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Implementation of Classical and Advanced Geophysical Techniques to Evaluate the Gas Potentialities in West Abu Dhabi, UAE

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Abstract

The evaluation of the unconventional HC potentials in Diyab formation was conducted in the west of Ruwais area, Abu Dhabi, UAE, through the implementation of classical, advanced, and smart seismic workflows techniques. The qualitative and quantitative prediction of rock properties of the Jurassic Hanifa formation is the main geological challenge to locate and identify the sweet spots for gas exploration along Jubaila and Tuwaiq Mountain. The most important and critical rock properties of Diyab Carbonates are Porosity, Water Saturation (SW), and Total Organic Content (TOC), in addition to the structural setting evaluation including locating potential closures, detection of faults and recognition of fractures locations and orientations.

Introduction

The aim of this seismic evaluation study is to achieve better geological and geophysical understanding of the deep unconventional plays in Diyab formation in West of Ruwais Area, focused on Hanifa source rock in addition to identify any possible potentialities in Jubaila Source Rock & Tuwaiq Mnt formations.

Location of the Area: West Ruwais area, was recently covered by a 3D seismic survey, and processed between 2019 and 2021. The total survey coverage of the area is roughly above 8500 km2, while the West Ruwais area is covered roughly about 1500 Km2, and the area of interest is about 735 km2 fig. (1). PSDM, PSTM, and Angle pre stack gathers were all integrated with the available well data in the area (3 Wells) to achieve validated TWT and depth structure maps in addition to rock properties, and petrophysical properties cubes.

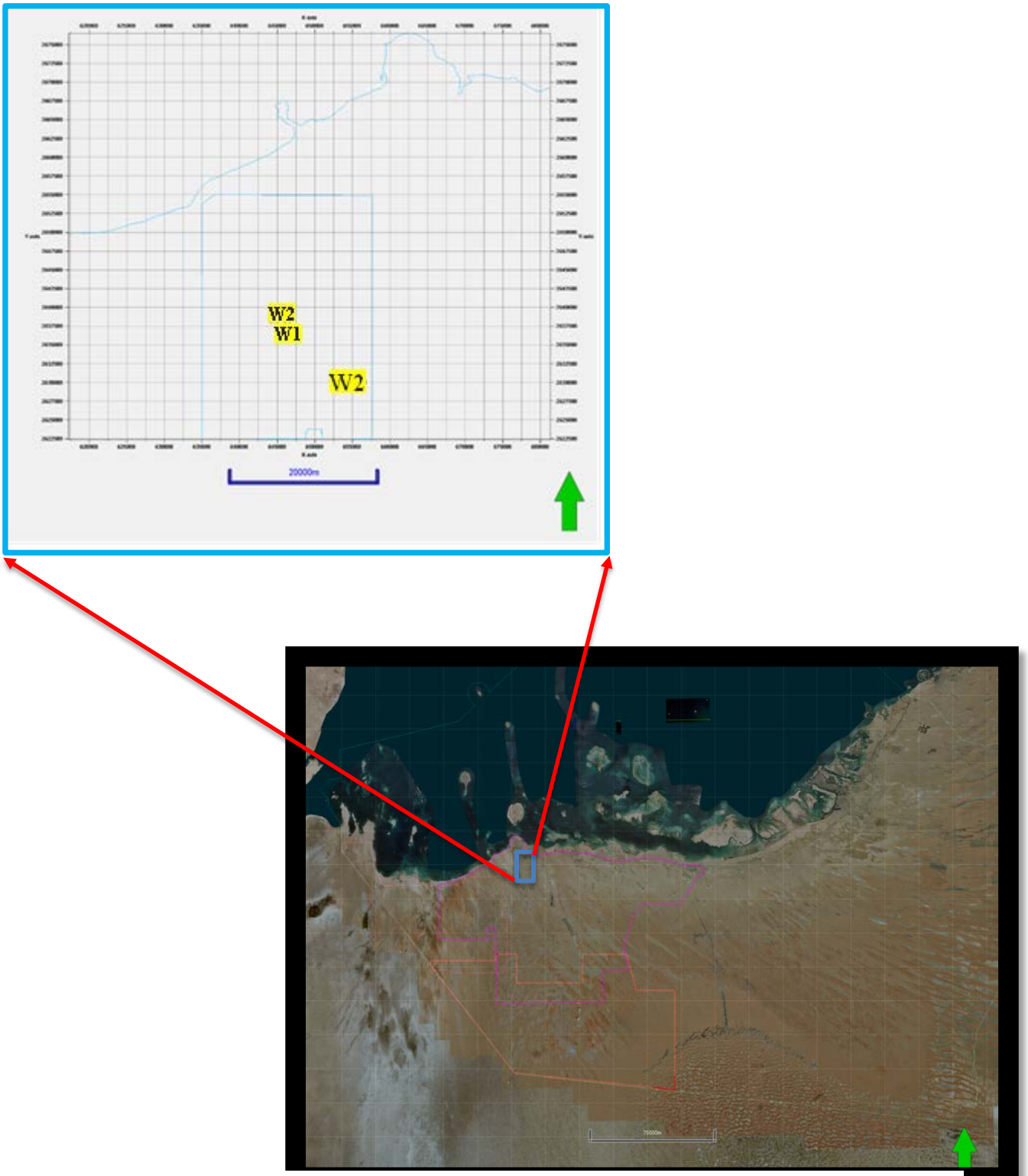

Fig. (1) Location of the Area

Geology Context

The Upper Jurassic, "Diyab Formation" is a lithology-based stratigraphic term used in the UAE for sediments of, (Oxfordian to Late Kimmeridgian), fig.(2b). Diyab Formation is known to be the source rock for several world-class oil and gas fields in the Middle East. It can be interpreted as a rough equivalent of the Tuwaiq Mt., Hanifa and Jubaila formations, a stratigraphic subdivision commonly used in Kingdom of Saudi Arabia (KSA). A distinct difference can be noted in the picking of the UAE Hanifa (in basinal settings mainly) which is equivalent to basal-Jubaila sediments in KSA, (M. Zeeshan., et al., 2017).

The contact between Diyab and the underlying Araej Formation is partly unconformable, the top of Diyab is commonly picked at the base of the Arab-D. The lower part of the Diyab formation (equivalent to KSA's Tuwaiq Mt. and Lower Hanifa formations) shows distinct thickness variations from shelf areas consisting of shoals and grainy deposits of up to 1000 ft thickness to less than 100ft in intrashelf basinal settings which dominate the depositional patterns in the western UAE fig.(2c).

The top of Hanifa as picked in the cross section shows the presence of evaporitic layer marking a distinct sea-level low attributed to the well documented region-wide top-Oxfordian sea-level drop fig.(2a). The upper part of UAE's Diyab Fm (Hanifa and Jubaila Fm in KSA) is mainly made up of basinfill sequences with partial source rock developments.

Diyab source rocks were subject to thermal stress allowing to generate both oil and gas to the major Jurassic/Cretaceous conventional reservoir. Present day maturity map is shown in Fig.(2d).

A significant investment is ongoing for the development of the unconventional Diyab in the Jafurah basin in Saudi Arabia. In the northwestern UAE, roughly 200 kilometers west of Abu Dhabi, is where the unconventional Ruwais concession and this study is located. Unconventional exploration and appraisal campaign took place during recent years. As part of the exploration campaign, many acquisitions including 3D seismic mega surveys, full set of logs and cores were completed on the exploration wells and hydraulic fracturing operations and production tests were performed & completed on the horizontal wells.

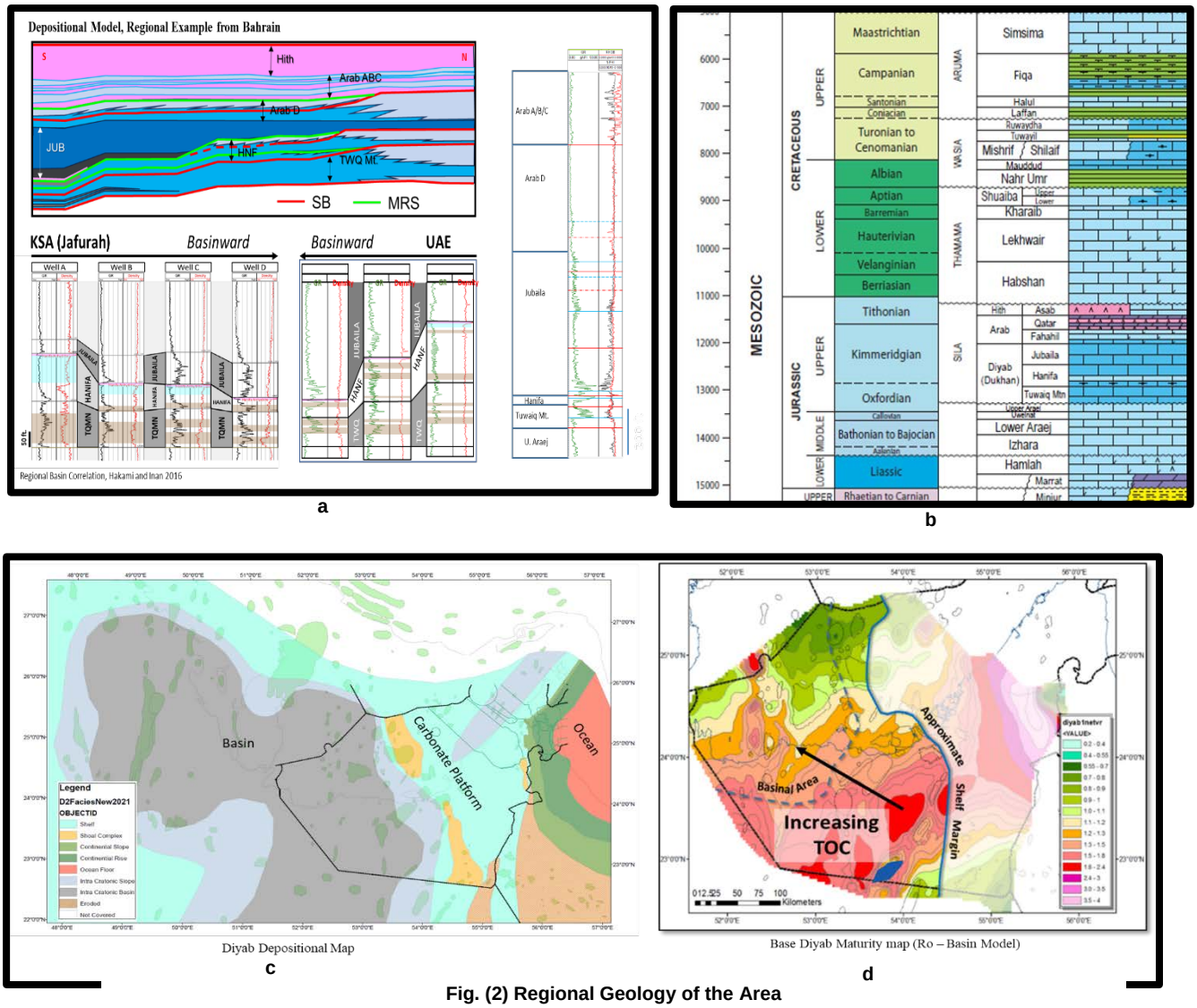

Fig. (2) Regional Geology of the Area

Techniques and Methodologies:

To achieve the aim of this study and to minimize the uncertainties in decelerating the play ruling rock properties and low relief structural setting of Hanifa Formation, three different techniques were utilized separately to reach to independent results which later matched and correlated to approach to a minimal uncertainties envelope of possibilities.

The initial techniques are part of the basic seismic interpretation workflow genetically including seismic to well tie, geological seismic marker identification, horizons picking, stratigraphic features detection, visual inspection to detect any possible fault segments, TWT to Depth conversion and calibration to available well data. This workflow was initially carried out on both PSDM depth and PSTM TWT seismic volumes to obtain structural and stratigraphic frameworks.

The second technique that was applied was the simultaneous inversion, which includes, wavelet derivation, trace alignment of the pre-stack angle stacks (near, near-mid, mid and far angles), seismic interepretation of intra reservoir units, low frequency model building, and the required QCs to produce the inverted elastic properties

A newely developed useful technique was applied through the application of genetic inversion that utilizes the well logs and seismic data to create a genetically inverted petrophysical properties such as, densities, water saturation and total organic content.

In addition to the above mentioned techniques, seismic stratigraphic attributes such as, ISO frequency component generation, relative acoustic impedance, RMS and fault/fractures ant track directional azimuth extraction workflows covering preconditioning, coherency and enhanced edge detection, were applied to assess for the study, although that the results of theses techniques are not shown in this paper.

The final step was to merge and integrate all the validated results from each technique to identify potential sweet spot areas, build a minimal uncertainty envelope and rank them accordingly. Consequentially four sweet spots were classified as potential areas for explorational and appraisal.

Seismic to Well Tie:

Three wells were used for the calibration, well to seismic tie, and inversion purposes for this study, The available check-shots are only recorded in two wells of them, accordingly, derivation of check-shots for the third well was adopted from the nearest well. Sonic calibration, synthetic generations were applied for the wells that have check shots and borrowed to the other wells to achieve optimized markers definitions both on Depth and TWT volumes. The seismic interpretation was conducted on, figure (3).

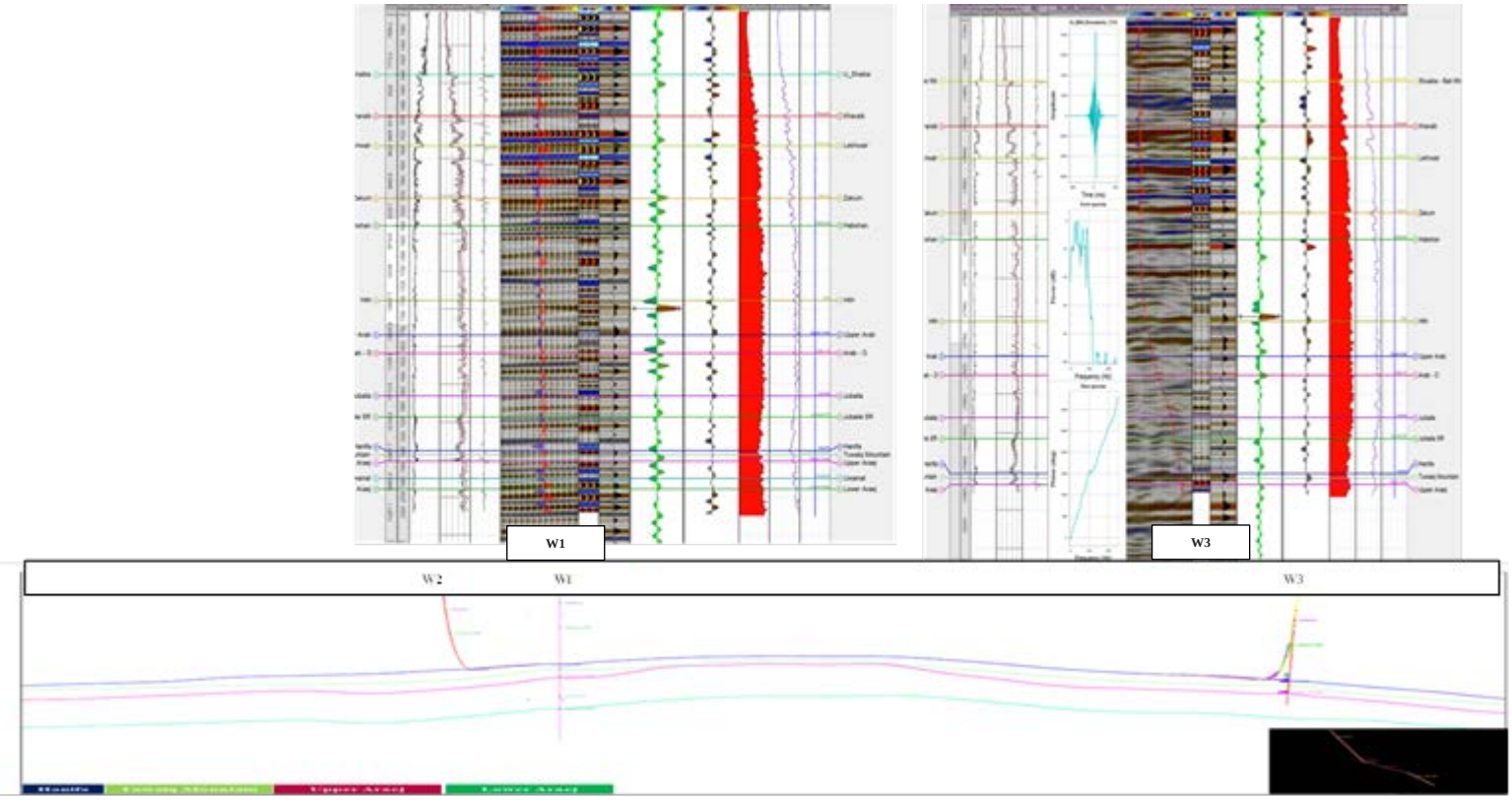

Fig. (3) Seismic to Well Tie

Interpreted Seismic Horizons:

Although that the focus of this study is the evaluation of Hanifa Formation source rock, and due to the limitations of the seismic resolution versus the Diyab members thickness, a set of horizons were defined according to the seismic polarities around the Hanifa, Tuwaiq Mountain, Upper Araej formations. Fig. (4) shows the 5 horizons which were selected to investigate the seismicity in the Hanifa to Upper Araej seismic package and to be used for more fine-tuned simultaneous inversion calibration and extraction of the seismic attributes. The interpretated horizons were picked through the seismic auto tracking method to avoid missing any polarity components and to preserve the seismic marker characteristics.

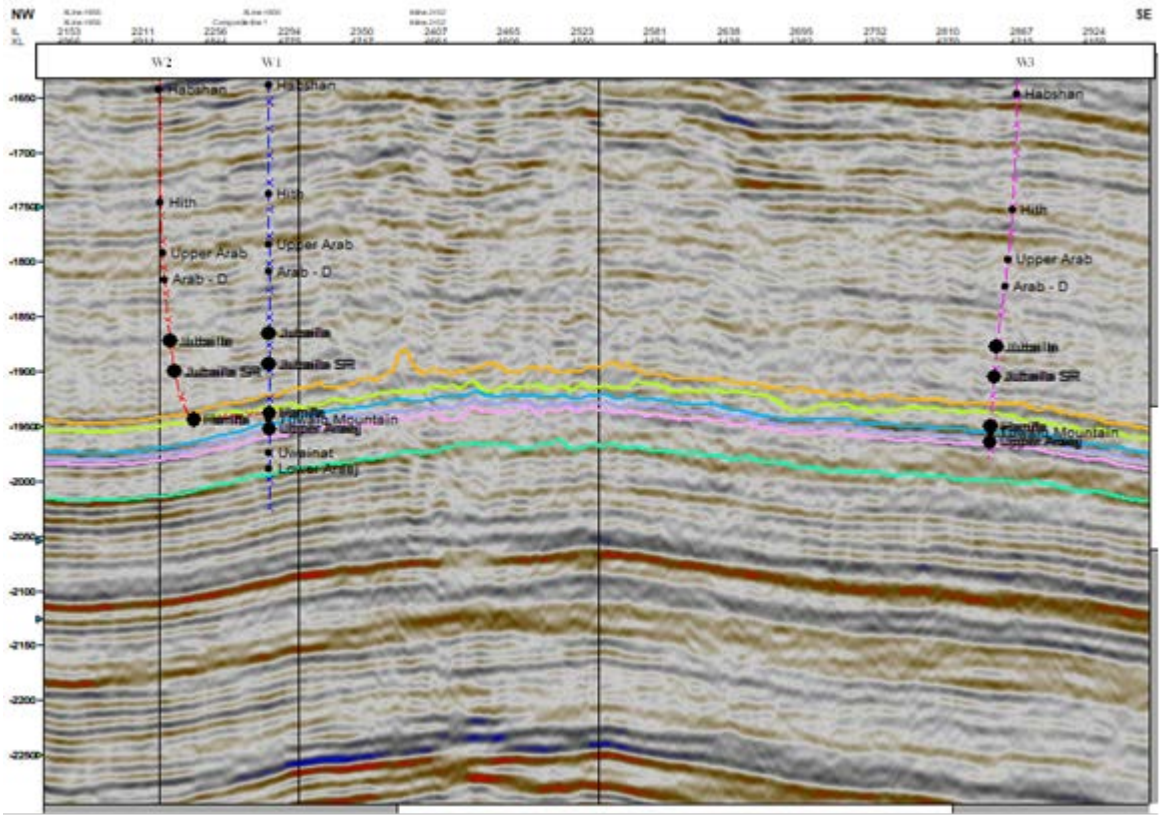

Fig. (4) Seismic Interpreted Horizons in TWT

Structural Mapping:

All the mapped horizons were interpreted on the PSTM angle stacks in TWT domain and then compared to the same geological seismic markers in depth domain that were interpreted on PSDM depth volume. Fig. (5&6) are showing that there are well noted consistency between the interpreted PSDM depth top Hanifa structure and the interpreted PSTM TWT Hanifa structure, where a synclinal feature can obviously be noticed to the N-E corner of the area of the study, while the central part of the studied area is characterized by a structural high that can be represented by a 4-way dip closure anticline. The structural high is bounding the three key wells that have been used for this study

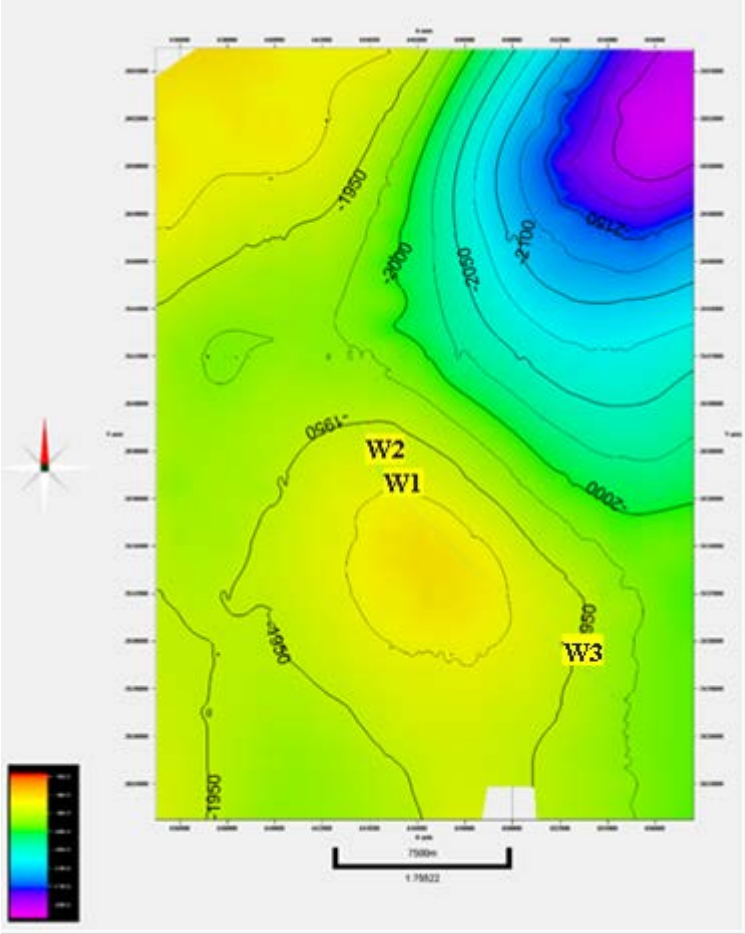

Fig. (5) TWT Structural Mapping on Top Hanifa

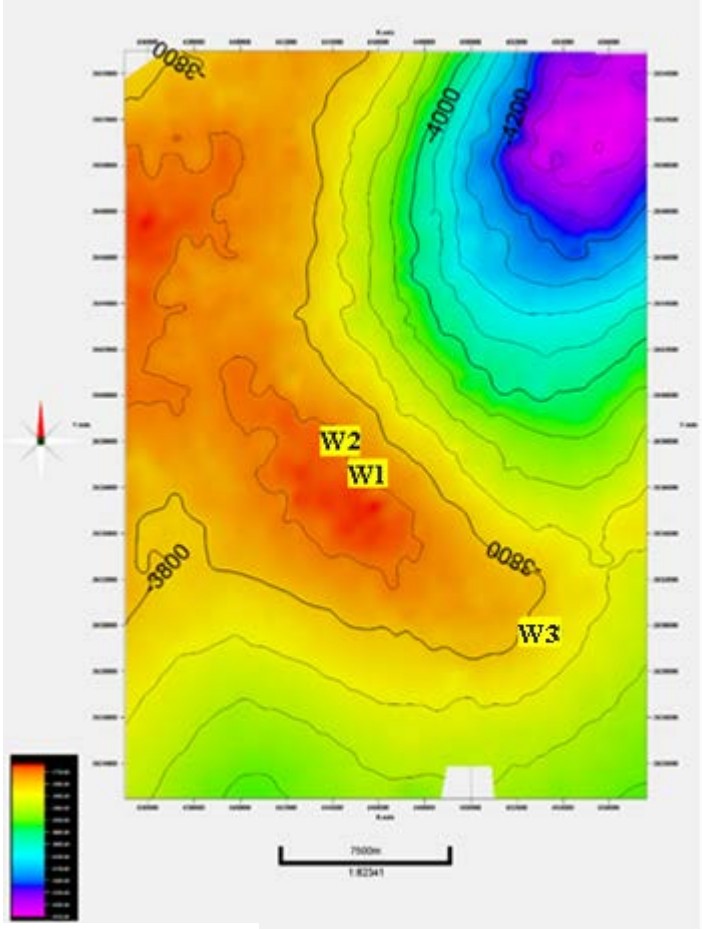

Fig. (6) Depth Structural Mapping on Top Hanifa

Simultaneous Inversion:

The simultaneous inversion process allows to perform inversion of 2D or 3D migrated seismic data in the form of angle stacks for simultaneous AVO inversion or full-stack (post-stack) seismic for acoustic impedance inversion, (Aki, et al., 1980.)

The process involves, data preconditioning, seismic interpretation on the angle stacks, derivation of integrated seismic wavelet fig. (7), low frequency modeling, data QC using, the blind well test, fig. (8), properties weight maps QC fig. (10), and inversion QC plots fig. (9). The results of the simultaneous inversion study are: acoustic impedance, P/S ratio/ density and Poisson's ratio, The QCs showed consistency of the results around the area of study and good match the available well data, and accordingly can be validated to continue for lithologic classification and rock type identification.

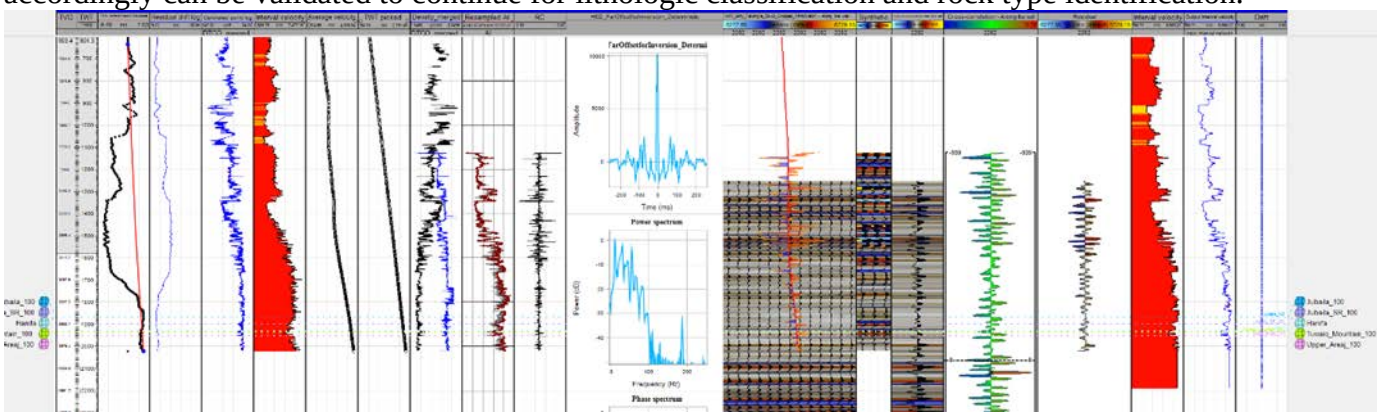

Fig. (7): Integrated Wavelet Derivation and Calibration QCs

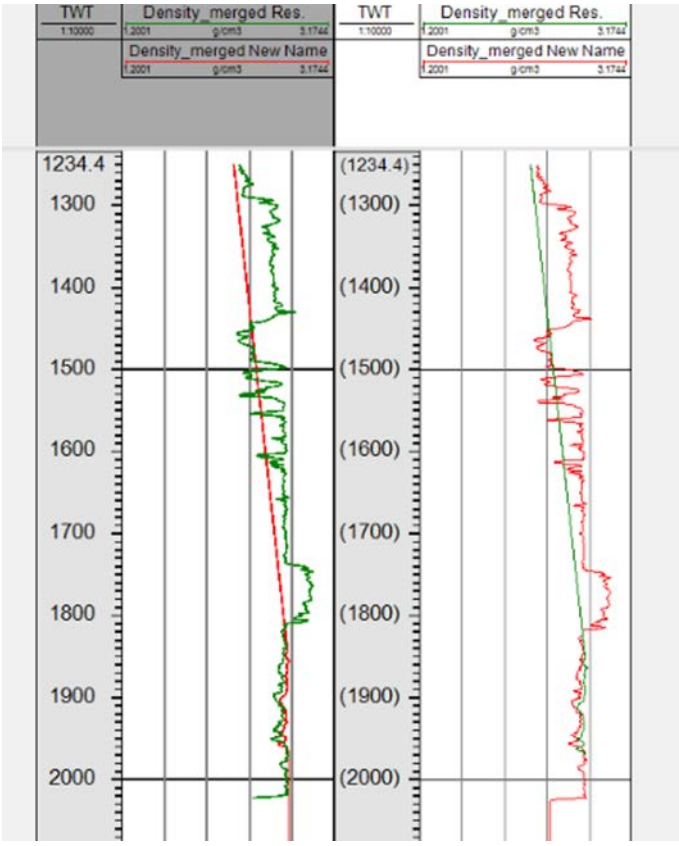

Fig. (8): Inversion QCs, Blind Well Test

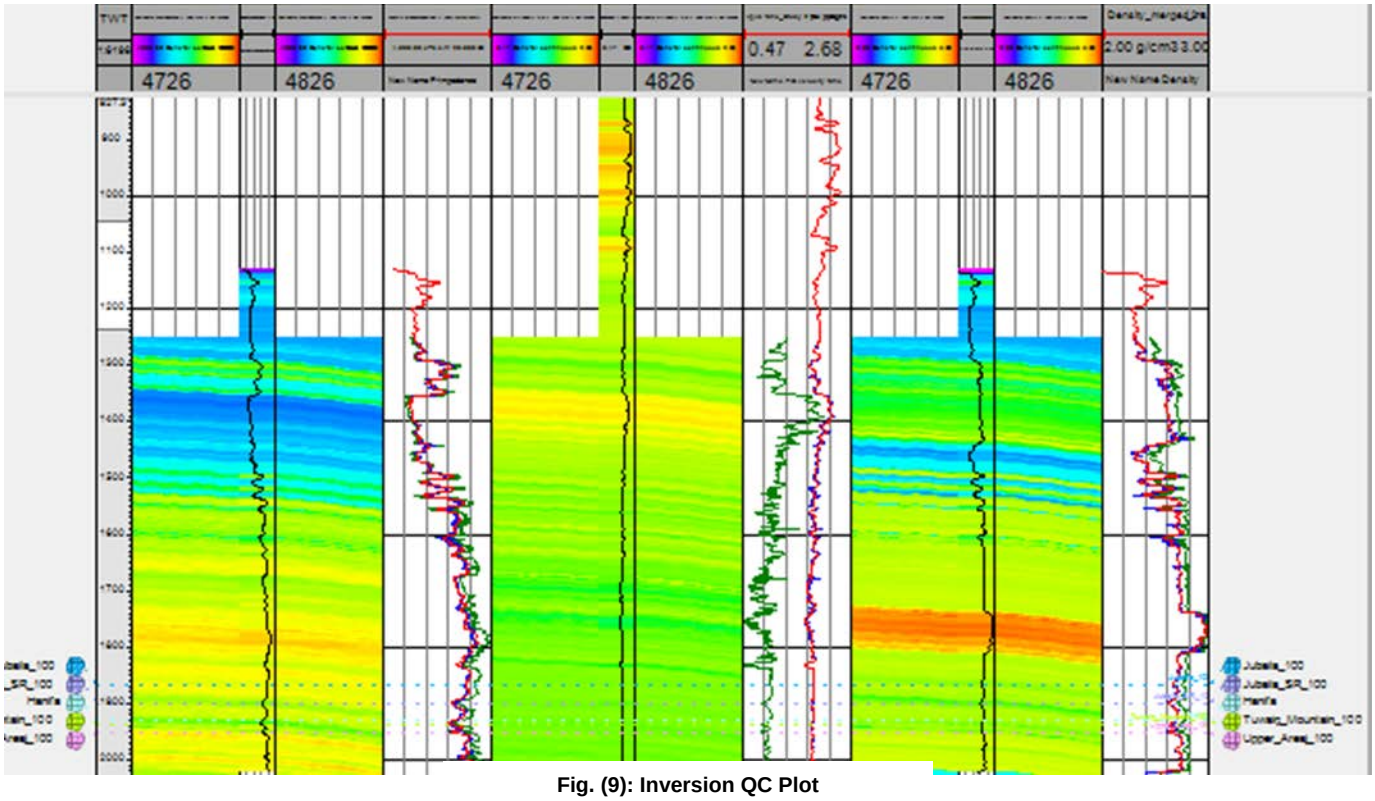

Fig. (9): Inversion QC Plot

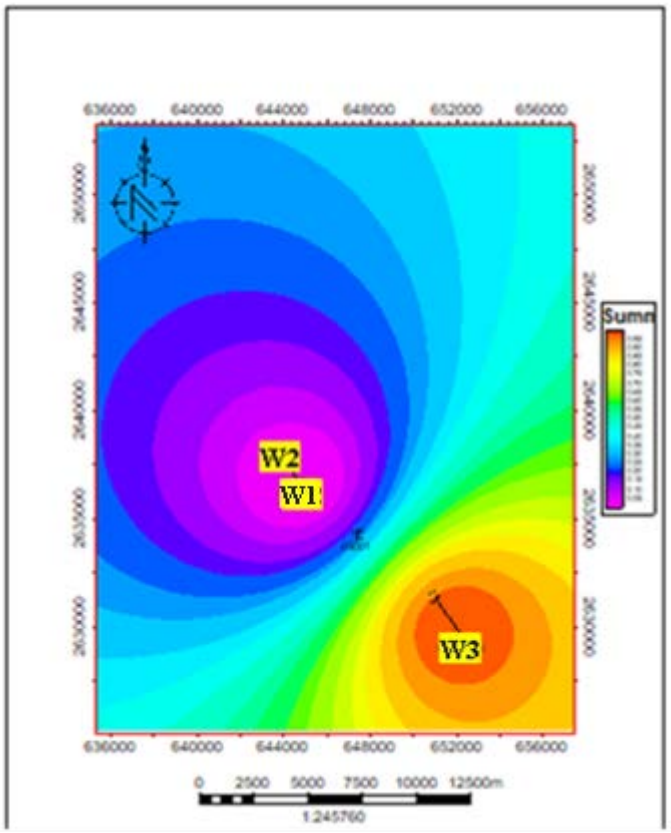

Fig. (10): Property Weight Map

Gathering of the Results:

Fig. (11, 12 and 13) are showing the surface maps of P-impedance, density and P/S velocity ratio respectively overlie on Top Hanifa TWT structure contour maps, where hot colors indicate higher densities, higher p-impedances, and higher p/s velocity ratios. The similarity between the high/low trends on all the properties maps can be observed, which can guide the identification of gas sweet spots, where lower values of the three properties can be associated to indicate higher possibilities of gas contamination within the formation. Vertically it was shown on fig.(9) that the comparison between the well logs and the inverted properties are showing very good match which validates the workflow and increases the confidence in the resulted properties

Genetic Inversion:

It's a newly developed technique, that utilizes neural network to produce inverted cubes from post-stack seismic normal amplitudes and selected property logs. The method utilizes a fast and simple workflow, that can significantly reduce the time needed to accomplish classical inversion methods which always requires dedicated data preconditioning, testing of the parameters, and machine production time. The genetic inversion technique requires inputs are limited to the seismic amplitude and the acoustic impedance well logs or micro-seismic point sets used as training data. The advantage of this process is that it is not only restricted to conventional acoustic/elastic impedance inversion, but it can be extended to any kind of petro-physical attribute/parameter, which is linked in a meaningful, and straightforward way to the seismic amplitude or derived attribute data. To be more explicit, all the parameters contained in the wave-equation are possible candidates (for example, velocity, density, porosity, bulk modulus...). In our case study, a direct genetic inversion was applied to the PSDM depth volume utilizing RHOB, PHIT, and SW logs that are measured in the forementioned three wells, results are shown in fig. (14, 15 and 16).

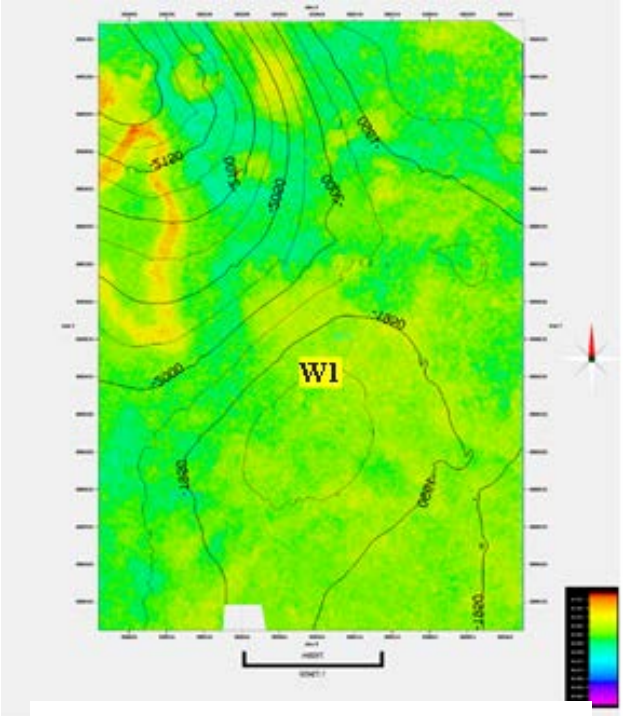

Fig. (11): Top Hanifa P-Impedance from Simultaneous Inversion overlaid by TWT Structure Contours

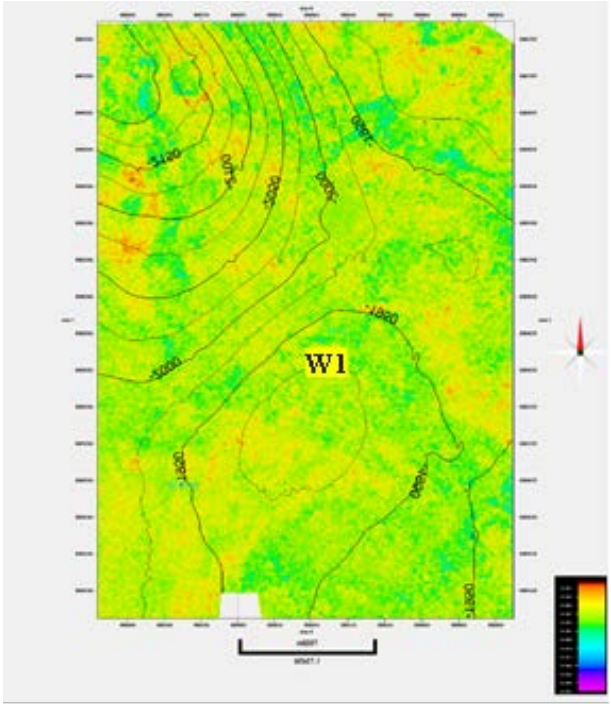

Fig. (11): Top Hanifa P-Impedance from Simultaneous Inversion overlaid by TWT Structure Contours

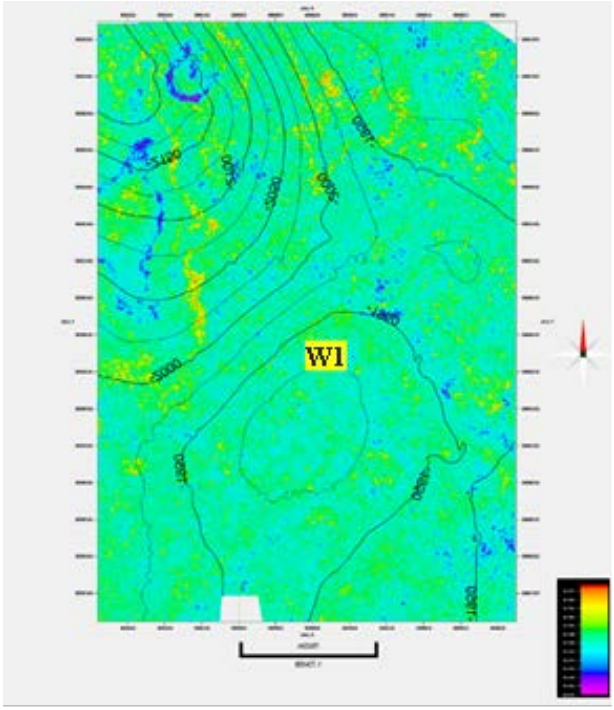

Fig. (13): Top Hanifa P/S Velocity from Simultaneous Inversion overlaid by TWT Structure Contours

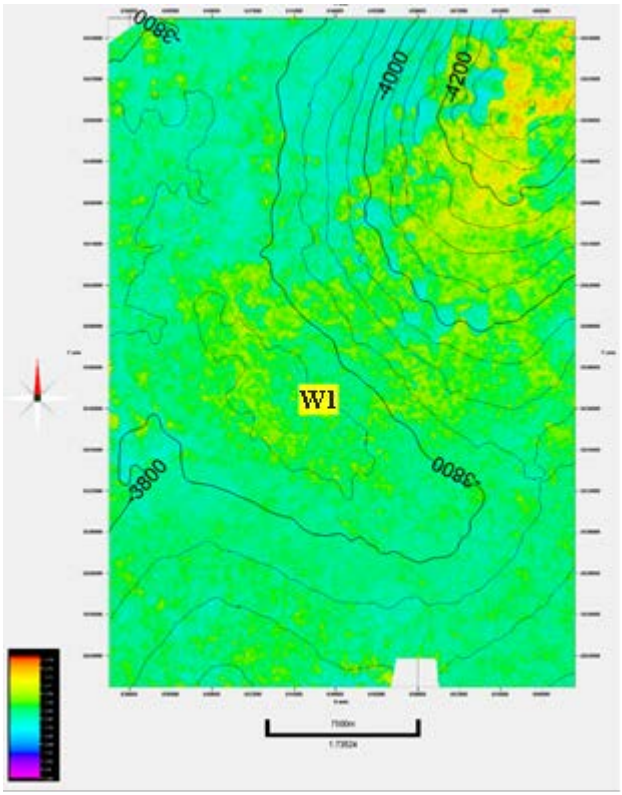

Fig. (14): Top Hanifa Density from Genetic Inversion overlaid by Depth Structure Contours

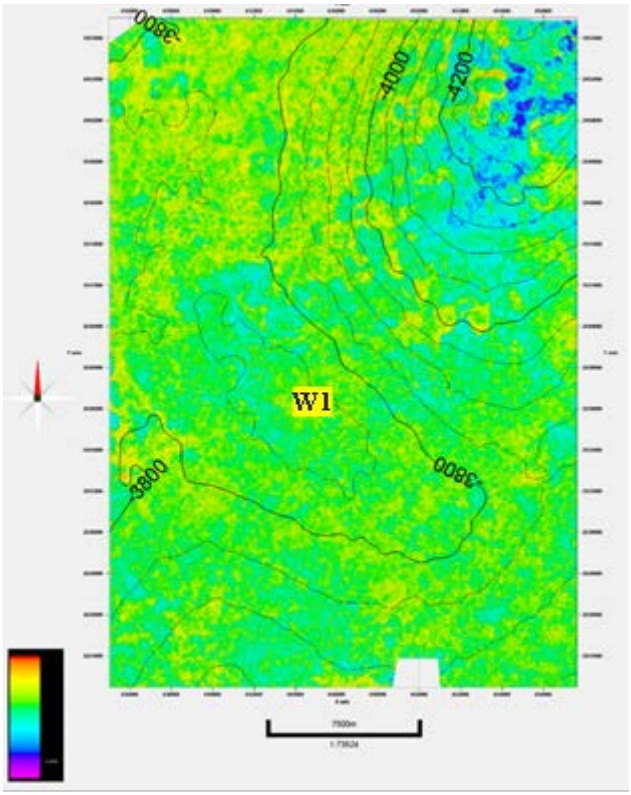

Fig. (15): Top Hanifa PHIT from Genetic Inversion overlaid by Depth Structure Contours

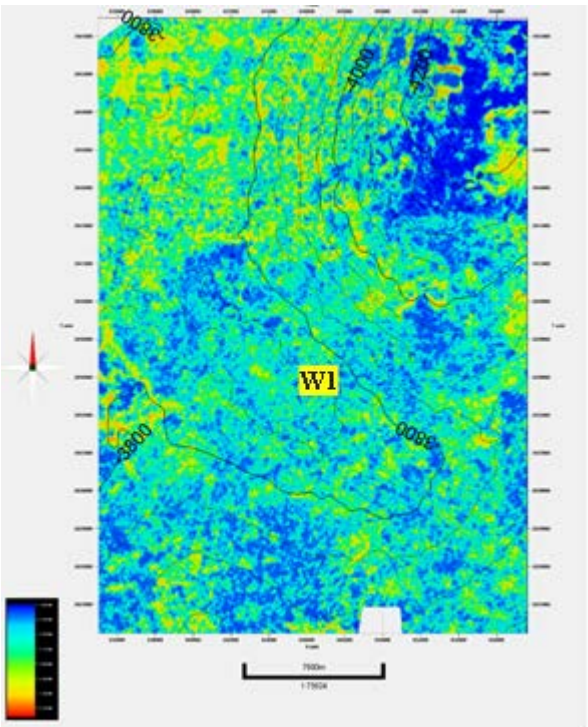

Fig. (16): Top Hanifa SW from Genetic Inversion overlaid by Depth Structure Contours

Fig. (14, 15 & 16) are showing the results of genetically inverted properties of density, PHT and SW, overlie the depth structure contour map of Top Hanifa. The hot color on each property indicates higher values, consequentially the selection of the sweet spots based on densities and porosities should be guided to the hot values, while the selection should go for the cold colors on the SW map. The results of the genetic inversion were validated and tied to the relevant logs, and it showed qualitative matching. Although the results are encouraging to utilize the genetic inversion technique for further studies in the area through the implementation of more petrophysical logs, but the comparison between the results of the simultaneous inversion and the genetic inversion, as for an example the inverted densities, fig. (12 & 14) shows that the density that has been derived after the simultaneous inversion technique have more reliable values, and more valid distribution. Accordingly, the application of the genetic inversion should be applied for qualitative purposes to generate the properties that can be difficultly produce from the other classical inversion techniques such as SW, TOC, porosity, etc.., and paying attention to tie and calibrate the results to the available well data. Fig. (17, 18 and 19) are showing the resulted properties in depth vertical sections, calibrated to the relevant logs. In general, the colorindicate a homogenous match to the log curves trends.

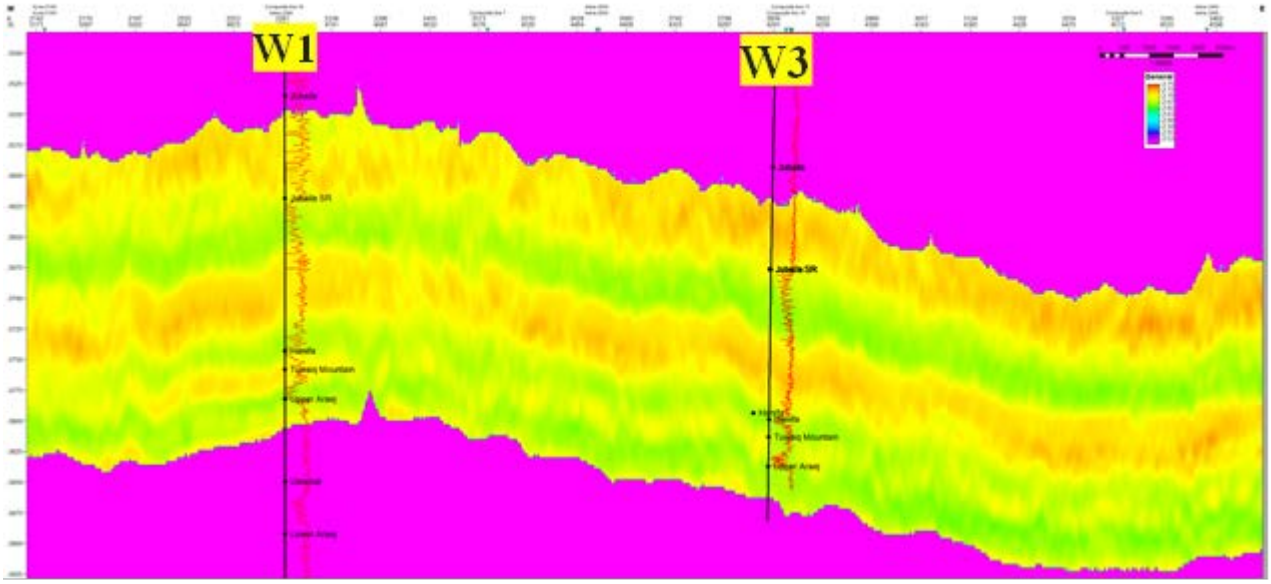

Fig. (17): Resulted Density from Genetic inversion in Depth Vertical Section

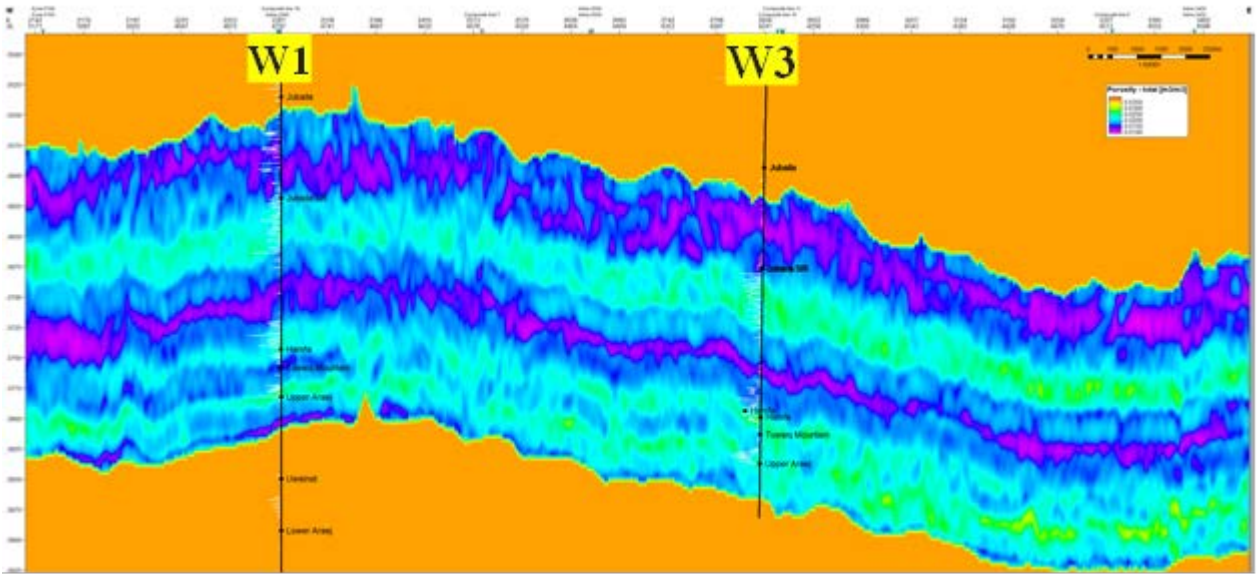

Fig. (18): Resulted Total Porosity from Genetic inversion in Depth Vertical Section

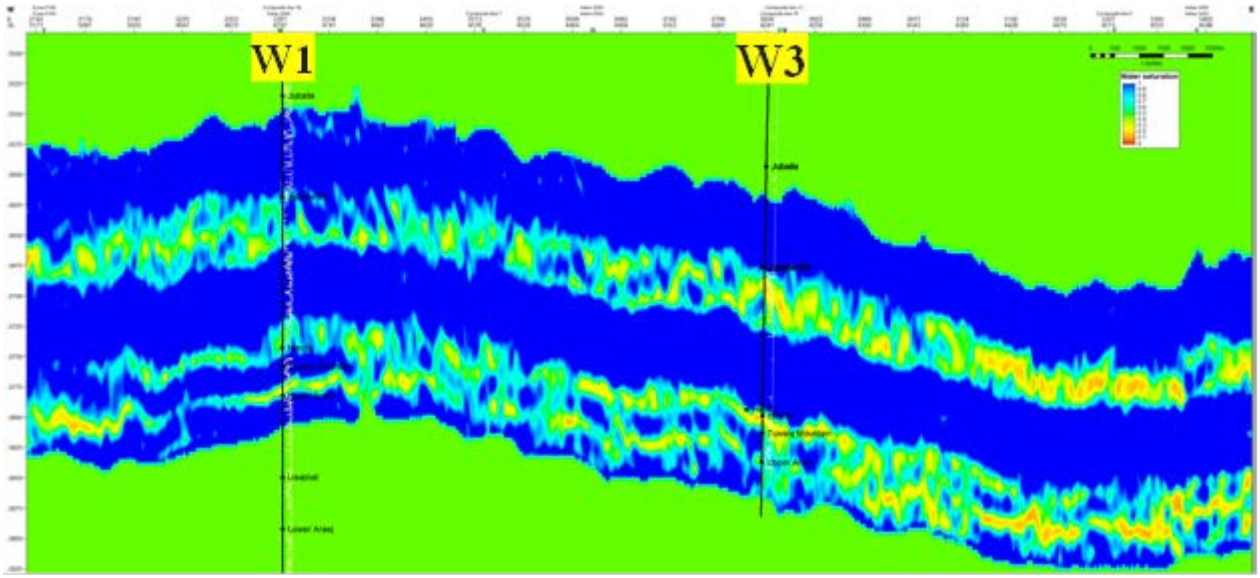

Fig. (19): Resulted SW from Genetic inversion in Depth Vertical Section

Summary and Way forward:

The gas sweet spot identification within the unconventional source rock is a sophisticated process that requires the implementation and integration of several techniques. The application of classical seismic interpretation integrated with advanced seismic inversion techniques can significantly help to identify the sweet spots, but the classical inversion techniques require long and time-consuming workflows, where the uncertainties can increase when as in many cases there are no sufficient well data, and where the selection of the parameters can't reach a conclusive result. Accordingly the integration of the genetic inversion which depends on the neural net work and machine learning can add great value to the studies where, the work flow is much simple and the direct solutions can limit the uncertainties that might result due to missing the correct testing parameters, in addition to it's ability to produce other properties that can be hardly derived from the classical inversion techniques, such as TOC, SW, PHIT, etc..

For this area of study further generation of petrophysical properties should be applied and more work should be done for lithological classification to achieve a validated quantitative evaluation of the area

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