Reservoirs Characterizing Based on Spectral Difference Anomaly at Lower-Frequency on Multi-Angle Stacking Gathers: Case Studies from China*

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Abstract

The characteristics of seismic reflection on fluid-bearing strata vary in different angle stacking gathers. One of the main characteristics is that the reflection amplitude varies with offsets, i.e. the well-known AVO (Rutherford and Williams, 1989; Castagna et al., 1998). Ghosh (2010) showed the difference of reflection amplitude is more distinctive on gas-sand strata than on dry sand. Another characteristic is that the spectral response also changes with both offsets and fluid types. Chen et al. (2008) performed spectral decomposition on far-angel stacking gathers. Their result showed that the spectral amplitude contrast between oil sand and brine sand is remarkable, and the oil water contact (OWC) can be more easily distinguished at the lower frequency. Goloshubin et al. (2006) presented an example that a certain spectral components of AVO attributes section show bright anomalies at the reservoir.

Based on the above facts and inspired by the idea of fluid indicators (Goodway et al., 1997; Russell et al., 2003), we present a methodology and workflow to characterize reservoirs based on spectral difference anomaly at lower-frequency on multi-angle stacking gathers. We applied this methodology to both land and marine seismic datasets from China. The results show that the detected hydrocarbon accumulations are correlated well with the real gas production of wells.

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Reservoirs characterizing based on spectral difference anomaly at lower-frequency on multiangle stacking gathers: case studies from China

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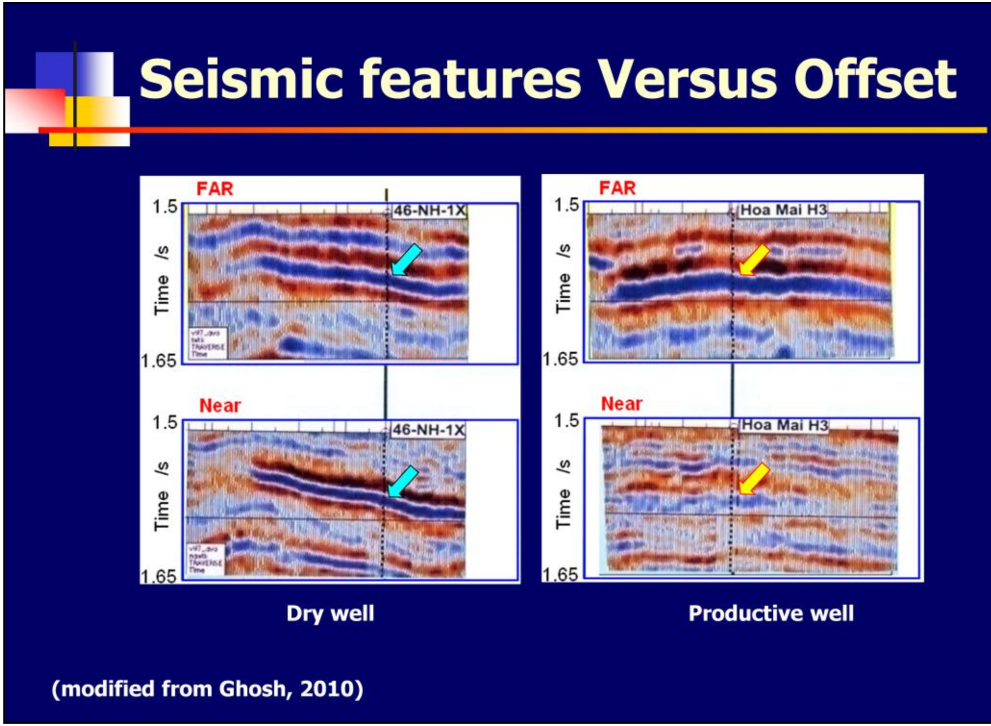
Spectral-related features Versus Offset

- **The characteristics of seismic reflection on fluid-bearing strata varying in different angle gathers:**
    - **Seismic amplitude versus offset, i.e. conventional AVO** (Rutherford and Williams, 1989; Castagna et al., 1998).
    - **Seismic spectral response of different components also changes with both offsets and porous fluid characteristics.** (Chapman et al., 2006; Chen et al., 2008)

Presenter's notes:

(1) There concern more about the seismic amplitude

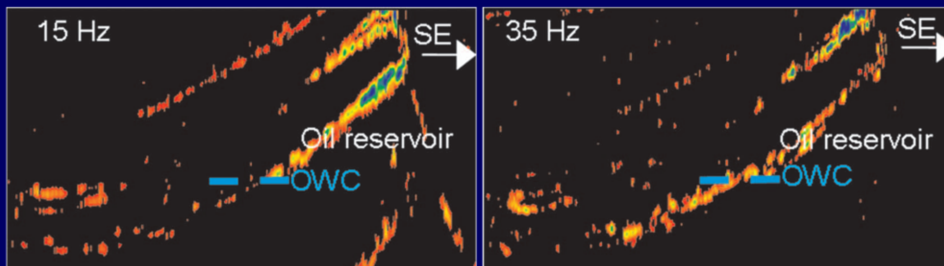
(2) Which demonstrate the seismic amplitude and the frequency-dependent characteristics versus offset and the properties of porous media.



Presenter's notes: The reflection from the dry shale (indicated by cyan arrows, and 46-NH-1X is a dry well) in both far and near angle stacking gather are strong, in which the amplitude variation is not evident. On the contrary, there are significant amplitude variations at the gas sand in far and near angle stacking gathers in Figure 1b (indicated by yellow arrows, and Hoa-Mai-H3 is a gas well).

Instantaneous Spectral Difference

- **Seismic spectral features show frequency-dependent characteristics**



Spectral decomposition of far-angle stacking seismic section

(modified from Chen et al., 2008).

Presenter’s notes: There is obviously spectral energy difference between the oil sand and the downdip brine sand at the lower frequency (15Hz). We can see the oil water contact (OWC) is very clear; whereas the quite obscure OWC image at the higher frequency (35Hz) section. This indicates that not only the spectral response variation of different fluid is particularly obvious in far-angle stack gathers, but the corresponding energy differences are more remarkable at lower frequencies.

Methodology

- Spectral Difference Attribute
  - Decompose seismic angle gathers into instantaneous spectral components.
  - Take into consideration of the spectral contrasts on both near- and far- angle gathers.
  - Remove the background and highlight the anomalies.

$$S_{fluid}\left(t,f\right)=\left[N_{(f)}^{2}\left(x,t\right)-c\cdot F_{(f)}^{2}\left(x,t\right)\right]\cdot F_{(f)}^{4}\left(x,t\right)$$

Here $S_{fluid}(f)$ —— **spectral difference attribute to highlight fluid image;**

$N_{(f)}(\cdot)$, $F_{(f)}(\cdot)$ —— **instantaneous spectral components decomposed from near and far angle gathers at the frequency,** f.

c ——adjustable factor for reduce non-fluid-related background whereas amplify fluid-related anomalies.

Presenter's notes: We generate several types of models to simulation, and then present an equation to highlight fluid images via instantaneous spectral differences on multi-angle stacking gathers, which can be expressed as

Methodology

- Define the characteristic frequency, f_{opt}
  - At which the most sensitive spectral component related to the anomalies.
  - At which the peak magnitude occur of the attribute.
  - independent of the factor c.

$$S_{fluid}\left(t_R, f_{opt}\right) = max\left[S_{fluid}\left(t_R, f\right)\right]$$

Here t_R —— time location of the target gas reservoirs;

Presenter's notes: We must determine a most fluid-sensitive frequency in calculating equation (1). Suppose we are given this frequency , which is obtained based on the frequency corresponding to the peak magnitude of equation (1) at the location of the target gas reservoirs. i.e., the amplitude of equation (1) reaches maximum at frequency , which can be denoted by:

we have found that is independent of the factor c. Therefore, is firstly determined previous to choosing factor c.

Methodology

- Define the adjustable factor, c
  - Constrained by production of wells
  - Enlarges the spectral difference between the fluid-bearing reservoirs and non-fluid-bearing strata or background.
  - Further suppresses the non-fluid-related reflecting energy

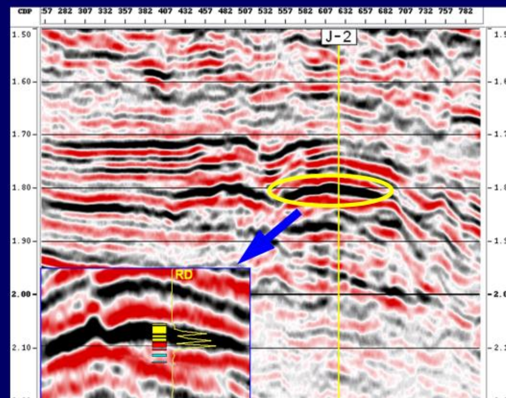
$$Y(c) = \frac{\max_{c}\left[S_{fluid}\left(t_R, f_{opt}\right)\right]}{\max_{c}\left[S_{fluid}\left(t_D, f_{opt}\right)\right]}$$

Here t_D —— time location of non-reservoirs;

Presenter's notes: We determine the factor c based on a criterion that enlarges the spectral response difference between the fluid-filled reservoirs and non-fluid-filled beds or background. Thus factor c further suppresses the non-fluid-related background. We can obtain factor c by optimizing an objective function given by

Field Data Example

- Seismic data volume from JX field near the Bohai Sea, China. There is a distribution of turbidite in the target interval.

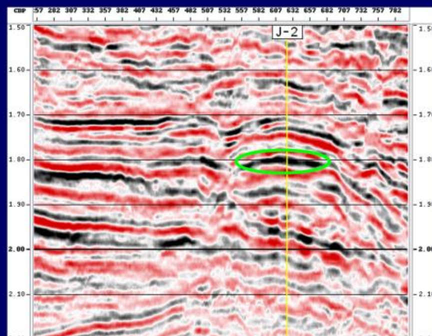


Full angle stack gather

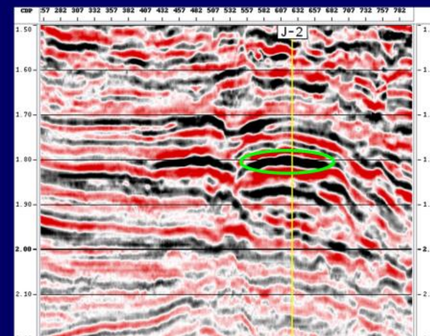
Data courtesy of China National Offshore Oil Corp. (CNOOC)

Field Data Example

- **Partial stack angle gathers.**



(a) near-angle (5-15º)

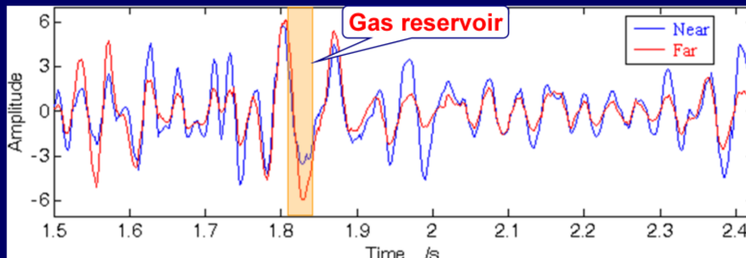


(b) far-angle (25-35º)

Data courtesy of China National Offshore Oil Corp. (CNOOC)

Field Data Example

- Relatively higher amplitude on the trace extracted from far-angle gather.



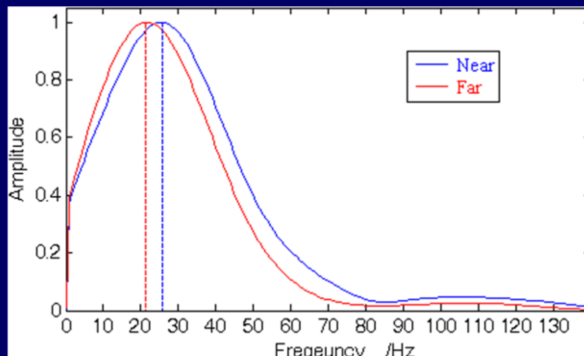
Seismic traces at the well J-2

Presenter's notes: SWT does not decimate the coefficient sequences, and the new approximation and detail components after each level of decomposition have the same length as the original sequence. Instead of downsampling the components in the orthogonal WT algorithm, the SWT modifies the filters at each level by padding them out with zeroes. Suppose we are given a sequence of length N, which is convolved with the high-pass filter H and with the low-pass filter L, respectively, and we do not decimate the results of the convolution

Cvetkovic and Marfurt (2007), inspired by Yu et al. (2002), found that applying filters based on the 2D SWT to seismic time slices could suppress both acquisition footprints and random noise.

Field Data Example

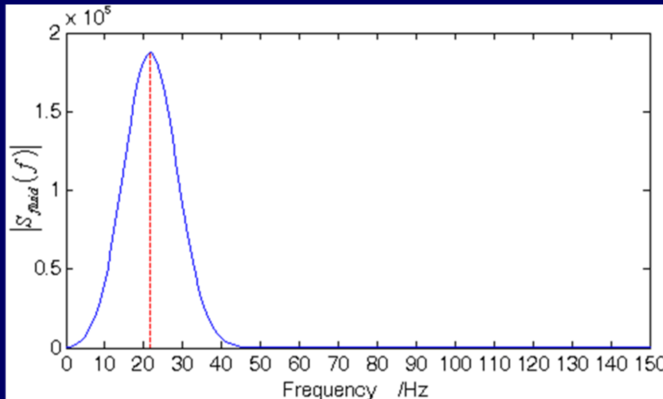
- Dominant frequency of the far-angle trace shifting to lower frequency



Instantaneous spectra of the seismic traces at the gas reservoir

Field Data Example

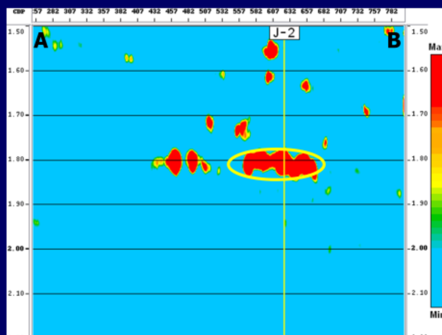
- Determine the optimal frequency



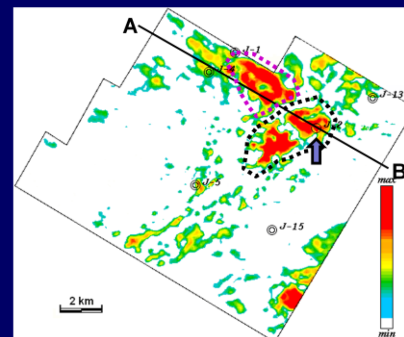
Spectral difference measurements of the seismic traces at the reservoir

Field Data Example

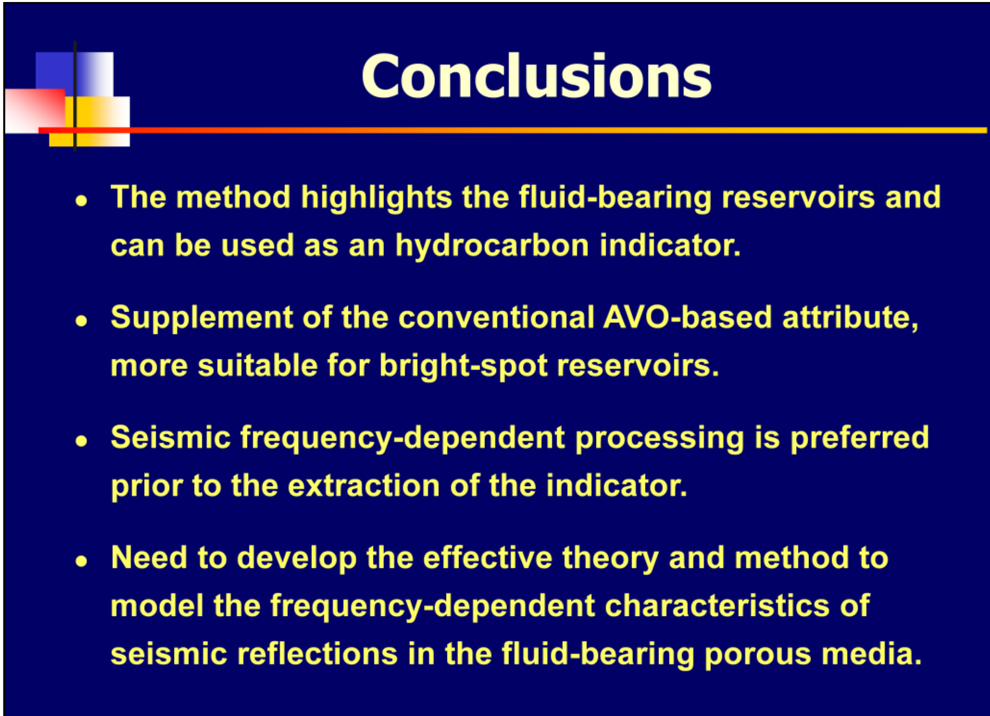
- All clearly show strong bright spots of gas reservoirs whereas non-fluid-related strata show weaker background.



Spectral difference attribute section



Spectral difference attribute slice extracted in the target interval



Presenter's notes: The methodology and workflow presented in this paper provide an effective and relatively fast measurement for fluid detection. This methodology can be used as an effective supplement tool for hydrocarbon identification. In real application, the reliability and robustness of this methodology would be highly improved by the constraints of multi-well production. In addition, just as Goloshubin (2006) advocated, if the frequency-dependent processing or target-oriented processing can be achieved, it would also remarkably improve the certainty in frequency-dependent methodologies for fluid detection.

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