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WELL-SITE DIAGNOSIS OF THE STRATIGRAPHIC TOP OF AGBADA FORMATION FROM INTEGRATED PHYSICAL AND SEDIMENTOLOGICAL DATA: NW NIGER DELTA

C. Unuevho
Department of Geology, Federal University of Technology, Minna

Abstract

Accurate lithostratigraphic correlation is the key to the successful performance of a well - site geologist's crucial functions. The recognition of the stratigraphic top of the Agbada Formation is a pre-requisite for effective lithostratigraphic correlation in the NW Niger Delta. It is the Agbada Formation that contains the drilling objective sands in this portion of the Niger Delta. The lithostratigraphic interval is determined by diagnosing sedimentary environments, using integrated physical and sedimentological data. The physical data are formation natural radioactivity [expressed as gamma ray values], spontaneous potential, and resistivity and penetration rate measurements. The key sedimentological data is the presence of glauconite. The stratigraphic top of the Agbada Formation is fixed at the base of the fluvial continental lithofacies. This is automatically the top of the shallowest marine shales. This approach is easier than using the marine fauna method to define the top of the shallowest marine shales. Integrated physical and sedimentological data gives a more credible result because the top of the Agbada Formation is not a sharp boundary. Real time accurate correlation is facilitated if MWD [measurement while drilling] or LWD [logging while drilling] resistivity and gamma ray data are available.

Introduction

Critical functions of the well-site geologist include identifying the drilling objective sands by lithostratigraphic correlation, detecting the presence of hydrocarbons, identifying suitable shales to set casing shoes in, and detecting overpressure zones in real time. Correlation is stating that two or more lithostratigraphic sequences are equivalent in character and position.

In NW Niger Delta [Figs. 1,2], the drilling objective sands are contained in the Agbada Formation.

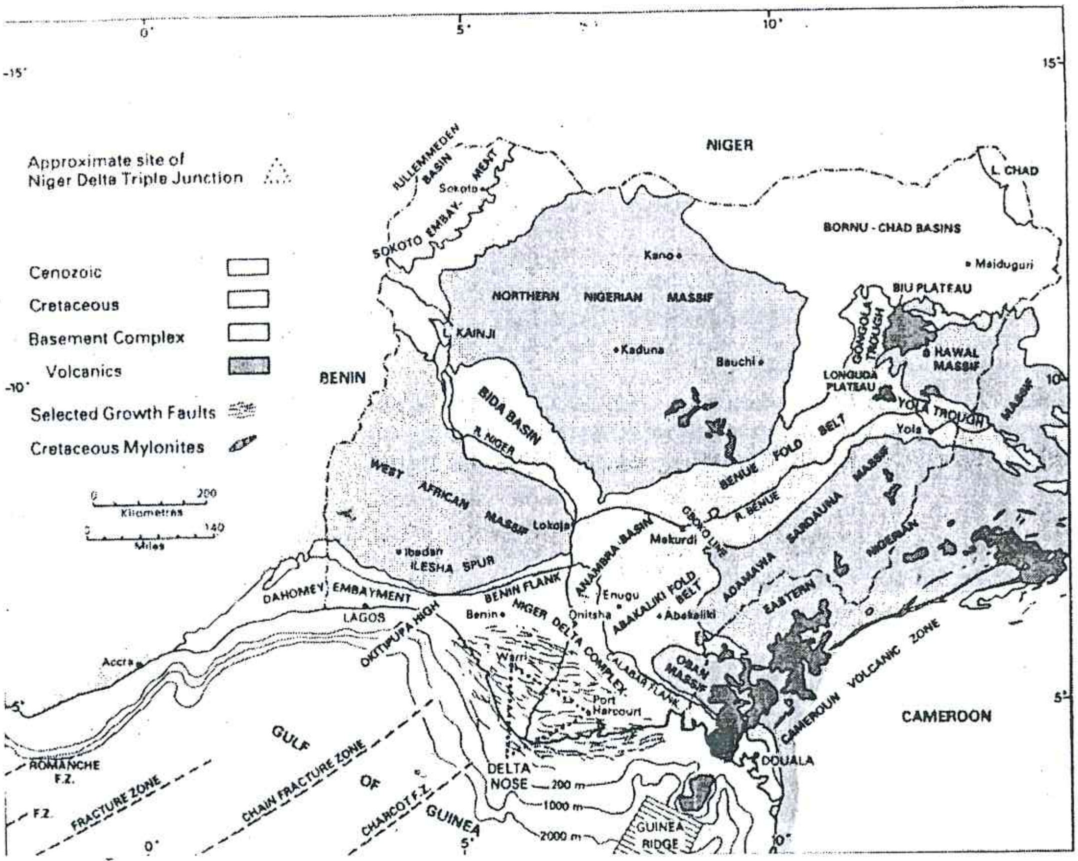


FIG 1: Generalized geological map showing Niger Delta and other main sedimentary basins of Nigeria. (After Whiteman, 1982).

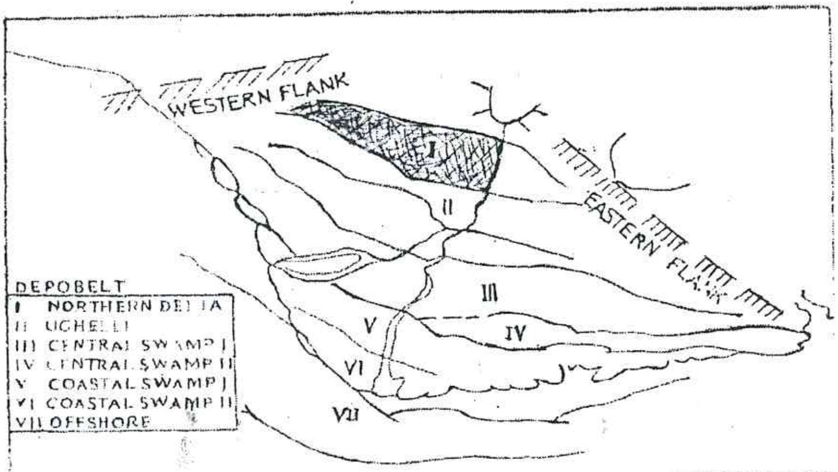


Fig.2: Schematic map showing NW Niger Delta as the western portion of the Northern Depobelt.

This is the stratigraphic interval from which all oil is produced in this part of the delta. Intermediate and deep casings are set in the shales of this interval. The lower portion of the Agbada Formation in this area commonly contains overpressure zones. Thus effective correlation at the well site hinges on accurate recognition of the stratigraphic top of the Agbada Formation. Doust and Omatsola (1990) states that considerable problems arise with the definition of the top of the Agbada Formation. It has often been misidentified at the well site, with the consequence of testing non-target sands for drilling objectives.

Results of well tests based on miscorrelations will give a false spatial distribution of reservoir fluid characteristics. Any reservoir development exercise anchored on such results cannot give optimum oil recovery from the reservoir. The time lost in correcting miscorrelations gives room for continuous mud invasion. This affects subsequent well-test results adversely. The downtime from the time lapse also affects drilling economics adversely.

Since lithostratigraphic sequences are produced by depositional environments, diagnosis of depositional sedimentary environments will facilitate the recognition of the stratigraphic top of the Agbada Formation at the well site.

The focus of this work is to demonstrate the methods for the identification of the stratigraphic top of the Agbada Formation at well sites in NW Niger Delta. This is achievable by diagnosing gross depositional environments using combined physical and sedimentological data.

Geological Overview

The Niger Delta sedimentary basin developed on the continental margin of West Africa in the northeastern end of the Gulf of Guinea [Fig I]. Its boundaries in its northwest, northeast and south are respectively the Benin Flank, Abakaliki fold belt and the Gulf of Guinea [Fig. I]. Its northwestern portion is an integral part of its Northern Depobelt, which is the northernmost and oldest of the six depobelts recognized in the basin [Fig. 2]. It consists of thick clastic sequences of Cenozoic sediments that rest upon thinner and deeper water Cretaceous facies, which in turn rests non-conformably upon a basement of transitional oceanic continental crust.
[Fig. 3].

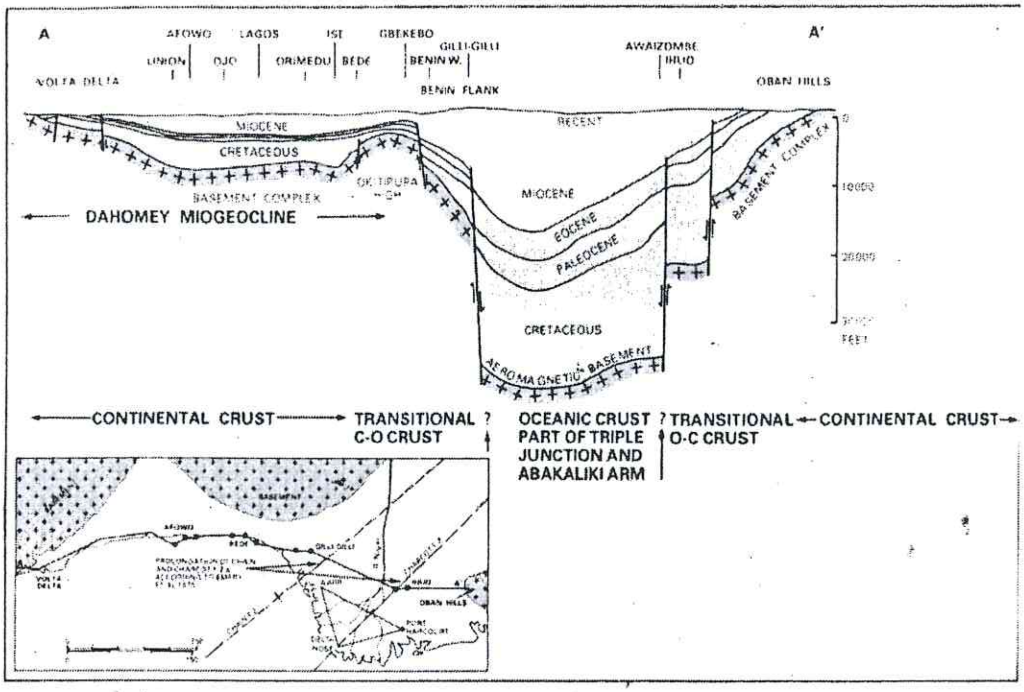


Fig. 3: NW (defined by Benin W, Gilli-Gilli and Benin Flank) on east –west generalised geological section from Volta delta through Dahomey miogeocline to Oban hills

(After Whitemen, 1982).

Three lithostratigraphic formations make up the entire sedimentary sequence: Benin Formation, Agbada Formation and Akata Formation with its Cretaceous sub-unit [Table. 1].

Age Range	Formation Name
L. OLIGOCENE TO MIDDLE MIOCENE	BENIN FORMATION
CRETACEOUS	AKATA FORMATION (LOWER)
L-M MIOCENE	AGBADA FORMATION
PALEOCENE TO UPPER EOCENE	AKATA FORMATION (UPPER)

Table. 1: Lithostratigraphy of Gilli-Gilli-1 as generalized schematic stratigraphic column for NW Niger Delta subsurface (Adapted from Udo and Ekweozor, 1985; Ozumba, 1997).

Akata Formation is the basal lithostratigraphic formation. In the northwestern Niger Delta, the age of this formation ranges from Upper Cretaceous to Upper to Eocene [Udo and Ekweozor, 1988: Ozumba 1997, Schlumberger 1985].

It is a continuous marine shale with minor deep-water sands and siltstones. It is commonly penetrated between 12000ft and 18000ft. The shales are soft, plastic, under-compacted and highly overpressured. The upper portion of the Akata shales produces oil, which either collects in their sand interbeds or migrates into the overlying Agbada Formation sands.

Different workers in the northwestern Niger Delta have dated the Agbada Formation differently: Schlumberger (1985) dated it Eocene, Udo and Ekweozor (1988) assigned Upper Eocene to lower Miocene to it, while Doust and Omatsola (1990) placed it within Late Eocene to Early Miocene.

Short and Stauble (1967) dated it Eocene in NNW Port-Harcourt. Its lithologic composition is a rhythmic offlap sequence of interbedded fluviatile, coastal fluvio-marine sands, sandstones, siltstones and marine shales. Successive offlaps are separated by a transgressive onlap phase of marine sands. The marine shales in the lower part of the Agbada Formation are source rocks. Most of the hydrocarbon is trapped by growth faults associated with rollover anticlines. The top of the Agbada Formation bottoms the Benin Formation.

The Benin Formation is formed in fluviatile continental environment. It consists predominantly of gravels and sands, broken occasionally by minor shale streaks and lignite fragments.

Methodology

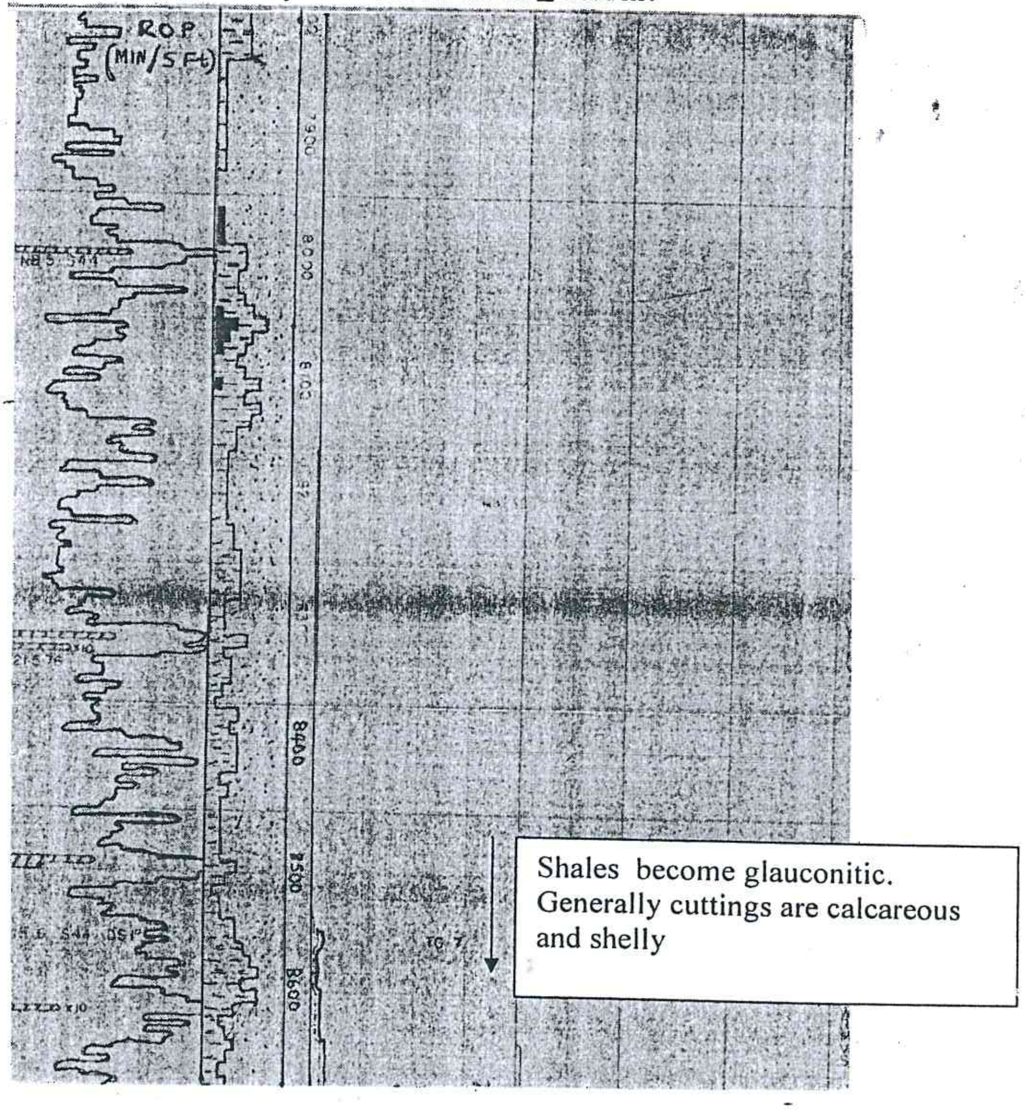
Wire – line [gamma ray – GR, spontaneous potential – SP, resistivity] logs, ditch cuttings and mud logs from four wells drilled in NW Niger Delta were analysed. The wells were renamed wells A, B, C, D to preserve their data confidentiality. Measurement recorded in wire - line logs and ROP log [rate of penetration, also known as mechanical log] were the physical data used. The ROP log data is an integral part of the mud log. Observations on ditch cuttings were the sedimentological data.

GR and SP log motifs and deflection patterns, degree of variations in GR readings in shales, and formation water resistivity [read in shales] were used in combination, to stratigraphically separate the continental environment's lithofacies. The presence of glauconite in sediments was used as a critical sedimentological data to separate the continental interval from the marine one. The stratigraphic horizon demarcating the continental interval from the marine one was taken as the stratigraphic top of the Agbada Formation. The combination of glauconite presence with log motif and deflection pattern, GR variation in shales and formation water resistivity constituted the primary tool for establishing the Agbada Formation's stratigraphic top [Cloud,1955; Short and Stauble 1967; Gribble, 1980; Schlumberger, 1985 and Selly,1985].

ROP data in conjunction with the abundance of calcite crystals and calcareous shell detritus in shales constituted the back up criterion.

Data Analysis and Discussion

In well A, the first appearance of glauconitic shale is at 8550ft, shown on its mud log [Fig 4]. Ditch cuttings below this depth are generally glauconitic, calcareous and shelly. From the depth's neighbourhood [precisely 8580ft] downwards, the composite log [Fig. 5] shows a shift in SP polarity from positive deflection in sandstones to negative deflection. The polarity changes from negative to positive deflection in shales. The composite log also frequently shows upward coarsening SP log motif from 8550ft downwards. At the same depth, formation water resistivity decreases markedly from ≥ 12 ohm – metre to ≤ 7 ohm – metre in shales. ROP values on the mud log [Fig 4] changes at the depth generally from ≥ 50ft /hr to ≤ 50ft/hr.

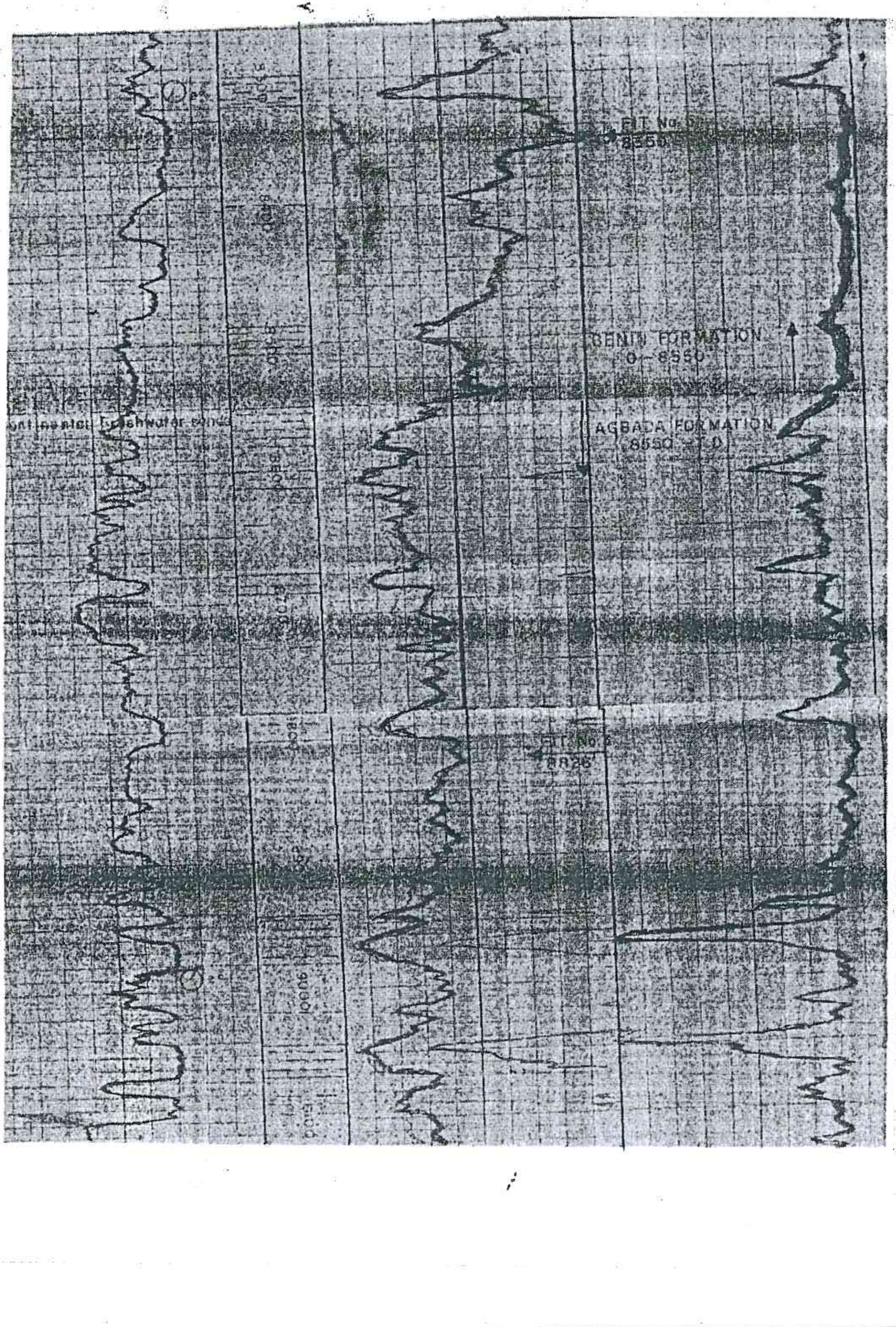


Shales become glauconitic. Generally cuttings are calcareous and shelly

Fig. 4: Part of Mud-log of Well A

SP (MV)	
-80.00	20.00

ILD (OHMM)		CONDUCTIVITY ILD (MMHO)	
2.00	20.00	0.00	2000.0



GR (GAPI)	
0.00	150.00

ILD (OHMM)		CONDUCTIVITY ILD (MMHO)	
0.200	200.00	2000.0	0.00

Well B's GR – ILD(resistivity) – CILD(conductivity) log [Fig 6] shows frequently alternating hot GR reading [high API values of shale deflection] and cold GR reading [low API values of sand deflection] from 8650ft downwards. Unlike shales above this depth, those below show little variations in GR reading [characteristic of clean shales] and low resistivity readings, generally ≤ 4 ohms – meter. Glauconitic shales appear first at 8650ft. From 8650ft downwards, GR log motif is generally upward coarsening (Fig. 6) while cuttings are frequently calcareous, shelly and glauconitic.

In well C, clean GR response in shales is common on its composite log [Fig. 7] from 8765ft downwards. This is accompanied by upward coarsening GR log motif, and a marked decrease in shale resistivity, generally < 7 ohm – meter. In this portion, shales and sandstones are frequently glauconitic, calcareous and shelly.

Well D's data from 8760ft downwards on its composite log [Fig. 8] and from its ditch cuttings observation, is similar to that from 8765ft downwards in well C. Well C and well D are in the same oil field.

The respective depths where log and sedimentological data began to show similarity is interpreted as the stratigraphic horizon marking the top of the Agbada Formation.

The GR and SP log motifs and deflection patterns in the Agbada Formation interval is due to its alternating sand – shale lithologic series. The series coarsens upwards from marine shales to neritic and littoral sandstones. The higher variations in GR response in shales of the Benin Formation are due to their higher heterogeneity than the marine shales of the Agbada Formation. The anomalous heterogeneity comes from miscellaneous materials [lignite fragments, silts, sands, carbonates] deposited with the shales turbulently in the flood plain at high flows.

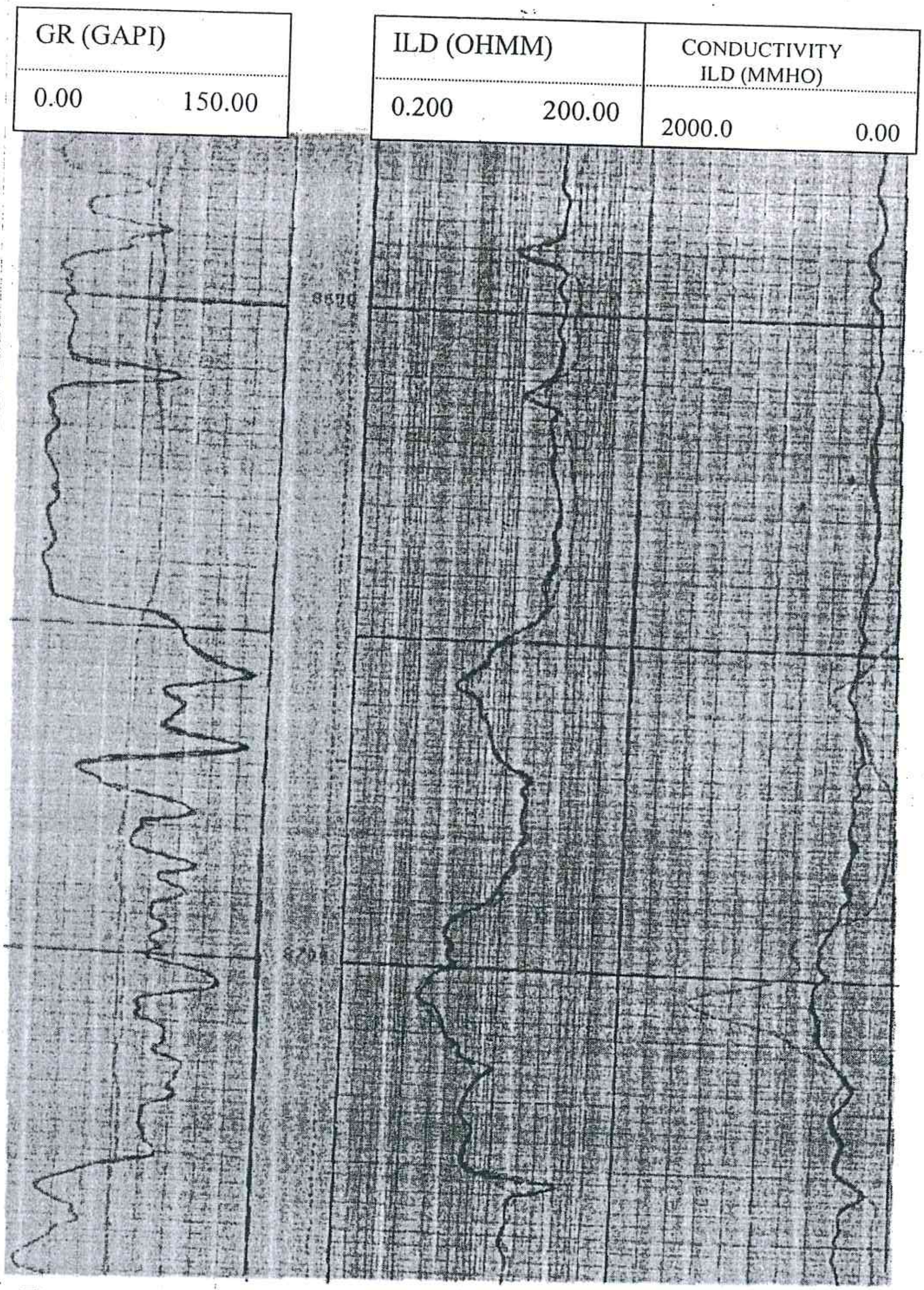


Fig. 6: Part of GR –ILD (Resistivity) – CILD (Conductivity) log for Well B.

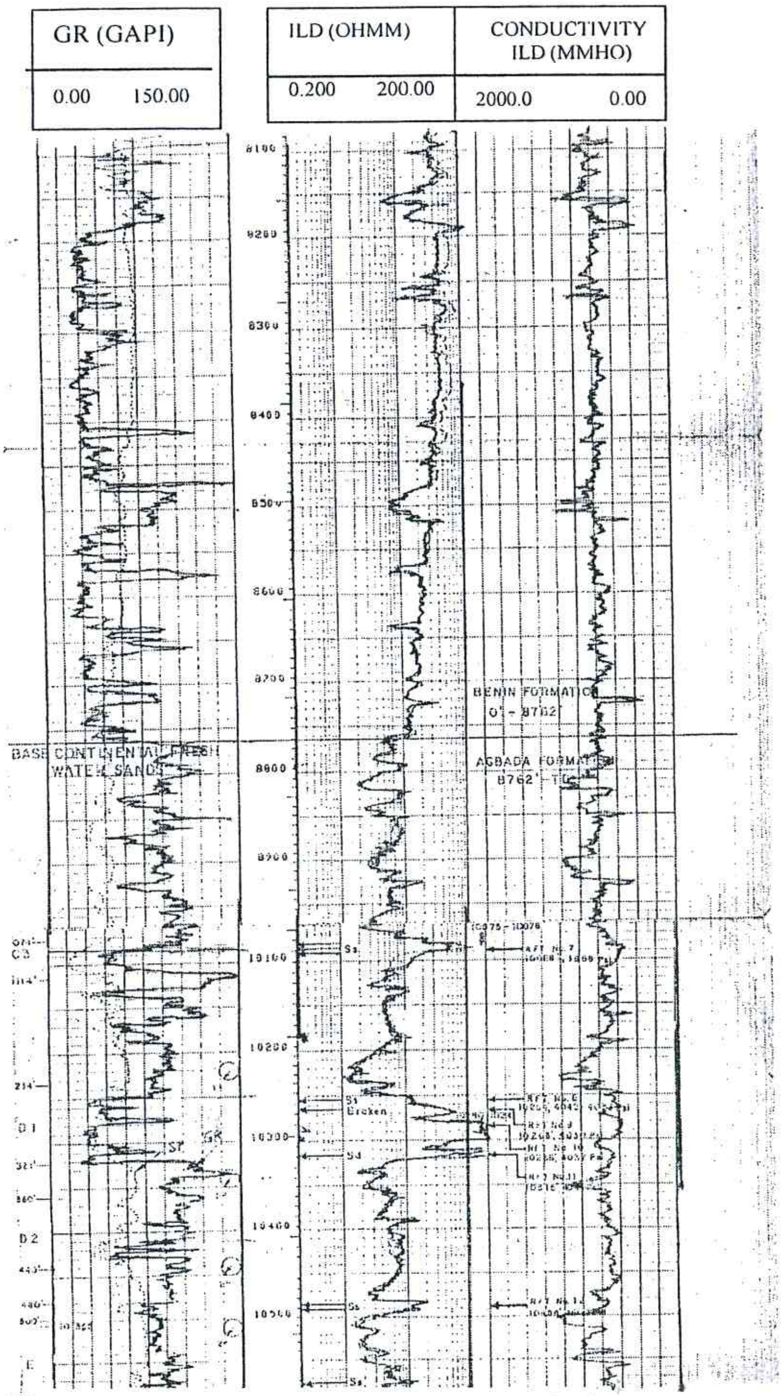


Fig 7: Part of Composite log of Well C.

The generally more homogeneous marine shales were formed by comparatively slow sedimentation in quiet water, where almost only clay comes to rest.

The association of glauconite with the shales indicates a slow sedimentation process. Gribbles (1988) and Serra (1990) stated that glauconite in a sediment indicates a slow rate of sedimentation. Homogeneity is cation controlled. Surface cations are generally limited to surfaces of suspended clay particles. On interacting with marine waters' ions, the surface cations flocculate only the clay particles. The flocculated particles are then deposited as clean marine shales.

The entire Benin Formation cannot contain glauconite because glauconite does not form in continental environments. Cloud (1955) stated that geochemical evidence suggests that glauconitic formation occurs in environment requiring marine water and reducing conditions. Serra (1990) stated that the presence of glauconite is considered a sound criterion of marine origin of the enclosing sediment.

The common presence of calcite crystals and calcareous shell detritus in Agbada Formation and their general absence in Benin Formation is because they dissolve easily in the somewhat acidic surface waters circulating through pores of the Benin Formation.

The sharp drop in shale resistivity from the Agbada Formation's stratigraphic top downwards, is due to change in formation water chemistry. The fresh formation water in Benin Formation makes its shales highly resistive, but increasing salinity in Agbada Formation water markedly reduces the shale resistivity. It is also the change in water chemistry that reverses SP log deflection as the bit crosses the base of Benin Formation into the Agbada Formation.

Conclusion

The stratigraphic top of the Agbada Formation type section was defined by Short and Stauble (1967) as the top of the highest shale bearing marine forams at Elele – 1, drilled 24 miles NNW of Port-Harcourt. The marine fauna only serves as a criterion for recognising a marine shale. The presence of glauconite is a more easily recognized marine index. Because glauconite recognition is time – effective, it is recommended as a routine criterion at the well site where the geologist's work pressure is high. Like many geological boundaries, the stratigraphic top of the Agbada Formation is often gradational. A credible and confident choice of the top in real time can only be made on the basis of integrated log and sedimentological data. Where MWD or LWD services are engaged, their data may be used in the same manner as wire-line log and ROP log data. Integrating them with observations on cuttings will facilitate early effective lithostratigraphic correlations at the well site.

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