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Research Article

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Ichnofacies Analysis of selected Wells in Niger Delta, Nigeria

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Abstract Bioturbation is the reworking activity by organisms in and around sediment surfaces and is a natural day to day and important process in the marine environment. This process brings about disruption and alteration to primary sedimentary lithologies, though commonly overlooked in the areas of reservoir quality assessment. In other to assess the effect of these reworking activities on reservoir quality (porosity and permeability), two core samples of approximately 32ft, recovered from the Miocene interval of the parallic Agbada Formation, located in the South-eastern offshore Niger Delta were subjected to conventional core/thin section analysis. The resulting datasets containing digital core images. petrophysical plug data and thin section reports. The results showed dominance of bioturbated lithofacies with the spread of the ruziana and Skolithos ichnofacie associations. It was revealed also that the cleaner sandstone facies have the best reservoir quality while the more bioturbated intervals of the entire cored sections had porosity and permeability values slightly higher than their rarely-lowly bioturbated counterparts.

Keywords Ichnofacies Analysis, Bioturbation

Introduction

Geologists have acquired extensive experiences studying trace fossils in outcrops with fewer ones having such experience with cores while almost none has been able to comprehensively use ichnofossils in cores to assess the quality of reservoir rocks..

Core samples unlike outcrop samples are expensive but give data that are accurately continuous and unweathered which the petroleum industries consider the best and most reliable source of data for determining paleogeography and paleoenvironment of deposits. Cores represent continuous, vertical succession of the subsurface lithologies that reveals detailed primary. secondary and biogenic structures, their intensities and distributions within cored intervals which when integrated, helps in the reconstruction of depositional environments as well as characterizing of reservoir qualities.

Location of Study Area

The study area is located in the Southeastern part of the offshore Niger Delta sedimentary basin of Nigeria between latitudes 4° and 4°30’N and longitudes 8° and B°30’E. It is bounded in the east by Cameroon, in the south by Gulf of Guinea and on the north by the Calabar flank.

Aims of this Research work

The aim of this research work is to carry out detailed lithofacies and ichnofacies identification of the core samples in order ascertain the effect of bioturbation on reservoir quality.

Review of the Ichnofacies Analysis of Niger Delta Sediments

The review of the studied Cenozoic sediments from the Niger Delta succession as conducted by various researching geologic groups have it that the sediments from the zone, have variations of both vertical (within well) and lateral (between well) types of bioturbation. The preserved sediments, range from virtually unburrowed sandstone to thoroughly bioturbated muddy sandstone within the cored Niger Delta successions, one particular trace fossil dominates over all others and that is Ophiomorpha nodosa [1], which was observed across the full range of near shore to distal offshore shelf zones. This burrow occurs in a variety of forms which include very large-scale forms at the maximum end of the documented size range for this trace. This pellet-lined burrow is today found over a range of near shore environment including lagoon and estuary floors, wherever the substrate consists mainly of sand-grade sediments.

In the Niger Delta sediment, the type of ichnofabric in which Ophiomorpha occurs can be used to help discriminate between shore face, estuarine and offshore sedimentary environ. This section summarizes the main ichnofabric observed in the depositional sub environment of the shallow marine delta [2] and [3]. Few trace of fossils are observed within the distributary channel (fluvial-dominated delta top) setting and few recognizable traces were observed within the deep marine canyon fill sediment due mainly to strong soft sediment deformation

The greatest diversity and abundance of trace fossils was seen within the shallow marine setting of the lower shore face to distal offshore shelf within the shore face to upper offshore deposit [4]. The observed variability in bioturbation was believed to be due to the distance from the active distributary channels which enhance water turbidity and rate of deposition. High depositional rates coupled with increased water turbidity at a river-dominated site on the delta front may produce completely or near un burrowed sediment. The lower delta plain comprises high to moderate energy sand-filled distributary channels and floodplain. interdistributary bay and swamp areas which are dominated by muddy fades. It is shallow water to emergent setting, with variable very low to high energy depositional conditions.

The Niger-Delta succession distributary mouth bar deposits generally occur within coarsening upward sequences, which shows an upward transition from muddy iriterdistributary bay deposits into cleaner very fine to medium-grained sands . The sands are dominated by unidirectional current ripple lamination and small-scale cross- lamination with common clay drapes and typically show only small-scale simple burrow forms of the Cruziana and $kolithos ichnofacies [5].

Primary laminations were typically poorly preserved in shore face sediments, which are composed of well-sorted very fine to fine sandstones [6]. The middle to upper shore face is a high-energy zone extending across the zone of shoaling and breaking waves and into the surf zone. Ichnologically, the shore face is typically associated with an assemblage of Ophiomorpha, Skolitlios. Conichnus, Diplocraterinn. Macaronichnus and Arenicolites.

In the upper shore face sediments from the Niger Delta, bioturbation ranges from moderate to abundant and is often characterized by a low diversity but moderate to high abundance of Ophiomijrpha [7]. In these deposits the Ophiomurpha burrow galleries are typically 1-3cm in diameter and can be lined or underlined with local spreiten laminae. In many cases there is generally a fairly uniform dispersion of Ophiomorpha traces suggesting that the amount at burrow overlap was low and that the sediments were deposited by relatively slow aggradations under moderately high hydraulic conditions [8] and [9].

The low diversity of burrow observed in these sandstones indicates a stressful environment, probably due to the high-energy conditions of the middle to upper shore face setting. The transition downward into the middle shore lace is marked by an increased in burrow abundance and burrow diversity. In many cases also the size of Ophiomorpha galleries and shafts decreases with the transition into a slightly lower energy setting. The middle shore face locally shows good preservation of storm layers which host opportunistic traces like Skolithos [10].

Materials & Methods of Study

The materials and datasets employed in this study /research work includes as listed below while the analysis were done in core lab.

- Petrophysical data of the proposed study well
- Location map of the study area.

- The well's core samples (for visual study)
- The core images of the study well.
- The photomicrograph/ thin section reports of the specific zones of interest.

Table 1: Summary of Niger delta Ichnufacies Broups (after Core lab research groups).

NIGER DELTA ICHNOFACIES ATLAS

MAIN DEPOSITIONAL ENVIRONMENT	ICHNOFACIES TYPES	OBSERVED TRACE FOSSILS
Delta Plain	Softground Scoyenia & Psilonichnus	The Scoyenia ichnofacies characterized marginal-marine settings and is typically represented by very rare simple tube-like burrows.
Tidal Channel & Back barrier Tidal Flat	Softground Psilonichnus & Skolithos/Cruziana	The Psilionichnus ichnofacies characterizes marginal-marine settings which show extreme variation in energy levels. It is typically represented mainly by low density vertical J and U burrows.
Trangressive Estuarine-Lagoon	Skolithos/Glossifungites	The Skolithos ichnofacies is indicative of relative high levels of wave and current energy, typically developed in slightly muddy to clean, well-sorted, loose or shifting sands. It is characterized by mainly vertical or U-shaped burrows, few horizontal structures, low diversity (although can be abundance of individual forms), mostly dwelling burrows of suspension feeders. The Glossifungites ichnofacies occurs within firmground substrates and characterized by vertical, branching or U-shaped burrows.
Foreshore Beach or Barrier Top	Softground Skolithos	
Upper Shore face	Softground Skolithos	
Lower to Middle Shore face	Softground Cruziana	The Cruziana ichnofacies is most typical of sub tidal, poorly sorted and unconsolidated substrates with moderate to low energy conditions. It is characterized by a mixed association of vertical, inclined and horizontal burrows; generally high diversity and abundance; mostly feeding and grazing structures of deposit feeders.
Offshore Marine Shelf	Softground Cruziana	

Method of Study

This study actually started when the cores arrived at the core laboratory and involved four basic stages and other sub stages which includes as follows;

- An initial core handing procedure on arrival at the laboratory
- Core preparation
- Core analysis
- Retrieved data study. Interpretation and final report presentation.

The Initial Handling of The Cure Samples:

This process involved a careful inspection of the cores to ensure no damages had been done to them during transit. Then laying out of the cores according to their respective depths, in guttering mounted on trolley for easy movement within the laboratory and then photographed under normal light using high resolution digital camera and finally exposed to core description.

Core Drying

Here the already cleaned core plugs were dried in a vacuum oven (to remove any residual fluid) at 85°C to avoid over heating and fracturing.

Core Analysis

The prepared core samples were at this point subjected to both conventional core analyses (Helium Porosity and Air permeahility) as well thin section analysis.

Helium Porosity

Porosity is the percentage storage capacity of a rock. It could both be calculated by summing pore volume and grain volume or by deducting grain volume from bulk volume, and can be mathematically represented as the ratio of pore volume/bulk volume in percentage.

Pore Volume

After grain volume had been measured, the samples were then individually placed in a hydrostatic care holder. Helium was then injected into the samples pore space and when helium was stabilized, the volume of the injected helium gas was then recorded.

Pore volume (Vp) = (Pi/P2) VrVr-Vi

Where:

Pi, P2 a Vr are the same as indicated above

Vi=volume of line connecting the care holder

Bulk Volume

Bulk volume of each sample was determined by adding the grain volume to the pore volume.

And porosity reported as percentage pare volume to bulk volume.

Air Permeability

Permeability is the measure of connectivity of pore spaces within a rock. This was calculated by loading each individual core plug of known length and diameter into a Hassler type core holder. Then subjected to a low confining pressure of about 15-20 bars to prevent gas flow around the plug sample. Air was then allowed to flow through the sample by applying a pressure differential across the sample. After which the flow rate and pressure [11].

Differential were measured, recorded and used to determine the sample permeabihty using Darcy's equation

$$Ka = \frac{211110 \text{ x Pa xii x Us xl}}{(PV-P22)xA}$$

Where

Ka = Permeability to air, mO

2000 = Orifice number

Pa = Atmospheric pressure, atmosphere

μ Viscosity of air, centipoises

The data obtained from the analysis were keyed into a computer system and graphical representations were made of them, using excel programme. More so the graphical pints were studied and the wells reservoir quality assessed with regards to the effect of bioturbation on it

Thin Sectioning

Thin sections were prepared for ten different samples but only three were allowed for use in the work to help in confirming the presence of bioturbation structures, composition and texture of the reservoirs. Here thin slices were cut with a diamond saw, then mounted on a plate and grinded to the correct thickness by means of successively finer and finer abrasive. The thicknesses were then checked by optical means.

Finally the sections were covered with a cover glass employing Canada balsam as a cementing material. The balsam was cooked fur about two minute at IBD°C until the heads were tenacious and solidified. The chips were warmed at 120°C for mounting. The sections were each viewed and photographed with the aid of a microscope under both plane and cross polarized light

RESULTS

Cores

Lithofacies Characteristics

Seven main lithofacies were identified in the overall cored sequence. These facies were described based on the lithologies. grain size, primary and biogenic structures [12]. This was done based on the classification and nomenclature scheme of [12] which follows the terminology proposed in the regional Niger delta study by Core laboratories in 1993.

The lithofacies classification shows that the cored succession has dominance of bioturbated lithofacies (with bioturbated sandstone, bioturbated muddy sandstones and bioturbated sandy mudstone) over unbioturbated ones. Also observed were dominance of sand rich facies over locally significant mud rich facies with a decrease in bioturbation as the sequence progrades from its lower muddy facie through cleaner sandy facies in core one while bioturbation increases from the lower cleaner and cross bedded sandstone facies to its upper muddy facies.

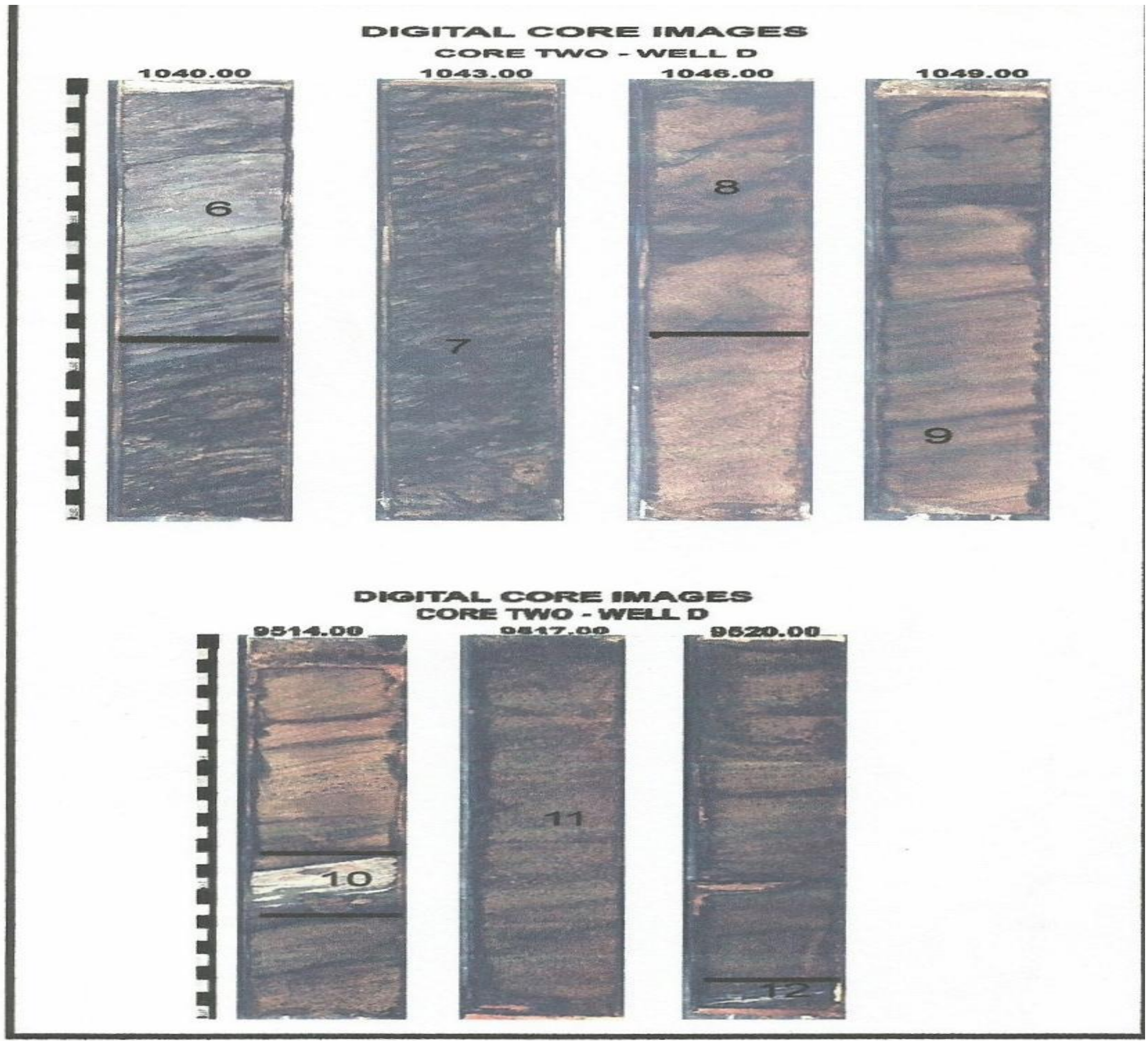

Plate 1: Core photograph

Laminated Sandstone Lithofacies

These are distinguished by their well developed parallel/sub parallel laminations. The locally laminated beds tend to grade vertically into units or beds with hurnmocky cross stratification (between depths D4BS and A464 feet's. They show minor to no bioturbation. Trace fossils include Skolithos and bivalve escape traces.

Muddy Facies

This association includes the muddy sandstone, silty mudstones and the sandy mudstone facies.

Ichnofacies and Interpretation

The ichnofacies identified overall the bioturbated cored succession comprise mainly the Cruziana assemblages. In the muddy facies. There was dominance of the Chondrites with local Teichichnus, Planolite and Xcnyenia, while the sandstone facies showed presence of Bivalve escape traces, Arenicolite, Ophiorniorpha. Asterosoma, Rhizocorallium and Skolithos associations suggesting deposits and traces of the range of shore face and channel environs. The presence of Asterosoma in both muddy and sandy facies only indicated that it is found in a wide range of environment.

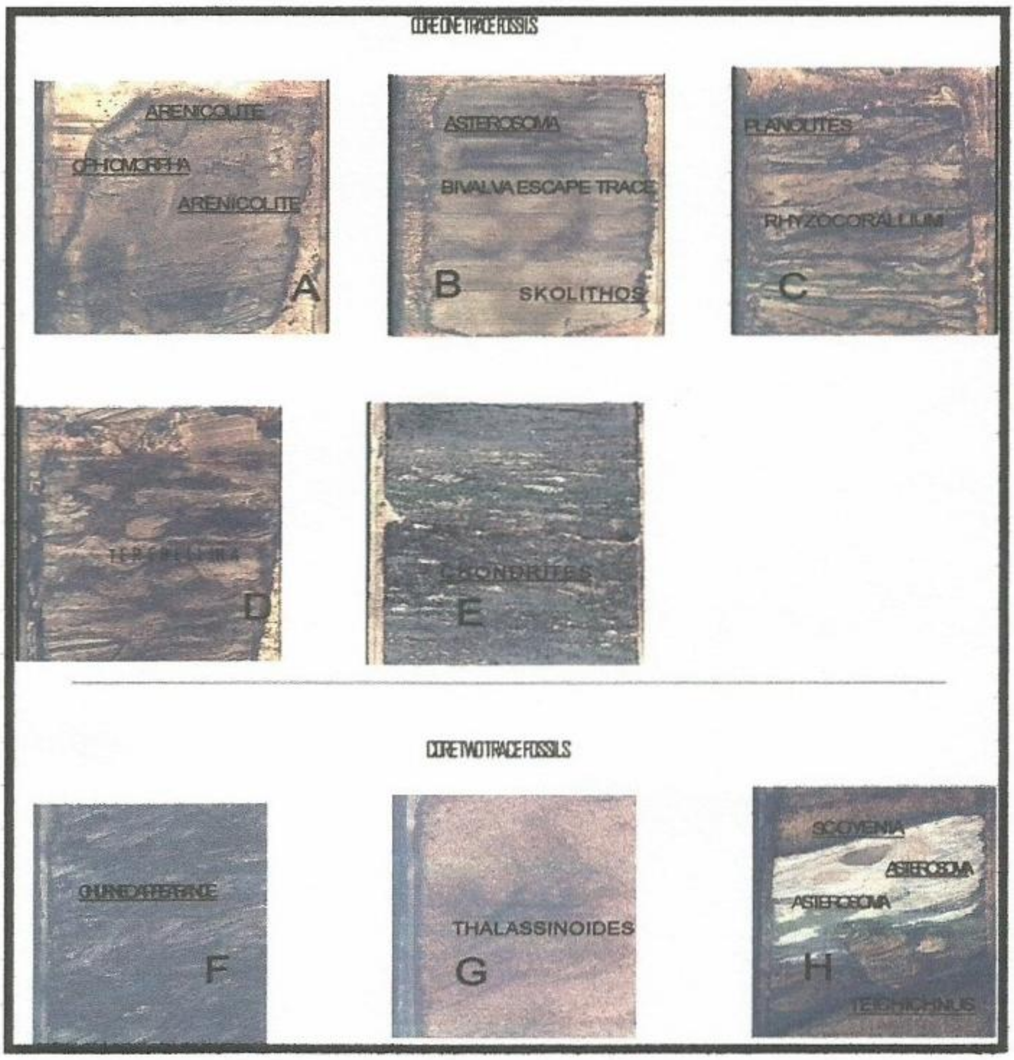

Plate 2: Visible Trace fossils Destroyed in the well of the core sample

Porosity and Variation Pattern

The porosity data for the plug samples from well show mainly very good to excellent values ranging from 12-32.3% with an average value of 28.9%. From the graphical plots it is observed that most samples fall within the range of 20-32.8% while only a few fell below 20%. The lower values correspond to the muddy facies [13].

Permeability and Variatidn Pattern

Permeability data of well shows values that range from locally poor to excellent ranging from as low as 2.D-BlBflmD with an average value of 2591.

The highest value correspond to the coarser cross bedded sandstone facies of core two, followed by the finer sandstone fades which occurs within core one sandstone of the variety of the shore face deposits. The remaining values fall below 4l5mD and is revealed to correspond to the muddy facies though there are also significant values that fall between 2.D-BBmD and they correspond to the finer grained sandy mudstnne facies that is almost churned in appearance.

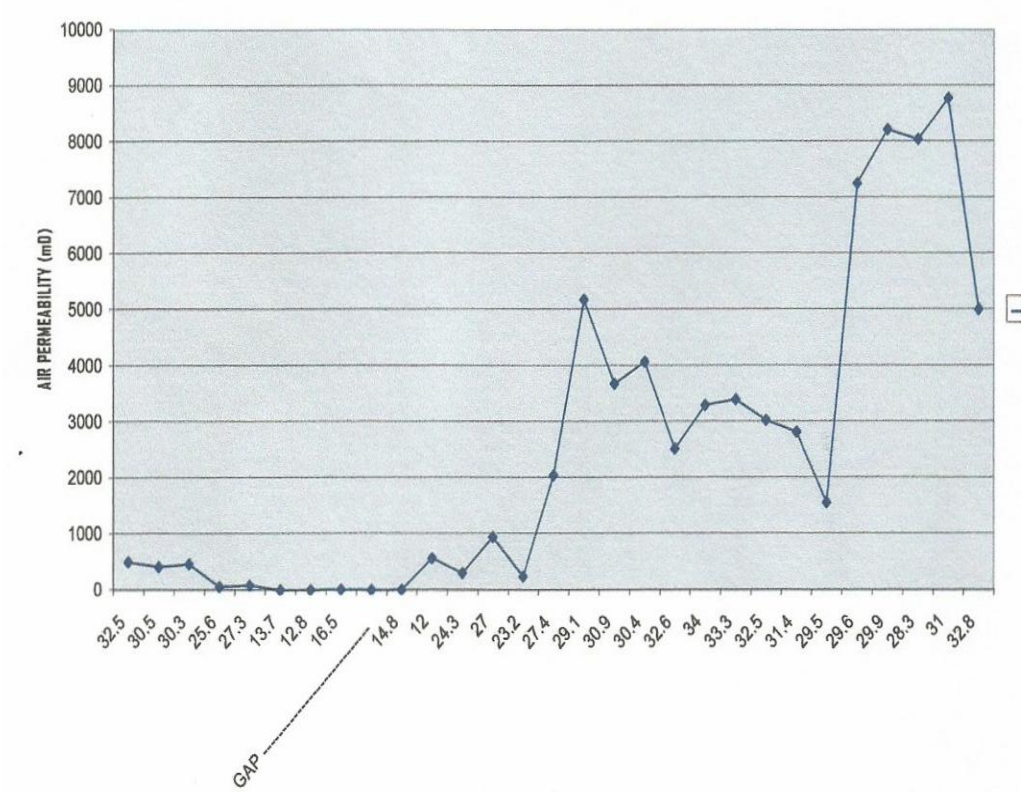

Figure 2: Porosity and Permeability Cross Plot

F Porosity/ Permeability Cross Plot

The graphical cross plot pattern shows a very good relationship between porosity and permeability for the sandstones in spite of the grain size variations with the lower permeability values corresponding to the muddy fades.

Lithofacies, Ichnofacies and Depositional Environments Against Porosity and Permeability

In integrating porosity and permeability with lithofacies, ichnofacies and depositional environments, it is revealed that there was a significant depositional control on reservoir quality. This is because the highest reservoir quality is seen to be associated with the cleaner sandstone facies within the cross bedded, bioturbated, wavy and hummocky bedded sandstones which is found within the shore face and estuarine depositional environments. While the muddy facies shows reduced reservoir quality due to the lower porosity and permeability values attributed to the presence of clay matrix within their pore spaces and its associated compaction and cementation effect.

Considering the ichnofacies, we have that the sandstone facies which represents middle to higher energy deposits typically have little or no bioturbation with less intensity while the finer grained sediments of the lower shore face and lagoon environments have more bioturbation with greater intensity. These deposits with more/intense bioturbation have higher values compared to their lowly to less intensely bioturbated facies

Thin Section Analysis Report

Thin sections analyses were carried out on plugs I from core one and plug 23 from core two. Both revealed dominance of quartz and feldspar as their framework minerals with detrital clays as their matrix except for plug I which has got some of its detrital clays replaced by siderite clay. Below are the photomicrographs and analysis report for the respective plugs.

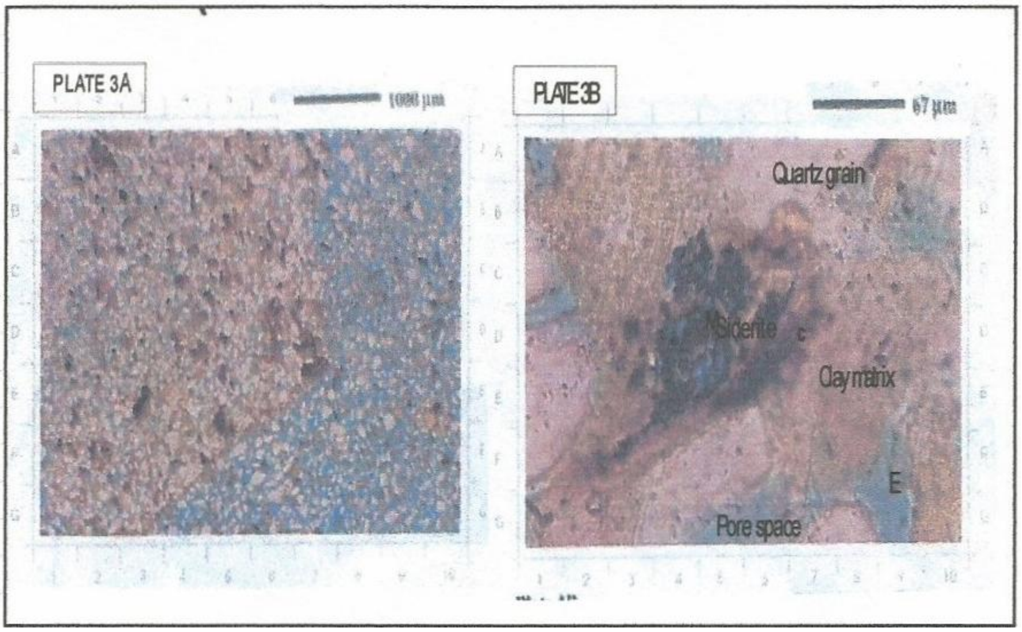

Plate 3: Thin Section Photomicrograps of the Core Plug

Plate 3: is the photomicrograph is the photomicrograph of a thin section taken from plug I of depth 9482.30 ft. It has —73% of quartz with-14% of feldspar as framework minerals and-5% detrital clay (burro-fills) as matrix though it seems to have been replaced by siderite clays. Porosity is excellent probably due to the presence of micro pore-spaces while permeability remains good despite the fine grain sizes and siderite patches which may act as mhior obstruction.

Discussion

Well core samples covers approximately 32ft with a gap separating them into core one and core two. Due to their textural trend, petrophysical and biogenic characteristics, a regressive sequence is inferred fur core one while a transgressive system is inferred for core two.

The study result reveals that the samples are dominated by the gruziana and Skolithos ichnofacies association within the sandstone facies, the finer grains are observed to have higher porosity values due to the presence of micro pore spaces while the coarser grained cross bedded facies are observed to have the highest and best permeability values. This indicates an inverse relationship existing between the porosity and permeability data of well [14] [15] and [16].

It was also revealed that the more bioturbated facies exhibited higher permeability and porosity when compared to their less bioturbated counterparts. Meaning that bioturbation has a positive effect on the reservoir quality and the entire core section were influenced by both textural and biogenic factors.

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