

## **“LITHO”**

### **A computerized approach to lithofacies identification**

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**Abstract:** It is well-known that logs respond not only to the petro-physical parameters of a formation but also to such geological parameters as mineralogy, texture and sedimentary features.

Several modern logging tools now in common use make new measurements to describe the formation lithology.

The high volume of measurements produced by modern logging techniques has necessitated the use of high-speed digital computers and analytical programs.

*LITHO* is a program which combines modern wireline logging measurements with a lithofacies database to produce an automatic lithological description of the formations penetrated by the borehole.

The database is defined from petrographical knowledge and calibrated against intervals whose lithology is well known. The database currently uses log recording of density, neutron, sonic transit time, gamma ray, photo-electric cross section and thorium, potassium and uranium concentration. External knowledge can be taken into account using Artificial Intelligence methods.

The application of *LITHO* to the Malay basin is demonstrated through an example presented in this paper.

#### **INTRODUCTION**

With the continuing progress made in petrophysical measurements, formation and reservoir evaluation methods, strong emphasis has been given to developing new logging techniques and interpretation routines to assist the geologists in solving complex geology and lithology problems.

In general, the lithology penetrated by the drill bit is determined from the analysis of cuttings recovered from mud circulation or cores cut only on limited—interesting—intervals. Determining the components and the thickness of the lithological column can become very difficult especially if problems are encountered during drilling (caving, mud swirling, loss of some soluble and fine constituents, loss of circulation).

The combination of physical parameters measured by the modern logging techniques (such as photoelectric cross-section (Pe), thorium and potassium concentration, dielectric constant) and the conventional measurements gives good lithological description of the formations.

*LITHO* is a new approach to obtain an automatic definition of the lithology from a given set of log responses.

## THE APPROACH

*LITHO* compares the recorded LOG values to a constructed LITHOFACIES DATABASE through a STATISTICAL analysis and describes the most probable type of rock (not the minerals).

At present the program uses any or all of the following input logs:

- Density Log
- Neutron Porosity Log
- Sonic Transit Time
- Natural Gamma Ray and
  - Thorium
  - Potassium
  - Uranium concentrations
- Photoelectric Absorption Index (Pe)
- True Resistivity

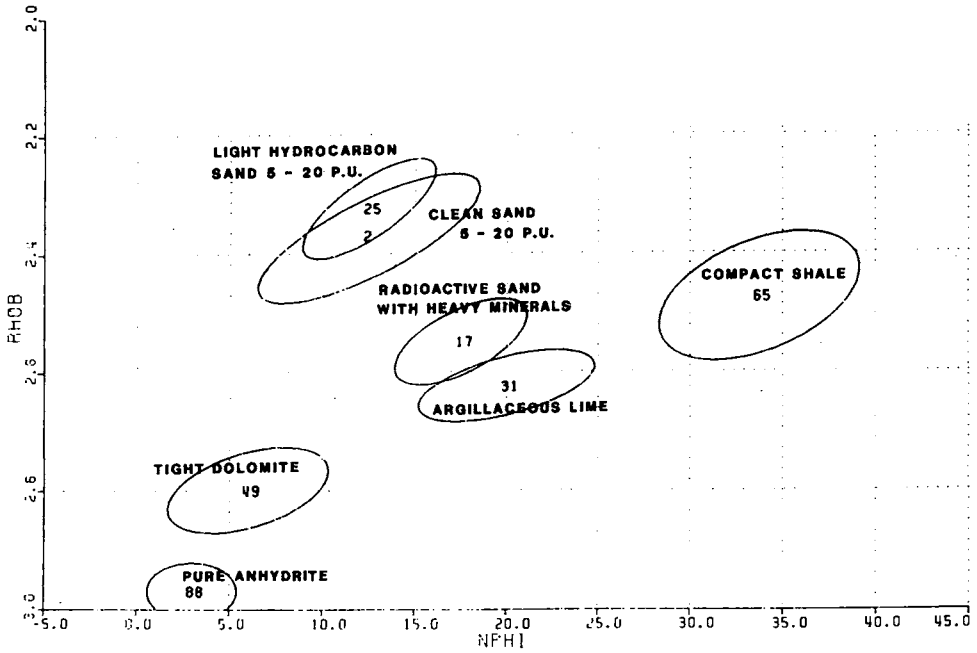
*LITHO* gives best results after the above logs have been corrected for environmental effects. However, for quick results, a database can be used at the wellsite that takes into account some of the effects of hole conditions, invasion, statistics, etc. Hydrocarbon bearing formations are described as such in the lithofacies since no correction is made to the logs for hydrocarbon effect.

The database is built on information gathered from laboratory data, studies made on core data and experiences gained on log response to different lithologies (mineralogy and elemental composition). It is made to be applied universally but it can be modified to better fit local conditions.

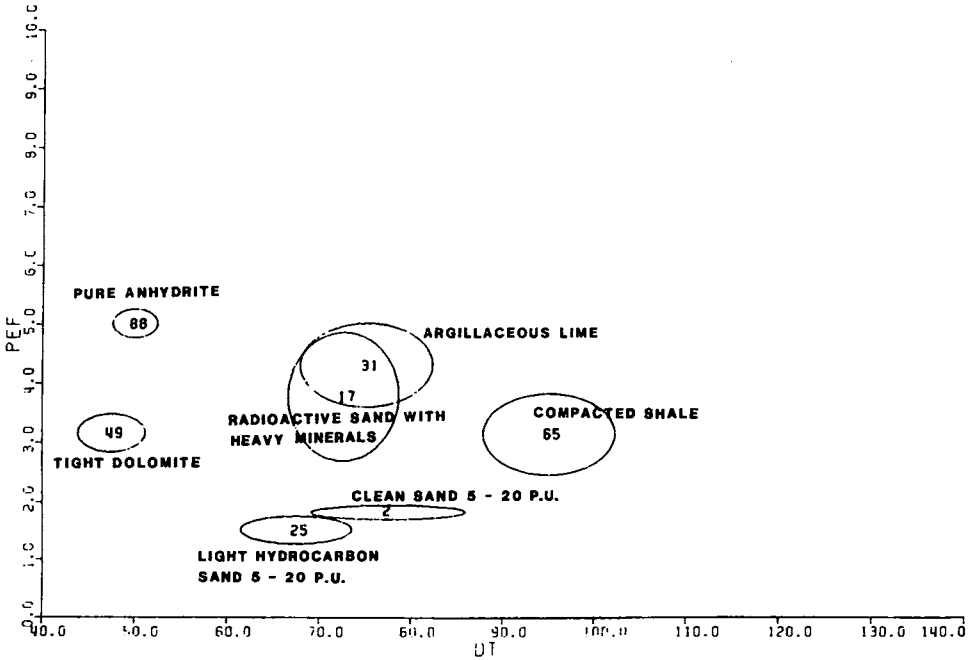
At a given depth, a set of "n" log readings ("n" is number of logs used as input to the program) can be represented as a point in "n" dimensional space. Over an interval covering a certain facies, the log readings will concentrate as a group or clustered points, since the log responses are similar.

In the database, each petrographic rock type is represented as a volume in the "n" dimensional space of logs in the shape of an ellipsoid. This allows for variations due to the nature of geology and data acquisition (Fig. 3). The size of each ellipsoid volume reflect the amplitude of all these variations. Rocks which have fairly fixed composition (e.g. anhydrite, gypsum, salt, etc.) would be represented by a small volume of database. But the volume representing shaly sands would be quite large, since they have varying physical characteristics and constituents. In practice lithofacies are split into subcategories. The discrimination of the facies increases with increasing number of input logs and hence increasing number of dimensions.

All the available logs are plotted against each other in two dimensions (cross-plots) giving ellipses of lithofacies. Then all these ellipses are combined together to give the ellipsoids defining the lithofacies in "n" dimensions. Fig. 1 shows examples of Neutron-Density and Sonic-Pe cross-plots with some electrofacies ellipses. Fig. 2



LITHOFACIES ELLIPSES IN NEUTRON - DENSITY CROSS-PLOT

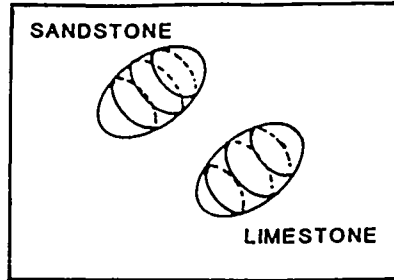


LITHOFACIES ELLIPSES IN SONIC - PE CROSS-PLOT

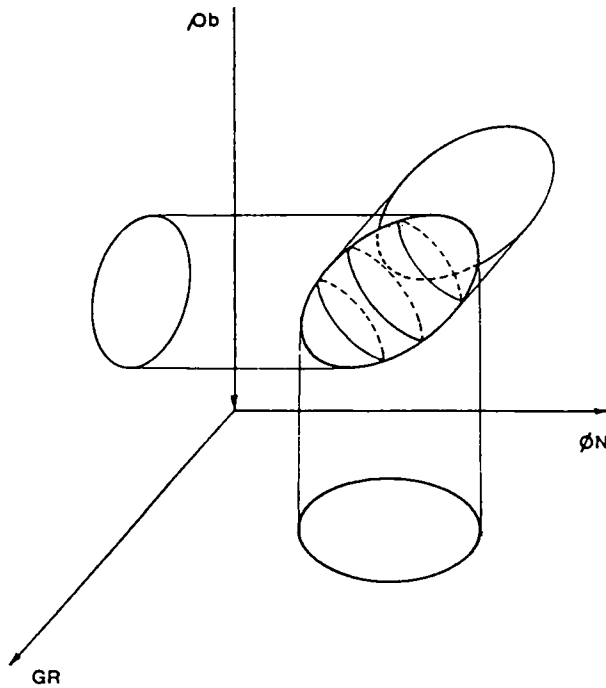
Fig. 1. Examples of Neutron-Density and Sonic-Pe cross-plots with some lithofacies ellipses.



## LITHOFACIES DATA BASE



### BUILDING MECHANISMS



EACH FACIES IS REPRESENTED BY A VOLUME TO ALLOW FOR

- GEOLOGICAL VARIATIONS (e. g. ACCESSORY MINERALS)
- LOGS VARIATIONS (e. g. ENVIRONMENTAL EFFECT)

Fig. 3. Lithofacies data base.

Sandstones are further subdivided into different categories depending on porosity range, cement type (calcareous, dolomitic, halitic), accessory minerals (heavy, e.g. pyrite, hematite), (radioactive, e.g. feldspar), heavy and radioactive, e.g. micas, zircon), and fluid content (oil and gas). There are about 30 sandstone categories in the program.

Shales lithofacies have four compaction grades (tight, compacted, average and uncompact), and includes special facies (lignitic, bituminous, and with heavy minerals). The clay mineral type can be deduced when Thorium (Th) and Potassium (K) values are available from a Natural Gamma Spectrometry Log. All other logs, especially the Photoelectric Cross Section (Pe), will bring in some discriminating power.

- Evaporites; when pure and thick (enough to be detected by logs) have very well defined log responses. They are therefore represented by small volume ellipsoids, owing to only minor changes in their composition and the statistical variations of the log responses.
- Carbonates; have been divided into limestone (less than 25% dolomite), dolomitic limestone (between 25 and 50% dolomite), calcareous dolomite (between 50 and 75% dolomite), and dolomites (more than 75% dolomite). Other carbonate lithofacies are included to take into account the presence of silica, anhydrite, heavy minerals (siderite, ankerite), clay (argillaceous), and radioactive minerals (apatite). Some rare types of carbonates like siderite and ankerite are also introduced to the database which in total has about 30 lithofacies.
- Organic rocks, are divided into three lithofacies as pure coal, lignite, and peaty, to reflect the small changes observed on the log responses in these types of coals.

#### — Igneous Rocks:

The igneous rocks (plutonic or volcanic) are divided into acidic (granite or rhyolite), acido-basic (granodiorite or trachy-andesite), basic (gabbro or basalt) and ultra-basic (peridotite or dunite) facies following their mineralogical composition. Density, sonic, natural gamma spectrometry tool (thorium, potassium and uranium contents) as well as the resistivity logs play a very important role to identify and differentiate the igneous rocks.

### STATISTICAL ANALYSIS

A statistical procedure, known as Bayes Decision Rule, is used to classify and assign each depth level to one of the reference lithofacies in the database. The main principle is to attach a probability distribution of log values to each lithofacies and then identify from which population the given set of log readings is most likely to originate. The possibility that a depth level does not belong to any of the specified lithofacies (in the database) is also considered.

Within each lithofacies the vector  $X$  of log responses is assumed to have an "n"—

variate gaussian distribution whose density is expressed as  $P(X/F_i)$ . This ties nicely with the ellipsoids of the lithofacies database which are interpreted as the volumes containing 95% of the points. These distributions allow us to calculate the probability of log readings when the lithofacies are known.

Our objective, to calculate and define the probability— $P(F_i/X)$ —of the lithofacies knowing the log values, can be obtained from the Bayes Formula:

$$P(F_i/X) = \frac{p_i P(X/F_i)}{\sum_j p_j P(X/F_j)}$$

The terms  $p_i$  in this formula stand for the prior probabilities of the lithofacies before inputting any logging data. They represent any prior information that may be available on the lithology. For example if there are no carbonate lithofacies in the region/field that we are studying, we can pre-set the  $p_i$  to zero for all carbonates facies.

When no information is available on the expected lithofacies they are all given equal chance, with all  $p_i$ 's set to be equal.

The lithofacies selected as the answer at a given depth level is simply that which maximizes the posterior probability. The computed posterior probability provides an index of confidence in the result. A point falling outside of all 95% ellipsoids is classified as "unidentified" facies.

### SPECIAL LOGICS

A rigid and straight-forward application of the Bayes equation may not be sufficient to solve some of the problems that may arise in practice. Therefore provisions have been made to incorporate some special logic functions in the program.

— The program can be guided by specifying the MAIN LITHOLOGY type in a given interval. This will disallow some lithofacies that may be plotting in the same ellipses in certain cross-plots. This information can be derived from local geological knowledge, analysis of other logs such as spontaneous potential, caliper logs, etc.

An incomplete logging program may not allow discrimination between two lithofacies (e.g. gas bearing limestone and clean water bearing sandstone may behave very similar on the density/neutron log). The ambiguity may be removed by recording the Photoelectric absorption index ( $P_e$ ) or inputting external knowledge or data.

— If the borehole effects are too serious (hole caving or barite, potassium salt KCl, gas in the mud), the affected logs will either define wrong lithofacies or result in unidentified levels. In such cases, the affected logs are not used over a certain zone (e.g. in the case of bad hole, caving) or over all the interval (in the case of KCl mud, the potassium content from the gamma spectrometry log). A flag is displayed to indicate that a log is not used over that interval, and the results may not be as reliable as for the other zones.

- In order to avoid holes in the database and hence resulting in a lot of unidentified levels, the ellipsoids have been defined with a certain overlap. But to avoid instability when points are at the boundary between two lithofacies a vertical continuity logic is built into the system.
- In thin beds, log responses are influenced by surrounding beds and the deflection often does not reach its true value to enable correct identification, though it may allow detection. Thus a minimum bed thickness can be specified to give the program the capability to retain thinner beds with very characteristic lithology (e.g. coal, shale and even sand beds).

### PRESENTATION OF RESULTS

The *LITHO* can be displayed in various ways to fit the needs of the user.

Fig. 4 shows a *LITHO* where the lithology column is bound with a GR (gamma ray) log. In Fig. 5 the lithology column is bound with the thorium and potassium curves from the NGT (natural gamma spectrometry) log. This stand-alone presentation can be used as an input to the geological columns on the well reports.

Another common way it is presented, is as shown in Fig. 6, is LITHO-GLOBAL CPI combined presentation. This enables the user to have both the petrophysical and petrographical (lithological) results obtained from the logs in one display.

All these results can now be plotted in colour for easier visual control of the data.

### APPLICATIONS

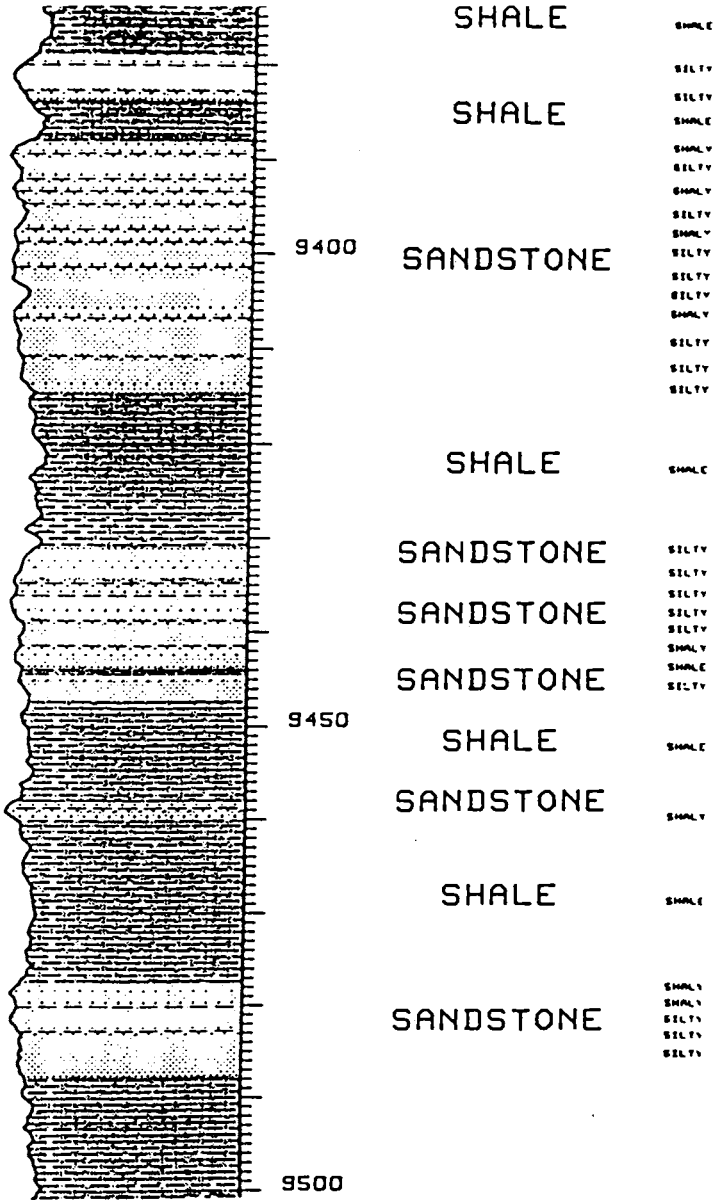
*LITHO*, when processed and displayed as a lithological column, at the wellsite can help the geologist to:

- Pick tops and bottoms of zones/formations
- Cross-check and depth match the cutting/mud log
- Select the depths to take sidewall core samples
- Select the depths of fluid sampling and/or pressure measurement points for the Repeat Formation Tester
- Define the intervals for drill stem testing
- Provide input information to wellsite formation evaluation

When processed in a Log Interpretation and Data Processing Center and used at the office, it has the following applications:

- Well to well correlations (can now be made in colour)
- Mapping of lithofacies thickness (isoliths), if needed after conversion to true vertical thickness
- Tie the geological section with seismic data, especially with Vertical Seismic Profiles
- Selection of interpretation model and parameters knowing the lithology and mineralogy

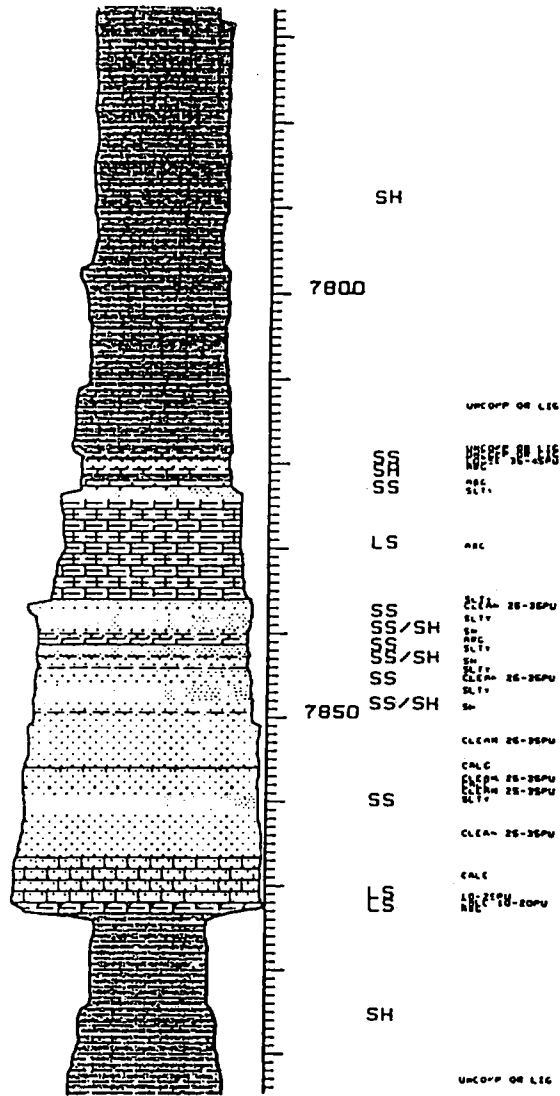




### EXAMPLE OF LITHO DISPLAY

- o GR CURVE BOUNDS THE LITHOLOGICAL COLUMN
- o BIG LETTERS FOR THE MAIN LITHOLOGICAL TYPE

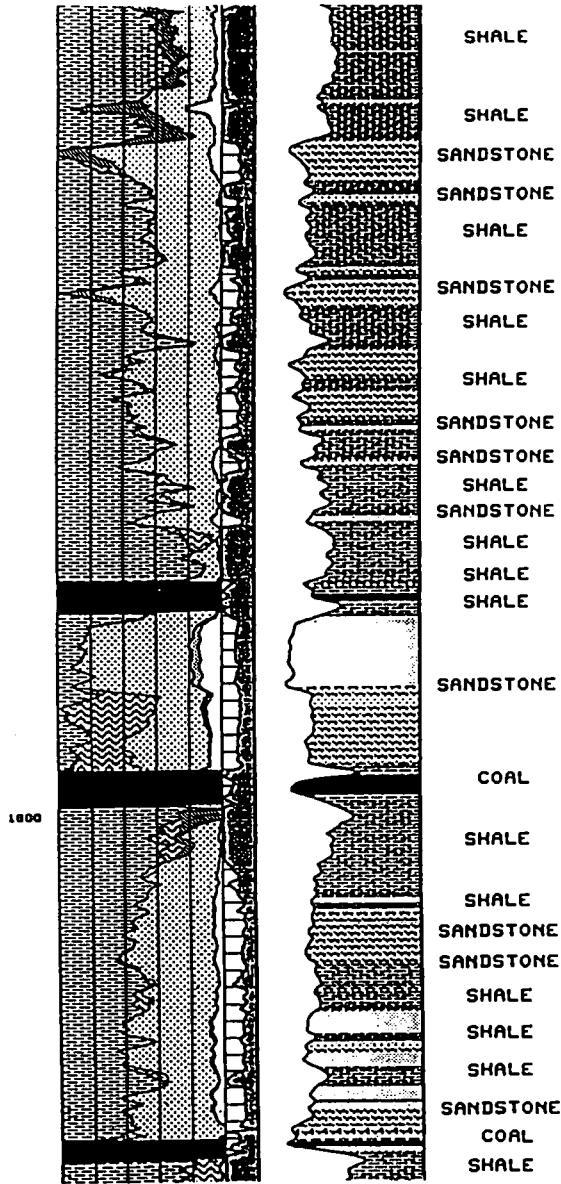
Fig. 4. Example of LITHO display bound by gamma ray (GR) log.



**EXAMPLE OF LITHO DISPLAY**

- THORIUM AND POTASSIUM BOUND THE LITHOLOGICAL COLUMN
- ABBREVIATIONS USED FOR THE TEXT

Fig. 5. Example of LITHO display bound by thorium and potassium curves from the natural gamma spectrometry (NGT) log.



**LITHO OUTPUT (RIGHT) COMPARED TO GLOBAL OUTPUT (LEFT)**

THE TEXT COLUMN HAS BEEN SIMPLIFIED TO CLARIFY THE DISPLAY BUT THE LITHOLOGICAL COLUMN STILL CONTAINS ALL THE DETAILS OF THE DIFFERENT FACIES

Fig. 6. LITHO-GLOBAL (CPI) combined presentation.

- The combination of lithological information derived from the *LITHO* with several types of computed dipmeter results (e.g. Dualdip, Geodip, Cluster) makes a very powerful geological tool in defining texture, stratigraphy and structure.

This integrated information obtained from the wireline measurements is now used to define the complete geological facies and lead to the determination of the depositional environment.

### EXAMPLES

*LITHO* database had been modified for application in the Malay basin. It has been tried in several wells covering intervals of different lithology. Comparisons with the cutting data, mud logs and detailed core analysis confirmed the confidence in the procedure and results of the program.

Fig. 7 gives a list of some of the lithofacies that are present in the database for the basin.

Fig. 8 to 11 show the ellipses of these lithofacies as they are presented in Density-Neutron, Sonic-Density, Gamma Ray-Neutron, Density-Sonic crossplots. The small numbers plotted on the crossplots show the grouping of actual log readings over the interval the plots were made. Each number shows the lithofacies assignment of each point plotted.

The LITHO-VOLAN (CPI) presented in Fig. 12 gives the main lithofacies as shale and sand. The sands are divided into two subfacies as clean and silty sands which is confirmed by the Volan results and cutting description that was available. The information on the sands and layering definition can be of help in correlations and reservoir engineering applications.

PLOT OF POINTS AND ALL ELLIPSES SELECTED EITHER BY MAJOR OR SUB DEFINITIONS

ELLIPSES PERCENTAGE CONTENTS = 50 %

LIST OF PLOTTED ELECTROFACIES

	RHOB	NPHI	DT	GR	PEF	RT	THOR	POTR
71 SHAL - STANDARD	2.40	52.5	112.5	105.9	3.10	0.00	25.0	2.35
81 SHAL - LIGNITIC OR BITUMINOUS	1.95	57.5	125.0	63.1	2.50	-0.17	25.5	2.40
4 SAND - CLEAN 30-45 PU	1.99	37.5	112.5	17.4	1.63	1.00	3.75	0.35
7 SAND - ARKOSE 25-40 PU	2.18	32.0	107.5	125.9	1.88	1.50	6.00	4.25
24 SAND - LOOSE HEAVY SILTY	2.20	47.5	120.0	35.5	2.75	1.00	10.0	1.10
29 SAND - RADIO LIGHT HYDRO 20-40 PU	2.00	27.5	91.0	79.4	2.75	1.42	27.5	2.35
77 SHAL - UNCOMPACTED	2.20	57.5	142.5	100.0	3.10	-0.12	25.5	2.40
85 COAL - PURE	1.65	40.0	122.5	22.4	0.50	2.00	10.0	0.35
86 COAL - LIGNITIC	1.50	50.0	130.0	22.4	0.60	2.00	10.0	0.35
65 SHAL - COMPACTED	2.48	33.7	95.0	105.9	3.10	0.00	25.5	2.35
22 SAND - RADIOACTIVE	2.50	20.0	77.5	56.2	2.83	2.15	17.0	1.10

Fig. 7. List of some lithofacies present in database.

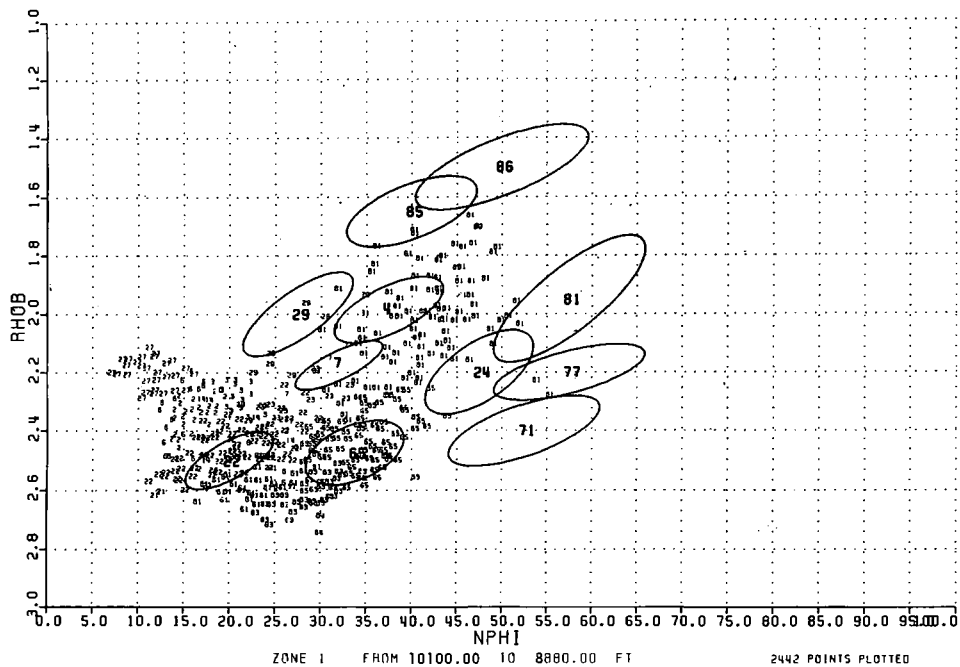


Fig. 8. Lithofacies ellipses presented in Neutron-Density crossplot.

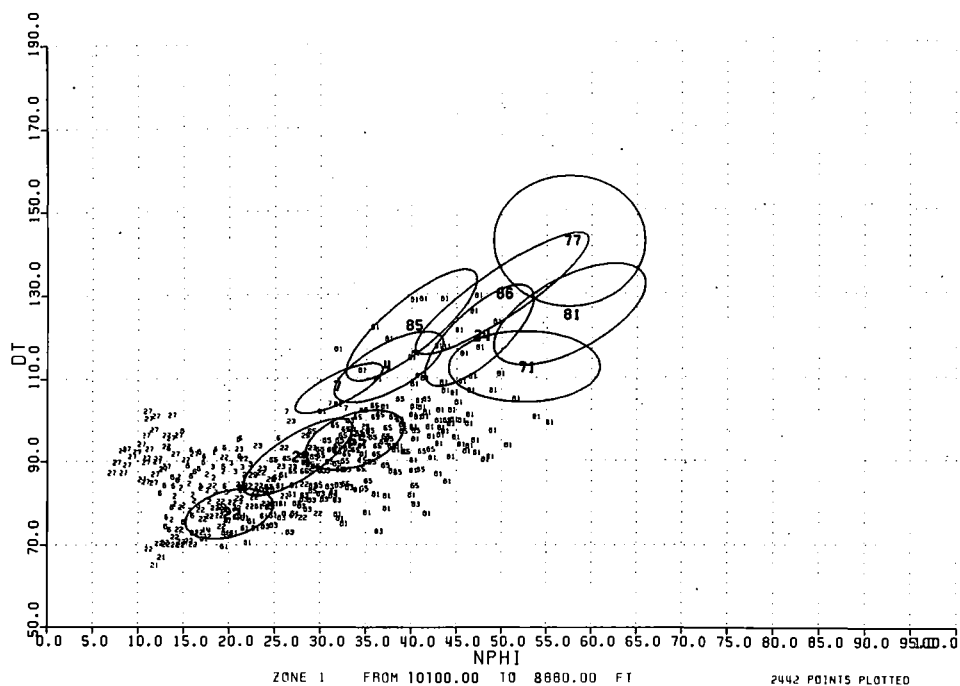


Fig. 9. Lithofacies ellipses presented in Sonic-Density crossplot.

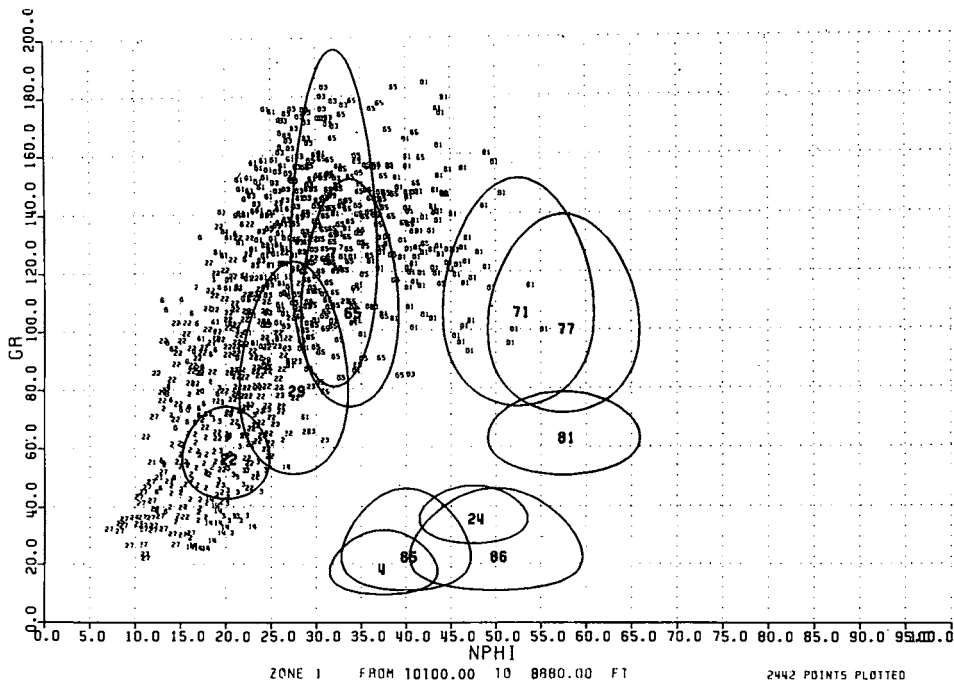


Fig. 10. Lithofacies ellipses presented in Gamma Ray-Newton crossplot.

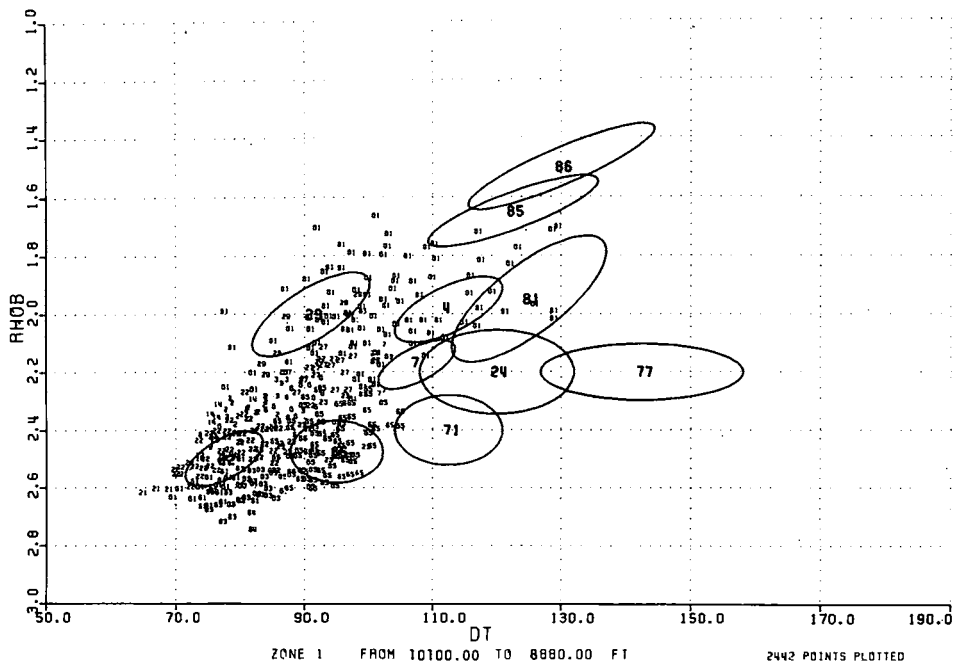


Fig. 11. Lithofacies ellipses presented in Density-Sonic crossplot.

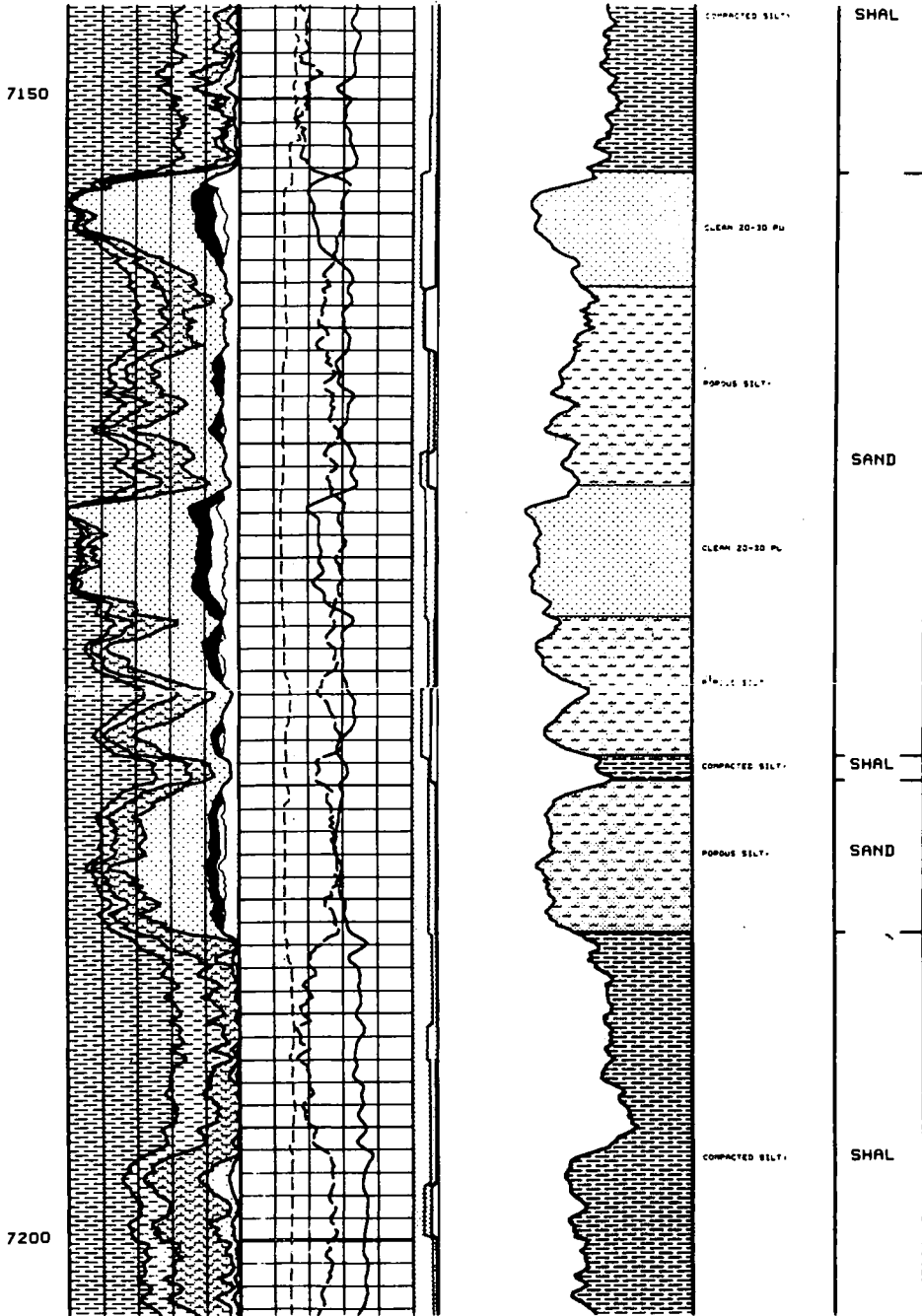


Fig. 12. LITHO-VOLAN (CPI) presentation.

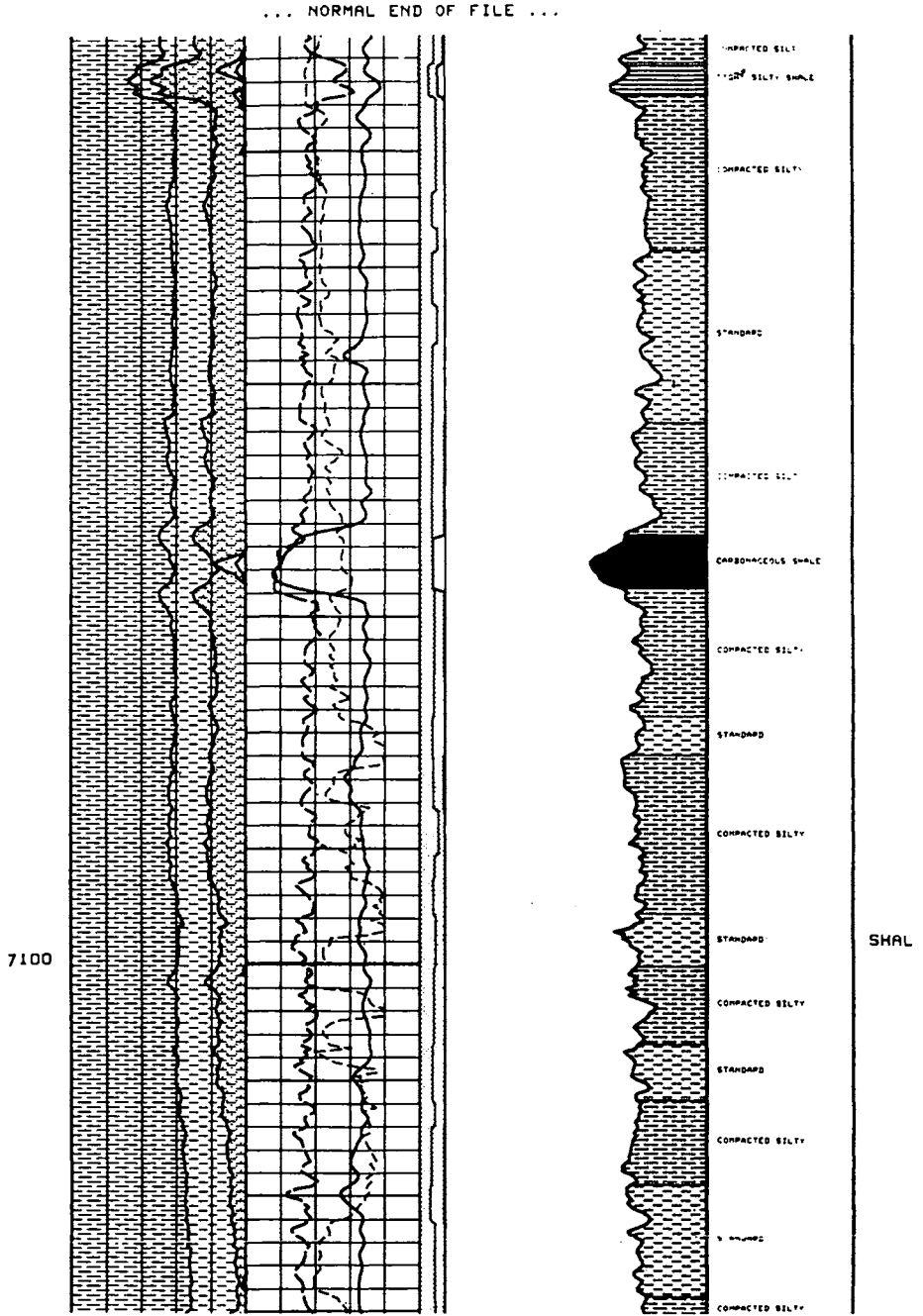


Fig. 13. LITHO-VOLAN (CPI) presentation of same well as Fig. 12 with shale section.



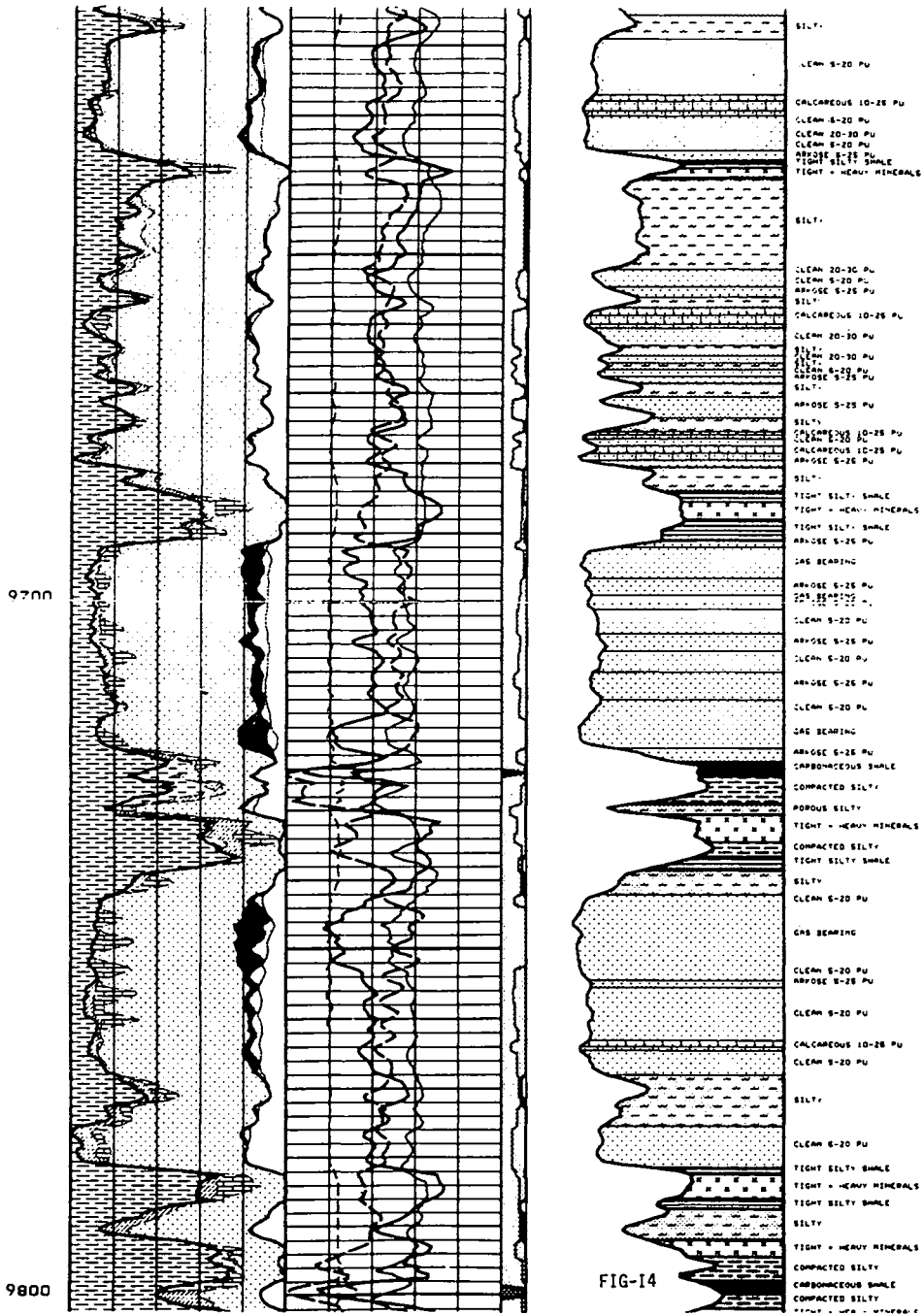


Fig. 14. LITHO-GLOBAL (CPI) of another well in a finely layered sand-shale interval.

Fig. 13 is an example from the same well which shows a shale section divided into three subfacies and a highly carbonaceous shale layer (which is referred as coal in the region, but defined as in the lithofacies in the cutting log).

The LITHO-GLOBAL (CPI), example Fig. 14, shows a finely layered sand-shale interval in another well in the Malay basin. The presence of heavy minerals and silt and the gas bearing intervals are recognised by the program. The layering definition demonstrates the value of *LITHO* in selecting depths of samples to be taken with the Core Sample Taker and pressure/sampling tests with the Repeat Formation Tester.

Comparison with the core description confirmed the results and the presence of these layers. The Gamma Ray log was used to bind the lithofacies column.

The combined application of LITHO, GLOBAL (CPI), DIPMETER and WELL SEISMIC results will be the next step in our efforts to help to solve the local geological problems.

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