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Intergration of Chemostratigraphic and Nannostraphic Characterization for Reservoir Studies in two Wells, Central Swamp, Niger Delta.

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ABSTRACT

Chemostratigraphy which is the use of elemental composition of rocks for subzonation and nannostratigraphy which involves the use of nannofossils for subzonation was used for reservoir studies of two Wells in the Niger Delta. Ditch cuttings from the two wells were used for the study. The major and minor elements were determined using Atomic absorption spectroscopy (AAS) and X-Ray Fluorescence (XRF). The Major and minor elements data was used to produce chemostratigraphic schemes for the studied Wells. Nannopalaeontological analysis was carried out on the samples and analysed for their fossils content in order to provide bio-data for nannostratigraphic age and sequence stratigraphic interpretation. The result showed that the sediments in the Wells were divided into the NN3, NN4 and NN5 corresponding to the Early to Middle Miocene. The elemental composition was also used to subdivide the Wells into five zones 1-5 with boundaries at 6900ft, 8000ft, 8400ft, 9400ft and 10200ft for Well 1 and 6750ft, 7650ft, 8200ft, 8800ft and 9,400ft for Well 2. At chemozone 5 dated 13.6 Ma, the elemental variation showed low TiO_2, low K_2O and high SiO2, at chemozone 4 dated 14.2Ma, the elemental variation showed high K_2O and low SiO_2, at chemozone 3 dated 15.6 Ma, the elemental variation showed low K_2O and SiO_2 and high Al_2O_3 and Sr/Ca ratio, at chemozone 2 dated 16.8Ma, the chemical variation showed low MgO and CaO while at chemozone 1 dated 18.0Ma, the observed chemical variation was high K_2O. The study employed the used of MFS and SB in determining the age at which particular chemoevents occur in the Niger Delta, this information could form a baseline and used when studying other Wells drilled in the Niger Delta.

Keywords: Chemostratigraphy, Nanostratigraphy, Reservoir Studies, Niger Delta.

1.0 Introduction

The elemental composition of sedimentary rocks can act as an important tool for resolving stratigraphic uncertainties that affect well-to-well correlation and facies analysis (Borman, 1997). Chemostratigraphy of sedimentary sequences requires the application of major and trace Elements geochemistry for the characterization and subdivision of sedimentary sequence into geochemically distinct units and correlation of strata in sedimentary basins (Craigie, 2015). Chemostratigraphic correlation is particularly applicable to sequences that have very poor stratigraphic control or very thick, rapidly deposited sequences that cannot be subdivided further by biostratigraphic data. Chemostratigraphic correlation can be carried out on a reservoir, as well as a basin wide scale for inter-well correlation. The major and trace element data generated for chemostratigraphic correlation purposes can also be applied to studies on provenance and basin evolution, diagenesis, reservoir characterization and interpretation of wireline logs (Calvert & Pedersen, 1993).

For this study, Chemostratigraphy was applied for Well subzonation, interpretation of depositional environments and integration with nannofossil data.

1.1 Aim of the study

The aim of this study is to determine the geochemical composition and geochemical zonation of the sediments in two wells in the Niger Delta and correlate these zones across the wells.

2.0 Literature Review

Craige (2015) in his work titled "Application of Chemostratigraphy in Cretaceous Sediments encountered in the North Central Rub' Al-Khali Basin, Saudi Arabia" carried out an inorganic geochemical studies on Core samples and ditch cuttings of Cretaceous sediments drilled from eleven Wells in the Rub' Al-Khali Basin, Saudi Arabia. The aim of the study was to generate a chemostratigraphic scheme for the Wells in comparison with existing lithostratigraphic schemes. The Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) and Inductively Coupled Plasma Optical Emission

Spectrometry (ICP-OES) was used to acquire data for the study. The Chemostratigraphic analysis was done based on data from 50 elements and ratios of key elements such as CA, Al, Zr, P/Y, Zr/P, Zr/Y, Zr/Nb, Mo and Zr. An Hierachical order of five zones, eighteen sub zones and four Divisions. The zones were given the labels C1,C2,C3,C4,C5 in ascending stratigraphic order. Definition of these zones was based on the changes in Al and Ca which shows a variation in bulk lithology in response to base level. The zone C1 was characterized by raised amounts Aluminium (Al) and reduced Calcium (Ca) representing mudrocks deposited in a lagoonal-prodelta environment. There was a surge in the base level enabled the formation of very high calcareous rudistic limestones in shallow marine environments this zone was labeled zone C2, as the base level increased there was still the deposition of calcareous mudrocks very high in Aluminium, this zone was labeled Zone C3. Zone C4 was marked by rudistic limestones that showed high values of Calcium and low values of Aluminium that were deposited in shallow marine environments, the zone C5 contained numerous mudrocks and argillaceous limestones deposited in a prodeltaic environment. Very subtle changes in bulk lithology were also modeled using P/Y, Zr/Y, Zr/P and Zr/Nb ratios, these helped to define the subzones. The study showed close linkage between the chemostratigraphic and lithostratigraphic correlations with the chemostratigraphic correlation showing higher resolutions.

3.0 Methodology

Ditch cuttings from two wells labelled 1 and 2 from the Niger Delta basin were used for this study, major and minor elements were determined using Atomic absorption spectroscopy (AAS) and X-Ray Fluorescence (XRF). The Major and minor elements data were used to produce chemostratigraphic schemes for the studied Wells. Production of chemostratigraphic schemes was done according to Craigie (2015) which includes plot of profiles for major and trace element, Aluminium normalized data plot for major and trace elements, a plot of profiles for ratios is carried out after which a suitable horizontal and vertical scale is chosen, identification of 12-14 key elements and ratios which would be applied for chemostratigraphic purpose, it is pertinent to ensure that the key elements show significant trends that can be used to identify chemozones, three or more chemozones are delineated and are thereafter checked to ensure that they correlate between study sections and finally the identification subzones in each zones.

Lucas *et al.*, (2016) applied chemostratigraphic techniques to determine the major and trace element ratios of drill cuttings from Goml-1 well, Benin flank of the Northern Niger Delta Depobelt. These elemental ratios were used to determine the environment of deposition of the sediments along varying depths and sections of the well. The samples were analysed using Atomic absorption spectrometry (AAS) with the K:Mn and Na:Zn ratios data obtained were plotted against depth.

Nannopalaeontological analysis was carried out on a total of two hundred and eighty (280) ditch cutting samples; one hundred and eighty (180) samples obtained from Well - 1(Intervals 6000 - 12000ft) and one hundred (100) from well – 2(intervals 5760 – 9360ft). These were processed for nannopaleontology and analysed for their fossils content in order to provide bio-data for nannoplanktons age, sequence stratigraphic and palaeoenvironmental interpretations for the wells

4.0 Results

4.1 Chemostratigraphic scheme of Well 1

Major Oxides Chemostratigraphic Plot for Well 1

Major elements and major element ratio profiles was plotted for Well 1, using the values of major oxides obtained from chemical analysis. The elements and element ratios represented are SiO_2, Al_2O_3, TiO_2, TiO_2/Al_2O_3, MgO/Al_2O_3, Na_2O/Al_2O_3, CaO, MgO, CaO/Al_2O_3, Cl, SiO_2/Al_2O_3, K_2O, Fe_2O_3/K_2O, Fe_2O_3/MgO, Na_2O, CaO+MgO, Fe_2O_3, MnO. Figure 1 shows the plot of the variation of these elements in the sediments at different intervals across the Well.

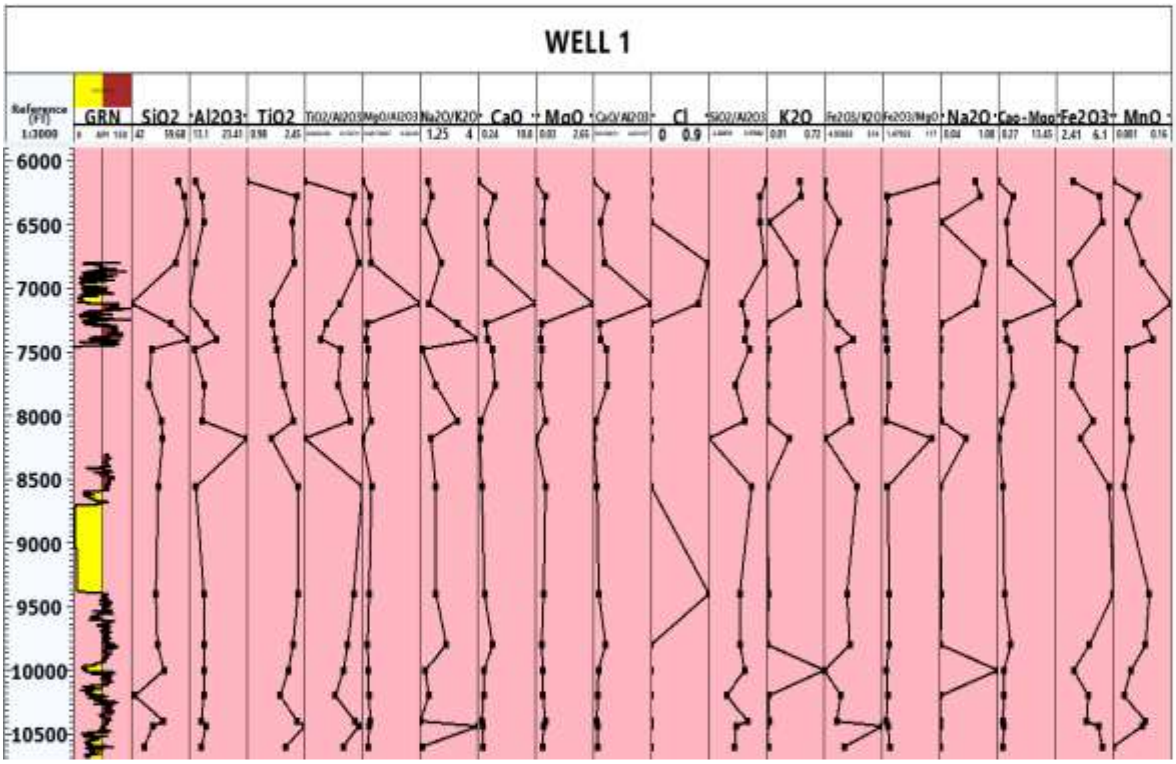


Fig 1: Major oxides Plot of Well 1

Minor Oxides plot of Well 1

Minor elements and minor element ratios profiles were also plotted for Well 1 using the values of minor oxides obtained from chemical analysis. The elements and elements ratios profiles plotted included Ba, Cr, Cu, Ga, Pb, Rb, Rb/Sr, Sr, Sr/Ca, V, ZnO, Zr. Figure 2 shows the plot of the variation of these elements in the sediments at different intervals across the Well.

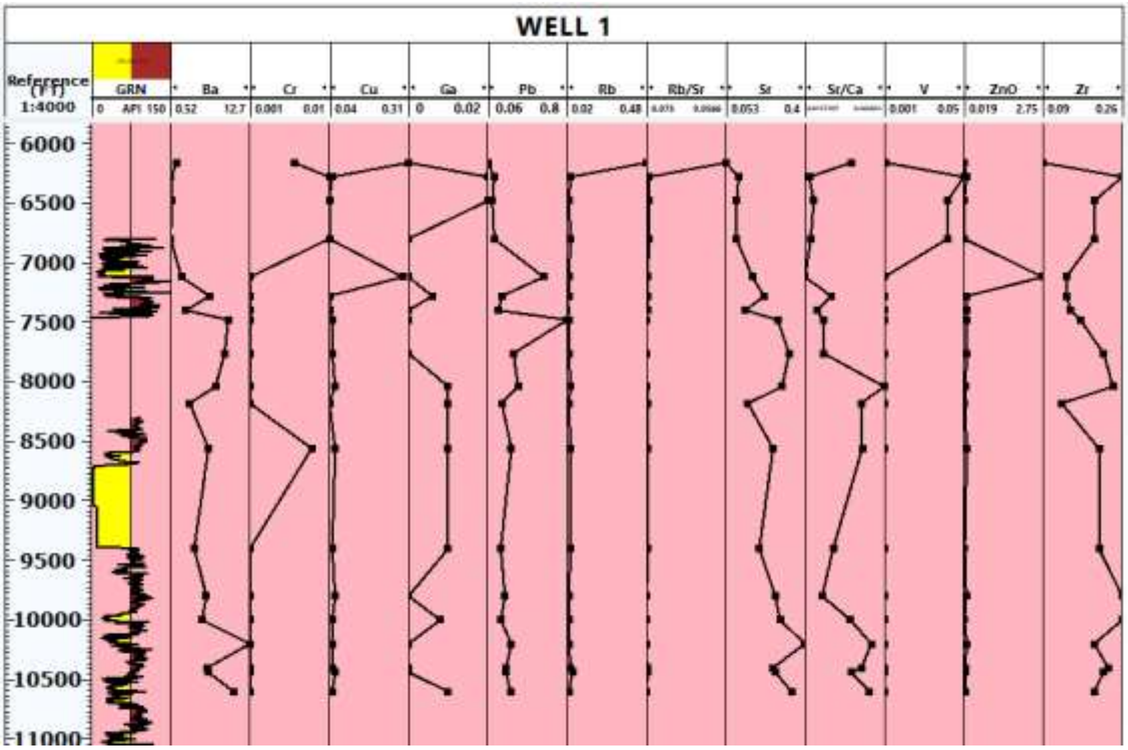


Fig 2: Minor Elements Plot of Well X1

Major oxides Chemostratigraphic plot of Well 2

Major elements and major element ratio profiles were plotted for Well X2, using the values of major oxides obtained from chemical analysis. The elements and element ratios represented are SiO_2, Al_2O_3, TiO_2, TiO_2/Al_2O_3, MgO/Al_2O_3, Na_2O/Al_2O_3, CaO, MgO, CaO/Al_2O_3, Cl, SiO_2/Al_2O_3, K_2O, Fe_2O_3/K_2O, Fe_2O_3/MgO, Na_2O, CaO+MgO, Fe_2O_3, MnO. Figure 3 shows the plot of the variation of these elements in the sediments at different intervals across the Well.

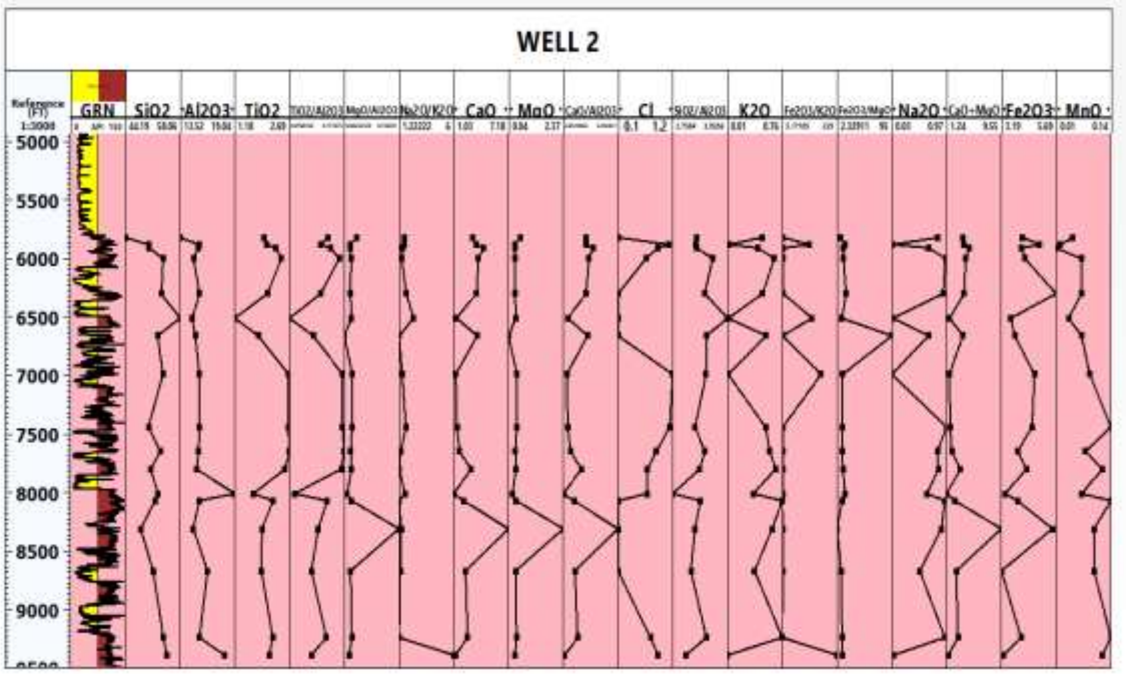


Fig 3: Major Oxides Plot for Well X2

Minor oxides Chemostratigraphic plot of Well 2

Minor oxides and minor oxides ratios profiles were also plotted for Well X2 using the values of minor oxides obtained from chemical analysis. The elements and elements ratios profiles plotted included Ba, Cr, Cu, Ga, Pb, Rb, Rb/Sr, Sr, Sr/Ca, V, ZnO, Zr. Figure 4 shows the plot of the variation of these elements in the sediments at different intervals across the Well.

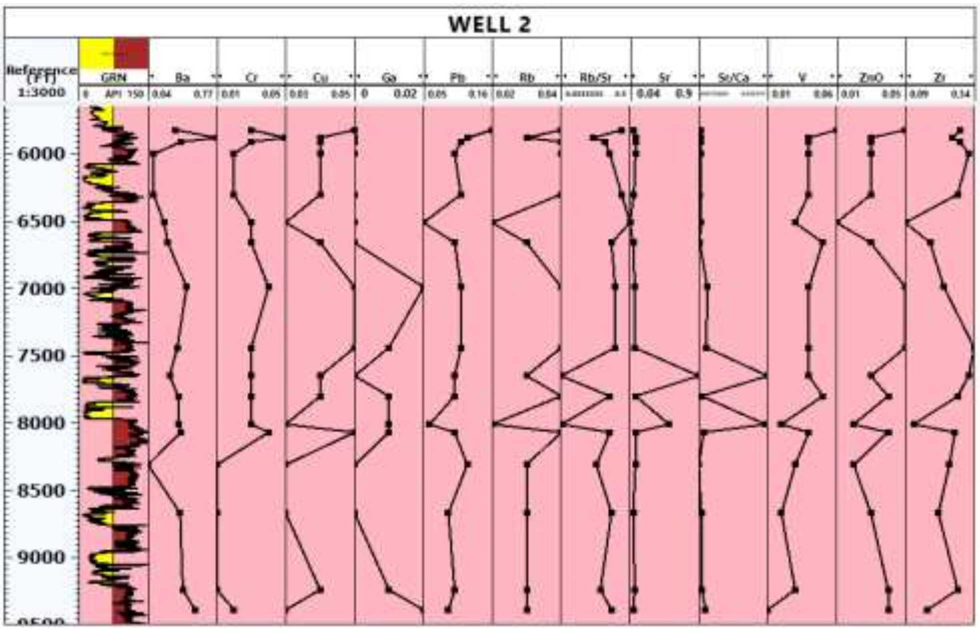


Fig 4: Minor element profile of Well 2

4.2 Chemostratigraphic zonation of Well 1

Chemostratigraphic zonation was carried out for sediments in Well 1, selected major oxides, minor elements and element ratios across Well X1 were used. The elements and ratios plotted included SiO_2, TiO_2, Al_2O_3, MgO, CaO, K_2O, V, Si/Al, Mg/Al, Sr/Al, Rb/Sr, these elements were plotted against depth to see the variation and trends in elemental composition of Well 1. These selected elements are key elements that show recognizable trend across the Well. The variation (Increase and decrease) of these elements and element ratios was used as a criteria to subzone the Well as each zone showed distinct variation in key elements that was different from other zones. These zones represent the various geochemical package present in the Well. The chemozonation of Well 1 is shown in figure 5.

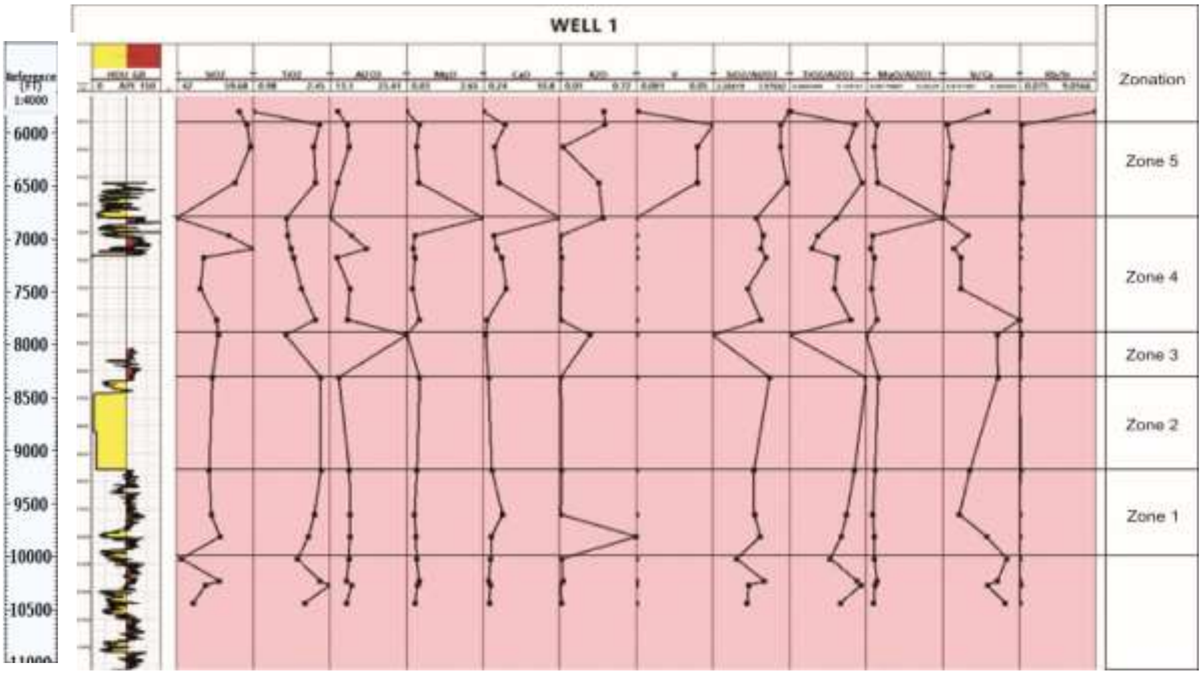


Fig 5: Chemostratigraphic zonation of Well 1

Fig 5 shows the chemostratigraphic zonation of Well 1 using key element composition and ratios.

The zones are as follows:

Chemozone 5: 5900ft- 6900ft

Chemozone 4: 6900ft-8000ft

Chemozone 3: 8000ft-8400ft

Chemozone 2: 8400ft-9400ft

Chemozone 1: 9400ft-10200ft

4.3 Chemostratigraphic Zonation Scheme for Well 2

Chemostratigraphic zonation was carried for sediments in Well 2. Selected major oxides, minor elements and element ratios across Well 2 were used. The elements and ratios plotted includes SiO_2, TiO_2, Al_2O_3, MgO, CaO, K_2O, V, Si/Al, Mg/Al, Sr/Al, Rb/Sr, these elements were plotted against depth to see the variation and trends in elemental composition of Well 2. These selected elements are key elements that show recognizable trend across the Well. The variation (Increase and decrease) of these elements and element ratios was used as a criteria to subzone the well as each zone showed distinct variation in key elements that was different from other zones. These zones represent the various geochemical package present in the Well. The chemostratigraphic zonation of Well 2 is shown in figure 6 below.

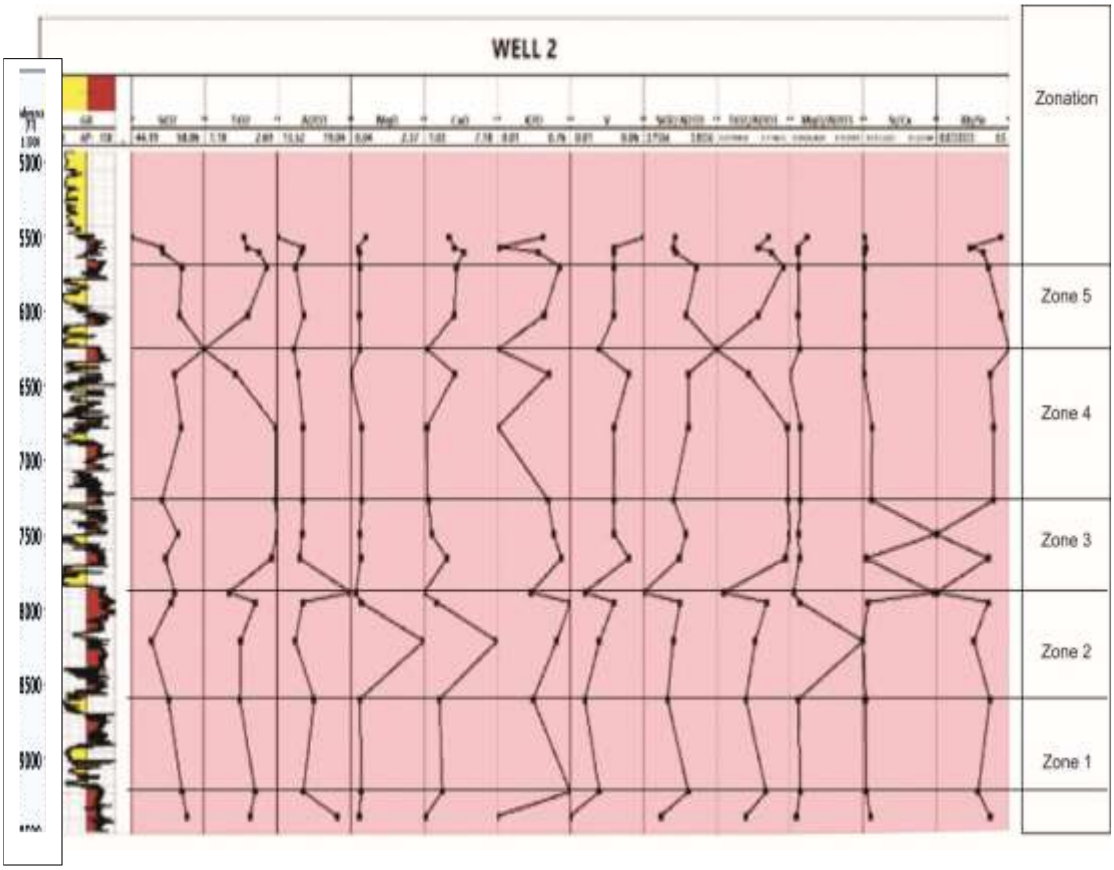


Fig 6: Chemostratigraphic zonation for Well X2

Fig 6 shows the chemostratigraphic zonation of Well X2 using key element composition and ratios.

The zones are as follows:

Chemozone 5: 6250ft- 6750ft

Chemozone 4: 6750ft-7650ft

Chemozone 3: 7650ft-8200ft

Chemozone 2: 8200ft-8800ft

Chemozone 1: 8800ft-9400ft

Criteria for Zoning both Wells

Identifiable trends in fig 1-4 where used for subzonation of the Wells. The criteria for zoning are as follows

Zone 1- Increasing values of K_2O and Sr/Ca ratio and low SiO_2 content

Zone 2- High TiO_2 value and TiO_2/SiO_2 ratio

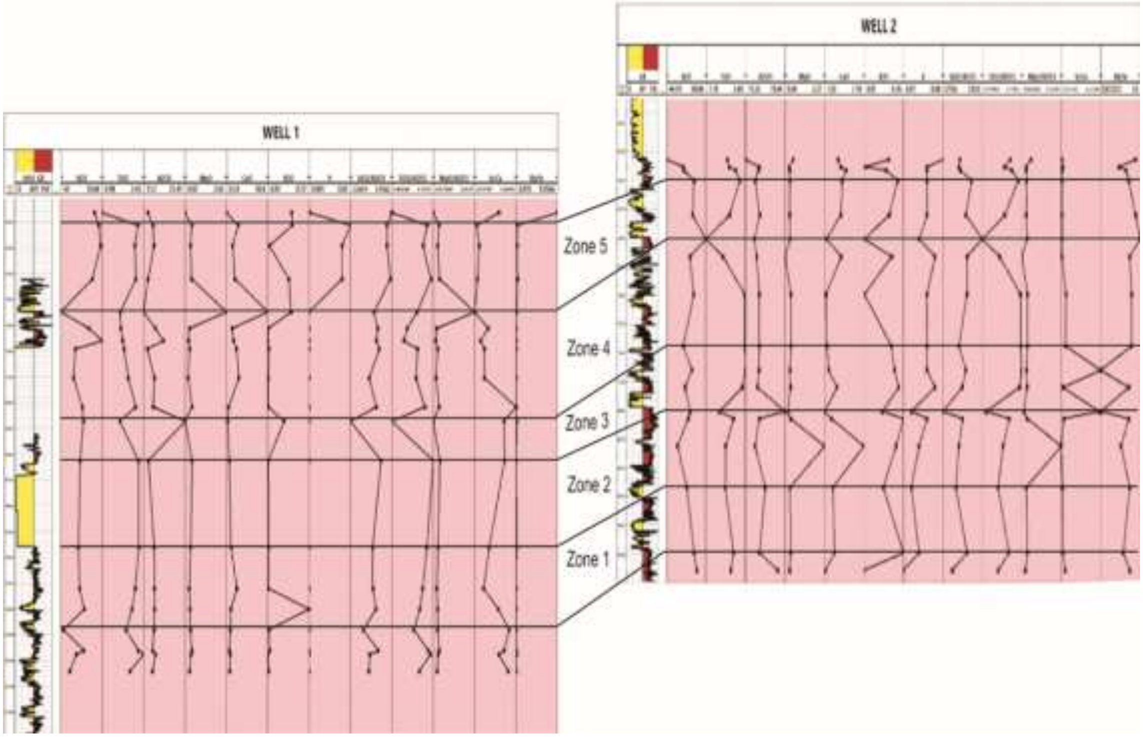
Zone 3- Decreasing K_2O and Al_2O_3 and increasing Si/Al and Ti/Al ratio

Zone 4- Increasing Si, Al, Ti and Sr/Ca values and decreasing Si/Al, Ti/Al, Mg/Al ratios.

Zone 5- Increasing value of Mg, Ca, K_2O and Mg/Al ratio and decreasing trend in Si, Ti and Sr/Ca ratio.

Chemostratigraphic Correlation of Well 1 and 2

After the use of identifiable chemical variation in zoning both Wells 1 and 2 into five chemozones representing different geochemical packages. These packages were then tied or correlated between Wells 1 and 2 as shown in Fig 7



4.4 Integration of Nannofossil and chemostratigraphic study for Well X1

Nannofossil data was used to date chemostratigraphic events in Well X1. The maximum flooding surface identified from nannofossil record was used to date the chemo events. The results showed that at chemozone 5 dated 14.2Ma there was low K_2O, high SiO_2, at chemozone 4 dated 15.6Ma, the elemental variation showed high MgO, CaO, K_2O and low SiO_2, at chemozone 3 dated 16.8Ma, the elemental variation showed low K_2O and low MgO and CaO, at chemozone 1 dated 18.0Ma, the elemental variation showed low Sr/Ca ratio and high K_2O.

At 14.2Ma, the high SiO_2 signify high amount of quartz and low K_2O signifies the low amount of feldspars as a result of weathering. At 15.6Ma, the high MgO, CaO and K_2O indicates the presence of carbonate materials in the sediments and the incorporation of potassium into clay minerals, low SiO_2 indicates low amount of Quartz and low clastic input. At the 16.8Ma, the low potassium oxide shows the maturity of the sediments as the feldspars have become weathered, the 18.0Ma showed high K_2O indicating the incorporation of feldspars in clay minerals. The result of dating of the chemo events with nannofossil data is shown in fig 8.

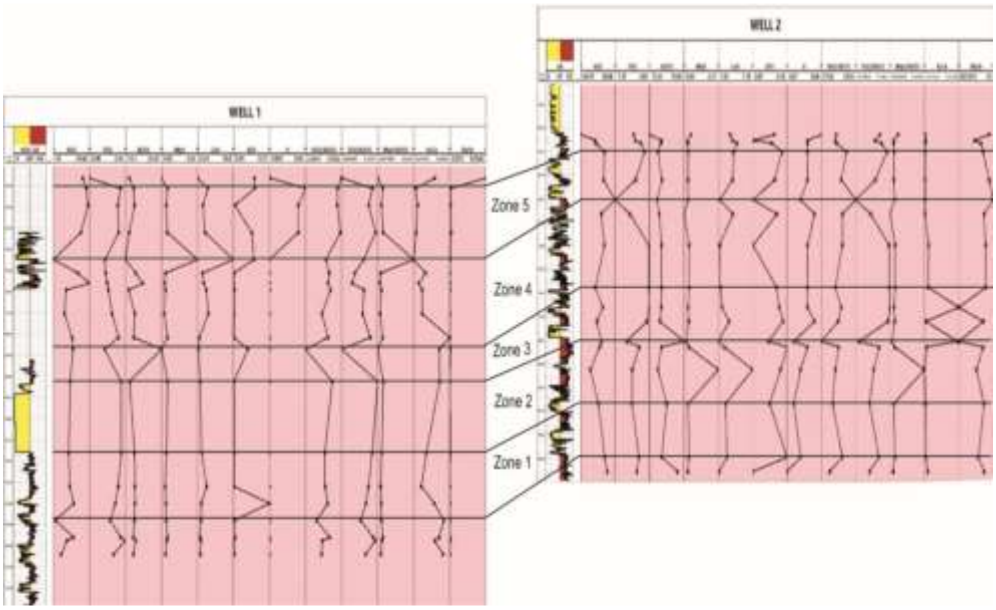


Fig 8: Chemostratigraphic correlation for Well X1 and X2

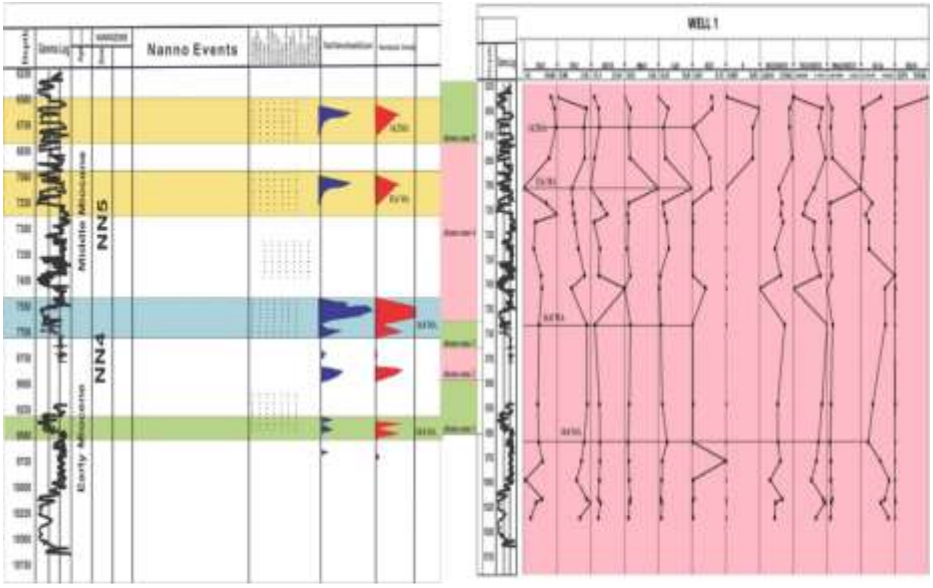


Fig 9: Dating of Chemoevents with Maximum Flooding surface for Well X1

4.5 Integration of Nannofossil and Chemostratigraphic study for Well X2

Nannofossil data was used to date chemostratigraphic events in Well X1. The MFS identified from nannofossil record was used to date the chemo events.

At chemozone 5 dated 13.6 Ma, the elemental variation showed low TiO_2, low K_2O and high SiO2, at chemozone 4 dated 14.2Ma, the elemental variation showed high K_2O and low SiO_2, at chemozone 3 dated 15.6 Ma, the elemental variation showed low K_2O and SiO_2 and high Al_2O_3 and Sr/Ca ratio, at chemozone 2 dated 16.8Ma, the chemical variation showed low MgO and CaO while at chemozone 1 dated 18.0Ma, the observed chemical variation was high K_2O.

The low potassium and high silica observed at chemozone 5 indicates the low occurrence of clay minerals at the 13.6 MA sequence boundary and high clastic sediment supply at the shelf environment where there are still high clastic input. The low silica at chemozone 4 dated 14.2 Ma is a result of deeper depth of burial and high sedimentation rate with low amount of quartz, at the 14.2Ma, the low potassium also lays credence to the transformation of K-feldspars to clay minerals. The high aluminium content at chemozone 3 dated 15.6 Ma shows that the sediments were fine grained with clay minerals dominating indicating the transformation of feldspars to clay minerals. At 16.8Ma, the low CaO and high MgO indicate the absence of carbonate materials while at chemozone 1 dated 18.0Ma, the high K_2O signifies the abundance of clay minerals. The result of dating of the chemo events with nannofossil data is shown in fig 10.

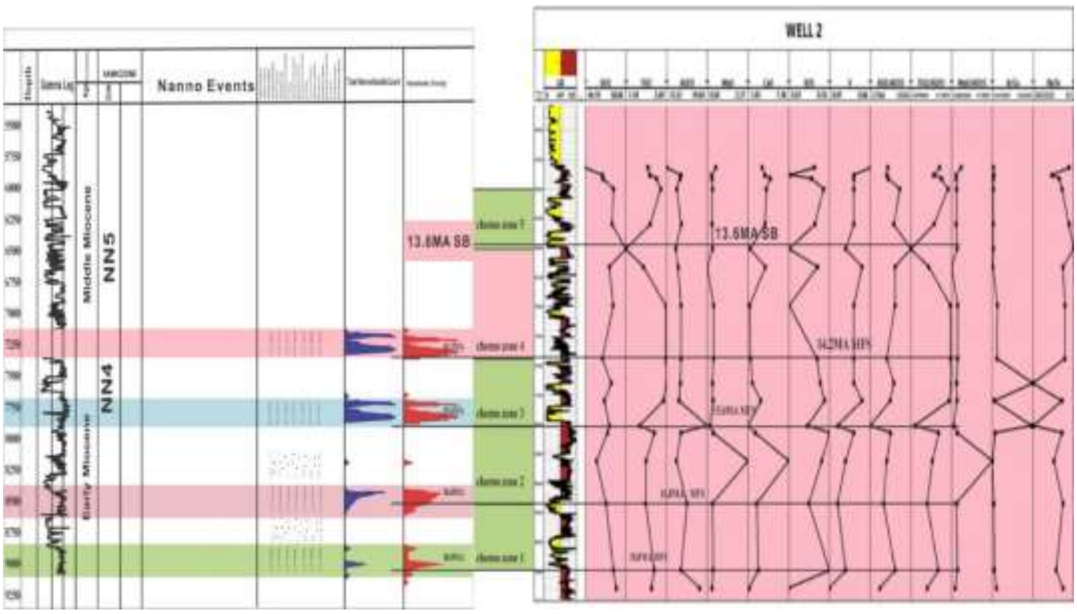


Fig 10: Dating of Chemoevents with Maximum Flooding surface for Well X2

4.6 Summary of Nannofossil and chemostratigraphic events

Table 1 Nannostratigraphy and chemostratigraphy summary of Well X1

Depth	Chemo Zone	Nanno Zone	Chemo Event	Nanno Event	Age
6000		Indeterminate	Increasing values of Mg, Ca, K_2O & Mg/Al, decreasing trend in Si, Ti & Sr/Ca ratio.	Indeterminate	Middle Miocene
6500	Chemozone 5	NN5	Increasing Si, Al, Ti & Sr/Ca values & decreasing Si/Al, Ti/Al, Mg/Al ratios.	FDO of *sphenolithus heteromorphus*.	
7000	chemozone 4			FDO of *Helicosphaera ampliaperta*. Continuous downhole increase of *Dicoaster deflandrei.*	
7500		NN4	Decreasing K_2O, Al_2O_3 increasing Si/Al and Ti/Al	Acme of *Cyclicargolithus floridanus, Discoaster deflandrei and Helicosphaera ampliaperta*	
8000	Chemozone 3		High K_2O values and low SiO_2		
8500	Chemozone 2	NN3 and older	Increasing values SiO_2, TiO_2 and Ti/Al ratio	LDO of *sphenolithus heteromorphus.*	Early Miocene
9000	Chemozone 1				
9500					
1000					
10500					
11,000					

Table 2: Nannostratigraphy and chemostratigraphy summary of Well X2

Depth(ft)	**Chemo Zone**	**Nanno Zone**	**Chemo Event**	**Nanno Event**	**Age**
6000		Indeterminate	Increasing Si, Si/Al, Rb/Sr. decreasing Ti, Ca, K & Ti/Al ratio	Indeterminate	
6500	Chemozone 5				
7000	Chemozone 4	NN5	Increasing Ti,/Ti/Al, decreasing k, Ca		
7500	Chemozone 3			Top occurrence of *sphenolithus heteromorphus*.	Middle Miocene
8000	Chemozone 2	NN4	Increasing Al, Sr/Ca, Ti, and V	FDO of *Helicosphaera ampliaperta*. Continuous downhole increase of *Dicoaster deflandrei.*	Early Miocene
8500	Chemozone 1		Increasing Mg, Ca, K, Mg/Al and decreasing Sr/Ca	LDO of *sphenolithus heteromorphus*. Good occurrence of Nannofossils.	
9000					
9500		NN3 & Older			
1000					
10500					
11,000					

4.7 Discussions

Major and trace element data enabled the subzonation of two wells in the Niger Delta, the geochemical characteristics of rock units can be related to mineralogy and provenance (Pearce *et al.,* 2010).

Sequence stratigraphic interpretation carried out using the combination of the log motifs, lithology, nanofossil occurrence and the global cycle chart of Hardendol *et al.,* (1988). The systems tracts were interpreted and mapped in the study Wells based on the log motifs of Well XI and X2 and the spatial distribution of the recognized constrained surfaces: MFSs and SBs using the nannofossil data.

The transgressive units were recognized in log sections with retrogradational or aggradational pattern and on the nannochart by areas with abundant and diverse fossil forms. The regressive phase was recognized in the log section in areas with progradational or coarsening upward log motifs and on the nannochart by areas with poor recovery of nannofossils. The transgression represented by the TST and the regression represented by the HST represents times within the geologic record when there was relative rise and fall in sea level, this rise and fall in sea level is responsible for the type of sediments in the Wells and also the fossil distribution and abundance. Sequence stratigraphic interpretation of sediments of Wells X1 and X2 yielded four HST and four TSTs respectively, typical of the Niger delta transgressive-regressive phase. The HSTs are characterized by intervals of coarsening and shallowing upwards. The sand units could be interpreted as shoreface sands deposited in the shelf region during rising sea levels. The environment of sediments deposition in this area is coastal deltaic, shelf, shallow marine. The interpreted maximum flooding surfaces (MFSs) and Sequence Boundaries (SBs) were tied to the interpreted geochemical zones using the variations in the major/minor oxides. The depths at which these chemostratigraphic events occurred which is been dated with the nannofossil data have very serious implication for hydrocarbon recovery and production in both Wells, as these events can be replicated in other wells and tied to form a regional biogeochronostratigraphic framework for a particular Field.

5.0 Conclusion

Nannostratigraphy and chemostratigraphy are state of the art geological tool in dating and subzonation of hydrocarbon Wells. Nannofossils are very excellent tools because of their minute size and wide range of occurrence in different environments and their high preservation in sediments. Elemental composition of sediments is also a reliable tool for subzonation and classification. The study have also shown the possibility of dating changes in chemical composition with nannofossil events. From this study it is concluded that in the Niger Delta at 14.2MA there is probable high SiO_2 and low K_2O, at 15.6MA there is probable high MgO and CaO,at 16.8MA there is probable low K_2O and at 18.0MA there is probable high K_2O.

This study has highlighted the various ways nannostratigraphy and chemostratigraphy can be used for dating, zonation and classification of sediments.

6.0 References

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