CHAPTER IV

APPLICATION OF GEOPHYSICAL LOGS FOR LITHOFACIES ANALYSIS

4.1 INTRODUCION

Conventional investigations of sedimentary lithofacies have been achieved using details of rock lithology, which are directly described from rock samples. Regarding subsurface exploration, core samples are necessary for construction of subsurface lithofacies as reported in chapter 3 for example. However, petroleum exploration generally intends to detect specific rock properties and geological structures that are suitable for hydrocarbon storage, whereas lithofacies of rock strata are just supplementary information obtained from further interpretation. Moreover, core samples are unable to be collected from all wells because mechanical coring for well operations is slow and very expensive. Therefore cutting samples are quantitatively collected instead.

Geophysical log is an alternative to carry out rock properties, particularly for subsurface strata, although it is indirect way. Geophysical logs are recording of geophysical data that are taken along borehole and are plotted continuously against well depth (Rider, 1996). These records are usually called well logs or logs. Logs are commonly composed of several measurements, such as natural radioactivity (gamma ray log), formation's velocity (sonic log), formation's bulk density (density log), formation's reaction to fast neutron bombardment (neutron log). All log types reflect physical properties of rocks. Details of geophysical log are shown in Appendix B. Geophysical logs are significant data because only cutting samples could not give precise information of the formation. Regarding geophysical logs, they are generally utilized by petroleum exploration routines for lithological interpret of relevant rock types; hence, they are potential tool for lithofacies determination. However, experiments and statistic processes have to be investigated to develop methodology.

Subsequently, methodology earned from this study is tested using unknown core well before publishing.

This research project is emphasized to investigate relationship between geophysical logs and lithofacies in Sirikit oil field; consequently it is tried to establish an application of well log to recognize lithofacies in the study area and perhaps adjacencies. Methodology for this study contains four steps as below.

First Step : Geophysical log values of observable lithofacies are examined and categorized into individual groups. This step is able to divide various groups of lithofacies that have similar lithology and type of sediment (e.g. sandstone group, claystone group etc). However they could not be specified to the actual lithofacies. Consequently, the following steps are carried out to fulfill the process.

Second Step : Makov's chain analysis is engaged to search for relationship between most concerned lithofacies and their stratified arrangements. This step may introduce possibility of sedimentary sequence of the Lan Krabu Formation, particularly in Sirikit oil field and adjacent areas. Results from this step would apply helpfully to recognize the unclear lithofacies that are situated close to the outstanding definable lithofacies.

Third Step : Geophysical log shape, Gamma ray log in particular, is obviously resulted by facies association, therefore this piece of evidence may support potentially to decide the appropriate lithofacies in the concerned sequence. For example, similarity in log values of C1, C2 and C3, lithofacies is difficult to identify among them using only log values. Facies association of the Lan Krubu Formation was subdivided into lacustrine-deltaic facies association and channel-floodplain facies association (Van Geuns and Burgisser, 1982) both associations yield completely different log shape. Details will be discussed later.

Forth Step : Relations between geophysical log values, lithofacies relationships and specific log characteristics are carried out and concluded; consequently, lithofacies successions diagrams are constructed using this source of information.

These processes are subsequently summarized as routine procedure before applying to tested wells that contain geophysical logs with and without description of core lithofacies. Details of these processes are described in the following sections.

4.2 GEOPHYSICAL LOG VALUES

Geophysical logging generally yield different values when it passes thorough dissimilar rock types. Therefore, it would be possible to use geophysical log values to determine lithofacies that are characteriszed by obvious different types of rock. However, classification of the lithofacies containing similar lithology of rock formation may still in doubt. Expect resistivity log, other values (e.g. gamma ray log, density log, neutron log and sonic log) are considered in this study. This is because resistivity log is more suitable for determining reservoir fluids, either water or hydrocarbon, filled in rock pores; the interpretation then leads to evaluation of hydrocarbon saturation. Consequently, resistivity log would be unsuitable for lithofacies classification in this case. All lithofacies of the Lan Krabu Formation suggested by Knipscheer (1997) are occupied as significant clue to categorize lithofacies of core samples. Details of Knipscheer's lithofacies have already reported in Chapter 3, whereas core samples available for this study are summarized in Table 4.1 and their described lithofacies are reported in Appendix A

Lithofacies obtained from core descriptions are subsequently imported into and calibrated using the PETREL program which these lithofacies of core samples can be schematically calibrated with geophysical logs before presenting in digital format. However, the main problem occurred in this process is core sampling depth. This is because cores are cut during drilling operation; hence, their depth ranges have to be recalculated by summation of all drill string lengths. Regarding this reason, core depths must therefore be adjusted to compatible log depths.

Table 4.1 List of available core samples and their information.
(Lithofacies of samples are described in Appendix A)

Well Name	Core No.	Reservoir	Top Depth(m.)	Bottom depth(m.)	Total Depth(m.)
LKU-A01	1	K	1397.40	1406.60	9.20
	2	K	1459.90	1474.50	14.60
	3	L	1508.06	1526.52	18.44
	4	L	1526.52	1544.81	18.29
	5	L	1650.10	1662.15	12.05
LKU-B01	1	K4	1784.40	1795.00	10.60
	2	M	2028.60	2046.88	18.28
LKU-C01	1	K3	1676.92	1689.10	12.18
	2	K4	1766.84	1776.59	9.75
	3	L	1881.00	1891.00	10.00
	4	L	1956.00	1965.00	9.00
	5	L	2007.61	2017.70	10.09
LKU-E02	1	K	1959.00	1966.00	7.00
	2	K	1966.00	1985.00	19.00
	3	K	1985.00	2003.50	18.50
	4	K	2003.50	2021.50	18.00
	5	K	2021.50	2023.10	1.60
	6	K	2023.10	2032.50	9.50
	7	K	2033.30	2043.50	10.20
	8	K	2043.50	2057.00	13.50
	9	K	2057.00	2067.00	10.00
LKU-E05	1	L	2090.00	2100.00	10.00
	2	L	2100.00	2118.10	18.10
	3	L	2118.00	2136.00	18.00
	4	L	2136.00	2154.00	18.00
	5	L	2154.00	2172.00	18.00
LKU-F01	1	K	1896.30	1893.60	0.30
	2	K	1896.60	1914.60	18.00
LKU-F04	1	L	2084.30	2092.00	7.70
	2	L	2104.00	2112.83	8.83

Table 4.1 (cont.).

Well Name	Core No.	Reservoir	Top Depth	Bottom Depth	Total Depth
LKU-G01	1	L	2065.00	2083.10	18.10
LKU-L04	1	K	1892.00	1901.50	9.50
	2	K	1901.50	1912.20	10.70
	3	K	1912.20	1921.80	9.60
	4	K	1921.80	1939.80	18.00
	5	K	1939.80	1944.90	5.10
	6	K	1944.90	1962.90	18.00
LKU-W01	1	K	2075.00	2084.00	9.00
	2	K	2084.00	2093.50	9.50
LKU-W02	1	K	1715.00	1723.50	8.50
	2	K	1723.50	1733.00	9.50
	3	K	1733.00	1735.00	2.00
	4	K	1738.00	1756.00	18.00
	5	L	2035.00	2053.00	18.00
	6	L	2053.00	2071.00	18.00
LKU-X04	1	L	2100.00	2109.00	9.00
	2	L	2109.00	2118.00	9.00

After that, each geophysical log type is picked up values from log peak The concerned log values of most lithofacies are statistically examined before picking up the most appropriated representative which means are apparently the best statistic among the others (e.g. range, medium, mode). This is because some data, falling for away from usual population, are excluded. Consequently, data is symmetrical distribution as show in Figure 4.1. Moreover, the standard deviation is generally averaged about 10 % of the mean value. Therefore, all mean values are able to represent the geophysical log values for each lithofacies (Table 4.2.).

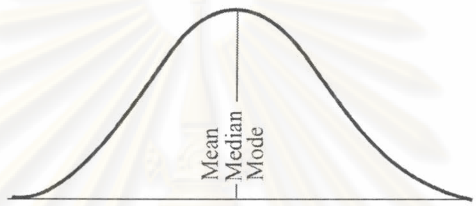


Figure 4.1 The normal distribution shows the three measures of central tendency are of identical value.

All of the sample mean values (x) are subsequently applied statistical testing for giving level of confidence. Acceptable sample mean values are determined to find population mean value (μ) at the level of confidence of 99%; in which eventually we will get an appropriated population mean in the form of range, i.e. μ_{min} - μ_{max}.

T-testing method is selected to make inference for mean of a single population under an assumption that population variance is not know which is suitable for studied data. Two subsidiary tests are issued to determine the range of population mean from each sample mean value.

This test is then applied to the geophysical log values of all lithofacies is Appendix C to obtain their representatively population means. Calculation is demonstrated for better understanding how population mean range is obtained. To determine μ_{min} or μ_{max}, hypothesis is set up with constant as assumed to be population mean. Applying assumed constant with equation below, the constant will be accepted as population mean on conditions:

- Calculated T (T_c) approaches but it is still less than $T_{\alpha\ 99\%}$ (μ_{min} calculation) and
- Calculated T (T_c) approaches but it is still more than $-T_{\alpha\ 99\%}$ (μ_{max} calculation)

Mean values are investigated with *t-testing* as an equation below.

$$T_c = \frac{x - c}{s / \sqrt{n}}$$

where X = sample mean

C = constant

S = sample variance

N = number of sample

Because sedimentary deposits in Sirikit oil field were accumulated by clastic sediments; therefore, gamma ray log is the most suitable log to distinguish between sandstone and claystone. The higher gamma ray values present relatively the higher percentages of claystone because gamma ray log is a record of formation's radioactivity. On the other hand, sandstone is recorded the lower gamma ray log value According to this step, all the lithofacies can be subdivided, particularly using gamma ray mean values, into 3 groups as present in Table 4.3.

Table 4.2 Summary of mean values extracted from geophysical log data of each lithofacies.

Lithofacies	Description	Geophysical log values			
		Means of gamma ray log (API)	**Means of density log** (gm/cm^3)	**Mean of neutron log** (Percent porosity)	**Means of sonic log** (Microseconds/mete)
C1	Mottled claystone	102.88	2.460	0.304	92.56
C2	Carbonaceous claystone	106.54	2.343	0.399	102.62
C3	Grey claystone	103.55	2.420	0.348	100.60
CS	Interbedded sandstone and claystone	90.65	2.464	0.303	88.67
P	Mixed silt, sand and clay	99.80	2.435	0.278	97.70
SC	Shell coquina	92.24	2.413	0.327	100.17
S1	Coarsening-upwards sandstone	74.56	2.396	0.256	91.49
S2	Fining-upwards sandstone	68.63	2.349	0.232	88.68
S3	Sandstone	88.03	2.424	0.276	91.36
S4	Thin bedded sandstone	79.27	2.410	0.231	82.40

Table 4.3 Lithofacies groups organized using gamma ray log value.

Group number	Lithofacies	Gamma ray value (API)
I	S1-S4	< 90
II	CS, P, SC	90-100
III	C1-C3	> 100

Most lithofacies of sandstone sequences (Group I), show lowest gamma ray value (less than 90 API) whereas lithofacies of claystone sequences (Group III) clearly yield highest value (usually more than 100 API). On the other hand, interbeded sandstone-claystone lithofacies, classed as group II, display value ranging from between 90 to 100 API.

In addition, the other types of log values would be individually considered to distinguish particular lithofacies in each group. Details of classification in most three lithofacies groups, previously divided using gamma ray values, are reported below.

Lithofacies Group I

Group I consists of lithofacies S1, S2, S3 and S4. Lithology presents clean sandstone. Average gamma ray value less than 90 API.

Lithofacies S2 has lowest gamma ray value when compare with the others. Highest value range is obtained from lithofacies S3; moreover, S3 also yield highest range of neutron log value. Sonic log is likely a good key to distinguish lithofacies S4 from the others, because lowest mean value of sonic log appears in S4. However, only lithofacies S1 cannot be clearly separated from the others.

Lithofacies Group II

They are composed of three lithofacies members (e.g. CS, P and SC) which generally yield moderate range of gamma ray log values (90-100 API). Lithologically, most lithofacies in this group are combinations between sand and clay with various proportions; that lead to ranging of gamma ray log values between sandstone lithofacies (<90 API) and claystone lithofacies (>100 API).

In addition, gamma ray log is a crucial tool to separate lithofacies P from lithofacies CS, because lithofacies P shows highest gamma ray value whereas CS gives lowest gamma ray value. Consequently, clay minerals accumulated in lithofacies P are likely more than those of lithofacies CS. This characteristic then effects gamma ray measurement as described above. For the lithofacies SC, they are clearly characterized by the highest values of both neutron log and sonic log, which make it obviously different from the former lithofacies. This is because lithofacies SC contains the higher porosity than others.

Lithofacies Group III

Lithofacies group III comprises claystone sequences (e.g. C1, C2 and C3). Average gamma ray log values are commonly more than 100 API. Lithofacies C2 yields highest gamma ray values (average 107 API) that is clearly different from the others. However, gamma ray log is not such good indicator to distinguish between lithofacies C1 and C3, because gamma ray log shows slightly different values of both two lithofacies. The best detector for lithofacies C1 is sonic log, which obtains lowest value of about 93 microseconds/meter. On the other hand, lithofacies C3 usually yields moderate ranges of most geophysical logs in comparison with the other claystone lithofacies.

Although geophysical logs reveal some differences among those lithofacies, they are mostly relative numbers varying within narrow ranges. Therefore, applying only absolute log values is not obviously qualified for lithofacies classification. The following steps of this study are consequently proposed for searching additional evidences to support and develop the procedure of lithofacies reconstruction.

4.3 MARKOV'S CHAIN ANALYSIS

Markov's chain analysis is a simple statistical technique for detection of repetitive processes in space and time. It has been used to analyze coal cyclothems (Doveton, cited in Reading, 1978: 7), alluvial sediments (Gingerich, cited in Reading, 1978: 7) and deltaic sediments (Read, cited in Reading, 1978: 7). Results from Markov's chain analysis introduce tendency of relationship among lithofacies.

Data are arranged in form of row and column arrays before counting frequencies of lithofacies in row array overlaying lithofacies in column array; results are summarized in Table 4.4.

Table 4.4 Results of Markov's chain analysis indicating frequencies of lithofacies in the first row overlaying lithofacies in the top column; bold numbers present highest frequency.

Lithofacies	C1	C2	C3	CS	P	SC	S1	S2	S3	S4
C1		4	11	**15**	1	-	1	12	4	4
C2	**10**	-	6	2	1	-	1	-	-	-
C3	18	10	-	14	**36**	9	7	1	3	3
CS	2	-	**53**	-	3	1	12	8	-	9
P	**14**	1	5	9	-	-	2	5	1	2
SC	**5**	-	4		-	-	-	-	-	-
S1	-	-	4	**22**	-	-	-	-	-	-
S2	4	1	7	**16**	-	-	-	-	-	-
S3	-	-	**7**	1	-	-	-	-	-	1
S4	1	-	3	**13**	-	-	1	2	-	-

The results clearly imply that superimposing of lithofacies CS over lithofacies C3 is the most frequent circumstance occurring among the sample set. Lithofacies C3 being above lithofacies P is the second most often situation. The other events are S1 over CS, S2 over CS, S2 over C1 and so on with lower frequency, respectively. These frequency numbers are consequently engaged to interpret vertical lithofacies relationship in the Lan Krabu Formation.

4.4 GAMMA RAY LOG SHAPE

Results from the former steps, both geophysical log values and vertical lithofacies relationships, are still uncertain for lithofacies interpretation. Consequently, this step of study is proposed; that is consideration of gamma ray log shapes. Regarding log shapes, they can be recognized especially from gamma ray log curves; these are related to facies associations. Gamma ray log is record of amounts of radioactivity occurring in formations; they are detected as sonde passed along the borehole. They are essentially related to amounts of clay proportions. High gamma ray contents presumably indicate extensive occurrences of clay minerals. On the other word, gamma ray log would imply grain size distribution of formations along vertical sections; these properties therefore display various shapes of different lithofacies associations. Therefore, gamma ray log shape is a schematic indicator significant to support and develop lithofacies constructed using geophysical log data.

In Sirikit oil field, the depositional environment of the Lan Krabu Formation investigated by Van Geuns and Burgisser (1982) is fluvio-deltaic environment; that contains two types of facies associations (e.g. lacustrine-deltaic facies association, channel-floodplain facies association).

Lacustrine-deltaic facies association is commonly characterized by gamma ray value decreasing regularly upwards the section forming funnel shape (Figure 4.2). On the other hand, channel-floodplain facies association presents bell shape gamma ray log (Figure 4.3); this shape is yielded by increasing of gamma ray values regularly increase upwards the section.

Generally, gamma ray log shape possibly indicates facies association which may lead to further interpretation of each lithofacies in the association. However, identification of certain lithofacies could be firstly carried out using some other evidences (e.g. log values and lithofacies relationship). Then gamma ray log shape can be used to confirm the rest of lithofacies.

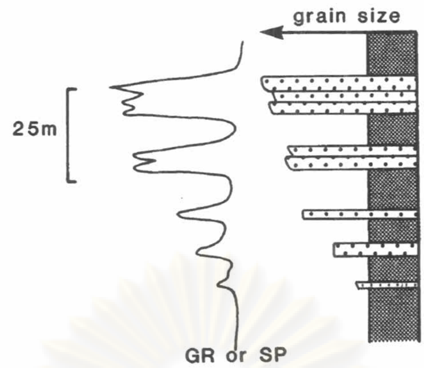


Figure 4.2 Funnel shape of gamma ray log reveals increasing of gamma ray values increasing from top to bottom; this is related to lacustrine-deltaic facies.

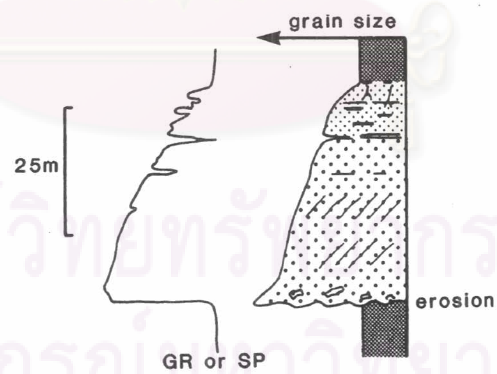


Figure 4.3 Bell shape of gamma ray log presents decreasing of gamma ray values from top to bottom; this is related to channel- floodplain facies.

4.5 LITHOFACIES DIAGRAM

In addition, consequence of previous steps can reconstruct lithofacies diagrams, that display relationships of lithofacies within each lithofacies succession. These lithofacies diagrams are also considered along with lithofacies sub-environment suggested by Knipscheer (1997). Two typical lithofacies diagrams of the Lan Krabu Formation are then proposed based on lithofacies association.

Lacustrine-Deltaic Lithofacies Succession Diagram (Figure 4.4) : is a sample coarsening-upward unit. They are composed of six lithofacies, including lithofacies C3, lithofacies CS, lithofacies P, lithofacies S1, lithofacies S3 and lithofacies S4. The observed data array (Table 4.3) are combined with vertical lithofacies relationship and log shape to generate the diagram.

Lithofacies P, C3, CS and S1 are formed as essential assemblages of the sequence; lithofacies P occurs as basement of sequence and are overlain by C3, CS and S1, respectively; besides lithofacies S3 and/or S4 occur occasionally as interbeded lithofacies throughout lithofacies P, C3 and CS. Both lithofacies S3 and S4 appear to be local deposits.

Channel-Floodplain Lithofacies Succession Diagram (Figure 4.5) : provides a sample finging-upward unit. This succession diagram is constructed on the same process of former lithofacies succession. Generally, lithofacies C3, CS and S2 are orderly arranged from the bottom of succession, whereas lithofacies S4 may present interbeded between lithofacies CS and S2. The top of this succession is covered by combination of lithofacies C1, C2 and SC that are suggested as coexisting depositions. However, sequences of these three lithofacies are not outstanding, therefore, they are drawn into the same level of the succession.

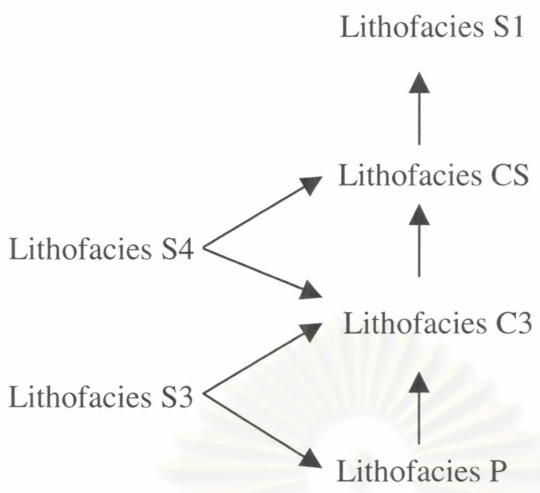


Figure 4.4 Lacustrine-deltaic lithofacies succession diagram.

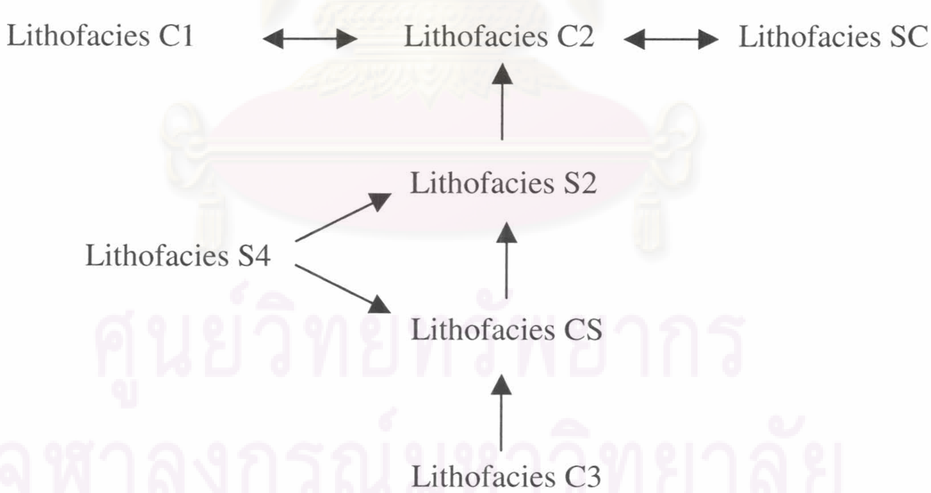


Figure 4.5 Channel-floodplain lithofacies succession diagram.

4.6 APPLICATION

Data earned from this study lead to an application for construction of lithofacies from log data. Procedure of this application is created for routine work. It includes four steps below.

1. Gamma ray log shape recognition is recommended to carry out firstly, because it would determine vertical boundary of individual sequence.

2. Gamma ray log values are subsequently determined, and then log samples will be categorized within three groups of lithofacies (see Table 4.3 for more detail).

3. Consideration of the other log values is the next step to specify key lithofacies in each sequence. The key lithofacies are actually characterized by certain log values as suggested in section 4.2.

4. Vertical relationships are eventually considered by correlation between lithofacies diagrams (Figures 4.4 and 4.5) and key lithofacies obtained from the former step. Consequently, most lithofacies will be carried out.

4.7 HYPOTHESIS TESTING OF APPLICATION

Application as introduced in section 4.6 is verified using two kinds of data sets, including well with known lithofacies and well with unknown lithofacies. Both types of well were drilled in Sirkit oil field. The first type is selected from thirteen wells that are also used as database in this study. They were interpreted lithofacies by Knipscheer (1997). Wells LKU-C01 and LKU-G01 are picked up to test and evaluate the application. Then well LKU-E17, was drilled in year 2000, is used for the next step of testing. This well contains lithological description, which may be used to correlate with lithofacies interpreted using geophysical logs. Results of both tests are reported below.

Testing of wells with known lithofacies : wells LKU-C01 and LKU-G01 are applied procedure suggested in the previous section at depths of 1956.00-1965.00 meters and

2065.0-2083 meters, respectively. Their log information and lithofacies are graphically present in Figures 4.6 and 4.7.

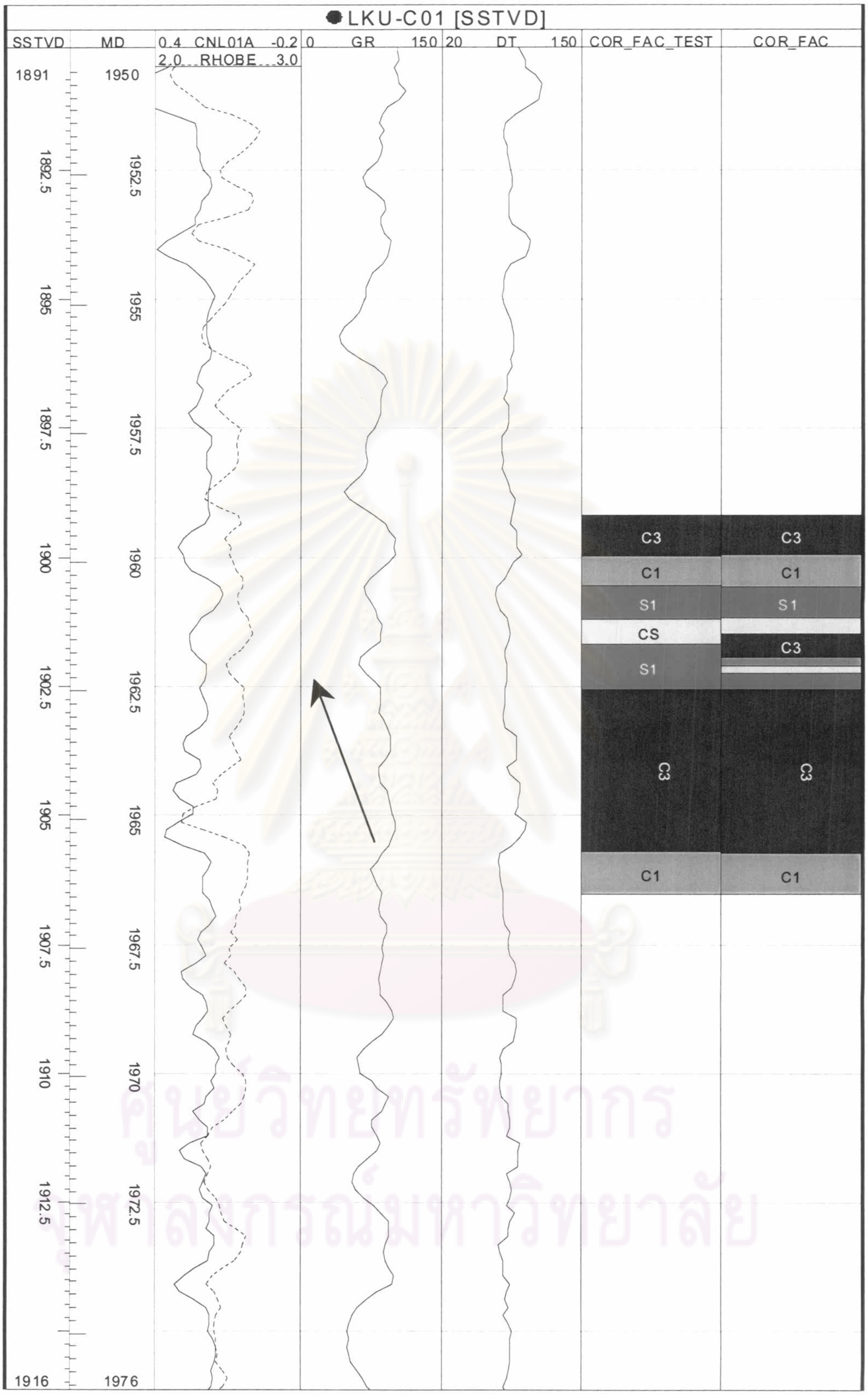


Figure 4.6 The visible characters of gamma ray log in well LKU-C01 presents a funnel shape. This log shape is reasonably related to channel-floodplain facies association.

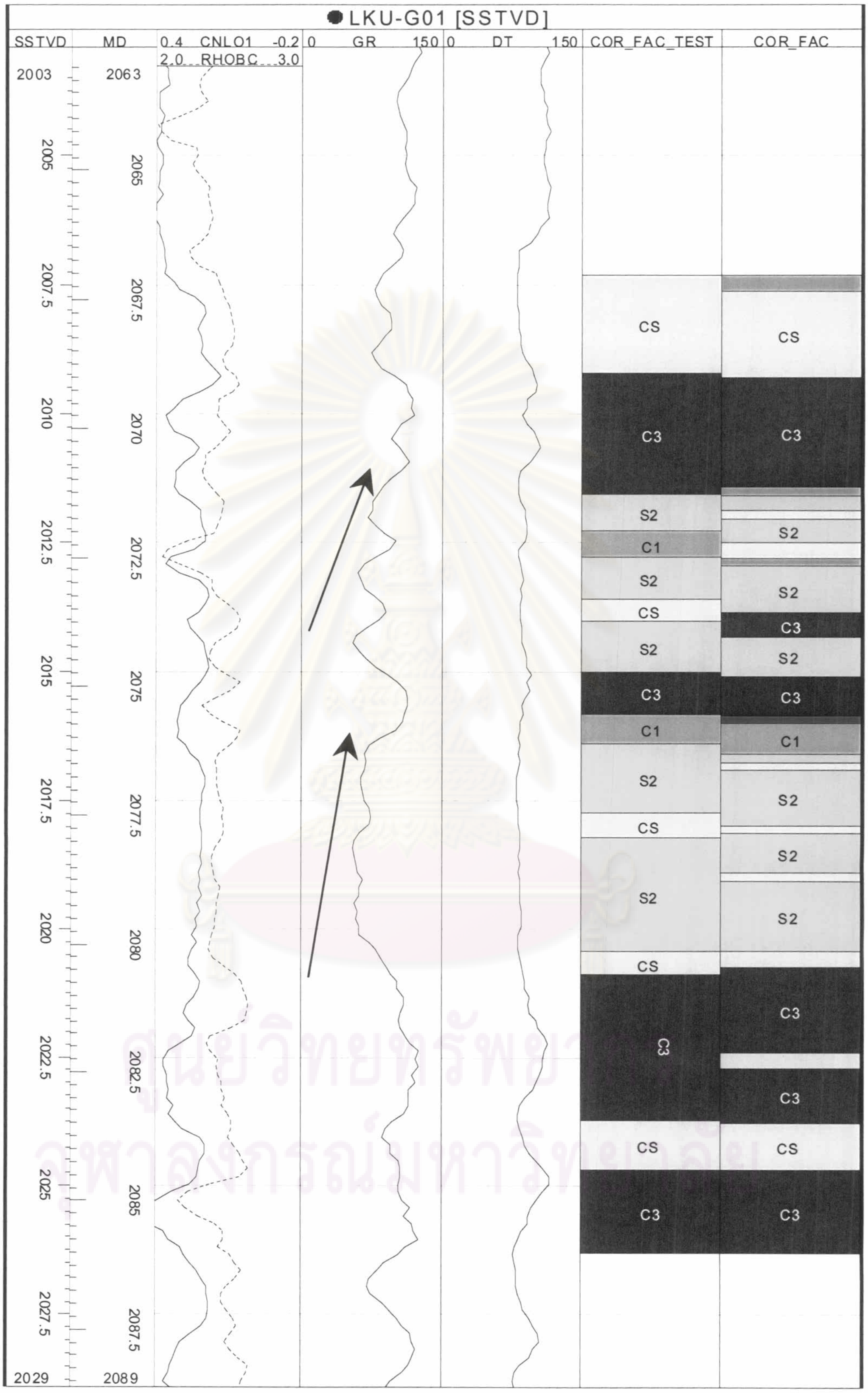


Figure 4.7 A couple of funnel shapes of gamma ray log in well LKU-G01 presumably indicate lacustrine-deltaic facies association.

Figures 4.6 and 4.7 reveal lithofacies interpreted using geophysical log in column COR_FAC_TEST and lithofacies described by Knipscheer in column COR_FAC. Results of hypothesis testing from LKU-C01 and LKU-G01are as follows:

1. Gamma ray log shape presents a funnel shape in LKU-C01 at depths between 1960.40 and 1965.60 meters. A couple of bell shapes are recognized in LKU-G01 at depths of 2067.00-2074.70 meters and 2074.70-2080.10 meters. They are unable to be defined gamma ray log shape in other depth ranges (Figures 4.6 and 4.7).
2. Gamma ray log values can be subdivided into three lithofacies groups which consist of lithofacies group I (e.g. at depths 2076.10-2077.50 meters in LKU-G01), group II (e.g. at depths of 2083.50-2084.40 meters in LKU-G01) and group III (e.g. at depths of 2080.60-2083.40 meters in LKU-G01).
3. All geophysical logs are considered together to specify key beds. In LKU-C01, key beds can be identified; they are composed of lithofacies C1 at depths between 1965.60 and 1966.40 meters and C3 at depths between 1962.50 and 1965.60 meters (Figure 4.6). Lithofacies C1 and C3 are recognized as key lithofacies by using gamma ray value, because their gamma ray values are the lower than those of the other lithofacies. Sonic log is considered to separate lithofacies C1 (e.g. at depths 2075.60-2076.10 meters in LKU-G01) with the lowest sonic log values from lithofacies C3 (e.g. at depths 2068.90-2071.30 meters in LKU-G01).
4. Other lithofacies are subsequently interpreted using the results from previous steps and lithofacies succession diagrams.
5. Interpreted lithofacies are compared with Knipscheer's lithofacies; results may be concluded that the interpretation of geophysical log is limited by bed thickness of lithofacies. In well LKU-C01, thin bed lithofacies S1 and S4 cannot be recognized from geophysical log; they have average bed thickness of about 0.30 meters. In addition, thin lithofacies C1 and CS are also not recognized in well LKU-G01. During this testing, it is found that the sonic log is the most useful data of distinguish between lithofacies C1 and C3.

Testing of well with unknown lithofacies: LKU-E17 was drilled in year 2000; core samples with diameter of about three to four inches were collected from the Lan Krabu Formation. Three core samples are considered for testing of application. Cores

1 and 2 are taken from depth ranges of 2326.00-2331.05 meters (5.05 meters long) and 2332.50-2352.49 meters (19.99 meters long), respectively. Both cores are arranged in same section in Figure 4.8 that presents some geophysical log details and proposed lithofacies. Lithological and geological characteristics are investigated. Top of the section reveals coarsening upward siliciclastic succession of very fine-grained sandstone. Tiny laminations of carbonaceous materials and claystone distribute towards base of the section. This sequence is interpreted as repeating cycles of mouthbar, delta front and open lacustrine successions. Core 3 was picked up from depth range of 2526.90-2552.13 meters and 25.23 meters long (Figure 4.9). This core is occupied by and fining-siliciclastic succession of silty sandstone and sandstone to dark grey claystone towards bottom. The sequence of core 3 is interpreted as delta front with distributary's mouthbar and lacustrine successions as same as cores 1 and 2. Lithological descriptions of these cores are graphically present in Figure 10.

Procedure of application is used to interpret lithofacies, based on log data, in well LKU-E17 (Figures 4.8 and 4.9). Gamma ray log shapes are firstly recognized for determining boundaries of individual sequences. Then, gamma ray log values are considered for most layers. Result from this step would yield lithofacies groups as described in Table 4.3. Next step, key bed is identified using the absolute geophysical values. Vertical relationship is subsequently by observed comparison with lithofacies diagrams (Figures 4.4 and 4.5). Finally, most litofacies are interpreted, based on geophysical log data, and they are correlated with lithofacies described from core lithology (Figure 4.10).

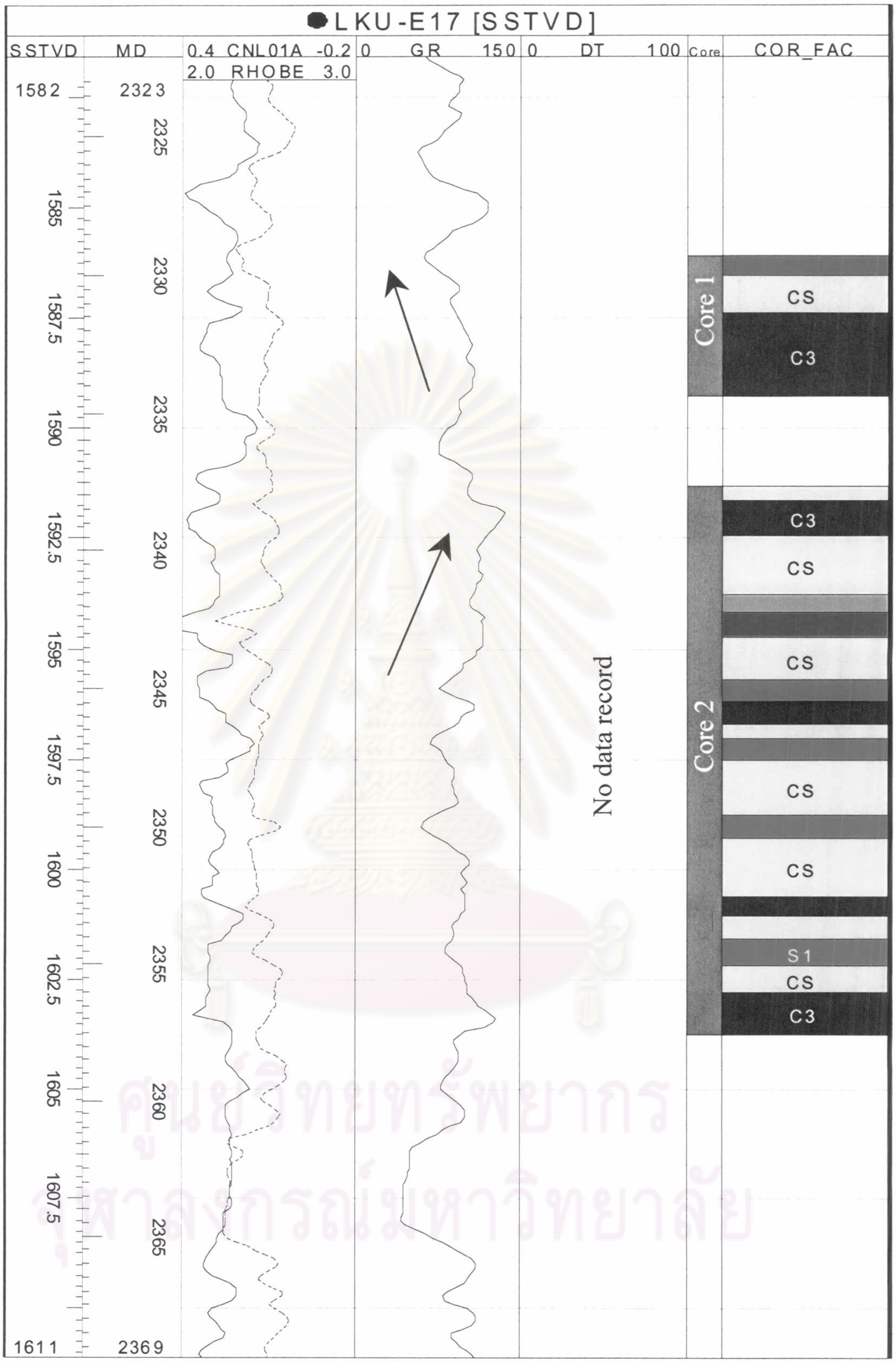


Figure 4.8 Gamma ray log shapes (both bell shape and funnel shape) and lithofacies interpretation for core no. 1 and 2 from well LKU-E17.

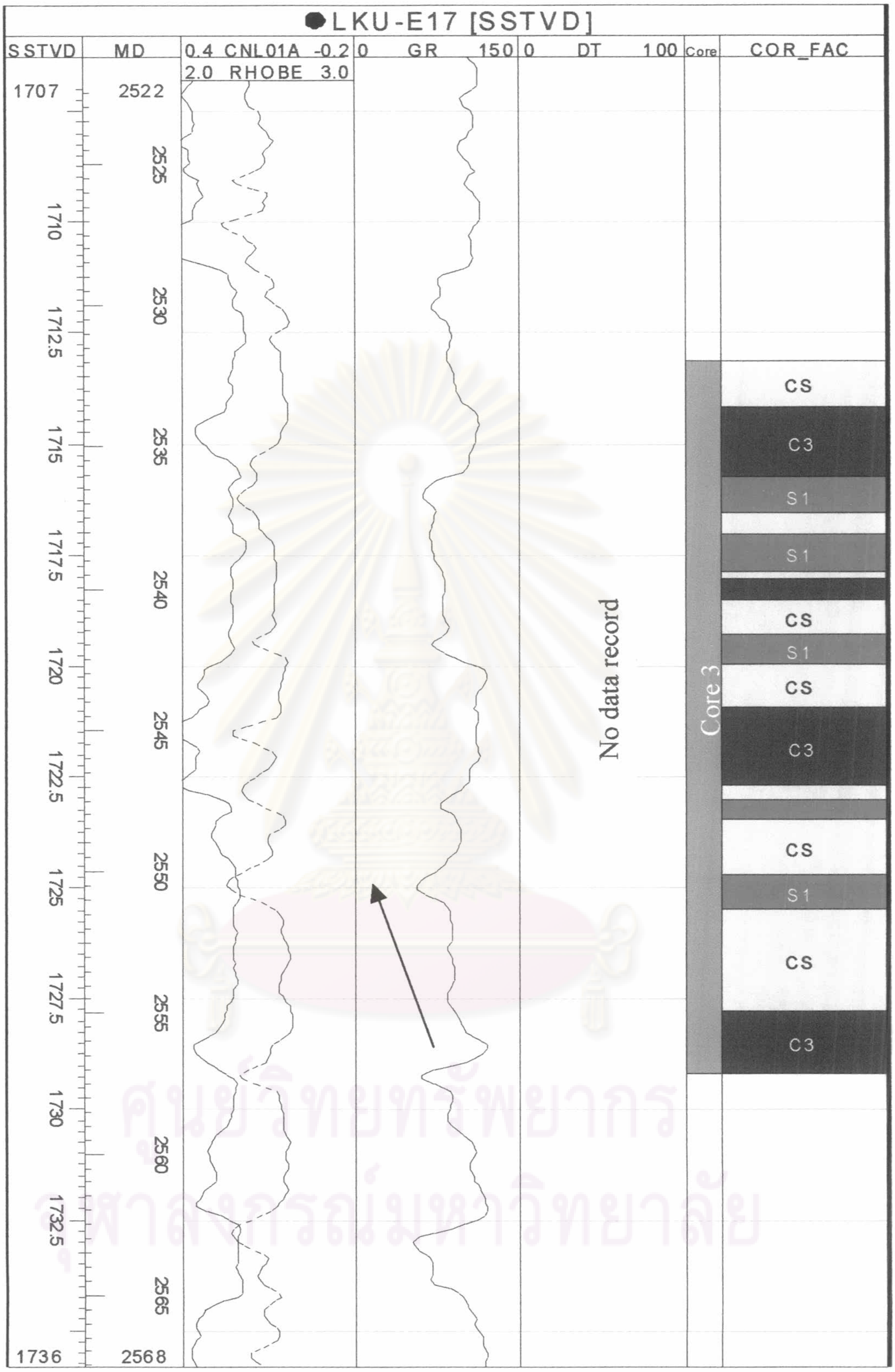


Figure 4.9 Funnel shape of gamma log and lithofacies interpretation for core no. 3 from well LKU-E17.

Figure 4.10 Description sheets of core no. 1, 2 and 3 in comparison with lithofacies interpretation from geophysical logs. Symbol + and - indicate the interval; which is added and subtracted from geophysical log depth.

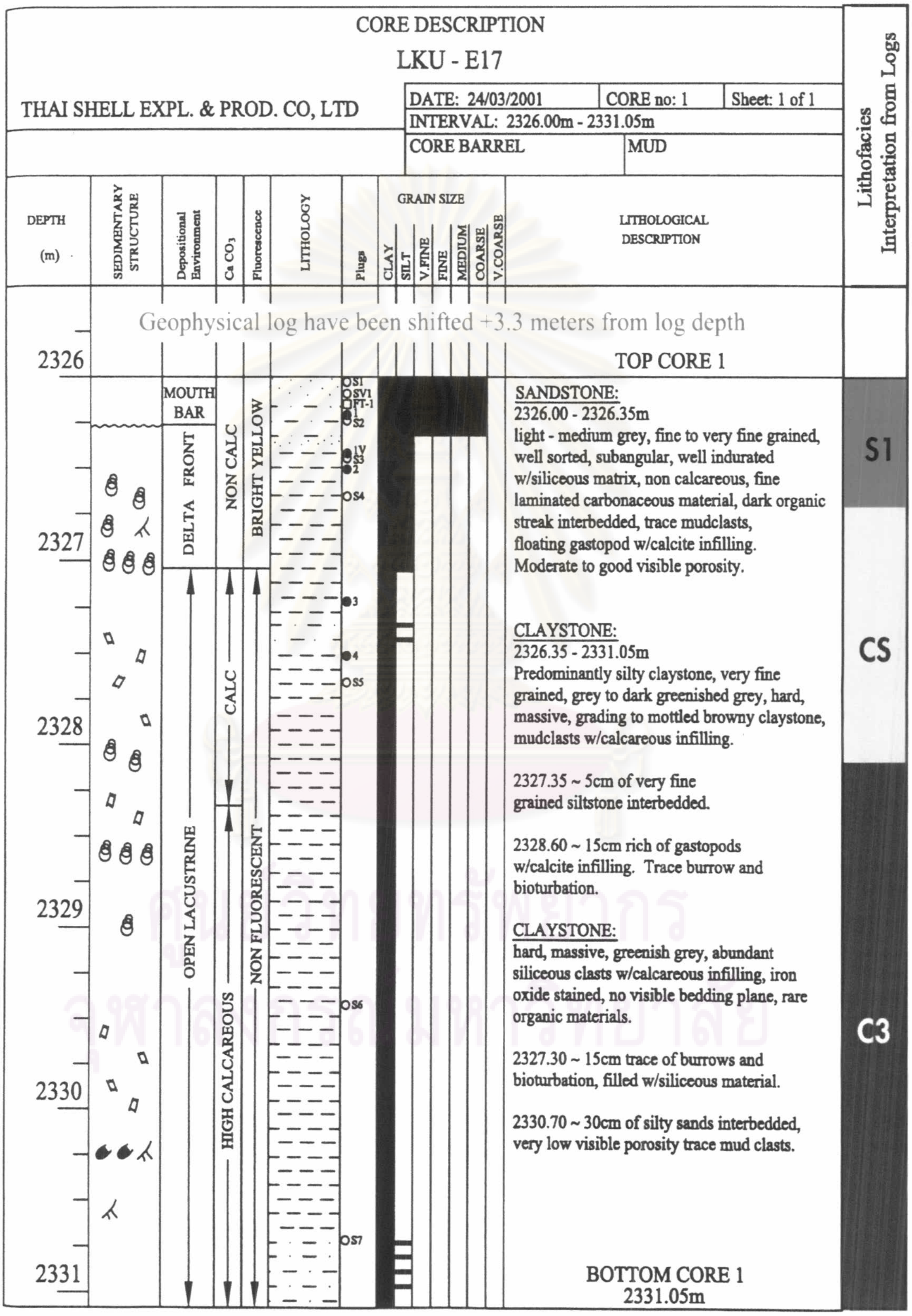


Figure 4.10 (cont.)

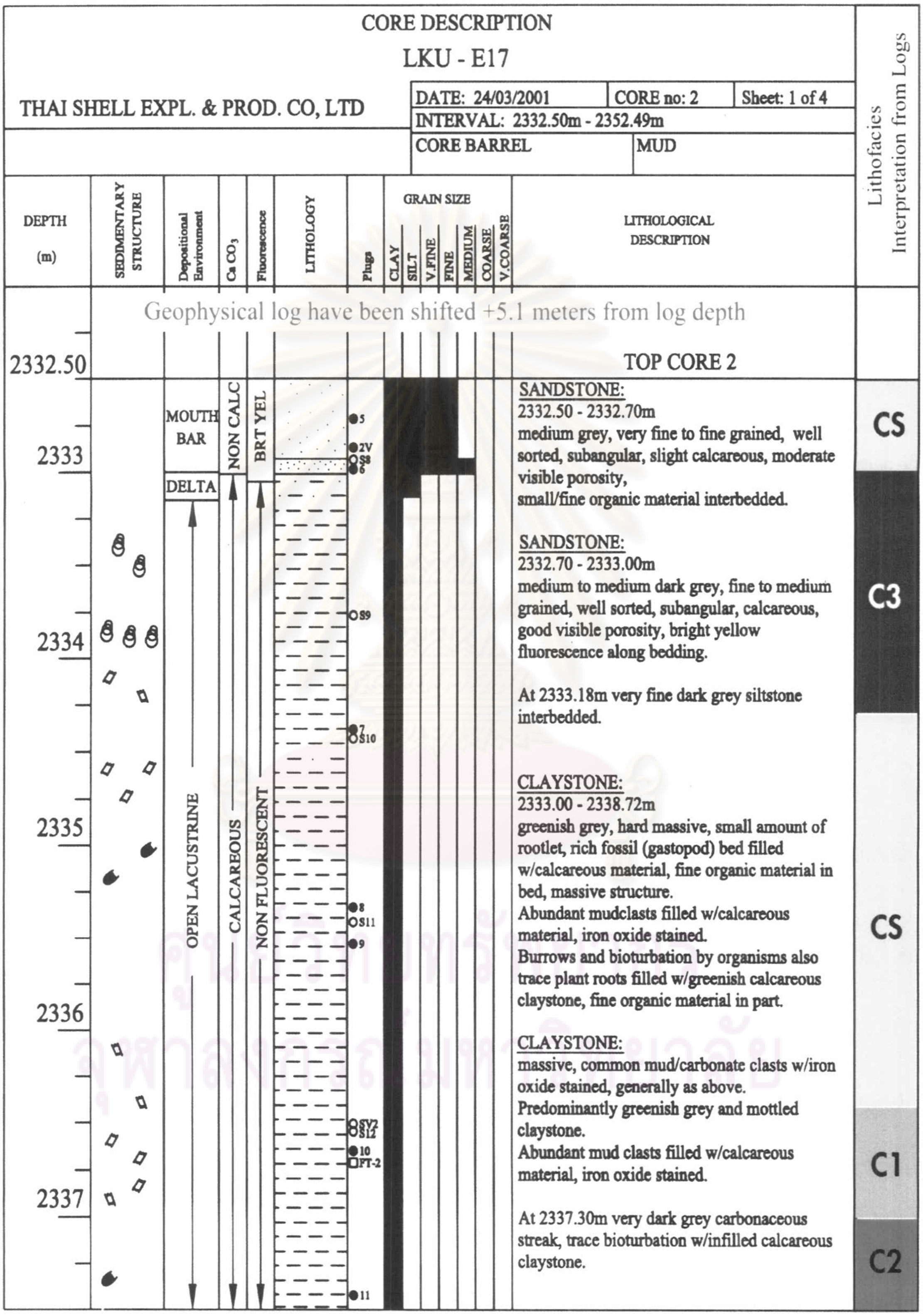


Figure 4.10 (cont.)

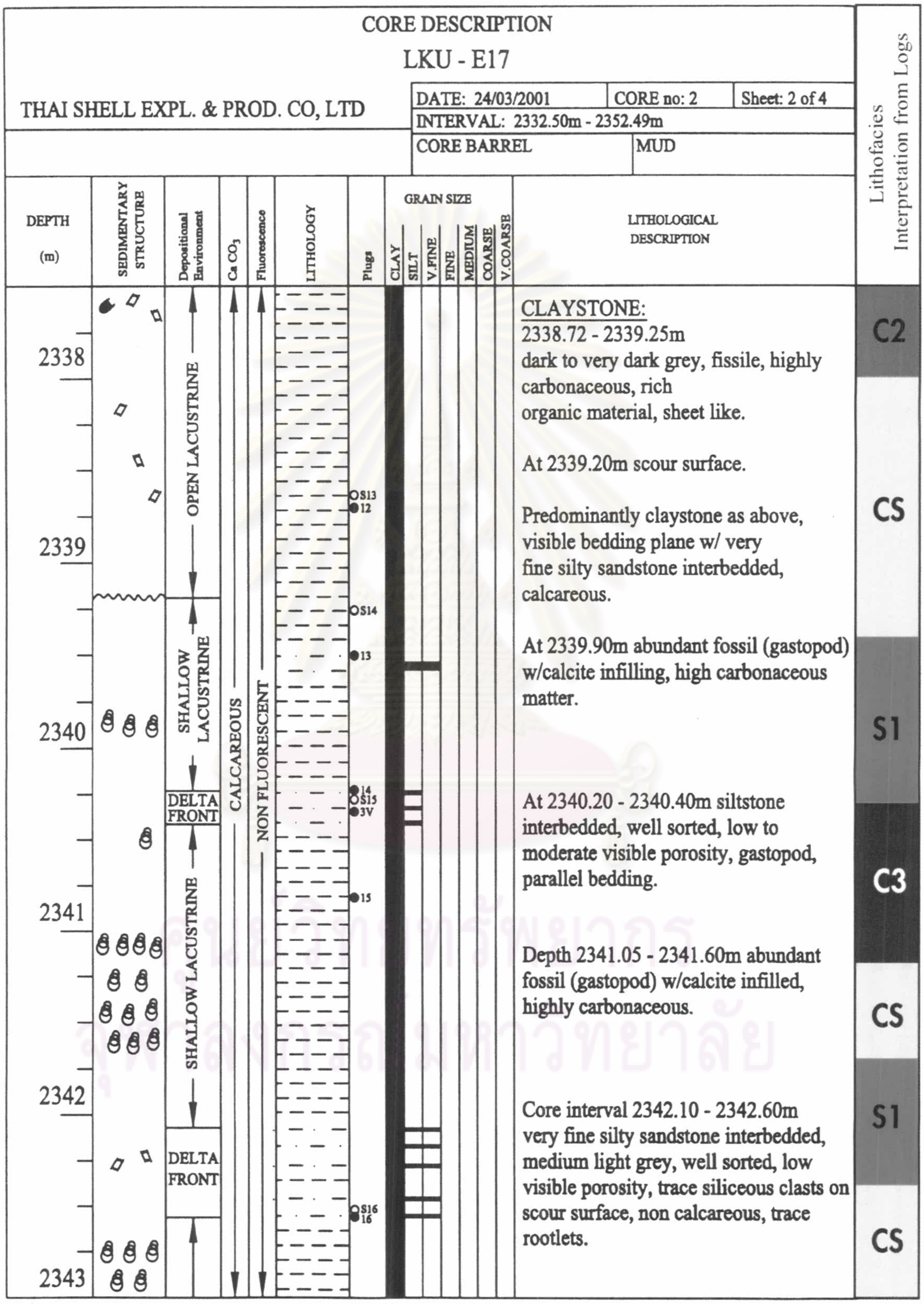


Figure 4.10 (cont.)

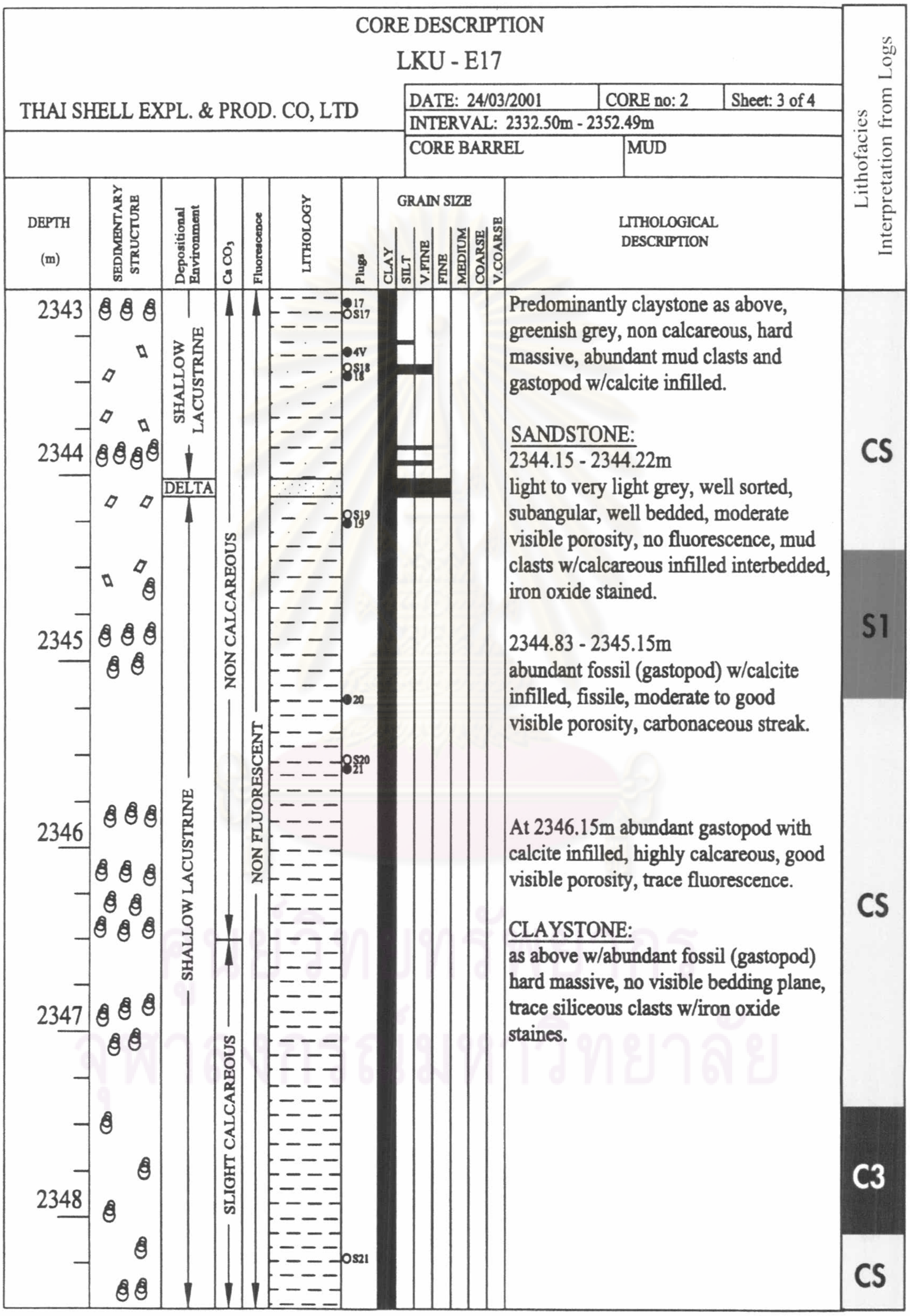


Figure 4.10 (cont.)

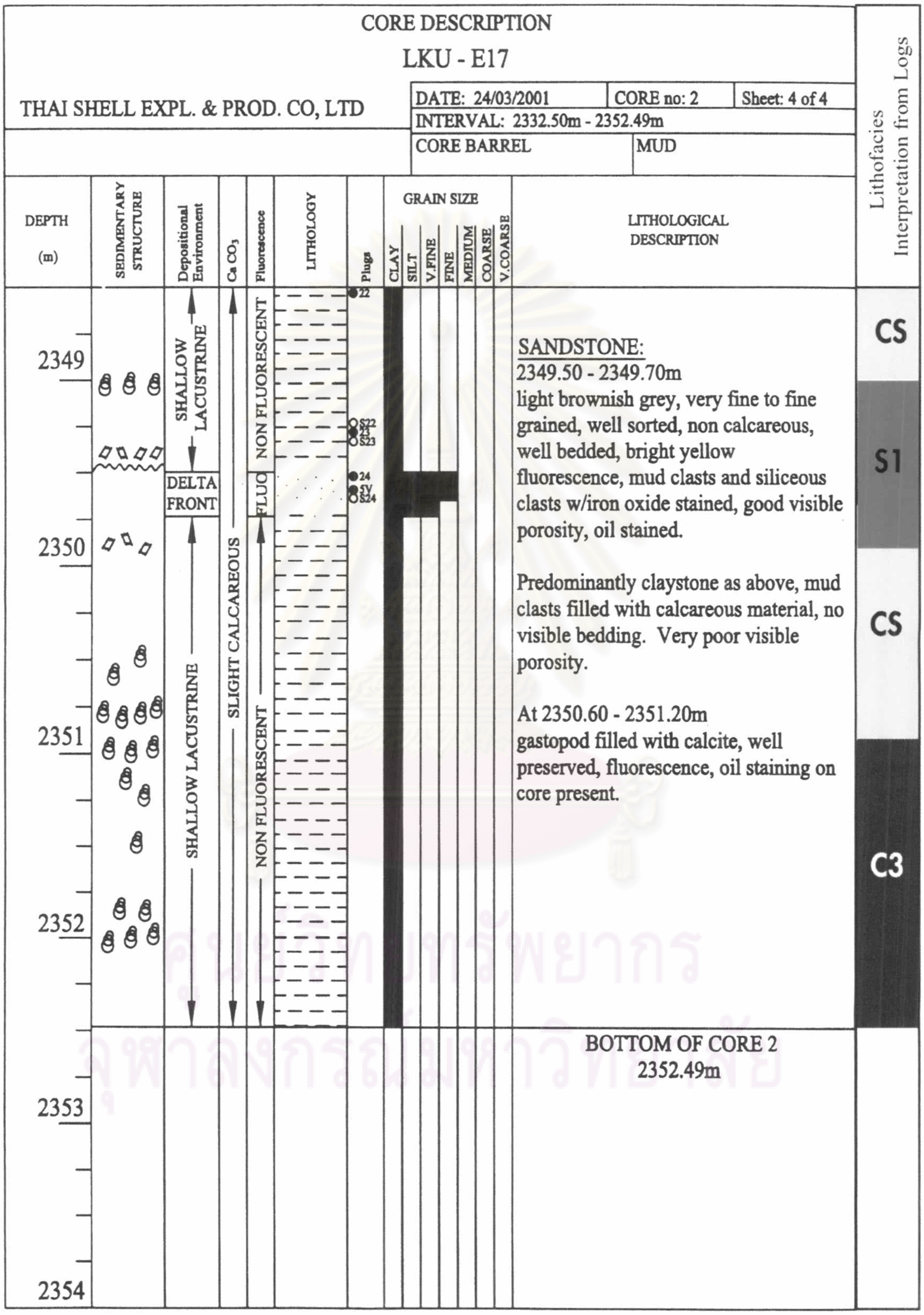


Figure 4.10 (cont.)

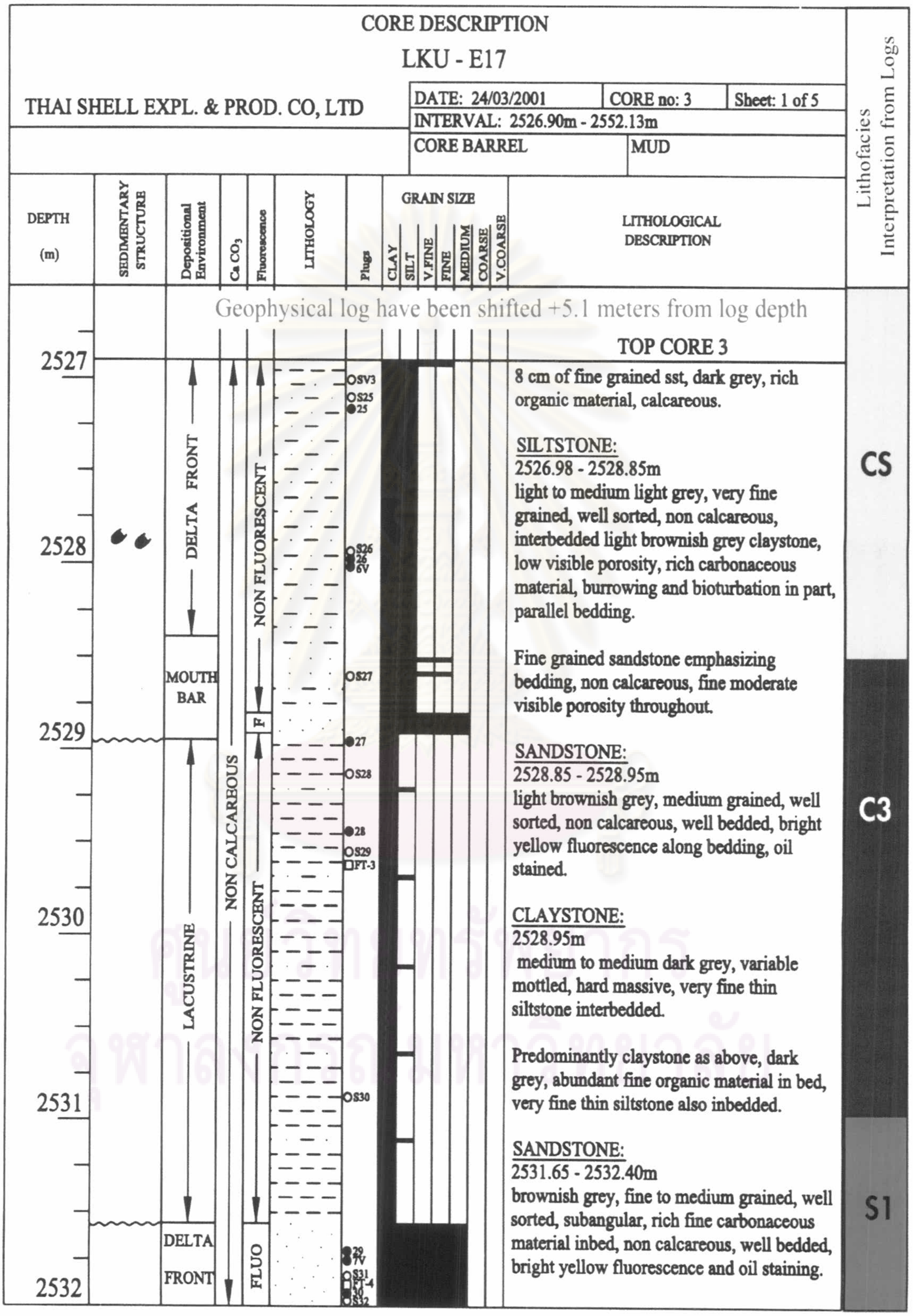


Figure 4.10 (cont.)

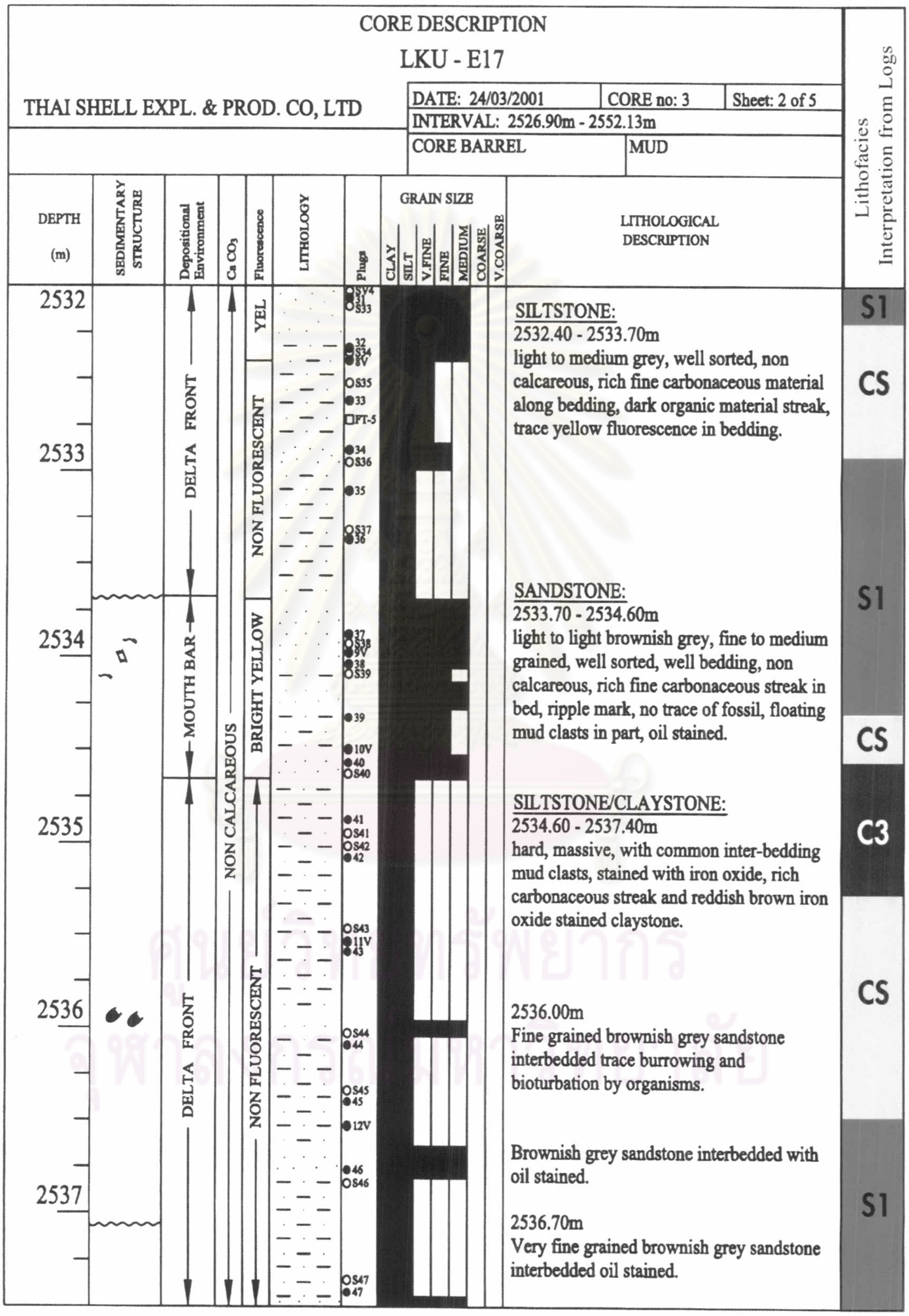


Figure 4.10 (cont.)

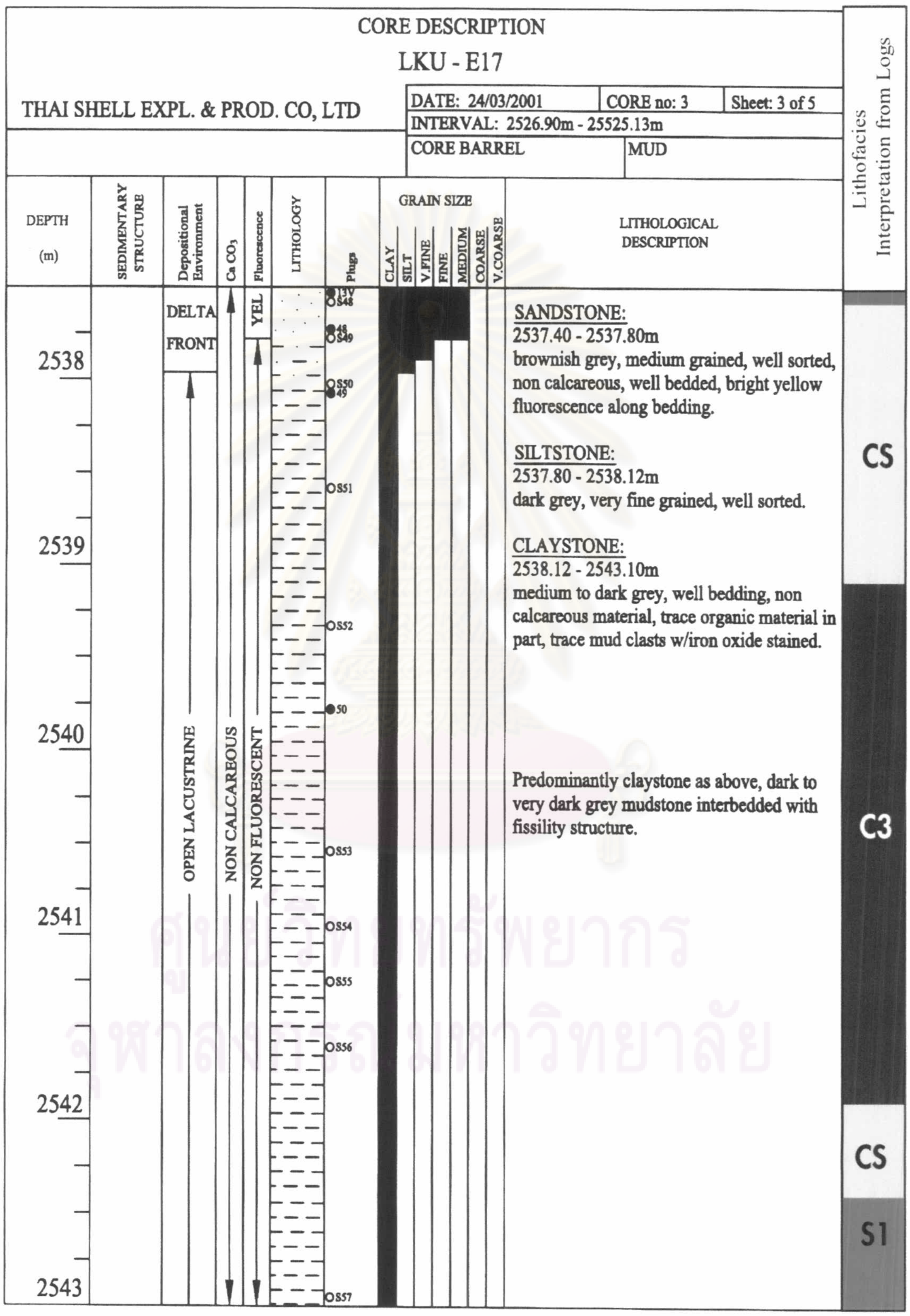


Figure 4.10 (cont.)

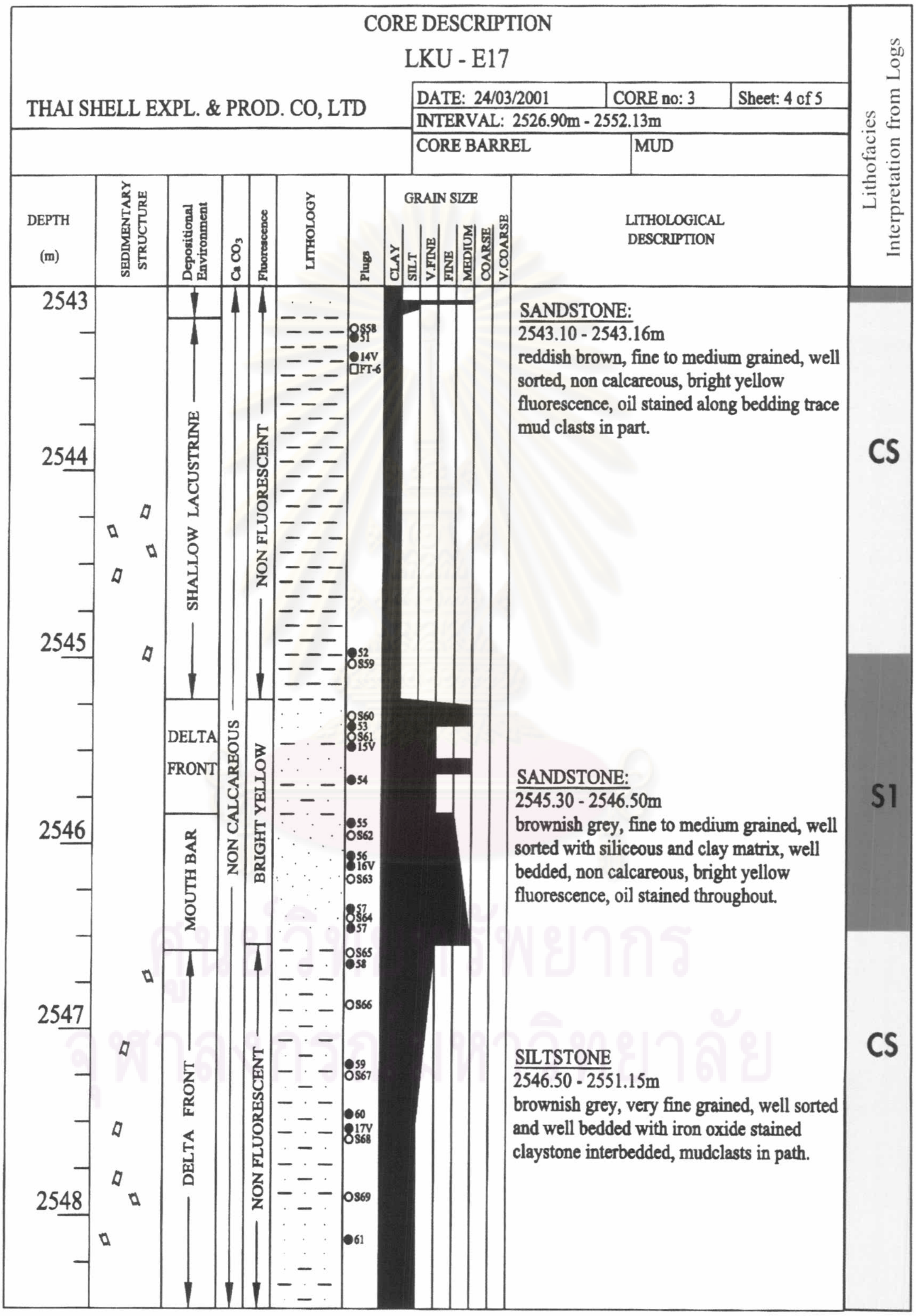
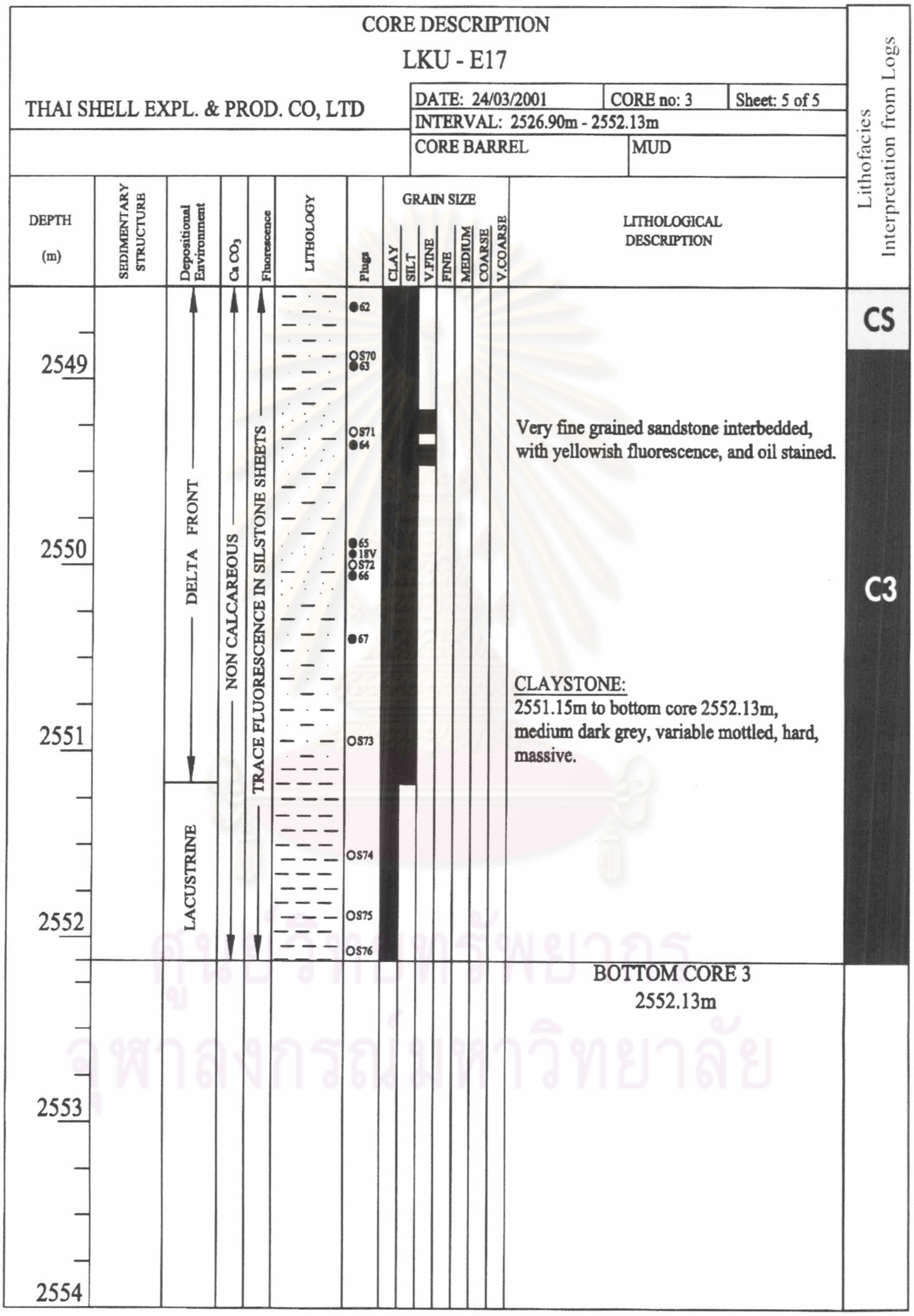


Figure 4.10 (cont.)



Results of hypothesis testing for lithofacies analysis from geophysical log data in well LKU-E17 are reported below.

1. Gamma ray log shapes under this test can be subdivided into three types (e.g. bell shape, funnel shape and uncertain shape). For example, funnel shape log presents at depths of 2329.30-2334.40 meters and 2550.10-2556.10 meters. Bell shape log is recognized at depths between 2338.50 and 2345.40 meters. Some intervals cannot be certainly defined gamma ray log shape such as depths of 2343.80-2350.70 meters. Result from this step indicates vertical boundaries for further lithofacies analysis.

2. Gamma ray log values of whole section are considered and they consequently yield all three groups of lithofacies as shown in Table 4.3 consisting of lithofacies group I, group II and group III.

3. Furthermore, most types of geophysical logs are observed together to specify key beds in each constraint indicated using log shape. At depths between 2331.40 and 2334.40 meters which is a part of funnel shape between depths of 2329.30 and 2334.40 meters. This key bed is therefore recognized as lithofacies C3 (Grey claystone). The other key bed is caught at 2342.30 to 2343.10 meters depth; this key bed is a bell shape at 2338.50 to 2345.40 meters depth. According to log values in Table 4.2, gamma ray, density and neutron logs indicate characteristics of lithofacies C2 (Carbonaceous claystone) for this depth range. Moreover, funnel shape, ranges of 2550.10 to 2556.10 meters, can be specified key bed of lithofacies C3 at depths between 2554.90 to 2552.13 meters.

4. Other layers are interpreted using suggestion of lithofacies groups and key bed lithofacies. In addition, lithofacies succession diagram is also significant for this study. The lithofacies diagram reveals relationships between lithofacies within the same succession. For example, a depth 2342.30-2343.10 meters obtains lithofacies C2 as a key bed for bell shape. Therefore, claystone, grouped by gamma ray log and associated with C2, is interpreted to lithofacies C1; that is mottled claystone (Figure 4.8). Another sample shows at depths 2550.10-2557.10 meters; lithofacies C3 as a key bed suggests that sandstone bed on top would potentially be

lithofacies S1. This interpretation is related to lacustrine-deltaic lithofacies succession diagram (Figure 4.4).

5. Comparison between core description and geophysical log interpretation presents that thin bed sandstone cannot be recognized from geophysical log; this may be demonstrated by sandstone beds at depths 2337.80-2338.10 meters and 2533.96-2534.05 meters, where they have 30 centimeters and 9 centimeters thick, respectively (Figure 4.10).

6. Organic materials are crucial assemblages to effect geophysical log record, particular in thin sandstone bed. At depths 2337.60-2337.80 meters, it is lithologically characterized by sandstone interbeded with organic materials (Figure 4.10), so that gamma ray value is classified as lithofacies group II. However, it is later identified as lithofacies CS. This is because organic material contains uranium content, that is a common source of radioactivity.

7. The most appropriate methods for lithofacies interpretation from case study of LKU-E17 is concluded in Table 4.5.

Table 4.5 Appropriate methodology for lithofacies interpretation using geophysical logs. (√ : significant method).

Lithofacies	**Gamma ray log shape**	**Geophysical log values**	**Lithofacies succession**
C1, C2, C3	√	√	√
S1, S2	√		√
S3, S4	√		
CS	√		√
P	√	√	
SC	√		

Base on Table 4.5, conclusions from lithofacies interpretation using geophysical log for LKU-E17 are presented below.

1. Gamma ray log shape provides strong evidence for log interpretation. The log shape influences all lithofacies except lithofacies S3 and S4 which are usually characterized by thin bed lithofacies.

2. Absolute geophysical log values are significant to recognize lithofacies. All values in each geophysicl log type are considered to interpret the particular lithofacies.

3. Lithofacies succession supports only thick- bedded lithofacies. Lithofacies S3, S4 and P, mostly range between 0.5 and 1.5 meters thick, could not be detected from geophysical log value and gamma ray log shape. Although lilthofacies SC does not present in LKU-E17 but the thickness of bed range approximately from 20 to 40 centimeters. From this reason, Lithofacies SC could not be recognized from geophysical log value and gamma ray log shape as well.