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Seismic Attribute Analysis for Reservoir Description and Characterization of M-Field, Douala Sub-Basin, Cameroon

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Abstract

Complexity of discontinuous reservoir units occurring within the shale-rich N'kapa Formation and the limitation of well-articulated interpretations deduced from 2D seismic data, led to a new approach of interpretation of the 3D seismic data of M-Field located offshore Douala Sub-Basin, Cameroon. The study aimed at determining the subsurface distribution of the delineated reservoir units in terms of geology, structures, stratigraphic architecture as well as the lateral and vertical distribution of each of the reservoir units across the field. Well log signatures were analyzed and interpreted to identify hydrocarbon bearing sands, which were subsequently mapped to the 3D seismic record using the generated 1D synthetic seismogram to tie the well information to the seismic volume. The delineated hydrocarbon bearing sand bodies were mapped as horizons on the 3D seismic record in addition to subsurface structural mapping to generate subsurface depth structure maps. Further still, amplitude variation surface seismic attribute analyses aid the delineation of geometry of depositional channels across the M-Field. Two horizons ($\mathbf{X_1}$ and $\mathbf{Y_1}$) were interpreted and used to generate surfaces attribute maps. The M-Field reservoirs present stratigraphic architecture which suggests levees or confined channel sands deposit as the dominant channel deposit. $\mathbf{X_1}$and $\mathbf{Y_1}$ are stratigraphic trapped hydrocarbon systems, however, while $\mathbf{X_1}$ is located up-dip, $\mathbf{Y_1}$is situated on a monoclinic slope in the down dip area of $\mathbf{X_1}$, such that $\mathbf{Y_1}$ stratigraphically seats on $\mathbf{X_1}$but eroded around $\mathbf{X_1}$. The high amplitude associated with the delineated erosional surface likely results due to difference in acoustic properties across the interface owing to difference in age and composition of the two units. This suggests that the delineated reservoirs are two different units which are not correlateable as earlier postulated.

Key words: Seismic data; Well logs; Correlation; Douala sub-basin

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INTRODUCTION

There has been a wide application of conventional seismic data interpretation for the purpose of mapping geological structures, subsurface stratigraphy and reservoir architecture with little or no emphasis on the inherent seismic amplitude variations[1]. However, the introduction of the 3D seismic revolution has made the use of amplitudes an integral part of seismic interpretation and also allowed more valuable geological information to be discerned as seismic attributes. Seismic attributes form an integral part of qualitative interpretative tool that facilitates structural and stratigraphic interpretation as well as offer clue to lithology type and fluid content estimation for detail reservoir characterization[13]. Integrating well log data, checkshots, seismic data and seismic attributes could reveal numerous architectural as well as structural anomalies and greatly reduce the risk associated with hydrocarbon exploration . M-Field is located geographically in the littoral region and geologically lies within the N'kapa Formation of the

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Douala sub-basin. This formation is characteristic of the Drift 2 tectonic event[3] and seismically characterized by low, medium to discontinuous seismic reflections[10]. The main purpose of this study is to through extraction and analyses of seismic attributes of M-Field identify various reservoirs, understand the geometry and architecture as well as establish the relative stratigraphic position of delineated reservoirs within the M-Field.

1. LOCATION AND GEOLOGICAL SETTING OF STUDY AREA

The study area is located offshore in the Douala Sub-Basin (Figure 1) that falls within the Douala/Kribi-Campo (DKC) Basin. The DKC Basin covers the northern end of the South Atlantic rift and constitutes the northern part of the Aptian Salt Basin of Equatorial West Africa extending to Namibia in the south[3]. It is one of a series of divergent passive margin basins covering a total area of 19 000km² including 7000km^2 onshore. It is subdivided into the Douala sub basin and the Kribi-Campo sub basin (due to the occurrence of the Kribi Formation). The formation is associated with the breakup of the Gwondwanaland[4] and was developed through a series of stages including the Pre-rift, syn-rift and post-rifting phases.

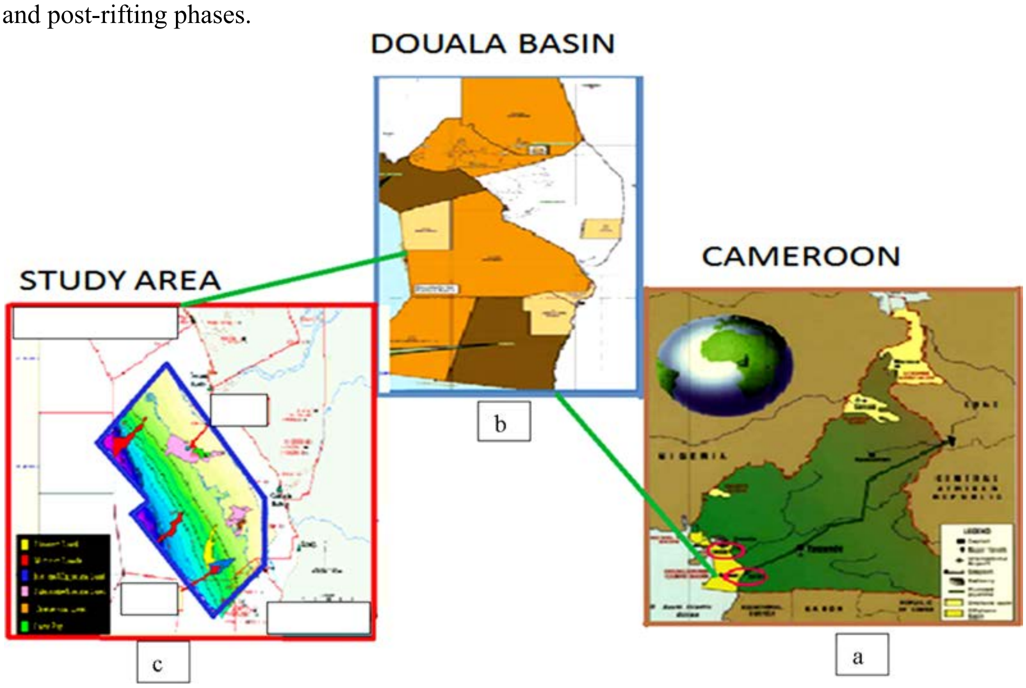

Figure 1
Location Showing Caeroon (A), the Doula Kribi Campo Basin (B) and the Study Area (C).

The formation is characterized by various source rocks, reservoirs and seals as well as traps. Eight lithostratigraphic units which include Mundeck, Logbadjeck, Logbaba, N'kapa, Souellaba, Kribi (Unnamed), Mantanda and Wouri Formations have been recognized (Figure 2).Reservoir rocks in the Douala Basin consist of Lower Cretaceous submarine fans and fan-delta sandstones with porosities ranging from 20 to 25 percent and permeabilities as high as 142 mD[14].The DKC was formed during the Mesozoic to Tertiary and its structural/stratigraphic elements are similar to the Rio Muni Basin in Equatorial Guinea in which the Ceiba, Okume and Oveng are producing. Recent studies carried out by[10] has established the onshore deposits into five seismic packages including the Mundeck, Logbaba, Souellaba, N'kapa and Matanda seismic packages based on the habit of 2D seismic reflections. The N'kapa Formation which is the formation of interest was deposited during the Palaeocene with no evidence of fault reactivation during the time when the Atlantic was still experiencing extension and neighboring basins were undergoing subsidence and associated eustatic sea level changes that resulted in extensive marine deposition within aerially restricted shelfs. It represents the top package of the Megasequence B dominated by silty mudstones and argillaceous sandstones and represents muddy shelf environment[10]. The reservoirs are mainly deep-water turbidite and characterized mostly by stratigraphic trap (syn-sedimentary) mounds and sand sheet as well as sub-unconformity traps formed beneath the Souellaba Formation.

2. MATERIALS AND METHODS

The study entailed the integration of 3D seismic reflection and wireline log data with other supporting information such as checkshot survey data, formation well tops and well reports to qualitatively and quantitatively determine

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the architecture, correlative and the spatial variability of important reservoir properties. The materials provided for the study include; Well data (LAS files) for two wells named as **X** and **Y** in this project, checkshot data for **Z**-Well, 2800km^2 3D seismic data (SEGY) with good resolution, normal polarity and a base map of the study area. Special attention was paid in primary zones of interest occurring within 2000-4000 ms.

Well logs which record different physical borehole parameters against depth were interpreted and subjected to various petrophysical analyses as well as litho-stratigraphic correlation across wells locations in order to establish the distribution and behavior of the lithological units across different well points. Well log parameters including gamma radiation, resistivity, density, neutron, sonic among others were utilized to identify porous and permeable hydrocarbon-bearing litho-units. In addition, other derivative reservoir parameters such as, reservoir thickness, Net-To-Gross (NTG), effective porosity ($Ø_{eff}$) and hydrocarbon saturation ($1-S_w$) were adopted from[8] (In press) to estimate the hydrocarbon potential of M-Field. Interpretation of the well data was carried out with the use of the lithologs (GR) and resistivity logs to identify the reservoir zones and pick out the reservoir tops and bottoms. Zones of low GR reading with corresponding high resistivity log readings were defined as the reservoirs (Figure 4). Three dimensional (3D) seismic reflection data comprising of in-lines and cross-line seismic sections were carefully analyzed in terms of horizon mapping and attribute extraction and utilized to generate horizon surfaces, depth structural maps as well as define the areal extents and invariably the Gross Rock Volume (GRV) of the identified reservoir units.

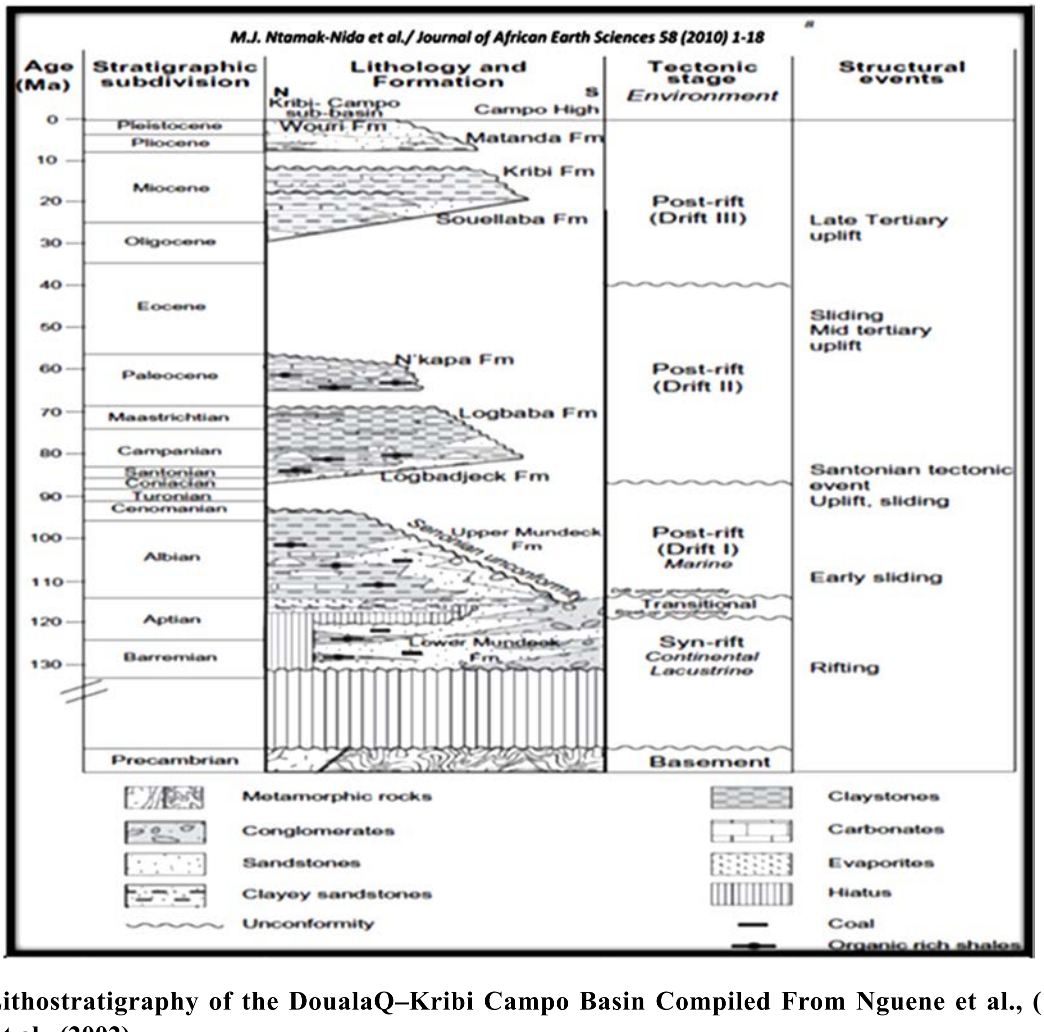

Figure 2
Tectono–Lithostratigraphy of the DoualaQ–Kribi Campo Basin Compiled From Nguene et al., (1992) and Laurence et al., (2002).

Horizon mapping of formations identified to be hydrocarbon bearing from well-log signatures involved identifying the equivalent continuous beds on the seismic section and interpreting them to their point of discontinuity or thinning-out. The horizons with significant hydrocarbon potential were located on the seismic by the posting of hydrocarbon saturated formation tops on the seismic record through seismic to-well-tie

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with the aid of generated synthetic seismogram.

Horizon mapping involved carefully tracing the continuity of the target horizons across the different in- and cross-line sections at every 5th and 10th in and cross-line seismic record using the *3D* auto track and/or manual track tool provided by Petrel interpretation software. Two horizons were carefully traced in total with each looped across the in- and cross-lines to generate horizon surface maps which indicate the spatial distribution of the formation within the subsurface, measured in seismic time (2-way time). Time surface maps were generated from the derived horizon grids with the aid of the *make surface tool* provided by Petrel interpretation software and subsequently converted to depth surface maps using the layer cake velocity model with the aid of sonic calibrated check-shot data [11]. The resultant depth surface maps were used to generate the gross rock volumes (GRV) of the different reservoirs. The GRV defined the oil accumulation region above the Oil Water Contact (OWC). Volumetric analyses were carried out using the STOIIP volume equation (Eq.1) to determine the volume of hydrocarbon initially in place in the two reservoirs. The STOIIP equation uses the various derived parameters such as GRV (thickness of rock unit above the hydrocarbon—water contact (OWC), NTG, effective porosity ($Ø_{eff}$), hydrocarbon saturation ($1-S_w$) as well as the Formation Volume Factor (FVF), which estimates the change in hydrocarbon volume in the form of expansion/shrinkage between the reservoir in the subsurface and the storage tank on the surface, to calculate the volume of hydrocarbon in the reservoir.

$$STOIIP=\frac{GRV*Øeff*(1-Sw)}{FvF} \qquad (1)$$

The deterministic approach was adopted to determine the hydrocarbon volumes in the various delineated reservoir sands[5]. One scenario was employed and involved the calculation of oil volume using average petrophysical parameters such as porosity, NTG and S_w derived from well logs, also using the initial oil formation volume factor[15]. Figure 3 presents the workflow which summarizes the different activity steps embarked upon to characterize M-Field, Douala Sub-Basin, Cameroon.

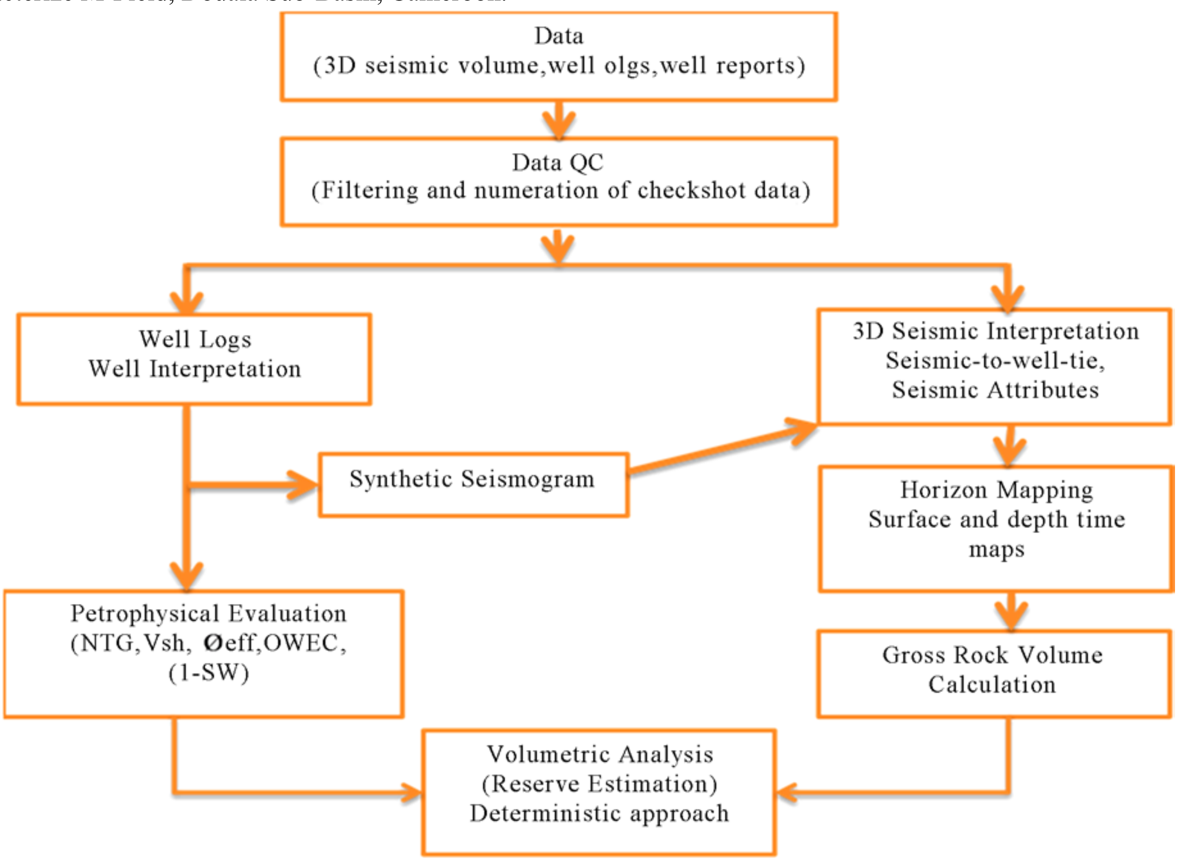

Figure 3
Workflow Adopted to Characterize M-Field, Douala Sub-Basin, Cameroon.

3. RESULTS AND INTERPRETATION

Two reservoirs were identified from Well X and Well Y including X_1 and Y_1 respectively (Figure 4). Well log analyses resulted in the tops of the reservoirs being picked at -2472 m for X_1 reservoir and -2966 m for the Y_1. The petrophysical parameters are summarized in table (1)[8].

The surface areas as well as the gross rock volumes for the X_1 and Y_1 reservoir sands are summarized in table (2). Relatively thin X_1 reservoir has effective (NTG=0.762) thickness of 4.72m and an aerial coverage of 104807900 m^2while Y_1 which is thicker than sand X_1 (NTG = 0.786) has a thickness of 15.09 m and a surface areal coverage of 457962240 m^2. Table 3 presents the summary of the oil saturation and the volumetric analyses using the deterministic approach giving STOIIP volumes of 7353557 m^3 and 79918083 m^3 for reservoir sands X_1 and Y_1, respectively.

Table 1
Quantitative Petrophysical Properties for X_1 and Y_1 Reservoirs

Reservoir	Top	Base	Gross	Net	N/G	AvPhi	AvSw	AvVcl
X	2495.2	2498.4	3.2	---	---	---	---	---
X_1	2502	2508.2	6.2	4.72	0.762	0.208	0.305	0.062
Y_1	2990.8	3010	19.2	15.09	0.786	0.422	0.174	0.062

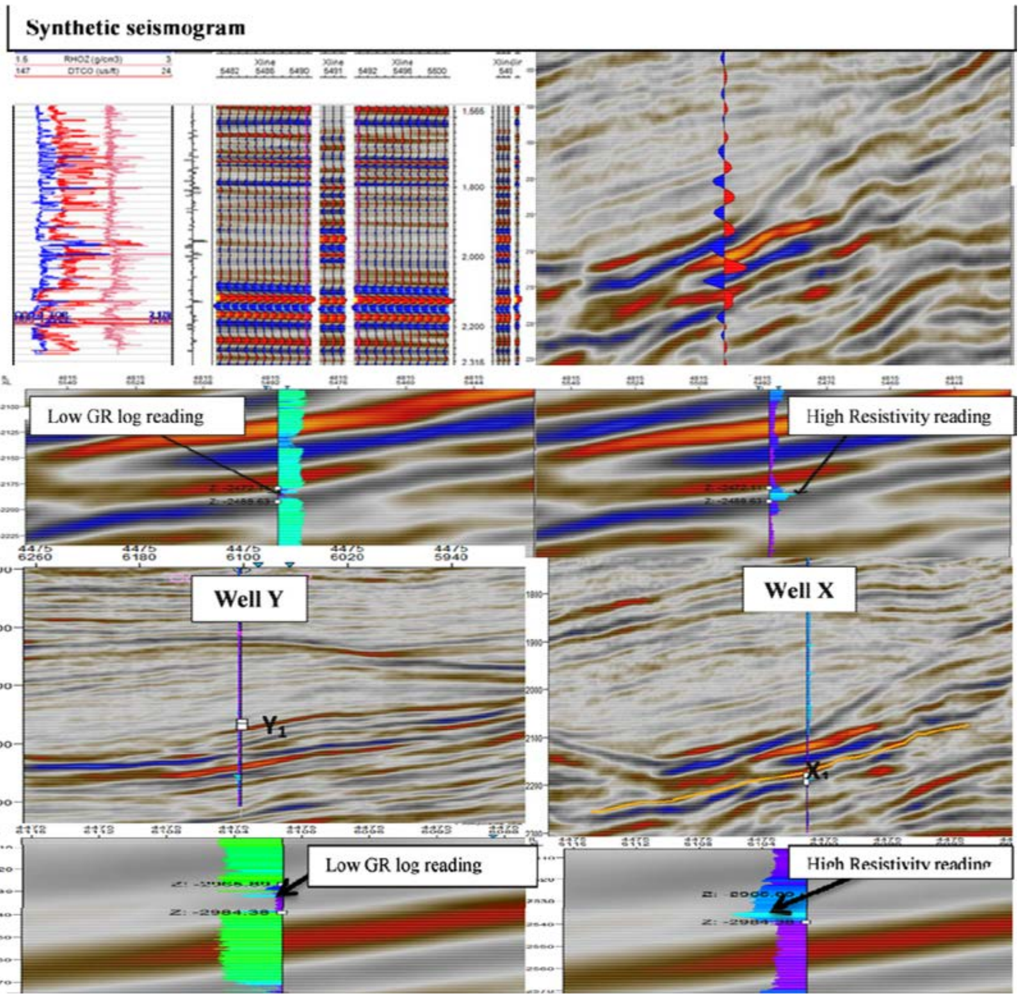

Figure 4
Synthetic Seismogram Used for Seismic-to-Well Tie and Wells X and Y Depicting Their Corresponding Reservoir Zone X_1 and Y_1 Respectively as Defined By Low GR and High Log Readings.

3.1 Seismic Attributes

Selected attributes including acoustic amplitude surface attribute and lower loop surface attributes extracted from the interpreted time surfaces X_1 (Figure 5A) and Y_1 (Figure 5B) respectively are presented in figures 6 and 7. A very strong channel-like acoustic amplitude anomaly is visible in both reservoirs, the channel generally trend ENE-WSW in X_1 (Figure 6B) and E-W in Y_1 reservoir (Figure 7B). Very strong patches of amplitude are also observed in the lower loop surface area amplitude maps for X_1 (Figure 6C) and Y_1 (Figure 7C). An attempt was made to establish the lateral extent of the two reservoirs across the entire area and to situate the stratigraphic relationship between the X_1 and by further extending the mapped horizon X_1 surface to intersect that of Y_1. In this way, it was possible to ascertain if horizon X_1 is a continuation of horizon Y_1. The attribute surface maps for the two extended surfaces are presented in (Figure 8) and it indicates that the two

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reservoir units are individual reservoir units that lie on top of one another. It is observed that Y_1stratigraphically seats above X_1 and has probably been eroded around X_1 indicated by a strong amplitude anomaly (Figure 8C) as a result of difference in acoustic property across the interface which could be related to difference in age and composition.

Table 2
Surface Area and Gross Rock Volume (GRV) for X_1 and Y_1 Reservoirs

Reservoir	Area (in 2D)(m^2)	Length (in 2D)(m)	Length (in 3D)(m)	GRV (m2)
X_1	30364700	70696	81429	104807900
Y_1	50870400	66996	75326	457962240

Table 3
Oil Saturation and Stock Tank Oil Initially in Place for X_1 and Y_1

Reservoir	Oil Saturation	Stock Tank Oil Initially In Place (STOIIP in m^3)
X_1	0.695	7353557
Y_1	0.826	79918083

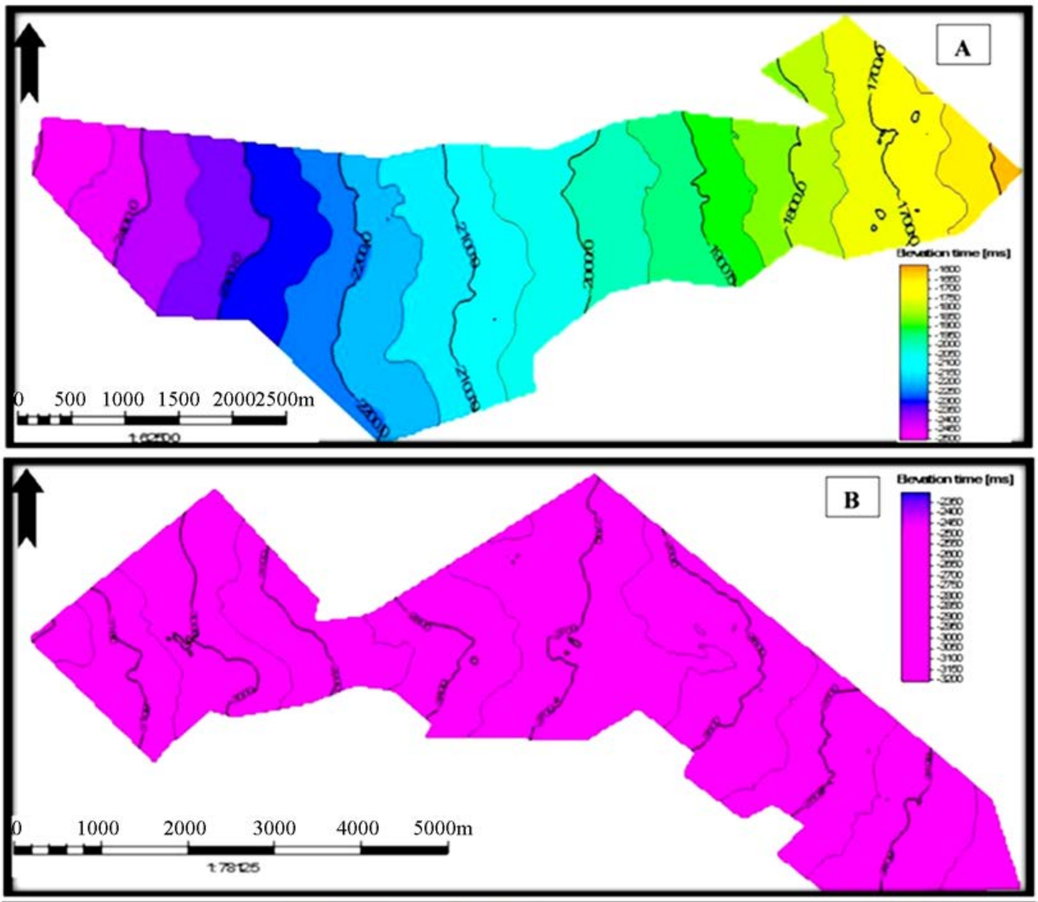

Figure 5
Time Surface Maps for X_1 (A) and Y_1 (B).

3.2 Discussion of Results

Integrated analyses, interpretation and synthesis of various information derived from well logs and 3D seismic volume aided the delineation of two (2) lithologic units with favorable petrophysical properties which were classified as hydrocarbon saturated clastic reservoirs. These reservoirs occur as thin beds within thick shale formations and tend to thin out within the shale formation. The delineated reservoir units presented characteristic cylindrical and funnel shape coarsening upward log motif signatures which indicate that the reservoir sands consist mainly of stacked thin sands and thick shale sequences.

The definitive log signatures and lithologic distribution suggest marine, middle bathyal, with a significant fluvio-deltaic and submarine canyon, with associated submarine fan lobe; distributary channel and levee fill system which suggests heterogeneous reservoir rocks across the study area[2]. The stratigraphic framework as generated from the 3D seismic volume indicates stratigraphic pinch-outs within thick shale deposits as the dominant trapping

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mechanism that confined hydrocarbon fluids to the different reservoir units (Figure 6 and 7). Such reservoirs are mostly lenticular sand bodies with a sand content of 10% - 50%. The attributes used are sensitive to channel edges and can be beneficial for channels identification, reservoir architecture and to interpret lithology and porosity as well. The strong, acoustic amplitude anomalies observed in both reservoirs indicate sand bodies which developed probably as channel and levee deposits trending ENE-WSW and E-W. This reservoir sandstone appears to have formed within the confines of a submarine canyon system. This canyon complex has a well-defined morphology on seismic amplitude map (Figure 5B). Such systems have been reported in the nearby Equatorial Guinea continental slope where we have the Ceiba canyon system[6]. The identified reservoirs occur within the shale-rich N'kapa Formation with the X_1reservoir deposited as a stratigraphic trapped hydrocarbon system located up-dip while Y_1 is also a stratigraphic trap situated on a monoclinic slope in the down dip area of X_1. The reservoirs were deposited as an ENE-WSW trending moderate to highly sinuous channel sands. The two reservoirs are non-correlative and the siting of future exploration wells is very critical and should be guided by the channel architecture.

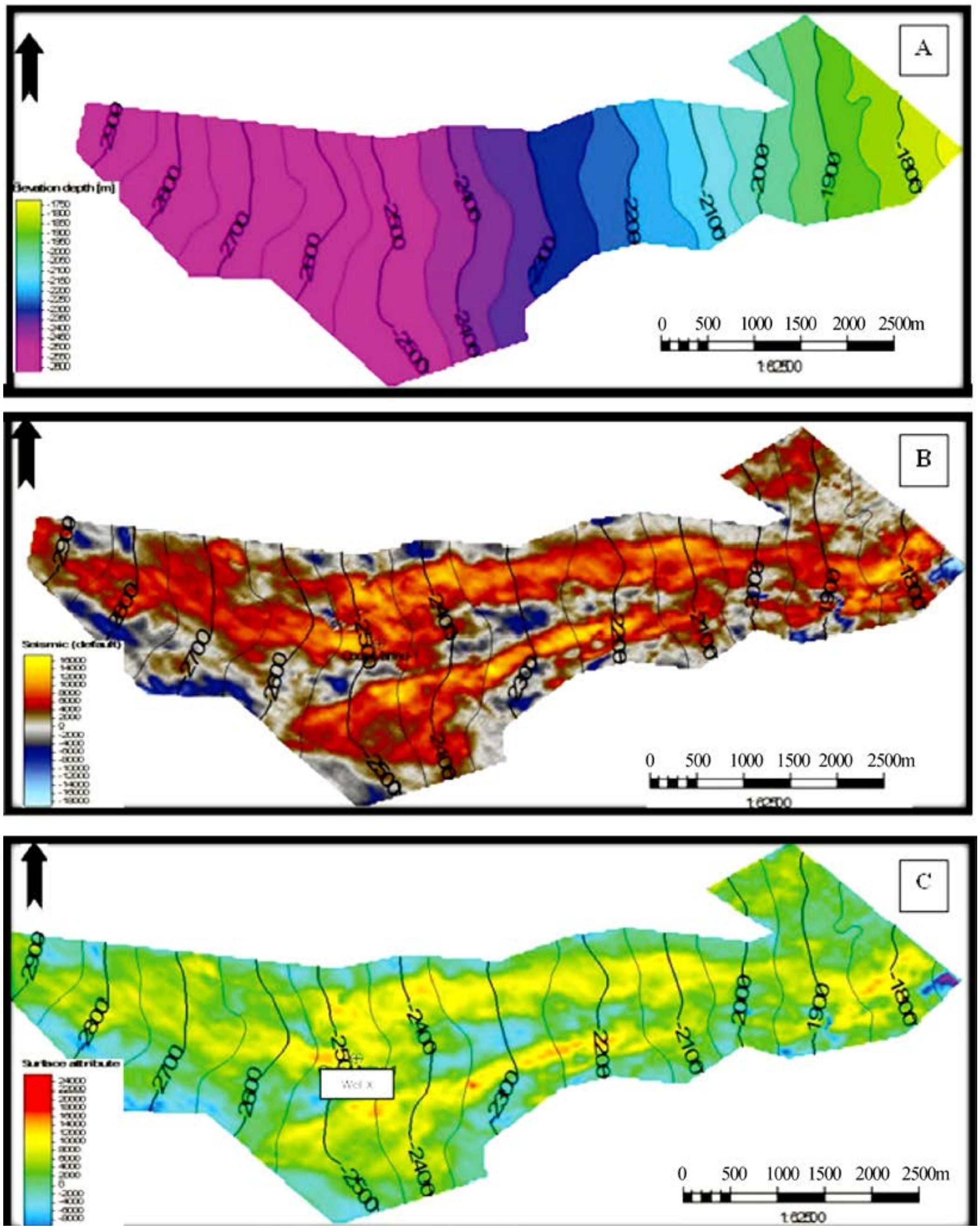

Figure 6
Depth Surface Maps (A), Acoustic Amplitude Surface Attributes (B) and Lower Loop Area Surface Attributes (C) Maps for X_1 Reservoir Indicating a ENE-WSW Channel Architecture.

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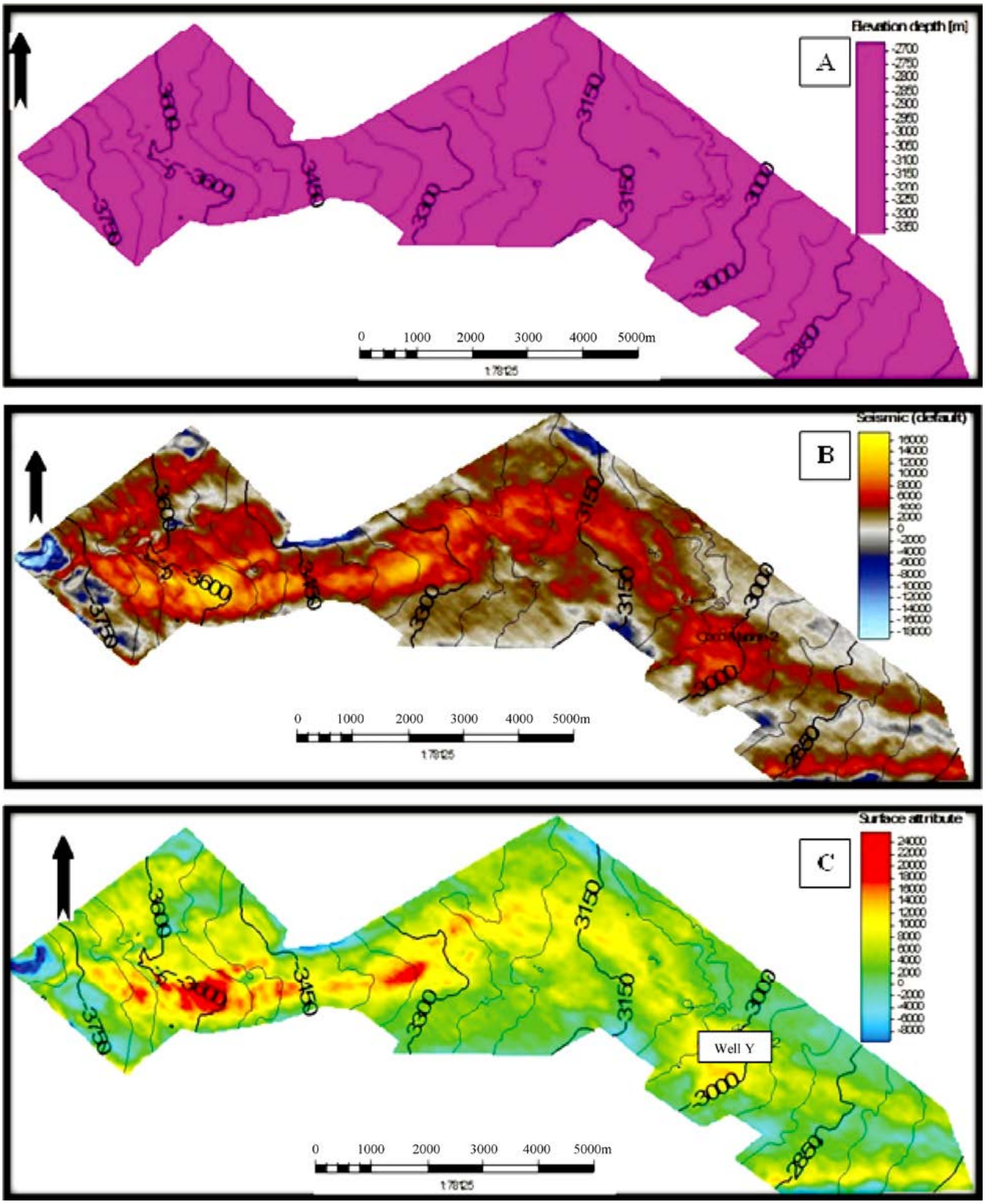

Figure 7
Depth Surface Maps (A), Acoustic Amplitude (B) and Lower Loop Area Surface Attributes (C) Maps for Y_1 Reservoir Indicating E-W Channel Architecture.

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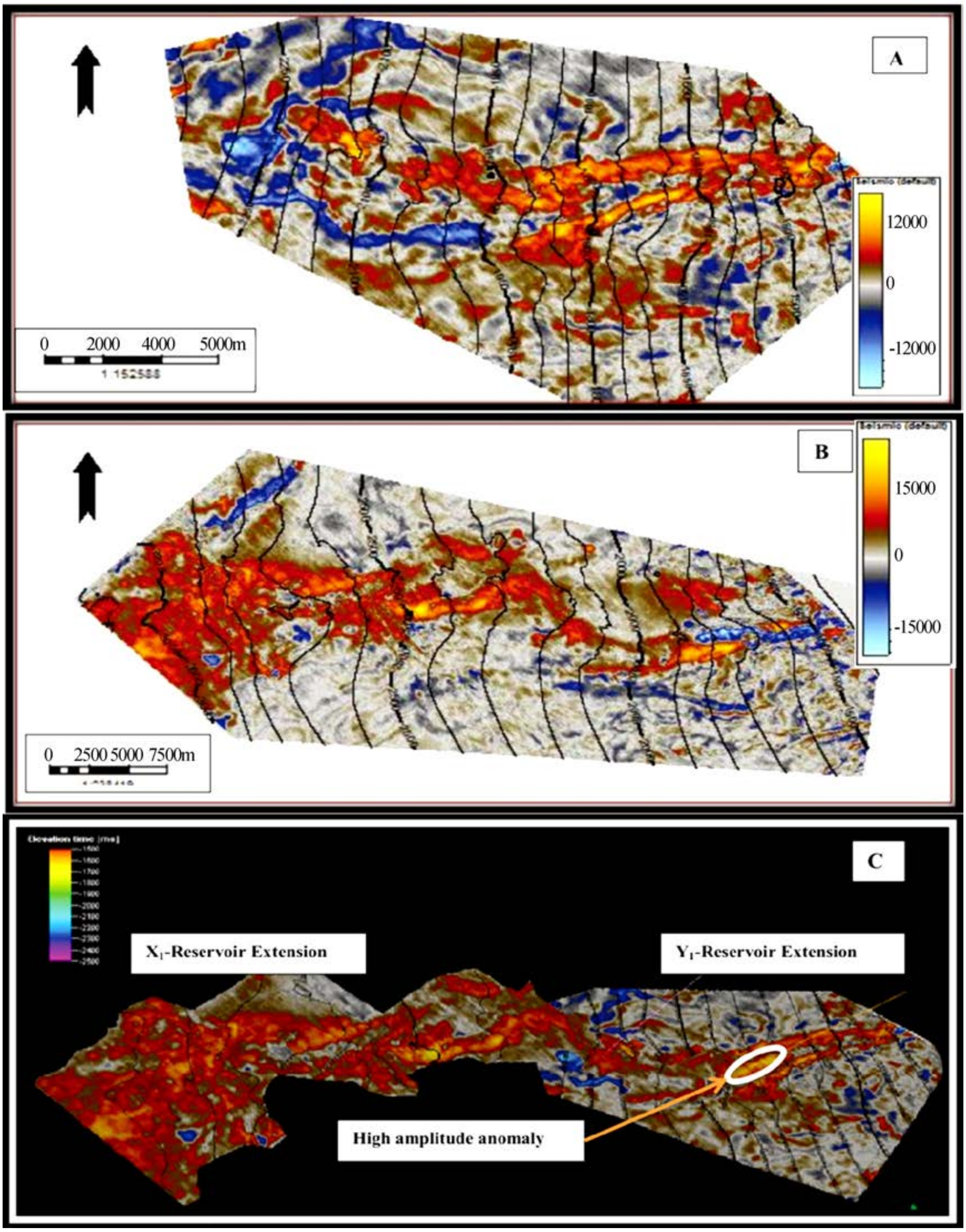

Figure 8
X_1 Reservoir Extention (A) and Y_1 Reservoir Extention (B) Indicating an Extensive Xhannelized System With Strong Acoustic Amplitude Surface Attribute Anomalies Along the Channels With Very Strong Amplitude as Y_1 Approaches X_1 Probably Indicating an Erosional Surface (C).

CONCLUSION

The integration of several subsurface information for the purpose of evaluating the reservoir qualities of M-field, located offshore Douala Sub-Basin in Cameroon has proved successful in identifying the channel architecture and non-correlative nature of the two identified reservoirs. This study integrated and analyzed well logs and 3D seismic volume, to define the hydrocarbon saturated units within the N'kapa Formation. Extracted surface seismic attributes, such as amplitude attribute helped to appreciate the lateral distribution as well as evaluate the hydrocarbon potential of the delineated channel, levee and pinch out sand systems. The distribution of some reservoir properties as presented by surface attribute maps could

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also guide the placement of future exploration wells for better and detailed subsurface information gathering.

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