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Time-Lapse Evaluation of Hydrocarbon Production Using Rock Properties and Attributes in Niger Delta

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***Abstract*— *This research work was validated through fluid replacement modeling. 4D inversion of the Base and Monitor seismic volumes was performed to generate acoustic impedance volumes, from which attributes were extracted and analyzed in order to evaluate their relative changes in response to hydrocarbon production and subsequent replacement by brine. Analysis of these inverted extracted attributes from PH2_v2 and PH2 horizon slices, also presented Lambda-rho, Density, P-impedance and Poisson ratio as having the most significant 4D changes within the producing well locations, while Porosity and Vp/Vs ratio showed the least response. Other zones JCI and HC2, which could be possible hydrocarbon saturated sands was also observed on both iT2v2 and PH2 seismic horizons from the Base and Monitor seismic volumes as they exhibited F low acoustic impedance, lambda-rho, and density. These potential reservoir zones was therefore investigated for probable by-passed hydrocarbon prospect in the field. Therefore, rock properties and attribute analysis can give Geoscientists greater confidence towards understanding fluid movement and better reservoir characterization over time.*

I. INTRODUCTION

Time-lapse seismic data is seismic data from the surface or a borehole acquired at different times over same area to assess changes in the subsurface with time. 4D seismic data are some of the several forms of time — lapse seismic data. 4D seismic monitoring is the process of repeating 3D seismic surveys at a given site in time - lapse mode. This technique allows us to make 3D images of changes in dynamic subsurface properties as a function of time.

Time-lapse technology is an integrated reservoir technique that is based upon the analysis of repeated 3D surveys. The surveys are acquired at a considerable time interval before a field starts producing and at various post-production stages, in order to make snapshots of the reservoir and monitor fluid movement and pressure changes in the reservoir during production. This is possible because changes in fluid saturation, pressure and other reservoir properties can produce differences in seismic response (Landro, 2001). Assuming seismic repeatability, these changes can be transmitted to changes in the reservoir rock properties and attributes. Thus, over time, rock properties and attributes are found to either increase, decrease or remain relatively unchanged in value. These relative changes in the reservoir rock properties and attributes, as a function of time, are results of hydrocarbon production, fluid injection and related activities. Thus, this research aims at determining the impact of these activities over a time interval on selected rock properties and attributes.

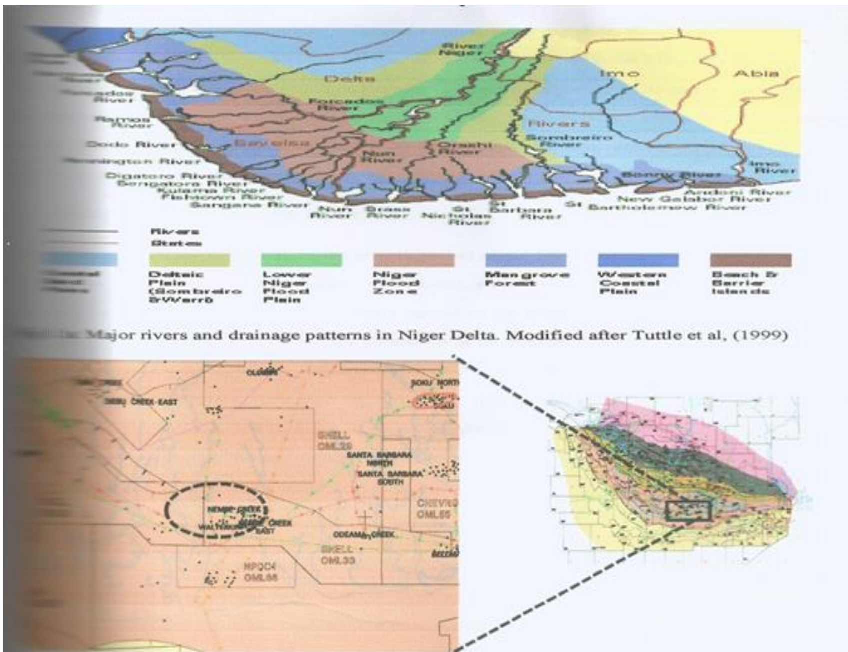

Fig. 1. Location map of the study area in the offshore Depobelt of the Niger Delta.

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Aims of the Study

This research aims to evaluate the effect of 4D (time — lapse) production of hydrocarbon on selected rock properties and attributes. Remarkable changes are expected on these properties and attributes due to fluid withdrawal and replacement, as well as temperature and pressure changes accompany hydrocarbon production and its subsequent replacement with brine.

The structure of the field is a complex collapsed crest, rollover anticline, elongated in the E-W direction. This field has a large STOIIP with an ultimate recovery of about 50%, thus leaving huge opportunity that technology such as time-lapse seismic and smart wells can impact. The information about the time when the base survey and the monitor survey was acquired is not certain. Stacked pay sand interval of the D2000 formation is the main hydrocarbon interval as covered by the 3D data with significant amount still left.

Location of the Study Area

The data-sets used for the study were acquired from an offshore Niger Delta oilfield, South —South Nigeria. The Niger delta is situated on the continental margin of the Gulf of Guinea in Equatorial West Africa, at the Southern flank of Nigeria bordering the Atlantic Ocean between latitude3°N and 6°N, and longitude 5°E and 8°E (flgs 1. la,b).

II. MATERIALS AND METHODOLOGY

Materials/Data Overview

The suite of well logs and seismic data (3D-Base and 3D-Monitor) were Directional surveys,

i. Checkshot,
ii. Well (reservoir) markers of the three wells, and
iii. Horizons

Seismic Data

A set of time-lapse 4D seismic volume (base and monitor volumes) obtained from the same for the research. The baseline data was acquired for exploration and development of the early life of the field while the monitor data was acquired later in order to image reservoir while monitoring production effects as well as probable bypassed oil Thus, the two seismic volumes have been processed in parallel to take advantage of effects. The Seismic data has a dominant frequency of 60 Hz. Crossline and inline from 4992 to 5771 and 1034 to 1529, respectively with the volume extending to 3000 milliseconds two way travel time (TWT), below which reflection continuity is generally poor. The seismic volume is characterized by a series of parallel reflections offset and deformed by major normal faults with collapse crestal faults in the overlying sediments. Major counter fault are evident in the cross line section through the volume and collapsed crest and roll over faults evident in the inline section through the volume and normal faults can easily be traced.

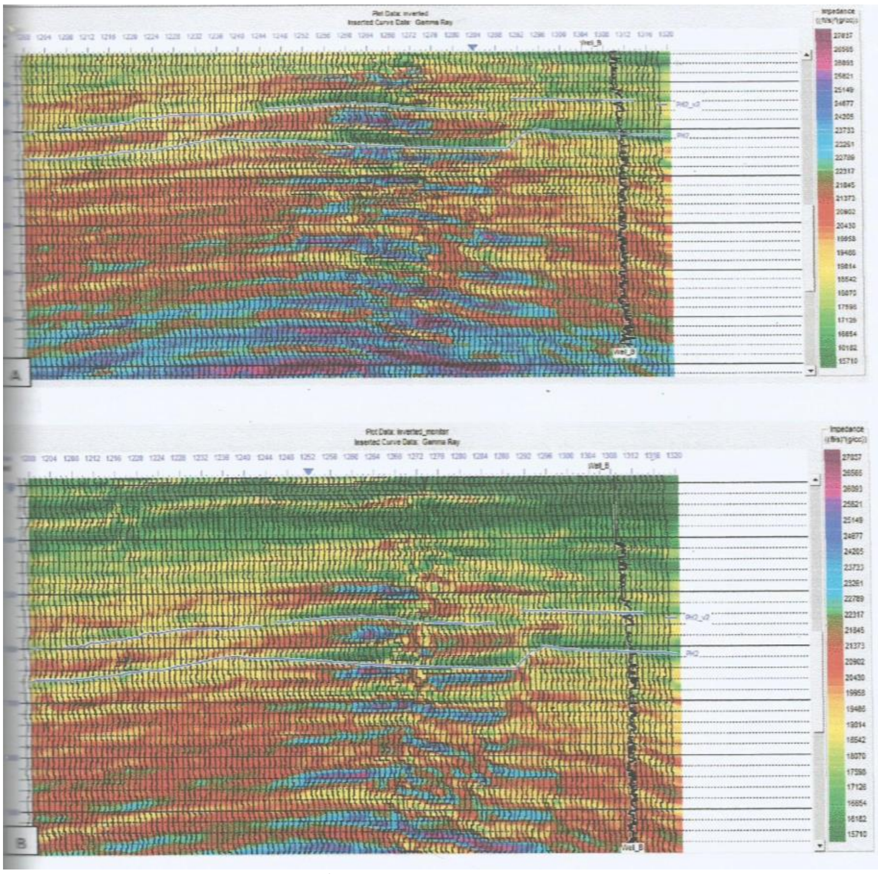

Fig. 2. Inverted Seismic section of (a) Base and (b) Monitor with PH2_v2 and PH2 Horizonns.

Well Logs (Conditioning and Modeling)

A suit of well logs from three wells A, B and C was used for this research. This recorded suite of logs can be grouped into two categories: properties that affect seismic wave propagation (e.g., compressional- and shear- velocity log and density log) and properties of interest for reservoir description but which indirectly affect seismic-wave propagation (e.g., porosity, water saturation, and clay content).

TABLE 1. Display of Logs available across three wells.

LOG TYPES/WELL	WELL A	WELL B	WELL C
DENSITY	YES	YES	YES
SONIC (P-WAVE)	YES	YES	YES
RESISTIVITY	YES	YES	YES
GAMMA	YES	YES	YES
CALIPER	NO	YES	YES
POROSITY	NO	YES	NO
NEUTRON	NO	NO	NO

These well logs are a result of physical measurements of the earth's properties taken within the space of a borehole. The logs are subject to borehole irregularities and the elapse of time between drilling and logging of the well. Thus, the major reason for processing well log to obtain consistent and accurate logs between the wells. Again, the logs must represent rocks as seen by the seismic (Jarvis, 2006). Some type of dispersion correction is therefore necessary to account for differences in frequencies between logging tools and surface seismic reflection data. Fluid substitution should be performed if inversion effects are present.

The P-wave and density logs were edited by applying a median filter with operator length of 10, which gave a good result. This helped to reduce high frequency noise as shown in figures 3 and 4. The median filter is used to remove or minimize errors arising from wellbore washouts, casing points, mud filtrate invasion, gaps, missing data or insufficient log suite.

Other essential log curves which were not directly obtained in the field were generated using geophysical models and algorithms. Median filtering was however not applied on these logs since their parent logs, P-wave, S-wave and density has already been filtered.

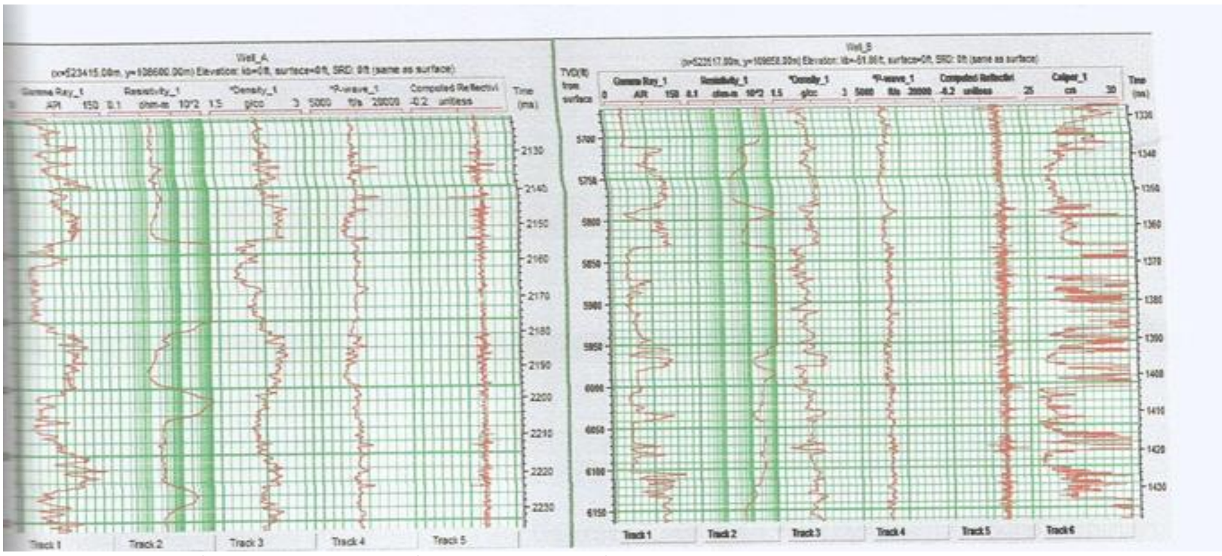

Fig. 3. Suite of raw well logs A & B before applying median filter to P-wave and density logs and also check-shot correction.

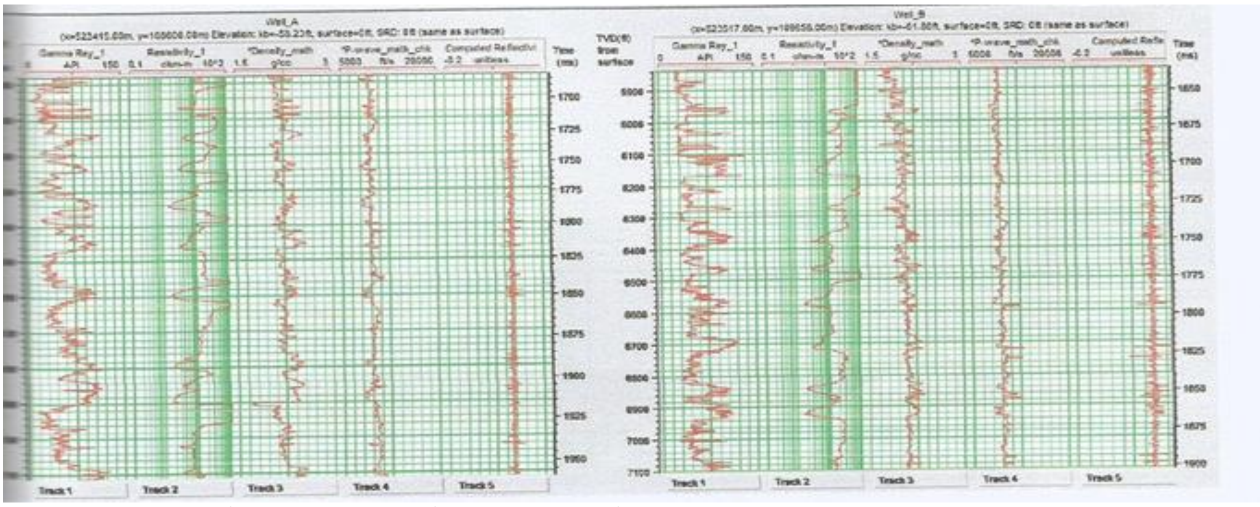

Fig. 4. Suite of raw well logs A & B after applying median filter to P-wave and density logs and also check-shot correction.

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Check-shot correction was also applied to the logs as this adjusts the sonic log velocities or the time-depth curve to match the time-depth relationship obtained from surface seismic data, thus ensuring suitability and accuracy in well-to-seismic ties and creation of synthetic seismograms. This was done by applying a drift curve which measures the difference between -depth curve and the check-shot data. The check shot was used to ensure proper placement of the wells at their appropriate depths and time positions. This is necessary because gram extrapolates the first Vp value to the surface, which usually overestimates the near velocity. When applying checkshot correction, three types of interpolation can be applied. They include

i. Spline Interpolation
ii. Linear Interpolation, and
iii. Polynomial Interpolation

For this research, the Spline type of interpolation which tries to match the depth-time curve at point was used thereby giving a good correction.

III. RESULTS AND INTERPRETATION

The Hampson-Russell suite provided a platform on which volumes of rock properties and attributes identified to be sensitive to fluid and lithology discrimination were extracted using the inverted acoustic impedance volumes and well logs data by implementing a probabilistic neural network algorithm. The results obtained from the cross-plot and fluid substitution analysis formed the basis on which the attributes were extracted. Slices for different properties and attributes are shown below.

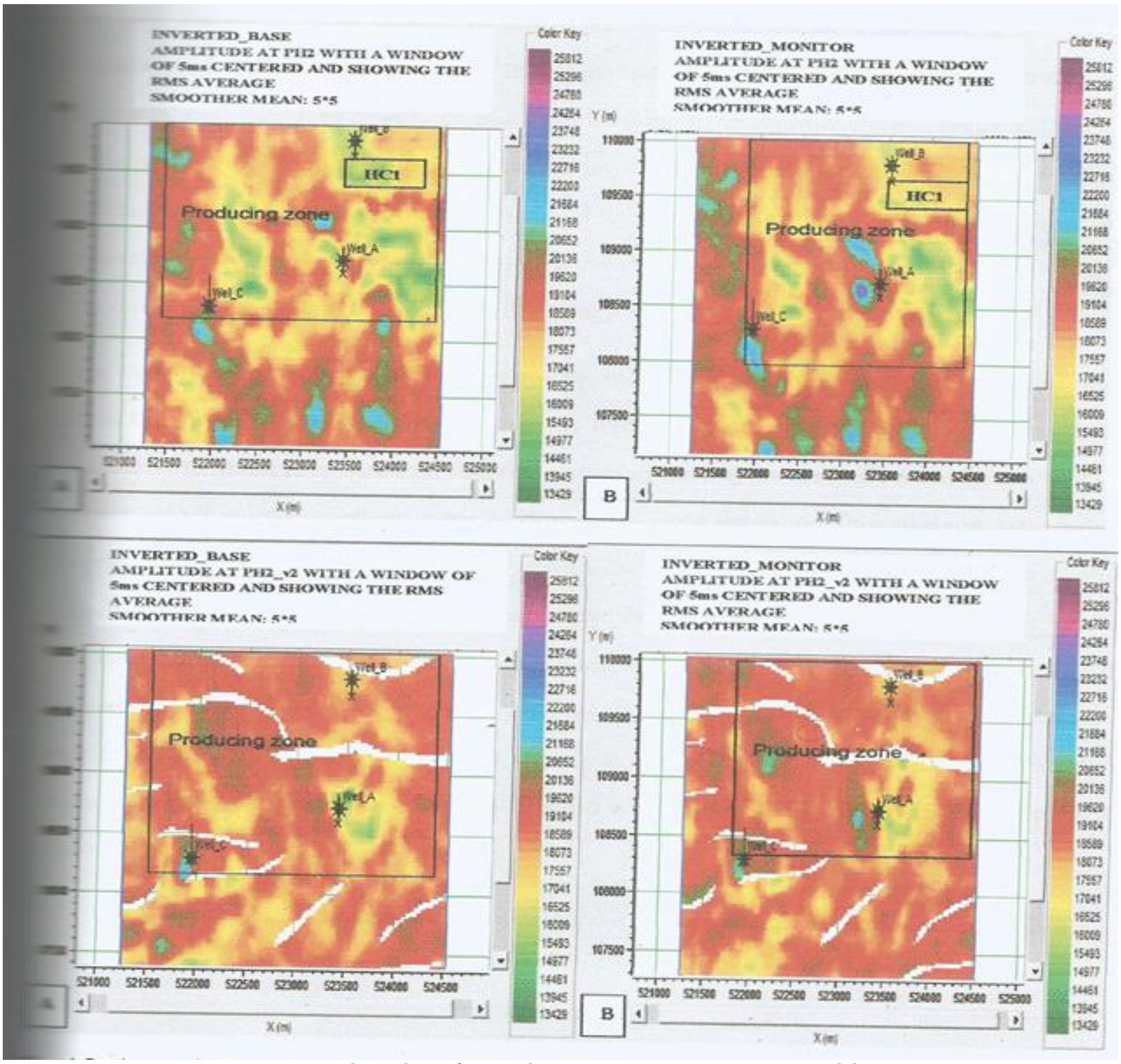

Fig. 5. Acoustic impedance slices of PH2 and PH2-V2 HORIZONS ON (a) Base and (b) Monitor.

The attributes extraction was performed along the PH2_v2 and P112 seismic horizons serving as reference point for taking the slices, with a window of l0 ms which implies 5ms above and below the picked horizons. Rock properties and

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attributes such as Bulk Density, Porosity, Water Saturation, Acoustic Impedance, Lambda-rho, Mu-rho and Poisson's ratio slices were extracted from the Base and Monitor volumes and analyzed. On analysis, we find segments with attribute signatures that correspond to those expected of hydrocarbon charged sands as established by cross-plot analysis. Changes in the rock properties and attributes were evaluated by comparing the baseline seismic and monitor slice with the 4-D difference slices generated from acoustic impedances. From the analysis, production induced effects due to fluid and pressure changes were mapped and sections of potentially un-drained/by-passed hydrocarbons detected.

Analysls of Acoustic Impedance Slices

Acoustic impedance generally, is tightly correlated with porosity and other lithologic features of interest. Results from inverted acoustic impedance volumes have higher resolution than conventional seismic data. This attribute can thus discriminate hydrocarbon charged sand from brine sand. From the slice, acoustic impedance values ranges from 13.4-18.0 x (ft/s*g!cc) to as high as 25.8 x (ft/s*g/ec).

Acoustic impedance slice of the Base taken at P1-12 seismic horizon showed relatively low acoustic impedance values in areas corresponding to hydrocarbon charged sand bodies within the producing well locations especially well B. A relative increase in acoustic impedance was observed in the Monitor over the Base, which may be attributed to hydrocarbon production over time and replacement with brine. Other zone (HC1) which may be probable bypassed hydrocarbon charged sand body was observed as it consistently showed low acoustic impedance values on both the Base and Monitor.

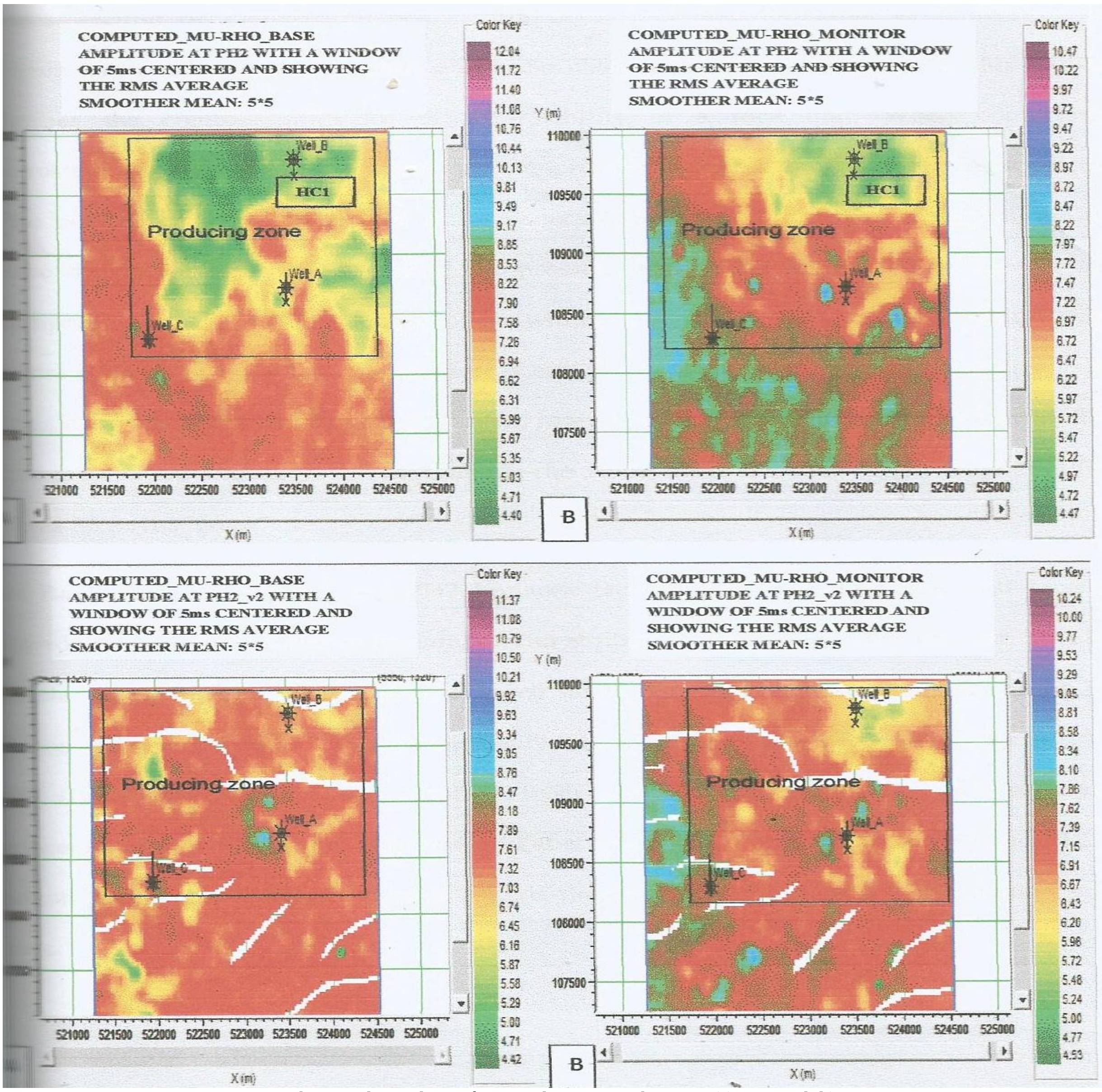

Fig. 6. Mu-Rho impedance slices of PH2 and PH2-v2 on horizons (a) Base and (b) Monitor.

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Acoustic impedance slice of the Base taken at PH2 v2 seismic horizon, which was bounded by faults that act as structural traps and centred on 5ms time window, also showed low acoustic impedance values within the producing well locations which correspond to hydrocarbon charged sands while an increase in this attribute was observed on the Monitor as indicated in figure 5. Again, this is owing to the withdrawal of hydrocarbon over time.

Analysis of Mu-Rho Slices

Generally, the Mu-rho attribute of Goodway et.al, gives quantitative measure of the variation in rigidity. Information with regard to lithology and distinguishable rock types — sands, shales, carbonates, coal and also quality of sand can be gotten from Mu-rho cross section. Depending on the sand quality, moderately consolidated clean hydrocarbon saturated reservoir sand exhibits relatively high values of mu-rho due to their high resistance to shearing, while unconsolidated clean hydrocarbon saturated reservoir exhibits low mu-rho values. From the slice, mu-rho values ranges from 4.40 (ft/s*g/cc) to as high as 12.04 (ft/s*glcc)2

Slices taken on PH2 horizon from base and monitor indicated relatively low values of mu-rho around the producing wells implying that the hydrocarbon sand here is unconsolidated, loose and poor with shale intercalation, thereby reducing rigidity as also observed in the cross-plot analysis. 4D time-lapse effect from hydrocarbon production on this horizon was however remarkable on the Monitor around and within the producing zone especially wells A and C. However, other zone (HC1) with consistent low value on the monitor could indicate bypassed hydrocarbon charged sand. The Mu-rho slice taken on PH2 v2 seismic horizon from the Base showed relatively high values of this attribute over the monitor around the producing well locations. This may be indicative of moderately consolidated hydrocarbon saturated sand. This attribute is however less discriminative of fluid types when compared to lambda-rho attribute (figure 6).

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