Stratigraphic analysis base on logs and cores: An overview

Rovicky Dwi Putrohari
Kondur Petroleum

Stratigraphy is a branch of geology that deals with stratified or layered sedimentary rocks. Stratigraphers basically classify sedimentary layers after examining their texture, composition, and arrangement. Most stratified rocks were originated as sediments deposited in layers in ocean and lake bottoms or on floodplains. By analyzing the relationships between strata (layers) for different periods of geologic time, stratigraphers can unlock the story of the Earth's history. This will lead to the discovery and exploitation of many resources, such as coal, metal and petroleum.

The stratigraphic analyses are dependent on the magnitude order of the data (tools) and also are related to the order of the analyses as shown on Table 1 (Batteman, 1988). Borehole geophysical data, called well log data, have been used intensively in the oil and gas exploration and has an order ranging from 10^2 meter to 10^{-2} meter. These geophysical well log data indirectly mimic the geological character of the rocks. Understanding of these logs requires an understanding of the physical properties of the rocks and principles of the well logging tools. Some illustration of what can be revealed from certain types of logs is summarized in Table 2.

In petroleum industries, correct correlation of stratigraphic units is vital to make reliable cross-sections and maps. The correlation includes determining laterally extensive marker beds and pattern matching of distinctive wireline-log patterns of any origin. For this purpose, the well data might be displayed using a variety of scales, ranging from 1:200 to 1:2,500.

The recognition of characteristic electric-log patterns and distinctive vertical-profiles are a useful tool for correlation. The technique is almost as old as modern sedimentology itself (Nanz, 1954). The wireline logs can be used to distinguish changing lithology, and thereby can determine vertical facies relationships and infer evolving environments. The technique depends on the distinctiveness of the vertical profile through a rock body and the ability to interpret this profile in terms of depositional processes and environment.

By matching the patterns, correlation are made on the basis of log shapes over certain intervals. Pattern matching might allow correlation even where lateral variations in lithological, facies, and thickness of units have occurred. The nature of the upper and lower contacts, i.e. abrupt or transitional (Serra & Sulpice, 1975), from different lithology units also reflects the stratigraphic relationship between them.

Information of Rock Composition

The composition of a rock can be expressed in two ways: 1) elemental and 2)mineralogical. This chemical elemental analysis is normally achieved by x-ray diffraction or neutron activation. The results can be in terms of percentages of elements present, or in terms of oxides of these elements (the oxygen being strongly bonded to each of the abundant elements). The mineralogical compositions, especially in sedimentary rocks, are usually composed of a mixture of at most four minerals or major constituents, which have a content of more than 5 %. The end member concept or major constituents, introduced in Krynine (1948) and extended by Pettijohn (1948) describes the composition of rocks based on this observation.

On well log data the elemental composition is determined by Natural Gamma-Ray log (including the Natural Gamma-Ray Spectrometry - NGS) which detects, in favorable cases, measurements of the proportions of the following elements:

-Potassium (K), thorium (Th) and uranium (U) by NGS.

-Carbon (C), oxygen (O), silicon (Si), iron (Fe), calcium (Ca), hydrogen (H) and alumunium (Al) by GST and Alumunium Clay Tool (ACT).

Only two exceptions (Mg and Na) can be calculated in the percentages. Neutron-based tools provide measurements of light elements (H, C, O and Si) which show in terms of slowing effect, and (Gd, B, Li, Cl, Fe) through thermal absorption measurements.

Geologists have seen that rocks are made up of a mixture of minerals. Consequently, it is the

Table 1 Evaluation Magnitude (Bateman, 1988)

Magnitude in meter	Formation Evaluation Technique	Purpose
10^6 10^5 10^4	Satellite Imagery Basin Geological Studies Seismic, Gravity, Magnetic	Gross structure
10^3 10^2 10^1	Borehole gravimeter, Ultra Long-Spacing Log Drilstem test (DST) Wireline Formation Test (RFT/SFT)	Local structure Productivity and reserves
10^0 10^{-1} 10^{-2}	Full diameter cores Sidewall Cores, most conventional well logs, Measurement while drilling (MWD/LWD) Microfocused Log, coreplug analyses	Local porosity permeability, age and lithology
10^{-3} 10^{-4} 10^{-5} 10^{-6}	Cuttings analyses (Mud logging) Core analyses X-Ray mineralogy Scanning Electron Microscope (SEM)	Local HC content Rock properties Rock and clay typing Micropore structure

Table 2. Comparative response of well logs to the four main geological parameter (Serra & Abbott, 1980)

Log Type	Composition	Texture	Sedimentary Structure	Fluid
Resistivity	**	***	**	***
SP	*	**	***	***
EPT (Propagation Time)	**	*	*	***
EPT (Attenuation)	**	*	*	***
GR	**	*	*	*
NGS	***	*	*	*
CNL	**	**	*	**
FDC, LDT (ρb)	***	**	*	***
LDT (ρ_e)	***	*	*	*
TDT (Σ)	**	**	*	**
BHC (Δt)	**	***	*	***
BHC (Attenuation)	*	**	**	***
GST, GLT	***	***	*	*
HDT or SHDT, FMS	*	***	***	*
CAL	*	**	*	*
HRT	**	***	***	**

physical properties of these minerals, and ultimately the atomic properties of their constituent elements, which influence the log responses. Stratigraphers and geologists are more interested in mineralogical than elemental compositions of rocks, because the mineralogical composition is more reflective of sedimentary processes involved. On a well log, in fact, the responses are a function of the characteristics of each mineral present in the rocks and of their relative percentages in the zone of investigation, and on the nature and percentages of the fluids occupying the pore spaces (Serra, 1986).

Lithology

In general there are no tools that can precisely identify the lithology of sandstones, shale, carbonates, coal, etc. However, if we believe that a rock rarely contains more than four different major minerals (a belief commonly used in practice), it is only necessary to have a preliminary knowledge of their types and their characteristics on log responses. This phenomenon is used by most petrophycisists in their wireline rock analyses by using computer-derived lithology determinations. The litho-programs on computer can easily identify the general compositions of the

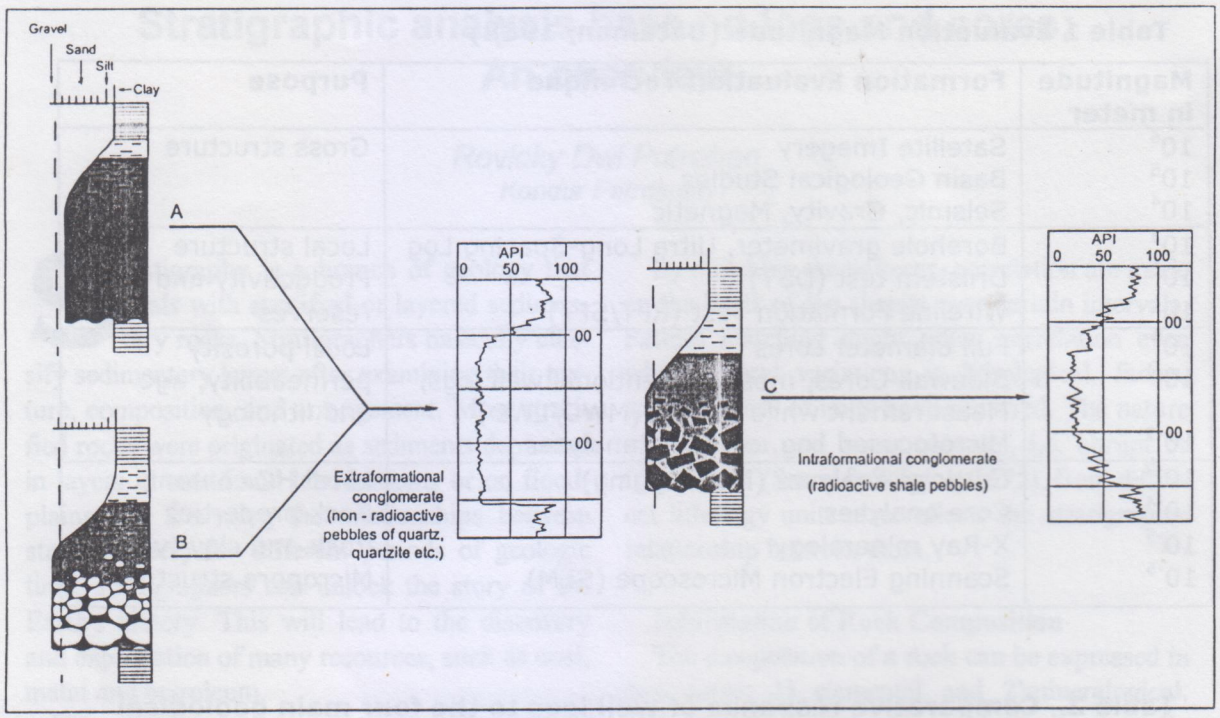


Fig. 1. Grainsize profiles and gamma log responses for some upward-finning sequences. Note how intraformational conglomerate on a channel floor may cause the gamma-ray log to apparently indicate an upward-coarsening sequence (Selley, 1985).

rocks. However, these programs still require basic knowledge of sedimentology and geology prior to determining the main mineral compositions.

Recent development of neural network analyses, a mathematical method, provides significant evolution in the determination of lithology. Probabilistic Neural Network (PNN) with classification mode may produce probability estimates in determining lithology. Of course, direct lithology information from core data will significantly increase the confidence level in lithology determination.

Information of Rock Texture

Rock texture describes geometrical aspects of the rock components and plays a very important part in the study of sedimentary rocks. Texture is a description of the grains or particles and crystals in a rock, i.e. their size, shape, appearance, arrangement and sorting, and the bounding of these grains and matrix. These textures control of their petrophysical properties of rocks, such as porosity and permeability, which are important parameters in hydrocarbon exploration and production.

As suggested by Serra (1986), some well log measurements contain textural information. But it is not always simple to determine the origin of influence because several textural parameters may have similar effects.

Grain size information

Grain size is the most valuable type of data for siliciclastic sedimentary successions (sand-shale sequences). However, there is no general universal relationships between the grain size and a log measurement. Many authors have observed relations between well logging parameters and grain sizes. They have shown that an obvious correlation exists between gamma-ray log and grain size measured on core samples. Gamma-ray increases when grain size decreases, because radioactivity is indirectly linked with fine-grained sediments, which consist of clay minerals. Many authors also found that these clay minerals are fundamentally of detritus (allogenic) origin and are of a structural or laminated type. Therefore, it is hardly conceivable that authigenic clays occupying the pore space would show such evolution (see explanation on the clay contents below), because in these cases, the percentage in the rock does not significantly evolve with granulometry (Serra, 1986). Figure 1 shows how the gamma ray log might fail to identify grain sizes of coarse sandstones to conglomerates.

Sorting and grain orientation

Since the resolution of well log data is mostly inadeguate for textural identifications due to the sampling interval, the highest resolution data are coming from the FMS (Formation Micro Scanner). Unfortunately, the FMS is still insufficient to identify sorting and grain orientation in fine sedimentary rock (< granule sizes). In these cases, conventional core data will be needed to provide the information.

Clay contents in rocks

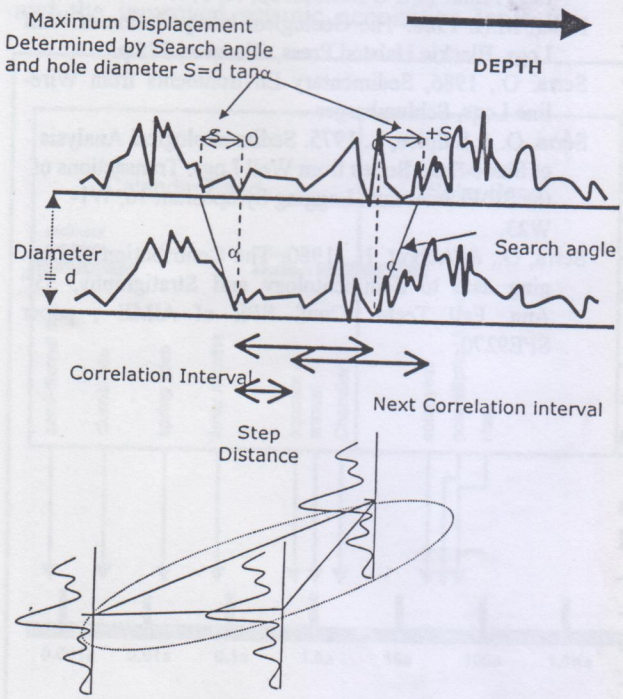
Clay mineral is important material in imprtant information in a log evaluation. Clay minerals are the most common material that exists in rocks. Some clay minerals are derived from alterations, of original grain particles, which can not be distinguished on conventional logging measurements. Physical characteristics of these clay materials (both these originally composed as matrix or those derived from alteration) are similar and give similar signatures in the log responses. These clays can only be distinguished visually through either megascopically by using loupe or microscopic on thin sections.

Gamma-ray and Spontaneous Potential logs conventionally are used for estimating clay content of the rocks. Unfortunately, the gamma ray logs only measure the total natural gamma-ray emitted from the rocks and cannot distinguish whether the clay is from an altered grain or part of the matrix composition of the rock. This information is very essential for sedimentology and stratigraphic analyses. Therefore, other information such as borehole rock samples such as cutting samples, sidewall core and convention core (full core) samples are very useful and in many cases are essential in defining some sedimentological parameters.

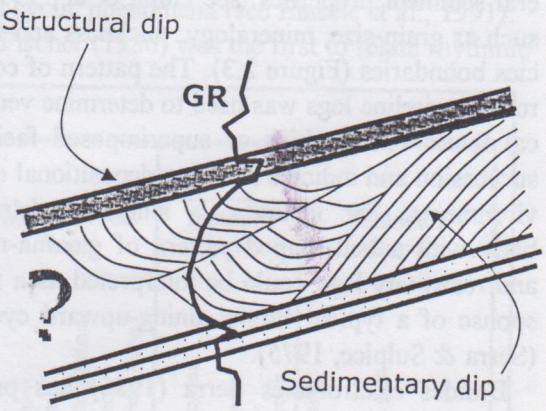
Information of Sedimentary Structure

Sedimentary structure is an inherent property of a rock. Whereas the texture deals with the grain to grain relations in a rock, structure has to do with discontinuities and major inhomogeneities. Therefore, the study of sedimentary structure is best studied in an outcrop scale than in a hand-specimen scale. This should include all geometrical aspects such as thickness, orientation, shape etc. Some sedimentary structures are textural dependent such as cross bedding will only found in a sand-range grain size.

The most common tool for planar structure determinations is a Dip-meter log. This log measures micro-resistivity of at least three points



a. Dip meter calculation parameters (Batteman, 1988)



b. Which dip do you need ?

Fig. 2. Parameters on dip meter calculations.

borehole wall. By using three point data, we can measure the dip and strike of a plane. This is important because we need to know whether the plane is a sedimentary structure, a structural dip , or another structural plane such as vein, fracture etc. Figure 2 shows the parameters on dip meter calculations.

The latest FMS logs have been intensively used for structure identification. This log can be interpreted without dip calculation for a qualitative aim. This qualitative interpretation sometimes gives more valuable information for sedimentology or stratigraphy purposes.

Facies and Sequence

Facies provide the context for mapping reservoir flow units, which more precisely describe variations in the rock properties that control fluid flow. The term *facies* has been used in many ways and has also been applied for well log data with the special term *electrofacies* (Serra & Sulpice, 1975; Rider, 1986). The electrofacies analysis could also include electrofacies zonation (e.g. Lloyd, 1983; Mulhern et al., 1986) which incorporates computation of lithology from logs. Several types of logs from (e.g. Gamma-ray, resistivity, sonic, density, and neutron porosity logs) can be assumed to indirectly represent several sediment properties (see Hurst et al., 1990) such as grain-size, mineralogy, thickness and facies boundaries (Figure 2.3). The pattern of correlated wireline logs was used to determine vertical facies relationships or superimposed facies succession and indicate evolving depositional environments. For instance, a single sandstone body with a bell-shaped pattern of gamma-ray and resistivity logs could be interpreted as a response of a typical fluvial fining-upward cycle (Serra & Sulpice, 1975).

Besides electrofacies Serra (1986) has proposed special terms such as *parafacies* and *electrosequence* for stratigraphy evaluation based on well log data.

The goal of the study of sedimentary facies and their arrangements or association in lateral and vertical sequences is to determine depositional environments. However, we should remember that the physical characteristic (or petrophysics) of the rocks not only reflect the mineralogy (the solid material). The solid materials are the main objects on stratigraphic analyses. But the well log signature is also a reflection of the fluid that filled the pore-spaces.

These special analyses of well log data for stratigraphic purposes is growing fast, concurrent with major developments in sequence stratigraphy methods.

Conclusions

- Well log data provide a significant subsurface information for stratigraphic and or sedimentological analysis. Most of the required data are available within a well log.
- The use of core data is very essential when the log response fails to identify the detailed composition, texture and structure of the rocks.
- Lack of understanding the physical parameters of the rocks and the basic logging tools physics will significantly mislead the potential of the well log data in stratigraphic analyses.

References

Batteman, 1988, Introduction to Well Logging, IHRDC (International Human Resources Development Corporation), Boston.

Hurst, A., Lovell, M.A. & Morton, A. eds. 1990. Geological Application of Wireline Logs. Blackwell, Oxford.

Krynine, P.D., 1948, The Megascopic study and field classification of sedimentary rocks, J. Geology, 56.

Llyod, P.M. 1983. Reservoir Facies Zonation Using Wireline Logs. AAPG Bulletin 67, 504-505.

Mulhern, M.E. et. al. 1986. Electrofacies Identification of Lithology and Stratigraphic Trap. Geobyte 4, 48-56.

Nanz, R.H. 1954. Genesis of Oligocene Sandstone Reservoir, Seeligson Field, Jim Wells and Kleberg Counties, Texas. AAPG Bulletin 38, 96-117.

Rider, M.H. 1986. The Geological Interpretation of Well Logs. Blackie Halsted Press, Glasgow. 175 p.

Serra. O., 1986, Sedimentary Environments from Wireline Logs, Schlumberger

Serra, O. & Sulpice, L. 1975. Sedimentological Analysis of Shale-Sand Series from Well Logs. Transactions of the SPWLA Annual Logging Symposium 16, W1-W23.

Serra, O., & Abbott, H., 1980, The Contribution of Logging data to Sedimentology and Stratigraphy, 55th Ann. Fall Techn. Conf. SPE of AIME , paper SPE9270.