

USE OF WAVELET TRANSFORMATION FOR GEOPHYSICAL WELL-LOG DATA ANALYSIS

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ABSTRACT

Geophysical well-log (bore-hole) data represent the rock physical properties as a function of depth measured in a well. They aid in demarcating the subsurface horizons, identifying abrupt changes in physical properties of rocks and locating cyclicity (if any) in stratal succession. Rocks document their depositional history, which geoscientists unfold by analyzing different geophysical data, such as well-log data, seismic data, etc. We have applied continuous wavelet transformation technique on one type of well-log data (gamma ray log) from three wells located in Bombay High oilfield, India. Our analyses have helped to identify the discontinuities, detect the horizons and check the presence of cyclic pattern (if any) in deposition. Among various wavelets that we have used, the Morlet wavelet has proved to be most appropriate to resolve the marker horizons in gamma ray log data. We also conclude that the choice of wavelet is dependent upon the rock intrinsic properties that vary greatly in the space domain (with varying depth).

Index Terms— Continuous wavelet transformation, Well-logs, Hydrocarbon reservoirs, Bombay High.

1. INTRODUCTION

A better understanding of the physical properties of reservoir rocks becomes more and more critical with advances in quality of exploration and production data and with depleting natural energy resources. The most comprehensive data sets in characterizing a hydrocarbon reservoir include well-logs, core analyses, seismic data, hydrocarbon composition, pressure test and production tests. In practice, due to economic considerations, only a very few wells are cored. Mature fields with many years of production usually have a large number of spatially distributed wells with various types of data. Thus, techniques to spatially correlate stratigraphic units in well-log data would greatly improve reservoir characterization

and help enhance production, especially for fields with limited core and good-quality seismic data.

Since high resolution well-log data can map trends, cyclic nature, and abrupt changes in sedimentation, they have been used extensively to analyze sedimentation and stratigraphic trends. Serra and Abbot (1982) introduced the concept of electrofacies (a similar set of well-log response that characterized a specific rock type and allowed it to be distinguished from others), which describes rocks in terms of their well-log characteristics to identify abrupt changes in sedimentation and sedimentary markers, well-to-well correlation and identify hydrocarbon bearing zones (pay zones).

Other methods used frequency transforms (Tiwari, 1987) and other statistical methods (Prasad *et al.*, 2005) to help understand trends in well log data. Jansen and Kelkar (1997) and Jennings *et al.* (2000) have generated semivariogram of petrophysical data to study periodicities and determined the degree of similarity between sample pairs as a function of separation distance within a rock column.

Since wavelet transformations can better identify the abrupt changes in cyclicity common in nature, they become important tools for seismic stratigraphy. For example (Chakraborty and Okaya., 1995) have shown advantages of frequency-time decomposition of seismic data. Wavelet analyses have been applied to hydrocarbon production data to estimate the preferential flow paths and the existence of flow barriers within the reservoir rocks (Jansen and Kelkar, 1997), denoising and conditioning of well pressure data (Athichanagorn *et al.*, 1999 and Gonzalez *et al.*, 1999), for upscaling of rock properties (Panda *et al.*, 2000) and determining high frequency sedimentary cycles of oil source rocks (Prokoph and Agterberg, 2000). Soliman *et al.*, (2001) identified of reservoir anomalies from pressure transient data. By using pattern recognition techniques, Vega (2003) identified the formation tops and discontinuities present in each well and improved well to well stratigraphic correlation. This has been an improvement in understanding subsurface rock section

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compared to the conventional correlations using visual inspection from well logs. Delineation of horizons within a sequence to a higher resolution will help in better understanding of the reservoir as a whole. In the present study, we have analyzed well-log data of three wells using wavelet transformation to delineate the discontinuities and marker horizons. We also have examined a variety of wavelets to identify an optimum wavelet that can best resolve well-log data.

2. DATA AND METHODOLOGY

2.1. Data

Data for the present study procured from Oil and Natural Gas Corporation Limited (ONGC), comprises of gamma ray logs, electrical resistivity logs, neutron porosity logs, bulk density logs and acoustic logs from three wells (designated as Well-A, Well-B and Well-C), from Bombay High Basin located in the western offshore of India (Fig. 1). Exact location and nomenclature of the above wells are confidential. In the present work we discuss the analysis and interpretational results of gamma ray logs.

Gamma ray (GR) logs record spontaneous emissions of gamma rays from the radioactive elements hosted in the minerals of rocks. We have selected GR logs for wavelet analysis because radioactive properties sensu stricto reflect the lithology of the reservoir, and are thereby best suited to demarcate different sedimentary horizons. The GR log data from the three wells correspond to measurements obtained in the depth range of 960m-1460m from sea-floor. The sample spacing is 0.1524m (6 inches), which is sufficient to resolve and understand the reservoir characteristics in detail.

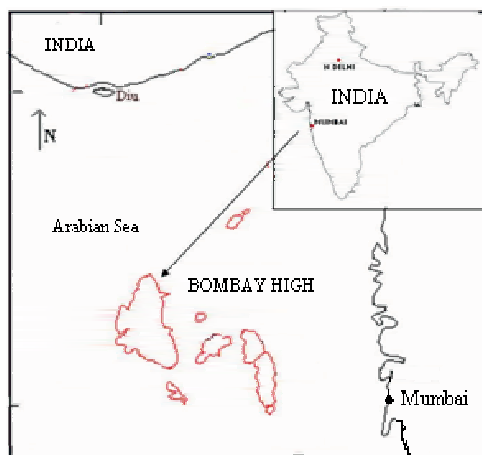


Fig. 1. Location map of Bombay High (not to scale)

2.2. Wavelet Analysis

Well-log data are nonstationary in nature and show cyclic trends and abrupt changes of rock properties. For many applications, the best representation of a signal is done in

the frequency domain by using spectral analysis methods. However, the most common methods for well-log data analysis are in the space domain. Fourier transformation has been the traditional method for spectral analysis. Wavelet analysis is more effective for analyzing nonstationary signals, in the sense that it facilitates time/space localization of signals more effectively than the conventional spectral analysis methods. It allows multiresolution analysis in which, a signal can be represented as the sum of different frequency components with different resolutions. The capability of representing a signal in several levels of resolution is the major strength of wavelet analysis (Goswami and Chan, 1999).

For boundary detection we used the coefficients from the continuous wavelet transform (CWT). The CWT separates out the frequency components of a signal. It is therefore important that the wavelet used gives the best resolution of these separated frequencies. We performed the wavelet transformation on the GR log of the three wells. However due to large length of the data sequence, CWT of data with some wavelets did not yield required resolution. Hence we have divided the data into three sets (Set 1, Set 2 and Set 3), with considerable overlapping amongst them. Care has been taken to ensure that information is not lost (due to edge effects) in this process. Then CWT was performed on each of the data sets and also on the full data of the three wells. Wavelet decomposition was done upto level 6, as at this level, the resolution of the wavelet analysis of the signal was satisfactory. We have used many wavelets viz., Coiflet series, Daubechies series, Gauss series, Haar, Meyer, Mexican Hat, and Morlet for the present study. Of these Daubechies 9 (db 9), Meyer and Morlet wavelets were found to be effective in demarcating the rock stratal sequence of the three wells with high accuracy, compared to that obtained using other wavelets. Fig. 2 shows plots of relative correlation/analyzing power of these three wavelets for the full data and also for all the three sets of all the wells. It is interesting to note that Morlet wavelet stands out to be the most suitable wavelet, effectively delineating the marker horizons in gamma ray log data. This is because, at level 6, (when the scale, $S \ll 1$), the Morlet wavelet (which is the complex exponential function multiplied with Gaussian envelope) becomes very narrow and thus aptly facilitates to resolve the nonstationarity in the signal. Fig. 3 shows plot of wavelet coefficients of full data sequence identifying the exact location of marker horizons in all the three wells. On the horizontal axes the scale is indicated. The GR log data, measured in American Petroleum Institute (API) units are also shown for individual wells. In Fig. 3, solid lines indicate the depths to the top of the pay zones, indicating very high gamma ray counts as observed from the wavelet transformation. Broken lines indicate probable continuation of these zones between the wells.

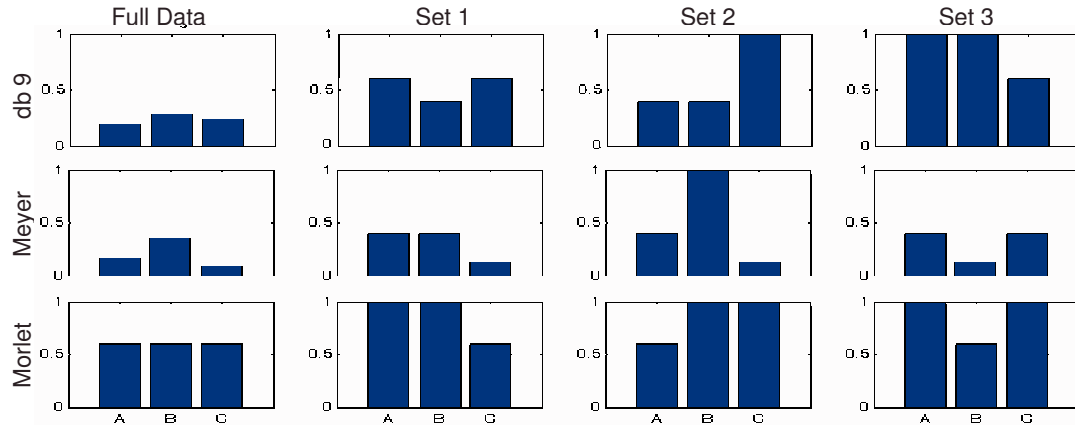


Fig. 2. Plots showing the relative analyzing power of Daubechies 9 (db 9) wavelet, Meyer wavelet and Morlet wavelet on GR log data. Analysis performed on the entire data (Full Data) as well as the individual overlapping sets as mentioned in the text. Horizontal axis represents the name of wells while the relative correlation (0 to 1) is represented in the vertical axis for all cases.

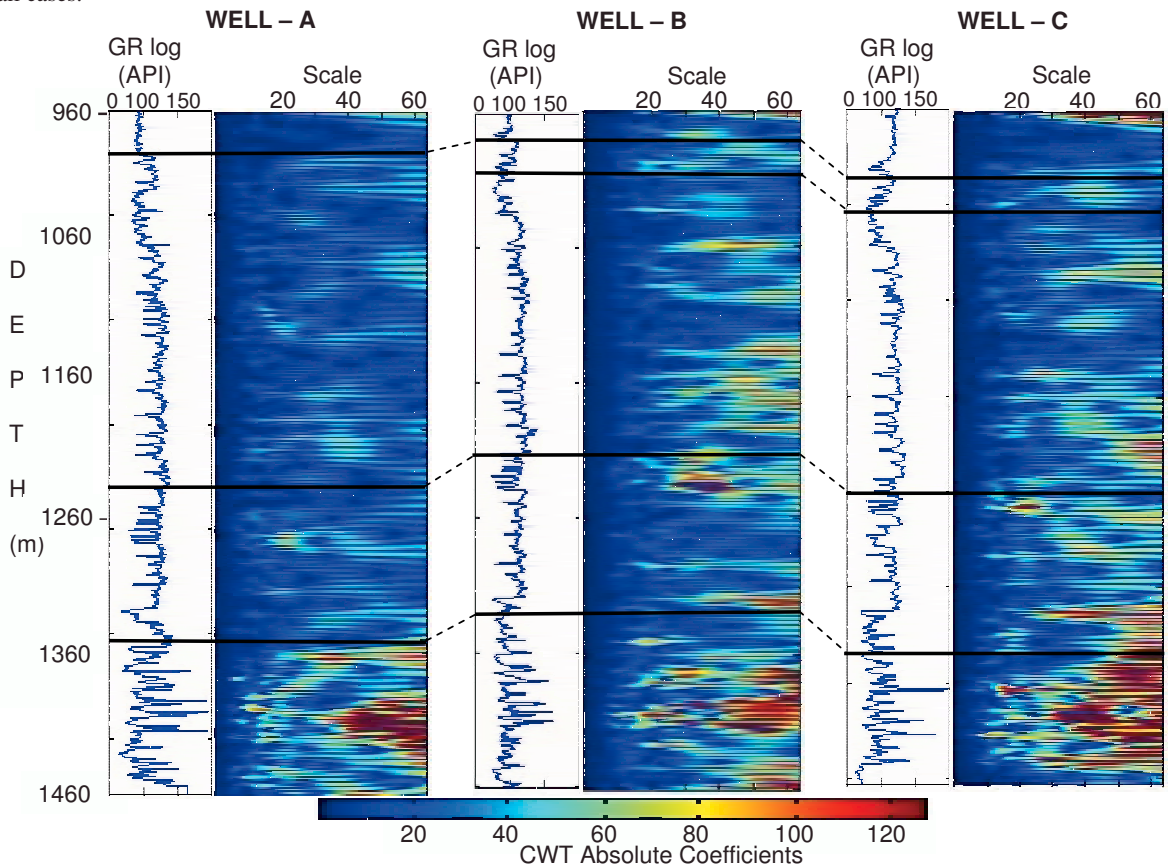


Fig. 3. Plot of CWT coefficients, obtained by applying Morlet wavelet to full data of GR log. Plot shows the depth locations of marker horizons that match with the known depth estimates. Solid lines indicate the depths to the top of the pay zones, indicating very high gamma ray counts as observed from the wavelet transformation. Broken lines indicate probable continuation of these zones between the wells.

3. RESULTS AND DISCUSSION

Among the various wavelets used, Daubechies 9, Meyer and Morlet wavelets could demarcate the rock sequence in the three wells (Fig.2). However, as seen in Fig. 2, of these three wavelets, the relative analyzing power of Morlet wavelet is high (see bottom panel of Fig. 2) and thus it could effectively resolve the marker horizons in the GR log data. In Fig.3, plots of CWT coefficients, obtained by applying Morlet wavelet analysis to full data length of GR logs of all the three wells show the depth to the top of the marker horizons, corresponding to high gamma ray count. These depth locations were identified by comparing with those of the wavelet analysis results of other logs, which in turn match with the known depth estimates.

Our results imply that for effective identification of marker horizons, not only a proper choice of wavelet is important, but also, the spatial (depth) variation of physical properties of rock. This is clearly evident from Fig.3, where CWT of GR log of Well-A could not delineate the marker horizon in the depth range 1000-1050m, whereas, in the same depth range, it could identify in Well-B and Well-C. Vega (2003) reported that he too could clearly demarcate the marker horizons from the gamma ray log data of his studied area using Morlet wavelet. Since our result also show that Morlet wavelet is the optimum one for gamma ray log analysis, an interesting question arises: Can we, at this juncture with certainty, say whether Morlet wavelet is ideal for gamma ray log data analysis? However, we strongly feel that this can be answered correctly, only after analyzing more gamma ray logs of other well also. It is pertinent to note that the application of signal processing methods on rock sections need to be carefully handled, keeping in mind, the geology of the studied sections, without which true understanding of these hydrocarbon bearing sections will not be evocative.

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