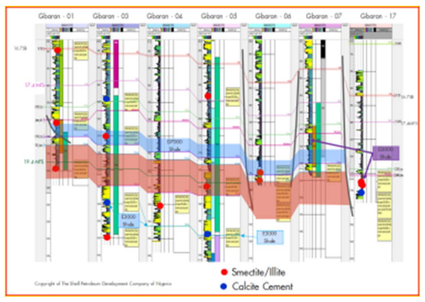
Formation Sensitivity Assessment of Gbaran Field A Study using XRD and Capillary Suction Time (CST) Analysis data.



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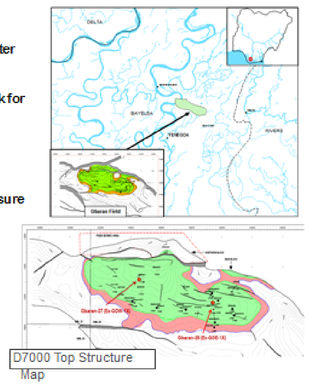
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OBJECTIVES AND DELIVERABLES

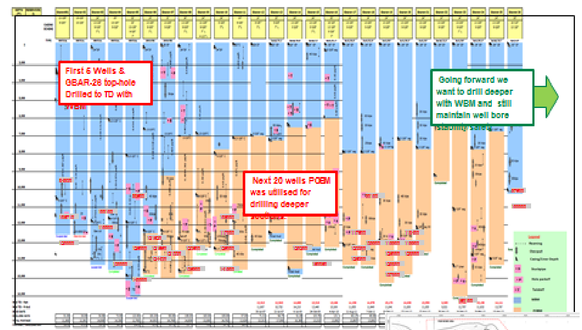
- Investigate the clay mineral distribution of the field and predict the spatial and temporal distribution of swelling clays (mixed layer Illite/Smectite)-Chemistry/Geology
- Understand the clay composition within the field with a view to select an optimal and economic drilling mud for drilling deeper intervals in the field – Chemistry /Well Engineering
- Verify that a new, environmentally friendly and more cost effective WBM (Water-Based Mud system) with 7% Potassium Chloride (KCl) would sufficiently sustain borehole stability- Chemistry and Well Engineering
- Deliver predictive occurrences of troublesome intervals across Gbaran field (illite/smectite & hard streaks/Calcite cemented intervals) with a view to faster drilling and saving costs- Geology

NIGER DELTA-GBARAN FIELD OVERVIEW

- ✓ located in the seasonal freshwater swamparea in OML 28
- ✓ Primary field providing feedstock for NLNG Trains 4,5 and 6.
- ✓ 758.1 MMBOE (2012 ARPR)
- ✓ Field reservoirs controlled by a simple hanging wall rollover closure
- ✓ The stack reservoirs range from early to middle Miocene age



BACKGROUND- DRILLING PERFOMANCE & MUD



- 26 wells have been drilled in the Gbaran field (27th currently being drilled)
- 5 of the earliest were drilled entirely with WBM while 20 were drilled with WBM

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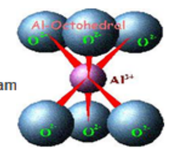
CLAY –DEFINITION& STUDY METHODS

Clay – Particle size

Clay Mineralogy Definition: the scientific discipline concerned with all aspects of clay minerals, including their properties, composition, classification, crystal structure, occurrence and distribution in nature.

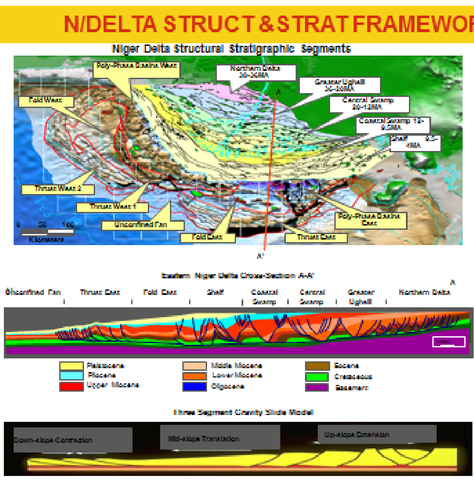
The methods of study include:

- X-Ray Diffraction
- Infrared spectroscopic analysis
- Chemical analyses of bulk and monomineralic sam
- Determinations of cationic exchange capacities
- - Electron-optical studies
- - Thermal studies by differential thermal analysis
- - thermo-gravimetric methods etc



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N/DELTA STRUCT & STRAT FRAMEWORK



CLAY MINERALOGY AND PROBLEM SHALES

Class	Characteristics	Clay minerals
1	Soft, highly dispersive (Gumbo), mud-making	High smectite some illite
2	Soft, fairly dispersive, mud- making	High illiite, fairly high smectite
3	Medium hard, moderately dispersive, Sloughing	High In ML illite, chlorite
4	Hard, little dispersion, Sloughing	Moderate illite, moderate chlorite
5	Very hard, brittle, no dispersion caving	High illiite moderate chlorite

Clay mineral classification

Clays	Shale s	H_2O (%) RH 60%	Mont -	Illiite	ML	chlorite
Anahuac	1	>4.0	40.0	5.5	-	-
Vermillion	2	-	25.4	42.0	-	6.7
Atoka	3	-	-	38.8	18.21	13.0
Midway	3	2.4 – 2.8	-	35.0	15.0	15.0
Wolf camp	4	1.5 – 2.0	-	14.8		3.2
Canadian Hard	5	0.4 – 1.0	-	48.3	-	8.3

Clay minerals percent in Problem Shales (O'Brien and Chenevert, 1973)

Fundamental Questions Relating to Clay Mineralogy of Shales

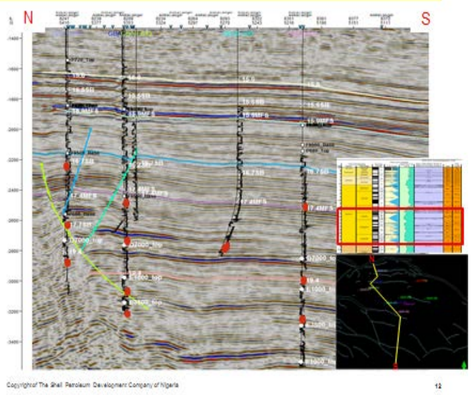
- Do Shales Swell (or Shrink) down hole *in situ* when interacting with drilling fluids?
- Do Shales act as semi-permeable membranes and promote osmotic flow?

Relevant clay mineral- Related mechanisms

- Interlamellar Swelling
- Cation Exchange and Increase of Osmotic Pressure
- Clay/Water Interactions

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STRATIGRAPHIC FRAME WORK- WITH SAMPLE POINTS



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CLAY MINEROLOGY – SHALE TYPES

KAOLINITIC SHALES

- Non-reactive clay mineral with respect to shale instability problems
- Kaolinitic shales highly unstable and KCl made does not help
- Failure mechanism is fluid invasion through micro-pores/fractures and mineralogical transformation

ILLITIC SHALES

- Non-swelling minerals, instability of not related to interlamellar expansion
- Exposed external surfaces have a higher charge density than that of smectite
- Thus, the instability of illitic shales is related to hydration and swelling in micro-pores in the same way as Smectite.

SMECTITIC SHALES

- Swelling shale
- Instability not related to osmotic swelling and computer simulated studies suggest that the one-layer hydrate is stable at depths down to 6 km.
- KCl and polymer treatment have high inhibiting effect on shale instability?
- Effect of mixed KCl and polymer solutions on smectite shales is due to the effect of shrinkage and encapsulation of the pore surfaces.

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CLAY MINERALOGY -PROBLEM SHALES

Solution	% Linear Swelling	Appearance	% Shale Recovery
Water	-	Total disintegration	1.5
10% $CaCl_2$	2.10	Partial disintegration	6.0
10% NaCl	2.00	Intact, easily crumbled	8.5
10%KCl	1.49	Intact, firm	46.0
10% KCl+Polymer	0.00	Intact, firm	91.6

Swelling and dispersion behavior of class 2 shale in various fluids (after O'Brien and Chenevert, 1973)

WBM: MIXED BY ITEM 5 - HIGH PERFORMANCE WBM

Key Components are:

- Deformable polymer forming a semi-permeable membrane
- Polyamine for Clay inhibition
- Aluminum compounds for plugging and inhibition of clay swelling
- Salt – Osmotic Effect

WBM: HIGH PERFORMANCE WBM SYSTEMS

3rd Generation – HPWBM –provide Shale Stability

Membrane effects: Reverse osmosis (low activity)

- Clay Stability
- Cuttings encapsulation
- High Rates-of-penetration
- Minimize Differential Sticking
- Torque and Drag reduction

INHIBITIVE WBM SYSTEM - KCl

Used as the bases of different mud systems

Provides shale inhibition using Potassium ion

Can be used in conjunction with NaCl

Benefits:-Inhibitive to many reactive shales

- -Fast penetration rates
- -Non- damaging to productive zones

Limitations: -May require supplementary shale stabilizers

- -

BACKGROUND- SAMPLE SELECTION

Sample Selection

- Depths of interest selected (SWS, Core & DCS) based on historically problematic sections
- Use of WBM while being envitally responsible could reduce well operations cost by ca, $1,000,000 p/well and engender sound environmental practice
- 48 samples from 16 wells selected and analysed (38 XRD/10 CST).

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BACKGROUND ANALYTICAL METHODS

- X-Ray Diffraction (XRD) is an analytical technique which reveals information about chemical composition, and physical properties of rocks. This analysis technique was used to obtain detailed composition of the clays and other minerals within the shales analysed.
- Capillary Suction Time (CST) testing is a rapid method for determining the sensitivity of small rock samples of varying salinities, including potential base fluids for fracturing systems. The technique provides numbers for use in comparing fluids. Water sensitivity and clay swelling control are tested for water based fluids.

CLAY MINEROLOGY

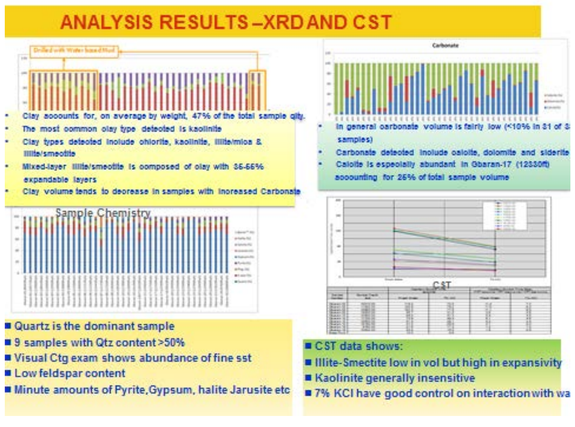


■ Clay Mineral Classification

Solution	% Linear Swelling (after 24 hr)	% Reduction (compared with H_2O)
Saturated KCl	0.56	79.0
3% KCl	0.94	64.0
3% NaCl	1.68	36.0
3% $MgCl_2$	1.83	30.0
3% $CaCl_2$	1.57	40.0

Swelling behavior of class 3 shale with polymer/salt solution (after O'Brien and Chenevert, 1973)

ANALYSIS RESULTS –XRD AND CST



- Clay accounts for, on average by weight, 47% of the total sample qty.
- The most common clay type detected is kaolinite
- Clay types detected include chlorite, kaolinite, illite/micas & illite/smectite
- Mixed-layer illite/smectite is composed of clay with 35-65% expandable layers
- Clay volume tends to decrease in samples with increased Carbonate

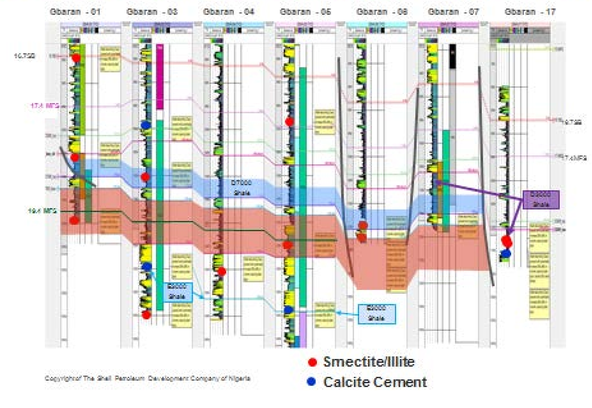
- In general carbonate volume is fairly low (<10% in 31 of 3 samples)
- Carbonate detected include calcite, dolomite and siderite
- Calcite is especially abundant in Gbaran-17 (12330ft) accounting for 26% of total sample volume

- Quartz is the dominant sample
- 9 samples with Qtz content >50%
- Visual Ctg exam shows abundance of fine sst
- Low feldspar content
- Minute amounts of Pyrite,Gypsum, halite Jarusite etc

- CST data shows:
- Illite-Smectite low in vol but high in expansivity
- Kaolinite generally insensitive
- 7% KCl have good control on interaction with wa

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STRATIGRAPHIC FRAME WORK AND MINERALOGY



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CONCLUSIONS

- Examination of the XRD and CST data indicates that these shales/sands are sensitive to fresh water.
- Kaolinite is most abundant but water-sensitive clay, mixed-layer smectite/illite, fairly low in volume is expandable (35%-55%).
- The use of 7% KCl additive (to drilling mud) reduces the clay/fluid interaction hence should be used whenever swelling clays are encountered.
- Susceptible intervals to watch are: Illite Smectite occurrences - C7000, D7000; Calcite Cementation – D7000, E3000 Tops
- Prediction of probable depths of occurrence before drilling possible and this can be integrated in the well engineering plan.
- Successful application has potential for cost savings in excess of $1M both in Rig downtime and cost of OBM.
- Good Environmental Management and commendation by the Department of Petroleum Resources

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RECOMMENDATIONS

- If drilling issues persist with the use of 7% KCl fluid or oil-based fluids, other factors should be considered as possible reasons such as:
- Use of additives that will help prevent clay dispersion and/or minimize clay-water interaction could help to evacuate cuttings more efficiently/faster.
- Drill bit type – The mineralogy of the samples are quartz/clay-rich with occasional carbonate presence therefore variable hardness. A drill bit should be chosen to accommodate potentially hard/soft sediments.
- Replicate study in other fields where further development is planned

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