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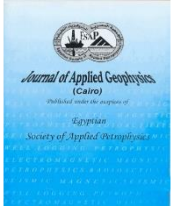

Original Article

Implementation of Seismic Data Conditioning in Complex Geologic Causatives: A case Study of Issaran Oil Field, Gulf of Suez, Egypt

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ABSTRACT

Obtaining high quality seismic imaging, for the interpretation in shallow carbonate oil reservoirs with complex structure, like Issaran oil field, is challenging. Many geologic causatives affect the image quality and posing numerous problematic conditions for seismic interpreters. To achieve the required higher performance, seismic data conditioning is a crucial step in the pre-interpretation phase. The case study presented in this paper is a shallow heterogenous carbonate reservoir, associated with a complex stratigraphic and structural regime. The definition of the prevailing geoseismic conditions (such as: low velocity layer, high velocity layers, thin beds, truncated horizons and terminated units) and their impacts on the seismic data quality is the focus of this case study. However, the main issue investigated is whether the seismic acquisition and/or processing parameters have resolved these geoseismic conditions or not, thereby showing that, the use of seismic conditioning is advantageous. First, the available 2D seismic lines data were resampled and converted by interpolating them into 3D pseudo seismic data, to get the benefits of 3D seismic interpretation. After that, multiple structural oriented filters were applied to the pseudo volume, for eliminating the residual coherent and random noises. This further improved the quality of seismic data and sharpened the fault discontinuities. Following that, structural attributes were tested, to investigate how the data conditioning affected the clarity of fault patterns. Based on the significant improvement in imaging quality, the seismic data conditioning workflow, that has been implemented, is beneficial for the field development in Issaran oil field, Gulf of Suez, Egypt.

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1. Introduction

Issaran oil field is located at the western side of the Gulf of Suez and 25 km to the south of the Southern El-Galala Plateau. Issaran oil field is operated by Scimitar Production Egypt Ltd. (SPEL), based on a petroleum service agreement (PSA) with the General Petroleum Company (GPC). Issaran oil field uses steam injection, as a technique for enhanced oil recovery (Samir, 2010 and Saoudi et al., 2014). Issaran oil field has a complex geologic setting and significant reservoir heterogeneity and variability. The Miocene stratigraphic sequence differs from the other oil fields in the conventional Gulf of Suez stratigraphy. The Issaran Miocene facies is represented by sabkha to shallow marine depositional environments (EGPC 1996; Saoudi et al. 2014; and Younis et al. 2019). In Issaran field, the target formations are mainly the Miocene carbonates strata, which are present at very shallow depths. Following deposition, the sediments were exposed to diagenetic processes (such as: dissolution, mineral replacement, fracturation and cementation). These alterations caused fractures and vugs, which resulted in significant geologic heterogeneity and anisotropy (Saoudi et al. 2014 and Younis et al. 2019).

Issaran reservoirs are present at depths ranging between 500 and 2500 feet. These relatively shallow depths imposed many issues on the seismic data quality. Moreover, the proximity of the carbonate reservoirs to the low velocity (unconsolidated) layer yields strong ground roll noises, that mask the low amplitude of the reflected data, especially those generated from deeper reflectors (Taner, 1997 and X. Wang et al., 2012).

Furthermore, the large difference in velocity between the carbonates and the clastics rocks cause that, most of the seismic waves to be reflected to the surface rather than transmitted to the subsurface. As a result, this decreases the signal to noise ratio at the deeper level (Taner 1997). All of these issues should be addressed before beginning the seismic data acquisition, processing and interpretation. This will enable the geophysicist to see their impact on each phase and select the proper solution for minimizing their effects on the seismic imaging.

This paper discusses the prevailing geoseismic conditions of Issaran field. The Issaran seismic data acquisition and processing parameters were also investigated. Moreover, the effect of seismic data conditioning on the prevailing geoseismic conditions in complex carbonate field and outlines how improvements can be applied. In addition, the structural oriented filters technique was used, to improve the characteristics of faults and subtle the geologic features of Issaran seismic data. Moreover, the small-scale faults, that have small displacement of about 40 feet were resolved by the seismic structural attributes.

2. Geologic Setting

The stratigraphic section of Issaran field is composed of pre-rift, syn-rift and post-rift sequences (EGPC 1996; Saoudi et al. 2014; and Younis et al. 2019) (Fig. 2). The pre-rift sequence is formed by the Precambrian basement complex rocks and the overlying Cambrian to Eocene section. The base is formed by the Nubia Sandstone, followed by a mixed facies section (Nezzazat Group) and the uppermost Cretaceous carbonate section and Paleocene shale and limestone of Eocene age (Bosworth and McClay, 2001 and Moustafa and Khalil, 2020).

The syn-rift sequence in Issaran field (during the Oligo-Miocene time) is characterized by very shallow and low energy marine depositional facies, laterally dissimilar to those deposited in the deep parts of the rift (Saoudi et al. 2014). The syn-rift sequences are subdivided to four distinct depositional sequences. The bottommost Nukhul Dolomite has variable thicknesses ranged between 40 and 220 feet, and characterized by a shallow marine environment (EGPC 1996). The Gharandal Formation is mainly composed of a thick body of shale, with three to four thin limestone bodies embedded in the shale. The topmost Lower and Upper Dolomite reservoirs are mainly made up of dolomite, with anhydrite nodules. Each reservoirs have 500 feet thick, with strong post-depositional diagenetic alterations (such as: micritization and recrystallization, dolomitization, neomorphism, dissolution and fracturing) (Younis et al. 2019). They are characterized by an intertidal to shallow marine environment (EGPC, 1996), which results in significant lateral and vertical heterogeneity. Nowadays, they are representing the two main reservoirs in Issaran field. They are separated by a wide-field Intra-Dolomite Shale, which is characterized by variable thicknesses ranged between 15 and 115 feet. The South Gharib Formation is composed of anhydrite and dolomite alterations, with average thickness of about 150 feet. The Zeit Formation is composed of anhydrite and shale intercalations, accompanied by thin sand lenses, with a maximum thickness of 20 feet at its base (Saoudi et al., 2014).

The post-rift sequence in Issaran field unconformably overlies the Zeit Formation, which is composed of thick unconsolidated loose sand and gravel, with limestone and clay intercalations. It is characterized by variable thicknesses ranged between 300 and 600 feet.

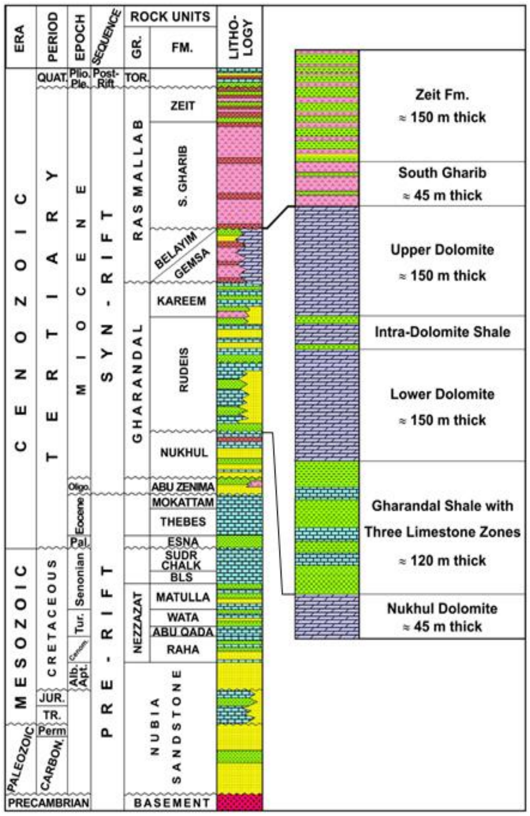

Fig. 1: Simplified stratigraphic section of the Gulf of the Suez. The detailed interval of the Miocene rocks represents the Miocene stratigraphy of Issaran field, after Saoudi et al., 2014.

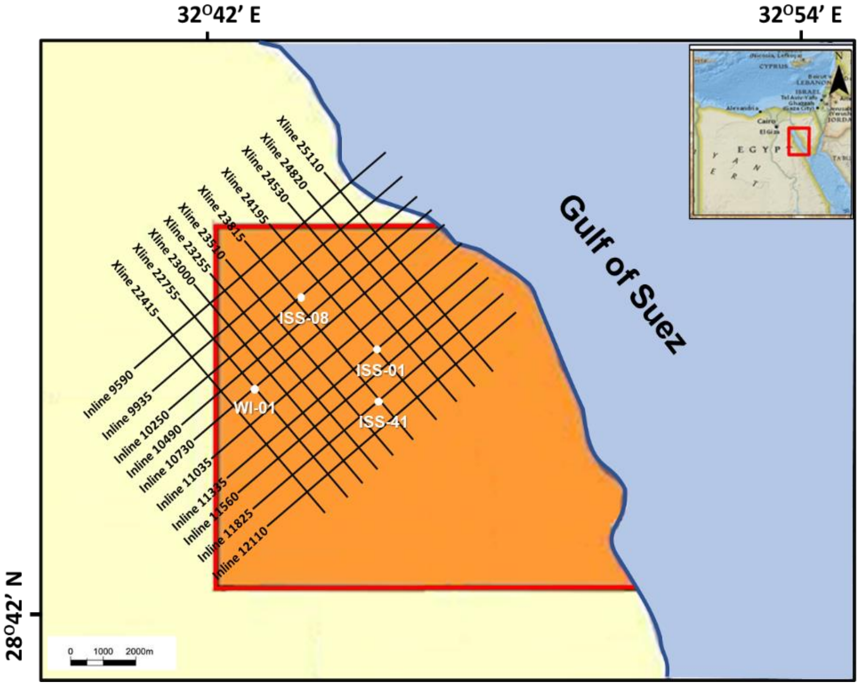

Fig. 2: Issaran Field map related to the Gulf of Suez province, with the available 2D seismic data (represented by black lines) and four wells. The red border represents the Issaran concession boundary and the blue line represents the present shoreline.

Issaran field is a geologically complex heavy-oil field, composed of heterogenous carbonates, with a complex structural regime. The field is situated at the central dip rift province of the Gulf of Suez, in which the strata dip towards the northeast (Robson, 1971; Moustafa, 1976; Colletta et al., 1988; Patton et al., 1994; and Bosworth et al., 2020). The field is controlled by tilted fault blocks, bounded by faults, which are oriented NW-SE (parallel to the clysmic trend) and faults-oriented NNE-SSW (parallel to the Aqaba trend). The Aqba faults act as transfer elements linked with the clysmic trend (Moustafa 2002). The strata dip towards the east-northeast, while the direction of fault throw is toward the southwest.

2.1 Prevailing Geoseismic Conditions

Issaran field is characterized by heterogenous carbonates and a complex structural history. This geologic complexity has a significant effect on the seismic data quality. So, it is preferable to consider the prevailing geoseismic conditions, before designing the seismic acquisition parameters and selecting the appropriate processing procedure. The geoseismic conditions are defined as the geologic (structural and stratigraphic) factors, that influence the seismic data characteristics (velocity, amplitude, phase and frequency). Issaran field has many geologic factors, that have an impact on the seismic data quality. These prevailing conditions are addressed from the available well data and are listed, as follow:

a. Low velocity zone: Issaran field is characterized by a rough terrain topography, with non-uniform unconsolidated surface layer of thickness ranging between 300 and 600 feet. This low velocity layer causes a difference in the arrival times for the recorded reflected seismic waves and dispersion for the seismic wave velocity. Additionally, it causes ground roll noises, with enormous high amplitudes, that mask the useful reflected data (Aigbedion, 2007) and produce fictitious structural features.

b. High velocity layers: The presence of anhydrite in the South Gharib Formation and alternations of anhydrite (high velocity) with shale layers (low velocity) in the Zeit sequence. Additionally, intercalations are present between the Miocene carbonates (high velocity) and clastics (low velocity), which cause rapid change in the velocity at their interfaces. As a result, Issaran seismic data are deeply affected by different types of multiples, such as the short period multiples, long period multiples, interbed and surface related multiples (Taner, 1997 and Wang et al., 2012).

c. Thin beds: Thin sand bodies with a maximum thickness of 26 feet presence at the basal part of Zeit Formation. Also, the Intra-Dolomite Shale layer in some parts of the field is reduced to 15 feet in thickness. Both have an impact on the seismic amplitudes of Issaran data. They also mis the rock unit’s boundaries, as a result of the seismic waves amalgamation for less than quarter of wavelength of the waves, due to the shale intercalations.

d. Terminated units: The Nukhul carbonates in Issaran field are well developed at the crests of blocks. This Nukhul carbonate sequence laterally changes into Gharandal shales in a downdip direction, providing significant lateral variability (EGPC 1996) in both the layer thicknesses and lithologies. This influences the seismic velocity and creates diffraction noises as well. The terminated unit’s effect is recognized at one point in the seismic section horizontally, where the seismic waves are amalgamated for less than quarter of wavelength of the waves.

e. **Truncated horizons:** Issaran field is affected by complex structuration (normal faults), that yield differences in the seismic velocities at the locations of the structural elements. Moreover, the structural features are generating diffraction noises and scattering of the seismic waves at their terminations (Jaglan et al. 2015). The specification in the linear structural elements may reflect comparable lithologic missing or repetitions. The effect of truncated horizons is recognized along fault plane itself along the seismic section vertically.

3. Data Acquisition and Processing

3.1. Seismic Data Acquisition

The seismic data of Issaran field were acquired at two different times (GPC internal reports by WesternGeco and SCGC companies). The first 3D seismic acquisition in 2001 covered the central part of Issaran field. After that, in 2009, the 3D seismic data covered the eastern and western parts of Issaran field were acquired. Both surveys have the same survey design with minor differences in their acquisition parameters. The two seismic acquisitions were designed for the shallow Miocene carbonates imaging, with narrow frequency bandwidths (5-70 hertz), short offsets (up to 1987 meters) and wide survey lines spacing. As a result, the imaging of the deeper reflectors is challenging. Furthermore, the relatively wide survey lines are minimizing the seismic data resolution. In conclusion, the acquisition parameters were designed regardless to the prevailing geoseismic conditions.

3.2. Seismic Data Processing

Seismic data processing for Issaran seismic data was carried out in 2013. One of the key objectives was to eliminate the significant noises contamination of the seismic data and increase the signal to noise ratio (GPC internal report by Spectrum-Geopex company). The seismic data processing plays a significant role in the seismic data enhancement, which eliminates the significant noises generated from the geoseismic conditions. These noises such as ground rolls and random noises are eliminated in a good quality manner, by applying a FK-filter and localized amplitude processing technique. Moreover, the refraction statics compensate the lateral variation of thickness of the weathered layer. These results improve the reflector continuity and seismic amplitude enhancement.

A dense velocity analysis was performed, through different stages within the processing sequence, due to the velocity heterogeneity related to the variability of the carbonate reservoirs. Additionally, a Kirchhoff algorithm was used for the Pre-stack time migration, that yields a better definition for the fault boundaries, by collapsing the diffracted waves along the faults discontinues (Liu, 2011) and increased the signal to noise ratio.

Finally, the short and long period multiples were eliminated successfully, using the predictive deconvolution and radon techniques, but the interbedded and surface related multiples were not eliminated, because of the minor differences in their velocities, compared to the primary reflected events velocities. It is difficult to discriminate between the primary event velocities, and the interbedded and the surface related multiples velocities (Wang et al., 2012). As a result, these multiples are masking the weak events, reflected from the deeper reflectors, which increase the difficulty of delineating the deeper structures.

4. Methodology

4.1. Available Data

The study area is covered by 20 2D intersected seismic lines in the time domain, which are tied by four wells, called; WI-01, ISS-08, ISS-01 and ISS-41, as shown in Figure (1). These 20 seismic lines were resampled and converted by interpolating them into a pseudo 3D seismic grid (Parra et al., 2018; El-Gharabawy, 2021; and Abdullah et al., 2021), using Petrel software, for enhancing the efficiency of seismic data conditioning.

4.2. Seismic Data conditioning

Seismic data conditioning is an important step for removing the residual coherent and random noises persisting, after the seismic data processing (Jaglan et al., 2015; Attia et al., 2020; and Ashraf et al., 2020). It is an essential step before the seismic data interpretation and after the geoseismic conditions are addressed. This is an addition, to studying the acquisition and processing parameters and their impact on the seismic data quality, particularly in the complex geologic areas, such as Issaran field. The original acquisition parameters of Issaran seismic data, that performed in 2001 and 2009, included many aspects of poor imaging, because of the selected acquisition parameters and/or older generation acquisition instruments. The imaging of fault patterns might often not represent the true picture of the subsurface structural framework. So, a conventional seismic interpretation (Helal et al., 2015) is not preferable to use.

Hence, the seismic data conditioning is favored, in which multiple filters are applied, to improve the signal to noise ratio. This is carried out on the available seismic data related to Issaran field, through a workflow (Figure 3), by using OpendTect software. It is beneficial for resolving either the major structural elements or the micro faults and even the subtle geologic features within the seismic data. This step accelerates the time consumed during the seismic interpretation, by improving the seismic attributes performance, after carrying out multiple structural oriented filters.

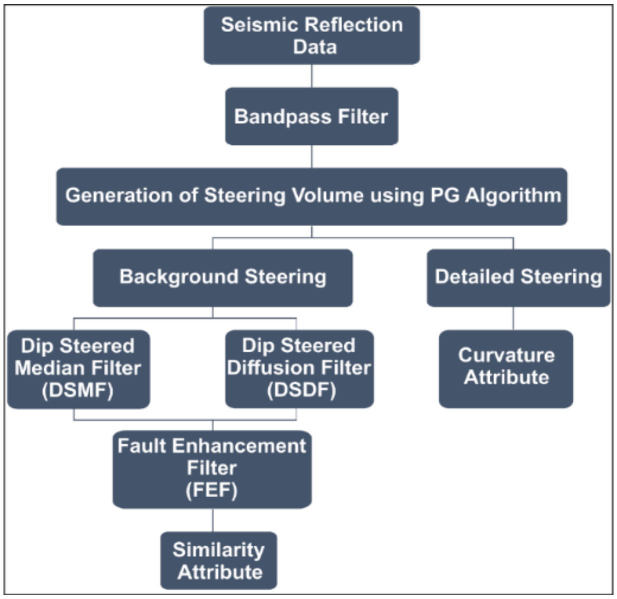

Fig. 3: Seismic data conditioning workflow applied to the available seismic data.

4.2.1. Frequency Filter

Before any conditioning step, the first aim is to prepare the seismic data to be noise free, without any frequency related noises. This can be accomplished by an approach, which is often applied in these cases - a frequency filter (e.g., bandpass filter) is used - for minimizing the residual coherent noises.

4.2.2. Steering generation

Steering generation is the most crucial part in the conditioning workflow, because it will influence the results of either the structural oriented filters or the seismic structural attributes. Seismic dips can be calculated, utilizing various methods; phase-based, amplitude-based and amplitude-frequency-based (Tingdahl and de Rooij, 2005; and Chopra and Marfurt, 2007a). In this work, a phase gradient algorithm is used (Odoh et al., 2014; and Jaglan et al., 2015) for steering generation, from which we can extract the information about the azimuths and local dips of reflectors, and associated discontinuities.

Two types of steering data were generated: background steering data and detailed steering data. The background steering data are heavily filtered and holds the regional information about the regional dip and azimuth of the structure of the studied area (Fig.4a). While the detailed steering data are the smoothed filtered, they contain the detailed information about the structure and geologic features (Jaglan et al. 2015) of the studied area (Fig. 4b).

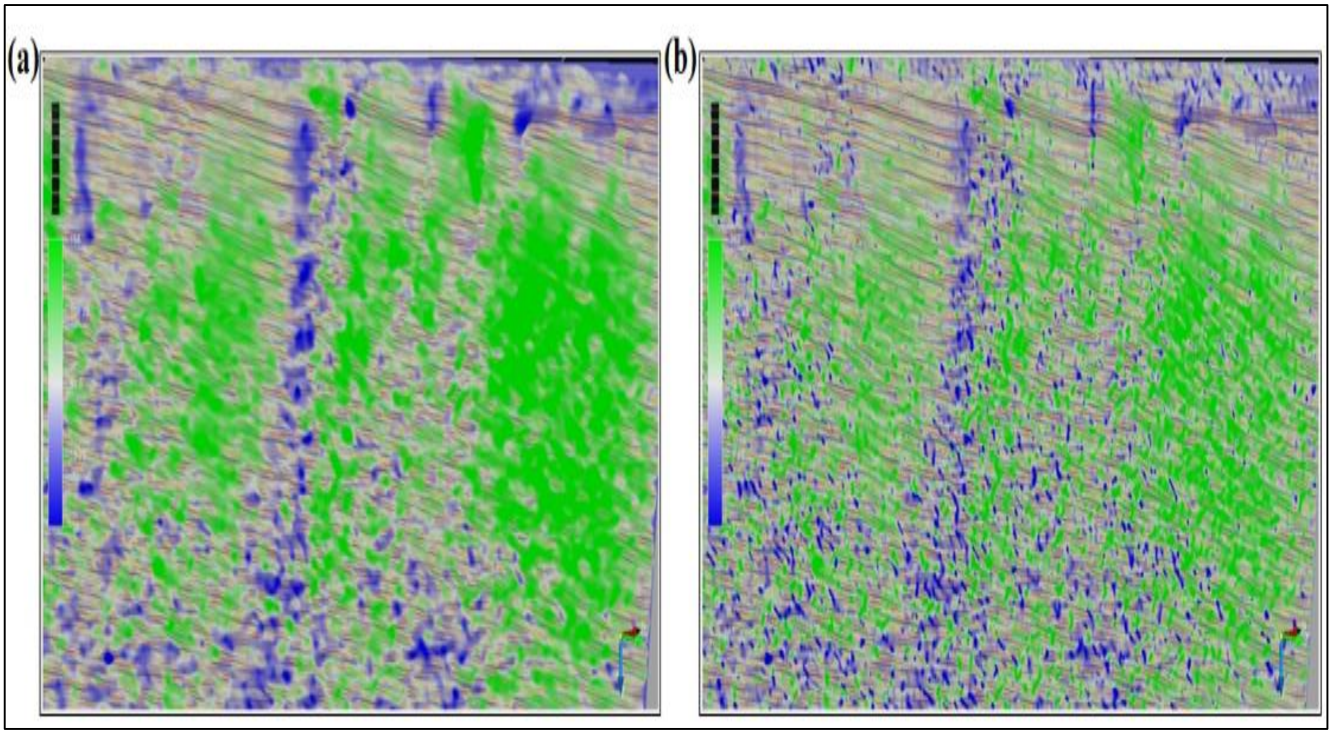

Fig.4: Generated full steered data are overlayed on the seismic inline 10730 dip section. (a) Background steering data. (b) Detailed steering data. The green color represents the dip, while the blue color represents the discontinuities.

4.2.3. Multiple structural oriented filters

Several structural oriented filters are applied to the studied data, utilizing the generated background steered data - to extract, as well as - to clarify the detection of the geologic major and micro faults and other discontinuity features. Three filters have been applied, starting with the dip steered median filter (DSMF), then the dip steered diffusion filter (DSDF) and finally the fault enhancement filter (FEF).

As illustrated in Figure (5), The DSMF removes the background random noises, resulting in enhancing the spatial and vertical seismic resolution. Following this, DSDF - for smoothing the continuous geological features - is applied. Except for the discontinuities yielded from the major faults and small-scale faults, otherwise the FEF is sharpen the fault planes and discontinuities, that are highlighted by DSDF, as shown in Figure (5d). Hence, the seismic structural attributes are optimized - to extract the faults and fractures - and facilitate the high confidence seismic interpretation.

5. Results and Discussion

5.1. Structural Attributes

Some structural attributes were extracted in this study, to perform the quality control of the applied structural oriented filters. This also was important for clarifying the structural configuration of Issaran field and for extracting the maximum information about the geologic discontinuities present in the study area. The similarity and curvature attributes were extracted, using the steered data. The similarity attribute was guided by the background steered data, while the curvature attribute was guided by the detailed steered data.

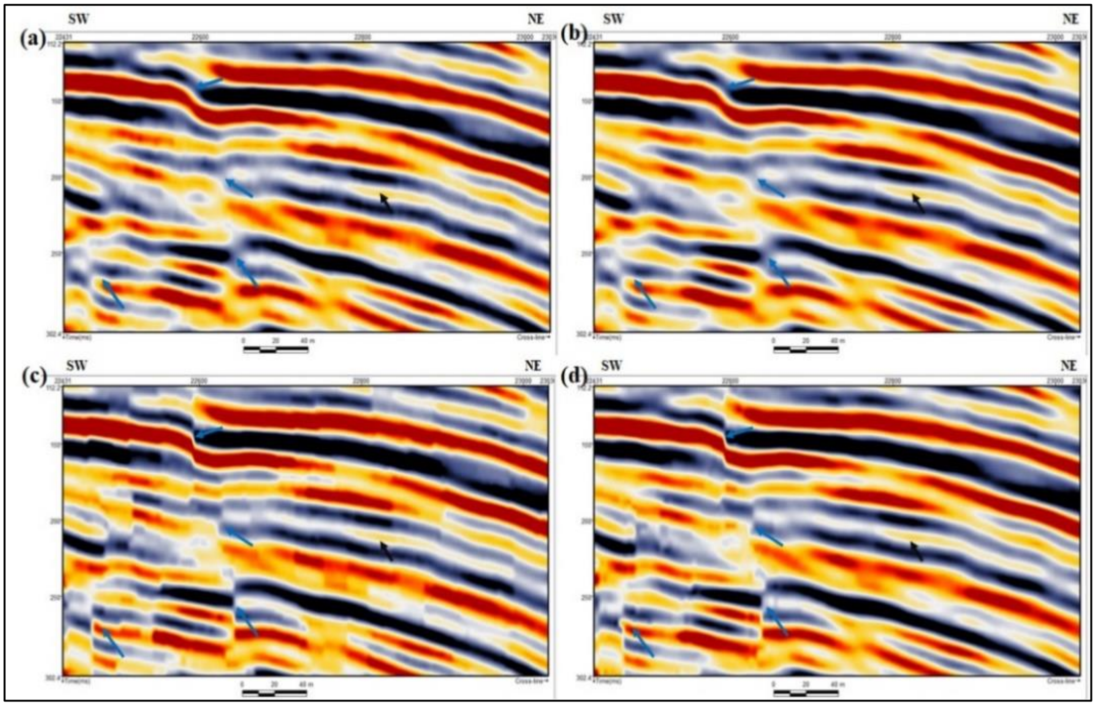

Fig. 5: Seismic sections reflect (a) bandpass filtered data; (b) dip steered median filter (DSMF); (c) dip steered diffusion filter (DSDF); and (d)fault enhancement filter (FEF). The FEF shows the best result of detecting the discontinues, at which the blue arrows pointed. The black arrow indicates the enhancement of lateral continuity for this weak reflector.

The similarity attribute is one of the coherence attributes, that measure the similarity between two traces or waveforms (Chopra and Marfurt, 2007a and Ashraf et al., 2020). In order to test the performance of the similarity attribute, it is extracted from the bandpass filtered data, dip steered filtered data and fault enhancement filtered data, as shown in Figure (7). Figure (7a) illustrates that, the major faults and the small-scale faults are subtle within the seismic data. Moreover, a black shadow is masking the structural configuration, particularly in the eastern part of Issaran field, as the blue arrow indicates. This result from the fact that, the reflectors in the eastern part of Issaran field are characterized by a high tilting gradient (Fig. 6), causing a shadow zone over the faults (Fig. 7a).

After, applying a dip steered median filter, the high tilting gradient effect and the random noises are eliminated in a high-quality manner, further improving the imaging of the structural configuration of Issaran field. This structural configuration is composed of two fault trends NW-SE and NNE-SSW, as shown in Figure (7b). Furthermore, the small-scale faults, that have small offset displacement, of down thrown of 50 feet, are detected with high confidence. The similarity attribute, extracted from the FEF data, sharpens the fault discontinuities and this provides more detailed image about the subsurface geology, as shown in Figure (7c). As a result, the seismic structural interpretation and visualization are improved.

The positive curvature attribute is defined as a surface, that has positive curvature at a point, regardless of the cutting plane. The surface curves, away from that point in the same direction, relative to the tangent to the surface (Chopra and Marfurt, 2007b; Odoh et al., 2014; and Ashraf et al., 2020). Figure (8) demonstrates a positive curvature attribute, extracted at time 252 msec and shows small-scale faults, that have a small offset displacement, of down thrown of 30 feet and that, weren't resolved by the similarity attribute, as pointed out by the yellow arrows in Figure (8). Moreover, the image shown in the blue ellipses in Figure (8) might indicate parts of higher fracture density, but this requires further investigation.

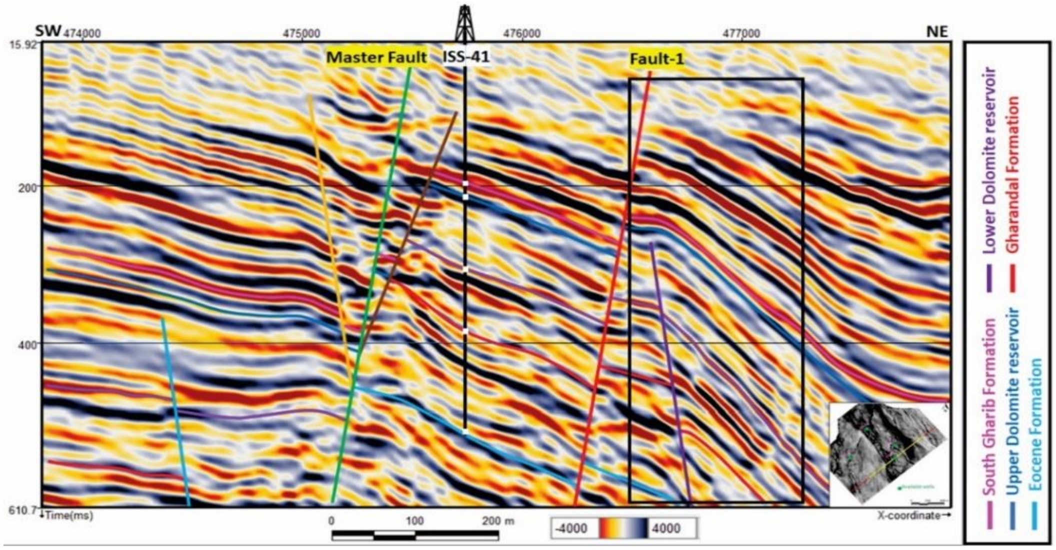

Fig. 6: Seismic inline 11825 dip section illustrates that, the reflectors on the eastern part of Issaran field are characterized by a higher tilting gradient (highlighted by the black rectangle) than the western part. Furthermore, the seismic signatures for the Upper and Lower Dolomite reservoirs vary from block to block.

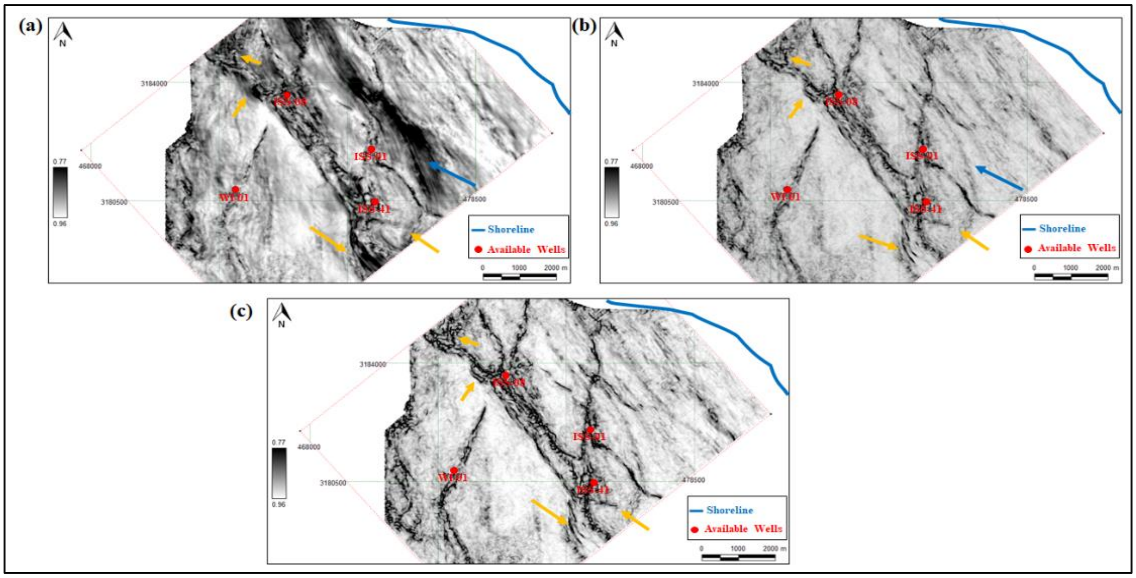

Fig. 7: A time slice at 252ms, shows the Similarity Attribute and illustrates the high tilting gradient effect (highlighted by the blue arrow) of reflectors in: (a) bandpass filtered data; noises are removed effectively, after filter application, (b) dip steered median filter, is sharpening the structural framework and the small-scale faults (highlighted by yellow arrows); and become better imaged, after application, and (c) fault enhancement filter; notice the FEF provides an excellent image, to resolve the structural configuration and small-scale faults.

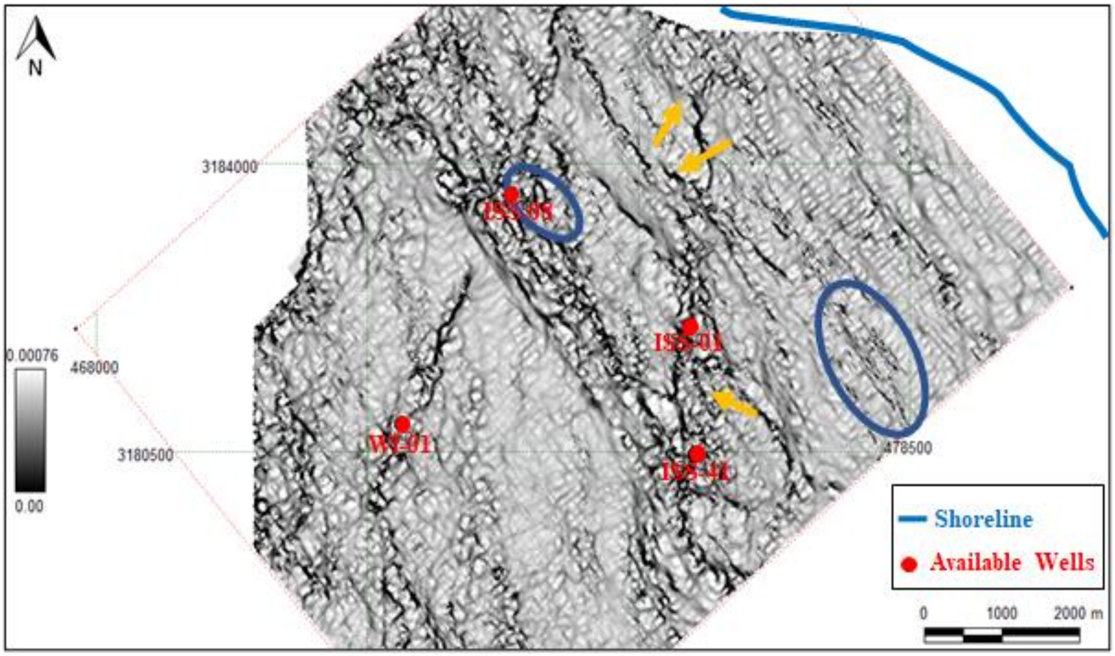

Fig. 8: Positive curvature attribute, at time 252ms, shows the small-scale faults and fractures zones, which aren't detected by the similarity attribute, as pointed out by the yellow arrows and the blue ellipses.

6. Summary and Conclusions

Quantifying and understanding the impact of geoseismic conditions in Issaran seismic data, before the seismic interpretation, have been beneficial for the seismic data conditioning. In shallow heterogenous carbonate areas, with complex structures, such as in Issaran field, this is significant to achieve a good seismic processing result. The seismic data conditioning plays a vital role in enhancing the image quality. Moreover, the detectability to resolve small faults with vertical throw less than 50 feet.

Whereas the bandpass filter removes the coherent noises effectively. The dip steered median filter is a powerful filter, which removes the residual background random noises, as well as the high gradient tilting effect of reflectors. As a result, it enhances the spatial and vertical seismic resolution. The fault enhancement filter is a robust filter, which sharpens the continuity of fault discontinuities, that are highlighted by the dip steered diffusion filter.

- Utilizing the multi-structural oriented filters is contributing to enhancing the quality of seismic data, in which the filters are able to enhance the detection of small-scale faults, fractures and geologic features, that are subtle in the seismic data, using the structural attributes.
- The similarity attribute, extracted from the FEF data, provides effective geological images of the subsurface structures. While the positive curvature is useful for capturing the small-scale faults and fractures zones in which the similarity attribute can't detect.

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Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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