Sequence stratigraphic framework of K-field in part of Western Niger delta, Nigeria

Sekvenčna stratigrafija naftnega polja K v zahodnem delu delte reke Niger, Nigerija

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Abstract: A sequence stratigraphic approach was applied to K-Field, within the western Niger Delta by integrating wireline logs of four wells; 001,003, 004 and 005; and high resolution biostratigraphic data of wells 001, 004 and well 005. The study is aimed at deducing key bounding surfaces, depositional sequences and their corresponding systems tracts as well as the palaeodepositional environment of the hydrocarbon bearing Agbada Formation in the study area.

Two sequence boundaries at 8900 ft (2697 m) and 9050 ft (2742 m), and one maximum flooding surface at a depth of 7650 ft (2318 m) were recognized in well 5 and used to subdivide the stratigraphic succession into depositional sequences and their corresponding systems tracts. Highstand and Transgressive systems tracts were recognized in each of the three depositional sequences. Marker shale, characterized by *Chloguebelina* 3 (16.0 Ma) was used to date the key bounding surfaces with the aid of the Niger Delta chronostratigraphic chart as Early to Late Miocene. The Highstand systems tracts are characterized by shale-rich upward coarsening sands, having poor reservoir quality while the lowstand systems tracts are characterized by thick sandstone units, indicating good quality seals to reservoirs. From the SP logs motifs, the depositional environments inferred include tidal channel, shoreface and shelf environments which typify a marine depositional setting.

Izvleček: Na podlagi karotažnih vrtin in detajlnih biostratigrafskih podatkov iz štirih vrtin (001, 003, 004 in 005) smo izdelali sekvenčno strati-

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grafijo naftnega polja K v zahodnem delu delte reke Niger. Namen študije je bil določiti glavne mejne površine, depozicijske sekvence, sistemske trakte in okolje sedimentacije. Podatke smo analizirali s programsko opremo Petrel.
V preučenih zaporedjih smo določili tri depozicijske sekvence, ki so ločene s sekvenčnimi mejami na globini 2697 m ter 2742 m. Za vsako izmed sekvenc smo določili transgresivne sistemske trakte (TST) in sistemske trakte visoke gladine morja (HST). Zgodnje- do poznomiocenska starost preučevanega zaporedja je bila določena na podlagi plasti kronostratigrafske lestvice delte Nigra in glinavcev s *Chloguebelino* 3 (16.0 Ma). Sistemski trakti visoke gladine morja vsebujejo z glino bogate peske, ki so rezervoar slabše kvalitete. Transgresivni sistemski trakti pa so sestavljeni iz debelih enot, ki so dobre zaporne plasti rezervoarja. Na podlagi SP-motivov iz vrtin smo določili naslednja sedimentacijska okolja: plimske kanale ter obalna in šelfna okolja.

Key words: sequence stratigraphy, depositional environment, Niger Delta
Ključne besede: sekvenčna stratigrafija, sedimentacijsko okolje, delta reke Niger

INTRODUCTION

The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta province (KLETT et al, 1997). The Niger Delta is a large arcuate type, situated on the west coast of central Africa between latitudes 3° and 6° N and longitudes 5° and 8° E (REIJERS et al, 1997). It ranks among the world's most prolific petroleum producing Tertiary deltas. This province contains one identified petroleum system known as the Tertiary Niger Delta (Akata-Agbada) petroleum system (EKWEOZOR & DAUKORU, 1984: KULKE, 1995).

Over 80 % of Nigeria's revenue comes from oil and gas, with the Niger Delta basin as the main target. In order to satisfy the need for increasing production of the vast hydrocarbon resources, it was necessary to improve the existing geological knowledge of the region by application of a modern concept of sequence stratigraphy.

Sequence stratigraphy, which is the underlying concept for this work, is the study of the subdivision of sedimentary basin fills into genetic packages bounded by unconformities and their correlative conformities. The knowledge of sequence stratigraphy can provide a chronostratigraphic framework for the correlation and mapping of sedimentary facies and for stratigraphic predictions.

Present study therefore focuses on developing sequence stratigraphic framework for K-Field within the Niger Delta basin, based on the integration of data from well logs and biostratigraphic data sets.

Study area and regional geologic setting

The study area is the K-Field, located in the onshore portion of the western part of the Tertiary Niger Delta (Figure 1). The K-Field, which contains four wells used in this study, is within the Shell Petroleum Development Company of Nigeria concession (Figure 1).

On the basis of sand-shale ratios, the subsurface Tertiary section of the Niger Delta is divided into three formations (Figure 2), representing prograding depositional facies. These formations are from oldest to youngest; Akata, Agbada and Benin Formations. The

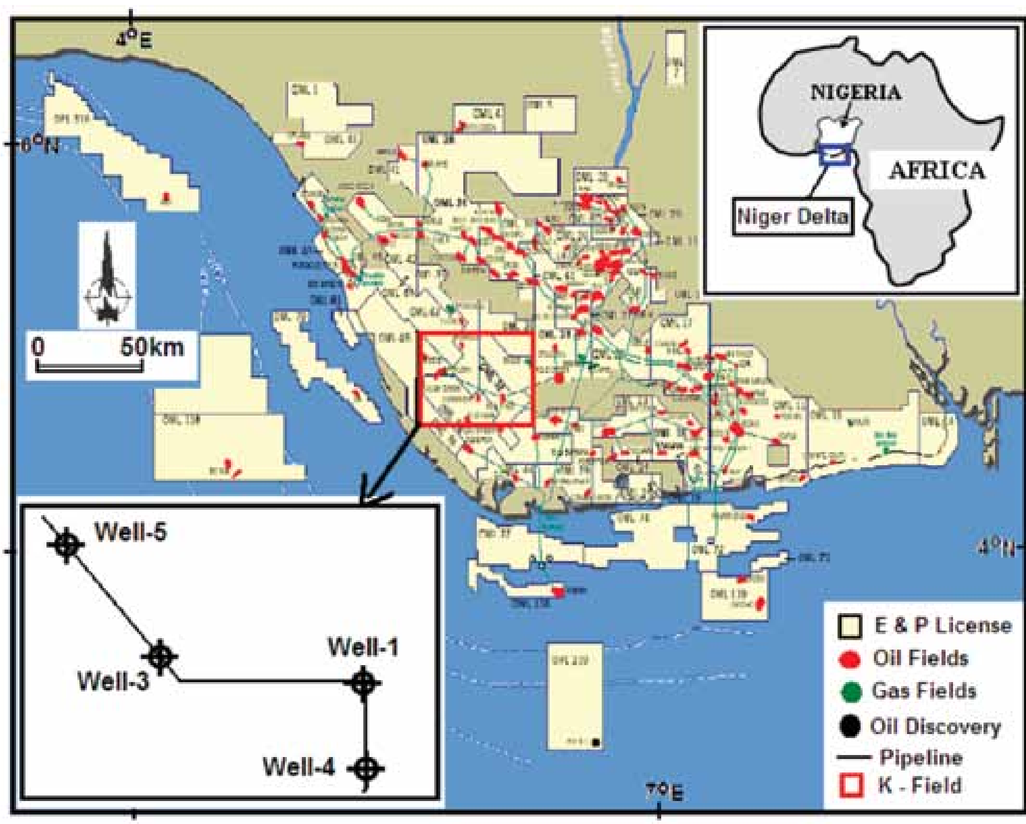

Figure 1. Concession map of Niger Delta showing location of K-Field with base map of four wells shown. Map of Africa inset (Modified from ENI/NAOC, 2002 Brochure on Nigeria

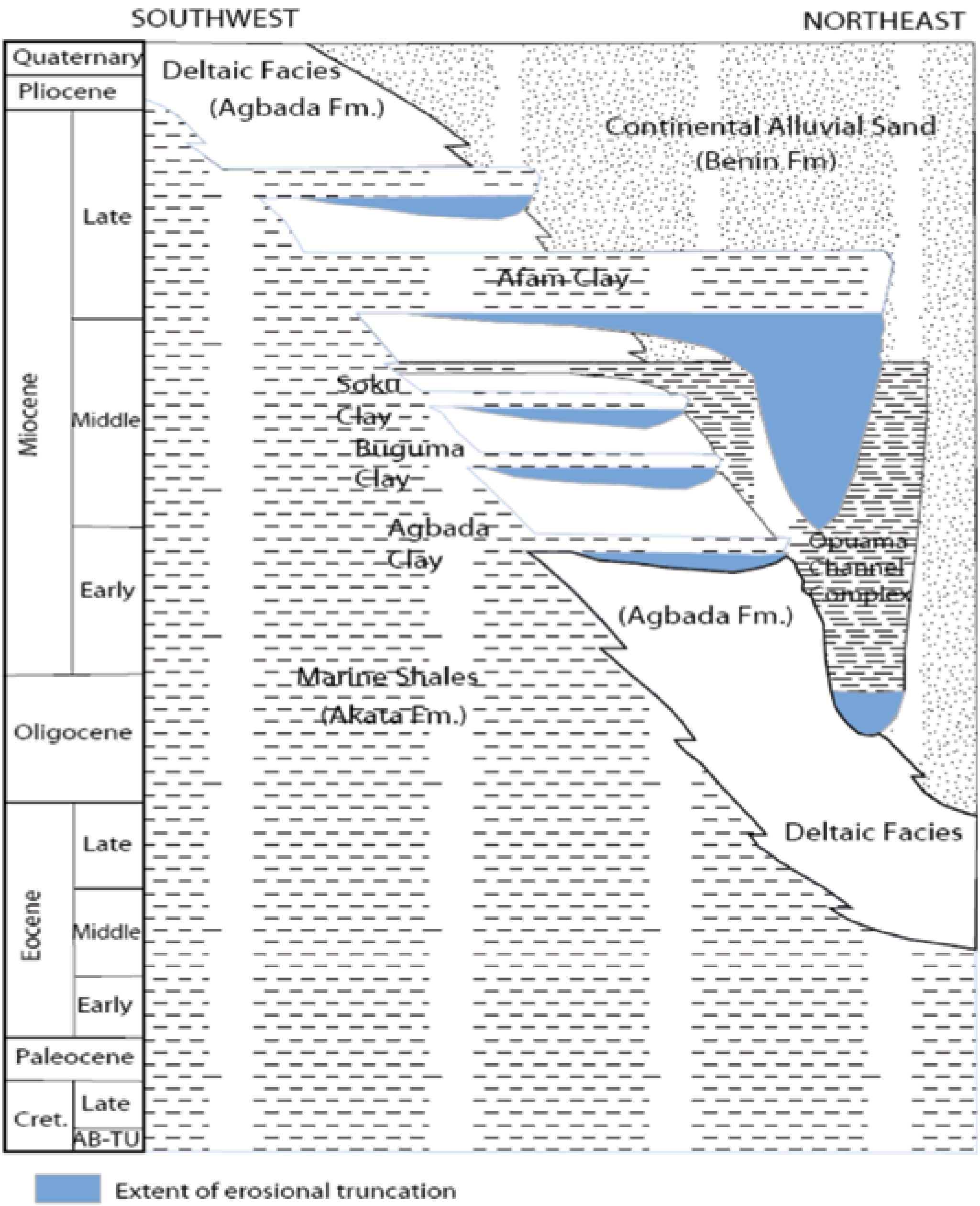

Figure 2. Stratigraphic column showing the three Formations of the Niger Delta (DOUST & OMATSOLA, 1990)

type sections of these formations are described in Short & Stäuble (1967) and summarized in a variety of papers (e. g. Avbobvo, 1978; Doust & Omatola, 1990; Kulke, 1995).

The Akata Formation at the base of the delta, is of marine origin and is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. Beginning in the Cretaceous in the proximal part of the delta and Recent in the distal offshore, the Akata Formation formed within a deep water environment, when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Stacher, 1995). It is estimated that the formation is up to 7 000 m thick (Doust & Omatsola, 1990). The Akata Formation underlies the entire delta, and is typically overpressured. Turbidity currents likely deposited deep sea fan sands within the upper Akata Formation during the development of the delta (Burke, 1972).

The Agbada Formation, which is the major petroleum-bearing unit, overlies the Akata Formation. The formation began in the Eocene in the proximal part of the delta and presently deposited in the nearshore shelf domain. It consists of paralic siliciclastics, over 3 700 m thick and represents the actual deltaic portion of the sequence. These clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. In the lower part of the Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds. The Benin Formation is the youngest lithostratigraphic succession in the Niger Delta and comprised sandstone, grits, claystone and streaks of lignite. It is about 2 000 m thick and ranges in age from Oligocene in the proximal part of the delta to Recent. The Benin Formation consists of thick sections of continental sediments with coastal plain and shallow marine sandstones. The formation water is fresh with high resistivity.

The structural development within the Niger delta is controlled by differential loading of the underlying prodelta shales of the Akata Formation, which consists of three basic elements; the northern (proximal) megastructure boundary fault, a southern counter-regional terminating fault and/or toe-thrust belt and the intervening central rigid block between the two fault systems (Evamy et al, 1978). Most known traps in the Niger Delta are structural, although stratigraphic traps are not uncommon (Figure 3). The growth faults which formed the structural traps developed during synsedimentary deformation of the Agbada paralic sequence (Evamy et al., 1978; Stacher, 1995). Doust & Omatsola (1990) described a variety of structural trapping elements, including those associated with simple rollover structures; structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures. NTON & ADESINA (2009) identified two major growth faults, three antithetic and two synthetic faults, offshore Niger Delta. They also noted structural closures as rollover anticlines displayed on the time/depth structure maps which suggest probable hydrocarbon accumulation at the downthrown side of the major growth fault. Schematic sketches showing the development of growth-fault-bounded depobelts during progradation of unstable Niger Delta clastics have been presented in KNOX & OMATSOLA (1989). The formation of interest is the Agbada Formation which contains the hydrocarbon producing reservoirs in the study area.

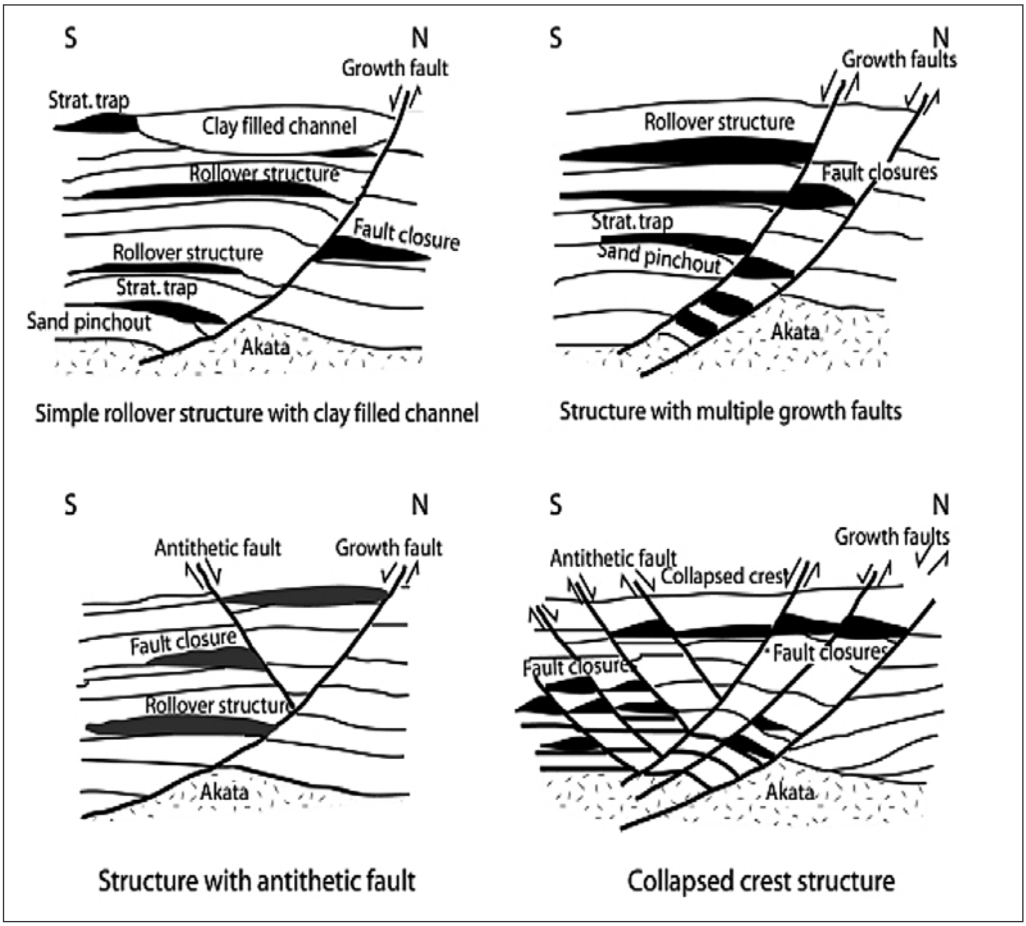

Figure 3. Examples of Niger Delta Oil Field Structure and associated trap types. (STACHER, 1995)

Materials and methods

A suite of well logs, in ASCII format , were obtained from four wells namely; 001, 003, 004, and 005, drilled within the K- Field in the western Niger Delta. Biostratigraphy data, summarized with Pollen(P) and Foram(F) zones from three wells notably; 001, 004, and 005 plus deviation data were utilised in this study. The above dataset were obtained from the Shell Petroleum Development Company of Nigeria Limited. The well logs, made of the gamma ray, self potential and resistivity logs were analysed using the PETREL software (version 2003) at the workstation of the Department of Geophysics, Federal University of Technology, Akure, Nigeria.

A detailed analysis and interpretation of the suite of well logs was carried out, followed by biostratigraphic interpretation of the data. The various analyses were integrated and interpreted to deduce a sequence stratigraphic framework of the Field of study. Detailed analytical procedures are documented in Ogungbemi (2009).

Recognition of Sequence Boundaries

The recognition of sequence boundaries (SB) in this study was based on the concept of Van Wagoner et al. (1990). The sequence boundaries were identified by a sand-rich facies, within a coarsening upward sequence. These are usually located between two maximum flooding surfaces and are recognized by an erosional surface between a lowstand and a highstand system tract.

Recognition of Maximum Flooding Surfaces

The Maximum Flooding Surface caps the Transgressive System Tracts (TST). It represents the most landward transgression of the shoreline. The 3rd order MFS identifiable in the Niger delta chronostratigraphic chart where mapped on the wells. It was identified through the biostratigraphic data made available and interpreted. When integrated with the biostratigraphic interpretation, it is also represented on the well log as the point where the resistivity logs which corresponds to the highest value on the SP logs.

Recognition of Systems Tracts

This was recognized by first locating the3rd order and 4th order maximum flooding sufaces within major condensed sections on the logs, followed by the location of the highstand system tracts, transgressive system tract and the lowstand system tract subdividing. The Lowstand System Tract comprises the basin floor fan, the slope fan and the prograding complex. The basin floor sands contain massive turbidite sands with the upper boundary characterized by hemipelagic shale (Vail et al., 1992). The slope fan consists of crescent-shaped channel bank units while the, prograding complex is a prograding unit with an aggradational offlap configuration. It rests directly on the underlying slope fan and basin floor complexes and is characteriesed by turbidities sands and shales. A maximum shale point generally marks the boundary between the slope fan complex and the lowstand prograding complex. The Trangressive System Tract is characterized by electrofacies that is made up of high gamma ray values indicating the presence of deep sea marine shale. The portion of the log with the lowest resistivity was selected as the maximum flooding surface when integrated with the biostratigraphic data. This is based on the concept of SANGREE et al., (1990).

The Highstand System Tract is bounded below by a downlap surface of maximum flooding and above by a sequence boundary. According to VAIL et al., (1990), log correlations in the highstand commonly indicate interbedded sand and shale lithofacies while the reservoir continuity is fair.

RESULTS AND DISCUSSION

Based on integration of the available data, the lithologic, depositional energy, stratigraphic surfaces and sequence stratigraphy of the field were analyzed and interpreted. These interpretations aided in the subdivision of stratigraphy into system tracts that aided in better correlation of the wells for an improved search for hydrocarbon in the study area as shown below.

Lithology and Depositional Energy

This study revealed that low SP log readings, ranging from 82.4 mv to 173.7 mv, are good reservoir quality sandstones while SP log reading ranging between 44.3 mv and 82.4 mv, indicates shale interval (Figure 4). This was used in the identification of the sand–shale ratio which aided in interpreting sandstone and shaly lithologies. These sandy lithologies were painted yellow, shaly lithologies were painted green and self potential logs were painted red for easy identification (Figure 4). Most of the sandstone units within the field have some shale intercalations as seen mostly on the upper part of the study interval. The thickness for the small reservoirs ranges between 15 m and 20 m while the very thick sandstone units range between 76 m and 305 m (Figure 4).

The depositional energy trend, which is useful for the identification of sedimentary facies (POSAMENTIER & VAIL, 1988), follows two sequences in this study. These are; those with finning upward and coarsening upward sequences (Figures 4 and 5). Those with fining upward sequences are seen to have lesser thicknesses. This forms the lithologic classification indicating the building up of sandstone from coarse to fine grains, with the coarse grains pointing to higher energy of deposition while the finer

Stratigraphic Cross Section of wells 005, 003, 001 and 004:Equally Spaced Logs
Datum : SSTVD Vertical scale = 1 in per 50 ft 08/08/2008

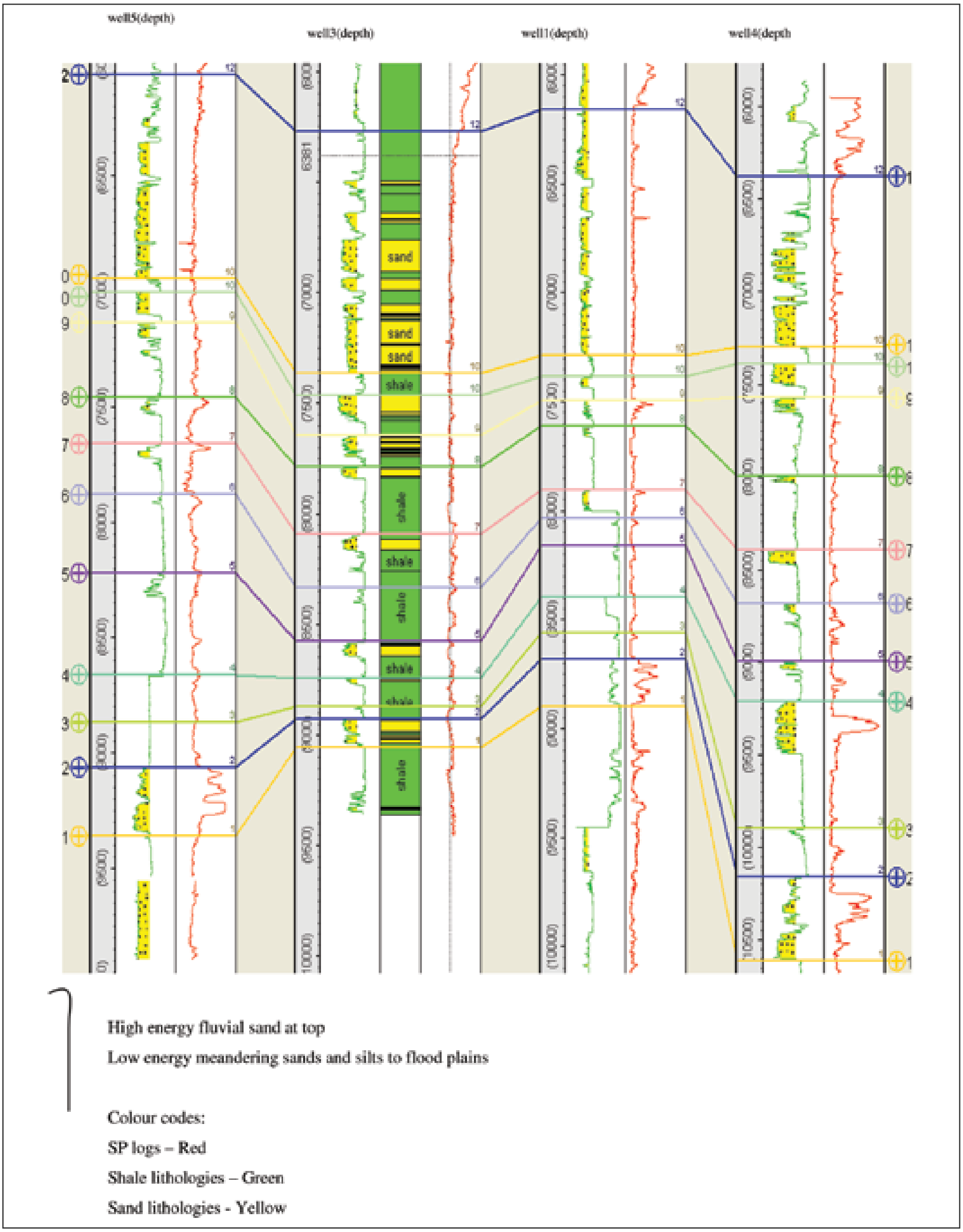

Figure 4. Correlation panels and depositional energy trends based on wells 005, 003, 001 and 004

Stratigraphic Cross Section "Well005.003,001and 004:Equally spaced logs
Datum : SSTVD Vertical Scale= 1 in per 50ft
08/08/2008

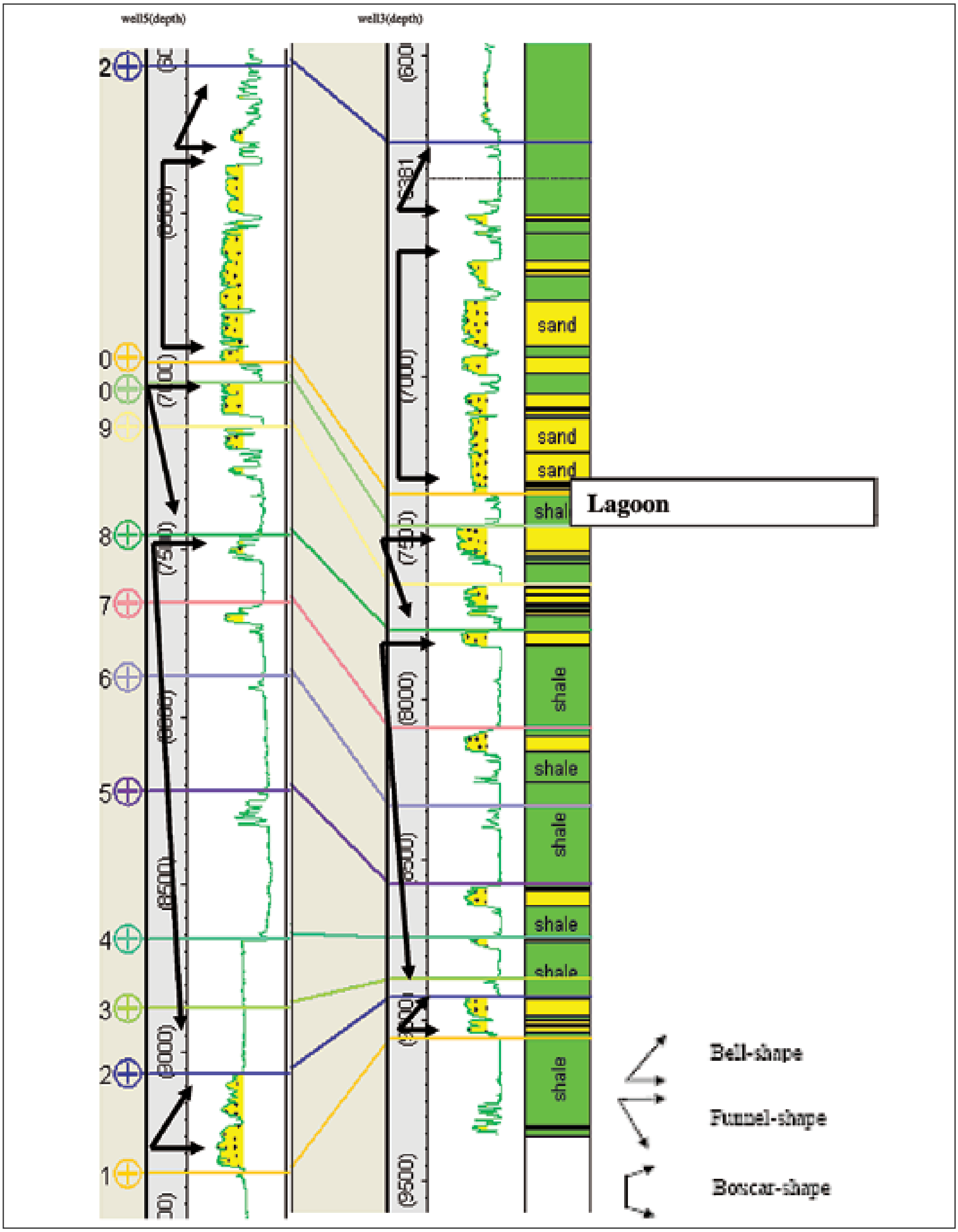

Figure 5. Log trends for depositional environment using Wells 005 and 003

grains indicate a lower energy of deposition. The coarsening upward sequences show a larger thickness of deposits, decreasing from sandstone at the top to shale at the base (Figure 5).

SP logs analysis in the studied interval show three types of log motifs, which are; funnel-shaped, bell-shaped and box car-shaped (Figure 5). The funnel–shaped motif is that which has been identified as upward-coarsening sedimentary sequences (Figure 5). These sedimentary sequences would be inferred to be a prograding complex deposited within a lowstand system tract. They are interpreted as fluvial channel deposited within a continental to coastal environment (Figure 5). These sequences have lesser thickness than others, ranging between 39 ft to 41 ft (11.8 m to 12.4 m).

In the bell-shaped motif, the SP logs of the study interval have a bell motif overlain and underlain by thick shales. They are seen to have upwards fining sedimentary sequences (Figure 5) with thicknesses ranging from 500 ft to 970 ft (152 m to 294 m).This occurs when marine sediments such as shales transgress over continental facies or fluvial sediments. They could also be interpreted as tidal channel sands deposited under high tidal influence over fluvial sands.

The box car-shaped SP log is a convex (outward) view with a box description. The motif is formed due to a build up of clastic sediments at a constant sea level leading to an aggrading sediment deposition. The box car-shaped SP log indicates the truncation of a rapid aggradational deposition with terminal boundaries. They can be inferred to as distributary channel sands. According to Selley (1991), three general categories of environments can be inferred from such depositions; these are tidal channel sand, fluvial channel sand delta distributaries channel sands. It can be deduced from this study therefore that the box-car depositional motif is significant of distributary channel sand deposited within a shallow marine environment.

Third order stratigraphic surfaces and sequences

The sequence stratigraphic framework for K Field is composed of three major third(3^{rd}) order Sequence Boundaries (SB) ranging from 15.9 Ma to 10.4 Ma and one major third (3^{rd}) order sequence of Miocene age, corresponding to Pollen zones P680 to P780 and Foram zones of F9300 to F9800 (Table 1). The maximum flooding surface was tied to the Niger Delta Chronostratigraphic chart (Figure 6)

Maximum Flooding Surface (MFS)

A major third order MFS was identified, and subsequent four fourth order Maximum Flooding Surfaces (Figure 7). The MFS identified was based on the positions of highest abundance and diversity peaks, on the biofacies data.

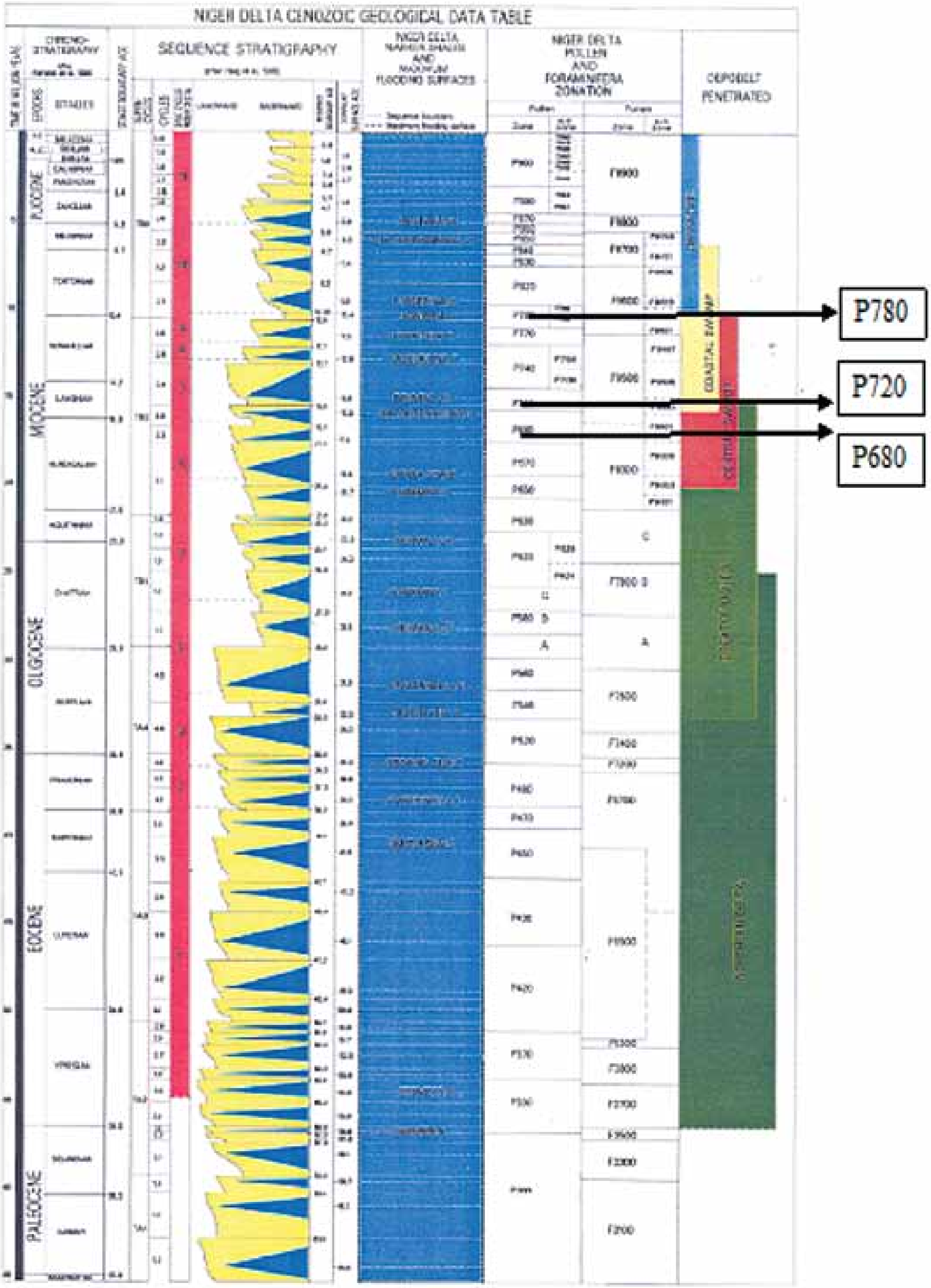

Figure 6. Niger Delta chronostratgraphic chart (HAQ et al, 1988)

On the well logs, they were identified as the flooding surface with the highest resistivity values. This correctly ties with the MFS identified at a depth of 7 650 ft (2 318 m).

Chloguebelina 3 MFS (16.0 Ma).
This MFS penetrated in the studied Field has been tied to the Chloguebelina-3 marker on the Niger Delta Chronostratigraphic chart (Figure 6). They were encountered by Wells 003 and 005 at respective depths of 7 850ft (2 379 m) and 7 650ft (2 318 m) based on well log interpretation. It occurs with the P680 and F9300 biozones. The log patterns show an upward coasening depositional energy succession and downward finning sedimentation with a laterally extensive shaly lithology.

Sequence Boundaries (SB)
The sequence boundaries were identified based on the interpretation of parasequence stacking patterns, log shapes and motifs. The third order sequence boundaries recognized are 15.9 Ma and 10.38 Ma (Figure 6). Resistivity logs which correspond to the lowest value on the SP log indicates the sequence boundaries mapped (Figure 7)

17.7 Ma SB
This is the oldest sequence boundary identified in the K-Field. It is penetrated by Wells 005 and 003 at depths of 9 050 ft (2 758 m) and 8 950 ft (2 722 m) respectively. This surface was not recognized on well 001 due to the depth in which it was drilled to. This was identified from the well logs with the aid of the biostratigraphic data (Table 1)

Deductions from biofacies interpretations typically show that such horizons are devoid of Pollens, with no indication of Foraminifera. The depositional environment deduced from the log signatures depicts a continental sediment deposited in a shelf environment (Figure 5) based on the concept of Busch et al., (1974).

10.38 Ma SB
This is the second sequence boundary penetrated in K-Field and it marks the

Table 1. Biostratigraphic data table

Well	Depth (ft)	Marker shales's (Faunal bed)	Dated Age(ma)	P Zones	F Zones	Epochs
1	6180	Nonion 6	10.3	P780	F9800	Miocene
	76.75	Chloguembelina 3	16.0	P680	F9300	Miocene
4	6400	Nonion 6	9.0	P820	F9800	Miocene
	7550	Chloguembelina 3	16.0	P680	F9300	Miocene
3	9000	Rich Bolivina 25	17.7	P670	F9300	Miocene
	10010	Rich Bolivina 25	17.7	P670	9300	Miocene
5	6080	Nonion 6	10.3	P780	F9800	Miocene
	7701	Chloguembelina 3	16.0	P680	F9300	Miocene

Stratigraphic Cross Section "Well005.003,001and 004:Equally spaced logs
Datum : SSTVD Vertical Scale= 1 in per 50ft
18/08/2008

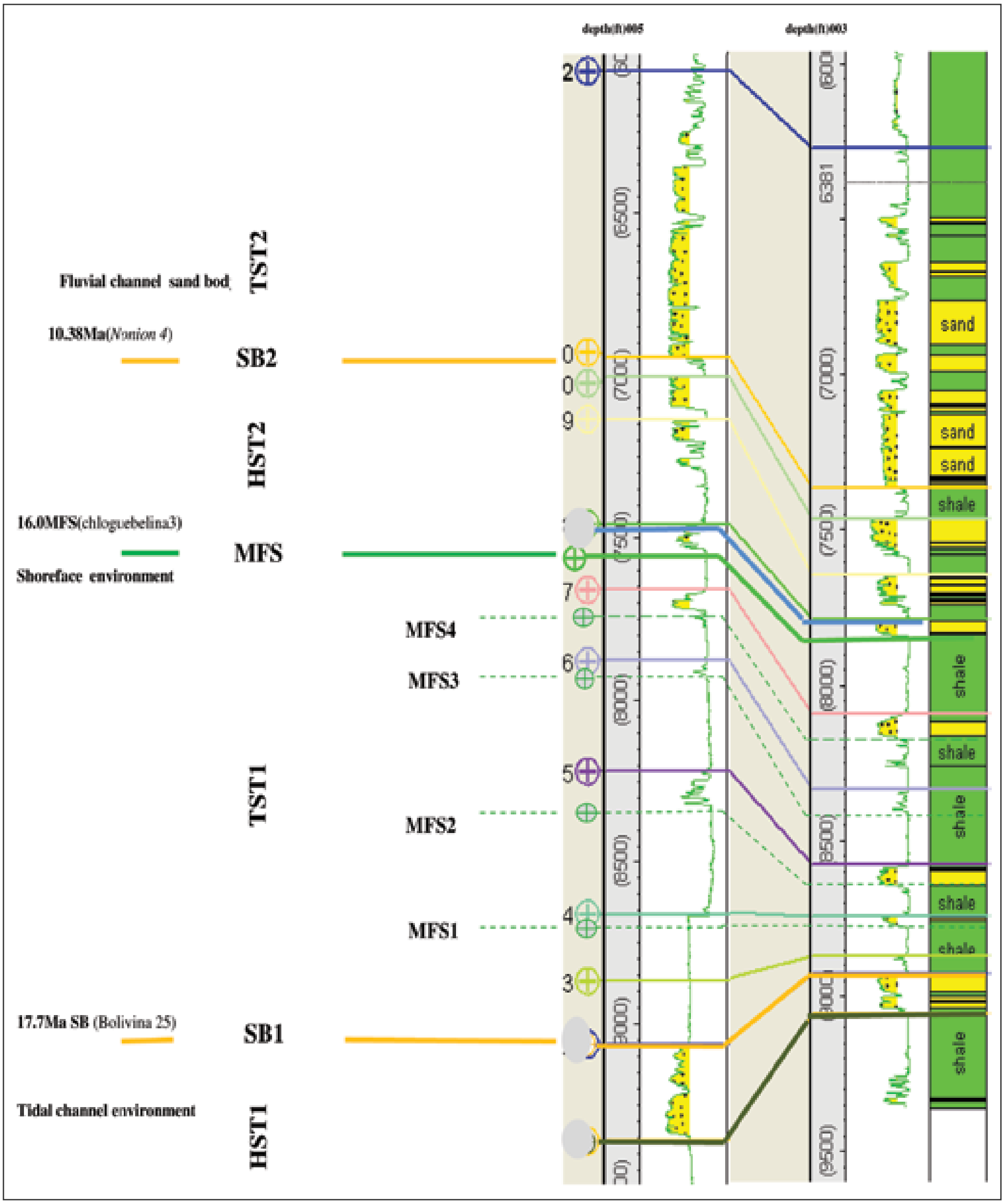

Figure 7. Sequence stratigraphic correlation and depositional environment setting of K-Field showing Wells 005 and 003

base of the Benin Formation. It was penetrated by Wells 005 and 003 at depths 7 000 ft (2 134 m) and 7 300 ft (2 225 m) respectively. This sequence has a blocky log shape which is depicted on the SP log (Figure 5) and indicates a channel sand deposit (Serra, 1985). This is well correlated to the Niger Delta chronostratigraphic chart (Figure 6).

Description of the third order depositonal sequences of wells

Sequence stratigraphic model developed for K-Field was based on the interpretation carried out on Wells 003 and 005 that penetrated different subsurface lithologies. Figures 4, 5 and 7 show the representation of the interpretation of the wells.

Well 003

The sequence 1 of this well ends at 8 575 ft (2 598.5 m) (Figure 7) and is capped by the Highstand Systems Tract. Sequence 2 of this well starts with a cresent shaped log pattern , which grades into a prograding complex. The basal unit starts at a depth of 9 055 ft and ends at 7 000 ft. It is bounded below by the shallow marine deposits (Figure 7) which marks the base of this Sequence Boundary. The Transgressive system tract covers a total depth of about 1 055 ft (320 m) as it exihibits an aggradational parasequence set terminated at the top by the major condensed section embedded in the 16.0 Ma Maximum Flooding Surface.The Highstand systems tract starts from the top of TST1 at depth 7 450 ft (2 257.6 m) to 6 950 ft (2 106 m). This systems tract terminates at the 10.38 Ma Sequence Boundary.

Well 005

The first sequence in this well started from the base of the well and ends at 8 945 ft (2 710.6 m) (Figure 7). This is capped by high system tract. The second sequence in this well starts at the depth of 8 985 ft (2 723 m) and the depositional episode commenced with the deposition of Trangressive Systems Tracts. These lie unconformably on the lower boundary, culminating in the Transgressive peak at the Maximum Flooding Surface with lowest shale resistivity and high value on the SP log at a depth of 7 550 ft (2 294.8 m). This in turn initiated the blocky sand of the the Highstand Systems Tract, which extends from the top of the Maximum Flooding Surface and terminates at 6 950 ft (2 112.5 m) and (2 226.7 m), at a position which marks the end of the second sequence boundary.

Depositional environment

The depositional environments were delineated based on SP log signatures. Depositional environments delineated in this study include the tidal channel complex and the shelf environment (Figure 7). The blocky shaped pattern is characteristic of the distributary channel sediments deposited in a shallow marine environment (Figure 5). This corroborates the findings of Ser-

RA, (1985) This signature is represented by a kick to the left of the SP baseline. Flooding surfaces, identified with marine shales, can be recognized below as a large right kick on the SP log (Figure 7). This significant signature typifies the shelf environment. The inner shoreface environment is marked generally by an upward decrease in shale content from the proximal to the distal portion of the field. This corroborates the findings of WILLIS & BENNETT, (1994).

A typical model constructed for the Field was done using Well 005 (Figure 7). It shows that the deposited sequence starts with a tidal channel environment, with an interfingering of sandy sediments which is capped by the Transgressive system tract with marine shale marking the maximum flooding surface which also hosts the condensed section. This sequence change into shoreface environment having sand bodies at the base. This typifies the concept described by EMERY et al., (1996) Subsequently, the next sequence recognized starts with a fluvial channel sand body, characterized by some extensive marine shale deposits (Figure 7).

SUMMARY AND CONCLUSION

The concept of sequence stratigraphy was applied to the K-field, within the western Niger Delta, Nigeria. This was based on biofacies analysis, well log shapes/trends, pollen and foram zones data which were utilized independently and later integrated with well logs to within a chronostratigraphic framework for the field.

Two sequence boundaries at 8 900 ft (2 697 m) and 9 050 ft (2 742.4 m), and one maximum flooding surface at a depth of 7 650 ft (2 318.2 m) were recognized in well 5 and utilized to subdivide the stratigraphic succession into depositional sequences and their corresponding systems tracts. Highstand and Transgressive systems tracts were recognized in each of the three depositional sequences. Marker shale, characterized by *Chloguebelina* 3 (16.0 Ma) was used to date the key bounding surfaces with the aid of the Niger Delta chronostratigraphic chart as Early to Late Miocene.

The Highstand systems tracts are characterized by shale-rich upward coarsening sands, having poor reservoir quality, while the transgressive systems tracts are characterized by thick sandy shale units, indicating good quality seals to reservoirs. Arising from the SP logs motifs, the depositional environments inferred include tidal channel, shoreface and shelf environments, typical of shallow marine depositional setting.

This model will therefore serve as a guide to the development of K-field and assist in further exploration activity.

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References

Avbovbo, A. A. (1978): Tertiary lithostratigraphy of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 62, p. 295–300.

Burke, K. (1972): Longshore drift, submarine canyons, and submarine fans in development of Niger Delta: American Association of Petroleum Geologists, v. 56, p. 1975–1983.

Busch, W., Schneider, G. & Mehnert, K. R. (1974): Initial melting at grain boundaries. Part II: melting in rocks of granitic, quartz dioritic, and tonalitic composition. *Neues Jahrbuch für Mineralogie, Monatshefte* 345–370.

Doust, H. & Omatsola, M. E. (1990): Niger Delta, In: Edwards, J. D. and Santogrossi, P.A., (eds.) , Divergent/passive Margin Basins, AAPG Memoir 48: Tulsa, American Association of Petroleum Geologists, p. 239–248.

Ekweozor, C. M. & Daukoru, E. M. (1984): Petroleum source bed evaluation of Tertiary Niger Delta--reply: American Association of Petroleum Geologists Bulletin, v. 68, p. 390–394.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W. A., Molloy, F. A. & Rowlands, P. H. (1978): Hydrocarbon habitat of Tertiary Niger Delta: American Association of Petroleum Geologists Bulletin, v. 62, p. 277–298.

Haq, B. U., Hardenbol, J. & Vail, P. R. (1988): Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: Wilgus, C. K., Hasting, B. S., Kendall, C. G. St., Posamentia, H., Ross, C. A., and Van Wagoner, (eds.).Sea-level –an integrated approach, Jour. Soc. Econs. Paleotol. Mineral. Spec. Publi. 42, p. 47–70.

Klett, T. R., Ahlbrandt, T. S., Schmoker, J. W. & Dolton, J. L. (1997): Ranking of the world's oil and gas provinces by known petroleum volumes: U. S. Geological Survey Open-file Report-97–463, CD-ROM.

Knox, G. J. & Omatsola, M. E. (1989): Development of the Cenozoic Niger Delta in terms of the escalator regression model and impact on hydrocarbon distribution, In: W. J. M van der Linden, S. A. P. L, Cloetingh, J. P. K., Kaasschieter, W. J. E., van der Graff, J., Vandenberghe, and van der Gun, J. A. M., (eds), KNGMG Symposium on Coastal lowland Geology and Geotechnology, Proceedings: Dordrecht, The Netherlands, Kluwer Academic Publishers, p. 181–202.

KULKE, H. (1995): Nigeria, In: Kulke, H., (ed.), Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica: Berlin, Gebrüder Borntraeger, p. 143–172.

NTON, M. E. & ADESINA, A. D. (2009): Aspects of structures and depositional environment of sand bodies within tomboy field, offshore western Niger Delta, Nigeria. RMZ – Materials and Geoenvironment, Vol. 56, No. 3, pp. 284–303.

OGUNGBEMI, T. S. (2009): Sequence stratigraphic framework of k-Field in part of Western Niger Delta, Nigeria,. Unpublished M.Sc thesis , Department of Geology, University of Ibadan, 73 p.

REIJERS, T. J. A., PETTERS, S. W. & NWAJIDE, C. S. (1997): The Niger Delta Basin, *in* Selley, R.C., ed., African Basins--Sedimentary Basin of the World 3: Elsevier Science, Amsterdam 3, pp. 151–172.

SELLEY, R. C. (1991): The third age of log analysis--application to reservoir diagenetic studies [abs.]: The Log Analyst, v. 32, no. 4, p. 381–82.

SERRA, O. (1985): Sedimentary environments from wireline logs: Schlumberger Technical Services, Paris, Document No. M-081030/ SMP-7008, 211 p. [Extracted from Serra, O., 1986, Fundamentals of well-log interpretation v. 2--the interpretation of logging data, chapters 4-6: Elsevier Science Publishers, Amsterdam, Developments in Petroleum Science No. 15B, 684 p.].

SHANNON, P. M. & NAYLOR N. (1989): Petroleum Basin Studies: London, Graham and Trotman Limited, p 153–169.

SHORT, K. C. & STAUBLE, A. J. (1967): Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 51, p. 761–779.

STACHER, P. (1995): Present understanding of the Niger Delta hydrocarbon habitat. In: Oti, M.N., and Postma, G., (eds.), Geology of Deltas: Rotterdam, A.A. Balkema, p. 257–267.

VAIL, P. R. (1998): Sequence stratigraphy workbook, fundamentals of sequence stratigraphy: 1999 AAPG Annual convention short course: Sequence stratigraphy interpretation of seismic, well log and outcrop data, presented by P. R. Vail and J. B. Sangree, March 19, 1998, Houston, Texas.

VAN WAGONER, J. C., MITCHUM, R. M., CAMPION, K. M. & RAHMANIAN, V. D. (1990): Siliciclastic sequence stratigraphy in well logs, cores and outcrops: concept for high-resolution correlation of time and facies, AAPG methods in exploration series, No. 7, 55 pp.

WILLIS K. J. & BENNETT K. D. (1994). The Neolithic transition - fact or fiction? Palaeoecological evidence from the Balkans. *The Holocene* v. 4, p. 326–330.