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Wavelet Transform Based Spectral Decomposition in Gas Hydrates Exploration

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Summary

Gas hydrates are crystalline form of methane and water, which are found in shallow sediments along the outer continental margin and permafrost region of the world. These are considered as one of feasible potential energy resource for the next generation. Gas hydrates have been delineated in Krishna-Godavari (KG), Mahanadi and Andaman regions by identifying anomalous seismic reflectors, known as the bottom simulating reflectors or BSRs on seismic sections. The presence of gas hydrates has later been established by drilling and coring of Indian National Gas Hydrates Program. From petroleum system point of view, we expect free gas below the BSR or gas hydrate-bearing sediments that act as cap rock.

BSRs are not always observed or are too weak to be seen on seismic data in some areas, even gas hydrates are present. So, we need to study some attributes that can help delineating underlying free gas. We have utilized spectral decomposition in time-frequency domain based on continuous wavelet transform [TFCWT], and present a case study to demonstrate the potential application for identifying free gas in KG basin. The results reveal compartmentalized zones of free gas below the BSR instead of continuous zone that appears on amplitude section.

Keywords: *Continuous wavelet transforms, Spectral Decomposition, Gas Hydrate, and Free Gas*

Introduction

Gas hydrates are naturally occurring ice-like crystalline substance consisting of mostly (99%) methane, and are found along the outer continental margins and permafromst regions. They are formed at high pressure and low temperature, when methane concentration exceeds the solubility limit. The bathymetry, seafloor temperature, total organic carbon (TOC) content, sedimentary thickness, rate of sedimentation, geothermal gradient indicate good prospects of gas hydrates along the Indian margin (Sain and Gupta, 2008; 2012). In fact, gas hydrates have been delineated by identifying BSRs on seismic sections based on their characteristic features in the Krishna-Godavari (KG), Mahanadi and Andaman offshore (Sain and Gupta, 2008; 2012; Sain et al., 2012).

Since gas hydrates are crystalline solid, their presence stiffens the sediments. Hence, gas hydrate-bearing sediments act as cap rock, and trap free gas underneath. The BSR often occurs at the base of gas hydrate stability field, and thus, it represents a physical boundary between gas hydrate-bearing sediments above and free gas bearing sediments below. Absence of BSR does not imply absence of gas hydrate / free gas system. So, we need to study some attributes like attenuation, reflection strength, instantaneous frequency, velocity anomaly etc that can indicate presence of gas hydrate and/or free gas (Ojha and Sain, 2009; Sain et al., 2009; Sain and Singh, 2011). Computation of another attribute utilizing spectral decomposition in time frequency domain based on continuous wavelet transform will further support the gas reservoir.

The drilling and coring by Expedition-01 under the Indian National Gas Hydrates Program (NGHP) have validated the presence of gas hydrates as predicted from seismic data in the KG, Mahanadi and Andaman offshore. The target depths of 15 wells drilled in KG basin under expedition 01

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of NGHP were up to BSR only. The analysis of seismic data in KG basin shows potential reservoirs of free gas much below the BSR. Here we have carried out a case study on the seismic data around site 10 in KG basin to find the usefulness of time-frequency analysis with the continuous wavelet transform (TFCWT) for identifying gas reservoir below the BSR. The method can enhance frequency shadow effect in the data. Motivation of using this approach below the gas hydrate reservoirs has come from its application to conventional reservoirs where spectral decomposition technique has been applied to illuminate gas reservoirs (Sinha et. al., 2005; Castagna et al., 2003)

Methodology

Presence of free gas in the sediments reduces the seismic velocity than that of the sediments without free gas, resulting in the drop of acoustic impedance. The gas reservoir beneath BSRs would behave like conventional gas reservoirs and can be characterized by their seismic attributes (Ojha and Sain, 2009; Sain and Singh, 2011). Frequency images from spectral decomposition techniques have been shown to illuminate known gas reservoirs in many basins around the world, and thus can be used to detect gas, if present below BSR.

Spectral decomposition method based on continuous wavelet transform (CWT) (in particular TFWCT with Morlet wavelet) is shown to have high frequency resolution at low frequency and high time resolution at higher frequencies (Sinha et al., 2005). Therefore, frequency images from TFCWT have been used in enhancing frequency anomalies in gas reservoirs as well as in mapping thin geological features. We have further extended this method to compute Teager-Kaiser (T-K) energy from TFCWT. de Matos et al. (2009) have shown the use of T-K energy from wavelet transform in hydrocarbon detection. We compare both frequency images as T-K energy images in this work.

Seismic Data and Spectral Decomposition

Several 2D seismic lines were acquired to evaluate the resource potential of gas hydrates around site 10 in the KG basin, where massive gas hydrates have been recovered by NGHP drilling and coring (Collett et al., 2008). For this work we have chosen a seismic line that is nearest to site 10. The seismic data was acquired with 12.5 m of shot and receiver spacing.

The data was time migrated as shown in Figure 1. In this section BSR is not easily interpretable. However, the arrow indicates BSR taking into account other source of information and gas hydrates stability thickness map (Sain et al., 2011) that often coincides with the BSR depth. Strong amplitude zones below BSR are indicative of gas zones. These zones have also been associated with low velocities (Sain, 2011).

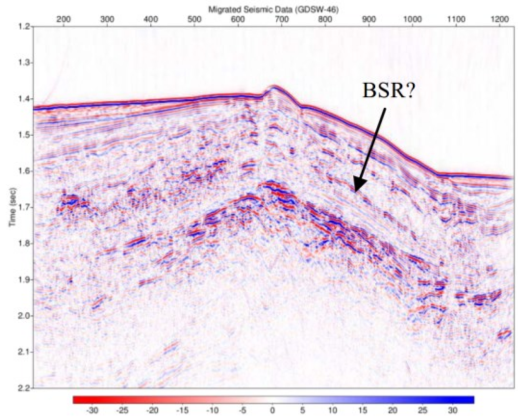

Figure 1: Migrated 2D seismic section in KG basin. Zones above the BSR have gas hydrate accumulations that has been confirmed by NGHP drilling.

Velocity analyses of seismic data provide low resolution compared to frequency and amplitude base seismic data analysis. Here we apply the TFCWT on the poststack data shown in Figure 1. The TFCWT is a variant of CWT where instead of time-scale map, we generate time-frequency map (Sinha et al., 2005). Transform based spectral decomposition has advantage over optimization based techniques because complete information is retained in the transformed space. Furthermore, Morlet wavelet has high frequency resolution and therefore, it is suitable for our purpose of resolving frequencies in low frequency range in which we expect frequency shadow effect due to gas.

The time frequency map is produced for each trace and then a single frequency image is generated by collecting single frequency data for corresponding traces. Figure 2 is a frequency image at 35 Hz. The corresponding image for 50Hz data is shown in Figure 3. We can clearly see that there is a high energy low frequency anomaly (Figure 2) which diminishes at higher frequency (Figure 3) anomaly, indicating the presence of gas reservoir.

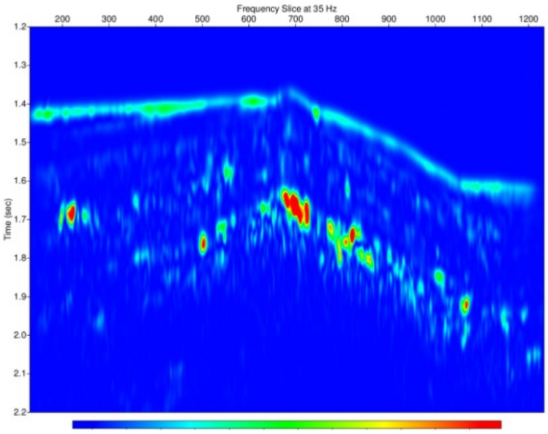

Figure 2: 35 Hz frequency image from TFCWT processing. Illuminated zones below BSR are likely to have free gas accumulations.

We have further computed Teager-Kaiser (T-K) energy from TFCWT map. This energy density function of a time signal takes into account both frequency and amplitude. Our computation of T-K energy is different from that of de Matos et al (2009) because the computation in this case is on frequency and not on scale. 35 Hz and 50 Hz T-K energy sections are shown in Figures 4 and 5, respectively. It is noticed that the sharpness in anomaly has increased in case of T-K energy section.

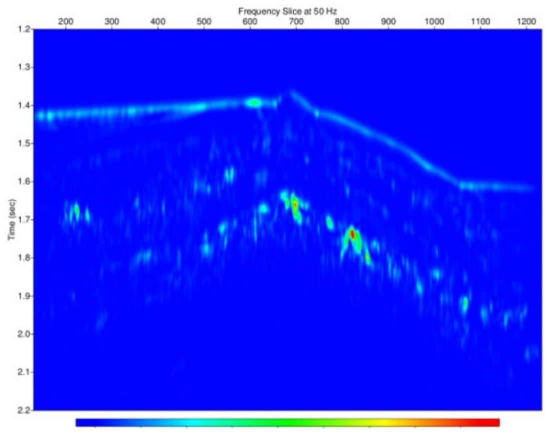

Figure 3: 50 Hz frequency image from TFCWT processing. Energy below BSR diminishes. Compare this section with 35 Hz section in Figure 2.

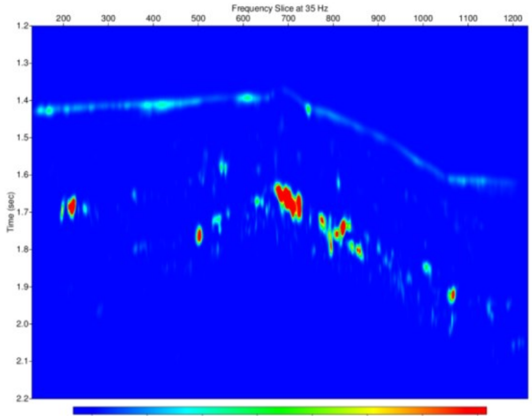

Figure 4: Teager-Kaiser energy section at 35 Hz frequency from TFCWT processing. Compare this section with 35Hz frequency image in Figure 2.

Summary

The velocity and amplitude analyses from seismic data had suggested the presence of free gas reservoirs below the BSR in KG basin. We have carried out the time-frequency analysis with continuous wavelet transform that clearly shows the evidence of free gas reservoirs below the BSR. This has bolstered earlier interpretation and demonstrates that this attribute can be used for delineating free gas reservoir below the BSR. From this study we can conclude that apparent structure with free gas that looks continuous on amplitude section is much more compartmentalized, as one can see from the discontinuous anomalies.

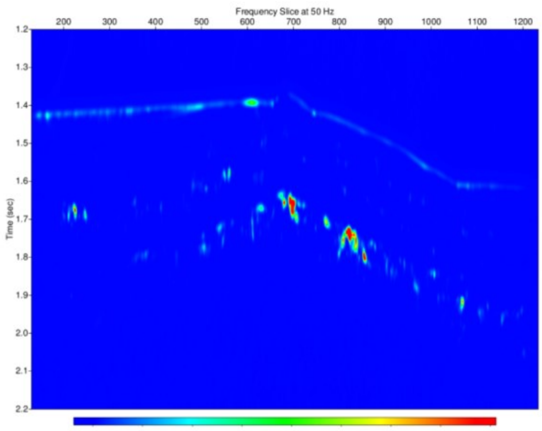

Figure 5: Teager-Kaiser energy section at 50 Hz frequency from TFCWT processing.

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