Interpretative Processing of Seismic data for Thin Sands: A Case study in Nardipur Low Area of Kalol Field, Cambay Basin, India.

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Summary

The Kalol field is well explored and is on sustained production from thin Kalol sand reservoirs. For a better delineation/ development plan of these sands, it is pertinent to know the structural complexities and areal distribution of these sand units from the 3D seismic data in the Nardipur low area. Zero-phase wavelets have long been considered the best interpretative wavelets for such type of studies. Post stack interpretative special processing of the 3D volume is, therefore, carried out using ProMAX software of Landmark to enhance the signal for identifying these thin sand unit.

The wavelet processing is a set of sequences used for the replacement of the source wavelet, the receiver response and the filtering effects of the earth by a wavelet of known and desirable characteristics. This special processing is carried out integrating with synthetic seismogram response near wells in the present study using post stack minimum entropy deconvolution (MED) technique. This technique exploits the non-Gaussian nature of the reflectivity series also. The paper brings out some examples of wavelet processed seismic sections to appreciate value addition over conventionally processed sections in identifying the thin sand response for interpretation.

Intoduction

The study area lies towards eastern part of Kalol field of North Cambay Basin, covering the western part of Nardipur Syncline (Fig.1). The stratigraphy in the area of study is well established from wells drilled in the Kalol field. The generalized stratigraphy is given in the Table1.

The Kalol formation was deposited in a deltaic complex system traversed by distributory channels influenced by tides and also having marshy – swampy environments marked by coal, shale, sand and silt units. The

Generalised Stratigraphy of Kalol Field

Age	Formation	Member/ Horizon		Lithology	Lithological Description
L. Miocene to Recent	Post-Babaguru & Babaguru				Arenaceous and argillaceous interbands.
Oligocene	Tarapur Shale				Monotonous shaly sequence.
Middle Eocene	Kalol Formation	Wavel Member	K-I		Mainly siltstone to fine sandstone sequence intercalated with shale and coals, occurring at a depth of 1200 to 1600m MSL.
			K-II		
			K-IV a		
			K-IV b		
			K-V		
		Kansari Shale			
		Sertha Member	K-VI		
			K-VII		
			K-VIII		
			K-IX+X		
			K-XI		
	Younger Cambay Shale	Nardipur Shale			Sandstone lenses interfingering with transgressive shales. Also known as Kadi Formation.
Lower Eocene		Chhatral Member	K-XII		
			Below K-XII		
	Older Cambay Shale				Dark grey monotonous marine shales.

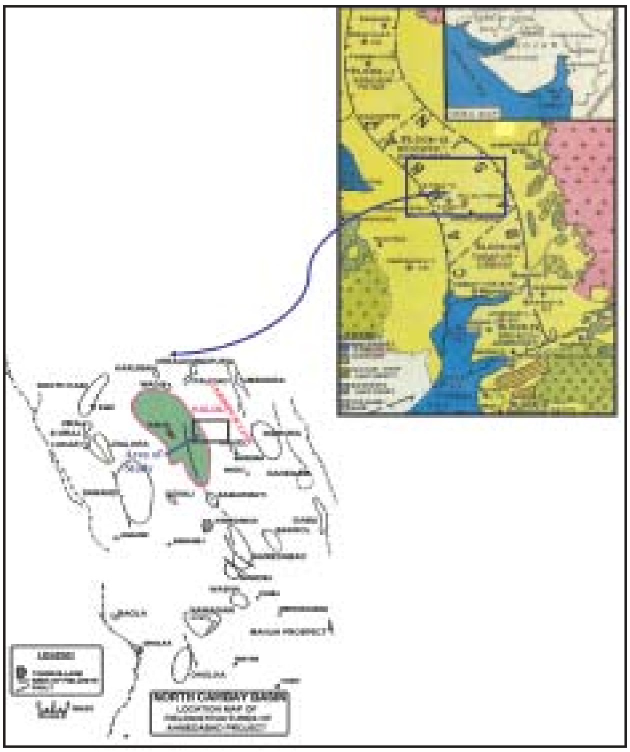

Fig.1: Index Map showing Kalol Field of Cambay Basin

sands encountered in Kalol formation are thin, lenticular and discrete in nature, mostly representing channel sands (Chandra and Choudhary, 1969).

The Kalol formation is divided into two regressive phases as Sertha and Wavel members separated by Kansari shale. Sertha member comprises of K-XI to K-VI units and Wavel member of K-V to K-II units. All these units are well developed in the field (Fig.2). However, K-IX unit is the main hydrocarbon producer in the field. Besides K – IX unit, K-V and K-IV units are also hydrocarbon bearing in many of the wells. On the western rising flank of Nardipur Low falling in the present study area, K-V reservoir unit is well developed and is a prolific producer (Fig.2).

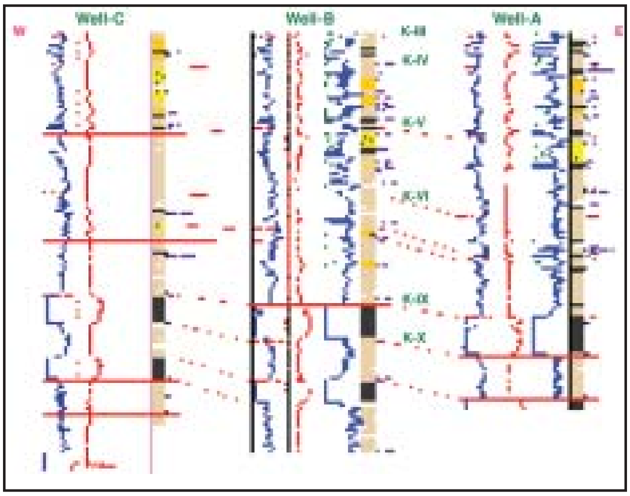

Fig.2: Lithological and log correlation of Kalol units along wells A, B and C

Mapping of these thin pay zones (less than 10m) within different units of Kalol formation and their vertico-lateral variation for reservoir characterization from 3D seismic data has attracted the attention to interpretative wavelet processing in the present study. This special processing is interactively performed on the post stack data using MED approach and matching with synthetic seismograms of available wells. A few representative wavelet processed sections are presented in this paper for evaluation of effectiveness of the process with reference to old post-stack migrated sections.

Background

Wood (1992) and Yilmaz (2001) outlined the principles of wavelet processing to replace a source wavelet with a zero-phase, interpretative wavelet without altering its amplitude spectrum. Brown (2004) summarised many benefits of the zero phase wavelet including its symmetry, minimal ambiguity of its shape in correlation, center and maximum amplitude coinciding in time with reflection interface and best resolution among other wavelets with same amplitude spectrum.

The wavlet processing sequence refers to estimating the basic wavelet enwrapped with the seismic response trace. It requires the designing of a shaping filter to transform the estimated wavelet to desired form, usually a stable broadband zero phase wavelet. This wavelet is finally applied to the seismic input. This can be achieved in many ways. There are two broad categories of wavelet estimation processes: deterministic and statistical. Cross-correlation of a synthetic seismogram with the seismic trace at the well location is an analytical technique but it limits its usage to areas of well data availability.

The other is the extraction of a wavelet from the data statistically and the study of its shape using deconvolution to make it stable. This approach relies upon the statistical information about reflection series to separate the wavelet from the seismogram. As number of unknowns are more than the knowns, the usual assumption is that the reflection series is a stationary and statistically independant random process. Most seismic deconvolution methods in practice are based on auto-correlation (second-order statistics) to correctly identify the amplitude and phase of the wavelet provided the reflectivity series is Gaussian and the wavelet is a minimum phase sequence. But actual reflectibvity series is neither Gauassian nor is the source wavelet in minimum phase. However the amplitude and phase of the mixed phase wavelet can be recovered if the actual distribution of the reflectivity series is known. Moreover, the non-Gaussian processses of higher order spectra are better described in terms of higher order cumulants preferablly fourth order cumulants. Quite contrary to power spectral density estimates (second order statistics), higher order spectra are capable of retaining phase information and hence are useful to estimate nonminimum-phase wavelets. But estimation of fourth-order cumulants is computationally intensive, be it linearised inversion (Lazear, 1993) or global optimization (Velis and Ulrych, 1996). Cummulant matching process proposed by Sacchi and Ulrych(2000) is analogus to the problem of estimating a minimum-phase wavelet from the autocorrelation.

Therefore, instead of using above processs we have used the Wiggins' minimum entropy deconvolution (MED) process (Wiggins, 1978) to match with synthetic responses at well location and then appyling to the entire data set. It is less intensive computationally and provides better interpretative data in terms of actual responses derived from seismic as well as synthetic seismograms integrating the well lithology for strtigraphic interpretation . In fact, non-Gaussian nature of the reflectivity series is exploited in this method by assuming it as a sparse time series. In MED, an inverse operator is iteratively retrieved by maximizing a measure of sparseness related to non-Gaussian character of the reflectivity series. The final estimation of the wavelet is calculated by inverting the MED operator. In the process fourth order deviations, equivalent to fourth order cumulants, are also accounted for while estimating the minimum phase from phase deconvolution. Phase deconvolution designs a pure phase operator by optimising the multi-dimension objective function to avoid some artifacts of MED if they exist at all.

Wavelet Processing

The input data is a well processed post stack migrated volume, devoid of random and coherent noises. Power spectra are generated on different lines spread over the area. The frequency bandwidth is of the order of 10-52Hz at a db power of 10 (Fig.3) with dominant frequency in the range of 30Hz. Comparing with the synthetic seismograms at well locations A, B and C it is observed that the desired response of many pays within sub units of the Kalol formation (e.g. K-IV, K-V and K-IX pays) is not observable with Ricker wavelet of 35Hz (Fig.4).

It is further infered that response of thin sands occuring within K-IV, K-V and K-IX units at these wells is distinctively observable in the synthetic trace of dominant frequency of 40Hz and above of the input ricker wavelet (Fig.4). Therefore, for sharpening the image, particularly for resolving the thin reflectors and to improve the fault definition the option of post stack wavelet processing was

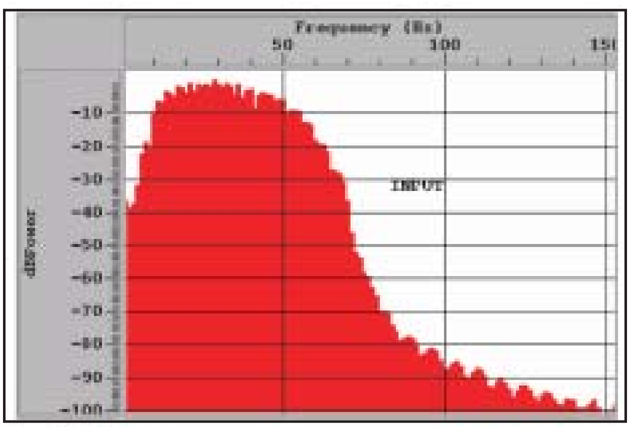

Fig. 3: Power spectrum before wavelet processing

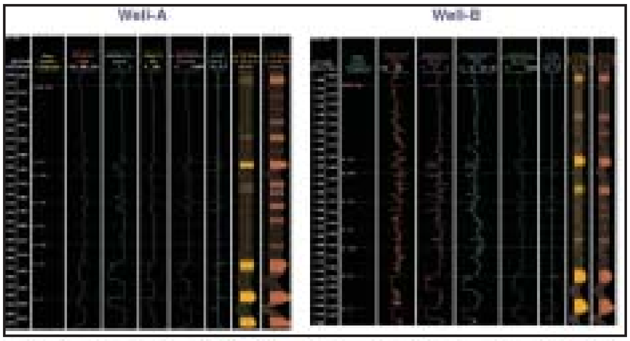

Fig.4: Shows the Synthetic seismogram of the wells “A and B” with different frequencies. Higher frequencies better differentiate the Kalol units.

considered. Since the input 3D volume is observed to be fairly clean, it was decided that no pre-conditioning of the data was required before wavelet processing.

Wavelet processing was carried out using the ProMAX software. In this process the average wavelet was derived from the data using the Minimum Entropy Deconvolution (MED) method. Extracting the average wavelet from the seismic data is an extremely computation intensive job and it was practically impossible with the available machine power to consider each trace of the 3D volume while deriving the wavelet. Therefore the inlines at an interval of 10 were selected and from each of the selected lines every 4 th trace was considered, including the lines passing through wells to match the desired output interactively for this job. In this method the spectra of the traces within a defined time window are averaged to produce the wavelet spectrum. The result is transformed to the time domain and the wavelet is output in the form of a trace (Singh et al., 2005).

Phase of the MED derived average wavelet is determined by phase decon operator which may have minimum 3 parameters and a maximum of 10 parameters as defined by the Processor after testing on the data. The number of filter parameters (i.e. suitable mathematical function) is important because it controls Fourier-domain smoothness of the resulting filter. Testing was performed to decide this parameter on a number of lines spread over the area. A representative test panel for different parameters is shown in Fig. 5. Since there is not much variation in outputs of different parameters displayed in the above figure, A three parameter filter was chosen for deriving the MED wavelet to save computation time.

An average wavelet was derived from the seismic volume and was used to design the shaping filter. In the process of generating the filter, the extracted wavelet is the input from which a filter is calculated. For deciding the length

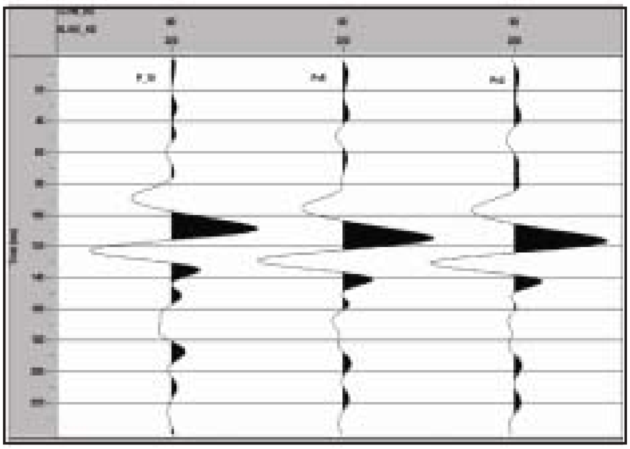

Fig. 5: Shows the testing result on number of parameters (P) for the Operator used in wavelet extraction.

of the filter different filters are generated using the filter length of 400, 600 and 800ms (Fig.6). These filters are applied on the extracted wavelet. It is observed that the filter length

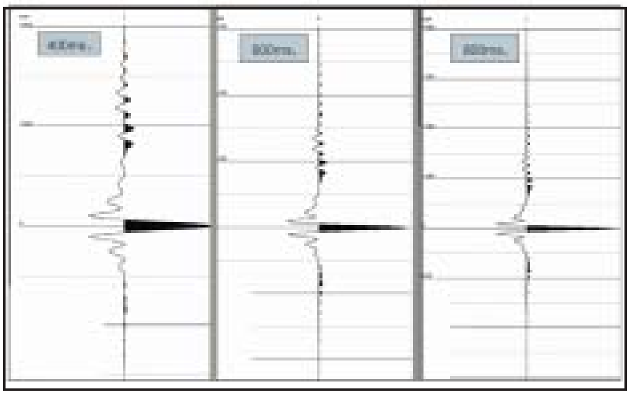

Fig. 6: Shows the Filter designed with different filter lengths to extract minimum phase wavelet.

Fig.7: Shows the results of the Filter testing – Filters designed with different filter lengths applied on the extracted wavelet.

of 800 ms has shown the better output (Fig.7).

The parameters for wavelet processing are summarized below:

Phase output option of wavelet	:	MED derived
Time gate	:	1100 – 1700 ms.
Trace length of wavelet	:	240 ms.
Filter length	:	800 ms.
Frequency range of extracted Wavelet	:	10-90Hz

The average wavelets, extracted from the 3D volume and designed filter are shown in Fig.8. The extracted wavelet is convolved with this filter and the output is a zero phase wavelet. Thus, when the input seismic volume is convolved with this filter, the output volume will have nearly zero phase trace data.

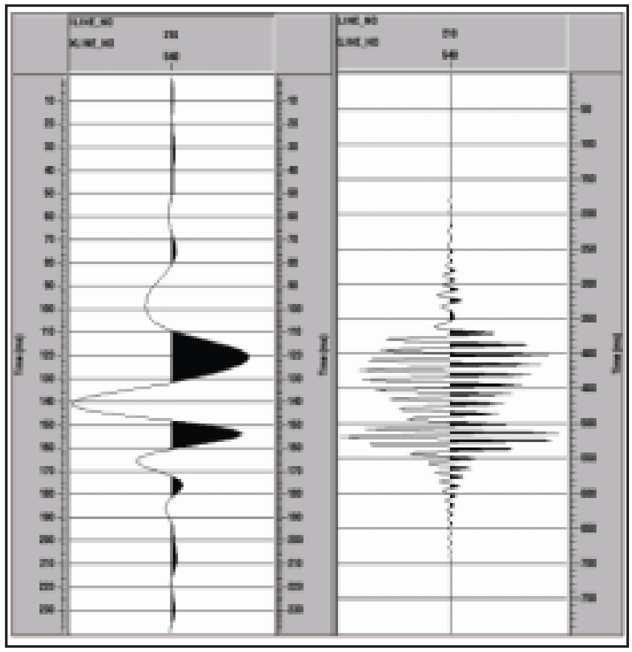

Fig. 8: Average Wavelet and designed Filter used for wavelet processing.

Discussion

The experience in real data situations imply that the selection of adequate deconvolution parameter is of primeval requirement which lays foundation for improvement in subsequent interpretative wavelet processing. Retention of genuine events is to be cross checked with the help of synthetic seismogram from sonic data or corridor stack of VSP data. In the present study wavelet process parameters mentioned above have increased the bandwidth and resolution of the data.

The frequency bandwidth (Fig.9) has been boosted up to a range of 70 Hz at a db power of 10 with a dominant

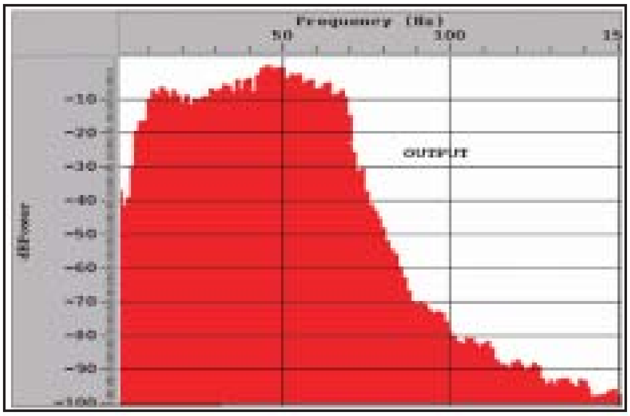

Fig. 9: Power spectrum after wavelet processing

frequency of 40-45Hz after the wavelet processing. Comparing the synthetic seismograms at wells A, B and C with the seismic input data and wavelet processed data it is evident that the markers of synthetic seismograms corresponding to prominent units of Kalol formation matches well with the seismic events of wavelet processed data (Fig.10). As discussed in MED approach, the best suitable window in terms of traces and time is chosen for wavelet extraction. Convolution of the input seismic data with the designed filter delivers new seismic volume having improved lithological boundaries of various sub-units of Kalol formation in general. As the central peak of the wavelet coincides with the timing of reflectivity spike it aligns the signal in the background of noise. It is evident in the examples of Figures 11-15.

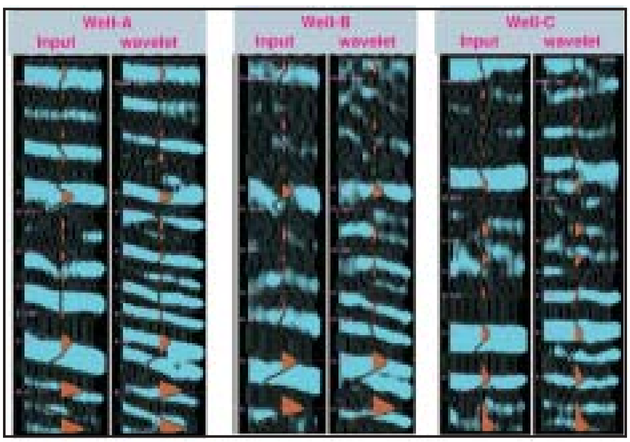

Fig.10: Shows the input and wavelet processed seismic data with synthetic trace of wells "A, B and C" superimposed.

The Inline- I before and after the wavelet processing clearly shows (Fig11) that the wavelet processing has improved the resolution of the seismic events predominantly between the time window of 1150 ms and 1500ms. Major as well as minor faults are easily identifiable in the wavelet processed data.

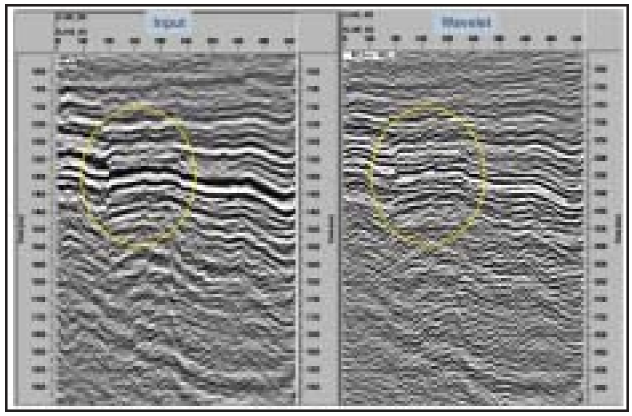

Fig. 11: Shows the comparison in with and without wavelet processed seismic data along part of inline – I. Encircled portion shows the improvement in the resolution of the events as well as in the position of the faults.

The Fig.12 shows the improvement in the resolution of the events corresponding to K-IV, K-V, K-VIII and K-IX units. In addition a channel feature west of well "A" is also seen in the top part of K-V unit which is producing hydrocarbons. The Fig.13 also shows all the kalol units from K-III to K-X better resolved compared to the input data.

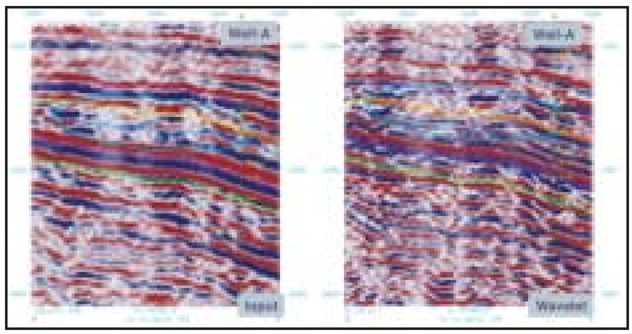

Fig. 12: Shows the improvement in the resolution of the events corresponding to Kalol units as well as channel-fill feature in the K-V unit passing through well "A" in the wavelet processed data compare to input data.

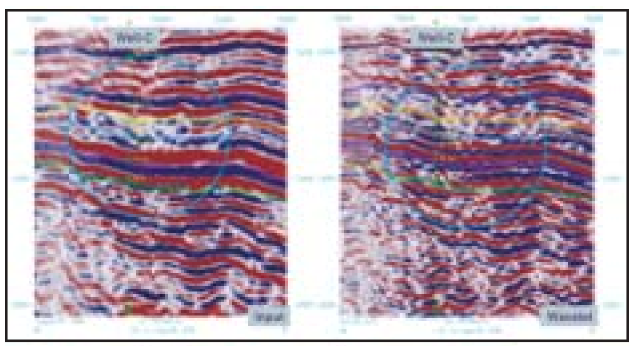

Fig. 13: Shows the improvement in the resolution of the events corresponding to Kalol units in the encircled portion passing through well "C" in the wavelet processed data compare to input data.

It becomes easy to correlate pay zone of K-VII unit in the wavelet process data near the well "C". Along Inline–II fault positioning becomes more visible at all levels (Fig.14). A channel-fill feature in the K-IV unit is easily observable in the processed section compare to input data. In these sections (Fig11-14) reflector corresponding to top of K-IX is invariably split into two events the upper one being continuous corresponding to top of coal unit. The Lower event is inconsistent indicating variation in the middle part of K-IX unit as a reservoir facies. In addition Time slice at 1320ms (Fig.15) falling within Kalol formation also shows overall improvement in defining the structural as well as startigraphic features. Some of the features are encircled on the figure. Thus Wavelet processed section has brought out the structural and startigraphic features more clearly compared to normal section which has helped in mapping the reservoir facies in the entire area of study. The detailed interpretational study of this data volume will be published subsequently.

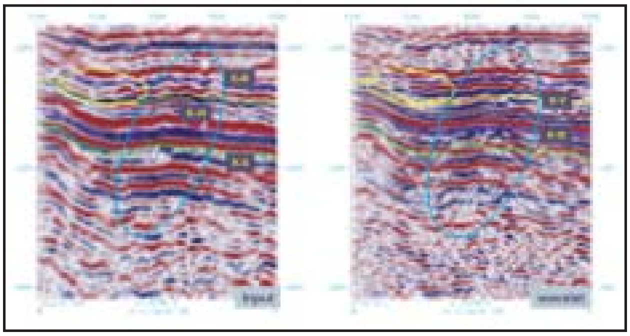

Fig. 14: Shows the improvement in the resolution of the events corresponding to Kalol units and positioning of the faults along part of inline- II in the wavelet processed data compare to input data. In addition a channel-fill feature is also seen in the K-IV unit.

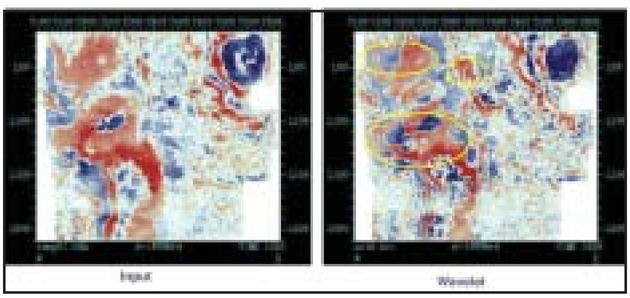

Fig. 15: Shows the improvement in the resolution of the encircled features in the time slice at 1320ms in the wavelet processed data compare to input data.

Conclusions

The wavelet processing using MED approach integrating with synthetic seismograms has paved the way to arrive at near real shape of the seismic response in the study area. It is less computational intensive in terms of higher order statistical approach. The lithological boundaries corresponding to different units of Kalol formation have been identified with better attributes. The conspicuous presence of faults as well as channel features is observable beyond doubt in the area. The enhanced resolution of the events helped in mapping the strati-structural setup of the reservoir facies. These factors establish the efficacy of the approach as an aid in value addition in terms of better interpretation for thin reservoir identification.

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