. statistical relationship between porosity and water saturation,
3. spatial correlation of porosity.

Study of Effects of Number of Blocks on Calculated Oil Reserve.

Generally, when Monte Carlo simulation is applied to oil reserve calculation, a reservoir is treated as a block. One value of each input variable is assigned for the whole block (or reservoir) for each simulation (realization). As already mentioned, it is an exception that a reservoir has uniform value of each input variable. In fact, it is more realistic that each input variable has different value at different location in the reservoir. Therefore, to improve the calculated results a reservoir should be divided into blocks. Size of the block will be dictated by amount of information obtained. If there are informations from several locations, a number of blocks may be large because there is sufficient information (either measured or estimated) to be assigned to a large number of blocks. However, if there are information only for a few locations, a number of blocks has to be small. In this latter case, though the reservoir is divided into a large number of blocks the calculated results will not be improved because so many values of input variable have to be estimated.

To investigate the effect of the number of blocks on the calculated oil reserve data for input variables listed in Table 4.4 are used. These data are used for all nine cases considered. Each case has different number of blocks as shown in Table 5.1. The number of simulations (or realizations) used for all cases is 600.

Table 5.1. The number of blocks in each calculation.

run number	number of blocks
1	1x1
2	2x1
3	3x1
4	2x2
5	5x1
6	5x2
7	5x5
8	10x5
9	10x10

Distribution curves of oil reserves for four cases (1x1, 2x2, 5x5, and 10x10 blocks) are shown in Figure 5.1. Mean and standard deviation of oil reserves for all nine cases are shown in Figures 5.2 and 5.3, respectively.

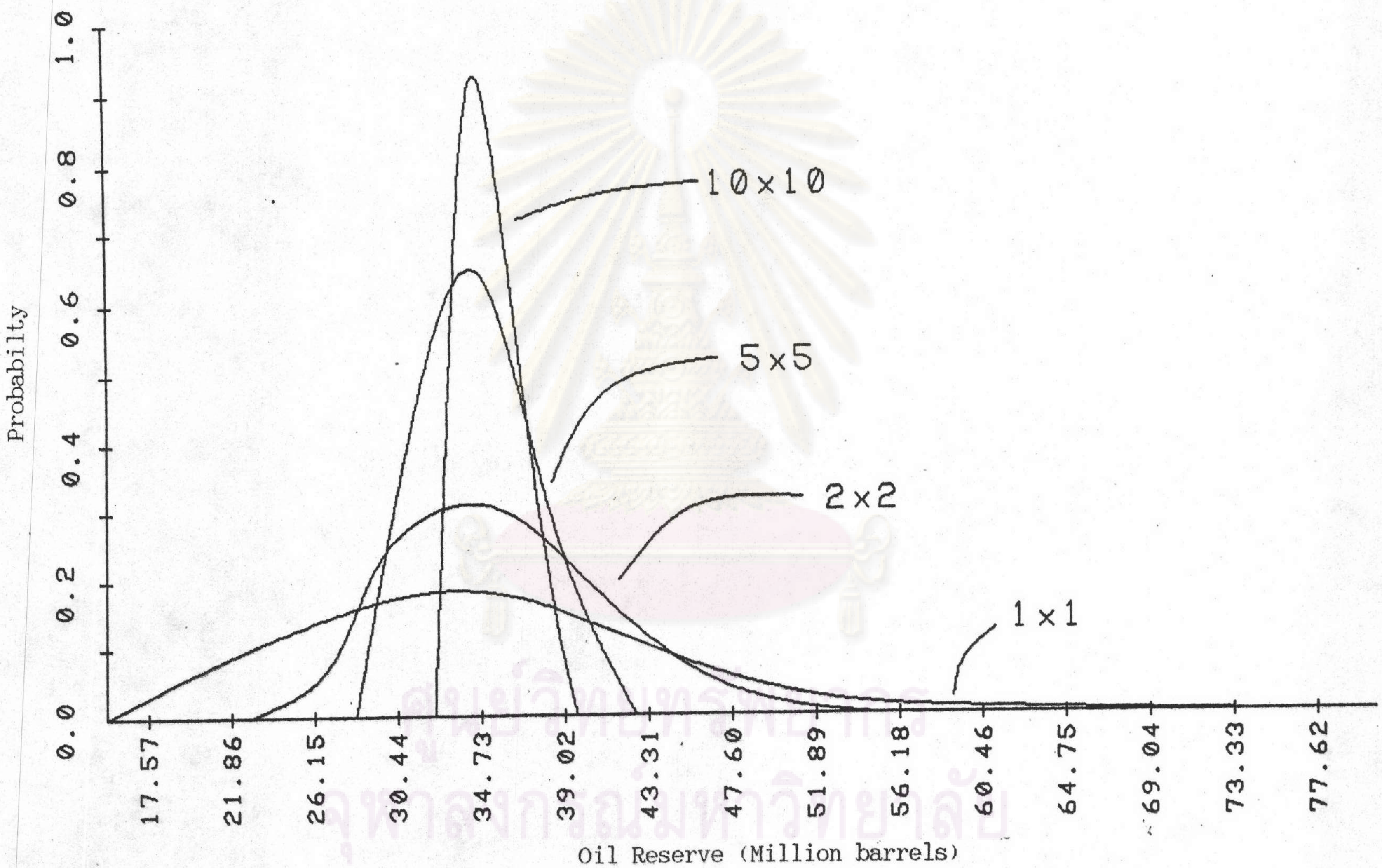

Figure 5.1. Probability density function of oil reserve at several number of blocks.

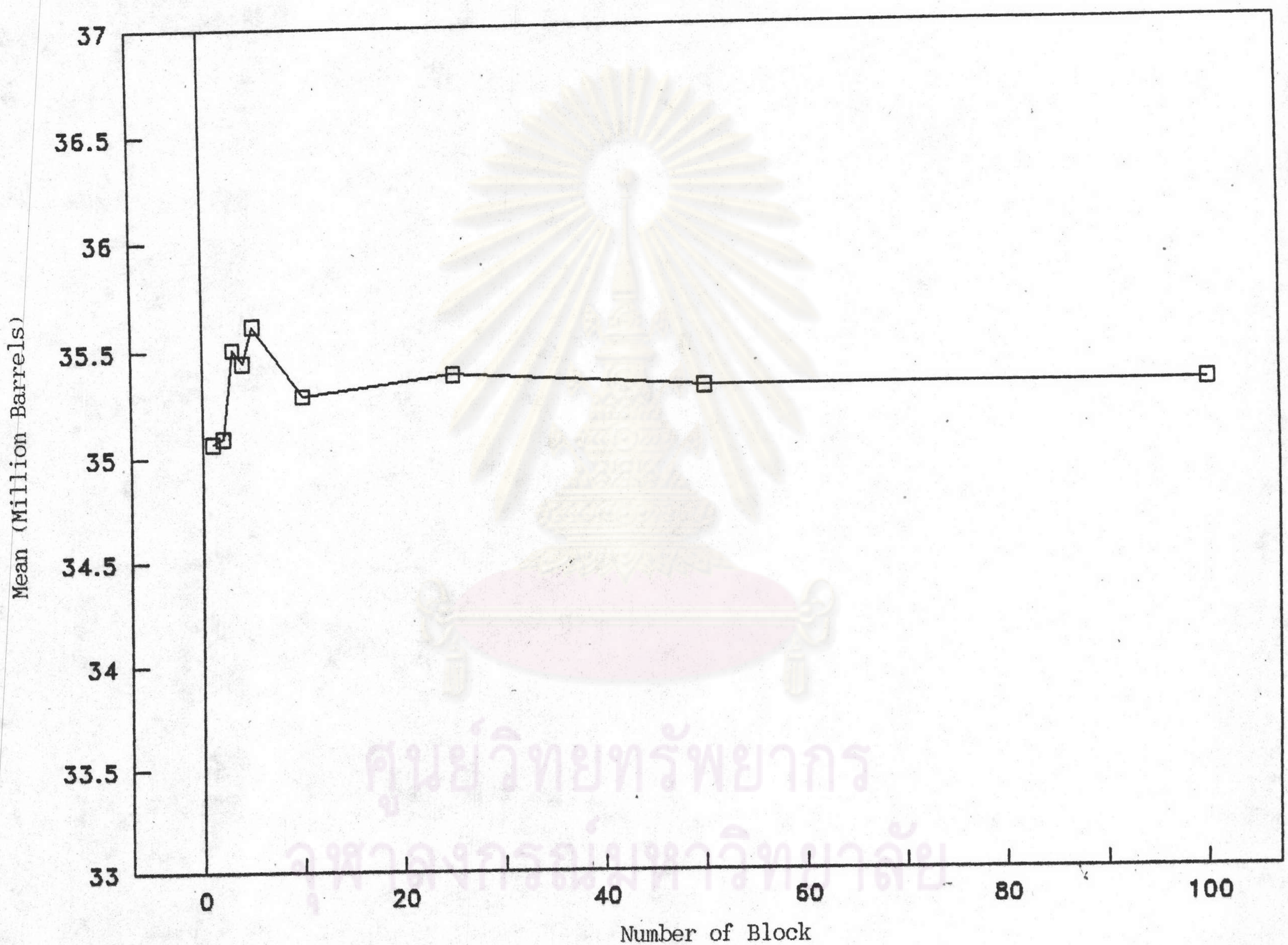

Figure 5.2. Mean of calculated oil reserve vs. number of blocks.

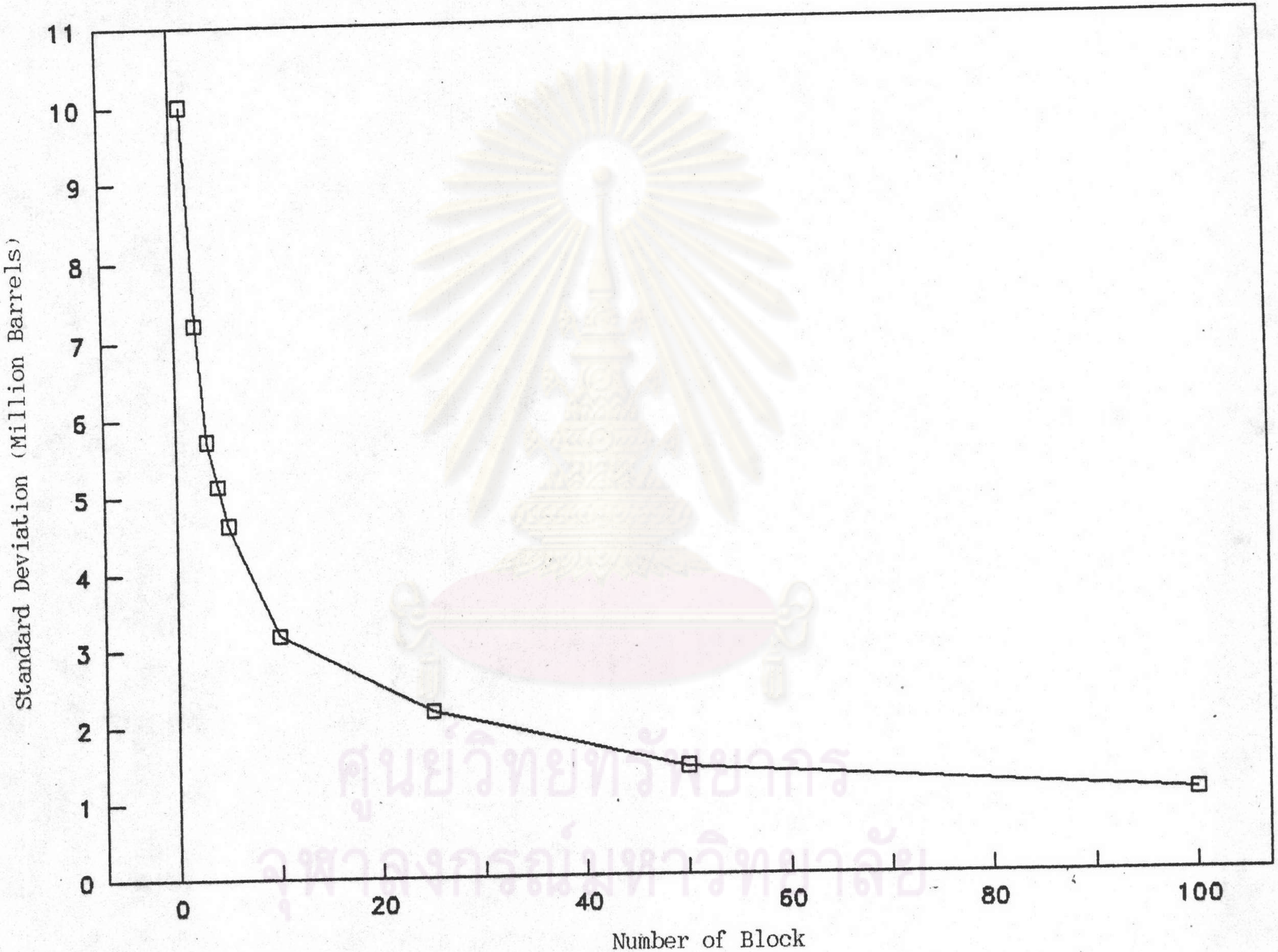

Figure 5.3. Standard deviation of calculated oil reserve vs. number of blocks.

From Figures 5.1 and 5.2, it can be seen that means of the calculated oil reserve for all nine cases are almost the same (vary from 35.07-35.60 million barrels). However, as a number of blocks increases, the values of standard deviation decrease as shown in Figure 5.3.

From the results obtained, it cannot simply be concluded that as a number of block increases, the uncertainty in calculated oil reserve decreases due to decrease of standard deviation. This can be explained by considering relationship between standard deviation (or even better, variance) and size of sample or volume of interest. This relationship is already wellknown in geostatistical literature. The fact is that as volume of interest is smaller, generally the variance would be larger; that is there is higher variation in value of the variable. For example, porosity values obtained from sample size of 1x1 cm. would have higher variation (equivalently high variance or standard deviation) the porosity values obtained from sample size of 1x1 m. This is because by using large sample size, the porosity values are obtained by averaging over a larger volume. On the other hand, by using a small sample size, the porosity values are obtained by averaging over a smaller volume. Usually range of porosity values obtained by using smaller sample size would be larger than range of porosity values obtained by using larger sample size. Therefore, there is higher variation in porosity values obtained by using smaller sample size.

In this study, when the number of blocks is increased and the same distributions for input variables are used, it is equivalent to the system that has the same range of variation in values of input variables for any size of blocks. This is not true in reality. Therefore, the conclusion that uncertainty in calculated oil reserve, which is dependent on uncertainties in input variables, decreases with increase in number of blocks is not correct.

Though such conclusion cannot be made, the results in this study illustrate a very important observation. That is, it must be made certain that the correct relationship between distribution curves of input variables and size of the block is used. To treat a reservoir as a single block, uncertainties in or distribution curves of input variables have to be carefully assigned. They (uncertainties or distribution curves) must be constructed based on the size of the reservoir. For example, a distribution curve for porosity should not be constructed using porosity values along the depth of the well obtained from log interpretation. These porosity values represent a small sample size assigned by log analyst. To use these small sample-size porosity values to construct a distribution curve of porosity for using with a single block reservoir, they must be transformed by correct and appropriate method so that their transformed values are representative for a single block reservoir.

The above observation is important for anyone doing a reserve estimation using Monte Carlo method. He must be very careful in constructing distribution curves for input variable, otherwise his results will be meaningless. Using a system of a single block reservoir, he must assign or estimate all values of input variables based on a reservoir-size block. By doing this he will obtain correct distribution curves for input variables.

Similarly, if it is decided that the reservoir should be divided into blocks as part of the process for oil reserve estimation, all distributions curve of input variables must be constructed from input-variable values which are based on the size of the divided block. The advantage of dividing a reservoir into block is that other statistical properties of input variables, such as relationship between input variables and spatial correlation, can be incorporated in the estimation process. This, hopefully, would improve the obtained results.

In short, it can be stated that the study of the effect of number of blocks on the calculated oil reserve leads to the important observation that the distribution curves of or the uncertainties in input variable must be corresponding to the size of the block used in calculation.

Study of Effects of Statistical Relationship Between Porosity and Water Saturation on Calculated Oil Reserve.

For the case that there is a statistical relationship between any two input variables involving in volumetric oil reserve calculation using Monte Carlo simulation, values of one variable will depend on those of the other. In this study the effects of statistical relationship between two input variables, porosity and water saturation, on calculated oil reserve will be investigated. If this statistical relationship affects calculated oil reserve, it should be included in oil reserve calculation using Monte Carlo simulation so that as much as properties of input variables are taken into account in the calculation process.

The developed computer program in this study has an option for including statistical relationship between porosity and water saturation. This statistical relationship will be incorporated into the calculation in form of an equation presented in Equation (3.3). For each Monte Carlo loop, a value of porosity will be generated using a random number and its cumulative distribution function, a value of water saturation will be then assigned using substitution of the value of porosity in Equation (3.3), and magnitude of the random part which, in turn, are obtained by using random number and specified distribution function.

In general, at a sampling point within a reservoir there is an inverse relationship between magnitude of porosity and water saturation. That is, when porosity is large, water saturation would, generally, be small. Therefore, it would be assumed that the relationship between porosity and water saturation is linear with negative slope and random part having normal distribution with mean equal to zero. It is also assumed that there is no correlation for the random part. The form of the equation for statistical relationship of porosity and water saturation is shown below,

$$S_w = A\phi + B + \delta \qquad (5.1)$$

In the calculation A and B are assigned to be equal to -0.8 and 0.7, respectively, and standard deviation of the random part is assigned to be equal to 0.05 and 0.10. Data for input variables are listed in Table 5.2. In the investigation, eight cases are considered (Table 5.3). The standard deviation of the random part is equal to 0.05 for the first four cases and 0.10 for the last four cases. Number of blocks used in the calculation are 25 and 625 blocks.

Table 5.2. Data for study effects of statistical relationship between porosity and water saturation.

Variable and their parameters
1. Area type of distribution: deterministic value value = 4,000 acres
2. Recovery factor type of distribution: deterministic value value = 0.12
3. Gross thickness type of distribution: normal distribution mean = 200 feet standard deviation = 10 feet
4. Net to gloss ratio type of distribution: deterministic value value = 0.6
5. Oil sand to net sand ratio type of distribution: deterministic value value = 0.7

Table 5.2 (continued). Data for study effects of statistical relationship between porosity and water saturation.

Variable and their parameters	
6. Initial oil formation volume factor	
type of distribution:	deterministic value
value =	1.2
7. Porosity	
type of distribution:	triangular distribution
maximum =	0.3
minimum =	0.1
mode =	0.24

The effect of statistical relationship between porosity and water saturation is investigated by comparing similar systems (same number of blocks and same properties for random part) with the case of having and not having statistical relationship between porosity and water saturation. For all cases, the number of simulations is 600.

Table 5.3. Conditions of each calculation for studying statistical relationship between porosity and water saturation.

case number	relationship	number of blocks	std. dev. of random part
1	no	5x5	0.05
2	yes	5x5	0.05
3	no	25x25	0.05
4	yes	25x25	0.05
5	no	5x5	0.10
6	yes	5x5	0.10
7	no	25x25	0.10
8	yes	25x25	0.10

For the cases without statistical relationship between porosity and water saturation, the distributions for water saturation (corresponding to cases having standard deviation of random part equal to 0.05 and 0.10) are obtained by using Equation (5.1) and whole range of possible values of porosity. The obtained distribution are as follows:

In the case corresponding to the (with-relationship) case with standard deviation of random part of 0.05,

distribution; triangular distribution

maximum = 0.676

minimum = 0.398

mode = 0.520

For the case corresponding to the (with-relationship) case with standard deviation of random part of 0.10,

distribution; triangular distribution

maximum = 0.790

minimum = 0.287

mode = 0.550

Probability density functions of resulted oil reserve are presented in Figures 5.4 to 5.7. The values of mean and standard deviation of resulted oil reserve for all cases are presented in Table 5.4.

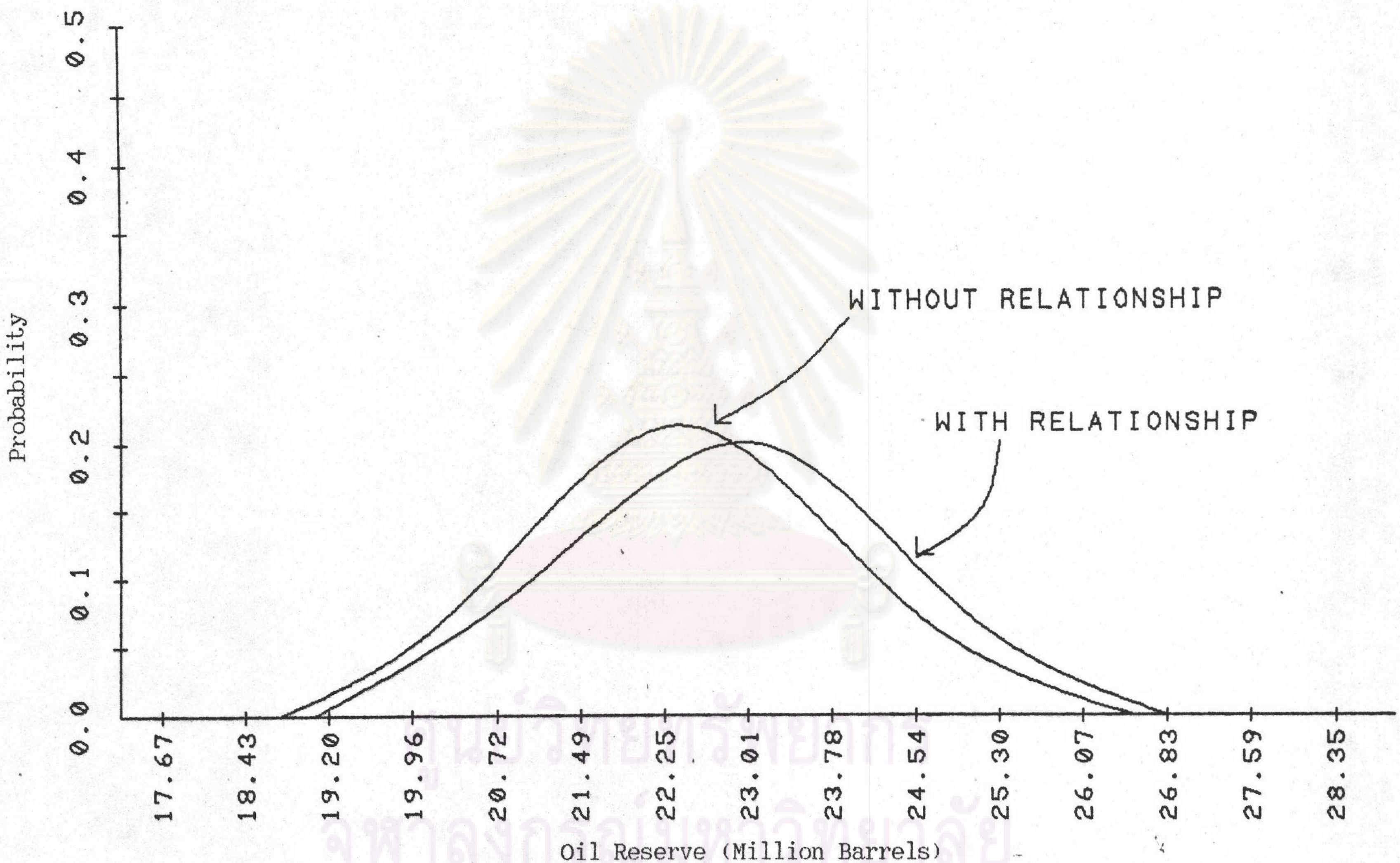

Figure 5.4. Probability density function of oil reserve for studying effect of statistical relationship between porosity and water saturation (number of blocks = 5x5 and std. dev. of random part = 0.05).

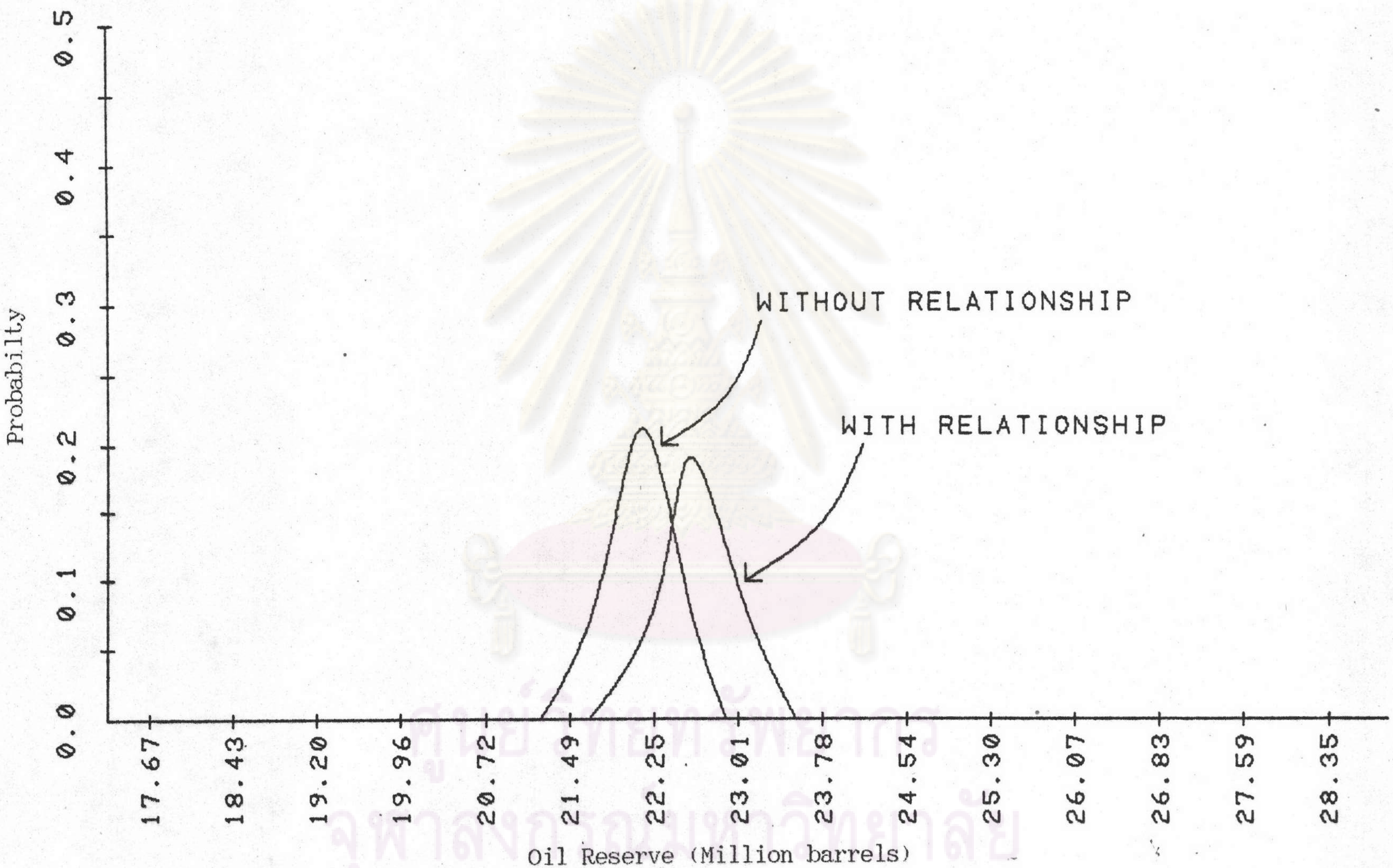

Figure 5.5. Probability density function of oil reserve for studying effect of statistical relationship between porosity and water saturation (number of blocks = 25x25 and std. dev. of random part = 0.05).

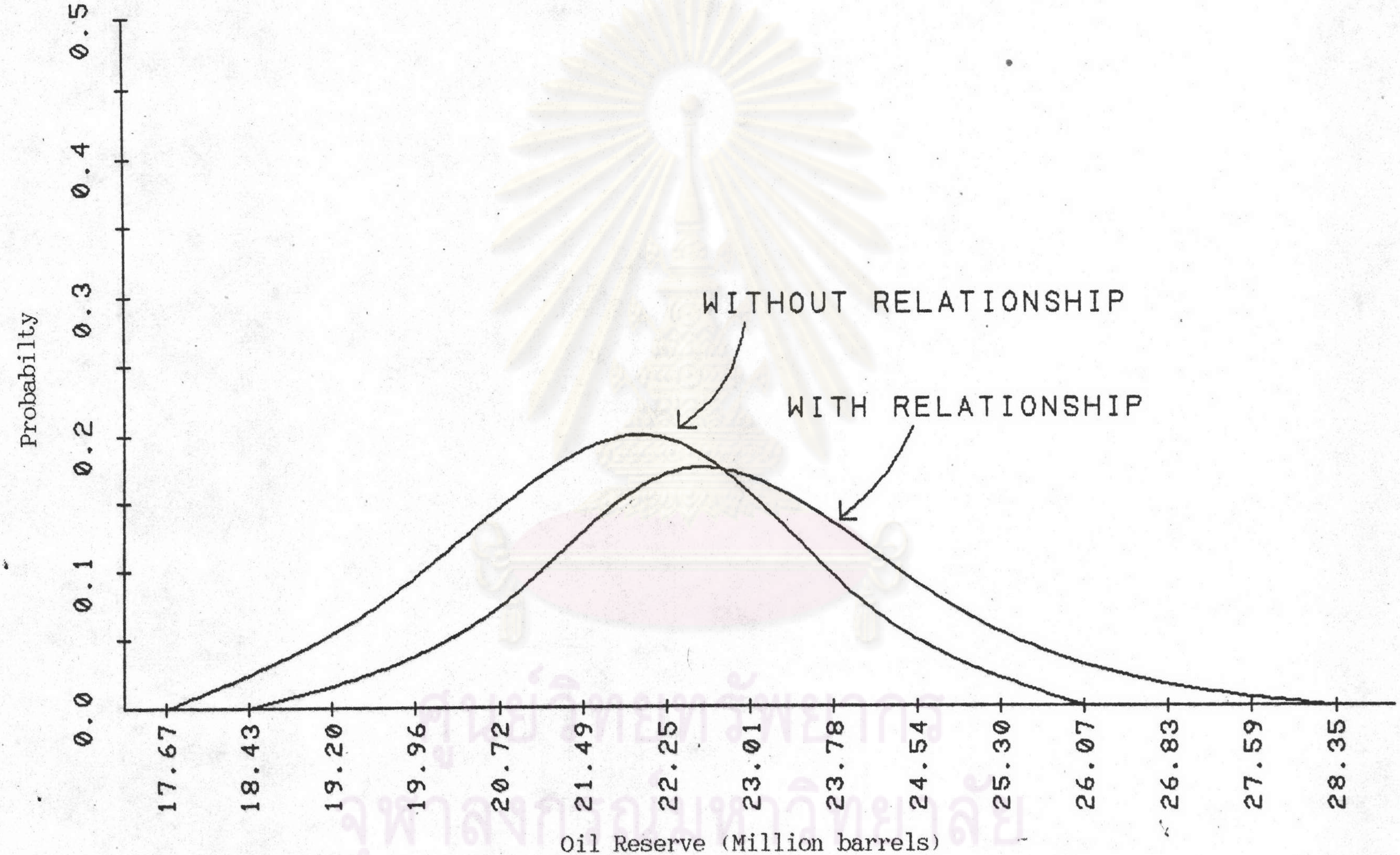

Figure 5.6. Probability density function of oil reserve for studying effect of statistical relationship between porosity and water saturation (number of blocks = 5x5 and std. dev. of random part = 0.1).

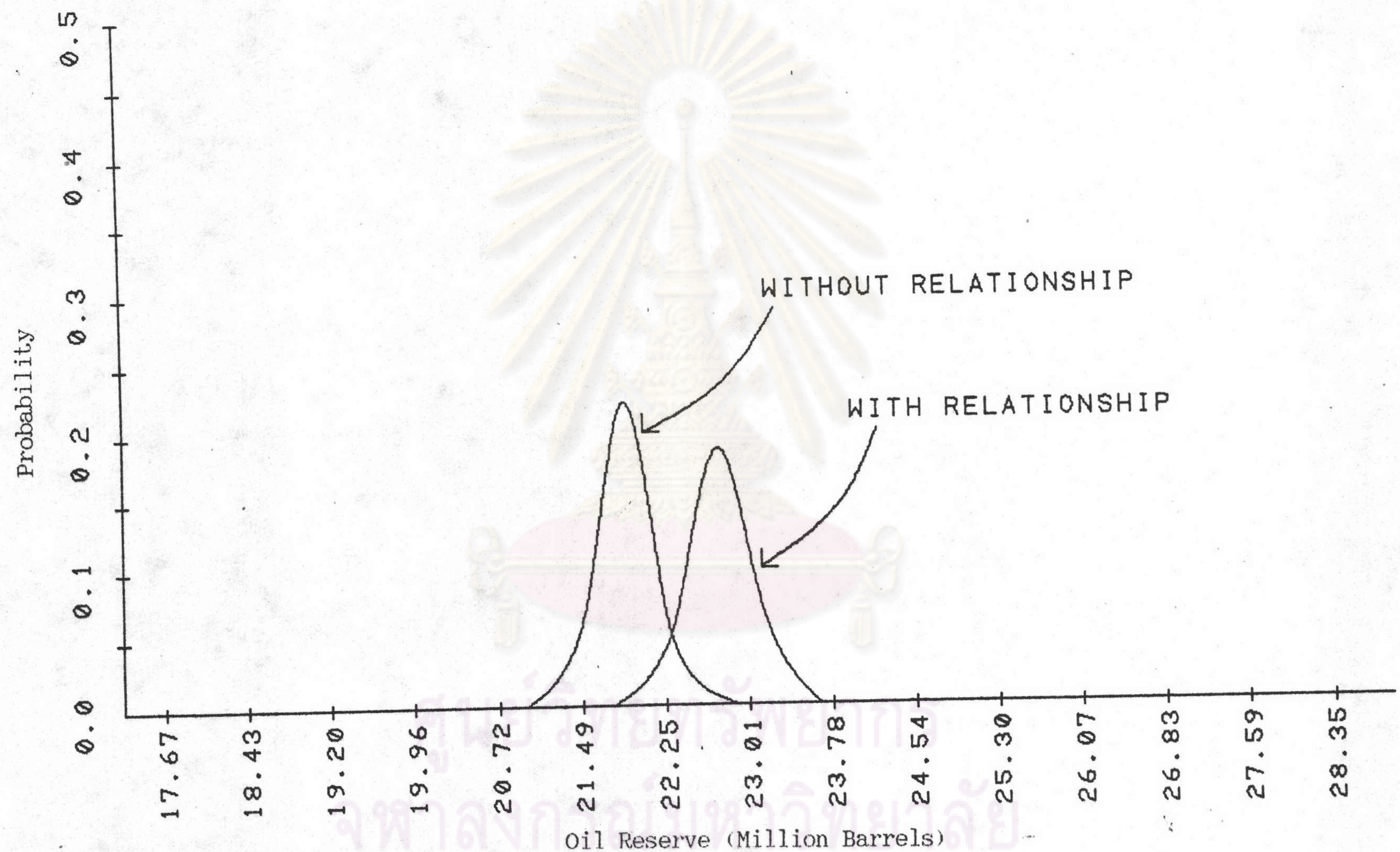

Figure 5.7. Probability density function of oil reserve for studying effect of statistical relationship between porosity and water saturation (number of blocks = 25x25 and std. dev. of random part = 0.1).

Table 5.4. Mean and standard deviation of resulted oil reserve (barrels).

relationship	no. of blocks	std. dev. of random part	oil reserve	
			mean	std. dev.
no	5x5	0.05	2.239×10^7	1.498×10^6
yes	5x5	0.05	2.276×10^7	1.689×10^6
no	25x25	0.05	2.239×10^7	0.307×10^6
yes	25x25	0.05	2.278×10^7	0.335×10^6
no	5x5	0.10	2.185×10^7	1.705×10^6
yes	5x5	0.10	2.274×10^7	1.915×10^6
no	25x25	0.10	2.186×10^7	0.347×10^6
yes	25x25	0.10	2.278×10^7	0.371×10^6

From the results presented in Figures 5.4 to 5.7 and Table 5.4, it can be seen that mean and standard deviation of calculated oil reserve are higher for the cases having statistical relationship between porosity and water saturation than for the corresponding cases with no relationship between those two input random variables. This seems rather strange at first. However, after detailed consideration of the results, the following interpretations are proposed.

For the cases with 25 blocks and standard deviation of random part of 0.05, the standard deviations of the calculated reserve are 1.498×10^6 and 1.689×10^6 barrels for the with-no-relationship and with-relationship cases, respectively. The with-relationship case has larger standard deviation of oil reserve because as the generated value of porosity is low, the generated value of water saturation would be high (according to the given relationship) causing the calculated value of oil reserve to be low. Similarly, when the generated value of porosity is high, the generated value of water saturation would be low causing the calculated value of oil reserve to be high. This would possibly cause range of values of calculated oil reserve to be wide leading to higher value of standard deviation of calculated oil reserve.

Oppositely, when there is no relationship between porosity and water saturation, when the generated value of porosity is low, the generated value of water saturation can be either low of high depending on the generated random number and the distribution curve of water saturation. Similarly, when the generated value of porosity is high, the generated value of water saturation can be either low or high. That is, any (generated) value of porosity (either low or high) would give any value of calculated value of oil reserve. This is different from the case having relationship between porosity and water saturation where the calculated value of oil reserve is low when the porosity value is low and the calculated value of oil reserve is high when the porosity value is high. All the reasons stated lead to the conclusion that the standard deviation of calculated oil reserve would be higher for the case having the relationship between porosity and water saturation than for the case not having this relationship. Similar conclusion can be stated for other case with different number of blocks or different value of standard deviation of random part in Equation (5.1).

It should also be noted that when number of blocks is larger, the standard deviation of calculated oil reserve is smaller. This phenomenon has already been discussed.

There is also difference in mean of calculated oil reserve for cases with and without relationship between porosity and water saturation. The difference is smaller for smaller standard deviation of the random part as expected. It should be noticed that for cases having statistical relationship between porosity and water saturation have approximately equal values of mean of calculated oil reserve. This is probably caused by the specified relationship between porosity and water saturation. Because the random part has normal distribution with zero mean, the mean values of calculated oil reserve is, therefore, not dependent on the magnitude of the standard deviation of random part. In addition, number of blocks does not have effect on the mean values of calculated oil reserve also as expected.

The statistical relationship between input variables involving volumetric oil reserve calculation affacts distribution of calcŭlated oil reserve. Therefore, this relationship should be considered in the oil reserve calculation using Monte Carlo simulation in order that the oil reserve will be obtained by using more information of available data.

Study of Effects of Spatial Correlation of Porosity on Calculated Oil Reserve.

In some case, input variables used for oil reserve calculation sampled from an interested reservoir may possess spatial correlation property. Spatial correlation property can be expressed through a covariance function. It is wished to investigated the effect of spatial correlation of input variables on the calculated oil reserve. The spatial correlation of porosity are selected for this purpose. The covariance function of porosity is assumed to be represented by exponential model. This model is well known in ground water literature and believed to be a good representation for statistical properties of porosity.

In simulating values of porosity assigned to various block, the spectral turning bands method is used with specified value of correlation length. It was decided that two systems will be used in the investigation. The first system consists of 25 (5x5) blocks while the second system consists of 625 (25x25) blocks. For each system seven runs are carried out. Different run uses different value of correlation length. The values of correlation length for all runs for the 25- and 625-block cases are listed in Table 5.5 and 5.6, respectively.

Table 5.5. Correlation length used in each calculation for the calculations at number of blocks = 25.

run number	correlation length (feet)	ratio of correlation length to width of a block
1	0	0
2	2640	1
3	5280	2
4	10560	4
5	21120	8
6	31680	12
7	39600	15

Table 5.6. Correlation length used in each calculation for the calculations at number of blocks = 625.

run number	correlation length (feet)	ratio of correlation length to width of a block
1	0	0
2	528	1
3	1056	2
4	2640	5
5	5280	10
6	10560	20
7	21120	40

For both systems, the case of no spatial correlation or zero correlation length is also carried out. The case of values of correlation length have magnitudes ranging from equal to block size to as large as 15 times (for 25-block case) or 40 times (for 625-block case) block size.

Data for other input variables are listed in Table 4.4. The number of simulations used for each run is 600. The results of the investigation are shown in Figure 5.8-5.13.

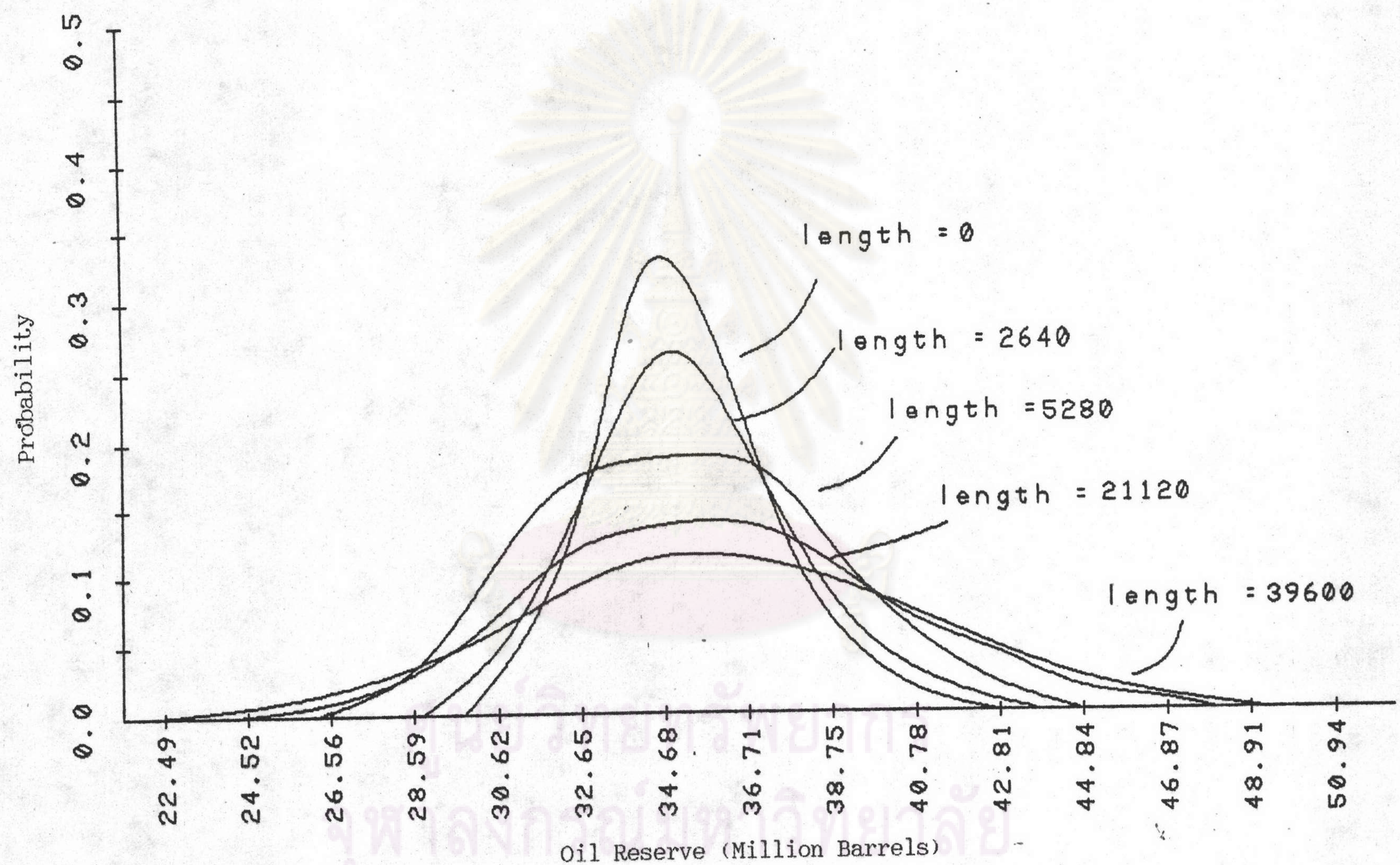

Figure 5.8. Probability density functions of oil reserve at number of blocks = 5x5 with spatial correlation.

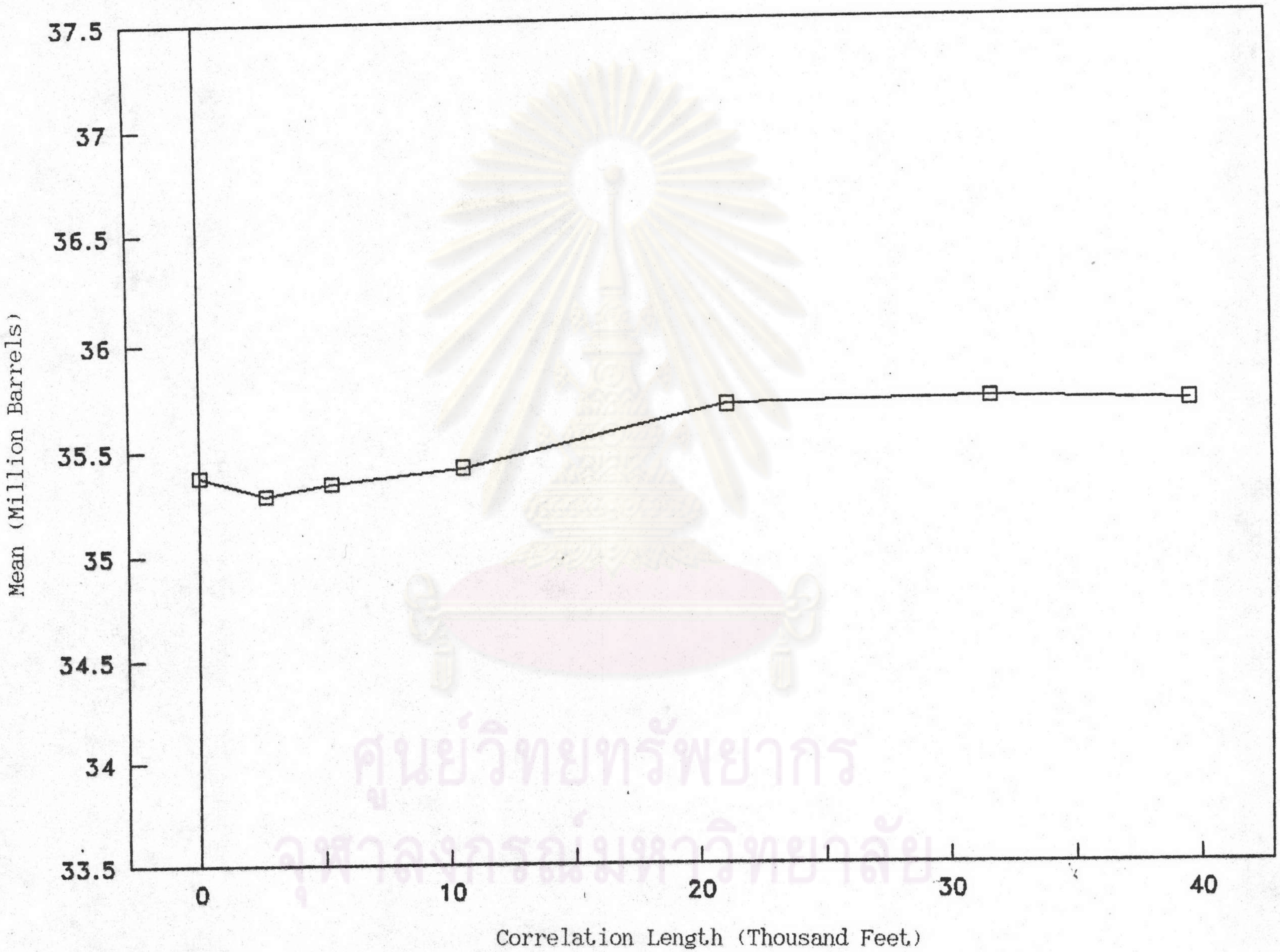

Figure 5.9. Mean vs. correlation length at number of blocks = 5x5.

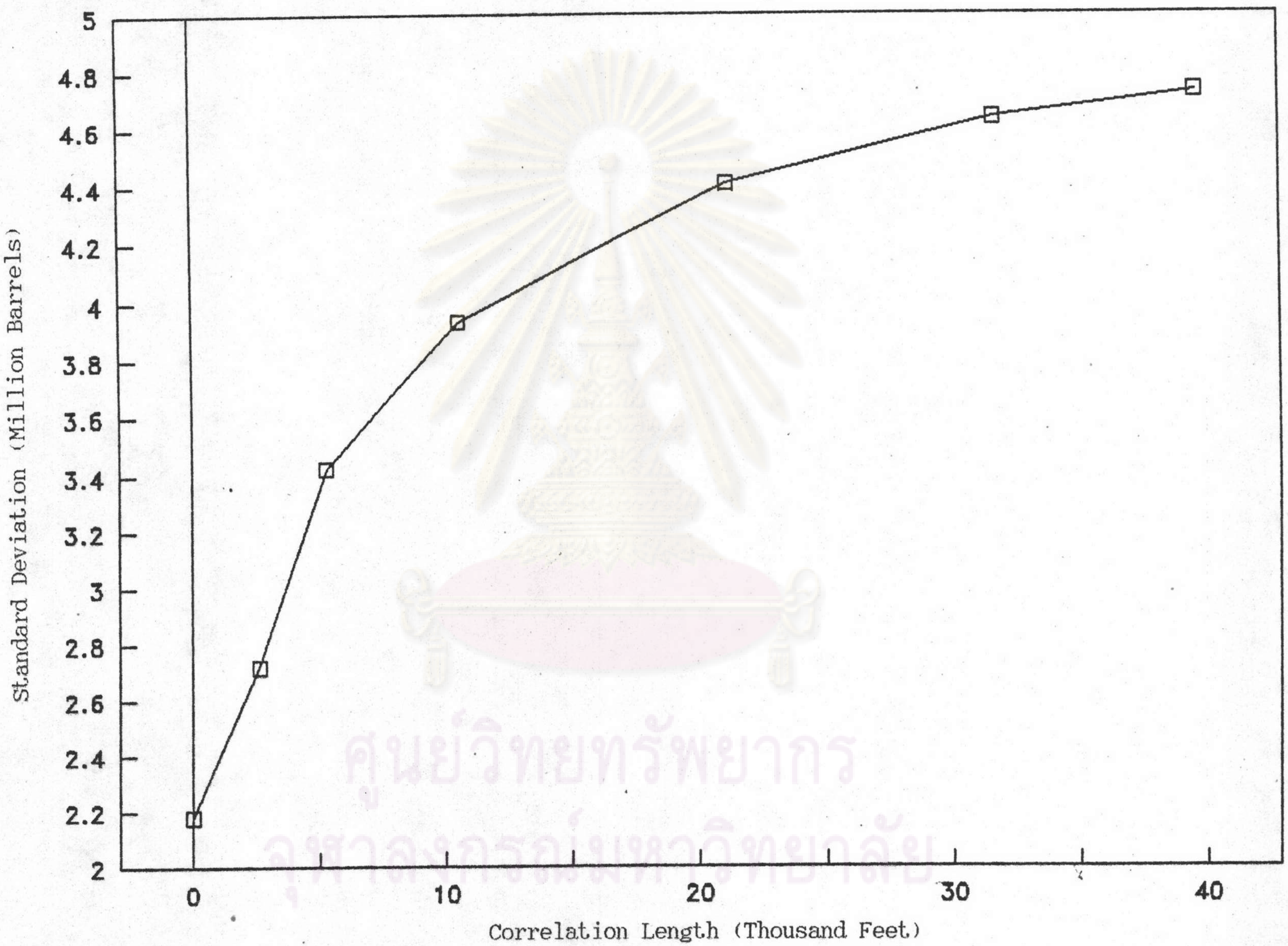

Figure 5.10. Standard deviation vs. correlation length at number of blocks = 5x5.

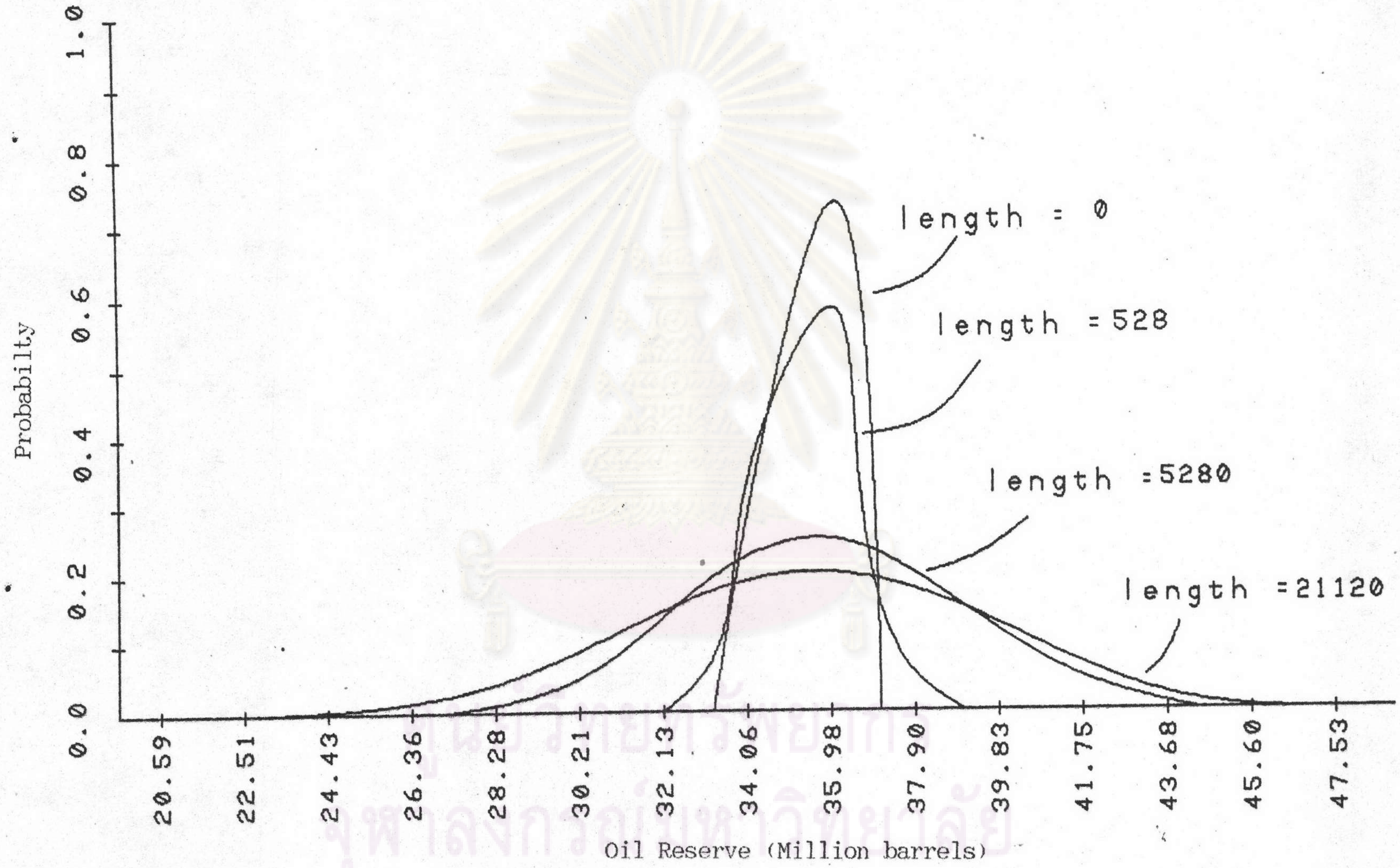

Figure 5.11. Probability density function of oil reserve at number of blocks = 25x25 with spatial correlation.

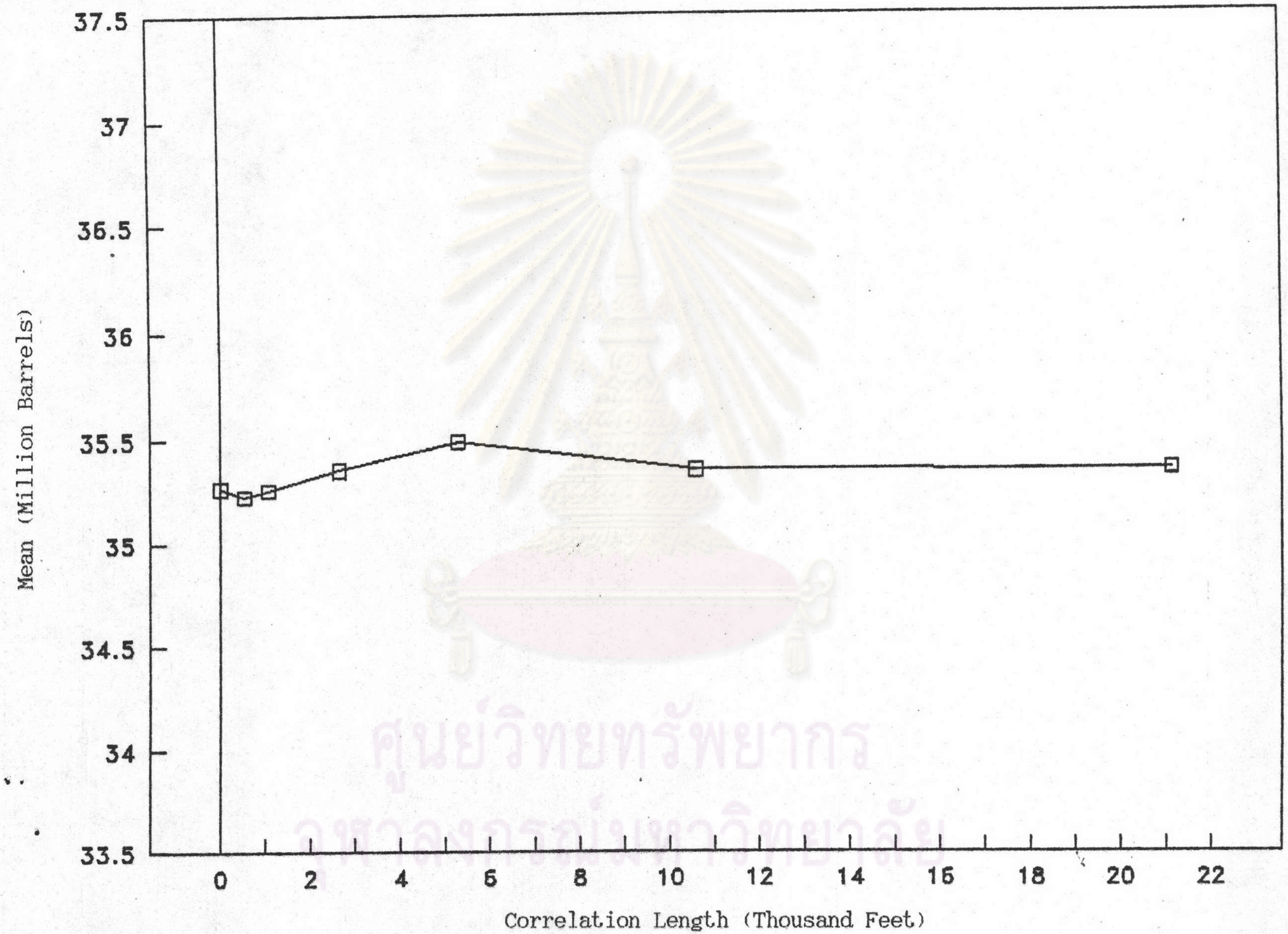

Figure 5.12. Mean vs. correlation length at number of blocks = 25x25.

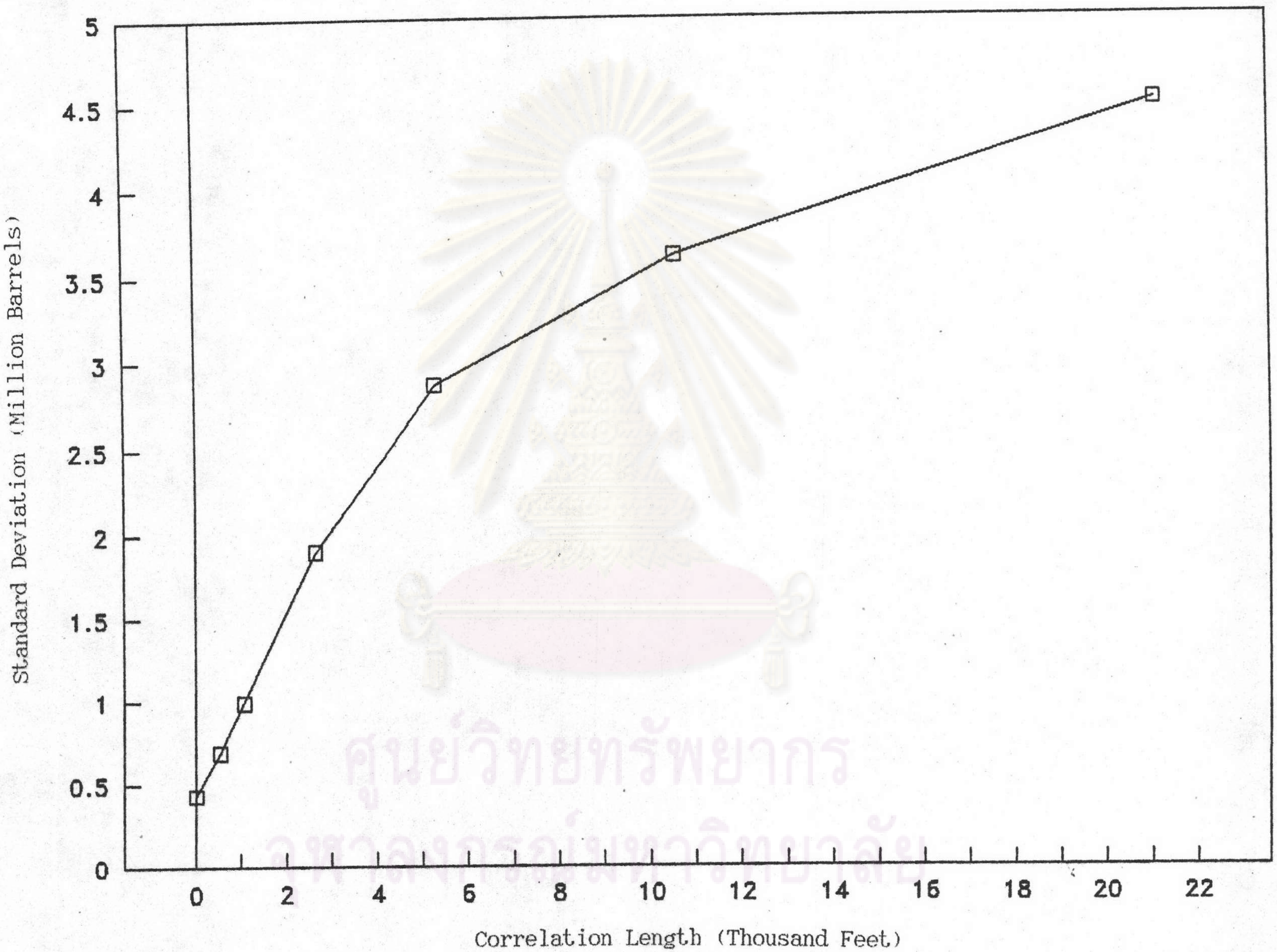

Figure 5.13. Standard deviation vs. correlation length at number of blocks = 25x25.

Figure 5.8 shows the distribution curve of each run for the 25-block system. It can be seen that as the correlation length is larger, the distribution curve becomes flatter. This is confirmed by the plot of standard deviation and correlation length to block size shown in Figure 5.10.

From Figure 5.10, whereas correlation length increases the standard deviation of calculated reserve increases. However, the increase rate becomes slower where correlation length increases. At high value of correlation length, the curve shown in Figure 5.10 is approaching a constant value at the standard deviation value of 4.8 million barrels.

While there is high variation in standard deviation of calculated reserve, the mean value is almost constant at the value of 35.6 million barrels as shown in Figure 5.9. This means that mean of calculated reserve is not dependent on the correlation length of porosity. It may be also concluded that mean of calculated reserve will not depend on correlation lengths of other input variables. This result is plansible because though values of porosity assigned to various blocks for each realization become less different when the correlation length of porosity is larger, the values of porosity for various realizations are still distributing over the range allowed by the same input distribution curve of porosity. This would cause the mean of calculated reserve to become stable at one value for all values of input correlation length of porosity.

The results for the 625-block system shown in Figures 5.11-5.13 indicate the same behavior as for the case of the 25-block system.

It should be noted that the curve of standard deviation of calculated reserve (vs. correlation length) is increasing and far from reaching a constant value. This is because correlation length used is still small compared to the size of the system.

From the results discussed above, the following conclusion can be stated.

1. The spatial correlation, expressed through correlation length, of an input variable has no effect on the mean of the calculated reserve.

2. The spatial correlation of an input variable has influence on the standard deviation of calculated reserve. This implies that as correlation length of an input variable increase uncertainty in calculated reserve decreases.

The above conclusion gives an important finding about effect of spatial correlations of input variables on the distribution of the calculated reserve. In addition, by deduction it may be concluded that if several input variables have spatial correlation the uncertainty of calculated reserve would even become less. However, this latter conclusion should be tested and confirmed before accepting.

From the finding about effect of spatial correlation on calculated reserve, it can be seen that spatial correlations of input variables for reserve calculation should be given special attention. In addition to construction of distribution curves for input variables, it should be tested if any input variable has spatial correlation.

It should be mentioned here too that during exploration period, there is, generally, not sufficient data to investigate if input variables have spatial correlation. However, after more wells are drilled during development and production stage, much more data can be collected and spatial correlations of input variable should be investigated. Therefore, it may be suggested that during exploration period a reservoir should be treated as a single block for reserve calculation purpose while during development and production stage, when sufficient data are collected, a reservoir should be divided into blocks. In addition, it should be emphasized that only distribution curve of input variables corresponding to block size be used in the reserve calculation using Monte Carlo simulation.