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Value Addition to the Conventional Seismic Data Processing through Preserving Low Frequency: A Case Study

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Summary

In seismic data processing we generally remove very low frequency which is the conventional approach but the preservation of low frequency become important in highly absorptive media, where we are interested in extracting the geological information associated with low frequency. The reflection coefficient is the function of frequency in fluid saturated media and anomalously high amplitude at low frequency can indicate presence of hydrocarbon which is normally not observed in conventional seismic data.

Continuous wavelet transform (CWT) is used for extraction of low frequency from the seismic data, which is a spectral decomposition method. This method is a non-unique process, in which a single seismic trace can produce various time-frequencies (Castagna, J. P, et al., 2003).The frequency spectrum is output of each time sample of the seismic trace. The application of spectral decomposition includes layer thickness determination, stratigraphic visualization and direct hydrocarbon detection, which have a great significance in hydrocarbon exploration.

Keywords*: Spectral decomposition, continuous wavelet transform, translation, scale, reflectivity*

Field of the study

Present study deals with low frequency dependent seismic data processing. More particularly it describes the advantage of preserving low frequencies in seismic data, which can be used for extracting underneath geological information.

Introduction

The concept of reflectivity of low frequency band of seismic energy related to presence of hydrocarbons is established theoretically for quite some time. Now efforts are being made to establish this in the industry for detection of hydrocarbons. There are numerous field examples in which low frequency components of reflected seismic waves show surprising imaging capabilities (Goloshubin, G.M, et al., 2006). It reveals from these studies that the low frequency behavior of reflection coefficient serves as a reliable tool for predicting fluid or hydrocarbon presence. Castagna et al. (2003) used matching pursuit decomposition for instantaneous spectral analysis to detect low frequency shadows beneath hydrocarbon reservoirs. A case history of using spectral decomposition and coherency to interpret incised valleys was shown by Peyton et al. (1998). Partyka et al. (1999) used windowed spectral analysis to produce discrete-frequency energy cubes for applications in reservoir characterization.

To study the effect of preservation of low frequencies in the real data, B-12 area of western offshore basin has been taken, which is shown in figure 1.

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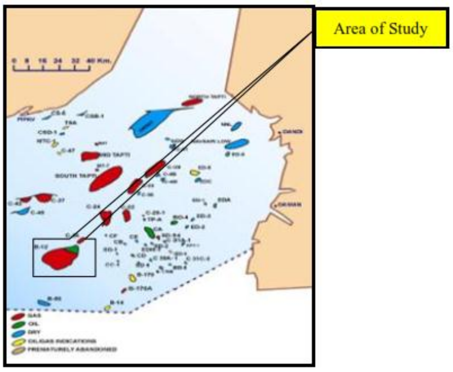
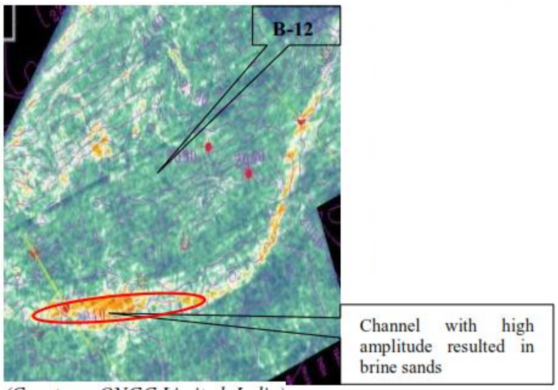


Figure.1: Location map of the area (B-12, Western Offshore Basin)

Geologically, major identified playtype in this area is Oligocene – Lower Miocene deltaic which comprises Mahua and Daman formations. The reservoir facies within this formation have assumed great importance as they have been found to host significant amounts of hydrocarbons. Daman sands have very high variability in petrophysical properties and it is difficult to identify the water and gas sand (which are generally thin 1-7m), in spite of using advance technologies of rock physics and 3D seismic data interpretation. (Figure. 2)



(Courtesy: ONGC Limited, India)

Figure.2: High amplitude anomaly identified from multi-vintage 3-D. After drilling particular channel sand was found water bearing. Gas was found in other lower levels having no anomaly.

Use of frequency dependent reflectivity for identification of these thin pay sand has been extended to the area of study which were hidden in full band pre stack time migration seismic data. By preserving low frequency, it is seen that high amplitude zones correspond to some pay zone within Daman formation. This area encompasses four 3D blocks. Initially the efforts have been made to merge the data of these four blocks, preserving low frequencies (preserved up to lowest end of frequency bandwidth in the present study) and relative amplitudes. For extraction of low frequency volume from the 3D seismic data, continuous wavelet transform (CWT) has been used. This transform deals with non stationary signals i.e. whose frequencies vary with time as in seismic data & utilizes scale and translation of a wavelet to produce a time-scale map.

Basic Theory

The continuous wavelet transform (CWT) is defined as the sum over all time of the signal $f\ (t)$ multiplied by scaled, shifted versions of the analysing wavelet function ψ:

$$C\,(scale,\ translation) = \int_{-\infty}^{+\infty} f\,(t)\,\psi\,(scale,\ translation)\,dt$$

Mathematically, it is defined as the inner product of a \family of wavelets $\psi\sigma, \tau$ (t) with signal f (t):

$$C\,(s,\tau) = \int_{-\infty}^{+\infty} \frac{1}{\sqrt{s}}\ \overline{\psi}\ \frac{(t-\tau)}{s}\ f\,(t)$$

Where s and τ are scale and translation parameters, respectively, and $\overline{\psi}$ is the complex conjugate of ψ (Sinha, S. et al., 2005).The results of the CWT are several wavelet coefficients, C, which are a function of scale and translation. Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal**.**

Translation τ related to the location of the window, as the window is shifted through the signal. It corresponds to time information in the transform domain and *scale* s is similar to the scale used in maps. As in the case of maps, high scales correspond to a non-detailed global view of the signal, and low scales correspond to a detailed view. Similarly, in terms of frequency, low frequencies i.e. high scales correspond to a global information of a signal (that usually spans the entire signal), whereas high frequencies i.e. low scales correspond to a detailed information of a hidden pattern in the signal (that usually lasts a relatively short time).

Wavelet transforms decompose an input signal into its constituent wavelets. Therefore, considering the superposition principle, the frequency spectrum of the input signal is the sum of the frequency spectra of the wavelets that sum to produce the signal. Based on this explanation the resulting time-scale map (scalogram) can be converted to a time-frequency spectrum by associating a pseudo-frequency to the scale.For example let us take a non stationary signal which is similar to seismic signal composed of four frequency components at 30 Hz, 20 Hz, 10 Hz, and 5 Hz shown in figure 3.

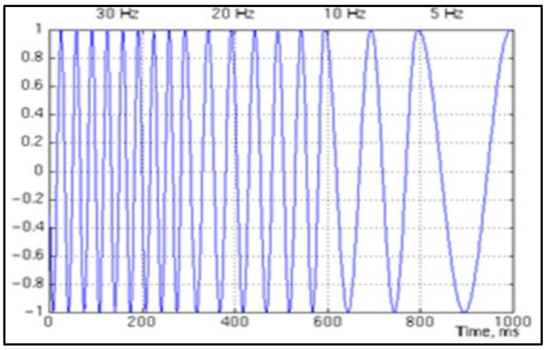


Figure.3: A non stationary signal composed of four frequency components at 30 Hz, 20 Hz, 10 Hz, and 5 Hz.

Now, the CWT of this non stationary signal is performed and shown in figure 4. Here axes are translation and scale, not time and frequency. Translation is related to time and the scale parameter is actually inverse of frequency. Smaller scales correspond to higher frequencies, i.e., frequency decreases as scale increases, therefore, that portion of the graph with scales around zero, actually correspond to highest frequencies in the analysis, and that with high scales correspond to lowest frequencies. The signal had 30 Hz (highest frequency) components first, and this appears at the lowest scale at translations of 0 to 30. Then 20 Hz component comes, second highest frequency, and so on. The 5 Hz component appears at the end of the translation axis and at higher scales (lower frequencies).

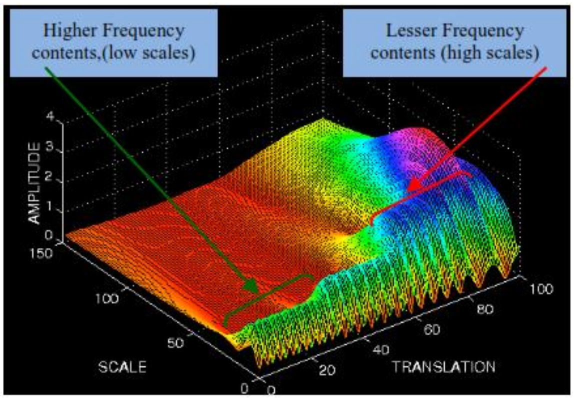


Figure.4: Continuous wavelet transform of signal shown in Figure.3 (Courtesy: Polikar, R., 2006)

Methodology

Pre processing, especially noise attenuation in the area was performed which has followed by sorting data in CMP (common midpoint) order before deconvolution, offset splitting and regularization. Broadly the processing steps included standard signal processing techniques without affecting the relative amplitudes and preserving low end of frequency band width. Afterwards pre stack time migration was done.

To examine low frequency, input data has been analyzed for the maximum frequency present in the study area. Then depending on the observations the maximum frequency present in the data was selected, denoted by Fmax. In present study it was approximately 70 Hz. The input data for low frequency analysis was PSTM stack volume in SEGY format. Using in-house developed Seisunix program 'SUCCWT' (complex continuous wavelet transform of seismic traces) low frequency volumes from input PSTM data were extracted. The SEGY PSTM data has been converted to seisunix format (SU) with the help of aforesaid seisunix program. After conversion in SU format, we have to analyze where the peak average amplitude has occurred with respect to scale. This peak average amplitude value with respect to low frequency extracted from the volume may signify the indication about hydrocarbon bearing zones. After testing all the parameters, various low frequency volumes were generated. Following empirical relation was studied for actual frequency and scale values:

$$\text{Actual Frequency} = F_{max}/2^{(scale/10-0.1)}$$

Where F_{max} is the maximum frequency present in the data, here scale is inversely proportional to the frequency.

S.No.	Scale	Fmax =70	Actual Freq at 70Hz	Fmax =100	Actual Freq at 100 Hz
1	1	70	70.00	100	100.00
2	2	70	65.31	100	93.30
3	3	70	60.94	100	87.06
4	4	70	56.86	100	81.23
5	11	70	35.00	100	50.00
6	23	70	15.23	100	21.76
7	25	70	13.26	100	18.95
8	27	70	11.55	100	16.49
9	28	70	10.77	100	15.39
10	29	70	10.05	100	14.36
11	32	70	8.16	100	11.66
12	33	70	7.62	100	10.88
13	34	70	7.11	100	10.15
14	35	70	6.63	100	9.47
15	36	70	6.19	100	8.84
16	37	70	5.77	100	8.25
17	50	70	2.34	100	3.35
18	75	70	0.41	100	0.59
19	100	70	0.07	100	0.10

Table1: Variation of Actual frequency with different scale values at maximum frequencies 70 & 100 Hz.

Testing of different scale values with respect to various F_{max} at70 Hz and 100Hz were studied on real dataset and tabulated in Table.1. Note that actual frequency became half as the scale changes from 1 to 11, for F_{max}=100.

It reveals from table 1 that actual frequency 15.23 Hz corresponds to scale value 23 (F_{max} =70), which is nearly equal to the actual frequency 15.39 derived for scale 28 (F_{max} =100). The factor which resulted different values of the scale is maximum frequency present in the data (F_{max}). This signifies the importance of F_{max} for frequency based analysis of seismic data.

Examples of usage

As stated in methodology, input for low frequency analysis PSTM stack volume taken which is shown in Figure.5a, where low frequency is preserved. In figure 5b the conventional approach for processing is adopted. Comparison of both the PSTM stack section shows that in zone 2150 -2250 ms, the continuity of reflection events is better. Amplitude spectrum of these two volumes was shown in figure.8. In section A, frequency is preserved up to 4Hz, whereas in section B, same is absent.

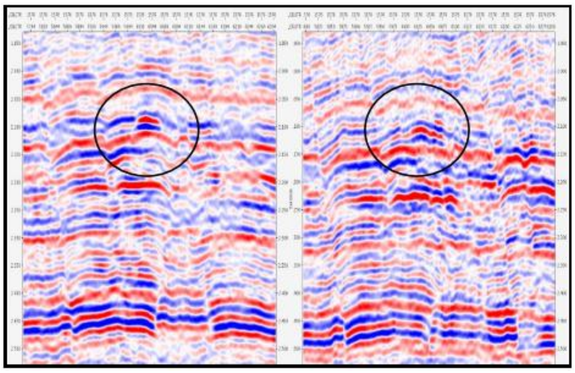


Figure.5a & b: PSTM stack section Low frequency preserved Vs Conventional

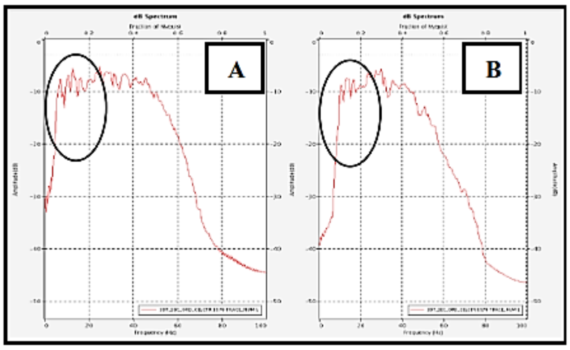


Figure.6: spectral analysis of Low frequency preserved PSTM stack Vs Conventional

Figure.7 shows the test result of different amplitude values extracted at various scales, here the peak value of amplitude (5107) corresponds to scale value 27 & actual frequency 11.55 Hz. Jagmeet Singh et al, (SPG, 2008) have studied the frequency dependent behavior of reflection amplitudes from seismic data and found 'amplitude highs', at low frequencies in producing zones, which disappear at high frequencies. To envisage the implication of low frequencies at input data (PSTM stack), various scale values were chosen.

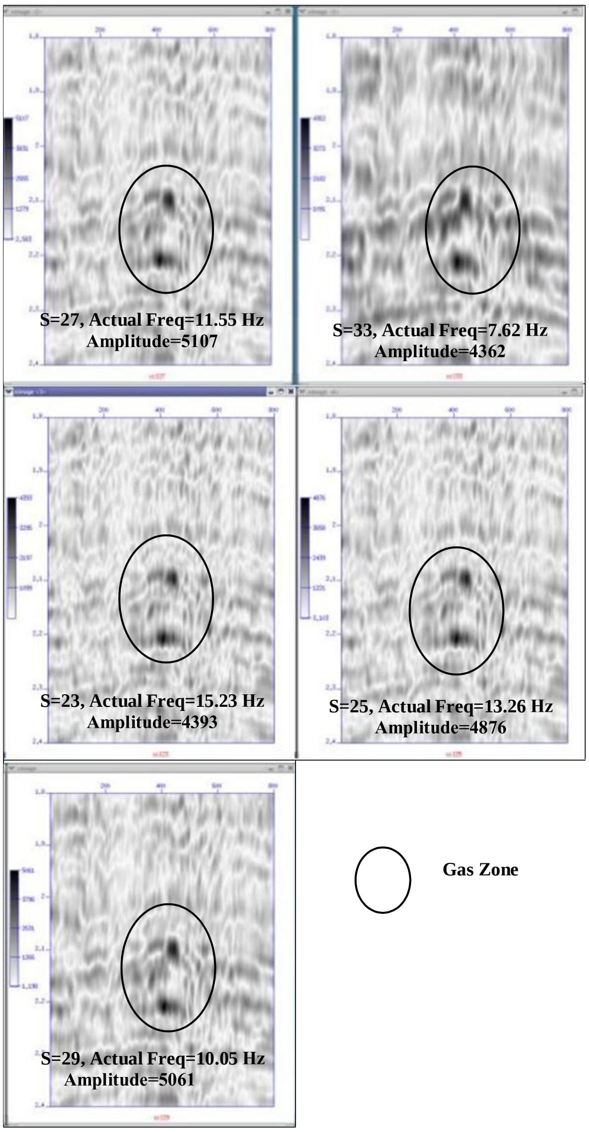


Figure.7: The test results for different average amplitude values of scales 27, 33, 23, 25 and 29.The peak value of the average amplitude is observed at scale 27 Hz which corresponds to 11.55Hz.

A graph has been plotted to see the variations of actual frequencies vs average amplitude and shown in figure 8. Peak average amplitude is seen at scale value 27, i.e. 5106. Actual frequency corresponds to 11.55 for F_{max}=70.

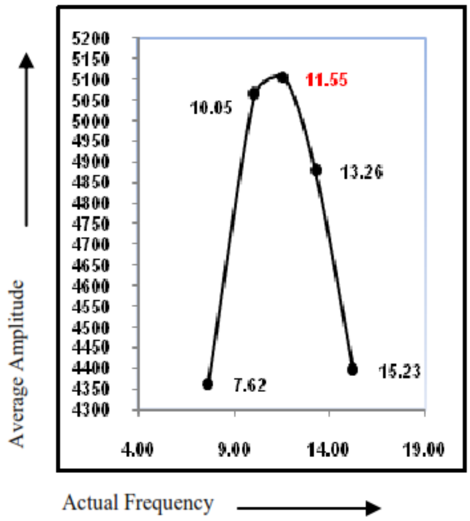


Figure.8: A Plot for average amplitude Vs actual frequency

Suitable low frequency (mono frequency) volume was generated using continuous wavelet transform (CWT) method for different scale values (here scale values were taken 33, 27 & 23 which corresponds to mono frequency volumes of 7.62 Hz, 11.55 Hz & 15.23 Hz respectively), shown in figure 9, 10 &11*(Refer Table-1)*. Here only those sections were shown which corresponds a noticeable difference in average amplitude values. Beyond these scales (lower side), the noise part was enlarged which resulted poor quality of outputs.

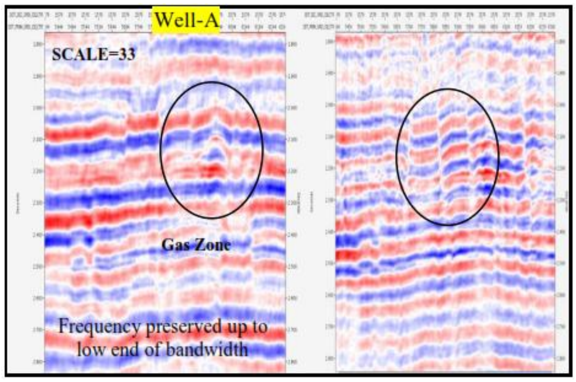


Figure.9: Mono frequency stack section at 7.62 Hz (Low frequency preserved Vs conventional)

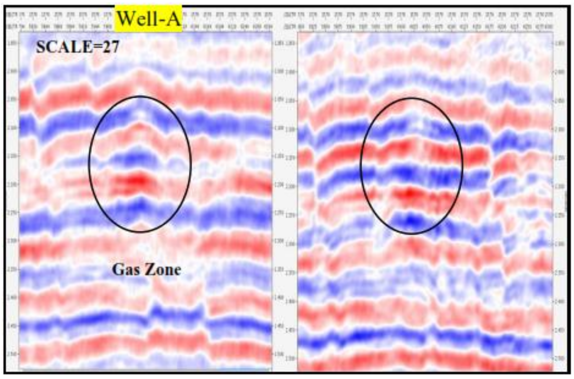


Figure.10: Mono frequency stack section at 11.55 Hz (Low frequency preserved Vs conventional)

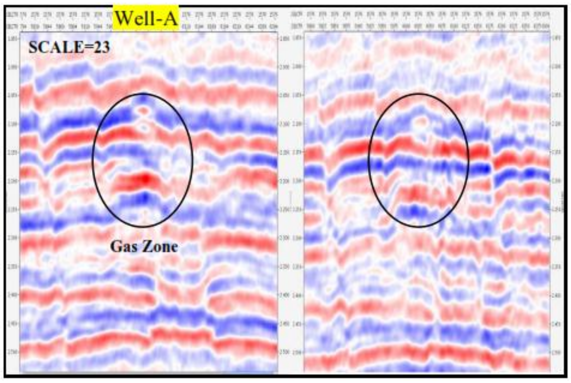


Figure.11: Mono frequency stack section at 15.23Hz (Low frequency preserved Vs conventional).

The illustrated seismic sections of these low frequencies conform to better resolution of reflection events and amplitude, which helps interpreter to delineate the hydrocarbon bearing zones.

The sequence of low frequency based seismic data processing is elaborated in figure 12.

Conclusions

This is a case study and gives the practical approach for low frequency based seismic data processing over conventional processing. Data is processed keeping in view the preservation of low frequencies and taking care while selecting band pass filter, wavelet matching and amplitude matching before merging at pre stack level. In a properly processed low frequency section / volume the amplitude

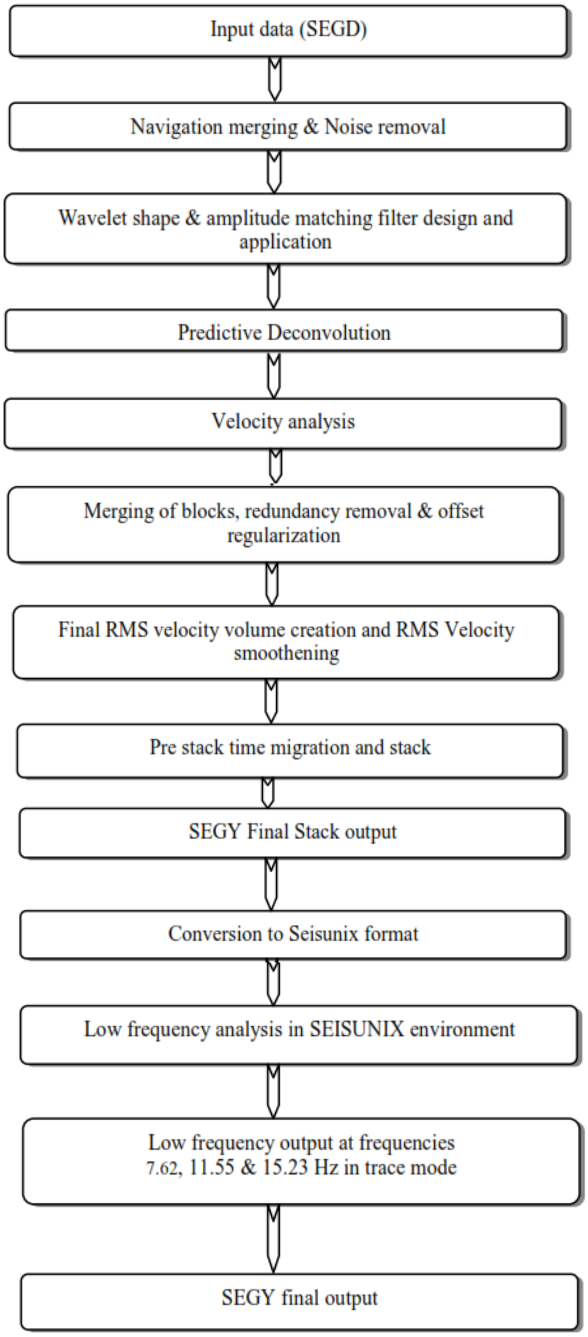


Figure.12: Flow chart of Processing Flow for low frequency study

brightening may be used as direct hydrocarbon indicator. The frequency dependent reflectivity which is supposed to be higher at lower frequency range for a fluid saturated interface should produce higher amplitude on a low frequency section compared to the surrounding (with no fluid saturation).From the seismic data suitable low frequency volume is generated using continuous wavelet transform (CWT) method.

Finally, the present study reveals that low frequency based seismic data processing over conventional processing is that the high amplitude is observed at low frequency which is not present at high frequencies in fluid saturated zones. It has great potential in situations when other approaches fail.

N.B. The views expressed here are those of the authors only and do not reflect the views of ONGCLtd.

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