Eni Agip E & P Division

Corporate Technical Services

Technological Area : Corporate Reservoir Services
Activity : Reservoir Characterization & Modeling

CLUSTER ANALYSIS

A SOUND METHOD FOR DATA INTEGRATION AND RESERVOIR CHARACTERIZATION

Quaderno Tecnico n°13

Foreword

During the '80s, Agip devised a methodology for reservoir internal characterisation based on a statistical treatment of log data through a cluster analysis algorithm.

This methodology, which was called "Cluster Analysis", enables us to obtain an objective zonation of the reservoir, based on the integrated use of core and log data (and any other information or measurement available).

A "Cluster Analysis" study allows the identification of reservoir elementary units, called "facies" or classes, with a characteristic lithological and petrophysical behaviour.

As a consequence, the petrophysical characterisation of these facies represents the key point of a reservoir study both in the case of a deterministic approach and when the use of stochastic methodologies of geostatistical type is envisaged.

This note is aimed at presenting an overview of the parameters which can be used for the facies characterisation and, consequently, of the possible uses of the cluster analysis results. To make this, reference was made to some "cluster analysis" studies carried out by GIAR during the last years.

Moreover, this note wants to give new impulses to the use of this methodology for reservoir studies taking into account the integration, promoted by AGIP, of the cluster analysis module in the new version of the "Tigress"application.

For this reason, this module is available to all Tigress users. With respect to the previous version of the cluster analysis program in VAX environment, it is simpler and less time consuming.

Examples of different outputs of the cluster analysis module on Tigress are presented in figures 1, 2,3 and 4 to show the good graphic quality of the resulting plot.

Introduction

The key point of the "Cluster Analysis" methodology is undoubtedly the class characterisation obtained after a particular cut on the dendrogram. The objective of this phase is the description of each "logfacies" from the lithological, sedimentological, mineralogical-textural, grain size and, above all, petrophysical point of view.
To make this, it is necessary to take into consideration and opportunely integrate all the data available: log quantitative interpretation, measurements from routine and special core analyses, mineralogical and grain size analyses, well test interpretation and sedimentological and textural information.
All these data can be managed by the Project Data Base of "Tigress" application used at present in GIAR and in some foreign affiliates. Moreover, some "Tigress" modules allow a rapid and easy correction and homogenisation of all the log data and an analysis of their statistical behaviour, both general and by classes.
Just in this phase, cluster analysis is a very useful tool since it allows a calibration of some very important parameters on the reservoir characteristics:

- overburden pressure measurements
- "m" and "n" parameters
- mineralogical composition
- Grain size

Moreover, cluster analysis is a complete methodology for reservoir description since it allows a very sound petrophysical characterisation, based on all the types of data available (log and their quantitative interpretation, cores, well tests) valid at reservoir scale.
In fact, it enables us to obtain, for all the field wells, an accurate definition of the main petrophysical parameters:

- Porosity
- Permeability
- Irreducible water saturation

The properties defined at the well represent the input for a correct spatial reconstruction of the reservoir petrophysical behaviour, to be used during the dynamic modelling.

Moreover, cluster analysis gives further opportunities during a reservoir study. For example, it can be a valid tool to identify anomalies inside the reservoir, to allow a lithological cut-off during the volumetric calculation of the hydrocarbon in place, to better orient the choice of the core samples for new analyses, etc..

Conclusions

"Cluster Analysis" is a very powerful tool for reservoir studies, very useful and reliable especially during the following working phases:

- petrophysical characterisation of the reservoir
- dynamic model initialisation
- reservoir layering

In fact all the lithological, mineralogical, textural and petrophysical properties of the reservoir can be analysed according to the facies classification resulting from a cluster analysis process.

The main parameters that can be considered in this phase are porosity, permeability, irreducible water saturation, grain size, volume of minerals and compaction factor.

Each facies is then characterised by a peculiar set of parameters, resulting from the integration of log, core and well test data.

This characterisation is representative of the whole field properties, because it is made on a field basis and not only on a well basis; this makes cluster analysis more appropriate for reservoir studies than other similar commercial products.

Once the petrophysical characterisation of the facies is done, one of the most useful output of cluster analysis is a set of synthetic curves of the main petrophysical parameters (porosity, permeability, irreducible water saturation).

This represents a big enhancement in reservoir characterisation because these data for all the wells are used to compute more reliable petrophysical maps for each dynamic model layer.

In the case of stochastic approach, geostatistical methodologies allow a spatial distribution of the facies, keeping the vertical detail of the cluster analysis results (log sampling rate). In this kind of approach the facies is used as a "rock-type"; the 3D distribution of the petrophysical properties of the reservoir is strictly related to the facies simulation and based on the results of the cluster analysis characterisation phase.

This approach allows a very detailed reconstruction of reservoir heterogeneities in the fluid flow model.

The examples presented in this brief technical note are relevant to the most common uses of cluster analysis in reservoir studies; other types of applications will be certainly made in the future according to the new techniques for data recording and the new challenges of reservoir characterisation.

1. Use of "Cluster Analysis" for data analysis and integration

The cluster analysis methodology allows an approach at reservoir scale (and not at single well). This enables us to relate some parameters to each facies and, as a consequence, to calibrate them suitably for the correction and interpretation of the basic data.
Some of these parameters, which are not always taken into consideration during the facies characterisation, are presented in the following paragraph to point out the improvement in a reservoir study.

1.1 Overburden pressure

If compared with the relevant measurements from logs, core analyses results can often be a little overestimated. This overestimation is related to the fact that cores, at surface conditions, tend to release the stress induced by boundary pressure at reservoir conditions.
This pressure, called "overburden pressure", varies with the reservoir depth and results in a compaction effect of the reservoir rock.
This pressure results from the combined effect of the burden of both the rock and the fluid columns on the reservoir cored zone.
The compaction studies carried out in laboratory enable us to obtain porosity and permeability values and, possibly, other parameters with different overburden pressures. These analyses should generally interest a set of samples representative of all the lithologies composing the reservoir.
On the basis of these measurements it is possible to reconstruct the PHI and K variation curves with the overburden pressure variations with respect to the value measured at atmospheric pressure. Moreover, by associating the facies value from cluster analysis to the samples on which the measurements are carried out, it is possible to obtain a PHI or K variation for each reservoir facies.
Fig. 5 shows an example of porosity variation curves vs. overburden pressure for different lithofacies. The various overburden pressure values applied during the test are on the abscissa, while on the ordinate there is the percentage of porosity reduction, referred to the value measured at atmospheric pressure.
When the overburden pressure value at reservoir depth is known, it is possible to recognise the correction to the core measurements on the diagram, according to the type of facies,.

1.2 “m” and “n” parameters

The “**m**” and “**n**” parameters, which are obtained from laboratory measurement plots, are important mainly during the interpretation phase of water saturation from resistivity logs.

In fact, the “**m**” cementation exponent represents the value of the porosity exponent in the formula for the Sw calculation. This parameter is mainly affected by the spatial organisation of the pores inside the rock. As a consequence, it is strictly related to the characteristics of each lithofacies.

Fig. 6 shows that a relationship exists between facies and “**m**” values; in fact the semi-logarithmic crossplot F vs. PHI (Formation Factor vs Porosity) highlights that the points belonging to different facies tend to locate along straights with different inclinations (characterised by a peculiar angular coefficient).

The “**n**” saturation exponent is the constant relating the resistivity index of a rock (Ro/Rt) to its water saturation; it is strongly affected by the rock wettability, which is directly related to the type of lithofacies.

For this reason, at facies variation, the “**n**” values from laboratory should show different behaviours, which can be highlighted on **n** vs. PHI, **n** vs. K or **n** vs. √ K/PHI cross-plots. Figure 7 shows how a particular behaviour of the saturation exponent has been identified in a recent study for each one of the facies present in the reservoir.

The possibility of relating the “**m**” and “**n**” behaviour to the facies from cluster analysis has remarkable advantages during the quantitative log interpretation. Thence, it is possible to use the zonation of the cluster analysis as a basis for the log interpretation in the well: a specific interpretation model, characterised by peculiar “**m**” and “**n**” values, is then used for each cluster analysis facies interval along the well.

1.3 Mineralogical composition

The possibility of characterising a facies also in terms of mineralogical composition represents a great opportunity when a good number of mineralogical and diffractometric core analyses are available.

In fact, in this case, the difference between rocks with similar characteristics can be made on the basis of the mineral composition present and, mainly, it is often possible to identify a particular mineral, whose presence can affect other rock properties. In this case, teh facies classification can be made according to the volume of this mineral.

This type of characterisation has been recently adopted during a cluster analysis study on a terrigeneous reservoir of shallow marine environment.

The typical mineral of this reservoir is chamosite, a authigenic component with a different impact on porosity and permeability; in fact, the chamosite crystals along the pore walls preserve primary porosity from secondary quartz overgrowths, while they remarkably reduce permeability.

For these reasons, the chamosite volume had an important role during the facies characterisation phase, since the final classification was made grouping classes with the same chamosite content.

The availability of the mineralogical analysis for the cluster analysis facies also allows a control of the volumes of the minerals calculated during the quantitative log interpretation; the main one is Vsh (shale volume) which is often used as “cut-off” parameter during the calculation of the average petrophysical parameters per layer.

1.4 Grain size

In the case of reservoirs in clastic sediments, the grain size can have an important role during the reservoir petrophysical characterisation.

In fact grain size is strictly related to the reservoir lithology and also represents one of the parameters which more affects the petrophysical properties.

For this reason, grain size can be a fundamental parameter during the petrophysical characterisation of the facies obtained through cluster analysis.

Figure 8 shows how in a reservoir study on the Adriatic offshore it was possible to characterise the reservoir on the basis of the relationship between grain size median and permeability.

This allowed a final gathering with four classes (one is not represented in the cross-plot since it was not sampled for core analysis, being completely shaly) starting from an original cut of 48 classes on the cluster analysis dendrogram. This characterisation method gives a lithological, petrographical-sedimentological and, above all, petrophysical value to each one of the four resulting classes.

In fact, on the basis of the facies sequence at the well and of the type of relationship identified (grain size median vs permeability), it is possible to assume the production characteristics of the wells for which no information on permeability is available.

2. Use of "Cluster Analysis" for reservoir characterisation

2.1 Porosity

Porosity is one of the main parameters for the petrophysical characterisation of the cluster analysis facies.

The data for characterisation come both from routine analyses on core samples and on the log quantitative interpretation (when present).

They are two very different types of data since in the first case they are direct measurements made in laboratory and in the second one the results of an interpretation of curves recorded inside the reservoir.

On the other hand, core data are relevant only to some intervals in some wells, while log interpretation gives a continuous porosity curve in all the wells treated.

For this reason, after an accurate depth matching of cores with respect to logs, it is necessary to verify that the two types of data are in accordance between them.

This control can be made superposing the PHI punctual core values to the PHI interpreted curve in each well or verifying the relationship between the two types of data by means of a PHI log vs. PHI core crossplot.

When the two types of porosity are consistent, it is better to use the data from log interpretation for the characterisation since it gives a more complete statistics for each of the facies identified inside the reservoir.

This is as much true when there are problems of failed core recoveries. In fact this phenomenon can completely false the statistical porosity distribution of some facies (often they are the less consolidated or more easily subject to mechanical fracturation).

Fig. 9 shows the great difference in the statistical distributions between the core measurements and the values from log interpretation for a facies mainly composed of not consolidated sands. All the high porosity values present in log data are totally absent in cores, due to failed core recoveries.

Fig. 10 shows an example of facies characterisation in a recent study; this characterisation was carried out on the basis of the distributions of porosity quantitative log interpretation data.

If the logs interpreted are not available, or the result of the interpretation is not consistent with the core measurements, only the last ones can be used during characterisation.

In this case the facies description obtained in all the wells through the cluster analysis is very useful to build a synthetic porosity profile in not cored wells.

This makes a porosity curve available in all the wells, to be used both directly in the calculation of the average PHI values per layer and indirectly as calibration parameter of the CPI in not cored wells.

The construction of the PHI synthetic profile is based on the statistical parameters representative of the porosity distributions per facies: they are generally the average value and the standard deviation (figs. 2 and 11).

2.2 Irreducible water saturation

As concerns irreducible water saturation (Swi), two types of data are generally available: the results of special core analyses and the log quantitative intepretation data. The first one represents measured values, even if they are relevant to few generally dispersed data, while the second one gives an intepreted water saturation curve, corresponding to Swi in the hydrocarbon zone, above the capillary fringe.

Facies characterisation from cluster analysis can be made relating irreducible water saturation to porosity; the relationship between these two parameters for each facies can be studied through a crossplot PHI vs Swi, integrating log and core data.

Figures 12 and 13 show two examples of relationships between these two parameters for facies with different characteristics; in both cases the modelling of irreducible water saturations in function of porosity was carried out through non linear relationships of the type:

$$Swi = a/\phi + c$$

The comparison between them shows how the two types of data have been weighted in a different way for one or the other facies. Fig. 12 presents the crossplot relevant to non consolidated lithology for which the core data are not very representative of the real petrophysical behaviour. As a consequence, the relationship was defined interpolating only Swi data from log intepretation.

On the contrary, the crossplot in fig. 13 is relevant to a very tight and well cored facies for which core and log data are in accordance. Thus, the same weight was given to the two types of data to correctly define the fitting curve for the petrophysical model.

The possibility of relating irreducible water saturation to the facies is in agreement with the rock type concept used in the dynamic modelling and represents a good opportunity for reservoir studies.

This is particularly significant in the case of a geostatistical approach based on the facies 3D simulation and the next attribution of the petrophysical parameters to the facies simulated.

In fact, on the basis of the facies and porosity simulation, it is possible to generate the relevant 3D Swi simulations on fine grid and, after an appropriate upscaling, to use them in the dynamic model as end point to calculate the initial water saturation for each model cell.

More detailed explications on the methodology for Swi characterisation and distribution and for the relevant definition of water saturations in the dynamic model is presented in MOST note of May ‘95 titled “New approach for treating water saturation in reservoir studies”.

Moreover, the facies characterisation as concerns Swi allows the construction of synthetic curves based on a porosity profile and the PHI-Swi relationships defined for each facies (the technique is the same as the one previously described for the Swi geostatistical simulations). These synthetic curves can be very useful if compared with the Sw curves resulting from the quantitative log interpretation. In fact they allow an evaluation of the results of these interpretations in the hydrocarbon zone and they clearly point out the height of the capillary fringe (zone where the two curves obviously diverge), as shown in fig. 14.

2.3 Permeability

Permeability is a fundamental parameter in the reservoir petrophysical characterisation since it has a remarkable influence on the fluid flow inside the reservoir. For this reason, it is important to study the spatial behaviour of this petrophysical property accurately and, above all, to use all the data able to give information on it.

The most common permeability data can be obtained from routine core analyses. It must be corrected both for overburden pressure and for Klinkemberg effect, when these corrections have not already been carried out in laboratory.

Core permeability is a punctual data referred to the sample on which the measurement is carried out; it is a fundamental information for the reconstruction of reservoir heterogeneities at small scale.

However, this type of data is not always exhaustive to define the behaviour of the facies in the reservoir; in fact the distribution of the permeability values from core data may often be poorly representative of the real petrophysical behaviour of the reservoir.

This is mainly due to the fact that, except in the case of continuos coring, cores represent only a limited reservoir portion which is generally the one characterised by the best petrophysical characteristics.

However, also for the best facies, cores can give an unrealistic distribution of the values, especially when there are remarkable lacks of recovery in not very consolidated lithologies.

For these reasons, it is absolutely necessary to integrate the core permeability data with the information from well tests. They represent indirect permeability measurements since they have been obtained from production test interpretation and they give information averaged on a rather large reservoir portion around the well column.

In order to consider a well test permeability value as representative of the petrophysical behaviour of a peculiar facies, very particular conditions must be present. They must be verified time by time (ex.: tested production interval almost completely composed of the facies itself, sufficiently long test, single phase fluid conditions, etc.).

For this reason, the choice of the most representative tests cannot leave apart the comparison between the intervals interested by the test and the column of the cluster analysis as well as a detailed investigation on the conditions at which the test took place.

Then, for the selected tests, the computed permeability must be transformed from effective to absolute, using the rel perm values available from special core analyses.

Now a porosity value, which corresponds to the average porosity of the tested interval, must be associated to each absolute permeability value.

To calculate it, data from quantitative log interpretation should be used since they are continuos in the whole tested interval. The use of core porosities is recommendable in the case of continuos coring or of poor quality of the log data interpreted.

Thus, the test result can be represented in a porosity vs permeability plot, together with the corresponding core analysis data. This allows a direct comparison between the two types of data and, accordingly, the attribution of a weight in accordance with their representativeness during the petrophysical characterisation phase.

An application of this methodology for the integration of test and core permeability is the one made in a reservoir study of 1995. One of the peculiar characteristics of this reservoir is the remarkable presence of loose sands whose petrophysical characterisation proved to be problematic; this was due both to a lack of core recovery and to a very selective sampling for laboratory analyses (the plugs were almost exclusively taken in consolidated intervals).

The availability of a good number of well tests enabled the integration between the two types of permeability data and a more correct evaluation of their representativeness.

Fig. 15 shows how the choice of the test to be used has been mainly based on the interval tests and on the availability of some permeability values for the same facies.

Taking as an example the facies corresponding to loose or poorly consolidated sands, the crossplots porosity vs permeability (presented in fig. 16) show that the permeabilities relevant to well test data are one or two orders of magnitude higher than core data.

In this case, it is evident how the statistic parameters of core data are not representative of the whole facies population. As a consequence, as concerns permeability, the petrophysical characterisation of this facies is based only on well test response.

Further details on the integration between core and well test permeability and the application from which this example was taken are presented in MOST note of February '95 titled " Flusso metodologico per l'integrazione quantitativa delle permeabilità da interpretazione dei well test con quelle da carote".

The facies characterisation in terms of permeability can be based either on a PHI-K linear relationship or on the statistic characteristics of the experimental K values distribution.

In both cases the characterisation allows a construction of permeability synthetic curves which can be very useful for the wells where neither core was taken nor well test was carried out.

In the case where all the facies are characterised by a linear PHI-K relationship, it is possible to build a synthetic permeability curve for all the wells where a porosity profile is available. In fact, the value of K_{sint} is calculated as a function of porosity, based on the PHI vs K relationship relevant to the facies present at each depth along the well (fig. 17).

This approach enables us to calculate a more realistic k synthetic curve, since different permeability values can correspond to a similar porosity value according to the different facies where this porosity has been identified.

However, in the case of poor correlation between PHI and K, the synthetic permeability curve can be built on the basis of the statistic characteristics of the K values for each class. Particularly, due to the fact that permeability distribution tends to a lognormal trend, the median combined with the interquartile range are used (figs. 2 and 11).

However, in both cases, the characterisation obtained for permeability (as also the ones of porosity and irreducible water saturation), represents a fundamental tool for the reservoir study, since it affects the next phases of the work:

- choice of the grid for the dynamic model The objective is to obtain layers as homogeneous as possible from the petrophysical point of view, so that the average value of each parameter per layer is really representative of the punctual data present in each layer. Fig. 18 shows the example of a vertical layering based on the synthetic permeability curves.
- permeability characterisation of the model layers. The availability of a continuos permeability curve in all the wells represents a valid support in the definition of the K areal behaviour in the different model layers. In fact synthetic curves can give average well values for each layer to be used during the mapping.
- petrophysical simulations, especially in the case of stochastic approach. In fact the use of geostatistical techniques enables us to simulate the spatial distribution of the facies recognised by the cluster analysis and then to attribute the petrophysical properties to the facies simulated. Thence the petrophysical characterisation is the basis to obtain permeability simulations (as well as porosity and irreducible water saturation) strictly related to the spatial distribution of facies (fig. 19)

3. Further use of "Cluster analysis"

Cluster analysis is a flexible and efficient tool to be used in different ways during a reservoir study. Three examples of the opportunities of the cluster analysis are presented here below.

However, it must be pointed out that, according to the problems of a reservoir and the objectives of a study, it is possible to investigate other uses of cluster analysis.

3.1 Identification of anomalies inside the reservoir

It is known that the choice of the logs to be used in the cluster analysis process is in function of the type of reservoir characterisation to be obtained (lithological, petrophysical, mineralogic-textural, etc.).

However, there are situations which can be defined "anomalous" and that cannot be very easily identified by traditional logs.

These types of "anomalies" are often highlighted during the characterisation phase of the cluster analysis since they have an impact on the petrophysical behaviour of one or several classes. In fact, in these cases, there is often an apparent inconsistency between the data from different sources.

For example, a class with rather homogeneous and well defined characteristics can show, as concerns a certain parameter, a frequency distribution of the values from core analysis with bimodal or plurimodal trend.

In these cases further investigations must be necessary for a better understanding of the problem. Particularly, to discriminate and classify the different behaviours inside the same class, we need to understand to which type of phenomenon they are related.

For this reason, it must be useful to carry out dedicated analyses which envisage also the use of non traditional techniques. For example the analysis technique "CT X ray" may be useful to identify, inside each facies, the presence of vugs. Accordingly, the use of some NMR recordings can help in understanding the phenomena of differential diagenesis.

As already said, this type of anomaly often affects the behaviour of the petrophysical properties also as concerns the same facies. For example, vugs result in a great variability of the porosity measured, while often differential diagenesis results in different permeability behaviours.

For example, in a recent reservoir study, permeability variations of two orders of magnitude were identified for a same facies, well characterised as concerns lithology and porosity. After further investigations, it was possible to relate this permeability behaviour with the cementation degree of the rock, as shown by the crossplot K vs PHI in fig. 20, which points out also the different content in micritic cement of the samples considered.

3.2 Definition of a lithological cut-off

In the case of volumetric evaluations in reservoirs composed of complex lithologies, one of the main uncertainties is represented by the choice of the cut-off to be used to exclude the "not pay" tight intervals from the total reservoir thickness.

Porosity and permeability and, sometimes, water saturation and shale volume, are generally used as cut-off parameters.

The definition of the threshold values to be used is generally very problematic.

In this case, cluster analysis represents a great opportunity for the cut-off choice to be used during the evaluation of the hydrocarbon in place.

In fact, both a lithological and petrophysical meaning is attributed to each class from the cluster analysis during the characterisation phase; this allows a rapid identification, through core comparison, of the classes which must not be taken into account for volumetric calculations.

In this case a lithological and not petrophysical cut off is carried out, excluding all the samples belonging to "tight" facies from the calculation.

For example, fig. 21 shows the characteristics of a facies used as cut-off in a reservoir study recently carried out by Agip.

3.3 Definition of a core sampling for new analyses

The facies descriptions at the well resulting from a cluster analysis process can also be used during the core samples choice when particular types of analyses can be required.

The most common example is the one concerning special analyses (capillarity, relative permeability, end points,), on which basis the rock types of the dynamic model must be built. The fundamental condition to make the model reliable is to have special analysis data really representative of all the facies present in the reservoir.

On the basis of the comparison between the core plug depth and the result of the cluster analysis at the well, it is possible to verify whether all the facies are sufficiently represented by the samples chosen for special core analyses. If not, it is possible to add some other samples, suitably chosen.

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Fig. 1

" WELL 3 "
CLUSTER ANALYSIS RESULT

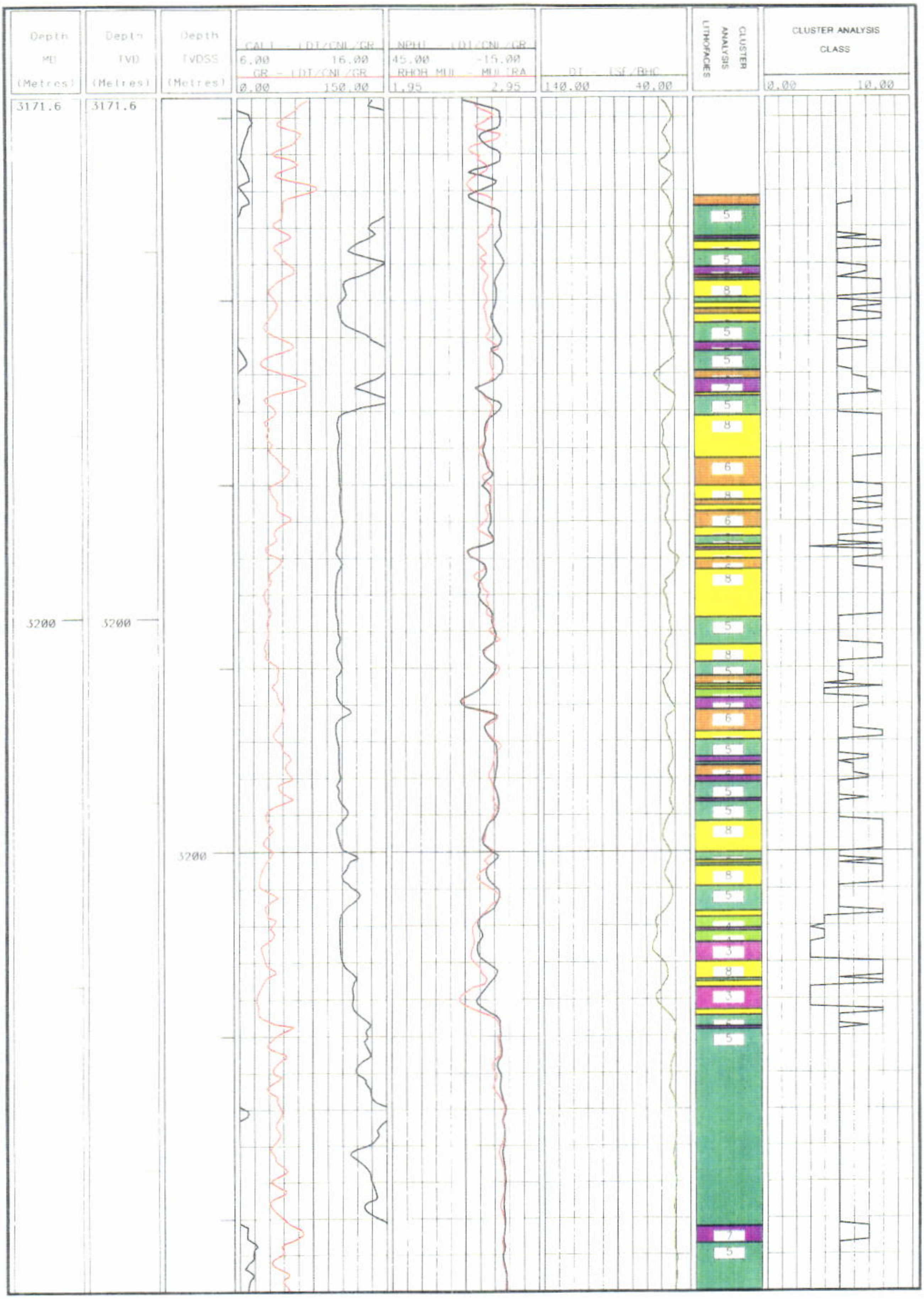


Fig. 2

" WELL 7 "
CLUSTER ANALYSIS RESULT AND SYNTHETIC CURVES

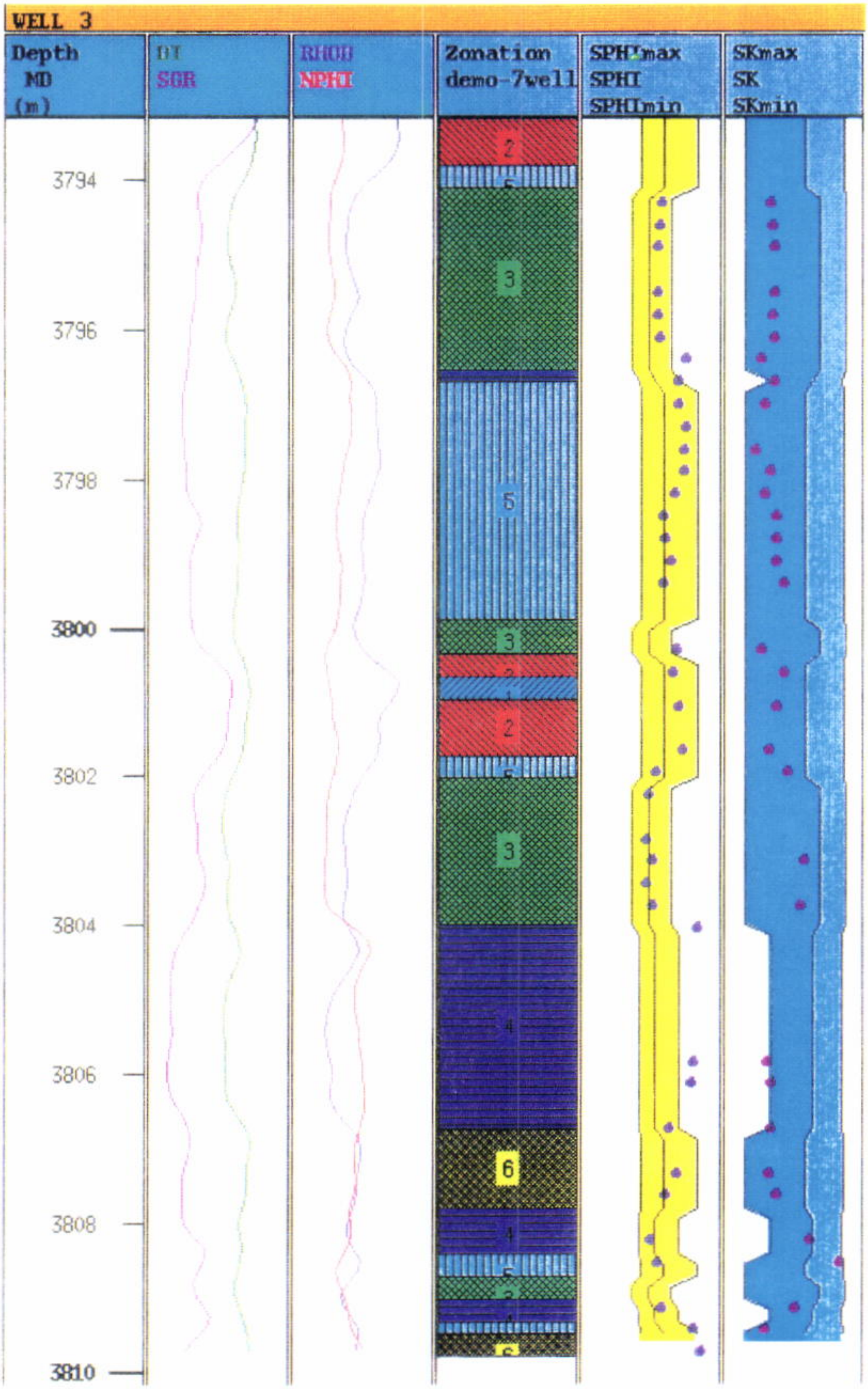


Fig. 3

" WELL 1 "
CLUSTER ANALYSIS RESULT AND QUANTITATIVE LOG INTERPRETATION

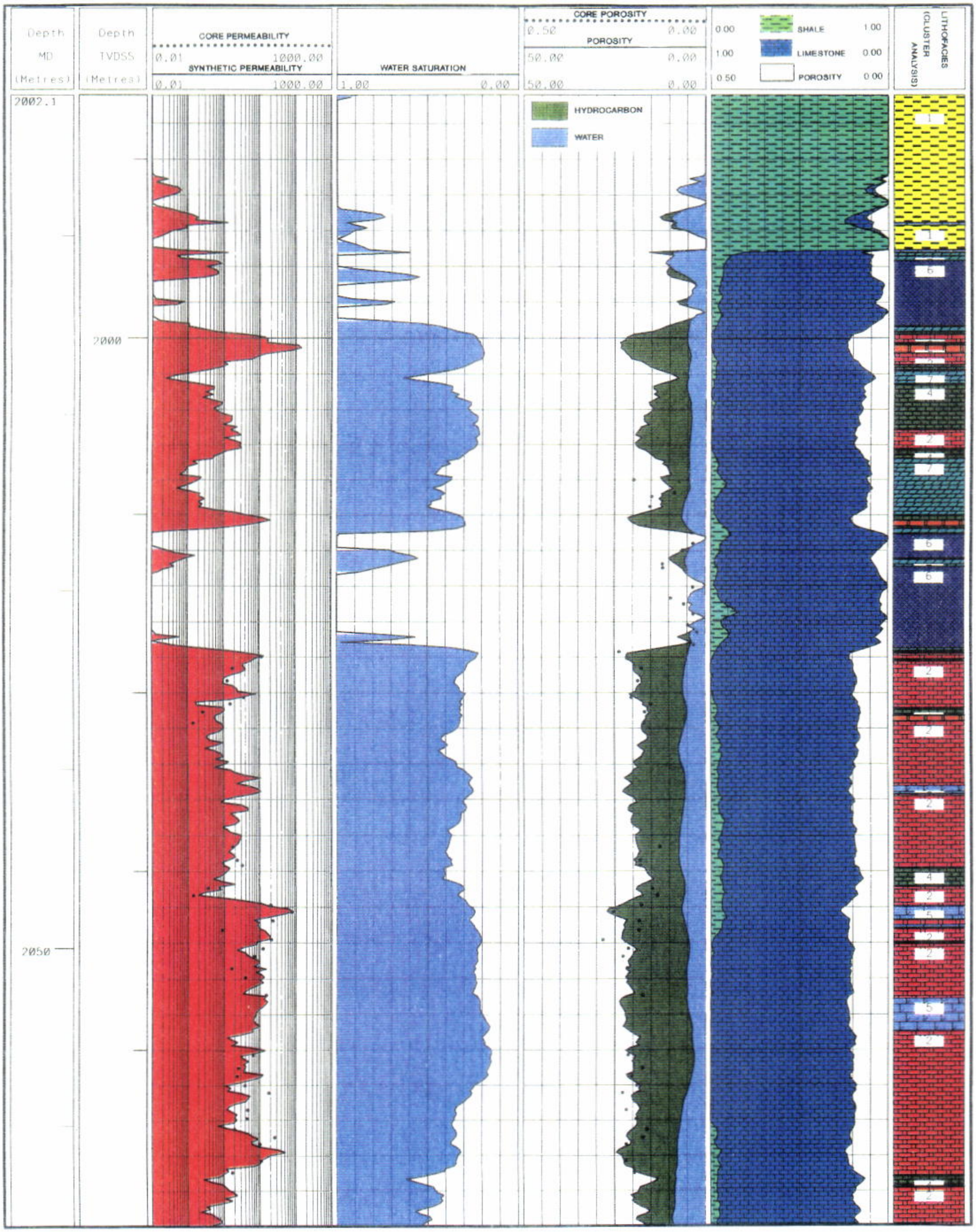
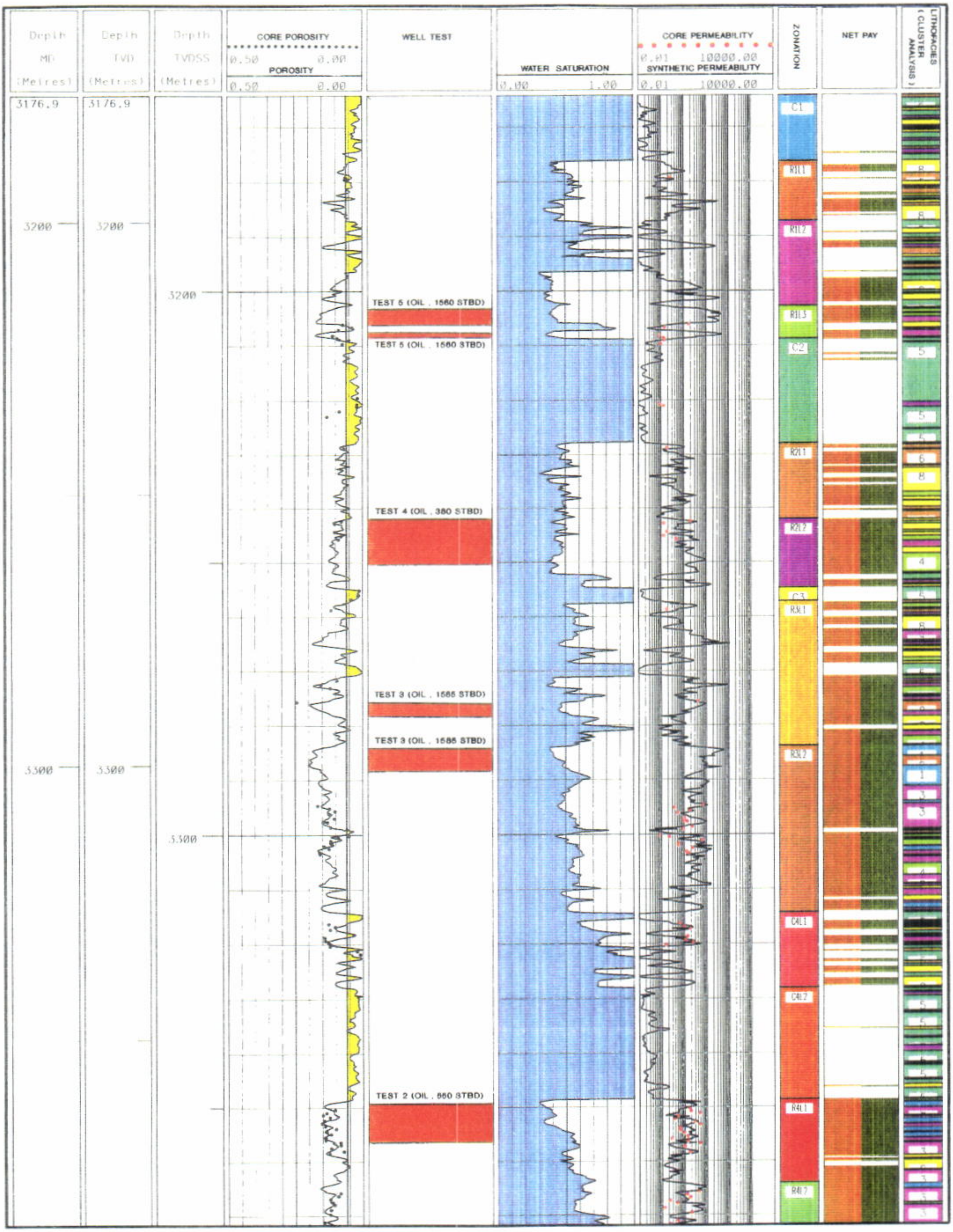


Fig. 4

" WELL 3 "
CLUSTER ANALYSIS RESULT AND WELL PRODUCTION CAPACITY



OVERBURDEN PRESSURE EFFECTS ON POROSITY PER FACIES

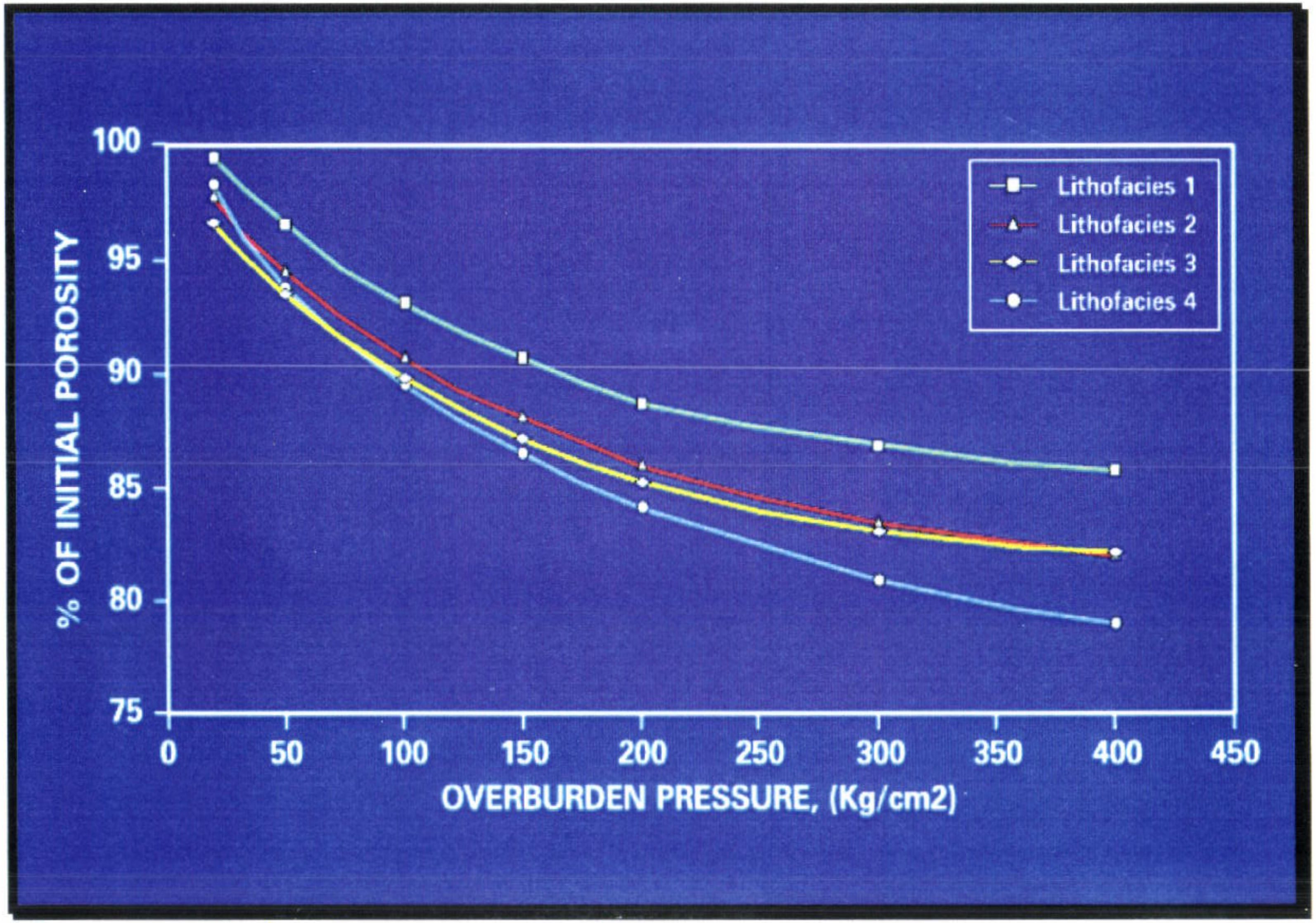
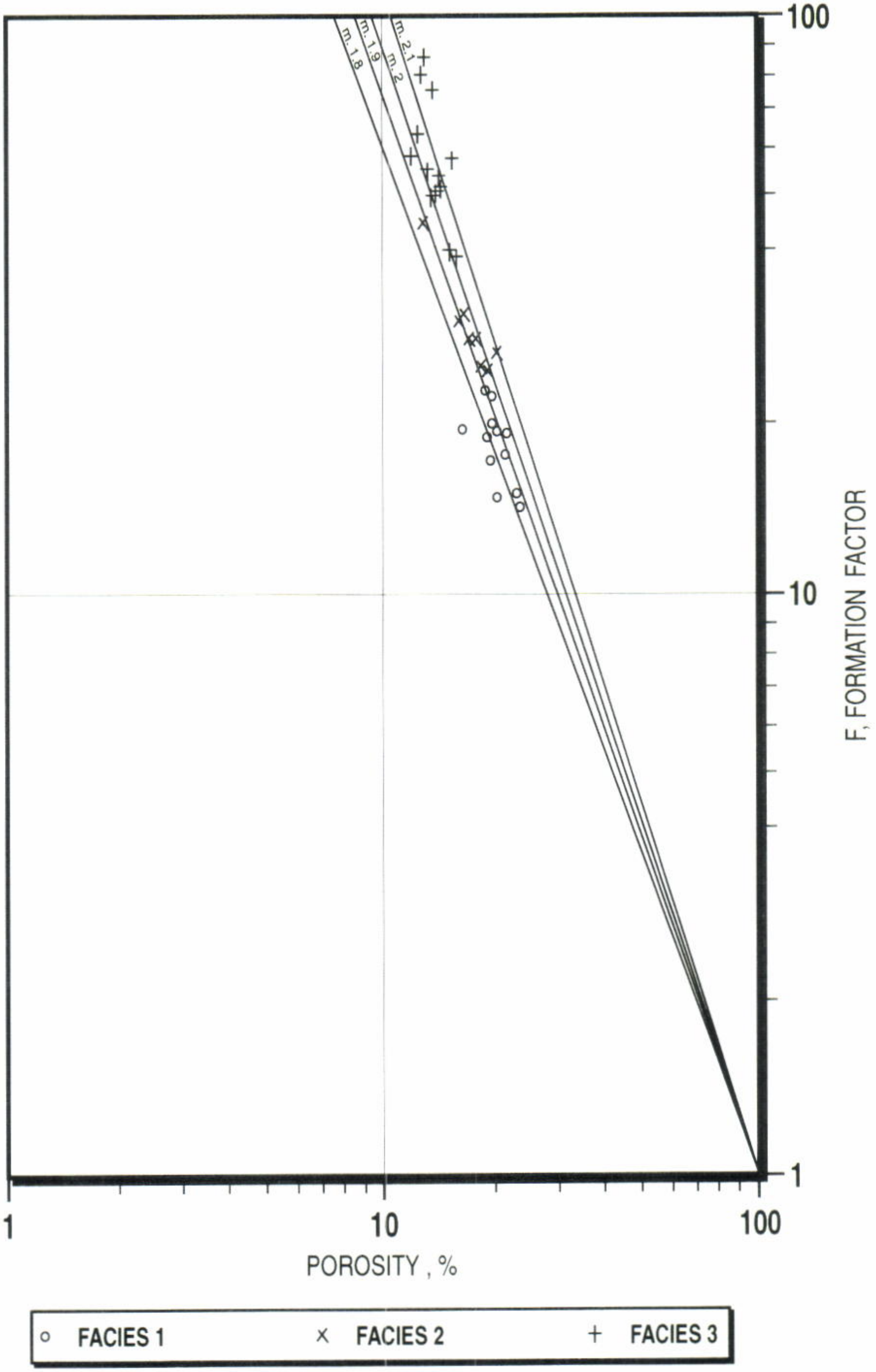


Fig. 5

Fig. 6

CEMENTATION EXPONENT "m" PER FACIES



SATURATION EXPONENT "n" PER FACIES

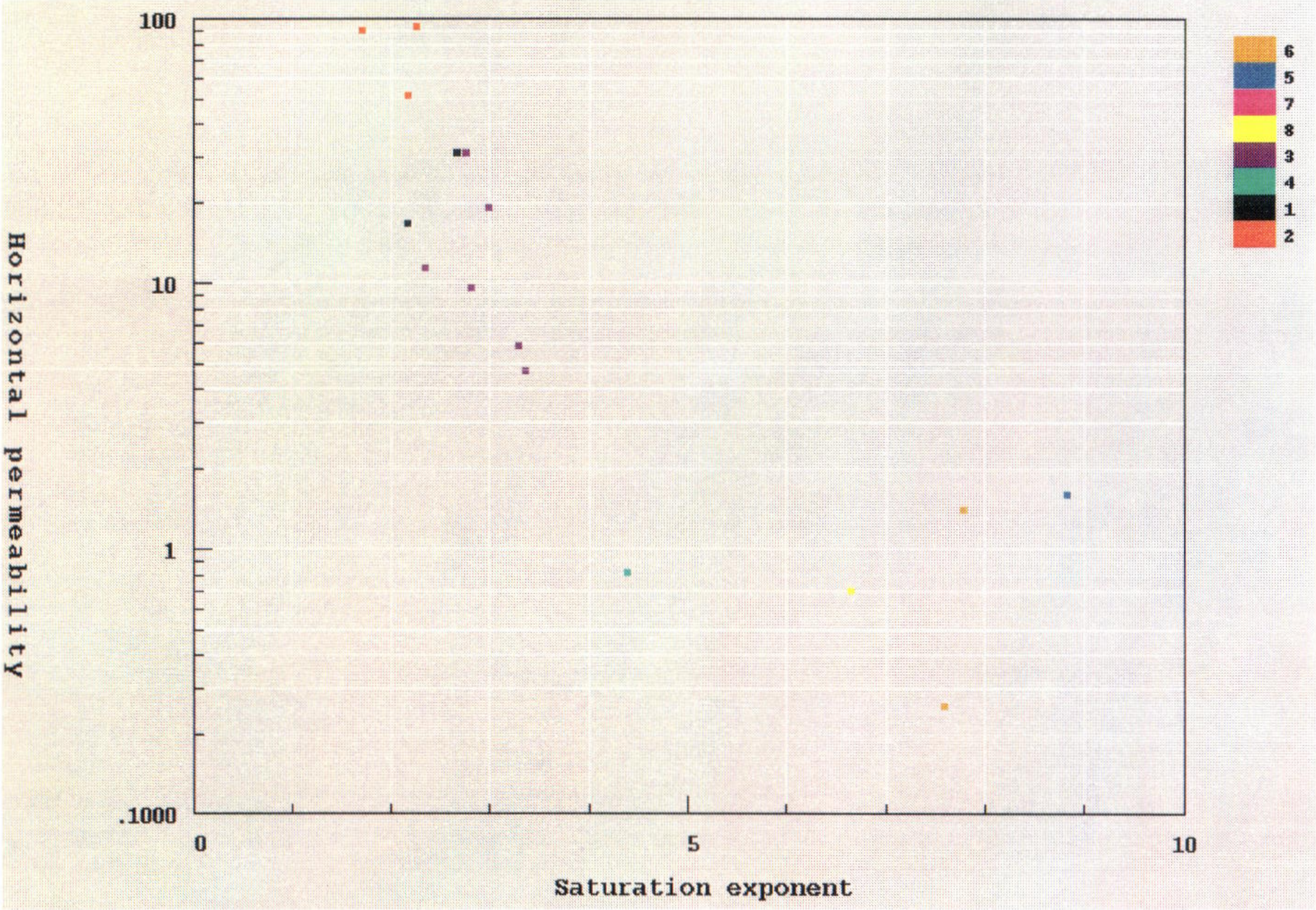


Fig. 7

Fig. 8

FACIES CHARACTERIZATION BASED ON GRAIN SIZE MEDIAN VALUES

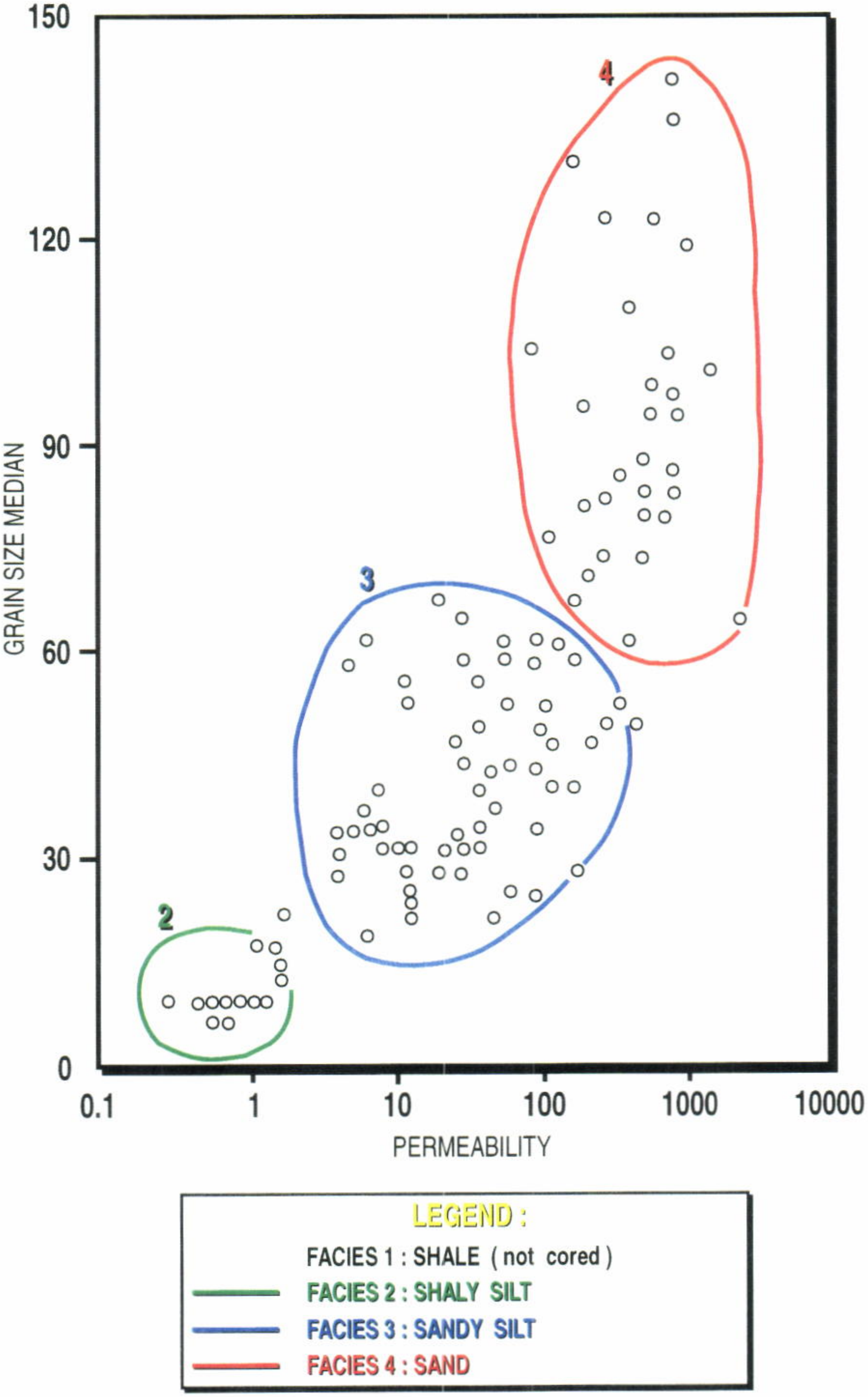
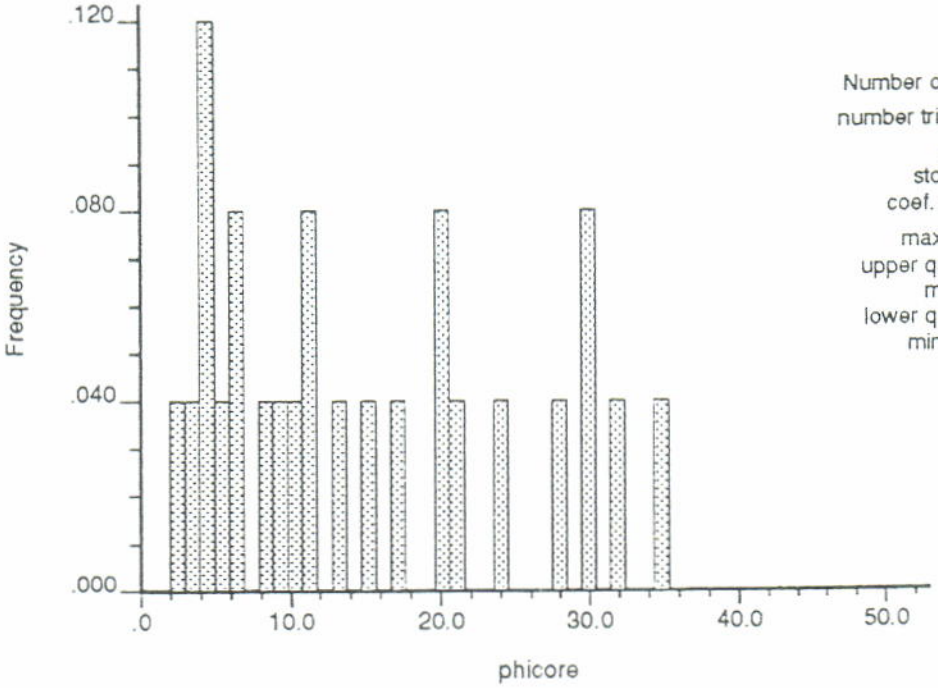
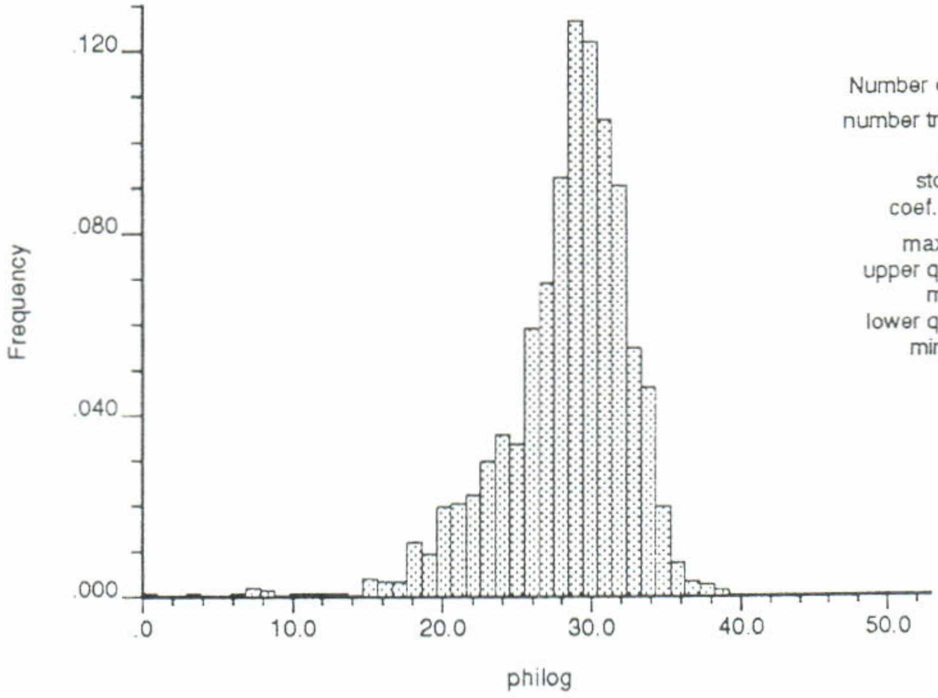


Fig. 9

COMPARISON BETWEEN CORE AND LOG POROSITY DISTRIBUTIONS

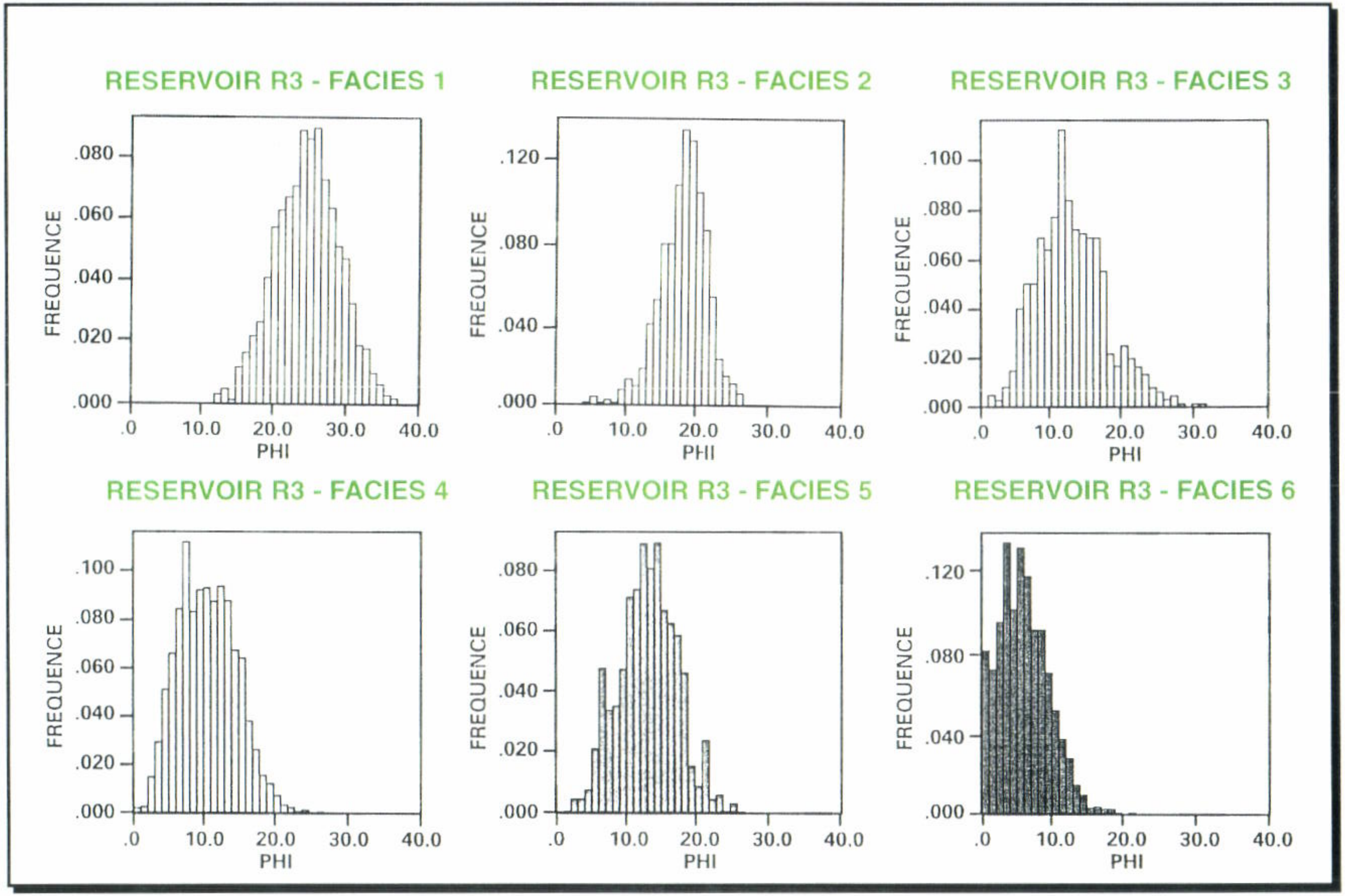


Number of Data	25
number trimmed	997
mean	14.9392
std. dev.	9.9827
coef. of var	.6682
maximum	35.0800
upper quartile	20.9300
median	11.7000
lower quartile	6.4000
minimum	2.2200



Number of Data	1518
number trimmed	20650
mean	28.2996
std. dev.	4.3705
coef. of var	.1544
maximum	38.9380
upper quartile	31.0800
median	29.0590
lower quartile	26.3210
minimum	.0000

PETROPHYSICAL CHARACTERIZATION : POROSITY



FACIES

1) SAND
2) DOLOMITE SANDSTONE
3) SHALY SANDSTONE
4) MARLS
5) SANDY DOLOSTONE
6) DOLOSTONE

Fig. 10

Fig. 11

" WELL 1 "
SYNTHETIC POROSITY AND PERMEABILITY CURVES

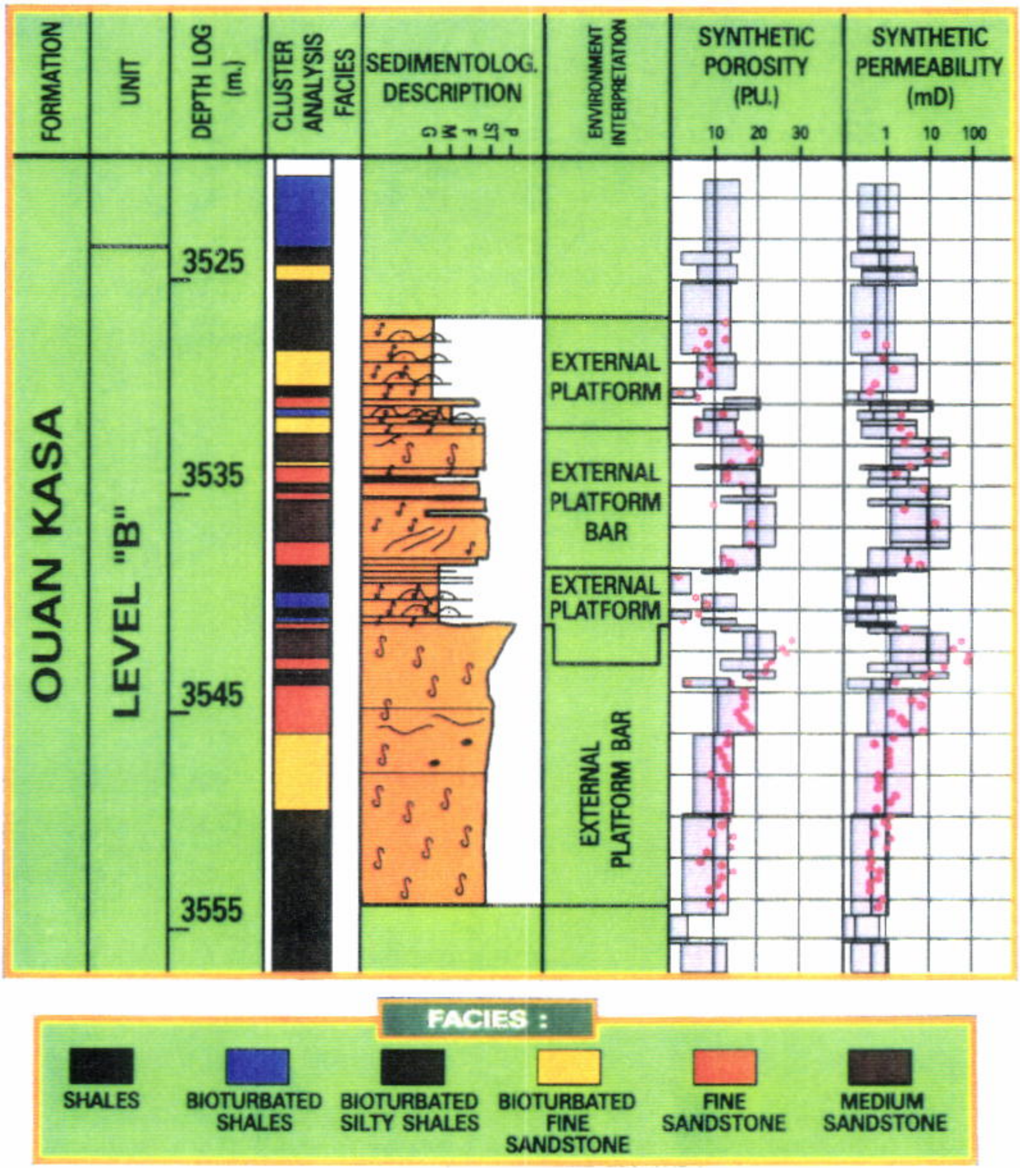
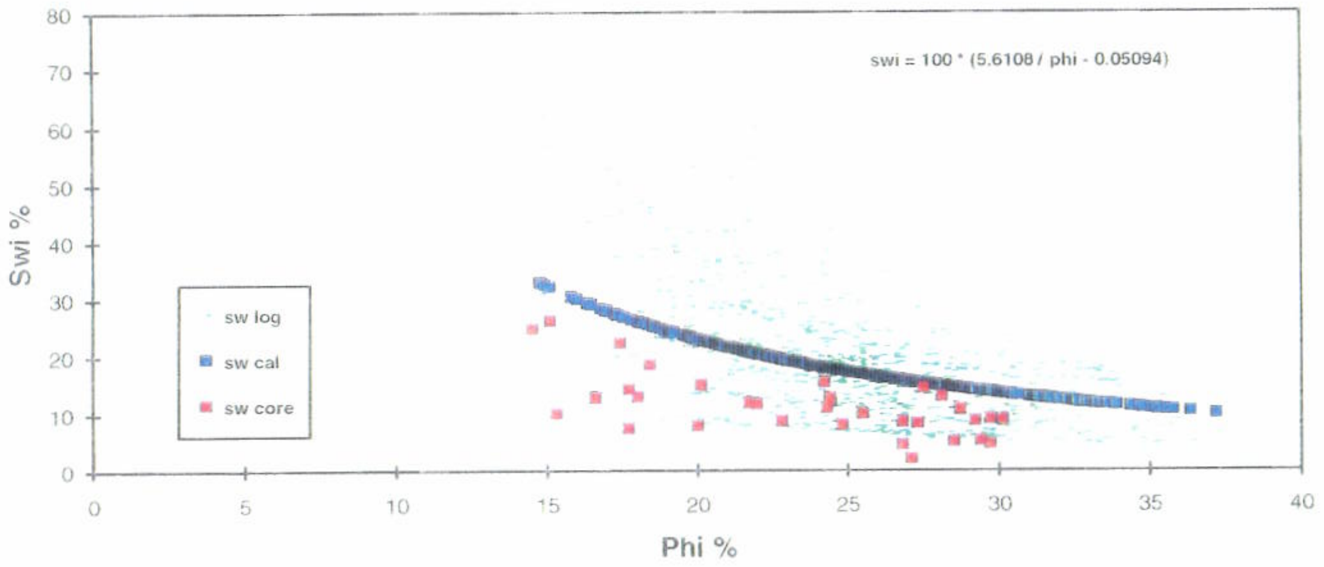


Fig. 12

FACIES 1 : LOOSE SANDS



FACIES 2 : SANDSTONES

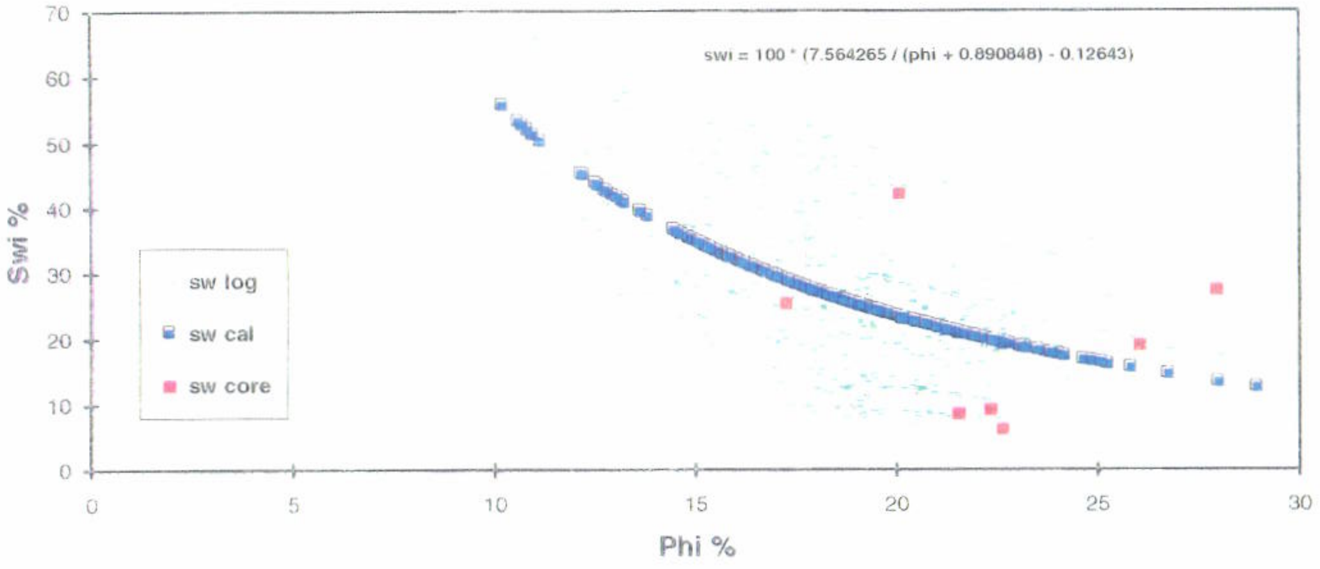


Fig. 13

IDENTIFICATION OF CAPILLARY FRINGE

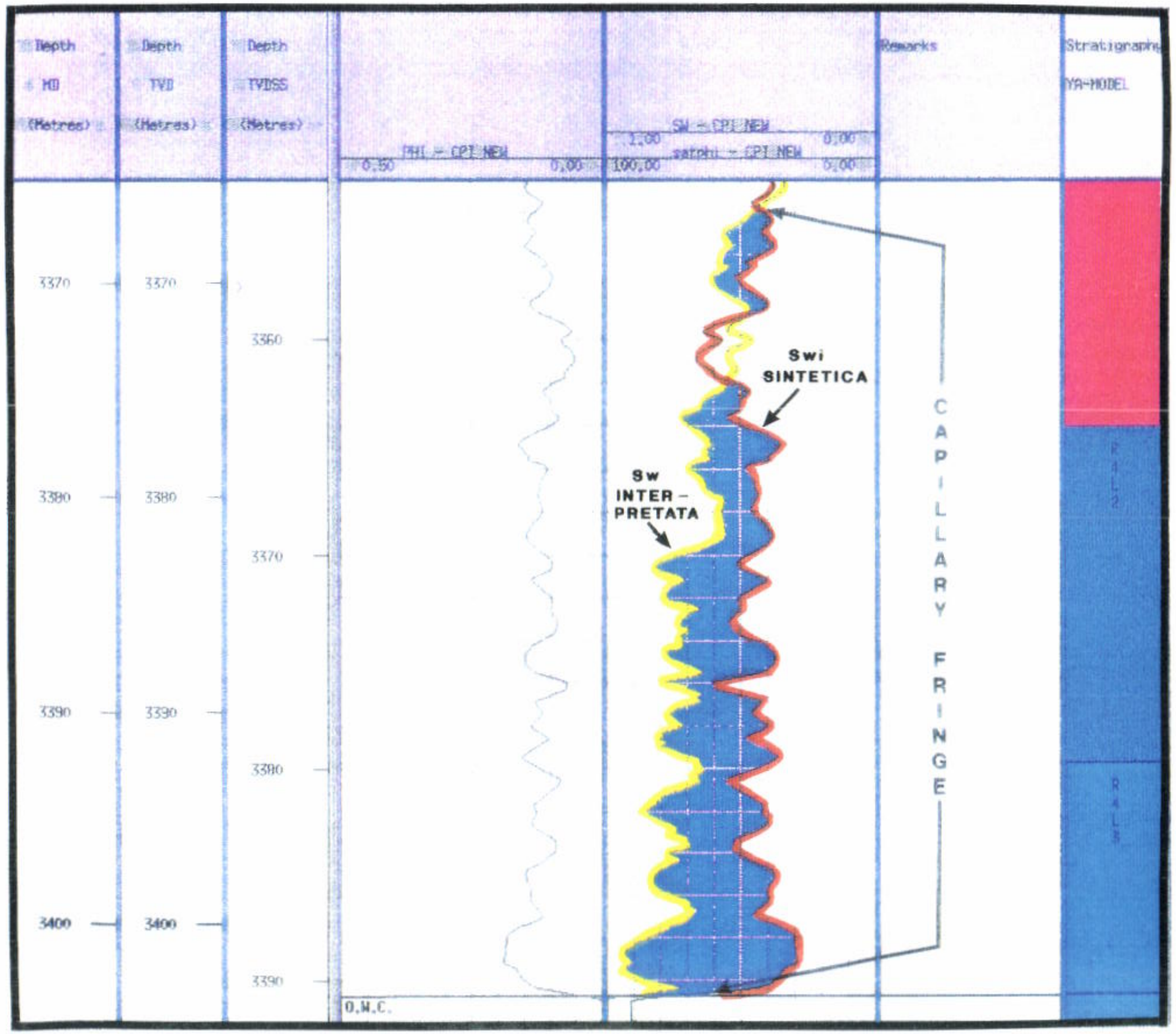


Fig. 14

" WELL 1 "
TESTED INTERVALS

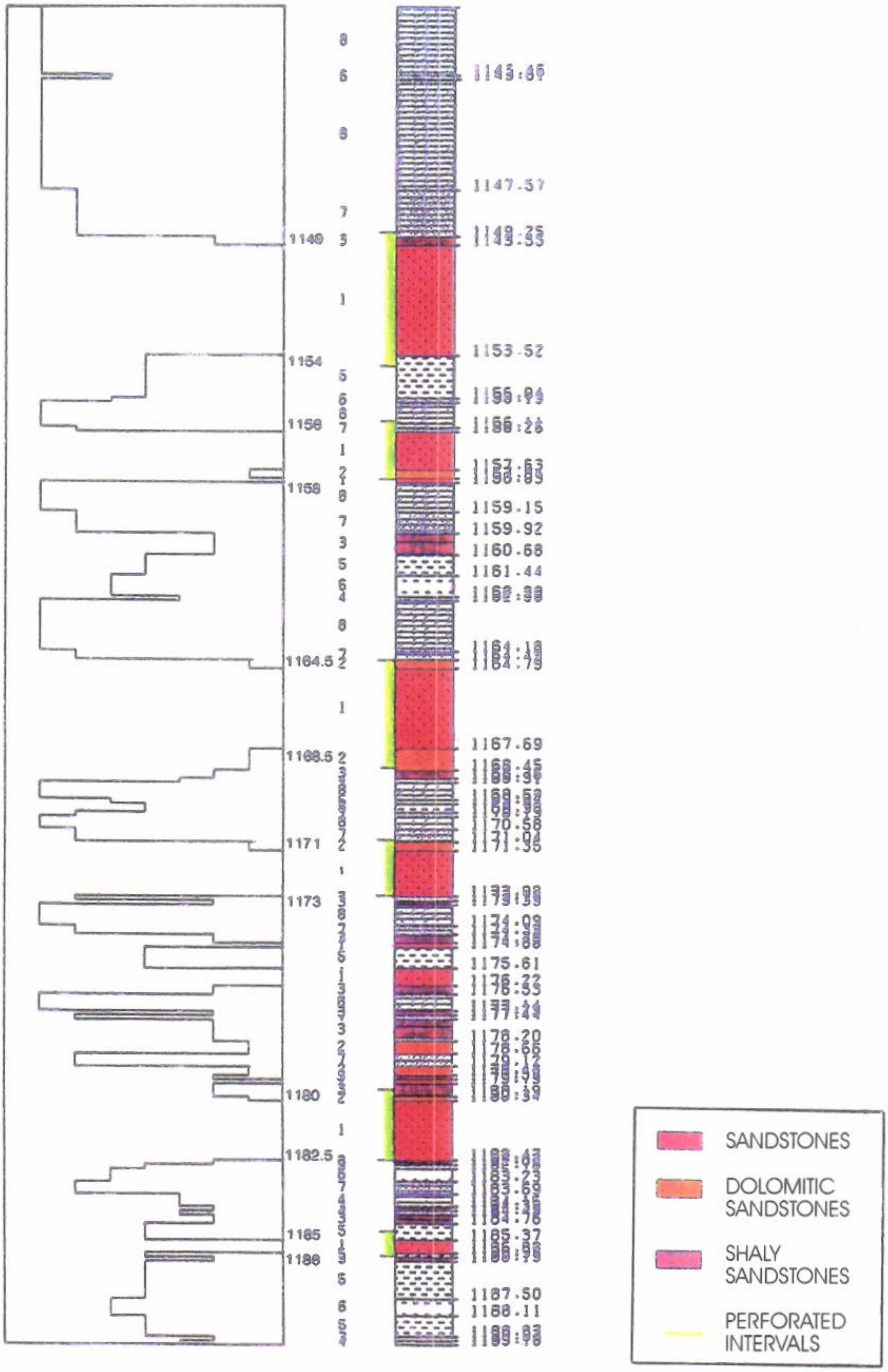
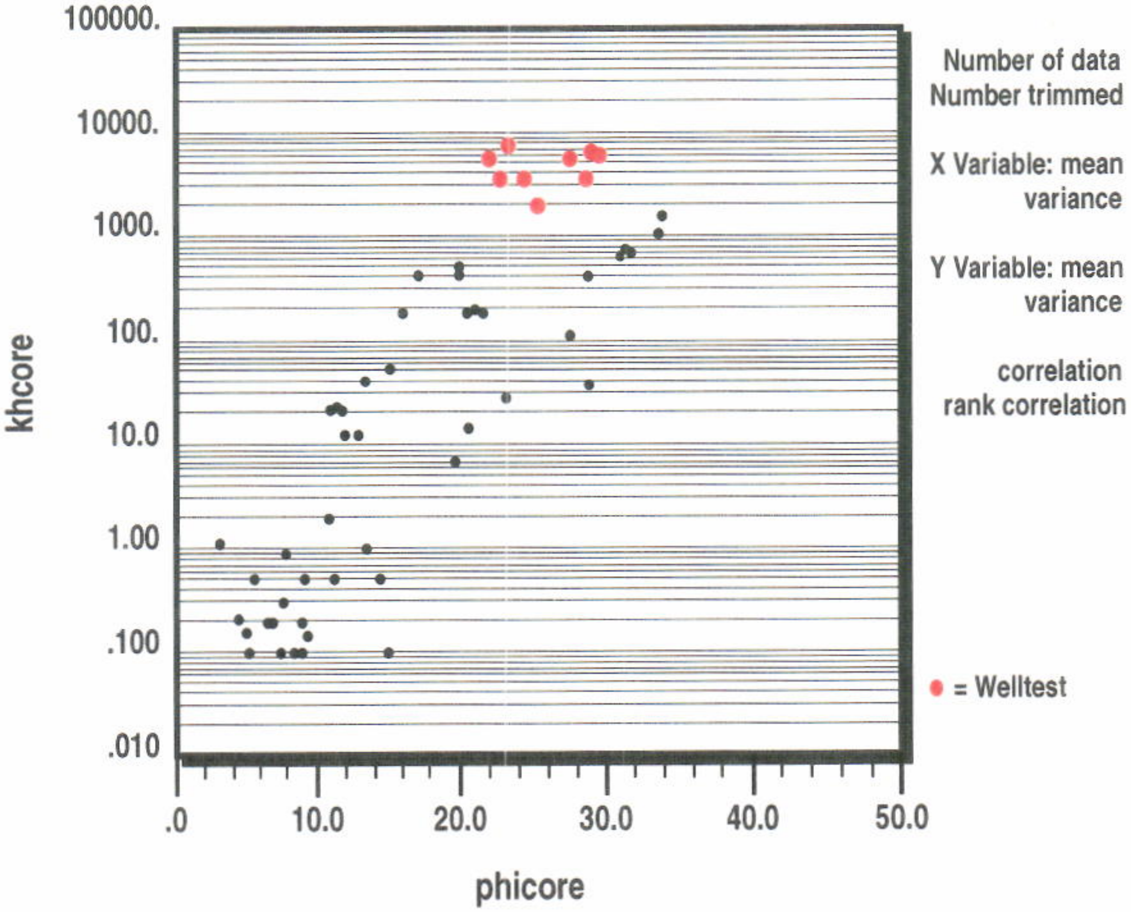


Fig. 16

FACIES 1 : LOOSE SANDS



SYNTHETIC PERMEABILITY CURVES COMPUTATION

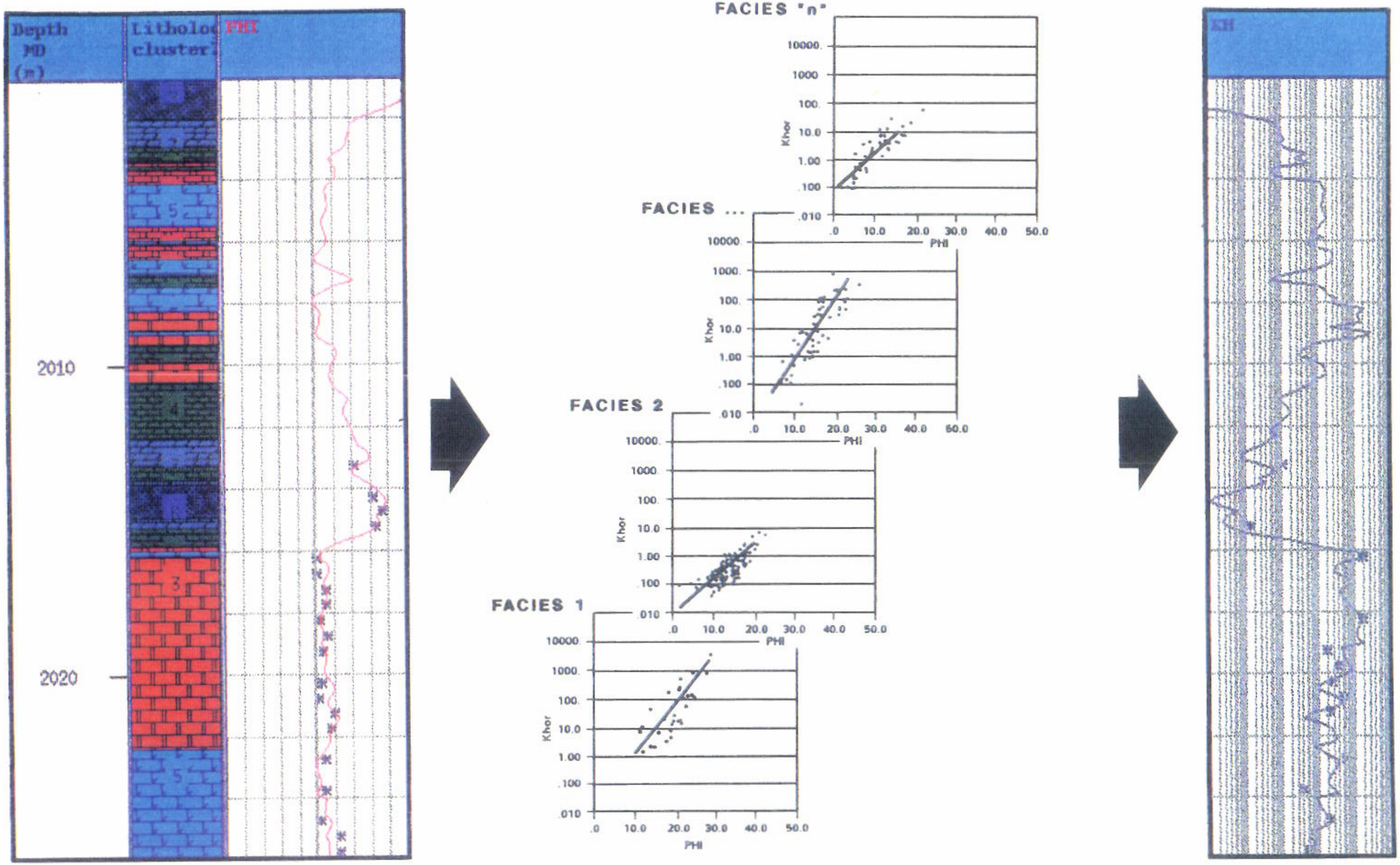


Fig. 17

FLUID FLOW MODEL LAYERING BASED ON SYNTHETIC PERMEABILITY

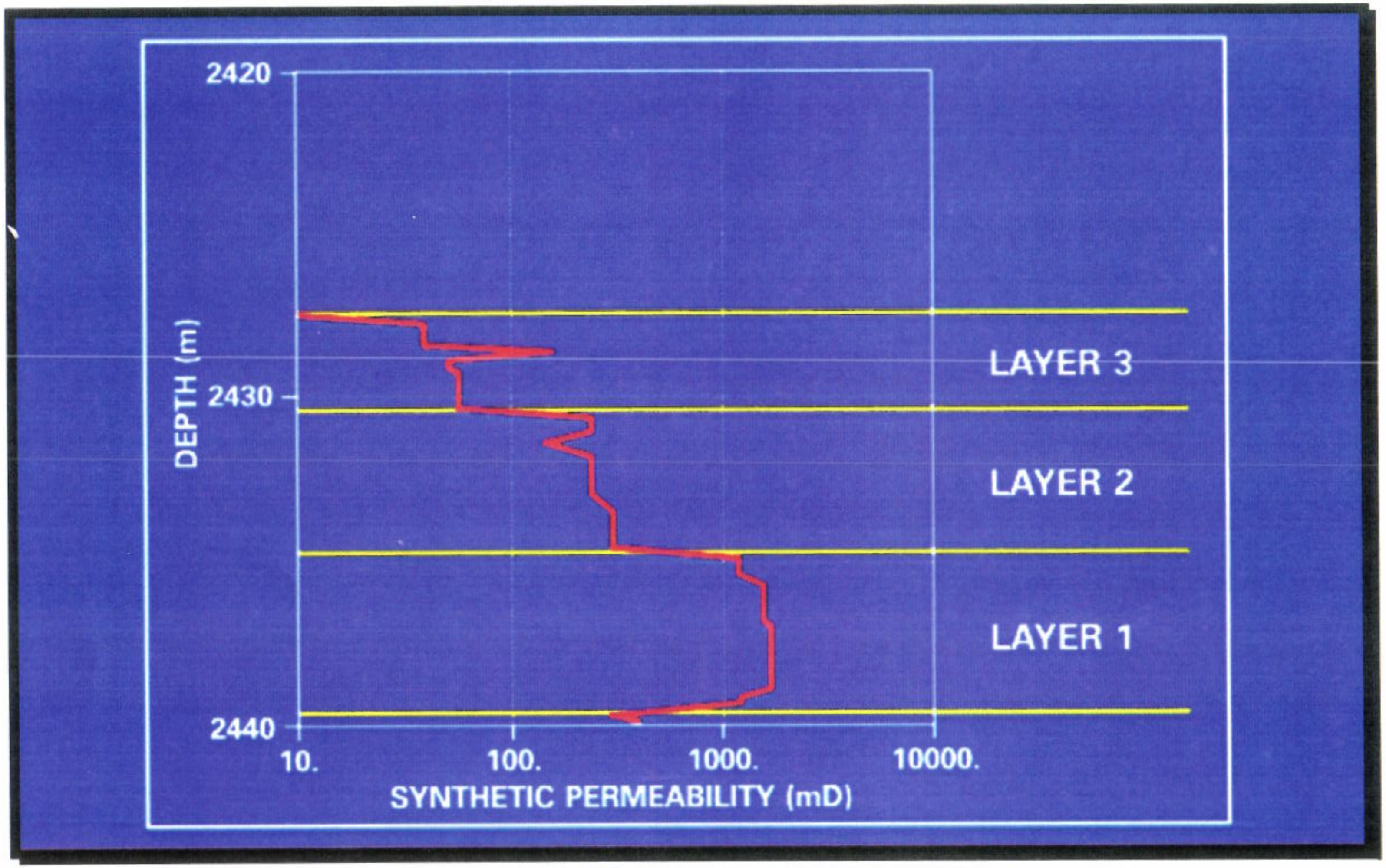
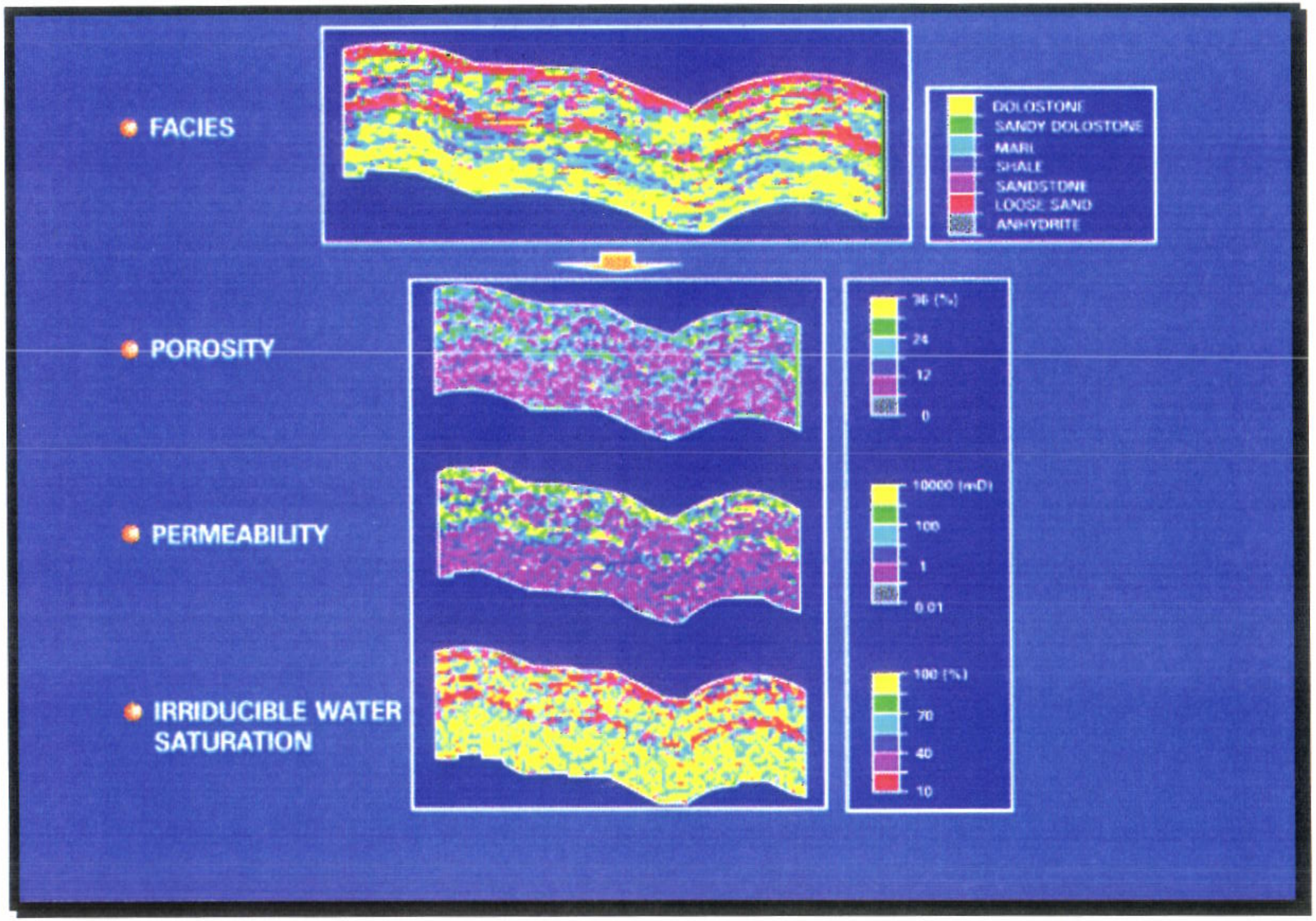


Fig. 18

Fig. 19

LITHOFACIES AND PETROPHYSICAL PARAMETERS SIMULATION



- FACIES
- POROSITY
- PERMEABILITY
- IRRIDUCIBLE WATER SATURATION

" FACIES 5 "
PERMEABILITY vs POROSITY CROSSPLOT
MICRITIC CEMENT PERCENTAGE

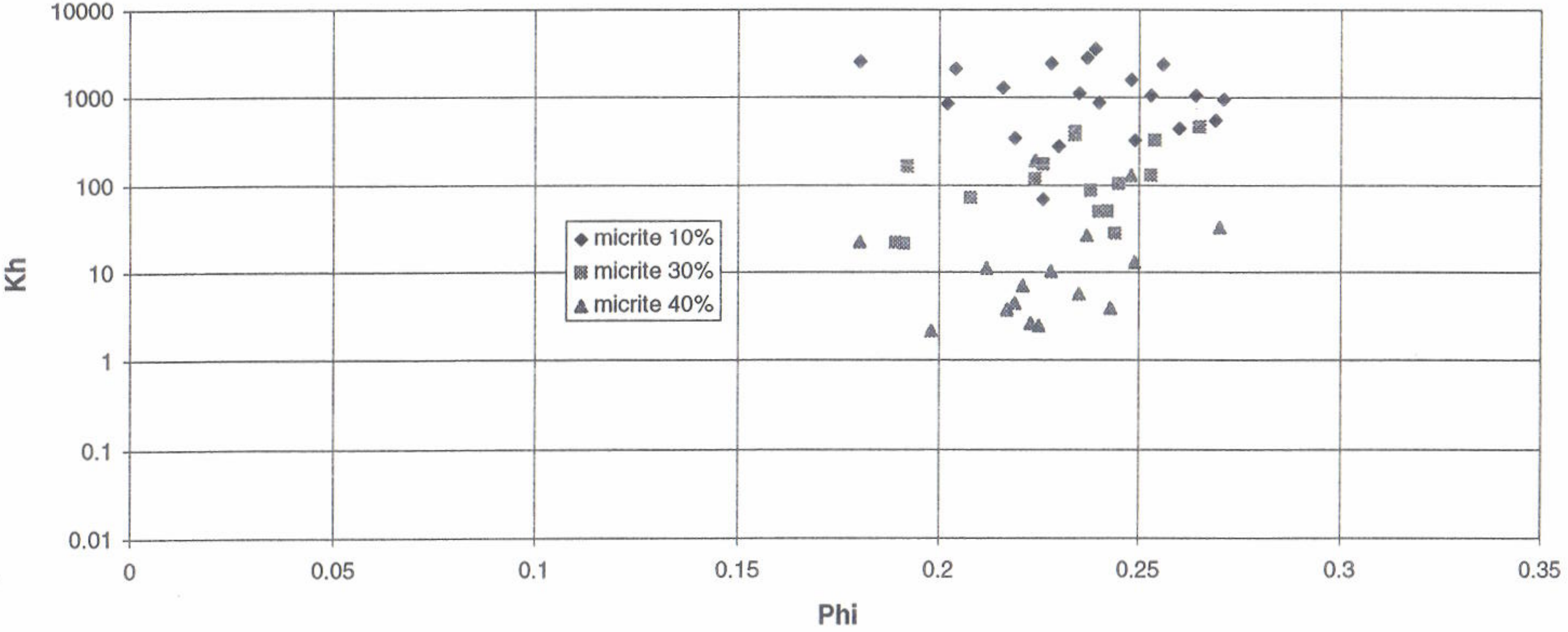


Fig. 20

LITHOLOGICAL CUT - OFF

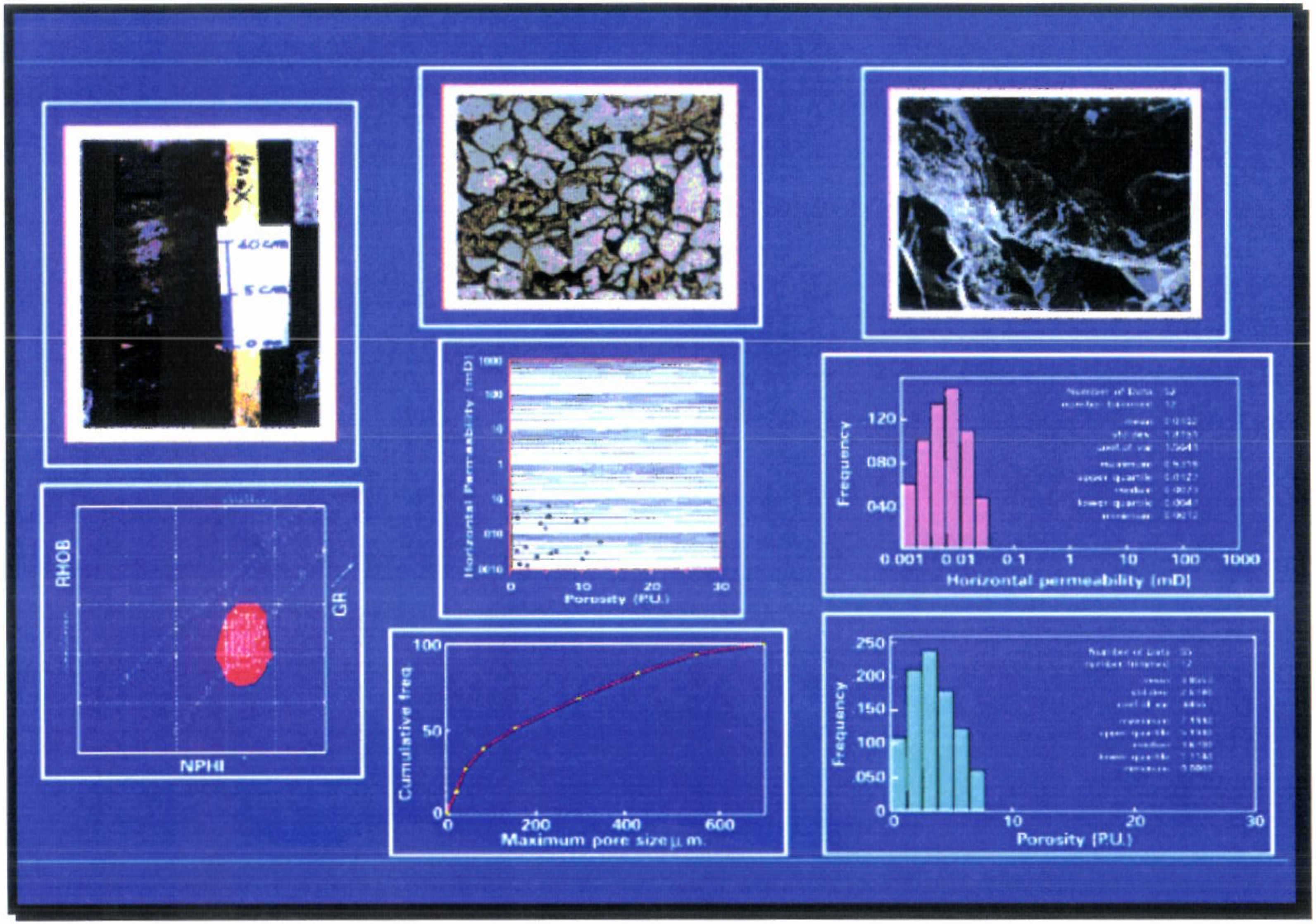


Fig. 21