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APPLICATION OF TIME LAPSE (4-D) SEISMIC DATA IN LOCATING HYDROCARBON PROSPECTS IN UDAM FIELD, ONSHORE NIGER DELTA, NIGERIA

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Abstract

Application of time-lapse seismic data in imaging the effect of production related changes and locating bypassed hydrocarbon prospects in Udam Field Onshore Niger delta has been undertaken. The study was carried out using suites of well logs, 3-D and time-lapse seismic data acquired at different vintages. The differences resulting from acquisition design and other non-production related variations were minimized between the surveys vie phase and time matching as well as shaping filter processes. The synthetic seismic model was derived to predict changes in the reservoir that basically result from gas injection. This production induced changes and other unknown hydrocarbon bearing intervals were revealed by the data slices created from the inverted base and monitor. The data slice of the inverted base along the HD reservoir intervals isolates the reservoir zones which are consistent with low values of instantaneous phase and frequency which are indication of hydrocarbon bearing sand. The production induced changes and other unknown hydrocarbon bearing intervals away from the wells were successfully isolated using difference slice (Monitor- Base). The results showed very low instantaneous phase and frequency around the wells locations and hydrocarbon bearing sand intervals away from the current well positions. The difference slices showed anomalous increase in values of instantaneous phase and frequency at well locations which are indication of production related changes. The delineated sand beds in the southeastern and western parts of the field were believed to accommodate bypassed hydrocarbons.

Keywords: *Seismic Inversion; Instantaneous phase; Instantaneous Frequency; TL-seismic data*.

1. Introduction

Niger Delta basin has gradually developed into a mature province for oil and gas production but more hydrocarbons could still be derived from the producing fields (old oilfield) using newer or uncommon methods. One of such methods is time-lapse seismic survey. TL seismic technology has assumed the status of developed tools for field monitoring and management. TL- seismic data is acquired by repeating 3-D seismic surveyed field that has undergone or still undergoing hydrocarbon production. Udam field is one of such field that has record limited hydrocarbon production in recent time despite various recovery processes it was undergoing. As a result, time-lapse seismic survey was carried out to analyze the effect of production in the reservoirs and to identify potential bypassed hydrocarbons. Information obtained from this can be used to maximize production or make further drilling decisions in the field. The success of TL seismic technology has been recorded in different basins of the world [1,4-5,6-7,9]. Unfortunately, the application of TL seismic technology to monitor production related changes in hydrocarbon field in the Niger Delta basin has recorded limited success probably due to the newness of the application of the technology in the basin. Lumley [8] stated in their pilot study that practice of time-lapse seismic technology in Niger delta is in developmental stage.

However, in this study, TL-seismic data of Udam Field in offshore Niger Delta was analysed using elastic impedance inversion and rock physics tools to monitor changes that may occur in the reservoir as a result of production process such as gas injection and to identify bypassed hydrocarbon zones. Rock physics basically enhances the understanding of the physical properties of the reservoir at drilled well location and help to link these properties to the seismic data and infer their variation in a lateral and vertical sense [10]. Therefore, integrating seismic inversion and rock physic tools can improve the fidelity of the results that aimed at delineating potential hydrocarbon zones (bypassed hydrocarbon) away from the wells. The bypassed hydrocarbons in the field are derived by comparing the coupled inversion of the baseline and monitor surveys that were acquired at different point in time in the field. The choice of simultaneous seismic inversion of the baseline and monitor is to eliminate or reduce the non-uniqueness that may sometime be associated with independent inversion of the seismic vintages. This help to effectively track the movements of fluid saturation that probably rise from production related effects. The objective is to evaluate these changes that are related to production process in the reservoir and ultimately, determine bypassed hydrocarbon zones the field.

2. Location and geologic setting

Udam Field is located at about 50km southeast of Port Harcourt, Rivers state in the South-Central Nigeria. Niger Delta is situated on the continental margin of Gulf of Guinea in equatorial West Africa, at the Southern end of Nigeria bordering the Atlantic Ocean between latitude 3° and 6° and longitude 5° and 8°. Anakwuba *et al.* [2] reported that Niger Delta province contains only one identified petroleum system referred to as the tertiary Niger delta of Akata-Agbada petroleum system. Aniwetalu *et al.* [3] stated that the Agbada formation located in the Tertiary Niger Delta represent the hydrocarbon producing interval while the Akata is the source rock. Niger Delta is delineated by the geology of the Southern Nigeria and South-Western Cameroun where the northern boundary is the Benin flank, an East-Northeast trending hinge line south of the West Africa basement massif.

3. Data description and method

The data used in this study include 3-D seismic data (baseline), TL- seismic data (monitor) suites of well logs, Strata and TL-Pro4D program. TL-Pro4D program contain necessary elements such as rock physics and fluid replacement modeling, synthetic seismic generations, interpretations and calibrations while Strata program was specifically used for seismic inversion. The baseline survey was acquired in the August 1995 covering about 80kms^2. In July 2015, a repeat survey (monitor) was completed over the baseline.

To predict changes in seismic response that basically results from gas injection in the reservoir, well log modeling was set up. Therefore, with velocity and density structure defined by well log data, zone of interest was also set defined in the systematic window and changes applied to the well logs. Before creating the new logs, relationship between velocities, density and gas saturation were defined and seismic properties as function of fluid saturation was calculated using Gassman equation. Biot-Gassman relation was used to calculate the matrix and fluid properties since we are monitoring the gas injection into siliclastic reservoir. Output saturation ratio of the oil, water and gas were defined and new logs created which reflect changes in both velocity and density that are consistent with gas saturation in the reservoir.

Synthetic seismic traces were calculated for each of these wells and variable thicknesses and fluid saturation of the gas banks were displayed. Therefore, to track other potential hydrocarbon zones beyond the well locations, coupled inversion of the baseline and monitor was undertaken. Prior to seismic inversion, the two seismic vintages were calibrated to minimize differences that may have resulted from the acquisition process. The correlation coefficient data slices (CCDS) which define the average correlation coefficient of the non-processed datasets and correlation time-shift (CTS) which also highlight the rough average bulk shift between the two vintages were der-ved. The phase and time shifts were calibrated to match these two datasets especially where effects of production are not expected and shaping filter applied to improve the datasets. There-fore, with the two dataset calibrated, low frequency model of the two seismic vintages were built to capture missing low frequencies in the seismic data using time doman filter of 10/15Hz. Postack inversion analysis at well locations was run to optimize parameters and coupled seismic inversion of the models were carried out. Difference slices created to map the reservoir changes and bypassed hydrocarbon zone in the field

4. Result analysis

In synthetic seismic modeling, variable gas thicknesses and saturation within the gas bank was derived. The model displays different gas saturations and their thickness levels as one toggle through gas saturation line from 0 to 7 in the reservoir (HD2000). For instance, at saturation line 6, the model displays the gas thickness of 90m at gas saturation of 50% (Fig.1).

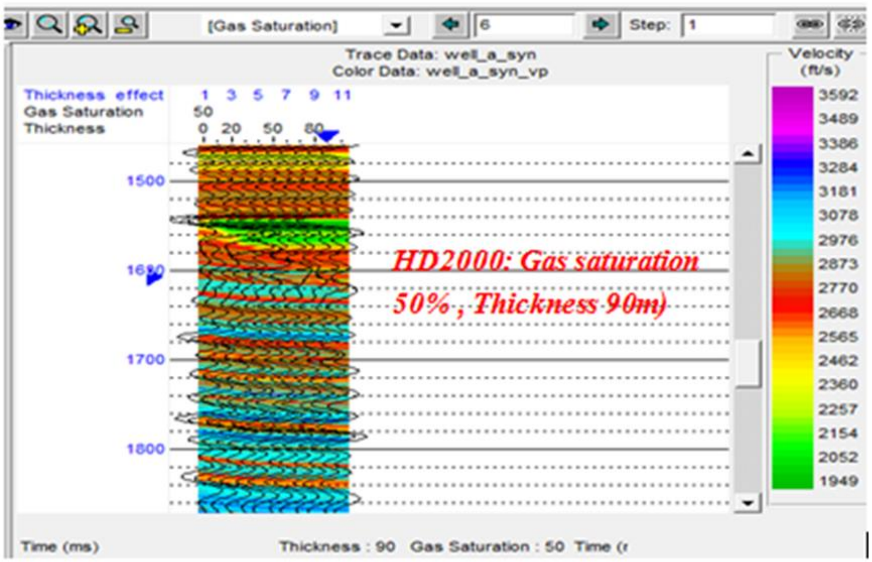

Fig.1. The synthetic seismic display showing variable gas thickness and saturation

With this result, the synthetic seismic display conveniently reveals the differences caused from the model changes in gas saturation because each saturation line predicts seismic response that basically results from gas injection in the reservoir. Varying gas saturations and thick-nesses were observed at each line. These represent the average gas injection and their thicknesses in the reservoir. There are also significant velocity decreases in the reservoir zones which are also consistent with corresponding changes in seismic character. Data slice differ-rence of the base and monitor revealed production induced changes and potential hydrocarbon bearing intervals away from the current producing zones.

The quality of the results is dependent on how the two seismic vintages (Base and Monitor) were cross-equalized. The result of average correlation coefficients of the non-processed datasets as revealed in the CCDS is less than 65% (Fig.2) while CTS shows the rough average bulk shift of 20 milliseconds between these two seismic vintages (Fig.3). The band of blue below 51% (0.51) observed around the well locations are left out of processing window during data matching so as not to reduce production related effects because they are important areas of interest. This necessitates the use of correlation threshold of 65.

The threshold is a vital parameter that relate to the program to exclude traces where the correlation is lower than 65 because that are areas where the effects of production induce changes are pronounced (Fig. 4.a). The shaping filter applied improved the datasets with correlation coefficient of 99% which indicate a significant level of improvement in the datasets (fig.4.b). The low frequency model created from the cross-equalized data were inverted and the compared (Fig.5). The monitor volume indicates pronounced production related effect as revealed by high elastic impedance distributions in the field. Data slices derived using instan-taneous phase and frequency attributes along the top of the reservoir revealed production related changes in the well locations and other unknown hydrocarbon bearing intervals away from the wells. The instantaneous phase and frequency attributes enhance the identification and delineation of hydrocarbon bearing sands. Low values of instantaneous phase associated with low instantaneous frequency are indicative of hydrocarbon within the sand reservoirs (fig.6a-b). Low values of the instantaneous phase slice of the inverted base observed around the well indicate presence of hydrocarbon in the sand reservoir (fig.6a). The production induced changes and other hydrocarbon bearing sand intervals were revealed by the instantaneous phase difference slice which represents the difference between the monitor and the base (fig.6b). Low values of instantaneous phase around the wells in the base appears to be replace with high values of instantaneous phase in the difference slice which are indicative of production related effects in the reservoir.

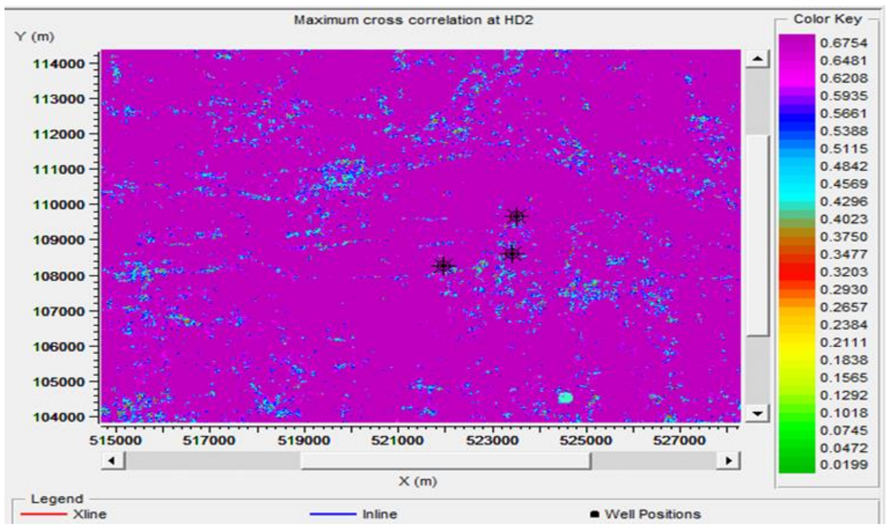

Fig.2. The correlation coefficient of non-processed data-sets

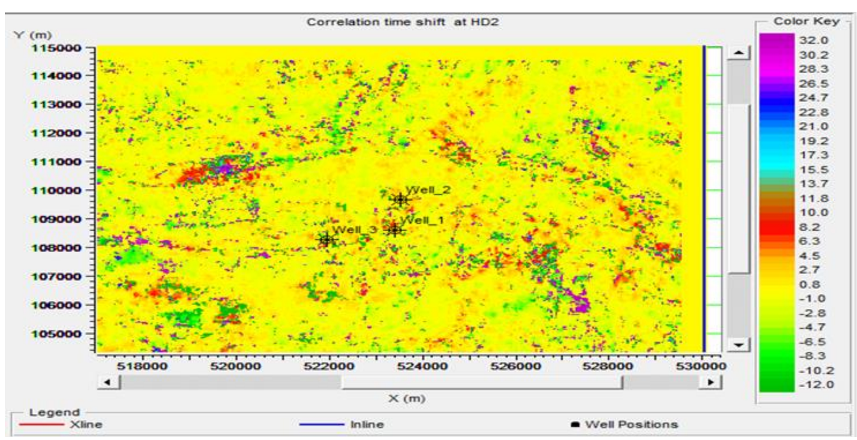

Fig.3. Correlation time-shift indicating rough average bulk shift between the seismic two vintages

This result was also validated by comparing the difference slices of the instantaneous phase and frequency attributes (fig.7a-b). The difference slice of Instantaneous frequency reflects similar trend in character with phase attribute (fig.7b). Both attributes revealed significant production induced changes around the well locations which represent area of known hydrocarbon intervals. The difference slices along the same reservoir interval obtained from the difference between the monitor and the base successfully isolate production induced changes around the wells (known hydrocarbon bearing intervals) and bypassed hydrocarbon intervals (unknown hydrocarbon bearing intervals) away from the wells. Finally, the unknown hydrocarbon zone A and B are the bypassed hydrocarbon intervals which when developed, is expected to revive or increase production in the field.

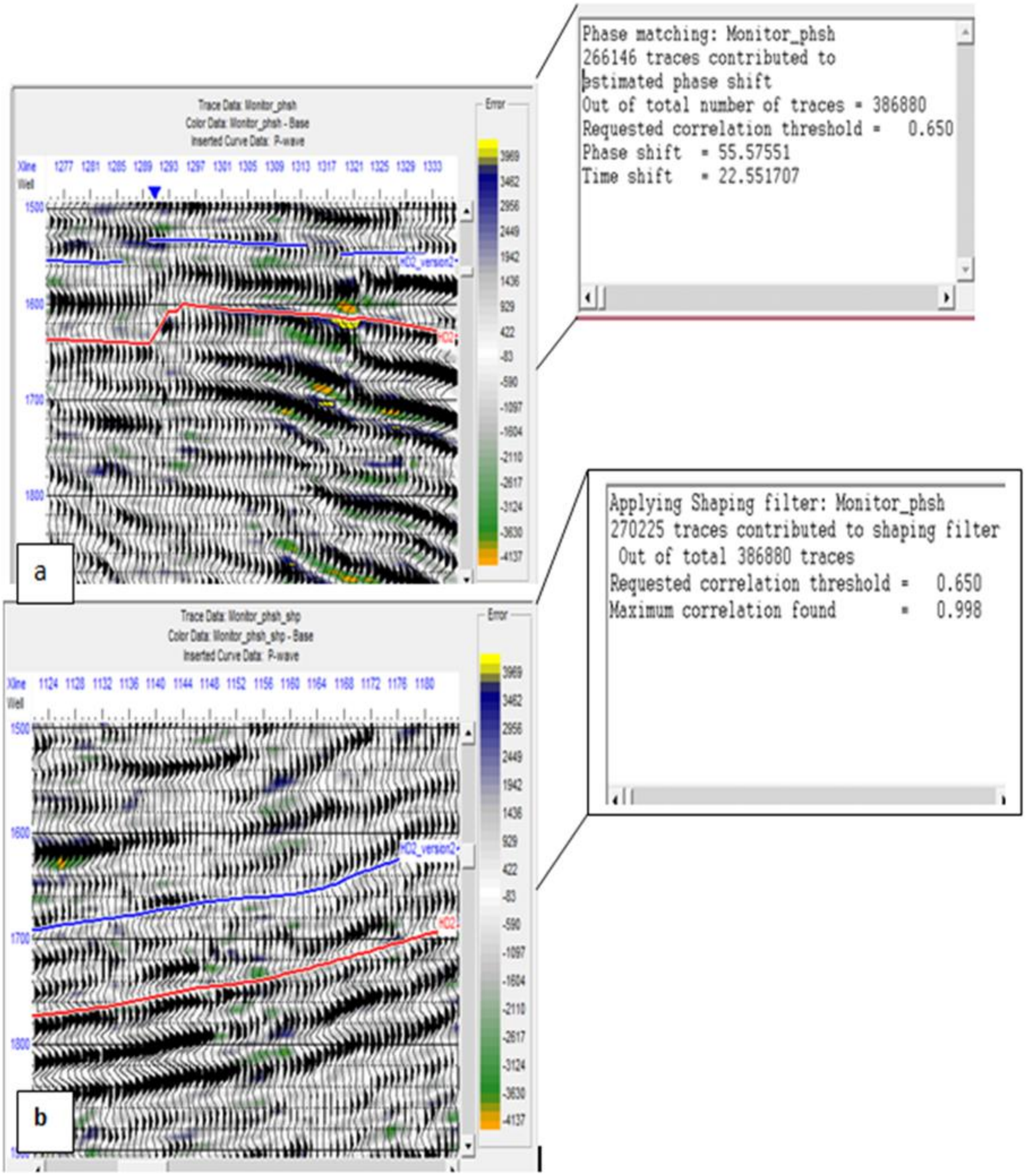

Fig.4a-b. Present the matched phase and shaping filtered volume of the data sets. The high energy levels in the phase matched volume were reduced in the filtered volume

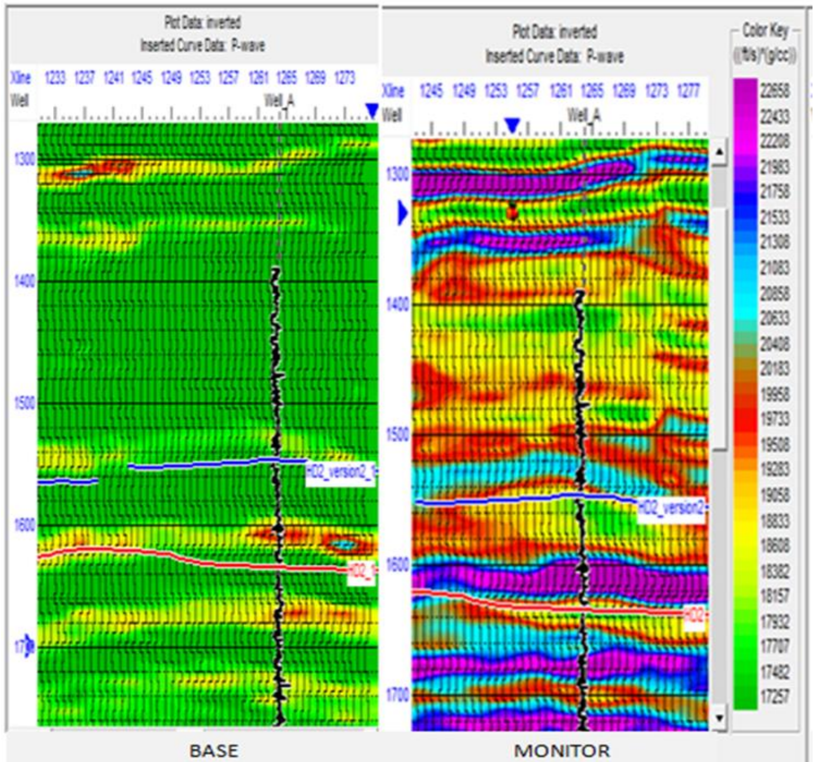

Fig.5. Inverted seismic volumes of the base and monitor indicating production related changes in TL-seismic volume.

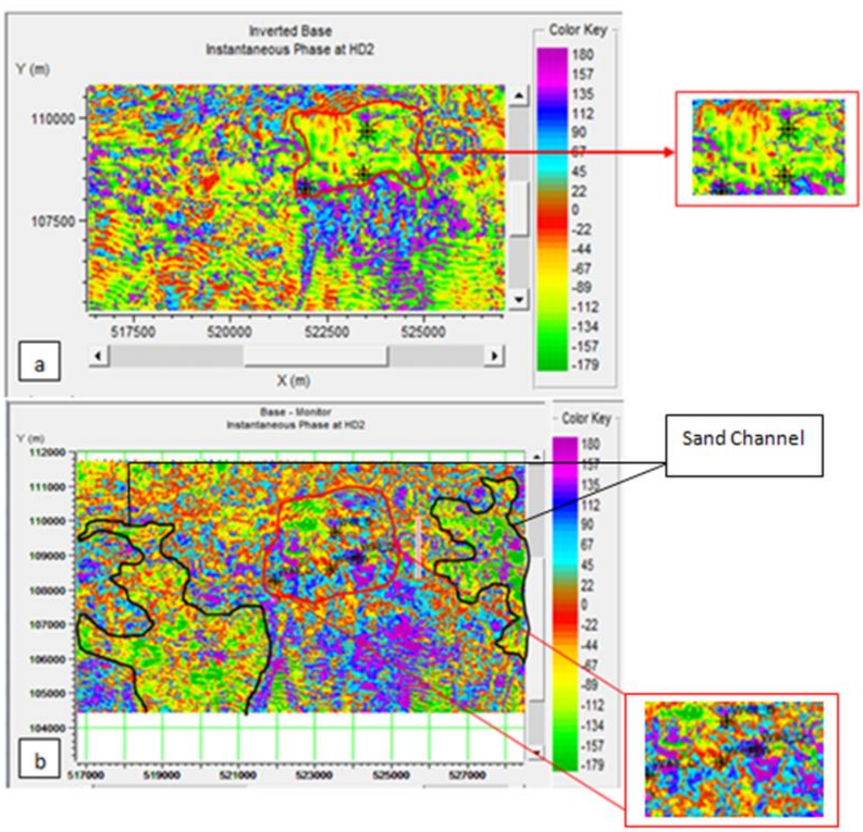

Fig.6a-b. Instantaneous slice of the inverted base and difference slice showing a. Base and b. Monitor

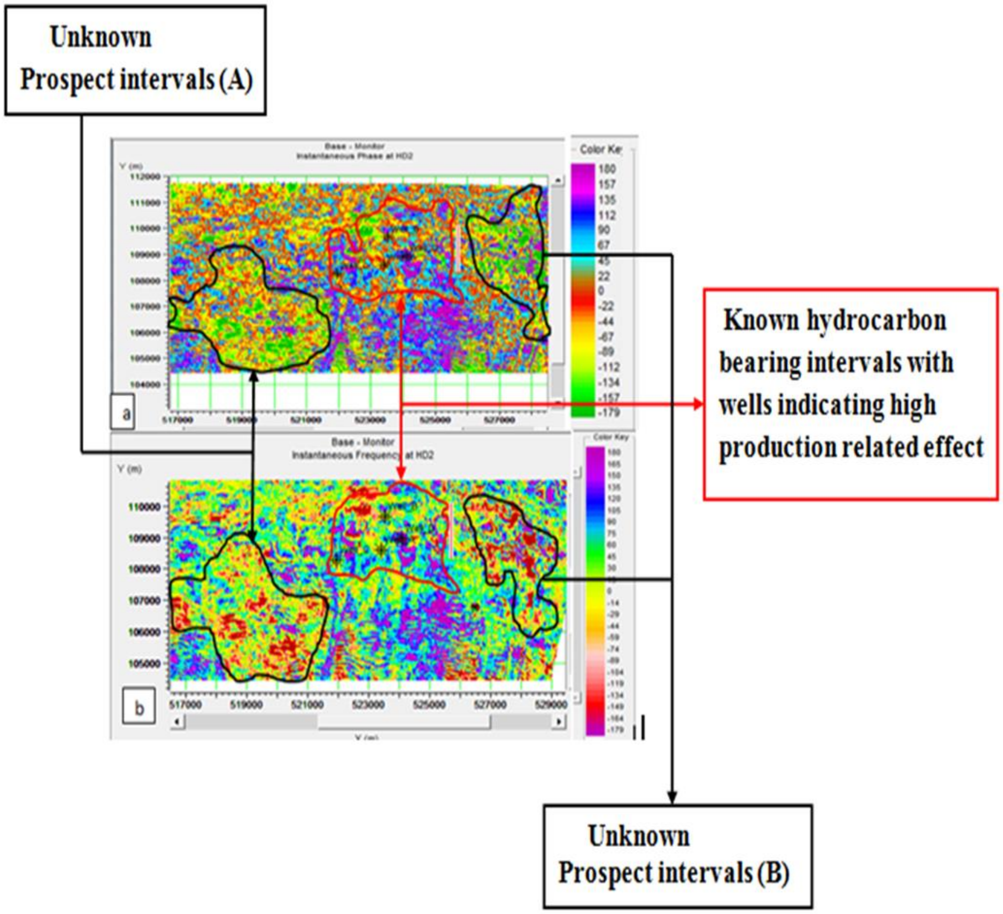

Fig.7a-b. Instantaneous phase and frequency of the difference slice of the base and monitor showing production related effect around well locations. The unknown prospect A and B are the bypassed hydro-carbon intervals

5. Discussion

The analysis of Time-lapse seismic data of Udam Field has revealed the effect of production related changes in the reservoir. The result showed that tracking the production related changes which include imaging the effect of fluid flow saturations and identification of bypassed hydrocarbon zones that could be developed for further drilling can also aid improving on the productive life of the field.

The analysis of the inverted base data revealed the static condition of the reservoirs. It described the lithology and fluids based on their acoustic impedance ranges. The zones in red, blue and purple showed an increasing order of acoustic impedance while zone in yellow and green correspond to reduction in acoustic impedance. Very low acoustic impedance values were noticeably observed in the base. These low impedance values were hydrocarbon charged sand bodies. The baseline data revealed the idle state of the field before hydrocarbon productions and other recovery actions. However, the effects of production induced changes in the reservoirs were captured by monitor data. The inversion of the monitor data presents the acoustic impedance inversion of the field condition after long duration of active production and enhanced oil recovery processes. The injected steam/CO_2 gas mixed with oil, lower its viscosity and drives the oil out of reservoir. However, its general effect is an increase in the water production rate and pressure in the reservoirs. The inverted monitor data showed abnormally high acoustic impedance values in the reservoirs which previously showed low acoustic impedance values as a result of the steam injection. The increase in acoustic impedance values in these reservoirs are indication of reservoir depletion. Unlike inverted baseline data, the positive or increase in acoustic impedance anomaly in the monitor data is a result of water, or CO_2 gas replacing oil in the reservoir. The low acoustic impedance values were also observed in the monitor data. These are probable by-passed hydrocarbon zones. These bypassed hydrocarbon zones were noticeable in the central portion of the field and also associated with low acoustic impedance values. The areal extents of the negative anomalies are mostly consistent with the production and pressure while lack of 4-D effects largely observed in the northern parts of the field are indication of areas where CO_2 is potentially bypassing portions of the reservoir or where no reservoir sandstone is present.

6. Conclusion

Time-lapse seismic data analysis of Udam Field was carried out to monitor and manage the reservoir changes due to production. The seismic vintages (base and monitor) were cross-equalized to boast confidence in the results. Low frequency models were created and elastic impedance inversion performed. But prior to this, the output saturation ratio of the oil, water and gas were defined and modeled using Biot-Gassman relation to determine the gas saturations and their thickness variability in the reservoir. The result revealed the variable thicknesses of gas and saturation banks which probably results from gas injection. Other production related effects and bypassed hydrocarbon in and away from the well locations were captured in the data slices created from the impedance volume along the HD2000 reservoir. The instantaneous phase and frequency data slices of the base revealed low values of the instantaneous phase and frequency around the well locations which are indication of hydrocarbon charge sands. In the data slices of the monitor, production related effects were revealed in the well locations which exhibit high instantaneous phase and frequency. Pockets of low values of the instantaneous phase and frequency observed away from the current producing zones are bypassed hydrocarbons which could the revived to increase more production in the field.

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