Entropy Concept In Determining Reservoir Continuity: A Case Study Of An Onshore Field In The Niger Delta.

Kelechi Azubuike-Ijomah, Maxwell A. Ijomah

ABSTRACT: The entropy concept was introduced to determine the degree of randomness of the lithofacies in succession using the pre-depositional ($E_{(pre)}$) and post-depositional ($E_{(post)}$) entropy system of an onshore field in the Niger Delta. The whole sedimentation process followed the type B symmetrical Hattori plot. It is interpreted as bypassing of sediments, forming a thickening and thinning sequence of sediments which is attributed to fluctuations and changing of environment of deposition as the flow pattern changes from deltaic to shallow marine environment. The broad random degree and lateral continuity of sedimentation process showed that the cross-bedded coarse grained sandstone (SCC) and parallel laminated mudstone (MPL) facies have the lowest lateral continuity, while the planar/parallel laminated sandstone (SPL) has the highest lateral continuity.

Keywords: Entropy concept, Type B symmetrical, Hattori plot, and Lateral continuity.

INTRODUCTION

Johannes Walther Law of facies (1894), states that the vertical succession of facies is produced by the lateral migration of one environment over another. However, where there are breaks in the succession, seen as sharp or erosional contacts between facies, then the facies succession need not reflect laterally adjacent environments but could well be the products of widely separated environments. That is, in a conformable stratigraphic section, facies are laid laterally and subsequently affected by non-deposition or post-depositional tectonic activities. Hence, sedimentary environments that started out side-by-side will end up overlapping one another over time due to transgressions and regressions. However, Walther's law can only apply to sections without unconformities and sub-dividing diachronous boundaries, for example, maximum flooding surfaces (mfs), transgressive surfaces (TS), etc, and sections without unconformities. The entropy concept is an extension of Markov chain process (as proposed by Hattori (1976) and only employed where lithologic sequence is found to be governed by a Markovian process. That is, where cyclicity is found to exist, the entropy concept is applied to evaluate the degree of randomness. Cyclicity in sedimentary system simply implies that one lithologic state determines the succeeding state. Hattori (1976), recognized two types of entropies with respect to each lithological state; one is post–depositional entropy and the second one is pre–depositional entropy. He used the interrelationships of Ei(post) and Ei(pre) to classify six types of sedimentary cycles based on studies of several lithological sequences belonging to different environments and grouped their entropy states as Asymmetric cycles, Symmetric cycles and Strongly disorganized cycle (fig. 1).

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The Bouma's model considered sedimentary cycle involving a set of lithological elements (e.g. A, B, C, D) and repeating in a different way through a succession. These sedimentary cycles were classified in three ideal groups regarding to the succession order; symmetric successions(A-B-C-B-A), asymmetric successions (A-B-C-A-B-C) and random cycle (A-C-A-B-C-A).

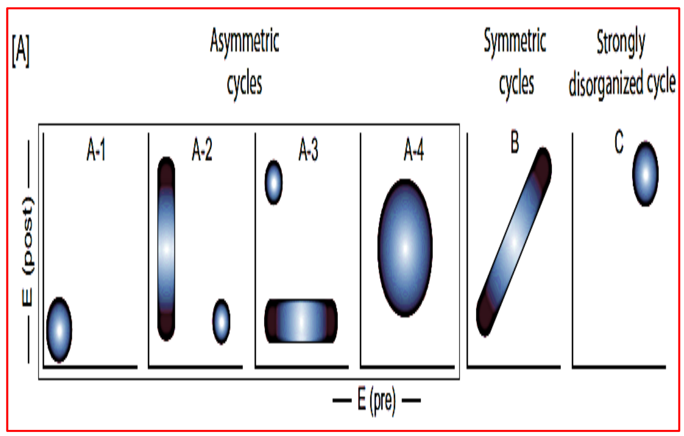

***Figure 1:** Sampled Entropy sets after Hattori (1976). The distributions A-1, A-2, A-3 and A-4 are representatives of asymmetric cycles. B: symmetric cycle and C: strongly disordered.*

The entropy model uses the Esystem to get a broad depositional environment evaluation by plotting Esystem against the number of states as modeled after Hattori (1976).

AIM OF THE STUDY

To determine the lateral extent and continuity of reservoirs within the study area by applying entropy method at studying the lithofacies units, and determine the depositional environment setting.

GEOLOGY OF THE NIGER DELTA REGION

Niger Delta is one of the world's largest tertiary delta systems. It is located in the Gulf of Guinea in West Africa, on the passive continental margin near the western coast of

Nigeria, between latitudes 3°N and 6°N and longitudes 5°E and8°E (Reijers et. al, 1996)(Fig.2). It has its boundary in the west by the Benin flank and in the east by the Calabar flank, which is a subsurface expression of the obanmassif (Stonely, 1966). It has its limits in the south by the Gulf of Guinea and on the north by older (Cretaceous) tectonic elements, such as the Anambra Basin, Abakilili Uplift and Afikpo Syncline (Ejedawe, 1981). It is one of the subaerial basins in Africa, having subaerial area of about 75,000 km^2, a total area of 300,000km^2, a sediment fill of 500,000 km^3 and sediment depth fill of between9-12 km (https://en.wikipedia.org/ wiki/Niger_Delta_Basin).

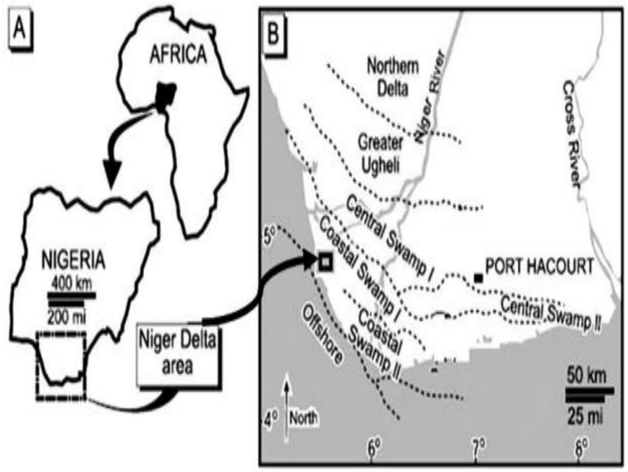

Fig. 2: *Location map showing the Niger Delta (Ahiarakwem et. al., 2012).*

Reijers 1997, broadly categorized the Cenozoic Niger Delta into three distinct facies belts: continental delta top facies, paralic delta front facies and the marine prodeltafacies. This facies describes continental, transitional and marine depositional environment respectively (Fig.3) The Niger Delta depositional environment and lithofacies studies based on paleoenvironment, sedimentology and stratigraphy established a model that distinguished different facies variation as a product of energy, wave dominated, constructural, arcuate-lobate tropical delta (Reijers, 1996).

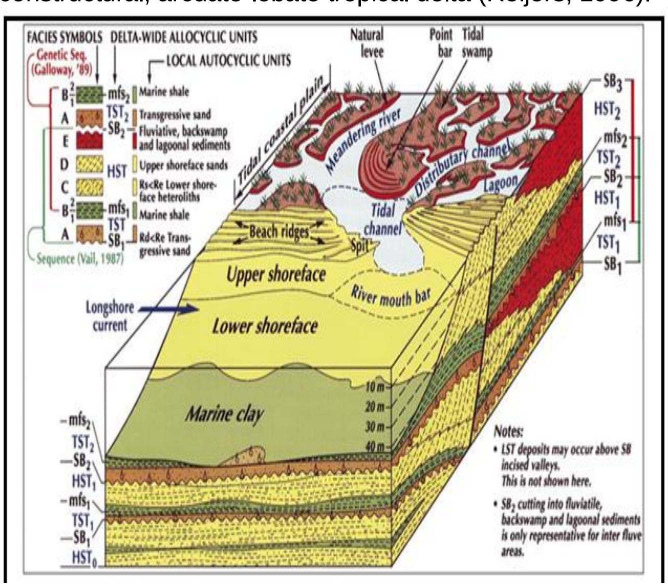

Fig.3: *Depositional Environments settings of the Niger Delta (after Webers 1971, Reijers 2011).*

The delta top environment is characterized by fluvial processes and this control deposition at the lower flood plain, while the tidal current influences coastward sweeping the river platform. The lithology of the subsurface describes the depositional environments, with sand-shale ratio, foraminiferal assemblages and mutual juxtaposition. The wave dominated delta observed today with prevailing southwest winds and long shore currents has persisted since the Miocene. The pre-Miocene delta could have had a more lobate, fluvial dominated character as it is less influenced by long shore currents (Doust et. al., 1989). Numerous offlap cycles is seen in the paralic sequence with thickness range of 15-100m (Weber and Daukoru, 1975). The sandy part of the paralic sequences comprises of barrier bars, point bars, distributary channels, tidal channels, river mouth bars, shallow marine bars and levees (Weber et. al., 1975). On a thickness scale of 15m to 60m (rarely 100m) is the offlapping regressive unit, exhibiting a well developed cyclicity, comprising at top: fluviatile backswamp and lagoonal sediment, barrier bar deposits, laminated fluviomarine sediments and marine shales while the base is transgressive marine sand. This basal transgessive sands are thin, shelly and glauconitic. As a result of reworking of the older cyclotherms, they are seen as deposited in waters deeper than 30m. The sands grade upwards through silty clays and barrier foot streaky sands into coarse barrier bar sands, which form the best reservoir units. Associate with the final fluviatile stage is the fluviatile, tidal or estuarine channel sand fills and they commonly disrupt the reservoir continuity. At the top of the cycle is the backswamp deposit consisting of silty clays, sands and coals.

METHOD OF STUDY

This work applied the entropy concept on an established area of Markovian presence|cyclicity, to determine the degree of randomness of the lithofacies in succession. Six lithofacies were studied: cross-bedded coarse grained sandstone (SCC), cross-bedded medium grained sandstones (SCM), planar/parallel laminated sandstone (SPL), wavy rippled sandy heterolith (SWH), parallel laminated mudstone (MPL), and wavy rippled muddy heterolith (MWH). We calculated for post depositional entropy and pre-depositional entropy, expressed as:

$$E_i^{(post)} = -\sum_{j=0}^{n} P_{ij} * \log\left(P_{ij}\right)$$

$$E_i^{(pre)} = -\sum_{j=0}^{n} Q_{ij} * \log\left(Q_{ij}\right)$$

Ei (post) and Ei(pre) together form an entropy set for state (i), and serves as indicators of the variety of lithological transitions immediately after and before the occurrence of (i), respectively. When Ei (pre) = Ei(post), it indicates a non-depency of any state on the other and when Ei (pre) > Ei(post), it indicates that the depency of any lithologic state on its preceding facie is minimal and it can thus possibly occur after a different state, when Ei (post) > Ei(post), it means that the dependency of a lithologic unit on its preceding facie is stronger than its influence on its succeeding facie. This is a clear statistical relationship that reasonably support the geological fact and conclusion that deposition of any lithology is largely dependent on a specific environment. Result is presented in tables 1a and 1b.

UPWARD POST-DEPO ENTROPY Ei(Post)

FROM	TO						Row Total
	SCC	SCM	SPL	SWH	MPL	MWH	
SCC	0	0.00	0	0	0	0	0
SCM	-4.75	0	0.5	0	0	0.00	-4.25
SPL	0	0.00	0	0.35	0	0.51639	0.86
SWH	0	0	0.22	0	0.430827	0	0.6500224
MPL	0	0	0	0	0	0.00	0
MWH	0	0	0.00	0	0.50	0	0.50

Table 1a: *Upward Post-Entropy*

DOWNWARD PRE-DEPO ENTROPY Ei(Pre)

FROM	TO					
	SCC	SCM	SPL	SWH	MPL	MWH
SCC	0	0.31		0	0	0
SCM	0.00	0	0.5164	0	0	0.00
SPL	0	0.00	0	0.22	0	0.52877
SWH	0	0	0.35	0	0.528321	0
MPL	0	0	0	0	0	0.44
MWH	0	0	0.00	0	0.39	0
Column TOTAL	0	0.31	0.86	0.219195	0.918296	0.97

Table 1b: *Downward Pre-Entropy*

A normalized entropy (En) was evaluated to eliminate increasing influence of lithologic facies states on Ei(post) and Ei(pre) (according to Hattori 1976). This is expressed as:

$$E_n = E/E_{max},$$

$$\text{Where, } E_{max} = -\log_2(1/(n-1))$$

Where, En is the normalized entropy, E is either post–depositional or pre–depositional entropy, and Emax is the maximum entropy possible in a system where n state variable operates. The value of E (system) varies between" $-\log_2 1/n$" and "$-\log_2 1/n(n-1)$". Result is presented in table 2 and Chart 1. Entropy for the whole sedimentation process as a measure of depositional system was interpreted (using Hattori 1976 method). This is expressed as:

$$E\ (\text{system}) = -\sum_{i=1}^{n}\sum_{j=1}^{n} rij \log_2 rij, \quad \text{where } rij = fij/n$$

FACIES	Ei(Pre)	Ei(Post)	En(Pre)	En(Post)	RELATIONSHIPS
SCC	0	0	0	0	En(Pre) = En(Post)
SCM	0.31	1	0.0645	0.2080146	En(Pre) < En(Post)
SPL	0.86	0.86	0.1789	0.17889255	En(Pre) = En(Post)
SWH	0.22	0.65	0.0458	0.13520949	En(Pre) < En(Post)
MPL	0.92	0	0.1914	0	En(Pre) > En(Post)
MWH	0.97	0.52	0.2018	0.10816759	En(Pre) > En(Post)

Table 2: *Normalised Entropy and Relationship*

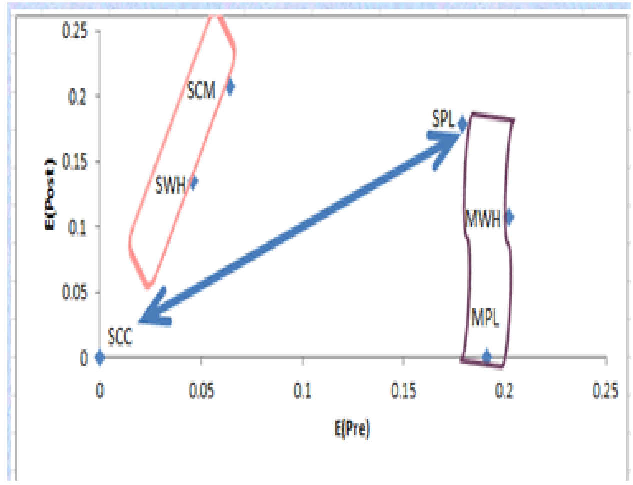

Chart 1: *Entropy Relationship of En(pre) and En(post).*

E-system

FROM	TO						Row To
	SCC	SCM	SPL	SWH	MPL	MWH	
SCC	0.00	0.34	0.00	0.00	0.00	0.00	0.34
SCM	0.27	0.00	0.27	0.00	0.00	0.00	0.53
SPL	0.00	0.00	0.00	0.44	0.00	0.27	0.70
SWH	0.00	0.00	0.44	0.00	0.17	0.00	0.60
MPL	0.00	0.00	0.00	0.00	0.00	0.34	0.34
MWH	0.00	0.17	0.00	0.17	0.27	0.00	0.60

Table 3: *E(system)*

RESULTS AND INTERPRETATION

From table 2, it is seen that En(Pre) = En(Post) for the cross-bedded coarse grained sandstone (SCC) facies and Planar/Parallel Laminated Sandstone(SPL), indicating there is no dependency of Pre-deposition or post-deposition existing there. For the cross-bedded medium grained sandstone(SCM) and the Wavy Rippled Sandy Heterolith (SWH), the En(Pre) < En(Post), implying that they have stronger dependence on the preceding facie to occur than on succeeding bed. For the Planar Laminated Mudstone (MPL) and Wavy Rippled Muddy Heterolith (MWH) facies, En(Pre) > En(Post), indicating that they have minimal dependency of occurrence on the preceding facie, meaning they could individually occur after a different state. It is seen in presented normalized entropy result that the ($E_{(pre)}$) and ($E_{(post)}$) for all the lithofacies ranges from 0 – above, implying they do not all overlie each other and some are not overlain by more than one state. A plot of the Esystem against the individual number of states (chart 2), interpreted the entropy for the whole sedimentation process following the type B symmetrical Hattori (1976) plot. It showed a thickening and thinning sequence of sediments which is attributed to fluctuations and changing of environment of deposition as the flow pattern changes from deltaic to shallow marine environment. This also illustrated the broad random degree and lateral continuity of sedimentation process; the cross-bedded coarse grained sandstone

(SCC) and parallel laminated mudstone (MPL) facies has the lowest lateral continuity while the planar/parallel laminated sandstone (SPL) has the highest lateral continuity.

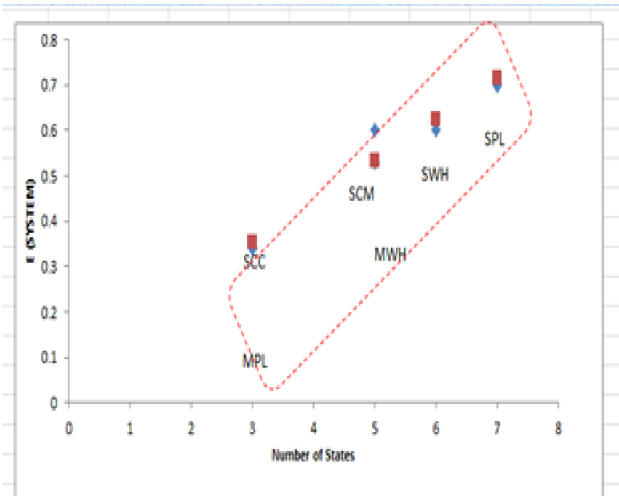

***Chart 2:** E(system) Depositional Environment Interpretation*

CONCLUSION

The lateral continuity of lithofacies is related to the reservoir continuity within the study area. The broad random degree and lateral continuity of sedimentation process showed that the planar/parallel laminated sandstone (SPL) has the highest lateral continuity while the cross-bedded coarse grained sandstone (SCC) and parallel laminated mudstone (MPL) facies has the lowest lateral extent continuity. The sedimentation process as established from Hattori (1976) followed the type B symmetrical plot, interpreted as bypassing of sediments, forming a thickening and thinning sequence of sediments which is attributed to fluctuations and changing of environment of deposition as the flow pattern changes from deltaic to shallow marine environment. This work can be used to improve reservoir management, predict reservoir performance and better future well placements within the study area of the Niger Delta.

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