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Spectral Decomposition and Seismic Attributes for Clastic Reservoir Analysis of Miano Gas Field, Southern Indus Basin, Pakistan.

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Abstract: This study has been conducted on Miano Gas field located in Southern Indus Basin, Pakistan. The aim of the study is to map the producing channel sands within the heterogeneous fluvial-deltaic stacked channel of sand system. Continuous wavelet transforms technique of spectral decomposition and full spectrum seismic attributes have been applied to a 3D seismic data of study area. Full spectrum attributes such as coherency, RMS, and dominant frequency helped to identify the reservoir geometries but, could not map the hydrocarbon potential zones due to their limited imaging capability. However, continuous wavelet transform used in combination with 3D- visualization technique can be used to successfully detect and map the producing sands and to analyze the attenuation effects associated with the gas sands both at shallow and deeper reservoir levels. This workflow may help to detect and map the remaining potential reservoir compartments within the fluvial-deltaic sand system of Southern Indus Basin of the country.

Keywords: Spectral, decomposition, Seismic Attributes and Miano Gas Field.

1. INTRODUCTION

This study has been carried on Miano gas field located in Lower Indus Basin, Pakistan. The aim of present study is to map the producing channel sands within the heterogeneous fluvial-deltaic stacked channel system of the study area. Continuous wavelet transform technique of spectral decomposition and full spectrum seismic attributes have been applied to a 3D seismic data set of Miano area. Rock physics parameters through gas sands models are also analyzed for detecting the hydrocarbon producing zones from these productive channel sands. Full spectrum attributes such as coherency, RMS, and dominant frequency helped to identify the reservoir occurence geometries but, could not be mapped the producing zones due to their limited imaging capability. However, continuous wavelet transform is used in combination with 3D- visualization technique may be used to detect and map the producing channel sands and to analyze the attenuation effects associated with the gas sands both at shallow and deeper reservoir levels. This workflow may be helpful to detect and map the remaining potential reservoir compartments within the fluvial-deltaic sand system of Lower Indus Basin of Pakistan.

2. GEOLOGY OF THE AREA

The N-S trending Indus Basin is bounded by the Indian shield to the east, the Kohat Potwar Plateau to the north, and the fold and fault belts of the Sulaiman and Kirthar ranges to the west **(Fig. 1)**. From the Permian to Middle Jurassic, the present-day Indus Basin is located at the continental margin of the Indian plate and formed part of the southern continent of Gondwana. Late Jurassic to Early Cretaceous rifting was followed by a northward drift of the Indo-Pakistan plate. This drift eventually resulted in the Tertiary collision of the Indo-Pakistan plate with the Eurasian plate. The structures and stratigraphy of the study area are mainly associated with rifting of the Indo-Pakistan plate from Gondwanaland Rifting of the Indo-Pakistan plate from Madagascar and in the Middle to Late Cretaceous may have caused some sinisterly strike-slip faulting in the region and hotspot activity and thermal doming at the Cretaceous-Tertiary boundary.(Kadri 1995;Shah 1977). This in turn caused uplift, erosion, extrusion of the Deccan flood basalts and probably the N-NW-striking normal faults. Gas is producing in the lower sands of Lower Guru Formation which is divided into four intervals, as A, B, and C& D. Producing sands, which are predominantly gas-saturated in depths between (1900m to 3800m) with average absolute porosities of 16%, reaching more than 35%, are mostly encountered within mainly thin fluvial-deltaic thin sand systems. These sands show anomalously high porosities and permeabilities at high temperatures and depths of 3000-3800 m. Medium to coarse-grained sandstones in a shallow-marine setting constitute the main producing reservoir in the field. The reservoir unit is characterized as deposits of a proximal wave-dominated delta system and barrier-bar complex with a variety of sub environments (Krois *et al.*, 1998). These are three westerly prograding, depositionally down-stepping clastic packages.Organic-rich shales within the Sembar Formation are the main hydrocarbon source rock for the lower and middle Indus basins. (Krois *et al.*, 1998).

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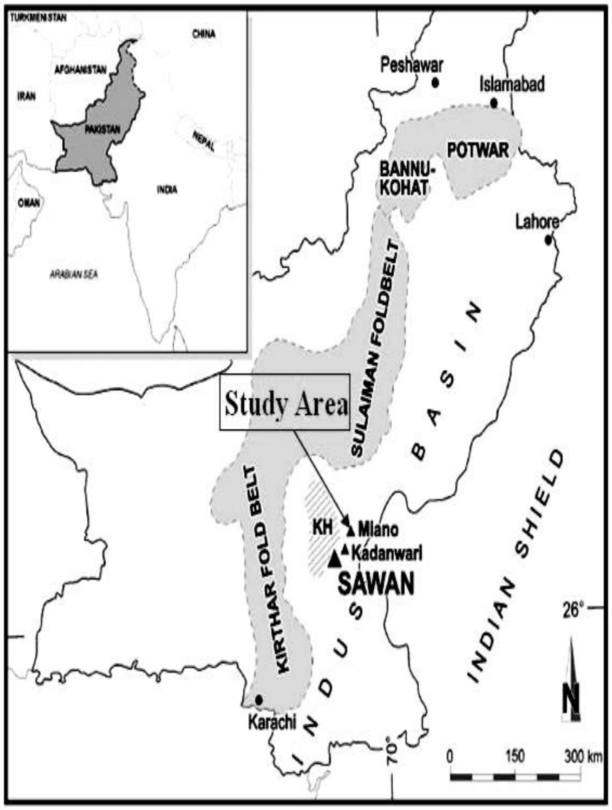

Fig. 1. **Map of Pakistan with the position of Miano Gas Field. (Berger *et al* 2009).**

3. MATERIAL AND METHOD

Synthetic seismograms were generated for wells to link logs (in depth domain) to time domain seismic data and to observe the seismic character of sands within the area. The synthetic seismogram was created by using the extracted wavelet along with the frequency spectra at well locations. Well to seismic ties were performed by establishing correlation between the seismic and synthetic seismograms by adjusting T-D functions through stretch and squeeze **(Fig.2)**. The zone of interest is about 1.5 s to 1.59 s (2900m to 3200 m) window of the reservoir zone was selected which includes fluvial-deltaic sands reservoirs of Early to Middle Cretaceous age and studied, so that these sands reservoirs can be delineated for the perspectives of lithology and the geomorphology. As from geomorphology, we could easily identify the reservoir sand encasing geometries. These geometries were possible point bars that can be beneficial for the reservoir identification and hydrocarbon detection.

Five key horizon namely H1 (Lower Guru), H2 (Sand 4), H-A (Sand 3), Sand 2 and Sand1 were marked and mapped throughout the 3D post stack migrated seismic data volume and interpolated to obtain continuous horizon surfaces through surface seismic attribute scanning of various seismic attributes. The white colored Gamma Ray (GR) curve is displayed for the reference of lithological variations.

Spectral decomposition is a tool for better imaging and mapping temporal bed thickness using 3D seismic data (Partyka *et al.*, 1999) and it aids in seismic interpretation by analyzing the variation of amplitude spectra. There is a Variety of spectral decompositions methods. Each method has its own advantages and disadvantages and different applications require different methods Castagana (2006).

The successive spectral decomposition images have diversified applications such as gas detection through amplitude attenuation in gas saturated reservoirs Castagna, (2003) In this study, we have applied CWT- transforms on full stack high reserolution3D seismic data to check the frequency response of fluvial-deltaic sand systems and calculated Iso-frequency volumes using the output spectra of spectral decomposition of CWT for reservoir of various thicknesses along with the gas pay zones identification.Then we have mapped these hydrocarbon gas zones thorugh the horizon slices of amplitude tuning cubes.We have also applied this technique to identify the thin and thick sands beds along with the gas zones detection through bright negative amplitudes correlated from the nearby drilled wells at the reservoir level of interest. In, addition to CWT-Spectral decomposition, we have calculated Coherency, RMS-Amplitude, and dominant frequency to have a reconnaissance study for possible point bars delineation associated with the hydrocarbon sands. Seismic coherency is a measure of trace to-trace similarity or continuity of seismic waveform in a specified window. The root mean square (RMS) attribute was calculated over selected windowed intervals of about 50 ms window tied to key horizon slices. RMS is a statistical measure of amplitude variation within a defined window and is a useful attribute when values run through the positive and negative domain like seismic. RMS attribute best represent the acoustic impedance contrast and to identify the sand prone lithologies are very easily identifiable with the help of this attribute in heterogeneous reservoirs.

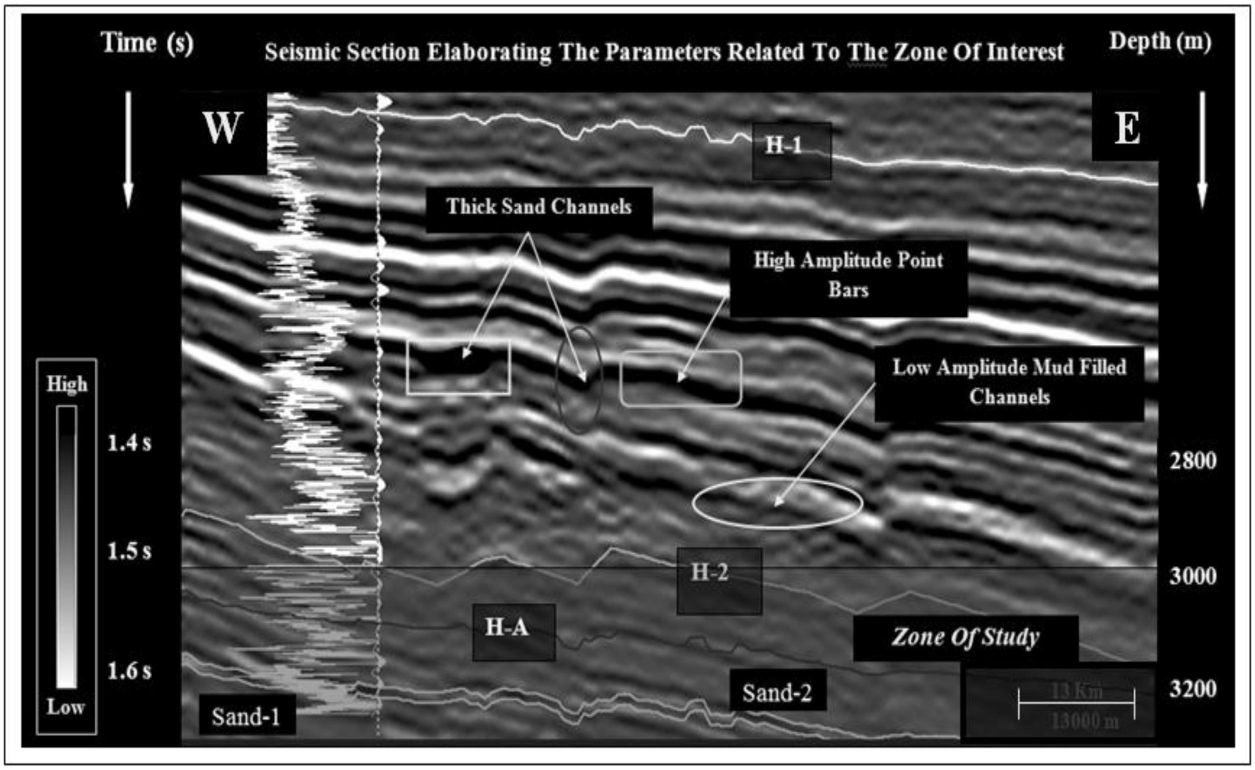

Fig. 2 The Conventional Seismic section. *White curve* represents gamma ray increases towards right, and white wiggles of synthetic seismogram.

4. RESULTS AN DISCUSSION

4.1 Seismic Geomorphology and Attributes Analysis:

As the area is structurally disturbed zone, so we have designed our research workflow by applying the seismic horizon slice attribute analysis scheme. Multiple attributes horizon slices of H-A, Sand 1, Sand 2, were thus selected in the zone of interest in order to characterize the reservoir compartment and to have clear image for both lateral and vertical variations in sand distribution patterns by observing different seismic attributes viz, Coherence, RMS – Amplitude, Dominant Frequency. In this section our main emphasis will be on dominant frequency and RMS-Amplitude horizon slices. For convenient analysis of horizon slices, we have confined our analysis approach on four parameters.

The interpretation of the four parameters is based on two basic equations.

a) [Velocity=Frequency *Lambda (Wavelength)].
b) [Acoustic Impedance = Velocity * Density].

1. Sinuosity.
2 Thick and thin sands point bars distribution.
3. Flow velocity and frequency variation effects on lithology and sinuosity.
4. Seismic geomorphology effects on the overall channels patterns.

4.2 HORIZON-A: HORIZON SLICE ANALYSIS

For our convenience we have portioned the region into eastern and western margins. Horizon slice of coherency seismic attribute is generated as the area is structurally disturbed **(Fig.3a)**.In the western margin of the coherency; we have very high sinuosity NE-SW trending channels feature are observed extending towards north. If we see on the RMS-Amplitude map **(Fig.3b)**, we have incised channels at the north western most margin of the region. These incised channels are initially narrow and then in the middle of the region, we get wide channels features where the flow velocity and frequency is high resulting into the erosion of the previous strata and these sediments were then deposited in the middle portion of the region. In western margin of the RMS –Amplitude we have more sinuous feature as compared to the dominant frequency **(Fig.3c)** where we have also sinuous feature but with low sinuosity. In RMS –Amplitude, point bars are also present almost in the middle region. Initially the morphology of the channels is wide where we get the slow flow velocity and the erosion of the sediments is less due to low flow velocity than the deposition of the sediments. At the Eastern margin of the RMS-Amplitude **(Fig.3b),** there are various discontinuities that are currently acting as the bounding surfaces for the sand distribution in the area. Sand distribution for the RMS-amplitude is from thin to thick point bars as we move from the southern margin to the northern margin of the study area. The regions where we get the narrow path for the channel, we get high velocity and high frequency, and we can infer that the low porosity shaly part is present in these zones. And the zones where we are getting the wide path of sinuous features, we can infer that the flow velocity is slow and we are getting the low frequency as well. And hence, we are getting the high porosity thick sands bodies in the form of thick point bars that are present on the opposite sides of the meander. As, we know from the velocity and frequency relation that the high velocity is directly proportional to the frequency and high frequency is interpreted as the thin shale beds. So, infact that there are some thin beds of shale present in the zone of wide channels. If we see in the dominant frequency horizon slice **(Fig. 3c)**, we can clearly see that initially the incised channels are wide and then they get narrow. Then in the middle portion of the survey we are getting the medium sinuosity channels features that are bounded by the intra-channels regional faults and discontinuities. Again the portion on the western margins of the dominant frequency horizon slice, we have observed channels and we can infer from velocity and frequency relation that the regions where we are getting the wide channel morphology, we are getting the slow erosion than the deposition, and hence we are getting the high porosity thick point bars. There are less discontinuities and intra-channels faults on the eastern margin of the dominant frequency **(Fig.3c)** than on the RMS-Amplitude.

4.3 SAND -1: HORIZON SLICES ANALYSIS:

In **(Fig.4a),** the incised channel is narrow to wide geomorphology, where we get the high velocity and thin sands present in the channels. From northern margin to western most margins we are getting the channel merging into other strata. While if we compare with the dominant frequency horizon slice we are getting the wide channel morphology for incised channel and the velocity is looking to be low and there are possible chances for the accumulation of the sediments deposition at the western margin **(Fig.4c).** And the channel is merging into another stratum as well. Both the incised channels are differing in the morphology and the velocity and so the sediment deposition is also variable in channels in both figures **(Fig.4b)** and **(Fig.4c).**The meandering belt (Fig.4b) is highly sinuous and the morphology of the channel is changing from high to medium sinuosity from northern margin to southern margins. Initially the flow velocity is very high and the erosion is more activated at the northern margins than in the southern margins **(Fig.4b).** If we see at the eastern margin of the dominant frequency horizon slice we have more small faults and the discontinuities that can be promising for the small hydrocarbon traps.

4.4 SAND -2: HORIZON SLICE ANALYSIS:

Initially the incised channels are very narrow in RMS –Amplitude horizon **(Fig.5a)** as compared to the dominant frequency horizon slice where the channels morphology is wide resulting in to low velocity, low erosion rate and so the less deposition of the sediments .Hence we cannot expect the deposition of the sediments in the incised channels at the southwestern most margin of the slice **(Fig.5b)**. At the eastern margin of the RMS-Amplitude horizon slice, we are getting the very high sinuous seismic geomorphology of the meandering channels, As a result of this morphology of the channels which are very narrow at the northwestern margin of the survey, they are getting wide to narrow appearance. In this area, we are getting very high velocity, high erosion rate at the north western margin, and at the middle of the survey we are getting low velocity regions, where the deposition exceeds the erosion rate due to low velocity effect of the channel speed. Hence we are getting not only thick sand point bars but also some thin beds at the southwestern most margin of the RMS-Amplitude horizon slice **(Fig. 5b)**.In Dominant frequency horizon slice (Fig. 5c**)**, the scenario is quite obvious and varies as compared to the RMS-Amplitude horizon slice. The small faults and discontinuities are almost same on both the RMS-Amplitude and dominant frequency horizon slices **(Fig.5b)** and **(Fig.5 c)** respectively.

5. SPECTRAL DECOMPOSITION ANALYSIS OF ATTENUATION EFFECTS ASSOCIATED WITH HYDROCARBON FLUIDS:

After intensive use of conventional seismic attributes in discerning the possible channel like features coupled with mapped horizons near the development well within possible channel feature prompted present further study for similar features in other parts of the study area. We have also applied Spectral decomposition analysis around the zone of interest lying between 1.5 sec to 1.65 sec. Low frequency and high amplitude hardly represents the distribution of hydrocarbon in study area. Therefore, integrating tuning cubes with common frequency cubes is essential factor for accurate hydrocarbon detection. In order to delineate the reservoir and to map the hydrocarbon gas productive zone, we have used both amplitude tuning cubes and common frequency cubes to detect the accurate location of the hydrocarbon. Conventional seismic attributes could give clue for the hydrocarbon presence but could not predict hydrocarbon presence, so the CWT-spectral decomposition is applied for hydrocarbon detection by analyzing the variation of amplitude tuning cubes and common frequency cubes. The core of this tool is to create a set of data cubes or maps, each corresponding to a different spectral frequency, which can be viewed through animation to reveal spatial changes in stratigraphic thickness over 3D seismic covered areas (Partyka. *et al.* 1999).

5.1 <u>Comparison of The Amplitude Tuning Cube Horizon Slices and The Common Frequency Section Related to Hydrocarbon Fluid Identification:</u>

In this comparison, we have not added the amplitude and common frequency sections of the 17 Hz and 22Hz, because we have found more accurate results towards the improved reservoir characterization from 28 Hz **(Fig.6a)** and 37 Hz **(Fig.7b)** sections regarding the hydrocarbon fluids detection. If we see in the **(Fig.6b)** and **(Fig.6b),** we can clearly see that the future prospect can be seen on the eastern margins of the study area which is indicated by the yellow ellipse. In 28 Hz **(Fig.7a),** we have good chances for the fluids but for the 37 Hz **(Fig.7b)**, we have accurately identified the prospect for the future exploration. Also we can clearly observe that the meandering channels are present in the western margins of the zone of study , depicting the point bars presence that are best delineated and elaborated by the amplitude tuning cubes horizon slices of spectral decomposition-CWT at 28 Hz **(Fig.6b)** and 37 Hz **(Fig.7b)** respectively.

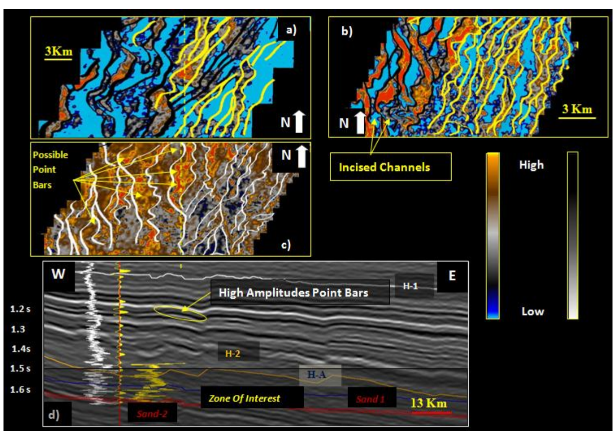

Fig. (3).Horizon slices at time 1.589 sec. a. Coherency, b. RMS–Amplitude c. Dominant Frequency & d. Conventional seismic section.

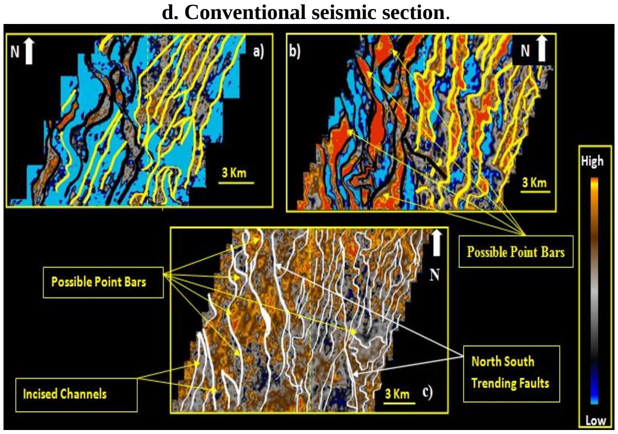

Fig. (4).Sand-1Horizon Slices at time 1.644 sec. a. Coherency b.RMS –Amplitude and c. Dominant Frequency.

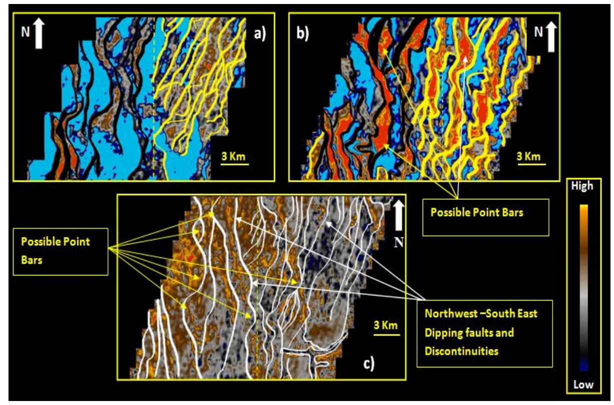

Fig. (5).Sand-2 Horizon slices at time 1.655 sec. a. Coherency, b. RMS –Amplitude c. Dominant Frequency.

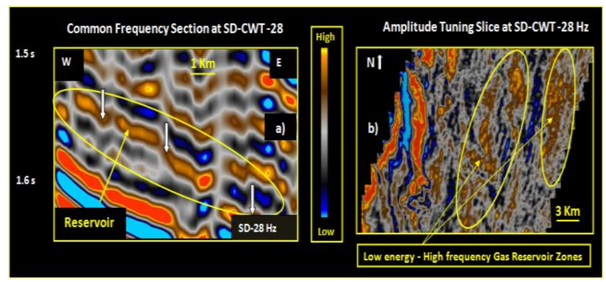

Fig. (6) a. Common frequency cube at 28Hz b. Amplitude tuning cube horizon slices at Sand- 1horizon

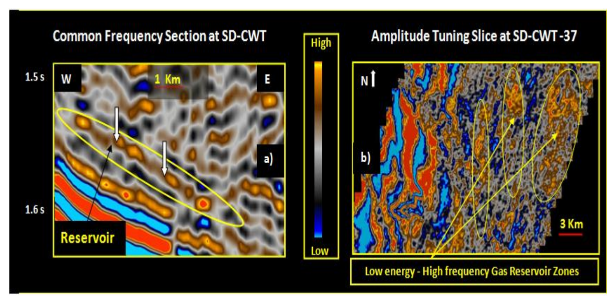

Fig. (7) a. Common frequency cube at 28Hz, b. Amplitude tuning cube horizon slice at Sand -1 horizon.

As we know that when the waves pass through a zone where the fluid is present, there is rapid change in the low frequency contents of the passing wave, and hence in the seismic energy also changes. High energy attenuation phenomenon is directly related with the hydrocarbon fluid such as gas. We also know that the low frequency corresponds to high energy and vice versa. At high common frequency cubes (Fig 7**)**, the bright amplitudes are the indicative of hydrocarbon fluid presence. In summary, 17Hz and 22 Hz show thick sands which can be beneficial for future prospects identification but, the common frequencies cubes such as 28Hz and 37 Hz shows the amplitude attenuation phenomenon may be more promising for the future hydrocarbon gas sands exploration**.**

6. CONCLUSIONS

We have applied spectral decomposition and full spectrum seismic attributes to a 3-dimensionl seismic data set of Miano area of southern Pakistan. Study area is regionally heterogeneous fluvial-deltaic depositional environments consisting of channels sand reservoirs. Conventional attributes such as coherency, RMS, and dominant frequency due to their limited imaging capability could not map the hydrocarbon producing zones. However, Continuous wavelet transform technique of Spectral decomposition can be used to successfully detect and map the potential in context of hydrocarbon at the reservoir level. Results revealed that continuous wavelet transform along with some other conventional attributes can be used for mapping of the producing channel sands and to successfully analyze for the attenuation effects associated with the gas sands zones. This workflow may be helpful to detect and map the remaining potential reservoir compartments through wells development for fluvial-deltaic sand systems of southern Pakistan.

7. ACKNOWLEDGEMENTS

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