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The role of accommodation/sediment supply regime/basin morphology in predicting coastal depositional style: A sequence stratigraphic framework approach for selected deep wells of oligocene-miocene sediments of coastal swamps in Niger Delta

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ABSTRACT

The Oligocene – Miocene sediments of Selected Deep wells in Niger Delta is represented by marine strata that were deposited in either fluvial- wave – or tide – influenced environments. The wire line log used allows the succession to be broken down into 5 sequences and system tracts that aided in the interpretation. The changes in depositional style as observed within the sequence stratigraphic framework are as a result of fluctuations in relative sea level, variations in the effectiveness of wave and fluvial energy, basin morphology and accommodation/Sediment supply regime. The study shows that during high accommodation space/low sediment supply, the trangressive systems tract, late lowstand systems tract and early highstand systems tract, which corresponds to low sedimentation rate, will have its dominant Depositional style determined by the underlying basin morphology. During period of low accommodation space and high sediment supply regime, which corresponds to late highstand systems tract, falling stage systems tract and early lowstand systems tract, the rate of sedimentation will exceed the available accommodation space. Thus, the underlying basin geometry will have no effect on the depositional style; this will result in the coastline exposed to direct effect of wave energy. From the Predictive model used in the study, which shows the influence of basin morphology, wave and fluvial energy effectiveness, low and high Accommodation/Sediment supply regime, 2 major Depositional style with highest preservative potential and their second preservative potential were noted.

Key Words: Depositional Style, Accommodation /Sediment Supply, System tract, Basin morphology, Niger Delta.

INTRODUCTION

Many authors hence discussed vertical and along-strike changes in waves, fluvial and tidal dominance/influence in various coastal deposystems and have related those changes to varying responses to regressive or transgressive shoreline migration. Most of these papers have also stressed the importance of variations in underlying Coastal morphology and rates of

Sedimentation and Subsidence in determining Coastal depositional style (eg Bhattacharya and Walker 1992; Boyd et al. 1992; Cross et al 1993; Posamentier and Allen 1999; Bhattacharya and willis 2001; Bhattacharya and Giosan 2003; Hoy and Ridgway 2003;Barton et al. 2004; Gardner et al. 2004; Ainsworth et al 2005). These studies, discussed the lateral and vertical facies Variations to patterns or trends in rates of accommodation development and Sediment supply or position within a sequence stratigraphic framework. Hampson et al. (1999) in a study from the Cretaceous Western Interior Basin of North America identified Switches between wave-dominance of deposystem during highstands to fluvial-dominance during relative Sea-level falls. Ainsworth (2003) shows that deposystems changes from fluvial-dominance during highstands to wave-dominance during lowstands in the cretaceous Western Interior Basin of North America.

During the Nigeria Paleocene a major transgression began with the Imo Shale being deposited in the Akata Shale of Niger Delta Basin and during the Eocene, the shore drift switched the Delta to Wave-dominated delta (Reijer et al, 1997). At this point, deposition of paralli Sediments began in the Niger Delta and the Sediments prograded South-wards. The delta sedimentation is assumed to be wave-dominated, Burke(1972). Galloway (1975), Wright (1985) and Bhattacharya and walker (1992) all class the Niger Delta as being an intermediate type delta exhibiting aspects of fluvial-, wave – and tide – influence (equilibrium state). Ainsworth et al (2005), presume that Niger Delta may be currently in an intermediate phase somewhere between extreme low and extreme high Accommodation and Sediment supply regime.

The aim of this paper is to utilize an integrated Oligocene-miocene log responses from selected deep wells, located in the Coastal swamps of the Niger Delta, to investigate Potential causes and feedback loops related to vertical and lateral changes in fluvial, wave and tide process dominance and to place these changes in a sequence stratigraphic context, with the view that fluvial and wave effectiveness regimes, basin morphologies, shoreline trajectories and low and high accommodation /Sediment supply sceneries are essential in predicting Depositional switches and style.

Niger delta-regional setting

The Niger Delta, located in the Gulf of Guinea, covers an area of over 70,000 square kilometers, (Fig 1). Although the modern Niger delta formed in the early Tertiary, deposition began to accumulate in rift zones associated with the separation of the Africa and South America Continents during the Mesozoic (Weber and Daukoru, 1975, Evamy et al, 1978, and Doust and Omatsola, 1990). Rifting was preceded by the intrusion of ring complexes (younger Granites) in the central basement of Nigeria, these plutonic rocks may be related to the upward-doming of the area prior to the rifting phase that followed. Synrift Sediments accumulated during the cretaceous to tertiary, with the oldest dated Sediments of Albian age. Marine successions of syn-rift clastics and carbonates were deposited in a series of transgressive and regressive phase (Doust and Omatsola, 1990)

The syn-rift phase ended with basin inversion in the Santonian, possibly related to a reversal in pole of plates movements. Subsidence resumed in Maastritchtian as regressive proto-Niger Delta (Anambra Delta) was initiated.

The proto-Delta continued to prograde during the late cretaceous from sediments sourced largely from north and east. The Niger, Benue and Cross rivers increased supplied sediments from the Miocene onward. The Delta has steadily prograded into the Gulf of Guinea in response to these evolving drainages, subsidence and ecstatic Sea level changes.

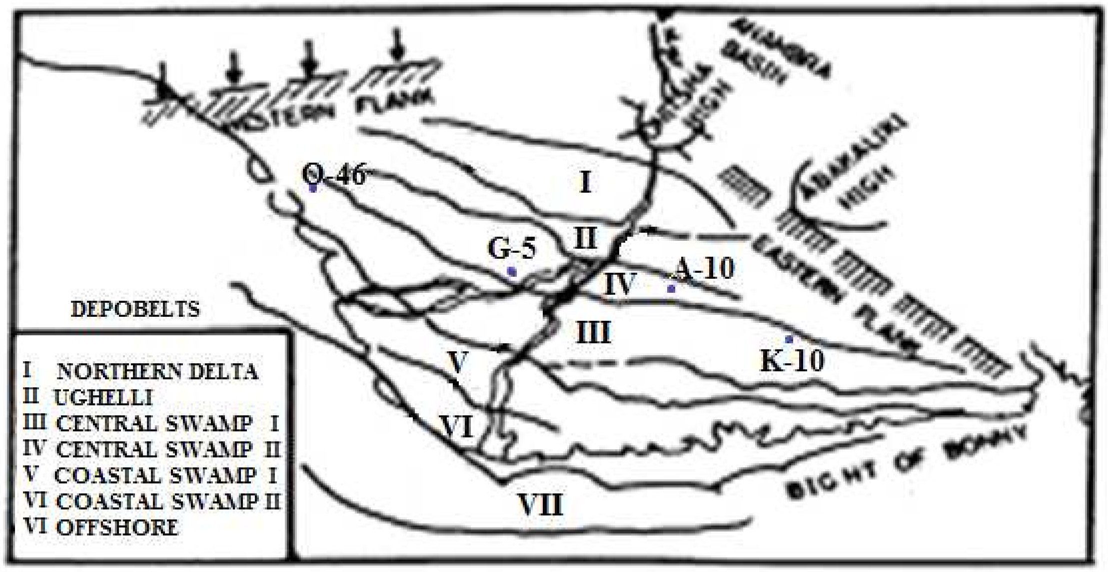

Fig. 1: Location Map of the Study Area

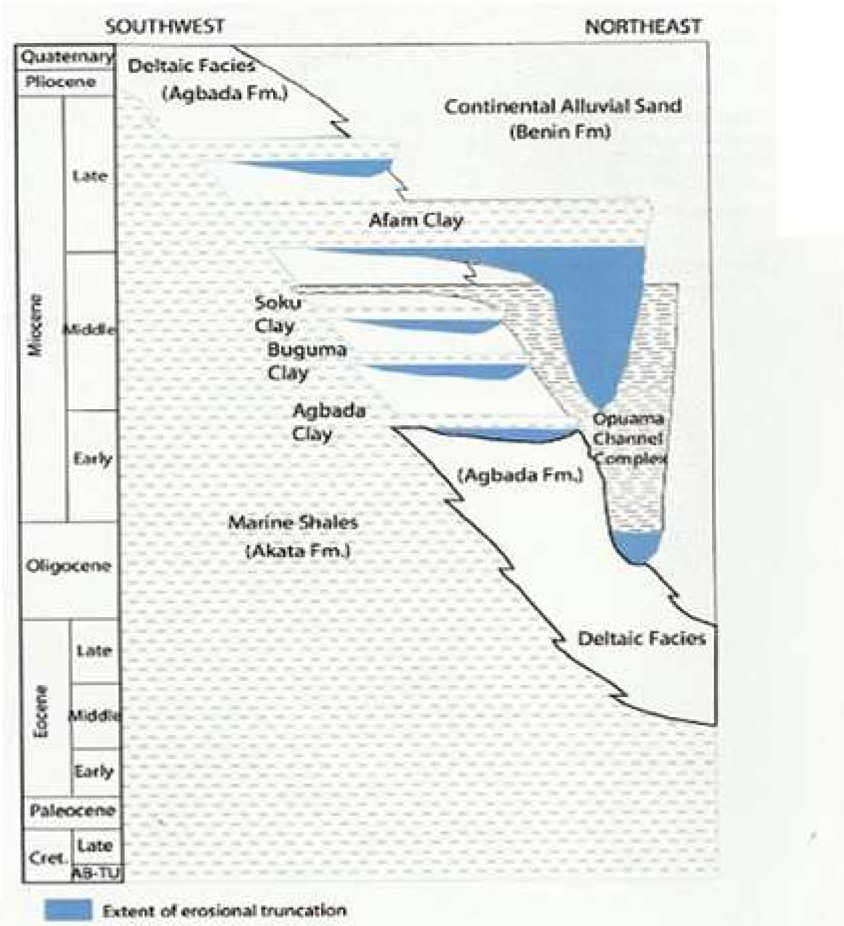

Figure 2 : Stratigraphic column showing the three formations of the Niger Delta. Modified from Shannon and Naylor (1989) and Doust and Omatsola (1990).

The present delta shoreline is smoothly convex seaward modified by wave and tidal processes. Niger Delta deposits are primarily a prograding package of off lapping strata, comprised of three distinct time-transgressive lithologic units, the Akata, Agada and Benin Formation, (Fig 2). At the base of the package the Akata formation, thick marine shale, is typically under-compacted, over pressured, and mobile. The Agbada Formation overlies the Akata and comprises alternating parallic sands and marine shale. Agbada contain most Niger Delta hydrocarbon accumulations; the interlayering of Sand-shale strata offering excellent opportunities for reservoir and top- seal formation. The uppermost Benin formation is a thick continental sand deposit. The basin consist of a series of discrete depobelt, each characterized by an individual proximal-distal facies trend within the Agbada Formation, sedimentation in these depobelts is a function of sediment supply and of accommodation space created by basement subsidence and growth faulting T.J.A. Reijers(1996). The study area which falls within one of the depobelts (Coastal swamp) started driving sediments in middle miocene and was fully formed in pliocene.

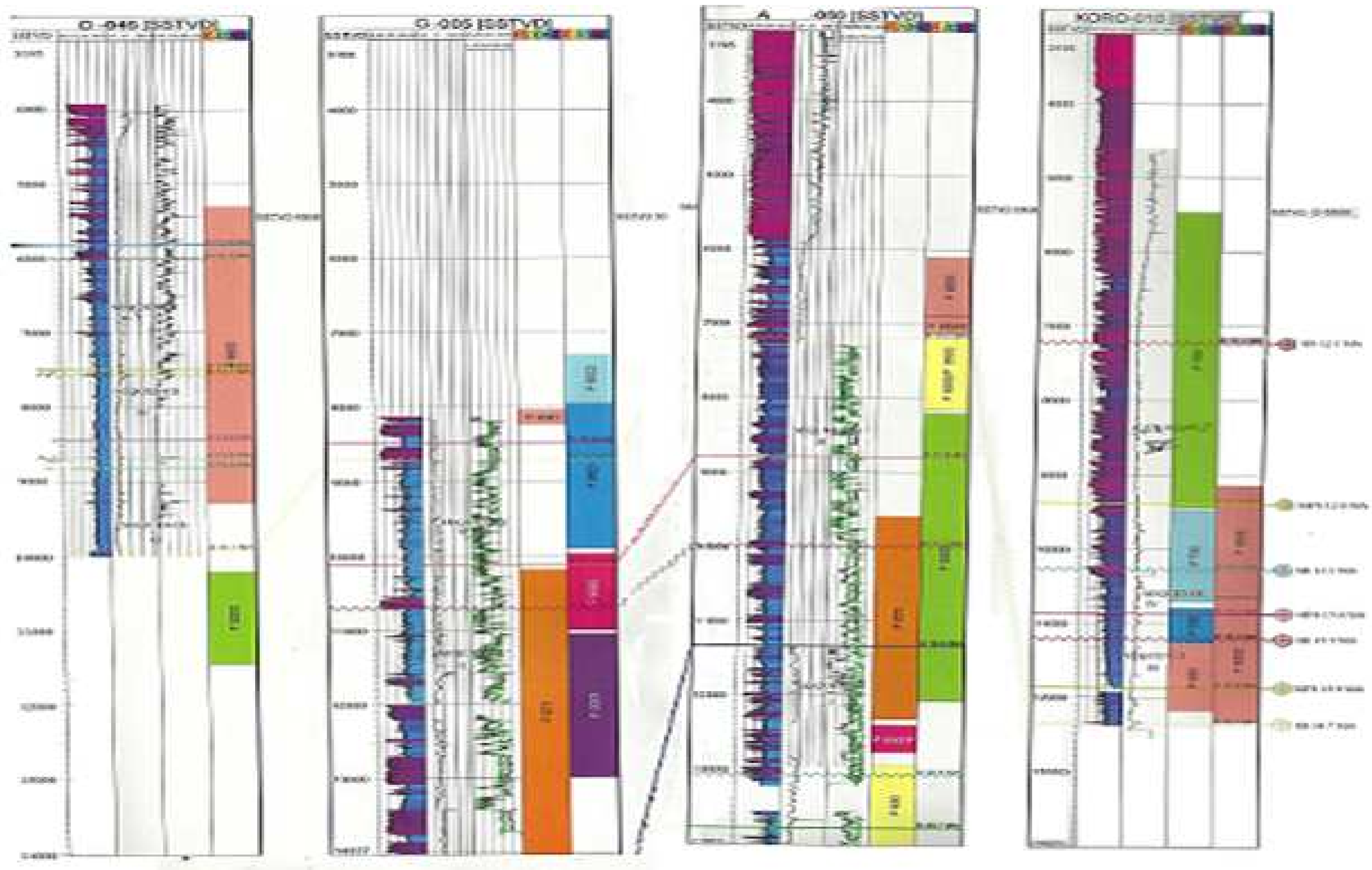

Fig 3: correlated log panels and its sequence

Interpretation techniques

The log suite was displayed at a consistent scale, chosen to enhance the log trend. The major trends on the logs were marked,(fig 3). Intervals of progradation, retrogradatioin and aggradations from stacking patterns in parasequences/parasequence sets where determined and candidates for maximum flooding surface where determined and sequence boundaries where interpreted from facies discontinuities, Absolute ages for these key surface were derived from curves of Haq et al. (1987). Faunal abundance/diversity, where used to interpret environments. Trends of parasequence thickening and thinning were interpreted, which suggest variations in the relative sea level rise/fall, which also suggests influence of accommodation/ Sediment supply as derived from Ainsworth et al (2005). The system tracts were interpreted using parasequence stacking patterns and the nature of the systems tract boundaries. A predictive model for Coastal depositional style (Ainsworth et al, 2005) was vital in determining the depositional styles,(fig 4).

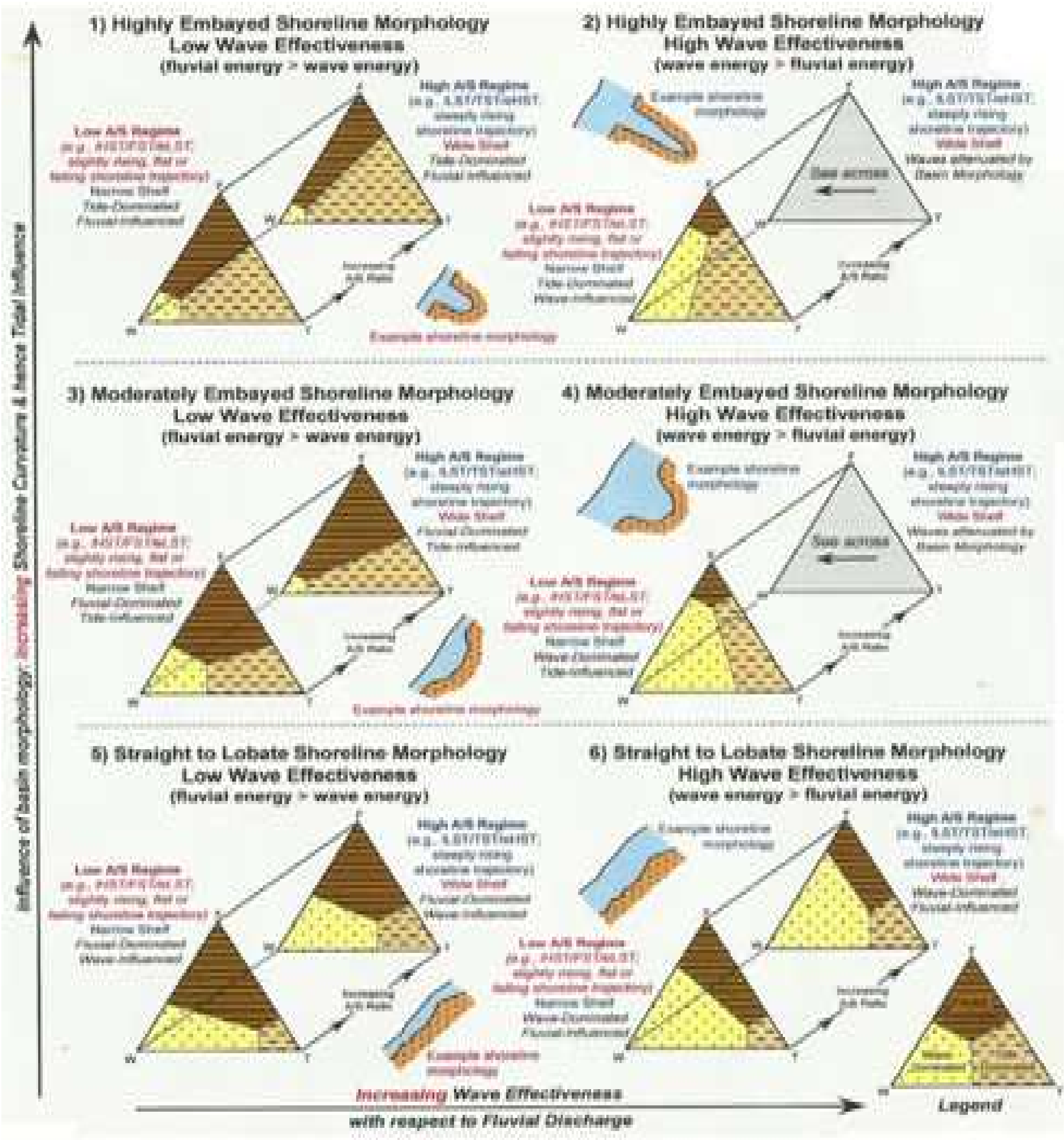

Fig 4 : Predicting Coastal Depositional Style (Ainsworth et al., 2005)

RESULTS AND DISCUSSION

The chronostratigraphic chart for the Niger Delta prepared by Haq et al (1987) was used as a guide in naming and dating the key surfaces. The age and the characteristics fauna are as shown in the chronostratigraphic chart, (fig 5).

Based on mitchum (1977) which recognized sequence as a stratigraphic unit composed of a relatively conformable succession of genetically related strata and bounded at its top and base by unconformities (sequence boundary), the studied wells were divided into five (5) sequences. Table 1 illustrates the Depositional styles.

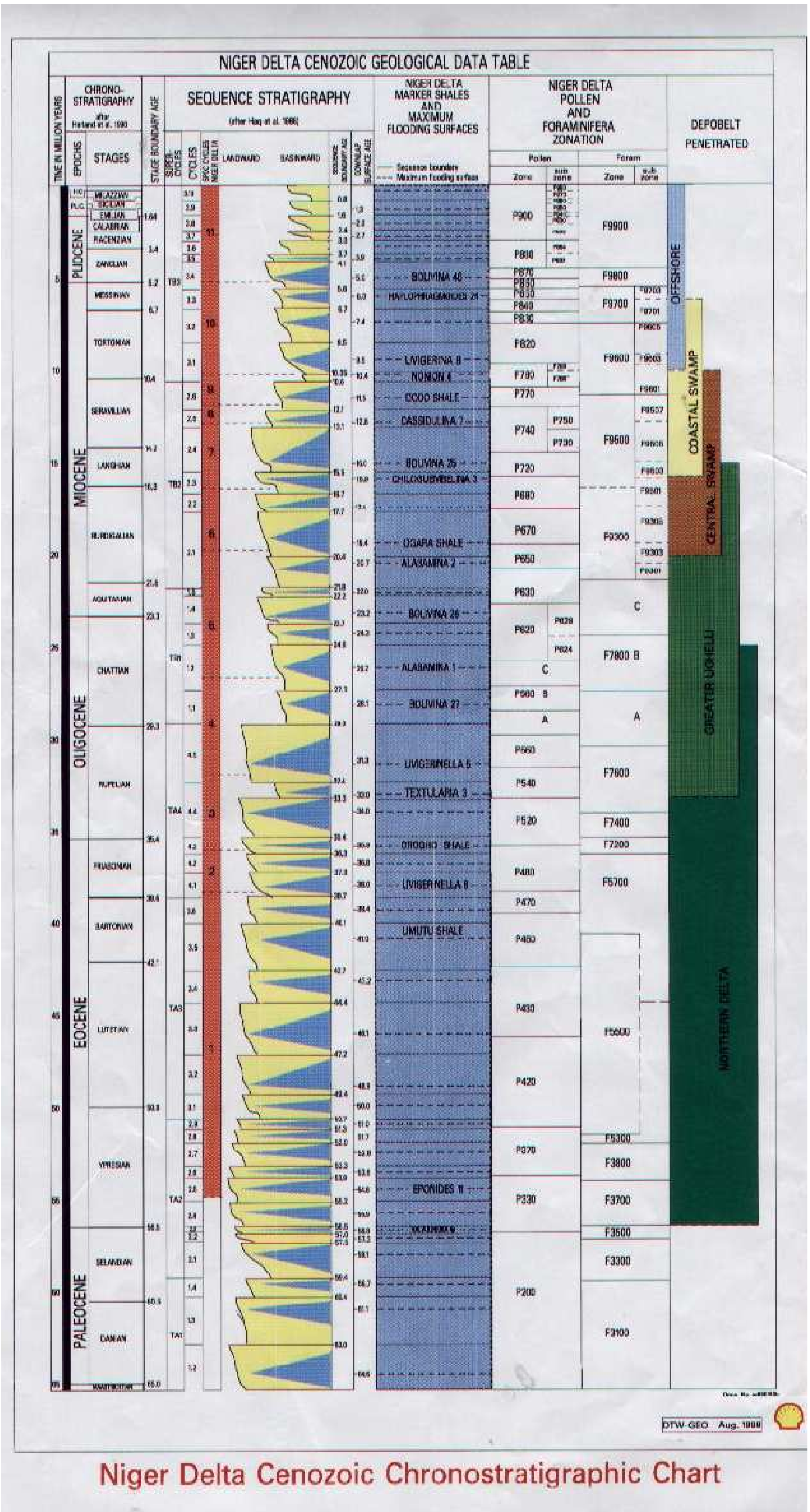

Fig. 5: Niger Delta Cenozoic chronostratigraphic Chart

SEQUENCE–1 (TIDAL DOMINATED FLUVIAL INFLUENCED)
The sequence shows a gradational coarsening – upward sequences of tidally influenced facies,there are also tidal flat sequences; small-Scale Channel units produced by tidal creeks and large scale estuarine-distributary channel sequences. The sand bodies are characterized by medium scale cross-strata developed in well to very-well sorted, medium fine grained sandstone. Cross-strata are predominantly unidirectional with tidal influence in the sequence. The tidal channel in the sequence forms erosive based units. In vertical successions they are gradationally over lain by channel Heterolithic units. The sequence has a high fluvial energy than wave energy, highly Embayed, high accommodation space; (late lowstand system tract, Transgressive systems tract and Early High stand systems tract) which signifies steeply rising shoreline trajectory (ainsworth et al. 2005).

SEQUENCE II (WAVE DOMINATED, FLUVIAL INFLUENCED TIDAL AFFECTED)
The sequence has a lithological sequence that is basically shale with occasional sand bands. Presence of low angle to planar lamination, and hummocky cross-stratification suggests wave dominance. They show coarsening upward sequence, which may represent beach ridges. The gamma –ray logs shows an upward decrease in shale content. The sequence shows a significant high wave energy than fluvial, with straight to lobate shoreline morphology, high Accommodation space (Late lowstand system tract, Transgressive systems tract and Early highstand system tract) which gives the sequence a steeply rising shoreline trajectory, (Ainsworth et al; 2005)

SEQUENCE – III (WAVE DOMINATED, TIDAL INFLUENCED)
Typical component facies observed include low angle hummocky cross stratified, sharp- based, fine bioturbated shales which suggest the dominance of wave and influence of tide. The sequence shows high wave effectiveness, with moderately Embayed shoreline morphology, high accommodation space (late lowstand system tract, Transgressive system tract and Early high stand systems tract) which shows a steeply rising shoreline trajectory. (Ainsworth et al ; 2005)

SEQUENCE – IV (TIDAL DOMINATED WAVE INFLUENCE)
There is gradational coarsening – upwards sequence of tidally influenced facies, resulting from the progradation of tidal sand ridges in K – 10. Erosive based tidal channel sequences are common in the sequence, with presence of interlaminated, shale and sand lamiae. Lithologic description shows shale with grey sand patches, which is an indication of tidal environment. The sequence has a highly Embayed shoreline morphology, with high wave effectiveness. The Gamma ray signature indicates a environment with a high Accommodation space, (late lowstand systems tract, Transgressive system tract and early Highstand systems tract) which indicates a steeply rising shoreline trajectory. (Ainsworth et al; 2005).

SEQUENCE - V (TIDAL DOMINATED FLUVIAL INFLUENCED)
The sequence shows a coarsening- upward sequence, with sand and shale intercalation or rthymite, which suggest a Tidal Dominated Environment. There is a gradual upward increase in sand percentage that suggests the influence of fluvial in the sequence. The coarse grain size and poor sorting of the sand reflects a fluvial influence. The large scale coastal plain sand in the sequence indicates its proximity to a fluvial source and a parallic to non-marine paleo environment. From the Gamma ray signature, it is expected that the sequence has a high Accommodation space (late lowstand systems tract, Transgressive systems tract and Early Highstand systems tract) meaning a steeply rising shoreline trajectory (Ainsworth et al 2005).

TABLE 1: SUMMARY OF DEPOSITIONAL STYLES OF SELECTED DEEP WELLS OF OLIGOCENE/MIOCENE SEDIMENTS OF COASTAL SWAMPS IN NIGER DELTA.

WELL NAME	DEPTH RANGE (FT)	SEQUENCE	SEQUENCE BOUNDARY AGE/RANGE	SYSTEM APPROXIMATED TRACT/ RANGE(FT)	POLLEN ZONE	PREDICTED SHORELINE MORPHOLOGY	PREDICTED DEPOSITIONAL STYLE	PREDICTED WAVE EFFECTIVENESS	PREDICTED ACCOMMOD N & SEDI SUPPLY REG
G – 5	10700 - ??	1	17.7 – 20.4ma	LST ? TST ? HST 10700 - 14027	P .670 - P.650	Highly Embayed	Tidal dominated fluvial influenced	Low wave Effectiveness (Fluvial energy greater than wave energy	High Accommo low sediment su
A – 60	10000 – 13000			LST 12900 – M13100 TST 11100 – M12900 HST 10000 – 111000					
G -5	8700 - 10700	2	16.7 – 17.7ma	LST 10500 – 10700 TST 9400 – 10500 HST 8700 – 9400	P.680 – P. 670	Straight to lobate	Wave dominated fluvial influence	High wave Effectiveness (wave energy greater than fluvial energy	High Accomm low sediment su
A – 60	7200 - 10000			LST 9900 – 10000 TST 7300 – 9900 HST 7500 – 7300					
O – 46	8650 – 9900	3	15.5 – 16.7ma	LST 9900 – 10000 TST 8800 – 9900 HST 8700 – 8 800	P.720 – P.680	Moderately Embayed	Wave dominated fluvial influenced	High wave Effectiveness (wave energy greater than fluvial energy	High Accomm low sediment su
K -10	11200 – 12500			LST 12300 – 12400 TST 11200 – 12300 HST ??					
O – 46	7480 – 8650	4	13.1 – 15.5ma	LST 8700 TST 7700 – 8700 HST 7600 – 7700	P.740 – P. 720	Highly Embayed	Tidal dominated wave influenced	High wave Effectiveness (wave energy greater than fluvial energy	High Accomm low sediment su
K - 10	10300 – 11200			LST 11200 TST 10500 – 11200 HST 10300 – 10500					
O – 46	6000 – 7550	5	12.1 – 13.1ma	LST 7600 TST 6400 – 7600 HST 6000 – 6400	P.740 – P.750	Highly Embayed	Tidal dominated fluvial influenced	Low wave Effectiveness (Fluvial energy greater than wave energy	High Accomm low sediment su
K – 10	7250 – 10750			LST 10200 – 10400 TST 9400 – 100200 HST 7400 – 9400					

CONCLUSION

The research indicates that ratios of Accommodation and sediment supply may have influenced the Depositional system, but other features such as the Paleomorphology is very vital in determining the Depositional style of the environment. The ternary diagram in fig 4 show the relative influence of wave, river input and tides on coastlines under the prevailing external conditions of basin morphology used as a proxy for tidal influence, relative effectiveness of wave and fluvial energy and ratio of accommodation space and sediment supply. As a general rule, the more curved or embayed a shoreline is, the more likely it is to experience higher tidal ranges due to the amplification of the tidal wave as it moves into the irregular coastal morphology (Ainsworth et al 2005). It is assumed that the depositional products of the ‘‘dominant’’ depositional process will have the highest preservation potential and those of the ‘‘influential’’ process will have the second highest preservation potential (Ainsworth et al 2005). The work have further supported research done by past workers, who proved that Niger Delta is an intermediate type delta exhibiting aspects of fluvial -, wave – and tide influences (equilibrium state) or an intermediate phase between extreme low or extreme high Accommodation space and sediment supply regime.

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