ABSTRACT
The nature of the frequency response depends strongly on the AVO behavior at an interface. In order to understand and predict the seismic response to fluid saturation for Class IV sands, we performed Synthetic geological models with a hydrocarbon-bearing zone. The synthetic seismic sections were produced by performing offset acoustic ray-tracing in GX Technology’s GX-II 2D forward modeling package based on existing well log information close to the study area, which can effectively model the characteristics of attenuation and frequency-dependent reflection. Then transform the seismic data centered in a target layer slice within a time window to the time-frequency domain using S-Transform time-frequency signal analysis and sort the frequency gathers to common frequency cubes. Strong low-frequency energy beneath a hydrocarbon reservoir (seismic low-frequency shadow) can be used as a hydrocarbon indicator (Taner et al., 1979). we observe the characteristics of the seismic low-frequency shadow in the common frequency cubes. Reservoir simulations reveal that the main mechanism of seismic low frequency shadows is attributed to high attenuation of the medium to high seismic frequency components caused by absorption in the hydrocarbon-filled reservoir. After modeling and validation of the technique with synthetic data, seismic analysis supported with SD technologies was performed to evaluate prospects located in real data. Results from a practical example of seismic low-frequency shadows show that it is possible to identify the reservoir by the low-frequency shadow with high S/N seismic data. This study is useful to identify reservoir and nonreservoirs and the results of this study are great importance in making plans for developing the reservoir.

INTRODUCTION
Seismic low-frequency shadows, indicating strong low-frequency energy beneath hydrocarbon reservoirs, first appeared in Taner et al. (1979). Afterward, it appeared in dictionary of exploration geophysics edited by Sheriff (1984; 1999 shadow” and indicated that it usually appeared beneath gas sands, condensate layers, oil layers, and fractured zones in tight strata. However, the observations are empirical with unknown physical mechanism. Ebrom (2004) summarized at least ten factors that might give rise to low-frequency shadows and planned to use low-frequency shadows to directly indicate gas zones and distinguish commercial from noncommercial gas-bearing reservoirs. Unfortunately, the goal of quantitative processing is still difficult to realize because of the unclear mechanisms and other influential factors. Castagna et al. (2003) improved the application of seismic time-frequency analysis for hydrocarbon identification. Detailed analyses of spectral characteristics have revealed that Classes I and III show different responses to fluid saturation at low and high frequencies (Chapman et al., 2005). It is possible to form a common frequency data cube, so we can study the characteristics of seismic low-frequency shadows by comparing different common frequency cubes. For example, if there are low-frequency shadows characteristics in low-frequency seismic common frequency sections (or slices) rather than medium to high frequency sections, the strata above the seismic low-frequency shadows are likely to be hydrocarbon reservoirs. This is caused by the attenuation of seismic waves. When a seismic
wave moves through an absorbing hydrocarbon reservoir, attenuation of the high-frequency components is greater than the low-frequency components. This is a reasonable hypothesis for the physical mechanism of seismic low-frequency shadows but we still need a more accurate theoretical analysis and seismic modeling. However, seismic low-frequency shadows are an important indicator of hydrocarbon reservoirs.

**Spectral decomposition**
Spectral decomposition techniques help us to understand scale and frequency dependent phenomena, essentially by allowing us to study the data one frequency at a time. In this study, S-transform is applied to deepwater seismic data from Gulf to get different instantaneous frequency volumes. The S-transform improves spectral resolution by using variable window length as a function of frequency (Stockwell, et al., 1996). Given a trace $f(t)$, we form the, or S-transform: which means that, for each choice of frequency, we have a new trace corresponding to that particular frequency.

$$ Sf(u,\omega) = \frac{1}{2\pi} \int f(t) \frac{\omega}{\sqrt{2\pi}} e^{-\frac{(u-\omega t)^2}{2\sigma^2}} e^{-i\omega t} dt, $$

we transform the synthetic section to the time-frequency domain by S-transform and sort the frequency gathers to common frequency cubes.

**ANALYSIS AND MODELLING**

**Synthetic Model**
We design a geological model with a hydrocarbon-bearing bed and specify the appropriate parameters for Class IV AVO. Class IV sands have a negative normal-incidence reflection coefficient, but decrease in amplitude magnitude with offset (Castagna et al. 1998). The hydrocarbon-bearing bed shown in Figure 1 has lower density $2 \text{ g/cm}^3$ and P wave velocity ($2100 \text{ m/s}$) and S wave velocity ($1220 \text{ m/s}$) and stronger attenuation than surrounding rock ($Q=5$). We simulate the midpoint seismic response of the geological model (CMP (or CDP) gathers), we get the synthetic section shown in Figure 2.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Numerical values used in the computations</th>
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<tbody>
<tr>
<td></td>
<td>(m/s)</td>
</tr>
<tr>
<td>Media</td>
<td>P wave velocity</td>
</tr>
<tr>
<td>Cap rock</td>
<td>3350</td>
</tr>
<tr>
<td>Reservoir</td>
<td>2100</td>
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Figures 3a to 3d show four common frequency sections and we see strong reflected energy from the top of the hydrocarbon-bearing bed. In the area beneath the hydrocarbon-bearing bed, strong energy appears in the common frequency sections with frequencies 8Hz and 14 Hz but the strong energy disappears when the frequencies are greater (25Hz and 60Hz sections). In Figures 4, we can identify the seismic low frequency shadows and use them as an indicator of the overlying hydrocarbon-bearing bed. High precision time-frequency analysis and the formation of common frequency cubes are important techniques for the observation, and application of seismic low-frequency shadows.

**Field data**
Detailed analyses of spectral characteristics have revealed that Classes I and III show different responses to fluid saturation at low and high frequencies (see Chapman et al. 2005, 2006). The gas discovery well also exhibits the characteristics associated with bright spot Class IV AVO. A series of iso-frequency sections is shown in Figure 3, there is a systematic decrease of amplitudes as frequency increases in the marked area, qualitatively consistent with the synthetic model for Class IV AVO shown in Figure 3. Following the work of Castagna et al. (2003), we formed “iso frequency sections” from the stacked data. Figure 4 highlights such a region, which is bright on 8-Hz and 14-Hz sections, but no bright spot is visible on the 30-Hz and 60-Hz sections. The effect was consistent for other frequencies; the reservoir was bright at low frequency, but did not stand out on the higher frequencies. This highlights the fact that in practice the concepts of amplitude and AVO anomalies are typically frequency dependent phenomena.

**RESULTS AND DISCUSSION**
Applications of spectral decomposition techniques to stacked seismic section from deepwater reservoir Class IV AVO show that we can identify the seismic low frequency shadows and use them as an indicator of the overlying hydrocarbon-bearing bed. High precision time-frequency analysis and the formation of common frequency cubes are important techniques for the observation, and application of seismic low-frequency shadows.

**CONCLUSIONS**

**KEYWORDS**
Seismic low-frequency shadow, reservoir identification, Class IV AVO, Synthetic seismogram

ACKNOWLEDGMENTS

Figure 1
Geological model with a hydrocarbon-bearing bed

Figure 2
Synthetic seismic section with attenuation

Figure 3
(a) to (d) common frequency sections from time-frequency analysis.

Figure 4
Selected iso-frequency sections of the stacked seismic data. We can see a systematic decrease of amplitudes with frequency in the marked target Areas, which is qualitatively consistent with the prediction of Fig. 3 for the Class IV AVO. The vertical axis is two-way travel time

REFERENCES