Local frequency as a direct hydrocarbon indicator

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Summary

As a seismic wave propagates, it loses energy due to spherical divergence, scattering, intrinsic absorption and reflection at interfaces where rock properties change. The amplitude and frequency responses of the reflected seismic wave are influenced by a variety of factors including: geologic structure, layer thickness, lithology, and pore fluid properties. When the seismic wave travels back to the surface, it also bring back the information related to stratigraphic features, rock property changes and hydrocarbon accumulations. Each reservoir has its own characteristic seismic frequency response because of its unique rock and fluid properties discriminating it from the surrounding environment. We utilize a spectral decomposition method to extract the characteristic frequency components from seismic data and identify low frequency anomalies. To understand the underlying physical factors of the low frequency anomaly, we build a set of wave-equation based synthetic forward modeling. The result of our analysis shows that seismic waves travel more slowly through gas zone than the background material is a main reason for seismic time series delay and low frequency anomaly in the thin layer reservoir. Our explanation has been applied in the analysis of frequency anomalies corresponding to gas-bearing sands in the Gulf of Mexico fields.

Introduction

Low frequency energy anomalies associated with reservoirs have been observed for many years. Taner et al. (1979) noted the occurrence of lower frequencies beneath gas and condensate reservoirs. Castagna et al. (2003) showed that gas reservoirs could be identified by low-frequency shadows. Li (2006) presented a method using the continuous wavelet transform to detect thick gas reservoirs. So far, there are no proven explanations for the low-frequency phenomenon. Many researchers applied attenuation concept to justify low frequency, because attenuation is like a low pass filter, it suppresses higher frequencies proportionally more than the lower frequencies, some oil /gas reservoir place, gas containing targets usually own a lower Q value than its background and exhibit a zone of anomalous absorption lying in a larger background region (Winkler and Nur 1982; Klimentos, 1995; Parra and Hackert, 2002; Kumar et al 2003). Yet, it is often difficult to explain observed shadows under thin reservoirs where there is insufficient travel path through absorbing gas reservoir to justify the observed shift of spectral energy from high to low frequencies (Castagna 2003). If low frequency anomaly was caused by pure attenuation factors, we can compensate the high-frequency components within that zone by applying a reverse Q filter. But, Yanghua Wang (2007) showed the low-frequency shadow zone still exists even after Q compensation.

The purpose of this paper is to analyze the mechanisms that influence local frequency components of seismic data in thin-layers (half-wavelength thickness). A detailed forward model is built to help for understanding the underlying physical factors and evaluation of the contributions of various factors (related to local fluid properties, lithology change and layer thickness variation) to local frequency anomalies. The result of our analysis shows that seismic signal travels in gas /oil zone at low velocities that in turn result in push down of reflectors and cause the delay in time series. Therefore, the existences of gas/oil low velocity zones are most likely to result in low frequency anomalies rather than anomalous attenuation in thin layer zone.

The factors influence local frequency of seismic data

The final seismic frequency content is a comprehensive result of many factors including the source wavelet, the lithologic properties of the layer, the application of seismic data processing, etc. There are many evidences show the presence of low frequency spectral anomalies with a high degree of correlation to the location of hydrocarbon reservoirs. To understand the physical reasons causing this phenomenon and to utilize it as an attribute of hydrocarbon indicator, I classify the frequency influence factors into two categories: One is called the global factors which change the frequency of the whole seismic section and determinate the background frequency of the seismic section. For example, the source wavelet, the seismic data processing procedure, and the regional geologic structure belong to this category; Another is called the local factors which only bring some regional or local frequency variation such as local lithologic properties changes, layer thickness variation, and the presence of abnormal geopressure. For the purposes to detect the hydrocarbon presence, our interests mainly concentrate on these local factors.

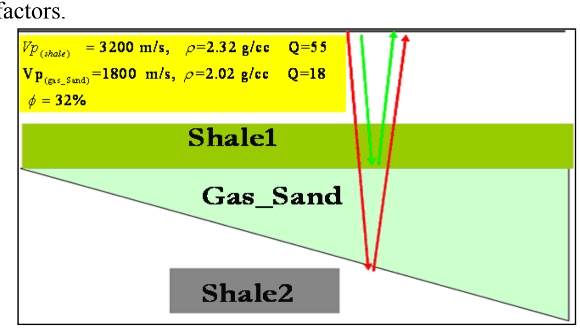

Figure1. The wedge model.

We use a systematic three-layer wedge model to study the effect of layer thickness, lithology, and fluid properties on the spectral response. A low impedance layer (e.g., gas sand) is sandwiched between two high impedance layers (e.g. shale).

The physical parameters of the layers are shown in figure 1. The porosity of the gas sand is 32% with initial water saturation is 0.1. The source wavelet is a zero- phase Ricker wavelet with a peak frequency of 30 Hz. The synthetic traces are generated by a plane-wave propagation model with attenuation in the top of figure 2. We start by analyzing the influence of layer thickness on the frequency response, particularly where the layer thickness is less than one-half wavelength. Because, in this region the reflected events from the top layer and the bottom layer will overlap and produce a compound signal whose peak frequency depends on thickness. After layer thickness increases beyond one-half wavelength, the two events can be separated in two-way travel time.

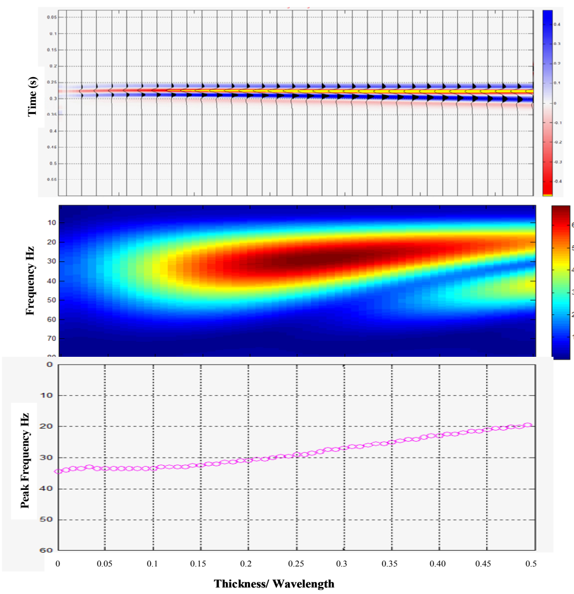

Figure 2. The top plot is synthetic seismic traces of the wedge model with a thickness of less than one-half wavelength. The middle is the frequency response in 2D display. The bottom is the peak energy location of the frequency. A trend of down shift could be observed as the thickness is increased.

The middle of figure 2 demonstrates the peak energy location of frequency shifts towards low frequency direction as the layer thickness increases. The relationship between the peak frequency and thickness is plotted in pink curve at the bottom of the figure 2. The slope of the curve changes is at a place of the quarter thicknesses. The maximum frequency difference is about 10 Hz between the quarter thicknesses and half thickness. The ratio of the change of peak frequency to the change of thickness is approximately 0.33. Using this ratio, a 20% layer thickness increase produces nearly a 2 Hz shift at the peak frequency. If the thickness of layer is fixed at half wave, figure 3 plots the results of that only change of Q value. In this case we keep everything at the same condition except for changing Q value from 55 to 18. The frequency difference for two Q values is less 1 Hz and it means that varying only the Q value does not affect the peak frequency as much and pure attenuation factor could not bring a large of frequency shift down in thin layer zone. However, if the velocity changes, it will gives the peak frequency shift more obvious. Figure 4 shows a 4.5 Hz peak frequency difference between two signal traveling at the different Vp velocities 2300 m/sec and 1800 m/sec, which represents gas sand and brine sand respectively. In this case, the velocity and density of the brine sand are calculated using Gassmann's equation. The low velocity of the gas sand causes time sag below the gas, which corresponds to a visible spectral shift toward low frequencies in the reflected signal. . Compare to pure Q value, the low velocity is a dominated factor influence the peak frequency location. This

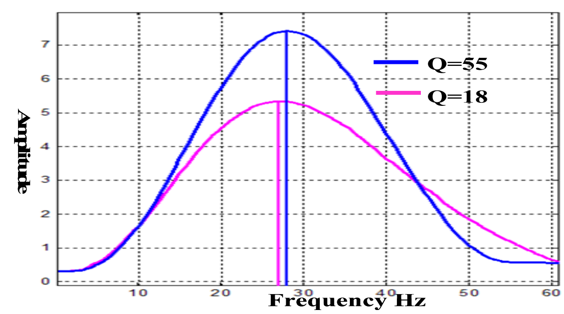

Figure3. The frequency response of the two signals with only changing Q values.

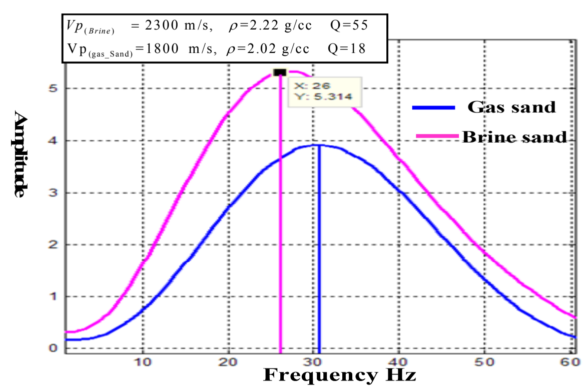

Figure4 **.** The frequency response of brine sand and gas sand.

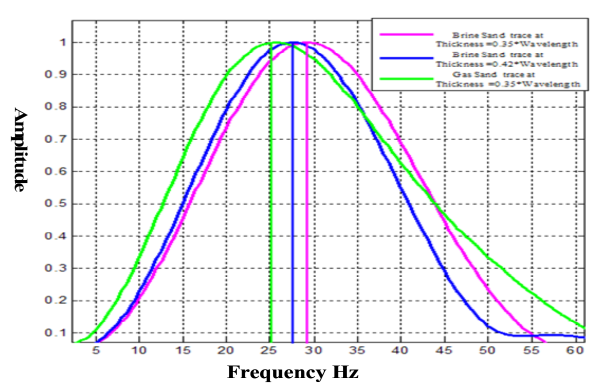

Figure5. A comparison of peak frequency shift between 20% thickness variation and pore fluid property.

relationship explains the commonly-observed association of abnormally high geo-pressure regions with low frequency anomalies: high geo-pressure reduces the effective pressure and results in a decrease in the velocity of the rock.

Figure 5 shows a comparison between the peak frequency shift that occurs when a 20% thickness change of brine sand (from 0.35 wavelengths to 0.42 wavelengths) and when brine sand is fluid substituted to gas at a constant thickness. The amplitude response is normalized to unity. Velocity changes with pore-fluid content cause a larger frequency shift (4.5Hz) than the 20% thickness variation (2Hz). This means that at in situ conditions the gas-containing reservoir may display a discernible low frequency anomaly if the thickness of the layer varies laterally less 20 percent.

Summarize the above analysis based on the synthetic model. The reservoir thickness and the acoustic impedance (velocity and density) are the major factors that control the spectral responses of the seismic signal in the thin layer zone. If the reservoir thickness is varied less than 20%, velocity is the dominant factor that influences the peak frequency shift.

Field Example

Time-frequency analysis is used to directly compute seismic frequency attributes from field data that includes the King Kong reservoir and a nearby dry hole (Lisa Anna). King Kong is a gas reservoir characterized by strong amplitude anomalies (O'Brien, 2004). Lisa Anna has a similar set of amplitude anomalies within the same stratigraphic interval on the southeastern flank of the basin (Figure 6). However, no commercial hydrocarbons were found in the Lisa Anna location; it was a Fizz reservoir. In the figure, the orange color represents a large negative peak frequency shift.

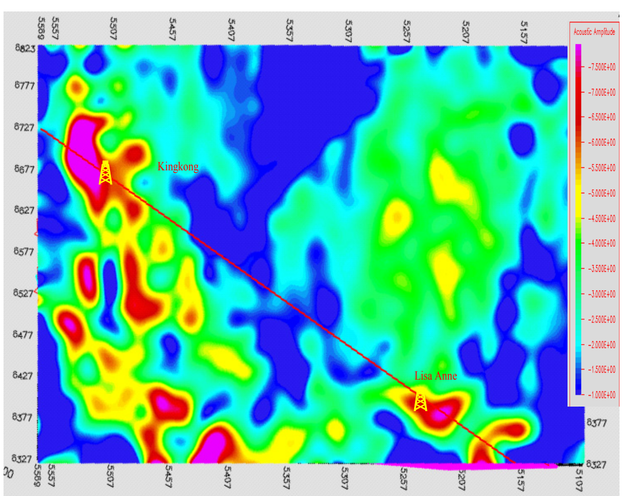

Figure6. An RMS amplitude map of target sand horizon with window at +/- 25ms.

The sand quality of King Kong and Lisa Anna is excellent, with porosities of 32-35%, and the thickness of the target sands are about 26 meters. Figure 7(top) presents the low frequency anomalies after removing the background trend at King Kong and Lisa Anne; their peak frequencies are about 11 Hz and 14 Hz respectively (figure 7 bottom).

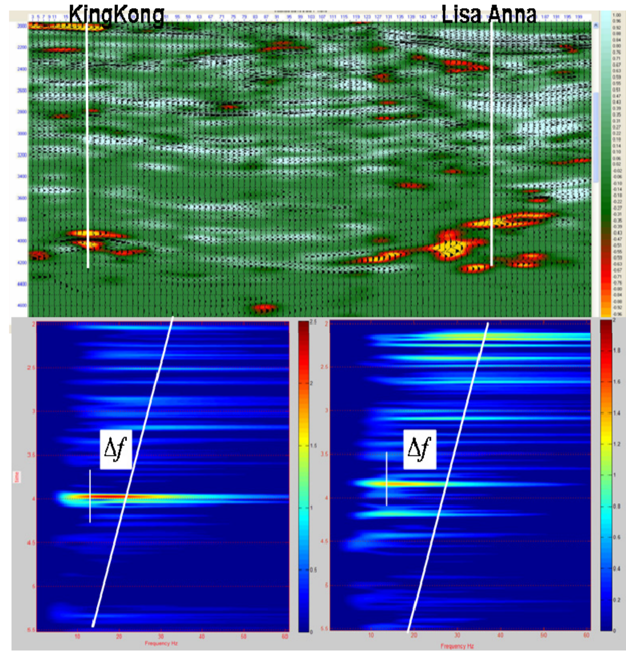

Figure7. The top is low frequency anomalies profile. Bottom is time frequency sections of traces (left Kingkong and right Lisa Anna). The orange color represents a large negative peak frequency shift.

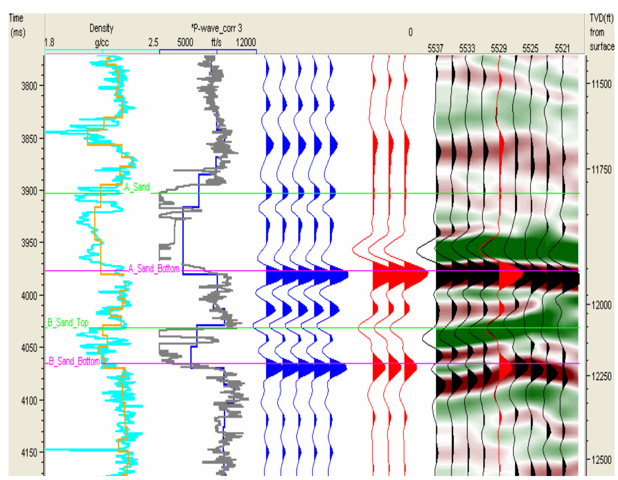

Figure8. Density log, sonic log, synthetic trace, correlation trace and seismic section of Kingkong well.

The maximum frequency shift is about - 4.5 Hz at the Lisa Anna location. Figure 8 shows the King Kong well log and its synthetic trace. From the previous analysis, we think that the low velocity at the target zone is the primary cause of the low frequency anomalies. Since main frequency of seismic data is about 25 Hz, shale's velocity of the top layer is about 2590 m/sec and the target sand's velocity is around 1846 m/sec. The thickness of the target sand is 26 meters which is smaller than half wavelength. From the previous analysis, there is insufficient travel path through the gas sand to justify the observed low frequencies due to absorption or attenuation. We think that the low velocity at the target zone is the primary cause of the low frequency anomalies.

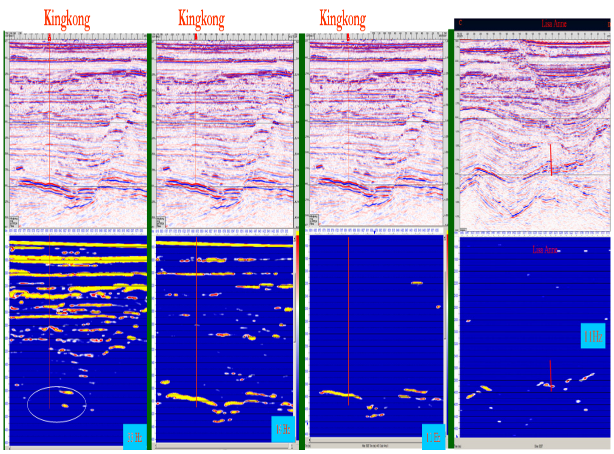

Figure 9. (a) A series of the common frequency sections (left three pictures) at Kingkong well. (b right) 11 Hz common frequency section at Lisa Anna.

Figure 9 is a series of common frequency profiles. The energy at 33 Hz does not appear in the reservoir location (the left figure). However, high energy at 11 Hz is seen at the target sand horizon near the King Kong well location and relatively weak energy appears at 11 Hz near well Lisa Anne; almost no energy at this frequency is shown in any other layers. This implies that 11 Hz peak frequency correlates to reservoir sands in this area. Figure 10 is a map of RMS energy at 11 Hz with a 50 ms window centered on the target sand. The gas-saturated target sand is nicely highlighted at this frequency and high gas concentration is also indicated by the magnitude of the energy spectrum (King Kong is a gas reservoir. Lisa Anna is fizz sand).

Conclusions

In this paper, we discussed the phenomenon of low frequency energy anomalies associated with reservoir zones. The results of numerical forward modeling in the thin layer zone show that when seismic waves travel more slowly through gas than the

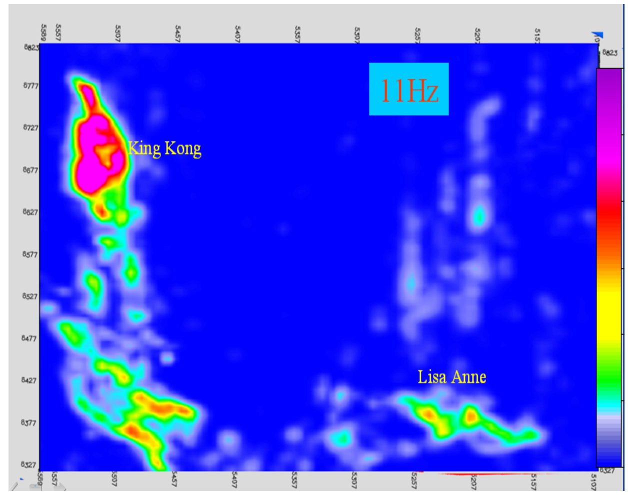

Figure 10. An RMS energy map at 11 Hz of target sand.

background material. This signal time delay is a major factor causing low frequency anomalies. A low attenuation factor Q is insufficient to produce large low frequency anomalies in thin layer zones (half wavelength thickness). Since unique rock and fluid properties exist in the surrounding environment, each reservoir has its own characteristic frequency response to the seismic signal. Local frequency components can be used to recognize hydrocarbon reservoirs.

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EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2009 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Batzle, M., and Z. Wang, 1992, Seismic properties of pore fluids: Geophysics, **57**, 1369–1408.

Castagna, J. P., and S. Sun, 2006, Comparison of spectral decomposition methods: First Break, **24**, 75–79.

Castagna, J. P., S. Sun, and R. W. Siegfried, 2003, Instantaneous spectral analysis: Detection of low-frequency shadows associated with hydrocarbons: The Leading Edge, **22**, 120–127.

KIimentos T., 1995, Attenuation of P- and S-waves as a method of distinguishing gas and condensate from oil and water: Geophysics, **60**, 447–458.

Kumar, G., M. Batzle, and R. Hofmann, 2003, Effect of fluids on attenuation of elastic waves: 73rd Annual International Meeting, SEG, Expanded Abstracts, 1592-1595.

O'Brien, J., 2004, Seismic amplitude from low gas saturation sands: The Leading Edge, **23**, 1236–1243.

Parra, J. O., and C.L. Hackert, 2002, Wave attenuation attributes as flow unit indicators: The Leading Edge, **21**, 564–572.

Tanner, M. T., F. Koehler, and R. E. Sheriff, 1979, Complex seismic trace analysis: Geophysics, **44**, 1041–1063.

Wang, Y., 2002, Astable and efficient approach of inverse Q filtering: Geophysics, **67**, 657–663.

Wang, Y., 2007, Seismic time-frequency spectral decomposition by matching pursuit: Geophysics, **72**, no. 1, V13–V20,

Winkler. K., and A. Nur, 1982, Seismic attenuation: Effects of pore fluids and frictional sliding: Geophysics, **47**, 1–15.