SPE 107774

Wireline Logs and Core Data Integration in Los Molles Formation, Neuquen Basin, Argentina

L. P. Stinco, CAPSA Capex

This paper was prepared for presentation at the 2007 SPE Latin American and Caribbean Petroleum Engineering Conference held in Buenos Aires, Argentina, 15–18 April 2007.

Abstract

In Agua del Cajón Block (Neuquen Basin, Argentina), petrophysical data was treated according to deductive and inductive methods in order to get the most from both approaches. Deductive methods comprise those methodologies that seek to differentiate the data by the computation of a set of component proportions whose identification is linked with wireline log data by a set of response equations. The model is built considering the number of components and the number of variables (data curves). Normally, measures to detect mismatches and gross errors are included in the techniques, although mathematical consistency is not a guarantee of geological accuracy. This situation is well represented by standard log analysis. On the contrary, inductive methods establish their classes or transformations based on the data set and do not depend on any predetermined correlation among the components. These methods tend to isolate distinctive patterns and to derive classifications or new variables that can be interpreted with a physical meaning. Cluster analysis is one example of these types of methodologies. In this study, wireline logs (spontaneous potential, gamma ray, shallow-medium and deep resistivities, neutron, density, sonic, photoelectric factor, and microrresistivity images) were calibrated according to the lithological variations –facies- described in cores taken from the reservoirs developed within Los Molles Formation. These facies which comprised crudely bedded gravel with imbrication (Gm), medium to coarse, even pebbly sand with planar crossbeds (Sp), very fine to very coarse sand with horizontal lamination (Sh) and massive mud-silt (Fm), were linked with electrofacies using multivariate analysis, particularly cluster analysis. The first two facies are the actual reservoirs targets within the field. After the analysis of ten wells within the field, a more thorough understanding of the petrophysical properties and a deeper understanding of the dynamic responses of the reservoirs was achieved.

Introduction

Agua del Cajón Block (Figure 1) is situated to the west of Neuquen city in the central part of the Neuquen basin. Within the block, two main fields are currently on production: El Salitral and Agua del Cajón. These fields were discovered in 1965 and 1973 respectively by YPF and operated by the state oil company until 1991 when Capex took over the operation. Currently, there are more than 300 wells in an area of 355 square kilometers.

Hydrocarbons in Agua del Cajón Block are structural and stratigraphically trapped within a variety of reservoirs developed in Cretaceous and Jurassic formations (Figure 2).

The units comprise conglomerates, sandstones and shales interpreted as being deposited in a variety of environments such as alluvial fans, fluvial, deltaic and submarine fans[1]. The submarine fan deposits of the Los Molles Formation are analyzed in this work.

In 10 wells of the field, formation evaluation and electrofacies determination were performed by applying an appropriate set of inductive and deductive methodologies. These ones comprised a number of procedures including data editing and normalization of the log data, standard log analysis and electrofacies determination. The analysis procedures were optimized with the help of cutting descriptions, cores and production test data. K-means cluster analysis in three dimensions was used to define four electrofacies which were calibrated according to the facies described in cores. Two of the facies are the actual reservoir targets within the field therefore this study helped in understanding the dynamic response of the reservoirs all over the field.

Methodology

The petrophysical data processing and analysis was performed following a number of interrelated procedures highly dependent on the quantity and quality of the data. This methodology comprises a number of procedures including: data editing and normalization of the log data, standard log analysis, electrofacies determination and summations.

The wells in the study area have spontaneous potential, gamma ray, shallow-medium and deep resistivities, neutron, density, sonic and photoelectric factor. Microrresistivity images were available in just two of them. Wireline log data was from several different vendors. The differences in response due to tool types used by each logging company were accounted for during the environmental corrections and log normalization procedure.

The petrophysical data was treated following deductive and inductive methods in order to get the most from both approaches. Deductive methods comprise those methodologies that seek to differentiate the data by the computation of a set of component proportions whose identification is linked with wireline log data by some suite of response equations[2]. The model is built considering the number of components and the number of variables (data curves). Normally, measures to detect mismatches and gross errors are included in the techniques although mathematical consistency is not a guarantee of geological accuracy. This situation is well represented by standard log analysis. On the contrary, inductive methods establish their classes or transformations based on the data set and do not depend on any predetermined correlation among the components. These methods tend to isolate distinctive patterns and to derive classifications or new variables that can be interpreted with a physical meaning. Cluster analysis is one example of this type of methodologies.

Log Data Editing and Normalization

Before starting to analyze the wireline log data, the following subtasks were performed: edition of the digital wireline log data including re-sampling to a common increment where necessary; comparison of the digital data with the paper logs and repaired where differences occurred; merging of logging runs choosing the best data from any overlaps or repeat sections; performing standard editing to remove obvious data errors and spikes; performing depth shifting for each logging suite to the resistivity suite; removing SP drift; performing environmental corrections; depth shifting of all core data to logs and added to the database; plotting out cross-plots and histograms of all curves.

Practice in using well log analysis as part of integrated reservoir studies has shown that multiwell normalization is necessary to ensure that results are accurate, consistent and comparative well-to-well. Once normalized, wireline log data can be effectively integrated, correlated and calibrated with core data. Consequently, correlations can be extended vertically to include layers that were not cored, and laterally to wells across the study area[3].

Standard Log Analysis

The petrophysical model comprises sandstones + siltstones + tuffs + shales + porosity. The term sandstones includes a variety of lithologies (clusters of electrofacies not yet defined) that certainly are reservoirs. For estimation of shale volume, the SP drift corrected and the GR were used. The total porosity was estimated from the neutron-density crossplot and the effective porosity was calculated from the total porosity by applying a correction proportional to the shale content.

Water saturation was estimated using the Simandoux model[4]. Cementation (m=2) and saturation (n=2) exponents were taken from standard core analysis results. Water salinity values, taken from measurements of produced water samples, were of 70,000 ppm.

In figure 3 a standard log analysis presents a comparison between core and log porosity. Additionally, it includes water saturation and volume of mineral estimation. The saturation model was accepted as valid through a direct comparison of the estimated results against production data.

Electrofacies Determination

The term electrofacies was originally defined as a set of log responses that characterizes a bed and permits to distinguish from the others[5]. They are determined by the physical properties of rocks to which the wireline logs are sensitive. It is worthy to mention that there exists a conceptual difference between electrofacies and geological facies related to their genesis. Electrofacies are based on characteristics taken from continuous remote measurements at scales of one meter and higher, whereas geological facies are based primarily on observational characteristics taken at scales down to millimeters[6]. Therefore, electrofacies is a set of technologies used to recognize rock types with common properties. These electrofacies are typically used to provide assistance in performing sequence stratigraphy and correlations. In addition they can be used to assign relationships for each rock type such as porosity/permeability equations.

References 2, 5, 6, 7, 8 and 9 suggest to use cluster analysis in *n* dimensions with each wireline log as a dimension for determining electrofacies.

Cluster Analysis

Cluster analysis is one of the most common multivariate techniques found. Conceptually, it is based upon the fact that data can be clustered within groups that differ according to a specific meaning[2]. Particularly, within a proper geological framework, dealing with petrophysical variables and measurement parameters, it is possible to find a logical meaning for each of them independently of the working scale.

In order to cluster the data it is necessary to follow a set of procedures. First, the data matrix of $n \times p$ (p variables at n depths) is changed into a matrix of $n \times n$ similar distances between pairs of data from the overall. Secondly, a cluster method must be selected. In this study, the "K-means" technique was used[10]. The K-means approach is a special case of a general approach called the EM (expectation and maximization) algorithm[11]. Given a specific number of clusters, this method is practical for much bigger data sets than any other algorithm. This approach repeatedly alternates between cluster assignment and re-estimating cluster centers. The user must choose the number of clusters to find. The system then populates the *n* dimensions with the same number of points approximately evenly spaced throughout the data. The iterative steps then move the points toward the data populations (like gravitational attraction) until no more movement occurs. The final positions of the points are then taken to be the central position of each cluster in the data.

The potential capability to use multivariate analysis to distinguish different electrofacies and consequently to link them with the facies recognized in the core was tested. Having validated the petrophysical model, the following steps included facies analysis from cores and electrofacies determination from wireline logs. Core data was available in well ADC-1048. The thorough paleoenvironmental interpretation[12] describes crudely bedded gravel with imbrication (Gm), medium to coarse, even pebbly sand with planar crossbeds (Sp), very fine to very coarse sand with horizontal lamination (Sh) and massive mud-silt (Fm). Figure 4 shows examples of the facies encountered in the core.

The number of wireline logs finally used was reduced to the minimum common logs run in all the wells: compresional transit time, density and a computed volume of clay derived from SP and GR.

Having selected the curves to use, it was necessary to verify that all the facies described in the core could be clustered using the correspondent curves. As it is shown in figure 5 it is feasible to cluster each depositional environment described in the core in a space defined by the selected curves.

Hence, it is possible at this stage, to apply multivariate analysis in order to cluster all data independently of the core descriptions. The number of clusters was varied and the results compared with geological data (drill cutting descriptions, core descriptions, and thin sections) and production data until an optimal set of electrofacies was found for the calibration well. Several different numbers of clusters were tried (12 clusters, 9 clusters and 7 clusters) against the chosen log curves. The optimal set preferred contained three electrofacies from seven clusters as being an appropriate number that resolved the most relevant facies. Figure 6 shows the clusters in a two dimensional crossplot.

A comprehensive analysis of figures 5 and 6 revealed that there was a direct correlation among geological facies with electrofacies. From the central position of each cluster was possible to determine the exact value of every wireline log that characterizes different electrofacies.

A software that solves the wireline logs responses for the central points defined for each cluster was used in order to effectively determine electrofacies[13]. The original number of clusters (7) was reduced to 3 due to the limited quantity of curves available. This selection process involved grouping of the clusters that were closer and behaved consistently from a geological point of view as well as discarding those of very limited representation in a number of individuals. Table 1 shows the central points used for each electrofacies.

Figures 7 and 8 show the electrofacies determination together with the core description. These figures shows the consistency of the different facies-electrofacies relationship.

Figure 9 presents the standard log evaluation and the electrofacies determination in the same figure.

Results

Summations in the reservoirs within the Los Molles Formations were performed for the 10 wells analyzed.

The data was used as input for the geological modeling and property maps were generated for the petrophysical variables.

The geological model could now be supported by the petrophysical study. Variations in net to gross (10% to 23%), porosities (5% to 10%) and shale content (15% to 55%) could now be explained properly.

Test results were consistent with the determined electrofacies.

Conclusions

1. A direct comparison among cutting descriptions, core data, production and seismic data with the results obtained from the standard log analysis and the electrofacies determination provided a useful tool for achieving a better understanding of the reservoirs developed within Los Molles Formation.
2. The geological facies recognized in the core have an electrical expression that could be used to interpret the reservoir behaviour in the block.
3. Dynamic behaviour of the reservoirs reflects the petrophysical conditions of the rocks which are controlled by the geological facies.

Acknowledgements

The author wishes to thank CAPSA-Capex for permission to publish this paper. Also G. Pando, C. Gómez and R. García for the valuable comments made during the study.

References

1. Zumel, J. *et al*: "*Los reservorios del Grupo Cuyo Inferior*", in Rocas Reservorio de las Cuencas Productivas de la Argentina, Simposio del V Congreso de Exploración y Desarrollo de Hidrocarburos, Schiuma, Hinterwimmer y Vergani (editores), IAPG (2002).

2. Moss, B.: "*The partitioning of petrophysical data: a review.*" In Developments in Petrophysics. Geological Society Special Publication N° 122. Ed: M. Lovell and P. Harvey. The Geological Society, London (1997).

3. Hunt, E. *et al*: "*Fundamentals of log analysis. Part V: Normalizing logs with histograms.*" World Oil (October, 1996).

4. Simandoux, P. “*Measures diélectrique en milie poreaux, application à mesure de saturation en eau, etude des massifs argileaux.*” Reveu de l´Institut Française du Pétrole: (1963) 193-215.

5. Serra, O. and Abbot, H.: “*The contribution of logging data to sedimentology and stratigraphy*” paper SPE 9270 presented at the 1980 55th Annual Fall Technical Conference and Exhibition, Dallas, Texas.

6. Doveton, J.: “*Geologic Log Analysis Using Computer Methods*.” AAPG Computer Applications in Geology, N° 2. AAPG, Tulsa, Oklahoma (1994) 170.

7. Elphick, R and R. Moore: "*Permeability Calculations from Clustered Electrofacies, A case Study in Lake Maracaibo, Venezuela.*" presented at the 1999 SPWLA Annual Symposium, Oslo.

8. Stinco, L. *et al*. “*Electrofacies and production prediction index determination in El Tordillo Field, San Jorge Basin, Argentina*.” Presented at the 2001 42nd SPWLA Annual Symposium, Houston, USA.

9. Stinco, L. “*Core and log data integration. The key for determining electrofacies*.” Presented at the 2006 47th SPWLA Annual Symposium, Veracruz, México.

10. Hartigan, J. and M. Wong. “*A K-means clustering algorithm*.” Applied statistics 28, (1979) 100-108.

11. SAS. “*JMP Statistical Discovery Software*.” Statistics and Graphics Guide. Cary, NC, (2000) 634 pp.

12. Miall, A. “*Principles of Sedimentary Basin Analysis*”, Springer-Verlag (1978) 490.

13. Mitchell, W. and R. Nelson. “*A practical approach to statistical log analysis*”, paper S. Presented at the 1998 29th SPWLA Annual Symposium.

Facies	VCL	DT4P	RHOZ
Gm	0.04	64	2.48
Sp-m	0.41	72	2.53
Fm	0.75	60	2.40

VCL (volume of clay, decimal)
DT4P (compressional transit time, microsec/ft)
RHOZ (bulk density, g/cm3)

Table 1

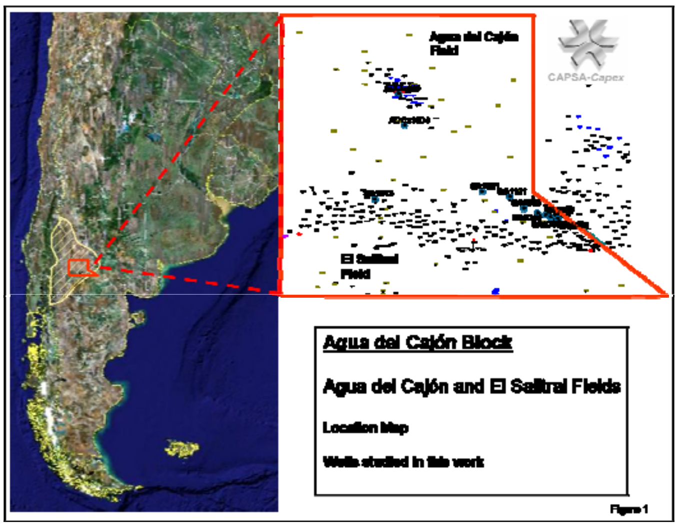

Figure 1

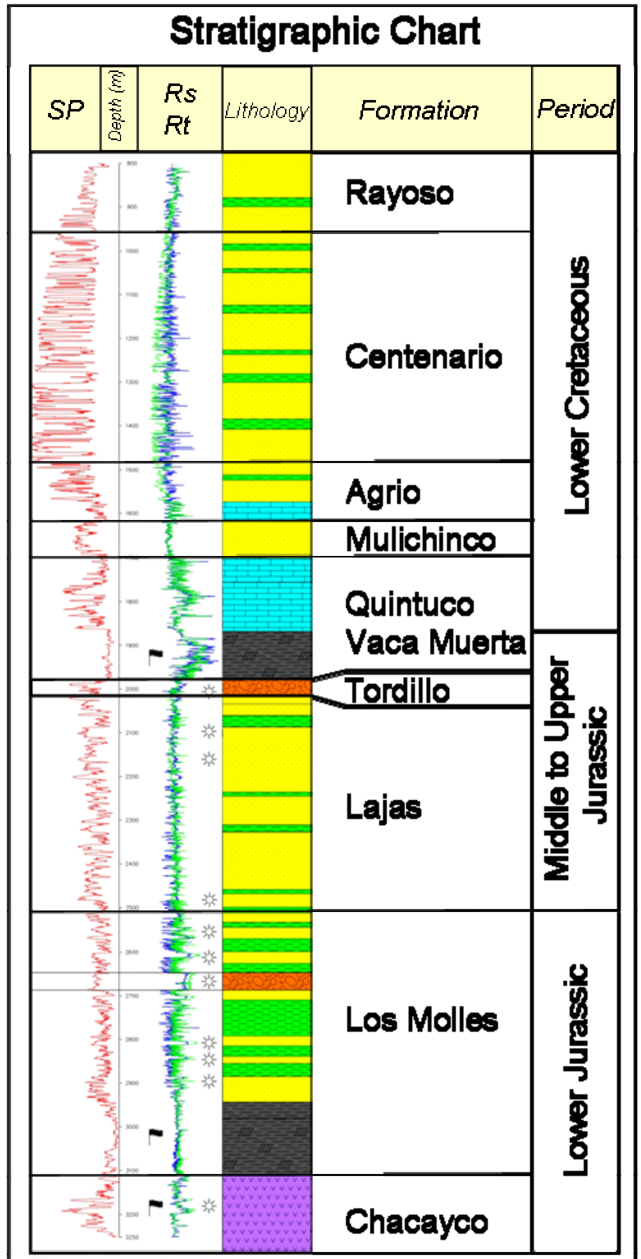

Figure 2

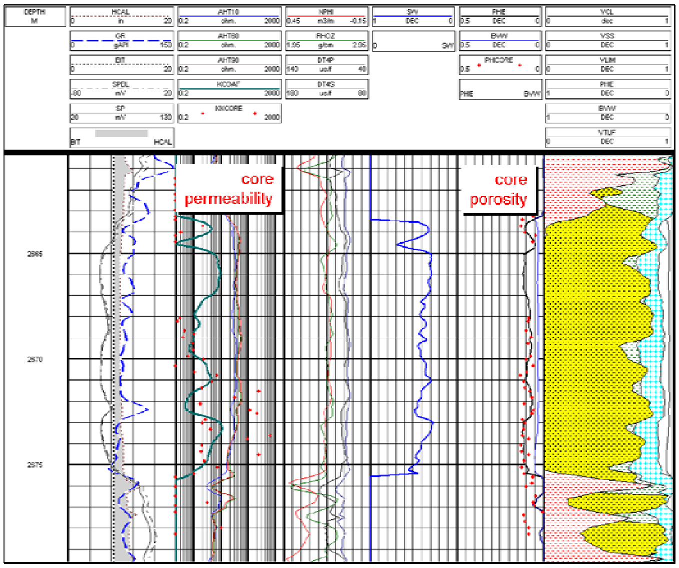

Figure 3

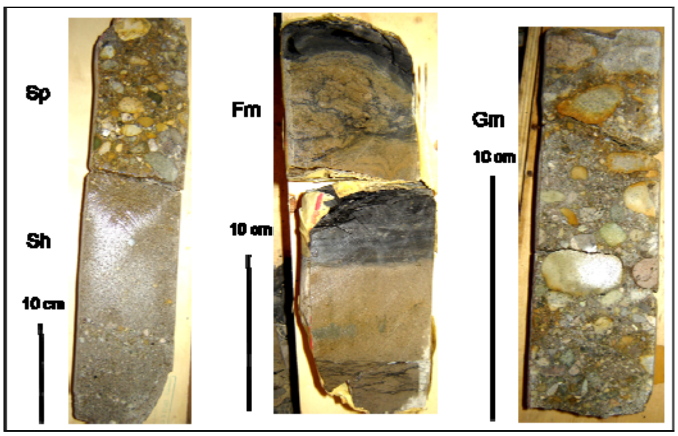

Figure 4

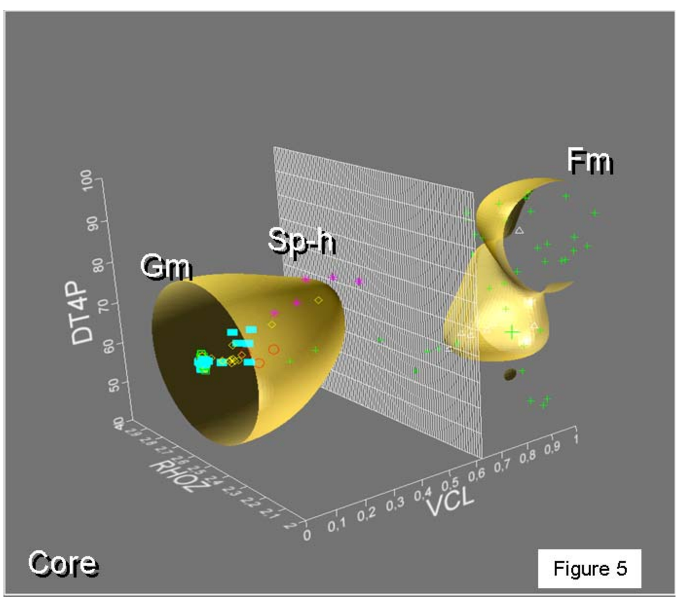

Figure 5

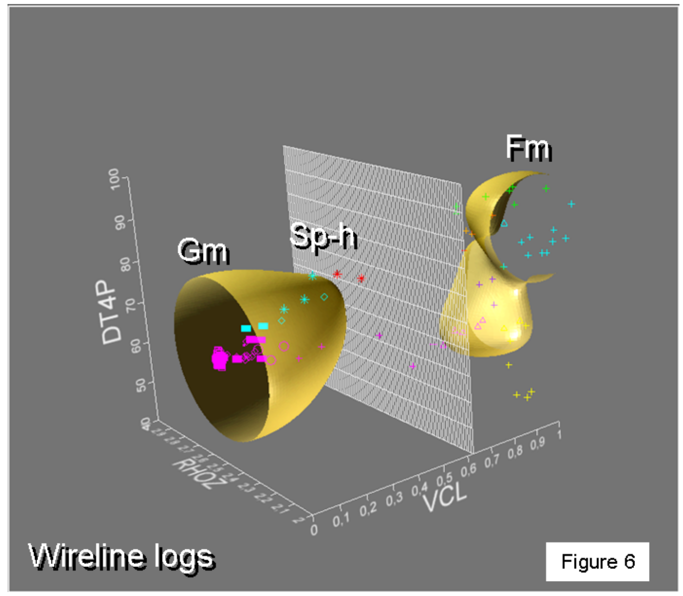

Figure 6

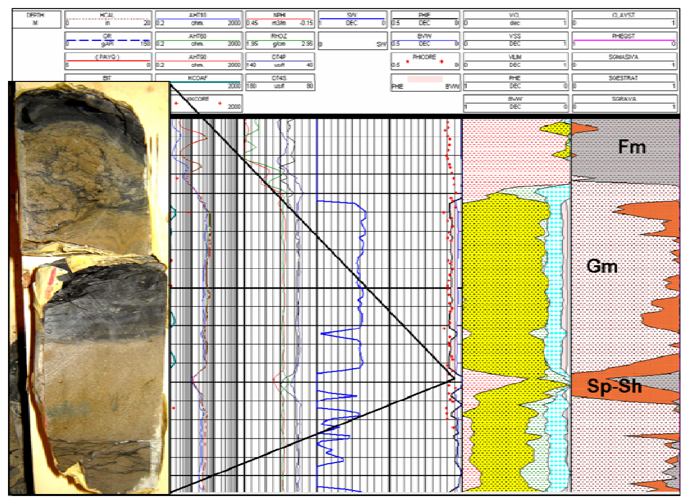

Figure 7

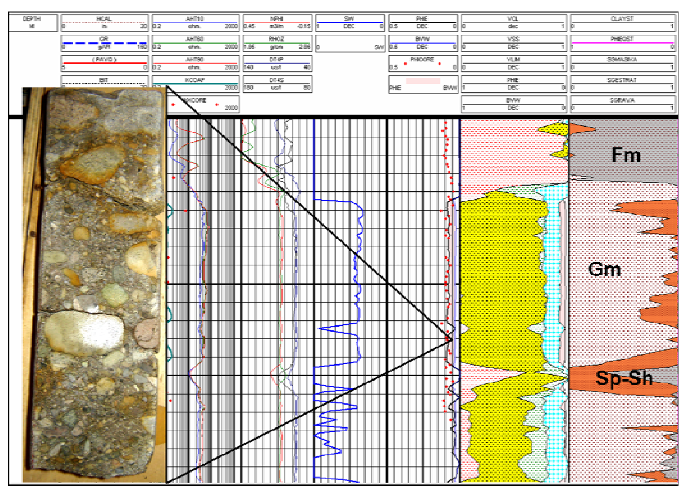

Figure 8

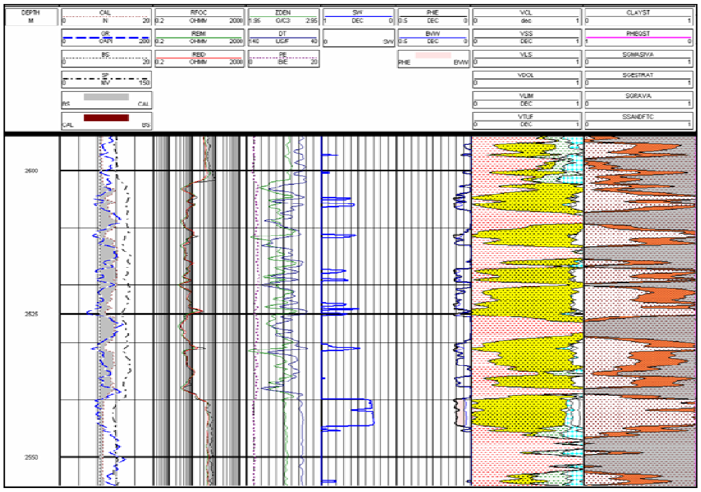
DEPTH
M
CAL
IN
0 20
GR
GAPI
0 200
BS
0 20
SP
MV
0 150
BS CAL
CAL BS
RFOC
OHMM
0.2 2000
REM
OHMM
0.2 2000
RED
OHMM
0.2 2000
ZDEN
G/C3
1.95 2.95
DT
US/F
140 40
PE
B/E
0 20
SW
DEC
1 0
0 SW
PHIE
DEC
0.5 0
BVW
DEC
0.5 0
PHIE BVW
VCL
dec
0 1
VSS
DEC
0 1
VLS
0 1
VDOL
0 1
VLUM
DEC
0 1
VTUF
DEC
0 1
CLAYST
0 1
PHIEQST
1 0
SGMASIVA
0 1
SGESTRAT
0 1
SGRAVA
0 1
SSANDFTC
0 1
2500
2525
2550

Figure 6