Petroleum Res. J. Vol. 13 (2001); P. 7–14, 3 Figs.

Formation Evaluation Seen by a Geologist

- a keynote lecture -

Oberto Serra*

رؤية الجيولوجي لتقييم المكمن

أوبيرتو سيرا

حيث أن قياسات سرود الآبار تعتمد اعتماداً قويا على العوامل الجيولوجية، فإن أي تفسير لهذه السرود سيكون بالطبع تفسيراً جيولوجياً. فهي تمثل المصدر الأساسي للمعلومات تحت السطحية. والسؤال هو: من يستطيع أن يفسر هذه السرود أفضل من الجيولوجي؟

بالطبع فإن الجيولوجي يجب أن يعرف الأسس الفيزيائية للمعدات المستخدمة وكذلك العلاقة بين المتغيرات الفيزيائية والتفسيرات الجيولوجية. ولسوء الحظ فإن تفسير سرود الآبار قد تم إحتكاره من قبل البيتروفيزيائيين. ويؤكد هذا الرأي التسمية التي أطلقتها جمعية محللي سرود الآبار المهنيين على مجلتهم Petrophysics وتناسي مجلس إدارة هذه الجمعية أن هناك آخرون من بين المختصين بعلوم الأرض يقومون بتحليل وتفسير السرود لأغراض أخرى.

إن البيتروفيزيائيين يتعاملون مع صيغ إختبارية رياضية، وعند تركيزهم على تحليل المكامن، فإنهم غالباً ما يتناسون الأخذ في الاعتبار التكاوين الجيولوجية التي حدث فيها ذلك.

ولا يمكن حصر تقييم المكامن في إيجاد الخواص الفيزيائية للمكمن، ولكن الأهم من ذلك هو وضع المكمن في إطاره الجيولوجي وذلك لربط امتداده الجانبي وحجم المواد الهيدروكربونية والسماكة الفعلية وبيئة الترسيب والتشوهات المحلية. هذا بالتأكيد هو مهمة الجيولوجي، ويجب أن يدرك البيتروفيزيائيون أن تقييم المكامن لا يمكن تحقيقه من خلال حل المعادلات الرياضية نظراً لوجود عوامل جيولوجية متعددة تؤثر على قياسات سرود الآبار.

ولذلك فإن تفسير السرود يجب أن يكون شاملاً وكاملاً، ويجب أن يتم دمج جميع المعلومات وأصولها وطبيعتها ومقاييسها المختلفة. إضافة إلى ذلك، فإن قياسات الرسوبيات المجمعة لأجل تفسيرها لا تمثل حجم الصخور الفعلي، وإن بعضها يتأثر بظروف قاع البئر، علاوة على ذلك، فإن بعض المعلومات لا تمثل الواقع الجيولوجي خاصة عندما تكون الوحدات الترسيبية رقيقة ومتعددة.

لهذا كله فإنني أقترح إتباع الطرق الجيولوجية لتقييم المكامن ويجب علينا أن نحدد بقدر المستطاع من جميع المعلومات الواقع الجيولوجي. والذي يتلخص في الآتي:

- التعرف على كل وحدة ترسيبية.
- إيجاد الخواص الجيولوجية لتلك الوحدات وذلك لحساب الحجم والامتداد الجانبي.
- تقييم الخواص الفيزيائية لتلك المكامن.

* Place Saint-Clair 14201, Herouville, France.

Abstract: *Since well log measurements depend strongly on the geological parameters, any log interpretation is by nature a geological interpretation. Logs represent a fundamental source of information in subsurface. Who can interpret them better than a geologist? Of course the geologist must know the tools physical principles and the links between physical parameters and geological attributes.*

Unfortunately, log interpretation has been "monopolized" by petrophysicists. SPWLA review's brand new title: Petrophysics, proves it and the board of directors of this society has forgotten that other geoscientists also analyse and interpret logs for other purposes!

Petrophysicists deal with empirical mathematical formulae. While focusing on reservoir analysis, they often forget to consider in which geological formation they occur.

Formation evaluation cannot be restricted to reservoir petrophysical properties determination. It is of the utmost importance to put back the reservoir in its geological context in order to link lateral extents and hydrocarbon volume to real thickness, environment and local deformations.

This is definitely a geologist's work. Petrophysicists must realize that reservoir evaluation cannot be achieved by solving equations. Too many geological parameters affect log measurements. Log interpretation must be global and total. It must integrate the whole set of data and their different origins, natures and scales. Moreover, log measurements, combined for interpretation, do not correspond to the same volume of rock and some of them are affected by borehole environment. In addition, some of the data do not represent the geological reality, especially if the units of depositions are thin and numerous.

Therefore, I propose to follow a geological approach to reservoir evaluation. We must determine, as much as possible from the whole set of data, the geological reality. This consists in:

- *recognizing each depositional unit,*
- *determining their geological setting in order to estimate their volume and lateral extent,*
- *evaluating their own physical properties.*

INTRODUCTION

Being conscious or not – it should be better to be conscious! – any log interpretation is by nature a geological interpretation as well log measurements depend fundamentally and strongly on the geological parameters (Table 1). Logging tools are the instruments of the geoscientist who studies subsurface formations. They provide one of the fundamental source of information in subsurface. As logging measurements depend on geological parameters, who can better interpret them than a geologist? You wouldn't think of a radiologist analysing medical images without knowing the anatomy! Why would you entrust your log-interpretation to a petrophysicists who wouldn't know about geology? Of course the geologist must know the physical principles of the tools and the link existing between the physical parameters and the geological attributes, as the radiologist must know the principles of the instruments that provide the images, in order to detect any bad functioning.

As previously suggested, any formation evaluation is in fact a geological interpretation. To be complete and valuable, this evaluation must not be limited to the determination of the reservoir petrophysical properties (porosity, permeability, water saturation). It must, as much as possible, allow the evaluation of its lateral extent and the hydrocarbon volumes in place. To achieve these goals it is of the utmost importance to put back the reservoir in its geological context, in other words in its depositional environment and its tectonic setting, in order to link its lateral extent to its real thickness and environment, and to the observed local deformations. This determination is based not only on well logs but also on surface and well seismic, on testing results and on core analysis. It must also include interpretation of the borehole images in order to recognize firstly each depositional unit composing the reservoir and their internal organization (texture and structure) from which the determination of the facies and the depositional environment will be possible, secondly the tectonic features that will allow the reconstruction of the structural shape through the determination of the folding, the presence of faults and fractures. This implies the study of reservoir and non-reservoir sections, the latter being often ignored by petrophysicists. The interpretation of all these data requires as well a good geological knowledge, which petrophysicists do not necessarily have. Consequently, the interpretation will be more complete and reliable if conducted by an experienced geologist knowing well log and seismic interpretation.

GEOLOGICAL REALITY

For many petrophysicists, a reservoir is, according to the definition, "a subsurface volume of rock that has sufficient porosity and permeability to permit the accumulation of crude oil or natural gas under adequate trap conditions"[1] and, I would add, their extraction. Referring to the logs, petrophysicists consider a reservoir each depth interval that presents typical responses. In addition, they often assume that the reservoir depositional environment does not vary from one well to the other. During their study, they do not take into account the information provided by borehole images or dipmeter data. They have to realize that a reservoir is generally composed of several beds or, more precisely, units of deposition. Each unit shows variable thickness and extent as a function of its depositional environment. In other terms, a unit is composed of a vertical and lateral succession of two types of geological objects: volumes (beds, strata, layers) delimited by surfaces. What is generally called a bed may often be subdivided into several depositional units as illustrated by figure 1. In fact, the petrophysical properties of a reservoir essentially depend on the petrophysical properties of each unit that composes it. Too often, standard logs, owing to their lack of resolution, reflect imperfectly the average petrophysical properties of a bed, not the real ones of each depositional unit that composes it.

Table. 1. Relative influence of geological attributes on well logging measurements (adapated from [4]).

Type of measurement		Parameters directly accessible	Relative importance of geological attributes on the measurement: Composition	Texture	Structure	Fluid
Electromagnetism	Resistivity / Conductivity (< or > 2 MHz)	R / C				
Electromagnetism	Propagation time of an electromagnetic wave	tpl				
Electromagnetism	Attenuation of an electromagnetic wave	eatt				
	Nuclear Magnetic Resonance	Time T2				
	Spontaneous potential	SP				
Natural radioactivity	Total natural radioactivity	GR				
Natural radioactivity	Natural gamma ray spectrometry	K, Th, U				
Interaction γ rays - rock	Bulk density	ρ_b				
Interaction γ rays - rock	Photoelectric Index	Pe				
Interactions neutrons - rock (nucleus)	Elastic collisions: epithermal neutrons, thermal neutrons, neutron gamma	IH - ϕ				
Interactions neutrons - rock (nucleus)	Die away of thermal neutrons	Σ				
Interactions neutrons - rock (nucleus)	Spectrometry of induced γ rays - by capture of thermal neutrons - by activation	Si,Fe,Ca,H S,Gd,Ti,Cl Al				
Interactions neutrons - rock (nucleus)	Spectrometry of induced γ rays by inelastic collisions of neutrons	C/O				
Acoustic	P waves (compressional): Slowness, Attenuation	t_c, A_c				
Acoustic	S waves (shear): Slowness, Attenuation	t_s, A_s				
High resolution	Dipmeter: Curve shape, Surfaces	Intern. org. + Dip				
High resolution	Borehole images: electrical, acoustic	Intern. org. + Dip				
	Caliper	d_h, t_{mc}				
	Thermometry	T°				

Petrophysicists deal with a reduced set of empirical equations to evaluate reservoir properties. You cannot expect to solve the complex geological puzzle by solving empirical equations involving only a few parameters. In fact the mathematical approach is restrictive and reducible in itself. For instance, take an arkosic sandstone. It results from granite or gneiss weak weathering. Therefore, its mineralogical composition includes quartz, microcline, plagioclases, micas, amphiboles, heavy minerals and some clay minerals, like kaolinite, plus a cement. That means that a minimum of ten minerals must be included in the lithological model. We all know that current most advanced software models cannot resolve this mineral complexity. Yet, log measurements are affected by those minerals and some other parameters as well. They contain this information.

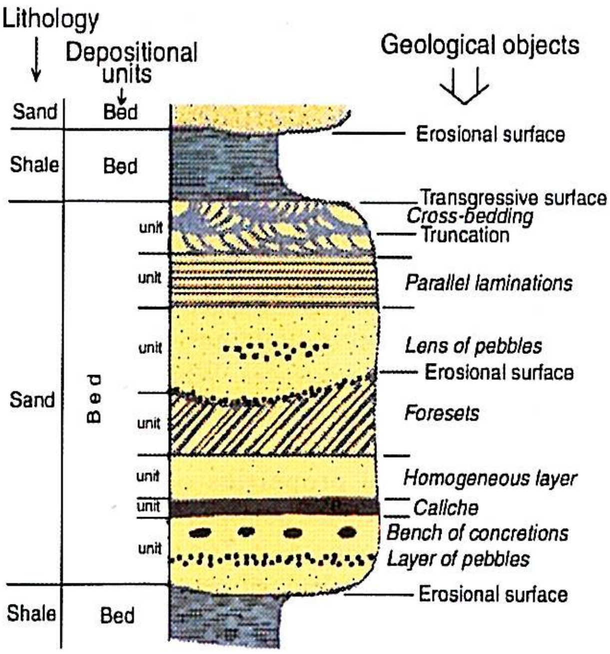


Fig. 1. Subdivision of a bed in geological objects (adapted from [2]).

Furthermore, subsurface data are of different origins (seismic, cores, logs, tests), scales (millimetres to kilometres) and natures (qualitative and quantitative). Many of them cannot be easily quantified. But the information they provide must be used to achieve a reliable interpretation.

The accuracy of interpretation will be improved by integrating the information provided by all available data (logs, images, cores, tests, pressure measurements, well seismics, surface seismic surveys, *etc.*). Accumulation of observations and real facts of different natures allows the interpreter to avoid erroneous conclusions. Any interpretation that would be based on a reduced set of information would suffer of a lack of reliability.

In the early stage of a field or basin study, integration of log and image data calibrated on core analysis, results of well and surface seismic surveys processing, guided by information provided by logs and dips, and test measurements, are a must. This will ensure firstly an accurate and reliable evaluation of the economic potential of formations, secondly a more precise description of the geometrical distribution of the depositional units absolutely necessary for the development of a field and its secondary recovery phase.

It is the reason why formation evaluation must be global and total and cannot be restricted to reservoir petrophysical properties determination. This evaluation is definitely a geologist's work.

Each depositional unit has its own petrophysical characteristics. The latter are function of its composition, its porosity and permeability which depend essentially on its texture, its internal structure, the diagenetic effects that it has undergone, and its fluid content. These characteristics result, on one hand, from the physical-chemical and environmental conditions of the setting of deposition (latitude, longitude, altitude, geologic period, energy in the medium of deposition), in other terms of its facies and depositional environment, and, on the other hand, from the evolution of these original characteristics during their geological history under diagenetic effects and tectonic stresses.

Each surface has its own transmissibility properties that both depend on its nature and origin and on the properties of the units that surround it.

INTERPRETATION MODEL

Any formation evaluation requires an interpretation model that depends on five interdependent sub-models (Fig. 2) :

- the borehole model
- the tool model
- the geological model
- the reservoir model
- the mathematical model.

GEOLOGICAL APPROACH

The geological model is the angular stone of the interpretation model as the measurements to be recorded (tool model) must be selected as a function of the problems linked to the type of formations that will be crossed. The tool model depends itself on the borehole model, and, finally, the reservoir and mathematical models that are selected for quantitative evaluation are also depending on the geological attributes of the reservoir to evaluate. The geological and reservoir models can be determined from the logs and images following a certain methodology as explained in Table 2.

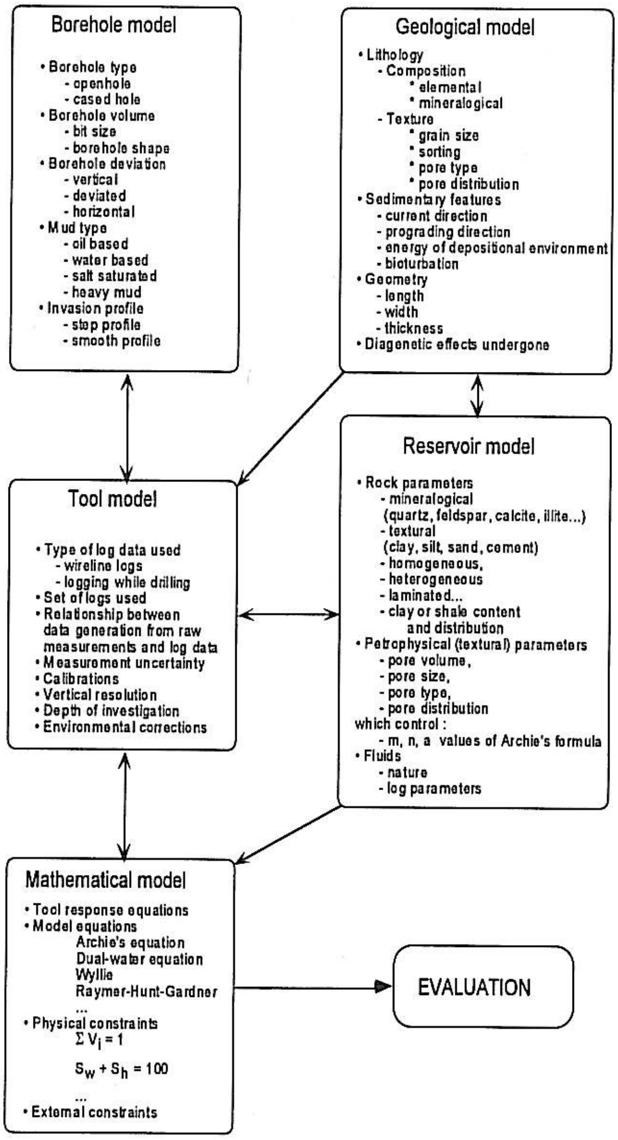
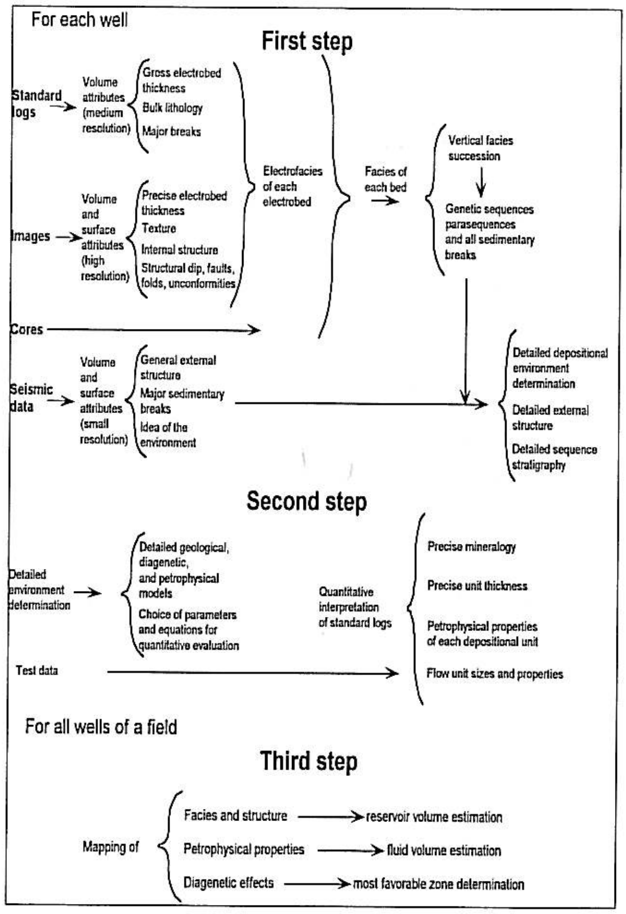


Fig. 2. The interpretation model and its five sub-models.

The "bed" notion, used in surface geology, must be adapted to subsurface and the type of logging data. It must be replace by the "electrobed" concept. An electrobed is the smallest unit that can be differentiated on logs from the surrounding units due to significant changes in logging parameters. The minimal thickness of an electrobed varies as a function of the logging type of measurement. It depends on the intrinsic and qualitative vertical resolution. In order to detect the thinnest units of deposition, imaging tools are required since they have the highest vertical resolution : approximately 1 cm. An electrobed identified on a log with lower vertical resolution may in fact be composed of several smaller units, each of them having their own petrophysical properties.

Table. 2. Interpretation methodology (modified from [31]).



Any modern reservoir interpretation must be able to recognize each depositional unit and evaluate its own properties. However, up to now, one was essentially interested in standard logs only able to detect volumes of a certain thickness. In addition, log measurements, combined for quantitative interpretation, do not represent the same volume of rock and some of them are affected by borehole environment. Lastly, due to the lack of resolution of several tools, some of the data do not represent the geological reality, especially if the units of depositions are thin and numerous. In relation to these drawbacks evaluation errors may occur.

Thanks to borehole images it is now possible to recognize each depositional unit at a very detailed scale and evaluate their own properties (Fig. 3). It is the reason why images are so interesting and fundamental in any modern reliable reservoir interpretation and formation evaluation. The additional cost, required for their acquisition, will be compensated for by saving one or more

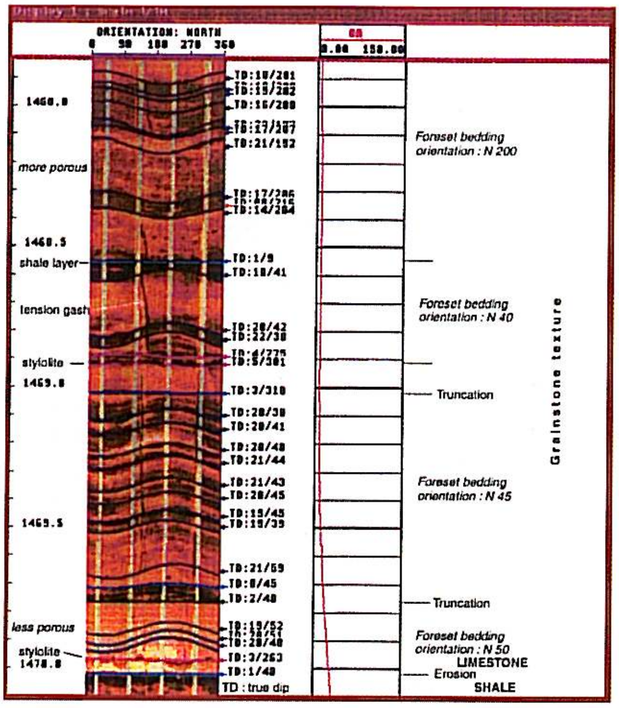


Fig. 3. Example of depositional units perfectly detected on a borehole image.

dry wells and, therefore, the information they provide will increase oil companies return.

The images allow us to:

- recognize each depositional unit,
- determine their internal organization : texture and internal structure,
- measure their real thickness,
- detect and classify each surface,
- evaluate their transmissibility properties,
- clarify the tectonic features: folds, faults, fractures,
- better understand the reservoir complexity and its dynamic behaviour.

It is also fundamental to quantify the information the borehole images provide (Table 3).

Geological interpretation of well logs requires the same type of work as studies of outcrops or cores (Table 4). As logs strongly depend on geological parameters, detailed and precise observation and description of events seen on logs and images, comparison with previous studies, interpretation based on experience, and prediction must be also the successive steps of geoscientists working on subsurface data.

As previously mentioned, any log interpretation is by nature a geological interpretation. The goal of the geological approach of well log interpretation is to convert the logging data into geological attributes. This requires an interpreter who knows both "languages".

Thus, recognizing each depositional unit crossed by a well and extracting information related to its lithology, composition, texture, structure (sedimentary and tectonic), thickness, geometry, diagenetic effects and reservoir characteristics, is the main goal of geological interpretation of well logs, images and dip data (Table 2).

Characterizing these geological attributes assists geologists in the description of the facies, genetic sequence, depositional environment, types of traps and stratigraphy. Based on these data and the other information provided by well and surface seismic, and tests, they will make a more reliable

Table 3: Quantitative borehole image analysis (adapted from [51]).

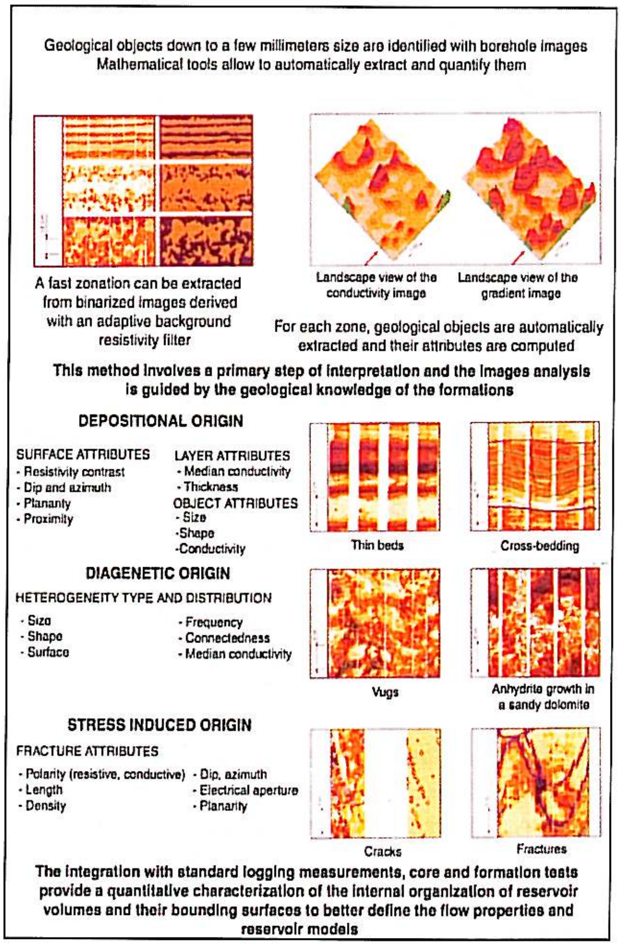
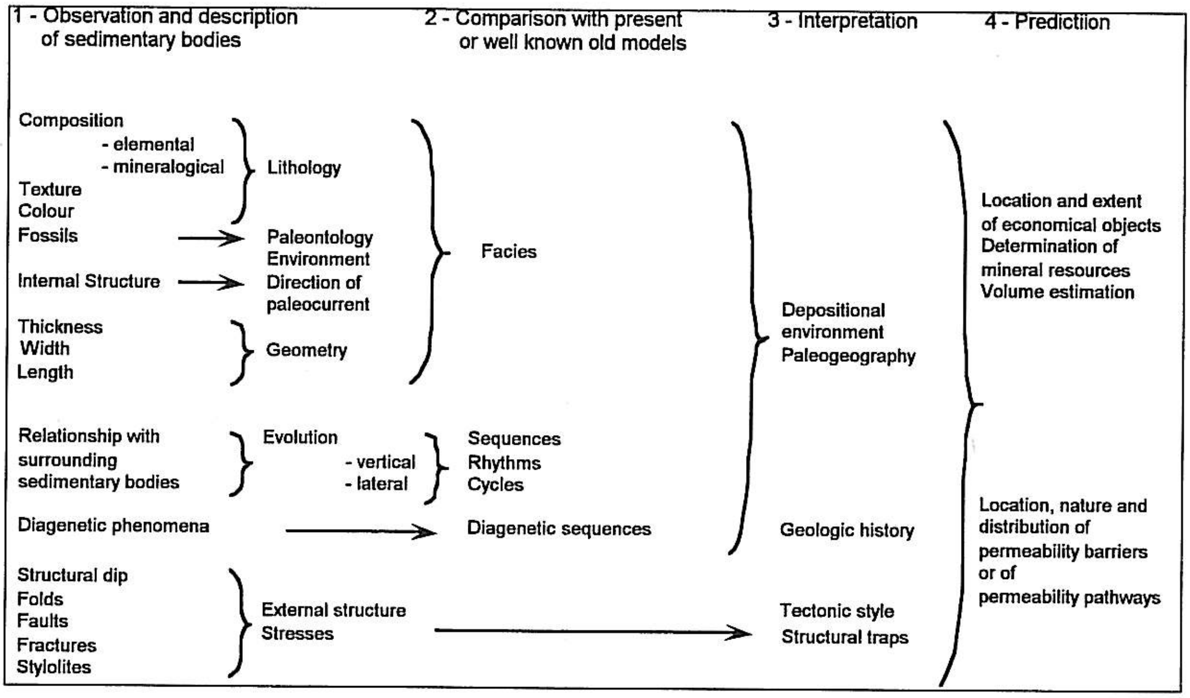


Table 4. Geologist's work to apply to well log data.



volume evaluation. In addition, from this information, reservoir engineers can determine the presence of permeability pathways or barriers and reservoir flow properties, allowing them to better determine the scheme of the field development and the calculation of the net pay.

As one can understand, the study of any formation starts with the determination of the lithology of each unit composing it, that is, its mineral composition and its texture as a whole. This first step requires a multiple crossplot and histogram analysis of standard log data for an accurate composition determination. Analysis of borehole images and nuclear magnetic resonance data will provide textural information. This study carries on with determination of the sedimentary features, from borehole images, which will inform us about the energy and biological activity in the medium of deposition, therefore about facies and the depositional environment through the analysis of the facies succession or sequence. This study will be completed by the determination of the transformations (diagenesis) and deformations (tectonics) undergone by the formations since their deposition.

Applying this approach to each well of a field will considerably improve the perception of your field. Data, provided by the analysis of each well, are the basic elements for a good and accurate mapping.

CONCLUSION

Formation evaluation requires more than well log and petrophysical knowledge. Being accurate, reliable and economic requires a geological approach. The latter should identify each depositional unit composing a reservoir and evaluate its actual properties. These units must be integrated in the geological setting (depositional environment and tectonic feature) in order to estimate their volume and extent. Due to their very high vertical resolution, images are fundamental to reach those goals. It is the reason why formation evaluation should be the responsibility of geologists knowing about the tool physics and the links existing between log parameters and geological attributes. Petrophysicists should exploit image information. Geologists should keep an eye on standard logs while interpreting images.

REFERENCES

[1] Bates, R.L. & Jackson, J.A. (ed.), 1980. *Glossary of Geology.* 2nd ed. American Geological Institute, Falls Church, Virginia, USA, 751 p.

[2] Blatt, H., Middleton, G. & Murray, R., 1980. *Origin of Sedimentary Rocks.* 2nd ed. Prentice-Hall Inc., Englewood Cliffs, New Jersey, USA.

[3] Serra, O. *et al.*, 1993. – True integrated interpretation. Poster presented at the 34th Ann. Log. Symp. SPWLA, Calgary, Canada.

[4] Serra, O. & Abbott, H., 1980. The contribution of logging data to sedimentology and stratigraphy. 55th Ann. Fall Techn. Conf. SPE of AIME, paper SPE 9270.

[5] Delhomme, J.P. & Motet, D., 1993. *Reservoir Description and Characterization from Quantitative Borehole Image Analysis.* AFM Reservoir Characterization Review, Africa and Mediterranean Region, Schlumberger, France, n° 5, pp. 5-19.