Subsurface Facies Analysis using Electrologs - A case study on Krishna Godavari Basin, Rajahmundry*

Jagadish Chandra Maddiboyina[1] and A. Narsing Rao[1]

Search and Discovery Article #41039 (2012)*
Posted October 22, 2012

*Adapted from extended abstract prepared in conjunction with oral presentation at GEO-India, Greater Noida, New Delhi, India, January 12-14, 2011, AAPG©2012

[1]Osmania University, Hyderbad, India (geojagadish@gmail.com)

Abstract

The present study gives insight knowledge about the facies variation across the Krishna-Godavari basin. The basin is located at the centre of the divergent eastern margin of the Indian Plate. The Krishna and Godavari rivers supplied copious amounts of sediments, which resulted in the development of the basin. Basin evolution had close relation to plate tectonics and the basin architecture shows several horsts and grabens. The sedimentation in the basin is restricted to paleo lows and grabens until the early Cretaceous. The tectonics and sea level fluctuations resulted in the development of present stratigraphy in the basin. Electrologs are good indicators of physical parameters of the formations penetrated by the borehole. The spontaneous potential and gamma ray along with resistivity and caliper are excellent sources for lithology determination. The resistivity logs Laterolog Deep, Laterolog Shallow, Microspherically Focused logs along with neutron porosity and formation density logs are useful for hydrocarbon zone identification. The dip meter, along with the above logs, is an excellent source of correlation studies. The micro correlation explains lateral and vertical facies variation across the Krishna Godavari basin. The micro correlation within a field reveals the heterogeneity of the field and helps in identifying hydrocarbon-bearing horizons. Based on electrolog studies the comprehensive subsurface variations of various litho units are studied and shifting depositional centers are identified in macro correlations. The depositional environments are derived from log signatures. Various favorable locations for hydrocarbons accumulations are also identified.

Geology of the Area

In the present area, the exposed rocks include the gneisses of Easternghat, sandstone and shale sequence of upper Gondwanas, Trappean Basalts and Mio-Pliocene Rajahmundry sandstone with laterite capping besides recent to sub-recent alluvium and other recent deposits. Easternghats are a series of rather detached hill ranges of heterogeneous composition that stretch intermittently from the northern part of Orissa to Nilgiris through coastal Andhra Pradesh. Easternghats are largely made up of Khondalites, Charnockites, Crystalline limestones and Kodurites. They represent a belt of block uplift as they contain rocks of high-grade metamorphism at depth. The Easternghat organic cycle took place around 1,670 million years ago. In the present area, the Easternghat hills are comprised of Khondalites, the paraschists of Fermer. They are garnetiferous, sillimanite gneisses and were originally called Bezawada gneisses, Kailasa gneisses etc., locally. The Khondalites of this area form ridges trending in a NE-SW direction, which is the regional strike of these rocks. The Khondalites are the oldest rocks exposed in this area and form the basement. The rocks are white, pink and light brown.

Geological Uses of Well Logs

Well logs are made by pulling a tool up the hole, and recording the data as a function of depth. They are used extensively in the petroleum industry for evaluation of the rocks, but this aspect will not be covered here. The interested reader is referred to the various logging company manuals, or to Asquith (1982). Geophysical logs are the fundamental source of data in many subsurface studies because virtually every oil and gas well is logged from near the bottom upwards. Almost all well logging is done by pulling the measurement tool up the hole on the end of a wire. Different types of logs and the properties they measure are shown in Table 1 and are discussed briefly below. On any well from the surveyed elevation of any bed or bed contact is obtained by subtracting its depth in the well from the surveyed elevation of the Kelly Busing (KB) on the drilling platform; this elevation is given on the top (header) of the well log.

Correlation of Logs

Correct correlation of stratigraphic units is necessary to make reliable cross sections and maps, and to conduct regional facies analysis. Complex numerical procedures for matching and correlation of logs (such as a method adapted from gene-typing techniques are shown in Figure 1; Griffiths and Bakke, 1990) may be the primary tools in the future. At present, most geologists match log patterns by eye (or by tracing and overlaying logs), allowing for variations in lithologies, thickness, and completeness of section. Three major correlation methods will be discussed: 1) markers beds, 2) pattern matching, and 3) slice techniques.

<u>Markers beds</u>: The log response (‘kick’) of a distinctive bed or series of beds can be used as marker even if the lithology origin of the bed is not known. Distinctive, laterally extensive groups of beds commonly result from transgressions, regressions, or erosional

episodes, which redistribute proximal sediment far across the basin. Markers that can be mapped regionally may therefore be related to, or include, important allostratigraphic surfaces.

Pattern Matching: This technique involves recognition and matching of distinctive log patterns of various origins. The correlated patterns may represent vertical facies successions superimposing the facies are shown in Figure 2. By matching patterns, correlations are made based on log shapes over intervals of meters of tens or meters, rather than on individual peaks, troughs, or markers within the succession. The logs can be moved up and down until the best overall fit is obtained are shown in Figure 3. Pattern matching is extremely useful because it can be used to correlate facies successions or allostratigraphic units as defined from cores or outcrop. It therefore facilitates investigation of regional facies relationships. Detailed pattern matching of individual facies successions may delineate surfaces of toplap, downlap or onlap and can therefore be used to define large scale or composite allostratigraphic units.

Slice techniques: As a method of last resort, when no other method yields results, an interval can be subdivided by arbitrary slice either into units of constant thickness or into units with thick proportional to the entire interval. Slicing an interval does not give true correlations; it is only a way splitting a section, which cannot be subdivided any other way. The implicit assumption is made that time lines through the interval are essentially horizontal. Where these assumptions are invalid, slice techniques may yield results, which are grossly in error. It is a means of last resort, but is necessary in some situations that do not yield to the other discussed above. The thickness of slices should be chosen to minimize complications. Slice techniques do not work well because of the lack of continuous beds and absence of laterally extensive facies successions. By noting the stratigraphic position and thickness of each lithologic unit with respect to a marker (commonly the top of the unit), the data is in a form of maximum utility when computerized. Thickness of slices can be changed easily until patterns emerge. The slice techniques may produce correlations, which cut across depositional units or unconformities if they are applied to units with sloping depositional surfaces.

Subsurface Maps

Mapping in the subsurface differs little from surface work except for the huge volume of data, which can be collected from large number of wells. Subsurface geological maps are either compilation of data, which helps for geological interpretation, as shown in Figure 4. For geological interpretation many different quantities have been made, but for stratigraphic and sedimentological purposes, there are three main types: 1) structure maps that show elevation of a surface, 2) isopach maps that show the thickness, and 3) lithological maps that show the composition of a unit in one of several ways. Interpretive maps and block diagrams of such aspects as facies distributions, paleogeographies, and sediment supply directions are also commonly prepared.

Subsurface Facies Analysis Using Electrologs

Facies mean the facial expression of a particular condition. A particular facies is developed by a combination of complex processes prevailing during the period of their deposition and variations in the source material. A log is continuous record physical parameters of different formation penetrated by a well. Any change in the facies reflects on their physical properties and on their log patterns. Thus these logs serve as a suitable means of correlation of equivalent strata from one well to the next. Correlations can be done by preparing vertical cross sections on a chosen datum. In order to have better correlation, select some marker beds (thick shale or limestone etc) which do not show much variation in their log characteristics and have wide areal distribution. The log signatures between these marker beds are compared and a full cross section is established. These cross sections will allow us to study the down dip or basin ward changes in characteristics and thus promote a better understanding of the problems on depositional environment and geological history. In general, the correlating lines are needed to be parallel trends to help identify an unconformity, fault or an error in correlation.

Thus, the correlation studies permit us to do accurate subsurface mapping and interpret the sediments in terms of their depositional environments. The correlational studies will reveal the following facts:

1. The elevations for formations present in the well relative to other wells, outcrops or geophysical projections.
2. Whether or not the well is within a given major geological structure.
3. The presence or absence of folds, faults and unconformities.
4. The thickening and thinning of lithological sections or lateral changes of sedimentation or lithology.
5. The geometry of the reservoir can be determined, which is one of the factors needed to compute reserves by the volumetric method.

Macro Correlation

Micro Correlation is the study of facies variations and analyzing on regional scale. In the present area of study, this was done by preparing a geological cross section from electrolog data collected from four wells. The depositional environments are interpreted based on facies variations and log signatures are shown in Figure 5.

In the present area of study, the electrolog data is collected from four wells namely A, B, C, and D. These wells are in the northern half of the basin with wells A and B located in West Godavari sub basin, A being towards the northwest of Tanaku and B towards the southeast of Tanaku. The other two wells are placed in the East Godavari sub basin, C being towards the Northwest of Razole and D towards the southeast of Razole. These wells are aligned sequentially from northwest to southeast with a trend nearly perpendicular to the general trend of Krishna Godavari basin. Hence, the cross section presents litho-facies variations across the basin.

Micro Level Correlation

Micro level correlation is the relation of lithology of a small area within the basin. This correlation helps us to know the architecture and structures within the logs. It helps to know the lithological contacts, closures, and extension of the lithology within the wells. From this correlation, we can prepare isopach maps by measuring the sand and shale contact. We can observe the contact of underlying and overlying lithology for understanding the depositional environments. Micro level correlation is carried out in wells of N, M and O within depth of 1,000 meters to 1,600 meters with reference to MSL. The correlation is done at a scale of 1:2,500. We observe various lithologies such as sandstone, shale and limestone in the three wells. From these wells we observe the alternation various lithology such as sandstone, shale and limestone in the three wells. From these wells, we observe the alternation various lithological extension and truncation in the wells. From observing the wells, a structural feature is a dome or high observed from this correlation. This structural high is observed at well M and lowered to the extremes of wells N and O. From correlation, we identify the extension of lithology and truncation of the lithology.

From the section, we can depict that major amount of truncations were found at well N where it is subjected to faulting as shown in Figure 6. From this correlation, we can identify the hydrocarbon trap and reservoir zone and the lithology, which acts as a reservoir and trap. The structural closure and faulting supports the entrapment of hydrocarbons. By using electrologs, we can identify the sedimentary environments and the sediment deposition. For example, if it is a channel bar deposit, spontaneous potential log and gamma logs show a bell shape in which the sediment fines upwards. If it is a bar deposit, spontaneous potential log and gamma ray logs represent a funnel shape in which the sediment deposition is coarsening upwards. These logs enhance for the environment, and the sediment deposited.

Hydrocarbon Prospects

In micro log correlation, we observe a variation in lithology such as reservoir and trap rocks, which are sandstone and limestone, as shown in Figure 7. This variation in lithology increases the chance for accumulation of hydrocarbons due to overlying and underlying adjacent reservoir and trap rocks. Sandstone acts as a reservoir rock, limestone and shale acts as a trap rock. The structural feature acts as a seal, which increases the chance for the accumulation of hydrocarbons.

Summary and Conclusions

1. In Figure 7, three prominent hydrocarbons zones were identified from 1,907-1,909 m, 1,932-1,934 m and 1,940-1,947 m. In the third zone 1,940-1,947 m, a sudden fall in resistivity is observed at 1,944 m, may indicate oil-water contact.
2. In Figure 5, a 360-meter thick shaly sequence is identified in Well A from 1,120-1,580 m, and it becomes 1,020 m thick in Well B. Its characteristic low resistivity and high gamma log signatures may indicate its origin to be under marine environment. This marine shale along with underlying fluvial sediments indicates a major transgression during a period of its deposition.
3. In Figure 5, the facies variation from arenaceous towards margin side to argillaceous towards basin side along with the shifting depositional centers may indicate the prograding of the basin.
4. In Figure 5, thick argillaceous sequence interbedded with sandstones and siltstones found to be intersecting for hydrocarbon exploration. The thick shaly sequence towards the basin may act as source rock and adjacent sandstone and siltstones may act as reservoir rocks.
5. In Figure 6, micro level correlation of Well N, M and O we observe different stratigraphical features for accumulation of hydrocarbons were observed at wells, i.e. sandstone, limestone and shale.
6. In Figure 6, between Well M and N at a depth of 1,200-1,300 m, we observe structural and stratigraphic traps in which the sand sequence is pinch outs overlying and underlying by a thick sequence of shale for accumulation of hydrocarbons.
7. In Figure 6 between Well N and O at a depth of 1,300-1,400 m, we find both structural and stratigraphic features were thick sand sediment is pinch out at Well N and O overlying by limestone which acts as a entrapment for hydrocarbons.
8. In Figure 6 at depth of 1,500-1,600 m, we observe major pinch outs such as limestone and shale overlying sand sequence, which acts as a trap following the structural closure for accumulation of hydrocarbons.

Selected References

Asquith, G.B., and C.R. Gibson, (eds.), 1982, Basic Well-log Analysis for geologists: Methods in Exploration 16, 216 p.

Griffiths, C.M. and S. Bakke, 1990, Inter-well matching using a combination of petrophysically derived numerical lithologies and gene-typing techniques, *in* A. Hurst, M.A. Lovell, and A.C. Morton, (eds.), Geological applications of wireline logs: Geological Society of London, Special Publication 48, p. 133-151.

Log	Property Measured	Units	Geological Uses
Spontaneous Potential	Natural electric potential(compared to drilling mud)	Millivolts	Lithology (in some cases), correlation, curve shape analysis, identification of porous zones.
Resistivity	Resistance to electric current flow	Ohm-meters	Identification of coals, bentonites, fluid evaluation.
Gamma-ray	Natural radioactivity-related to K, Th, U	API units	Lithology(shaliness), correlation, curve shape analysis
Sonic	Velocity of compressional sound wave	Microseconds/ meter	Identification of porous zones, coal, tightly cemented zones.
Caliper	Size of hole	Centimeters	Evaluate hole conditions and reliability of other logs
Neutron	Concentrations of hydrogen (water and)	Percent porosity	Identification of porous zones, cross plots with sonic, density logs for empirical separation of lithologies.
Density	Bulk Density (electron density) includes pore fluid in measurement	Kilograms per cubic meter (gm/cm3)	Identification of some lithologies such as anhydrite, halite, nonporous carbonates.
Dipmeter	Orientation of dipping surfaces by resistivity changes	Degrees (and direction)	Structural analysis, stratigraphic analysis

Table 1. Log types, properties measured, and geological uses.

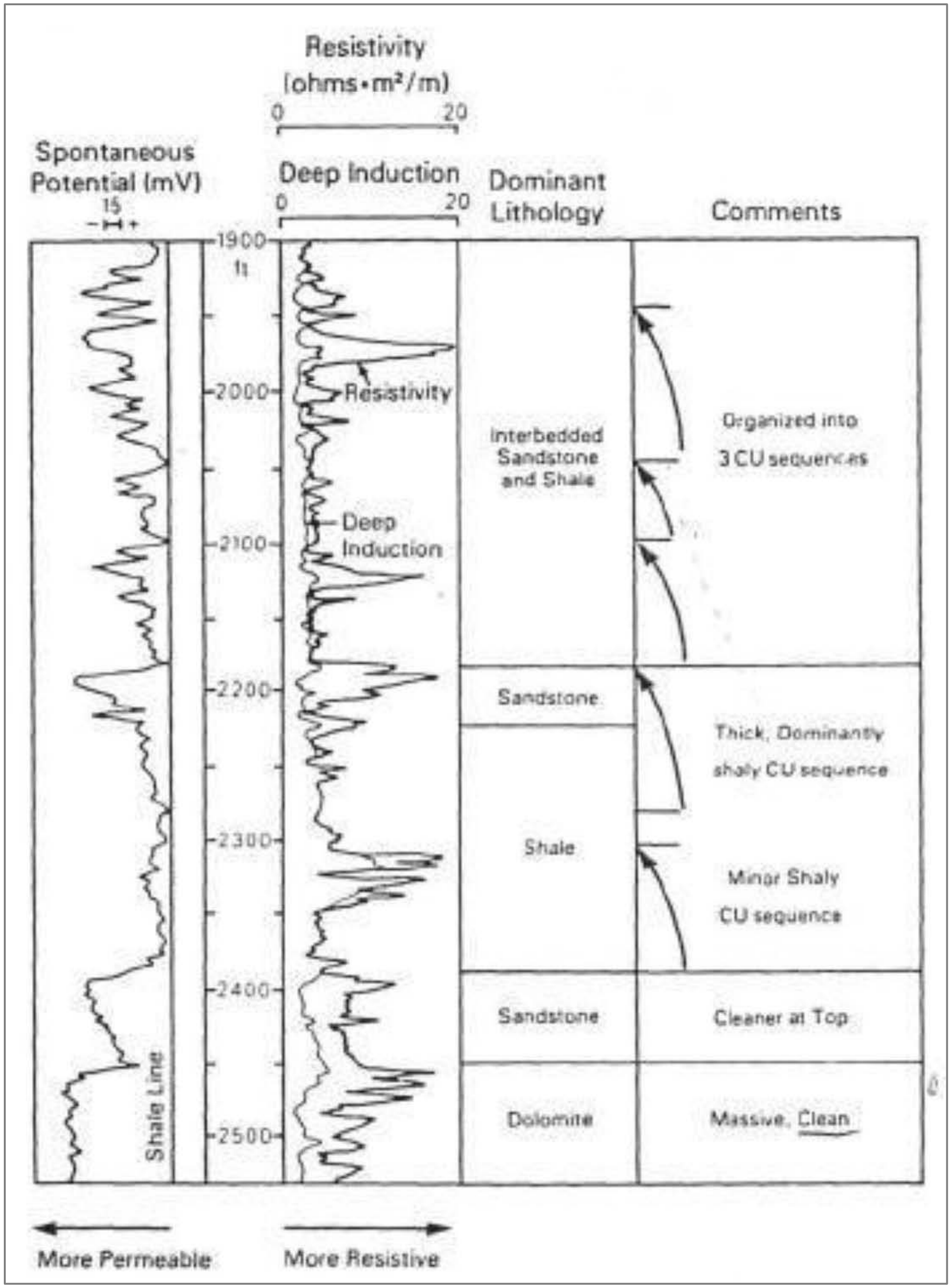

Figure 1. Study of lithology using log parameters.

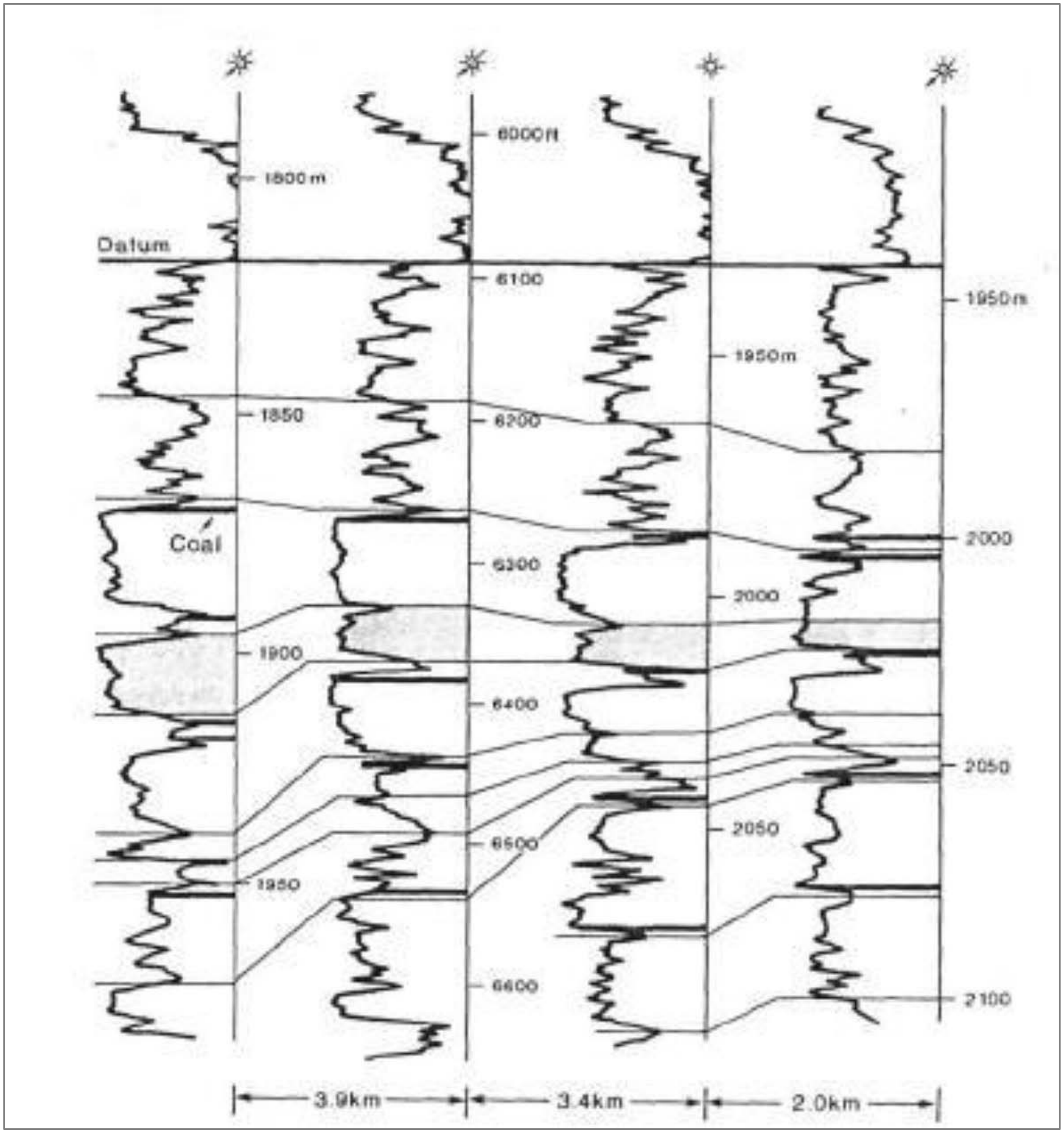

Figure 2. Correlation of vertical facies

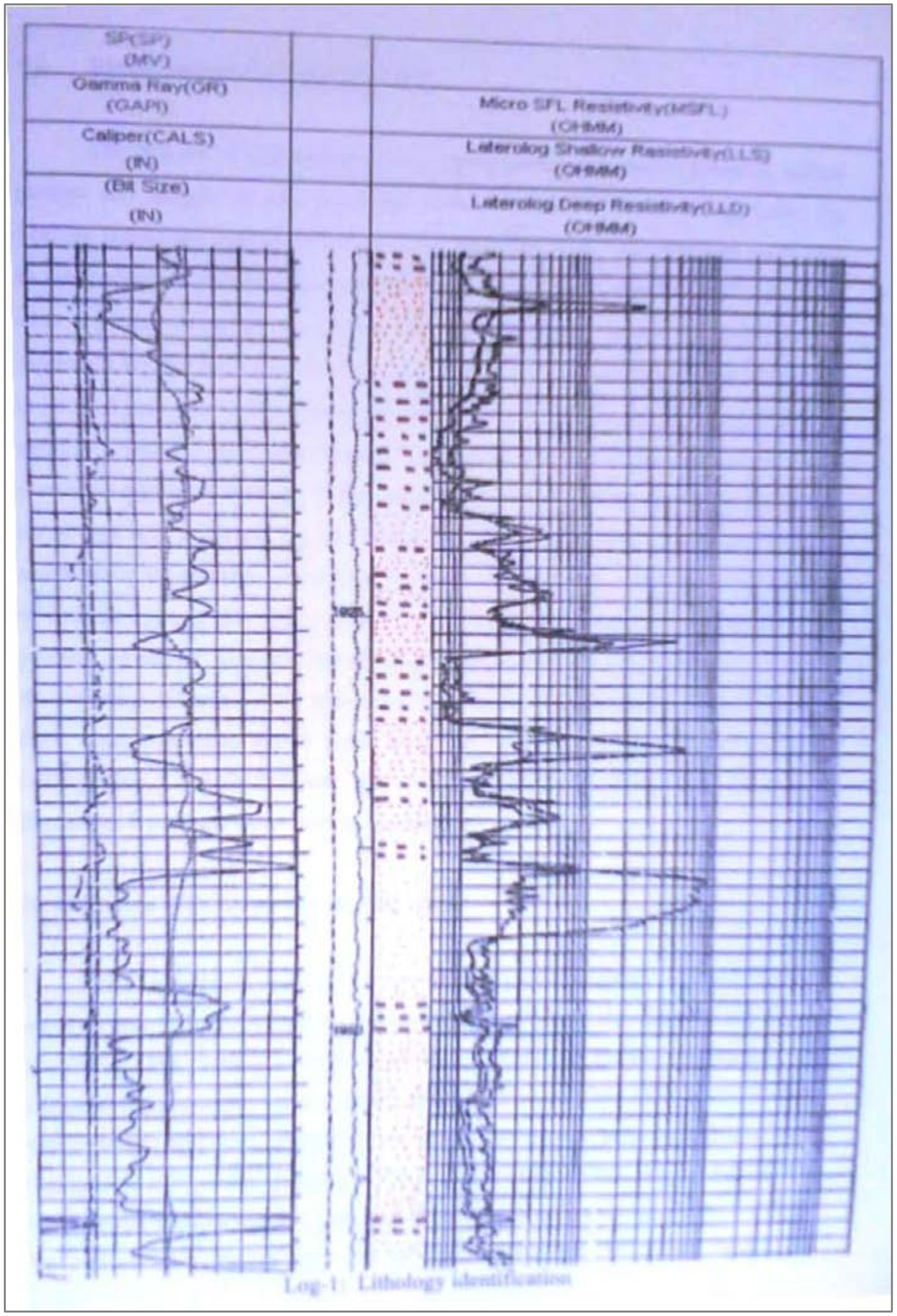

Figure 3. Lithology identification.

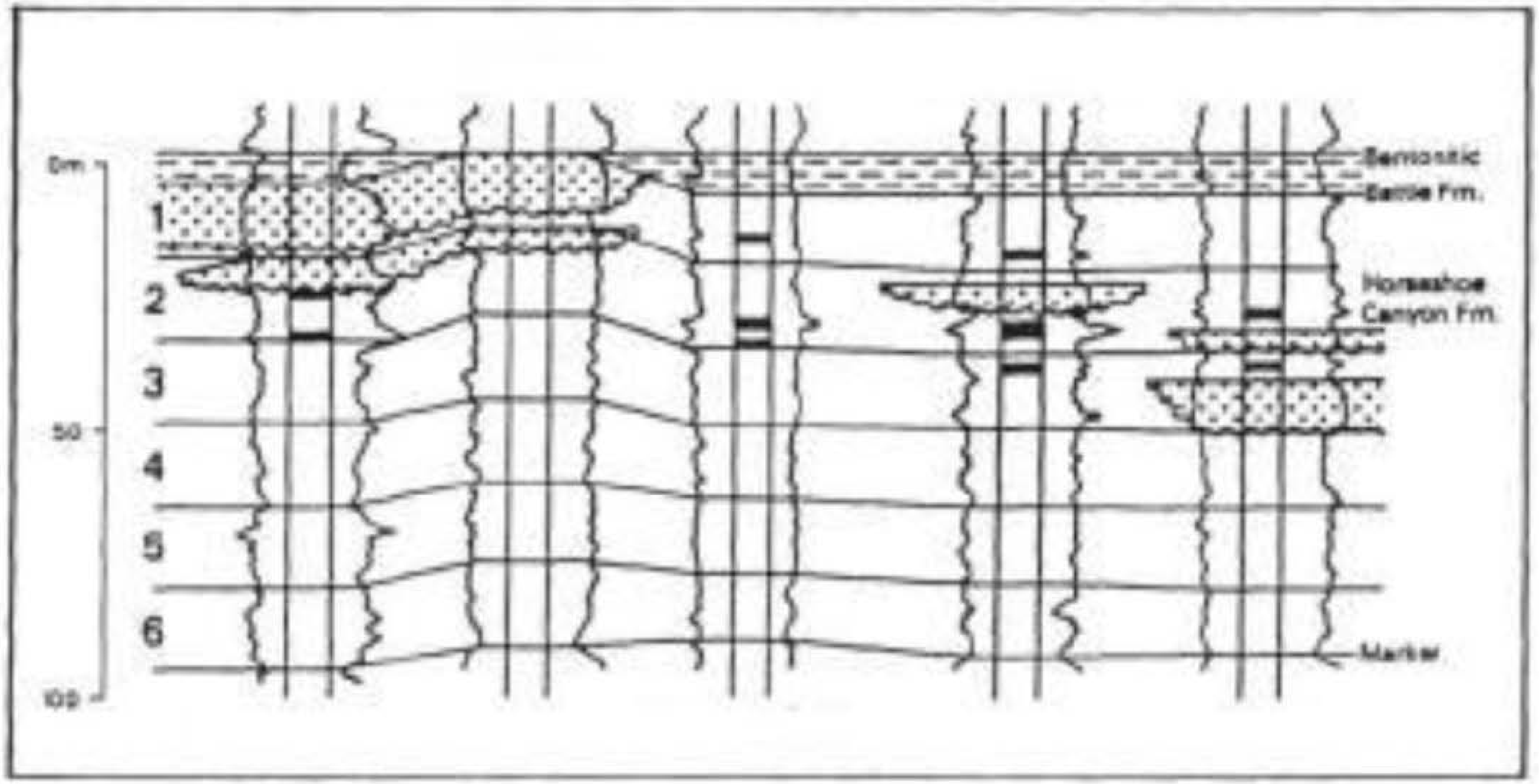

Figure 4. Facies variations across wells.

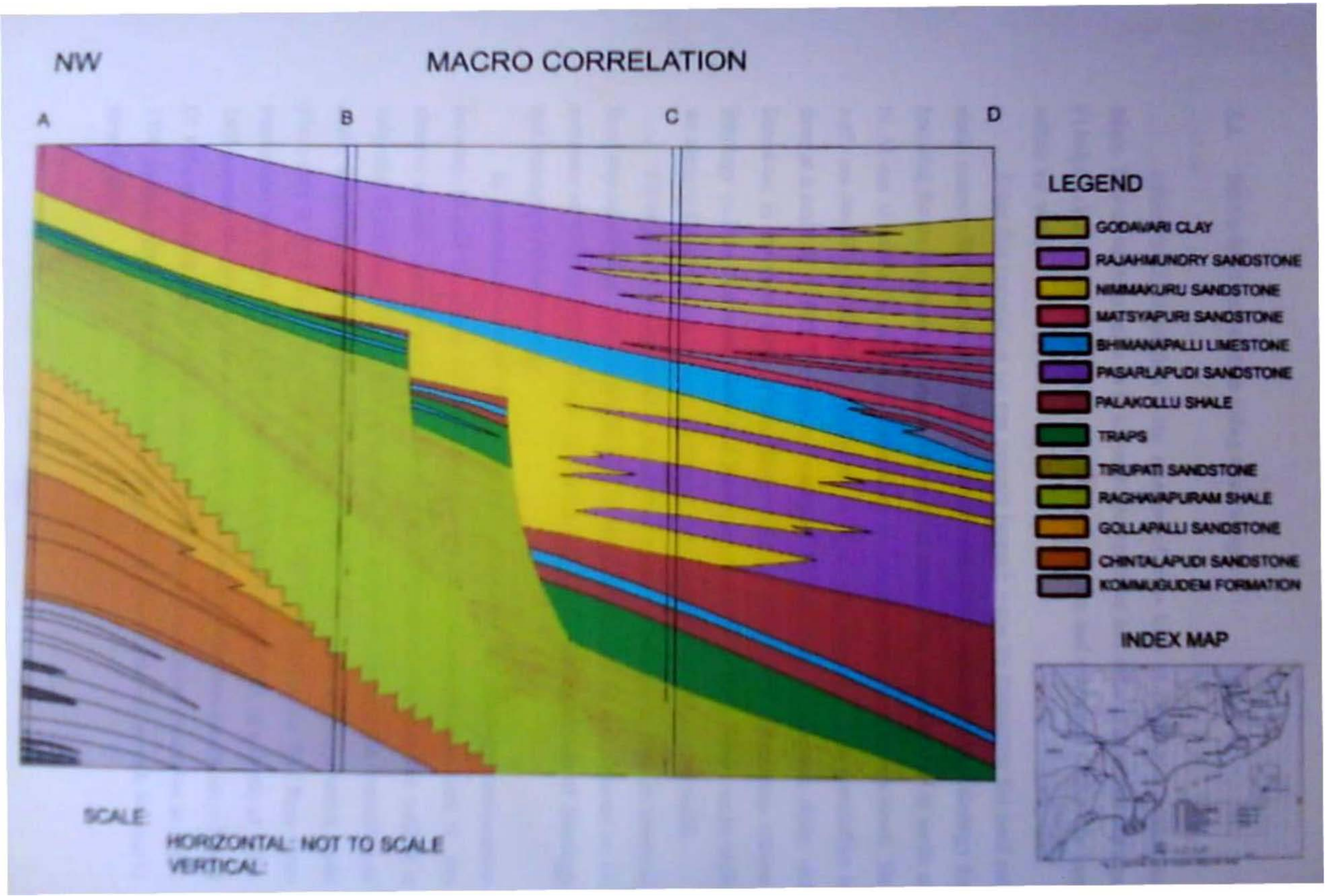

Figure 5. Macro correlation.

Figure 6. Micro correlation

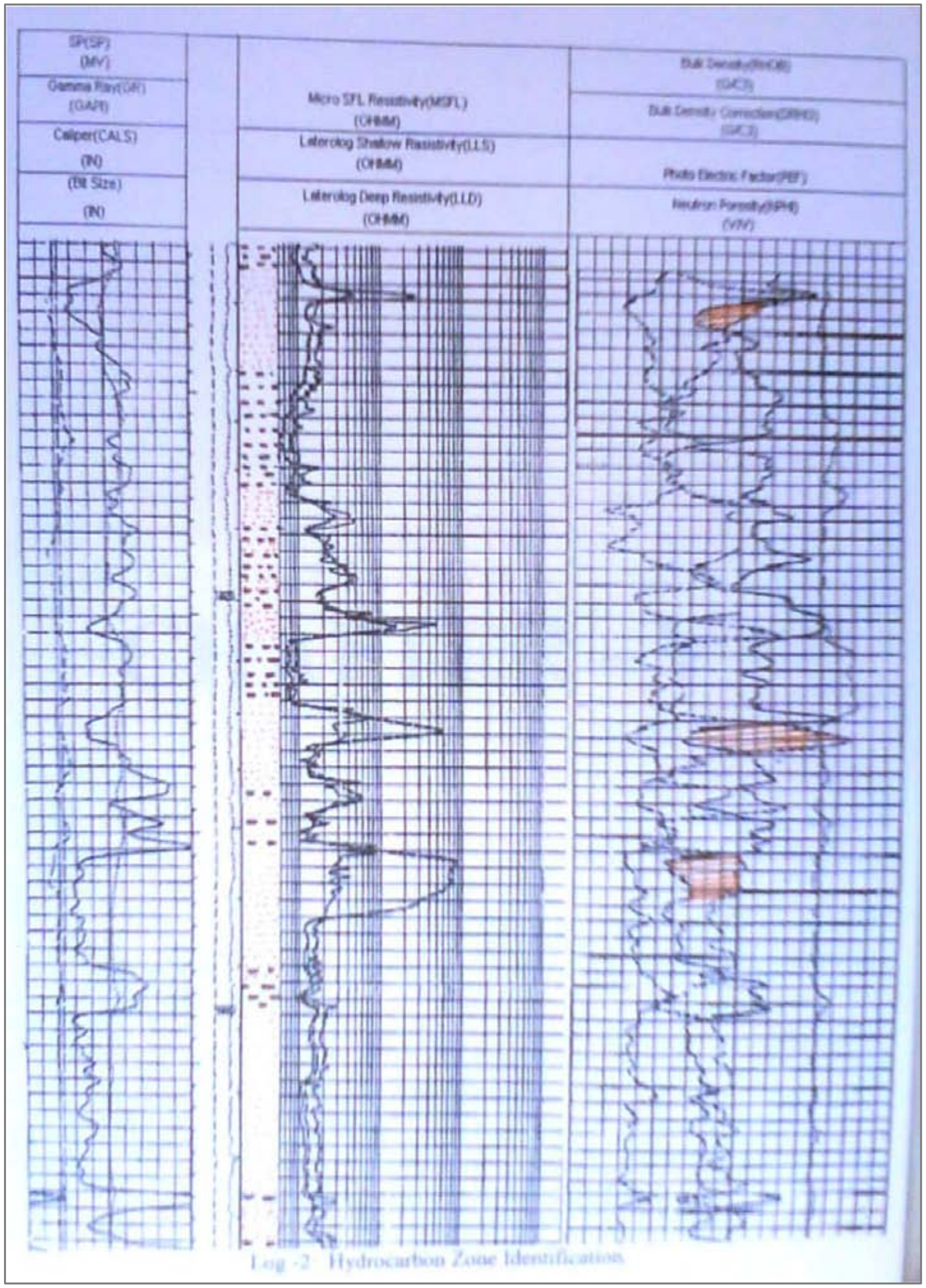

Figure 7. Hydrocarbon zone identification.