Seismic Inversion to Improve the Reservoir Characterization: Case Study in Central Blue Nile Basin - Sudan

S. E. Musa, N. E. Mohamed, N. A. Ahmed

Abstract**—**In this study, several crossplots of the P-impedance with the lithology logs (gamma ray, neutron porosity, deep resistivity, water saturation and Vp/Vs curves) were made in three available wells, which were drilled in central part of the Blue Nile basin in depths varies from 1460m to 1600m. These crossplots were successful to discriminate between sand and shale when using P-Impedance values, and between the wet sand and the pay sand when using both P-impedance and Vp/Vs together. Also some impedance sections were converted to porosity sections using linear formula to characterize the reservoir in terms of porosity. The used crossplots were created on log resolution, while the seismic resolution can identify only the reservoir, unless a 3D seismic angle stacks were available; then it would be easier to identify the pay sand with great confidence; through high resolution seismic inversion and geostatistical approach when using P-impedance and Vp/Vs volumes.

Keywords**—**Basin, Blue Nile, Inversion, Seismic.

I. Introduction

OIL exploration in Sudan began in the early fifties in offshore of the red sea by AGIP. Chevron started the oil exploration in 1974 in interior rift basins including Blue Nile Basin. The first well in this basin was drilled by Chevron in 1982. The Blue Nile basin (Fig.1) is a NW–SE trending rift basin, lies between longitude 13º – 15º N and latitude 33º- 35º with about 38x103 km^2 areal extend. Beside the gravity and magnetic surveys an extensive 2D seismic acquisition campaign was conducted in the basin during the period of 1980 to 2008.

II. Petroleum Geology and Structural Setting

Blue Nile basin is considering one of the eldest basins in Sudan and contains a thick sequence of non-marine sediments, which range in age from Jurassic to "Permo-Triassic", which is still remain questionable. The basin is a generalized stratigraphic column (Fig.2) which illustrates the rift and sag episodes in relation to basin filling and sedimentation. The sandstone formation of the fluvial channels of the Dinder II (Neocomian-Barremian) and the Dinder III (Late-Middle Jurassic) Formations can be considered as primary reservoirs in the basin, and the top seal is interbedded shale in Dinder I and Dinder II Formation for top seal and faults for lateral seal. The Blue Nile is a N-to-NW- trending, and sub-paralleled to the Red Sea and rifted in response to the Africa-Arabian extensional forces [1] Late Jurassic rifting is best documented in the White and Blue Nile rifts of the Sudan, and records east-west extension in half-graben that were connected by large-scale shear zones and pull-apart basins. East-west striking shear zones, including the Umm Hani and South Sudan shears, served as basin-terminating structures in the Late Jurassic rift system [2]

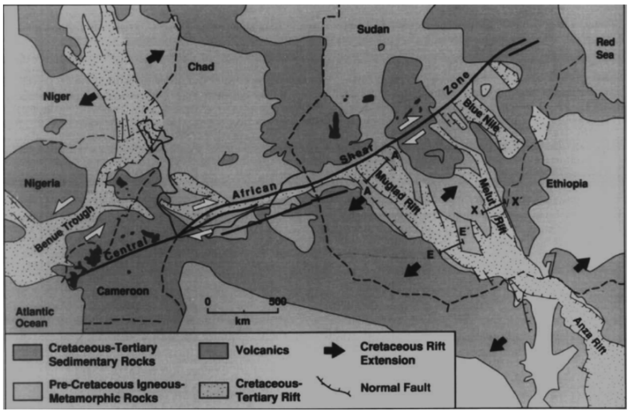

Fig. 1 Central Africa Rift system tectonic map and the main basins including Blue Nile Basin (Modified from [3] and [4])

III. Methodologies

Seismic inversion is the process of converting seismic reflectivity data to models of elastic properties of the subsurface [5], and it is one of the seismic stratigraphy techniques, in which "Every little wiggle has a meaning all its own [6]". Inverse modeling is also based on the convolutional model. It assumes a noise –free seismic trace to start with and attempts to derive the earth's reflectivity from it, then acoustic-impedance values, and finally the geology. The process is called Inversion [6].

The main input in this study is the seismic, well data and the seismic interpreted horizons. The analysis of the log data is a key step in assessing relationship between physical rock properties such as lithology, fluid content and porosity. The objective of the well log analysis is to identify which rock

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properties, obtainable from the inversion, offer the best separation for reservoir characterization.

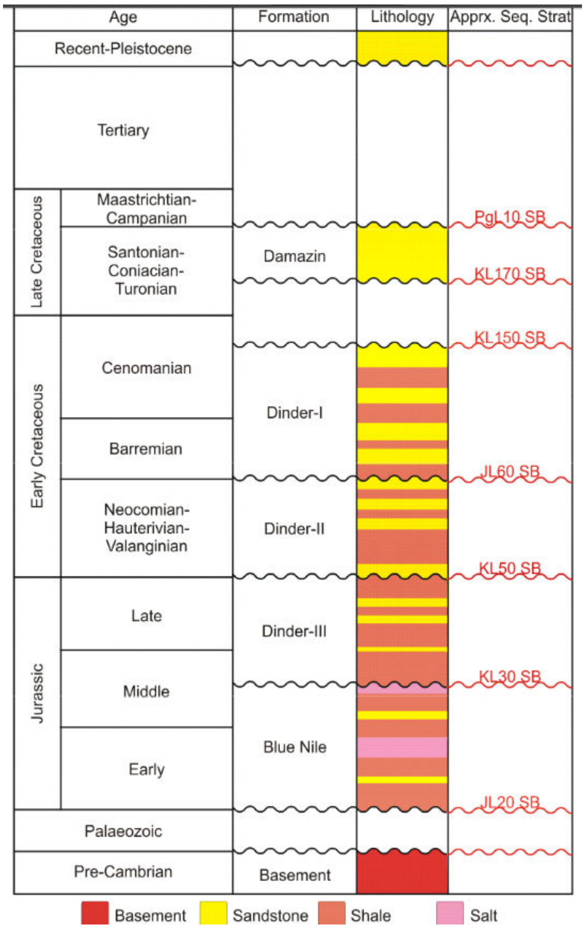


Fig. 2 Generalized stratigraphic chart of the Blue Nile Basin, [7]

In this study, the crossplot P-impedance versus Vp/Vs was illustrated with different colored curves as in Figs. 3-6.The main outputs are both relative impedance and absolute impedance. The relative impedance honors the band-limited seismic and it helps refining the geophysical interpretation because it removes the tuning and side lobe effect and gives layer boundary rather than seismic amplitude interface [8].

The absolute impedance contains both the band-limited frequency from seismic and the low frequency which is obtained by building a low frequency model from wells to compensate the missing frequency in the seismic. The interpolated model (low frequency model) is constrained geologically by horizon interpretation [9].

IV. Theoretical Background

Acoustic impedance (AI) was calculated by multiplying the velocity (V_P) and density logs ($\boldsymbol{\rho}$):

$$(\mathrm{AI}) = V_p \rho \tag{1}$$

Since density variation is very small, compared with velocity variation, that is putting($\rho 1 = \rho 2$), the direct (A-V) relationship can be obtained using (2):

$$V_2 = \frac{(1+\mathrm{A}).V_1}{(1-\mathrm{A})} \tag{2}$$

This is an inverse problem in which the acoustic impedance (expressed by velocity) can be obtained from the seismic-amplitude data. If the velocity (V1) of the surface layer of a layered medium is known then using the inversion formula in (2), the velocity (V2) of the next layer is computed. By repeating the computation, velocities of the rest of layers are sequentially determined.

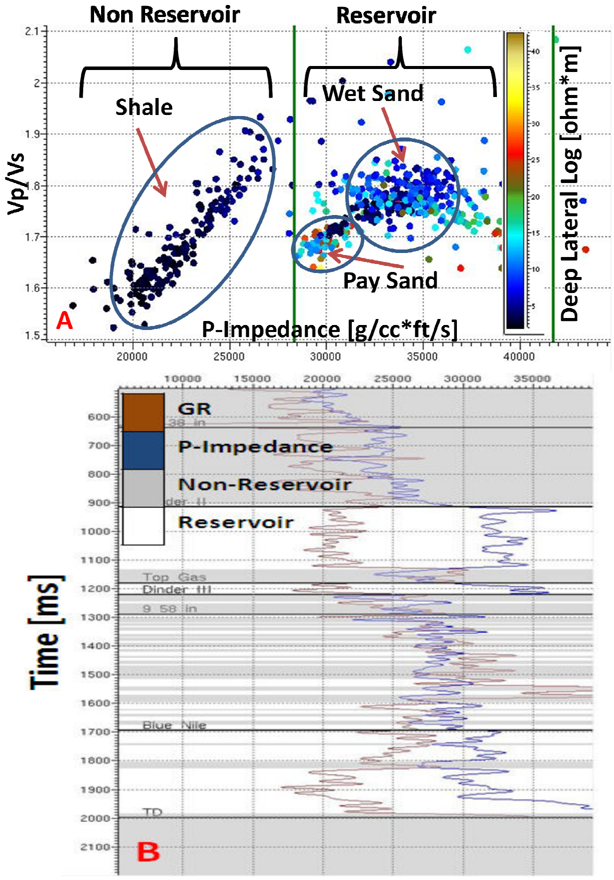


Fig. 3 (A) Crossplot of P-impedance (g/cc.ft/s) versus Vp/Vs (ratio) in HSN-1, with Deep resistivity (ohm.m) as color scale, the crossplot interval from 1460 -1600 m. From this crossplot, it was concluded that P-impedance can discriminate between sand and shale. The values above 28000 (g/cc*m/s) represent the Sand, (B) the corresponding well log

Normally this approach is applied in transforming a seismic stack section into acoustic impedance section, or into what is called pseudo-impedance when density is ignored. The computations are normally carried out by software especially designed for this purpose.

For Vp/Vs which is an expression for the Poisson's ration we derived as in (3):

$$\text{Poisson Ratio } (\sigma) = \frac{(V_p{}^2 - 2V_s{}^2)}{2(V_p{}^2 - V_s{}^2)} \qquad (3)$$

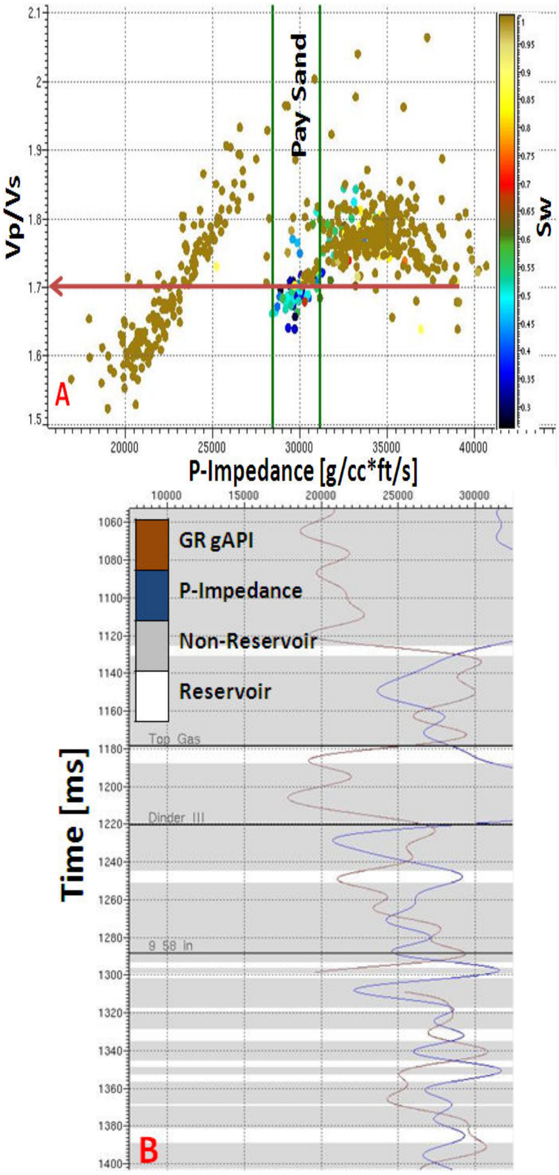


Fig. 4 (A) P-impedance versus Vp/VS in water saturation color scale in HSN-1.Crossplot interval from 1460-1600 m. The Pay sand could be isolated in log resolution by using rang values (green lines) in P-impedance axes, and also it can be confirmed by using the value (1.7 and below) as a cutoff from Vp/VS (B) the corresponding well log

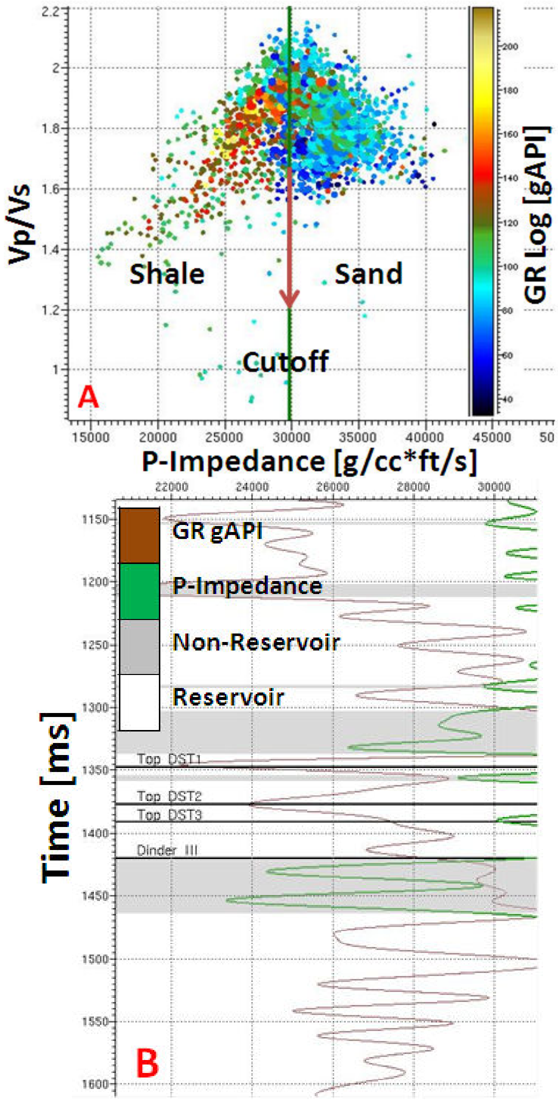


Fig. 5 (A) P-impedance versus Vp/Vs using Gama ray scale in TWK-1 well. Crossplot interval varies from top Dinder II to top Dinder III. In this crossplot it is very clear the discrimination between sand and shale and it is easy to determine the cutoff of~28000 g/cc.ft/s. (B) the corresponding well log

V. Inversion Results

Impedance data is generated through seismic inversion technique, which uses seismic data, well logs, and interpreted horizons to generate the 2D impedance sections. After data analysis in term of quality, the first step is to tie the seismic and well data. This required a depth to time conversion for the well data and estimation of the seismic wavelet. Second, an impedance model (layered geologic model) is made using the calibrated wells, seismic velocities and the seismic horizons. Third, the impedance model and seismic wavelet are used to invert the seismic data to P-impedance sections. Quality control for all the process throughout this workflow is extremely important.

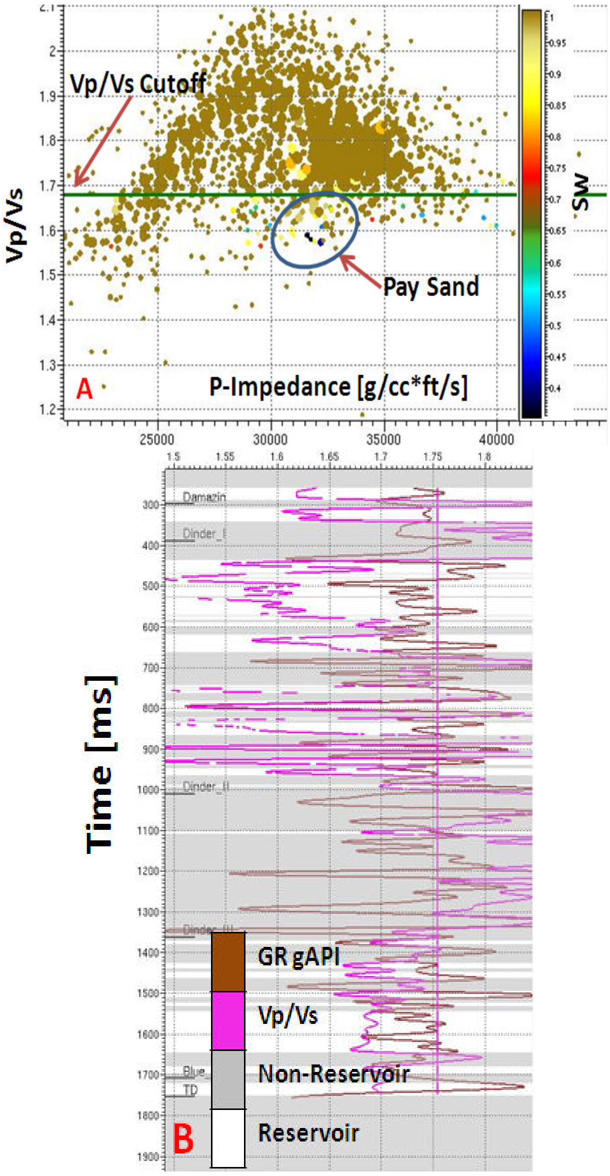


Fig. 6 (A) P-impedance versus Vp/Vs and water saturation as color scale in TWK-1. At Vp/Vs 1.7, the pay sand can be discriminated from wet sand, but using Vp/Vs alone will not identify the pay zones that some shale will interfere. The process should be used both P-impedance and Vp/Vs. (B) the corresponding well log

Fig. 7 is an absolute seismic inversion section illustrated the distribution of sand and shale as an indicator to predict some stratigraphic traps in the western side, compared with the interpreted seismic section, which is the main input for the inversion section.

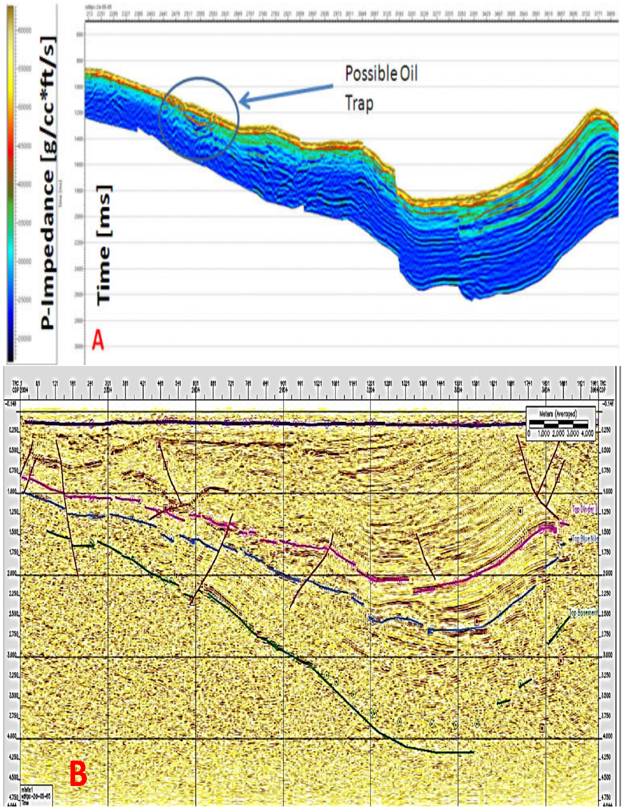
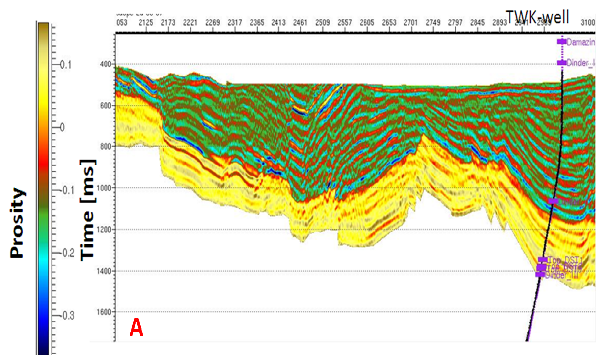


Fig. 7 Absolute seismic inversion in the (A) section shows the distribution of the sand and shale to predict some starigraphic traps in the western side (B) The seismic section, which is the main input for the inversion section

Acoustic impedance is a physical property of the sub-surface and changes in impedance can often be related to changes in specific reservoir properties such as porosity, lithology and saturation. The existence of the dry gas in well HSN-1, and the wet gas found to the west in well TWK-1, gives the potentiality of the light oil in west of TWK-1 as shown in Fig. 8.



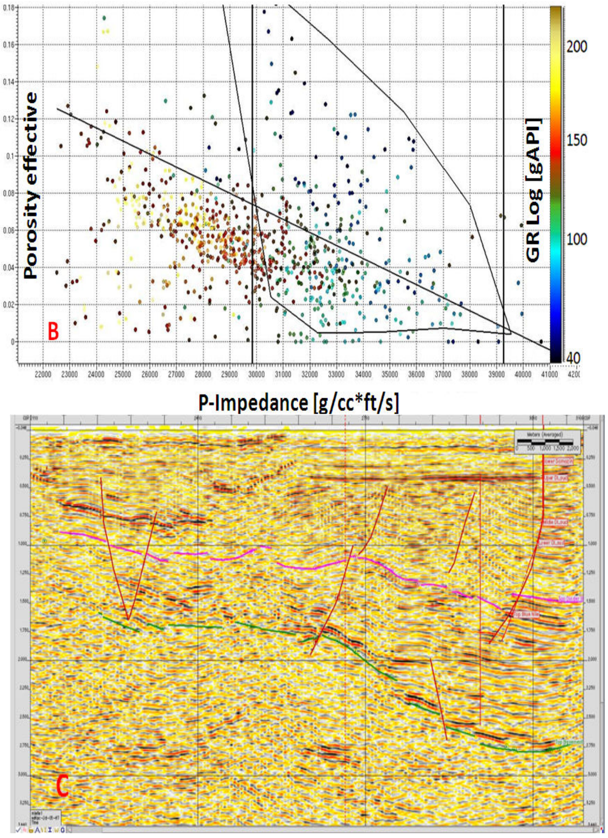


Fig. 8 (A) Porosity section (B) Crossplot represents the function which used to transform the impedance to porosity (C) Is the seismic section, which is the main input for the section (A)

VI. Conclusion

Blue Nile Basin is considered as one of the most potential hydrocarbon basin in Sudan, the complicity of the area in term of structure and facies make the reservoir characterization a tough task. Seismic inversion technique used in this study proofed to be a suitable technique to help the geomodeler to characterize the reservoir. The applied seismic inversion was successful in characterizing the reservoir. All these results can be summarized as followed:

1. The deterministic seismic inversion resolved the reservoir successfully.
2. It is found that using P-Impedance values discriminated sand from shale which reduces the exploration risk.
3. From used log resolution, the Vp/Vs together with the P-impedance discriminated significantly the pay sand from wet sand, which is applicable only in high resolution seismic inversion.
4. Stratigraphic parameters should be considered in further seismic acquisition and processing in the study area.

The presence of dry gas at HSN-1 at eastern side and the presence of wet gas at TWK-1 at western side give a clue to find light oil in the western part of the Blue Nile Basin

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