Seismic attribute identification through waveform analysis of gas hydrates

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INTRODUCTION

What are gas hydrates?

Gas Hydrates are naturally occurring ice like compounds formed by the combination of gas (mainly methane) and water under conditions of moderate-low temperatures and high pressure.

Where are gas hydrates found?

- Deep shelf where high pressure is supported by the thickness of the water column where temperature remains low – at depths of several hundred feet below the ocean floor.
- Onshore, below the permafrost, where hydrostatic pressures are high.

Why gas hydrates?

- Trap methane, providing energy resource potential.
- Altering oceanic and atmospheric conditions can cause trapped methane to escape into the environment.
- Break down of methane impose pressures on surrounding geology and lead to slope failure.

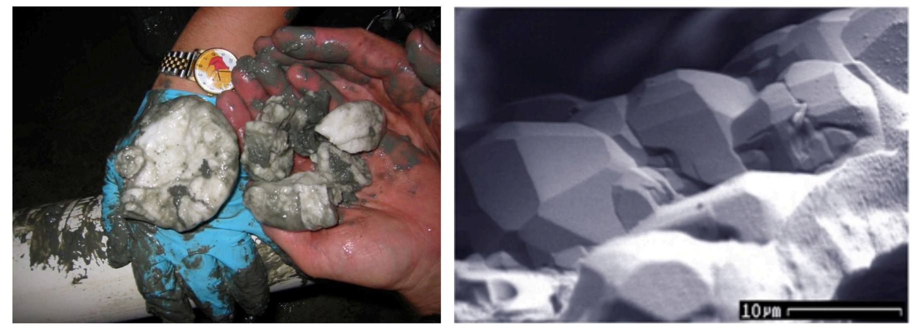


Figure 1: Chunks of white gas hydrates covered with sediments, retrieved from beneath the seafloor of the Gulf of Mexico, and scanning electron microscope image (Image from the USGS)

Map of study location

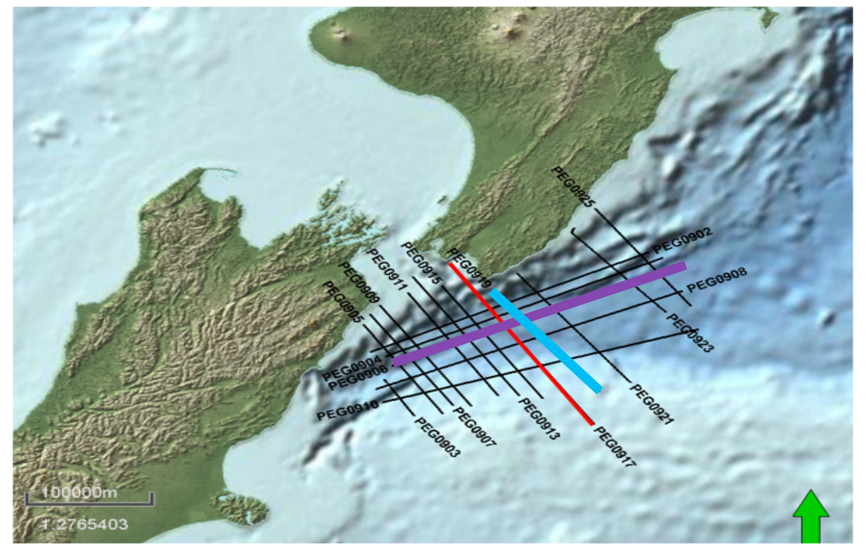


Figure 2: Location of study. Eastern coast on the southern end of North Island, New Zealand. The study is focused on the 2D profile of inline 17 trending southeast to northwest.

THE PROBLEM – BSR's

- The top of the Gas hydrate stability zone runs parallel to the seafloor and so to does the seismic response, known as the Bottom Simulating Reflector (BSR).
- Their presence is discerned in the seismic due to the sudden decrease in Acoustic Impedance. The reflection exists at that boundary between the upper rigid gas hydrate filled sediments and lower free gas.
- Unfortunately, not all gas hydrate accumulations result in a clearly imaged BSR.
- We aim to determine the presence of gas hydrates in strong BSR's vs weak BSR's
- Detection of the attenuation effects of gas hydrates by applying methods of statistical analyses on waveforms.

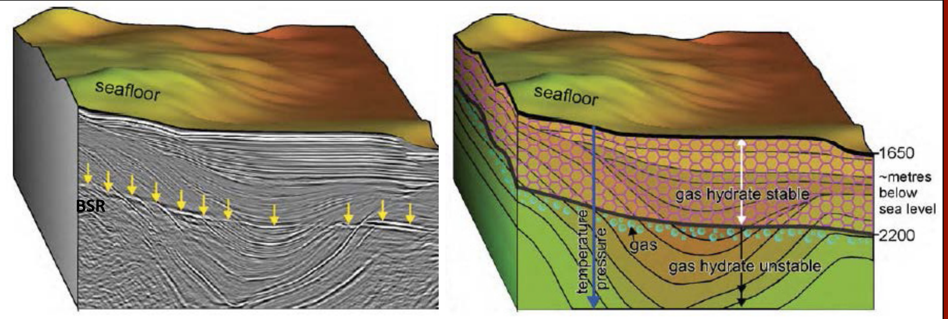


Figure 3: Block diagrams indicating the location of the BSR in seismic (a), and (b) the gas hydrate stability zone overlying free unstable gas. (Retrieved from Griffin et al. 2015).

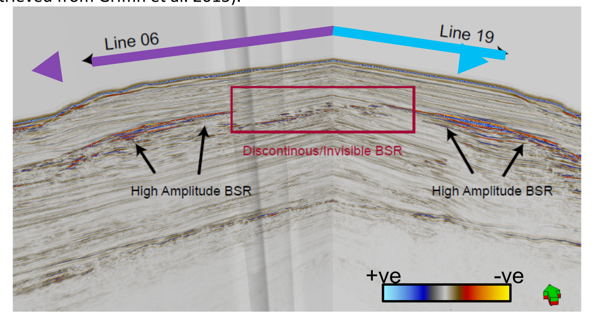


Figure 4: Overlapped 2D seismic lines (line #6 and #19) indicating a discontinuous/weak BSR response between two high aamplitude BSR's.

FREQUENCY ATTENUATION

- Filling of pore spaces by gas hydrate reduces the porosity that is available to the pore fluid, therefore increasing the elastic moduli (Dvorking et al., 2014).
- Additionally its presence within sediments increases the bulk and shear modulus, therefore increasing P and S wave velocities (Riedel et al., 2010).
- It is expected that there is a decrease in P-wave velocities in the presence of free gas – hence the physical prosperities of these sediments which contain gas hydrate result in attenuation effects on the frequencies of the seismic data.
- Ambiguity in interpretation of geophysical data needs other techniques to define the sediment properties that highlight gas hydrate presence or its lack thereof.

- Study of seismic attenuation attributes with applications on conventional and unconventional reservoirs.
- Proposed a suite a seismic attenuation attributes to observe quantitative spectral changes between shallower reference and a deeper target horizon to detect anomalous spectral energy loss. Two of these being Kurtosis and Skewness

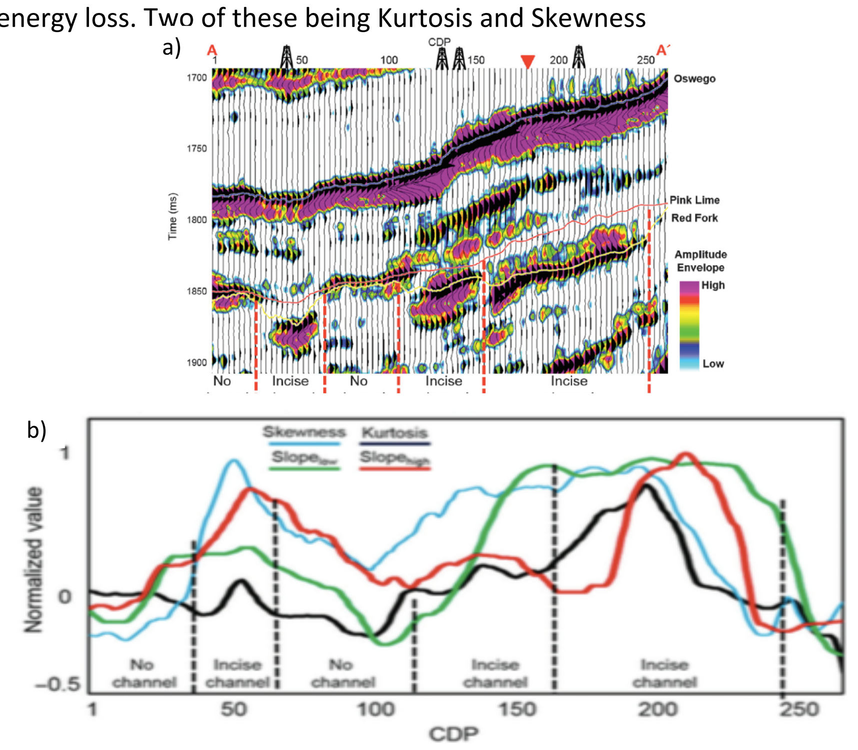


Figure 5 : Seismic attenuation attributes between the pink and yellow horizons in (a) are computed. (b) Shows the results of ttenuation estimation using spectral slopes of low and high frequencies, skewness, and kurtosis. (Retrieved from Li, F., Marfurt, K. et al ,2016)

METHODS AND WORKFLOW

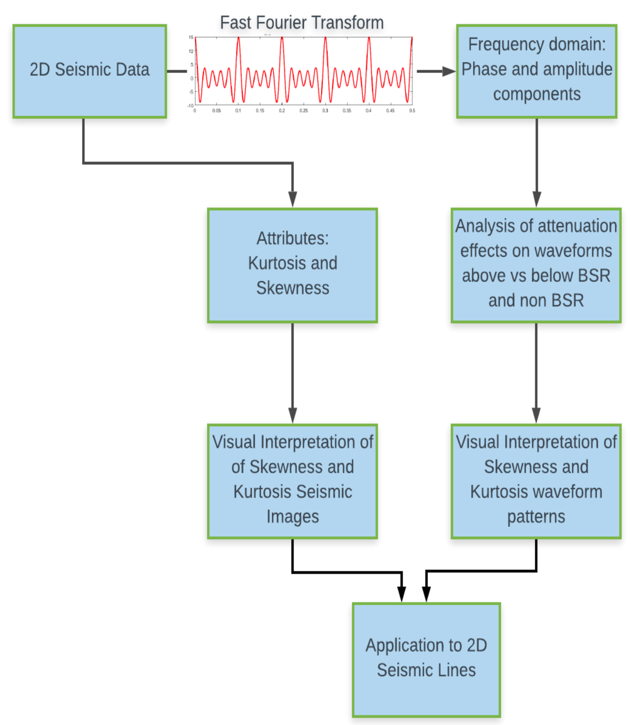


Figure 6: Layout of the Project's Initial Workflow for applying Skewness and Kurtosis methods

Phase 1

- Investigation of the 2D Pegasus Basin Line #17 and identifying the BSR's in the seismic amplitude data.
- Statistical methods of kurtosis and skewness applied as attributes for interpretation and for analysis on the attenuation of seismic signals.
- A 40 millisecond sliding window is applied along each trace to provide the following preliminary results for each statistical method.
- Fast Fourier Transform used to obtain the phase and amplitude components of frequency from the seismic time domain.
- Frequency Components will be used understand the response of the waveforms with application of skewness and kurtosis.

Phase 2

- Applying other spectral decomposition algorithms, using the AASPI software.
- CMP (complex matching pursuit) and CWT (continuous wavelet transform) spectral techniques used to decompose the seismic data into its phase and amplitude components.
- The spectral results are observed at varying frequencies, from 10Hz to 100Hz in increments of 15.
- Spectral results of single traces observed.

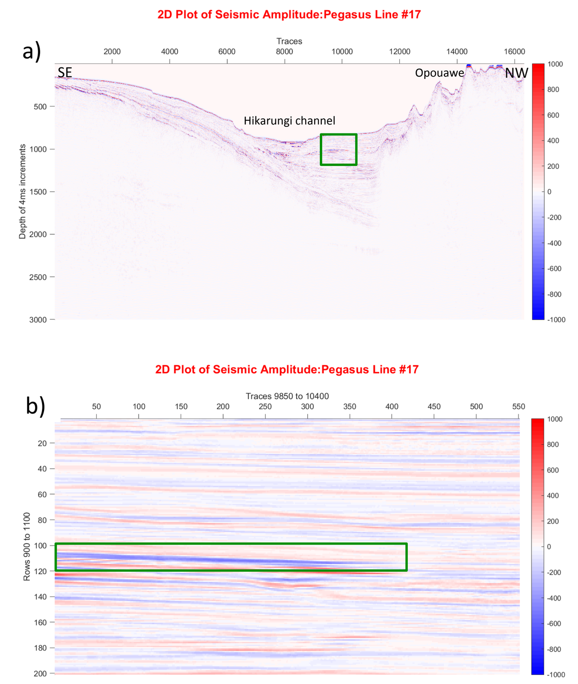


Figure 7: a) represents the 2D seismic information of Line #17 (highlighted as red in figure 2) and b) provides a closer look at the the strong BSR which describes the base of the Gas Hydrates Stability Zone.

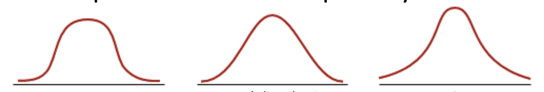
WHAT ARE SKEWNESS AND KURTOSIS?

Kurtosis

- Is the normalized form of the fourth central moment μ_4 (a moment of a univariate probability density function taken about the mean μ_1.
- It measures the degree of tailed-ness in the variable distribution

$$k = \frac{E(x-\mu)^4}{\sigma^4}$$

in which μ is the mean of x, σ is the standard deviation of x and E represents the expected vale of the quantity



Platykurtic distribution Thinner tails Kurtosis < 3 Flat top	Normal distribution Mesokurtic distribution Kurtosis = 3	Leptokurtic distribution Fatter tails Kurtosis > 3 Peaked top

Skewness

- Is the normalized form of the third central moment μ_3.
- It measures the degree of symmetry or deviation from the mean of the dataset.

$$s = \frac{E(x-\mu)^3}{\sigma^3}$$

in which μ is the mean of x, σ is the standard deviation of x and E represents the expected vale of the quantity

Negatively Skewed distributic or Skewed to the left Skewness <0	Normal distribution Symmetrical Skewness = 0	Positively Skewed distribution or Skewed to the right Skewness > 0

- In order determine the whether there are accumulations of Hydrates in areas of weak BSR, we are applying both statistical methods of measurements (Skewness and Kurtosis) as attributes for interpretation and to determine the relationship of their values to the phase and/or frequency components of waveforms in areas with clear BSR's and without clear BSR's.
- We expect to gain further insight on the distribution of the population of the sample (i.e the seismic trace), to determine how it deviates from a normal Gaussian distribution.

PRELIMINARY FINDINGS

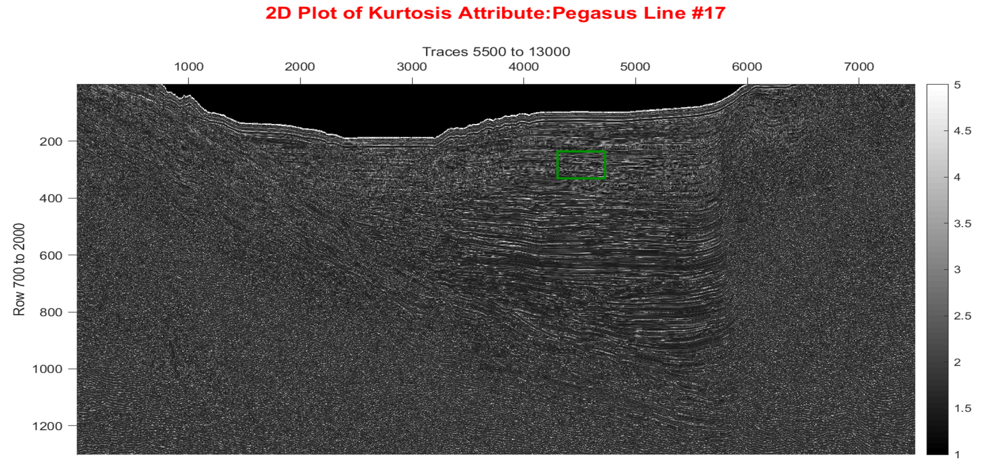


Figure 8: 2D Plot of Kurtosis Attribute identifying the location of the observed BSR.

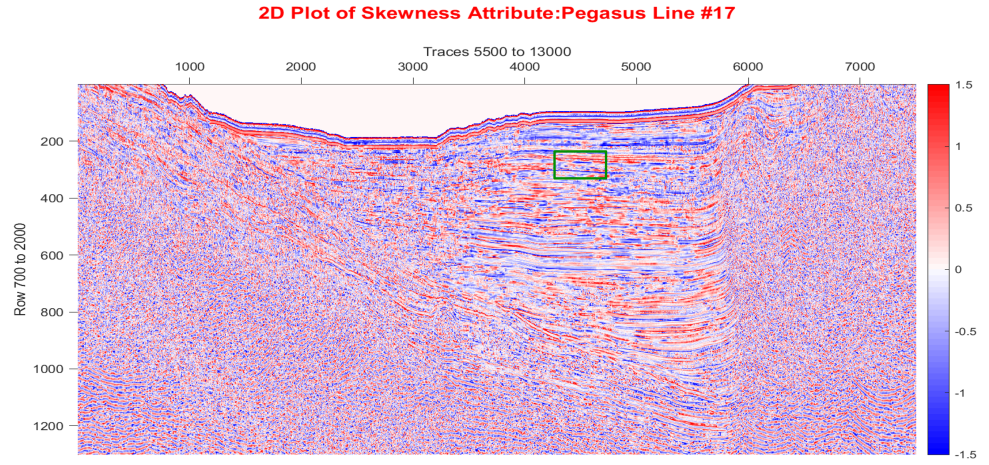


Figure 10: 2D Plot of skewness attribute identifying the location of the observed BSR.

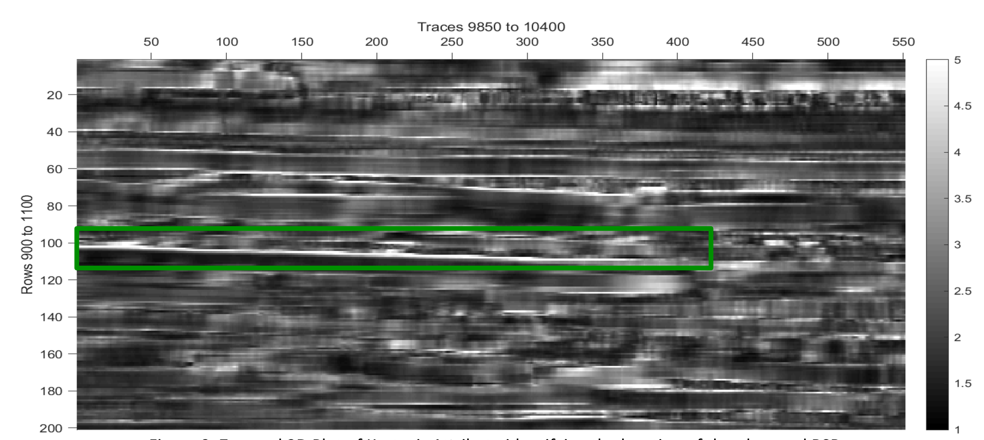


Figure 9: Zoomed 2D Plot of Kurtosis Attribute identifying the location of the observed BSR.

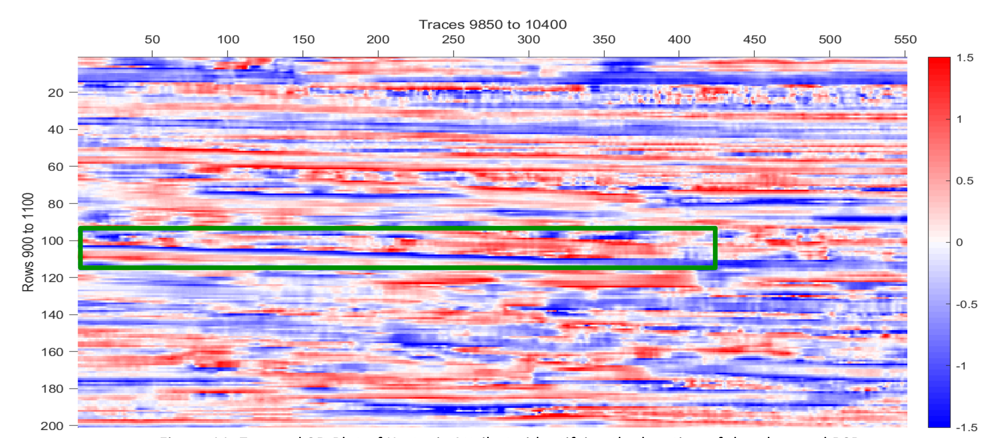


Figure 11: Zoomed 2D Plot of Kurtosis Attribute identifying the location of the observed BSR.

ADDITIONAL PRELIMINARY SPECTRAL DECOMPOSITION RESULTS (AASPI SOFTWARE APPLICATION)

Magnitude components of CMP and CWT along seismic traces

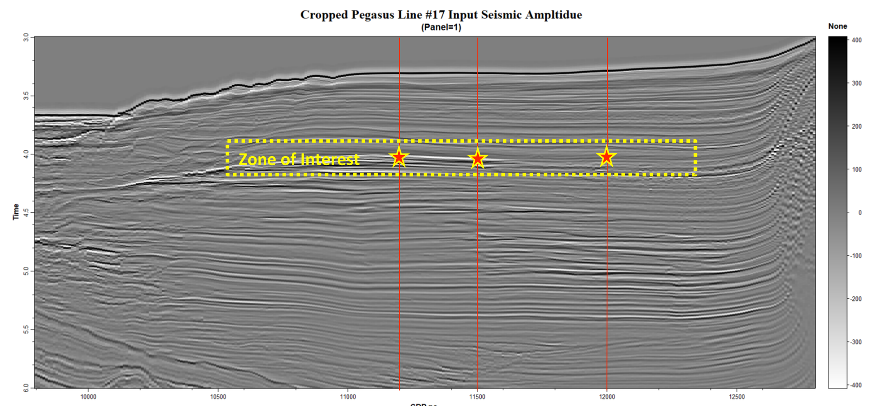


Figure 12: Seismic profile indicating the traces that are observed in the spectral decomposed results. The Zone of interest highlights the high negative BSR reflector and the weaker/non BSR region toward the right.

- CWT magnitude is the square root of the energy correlating with the trace.
- In CMP, a model parameter (single wavelet at a fixed time representing the energy of the trace) is least-squares fit to the data.

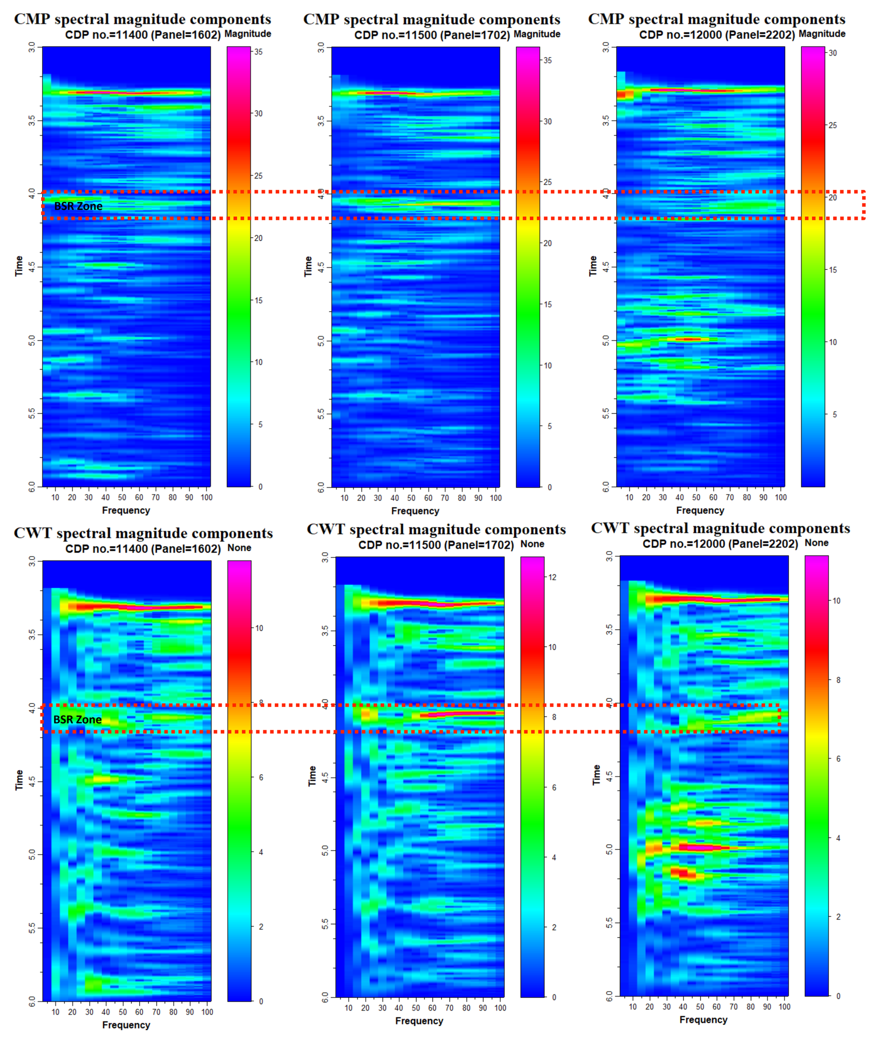


Figure 13: Results of the spectral magnitude components for both CMP and CWT. CDP no. 11400 and 11500 lies within the strong BSR reflector whereas CDP no.s 12000 lies in the zone outside of the strong seismic BSR.

CMP and CWT at varying frequencies

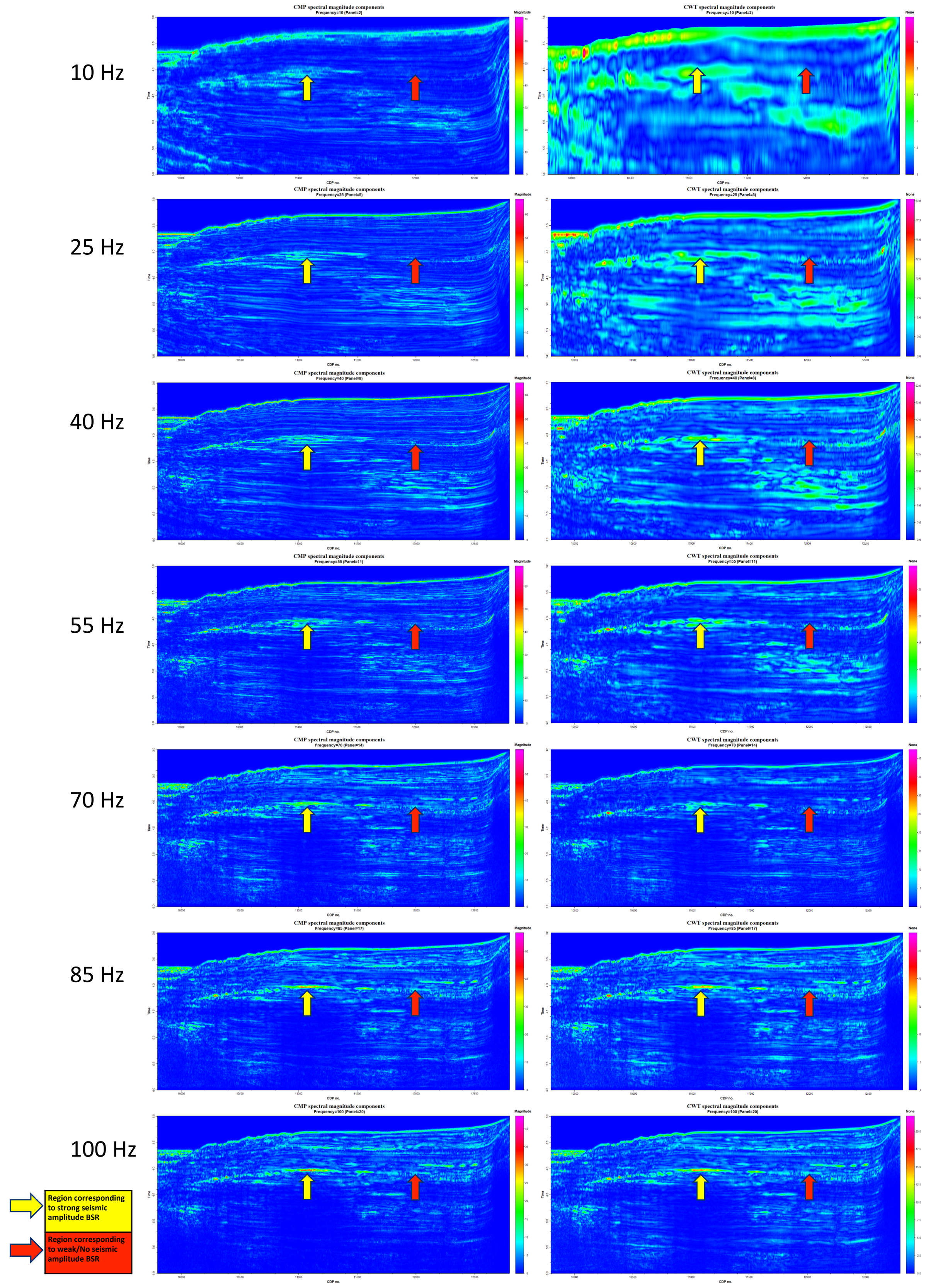


Figure 14: Varying cmp and cwt frequency from 10Hz to 100 Hz in increments of 15.

DISCUSSION

- From the kurtosis attribute, we observe a rightward trend of low positive kurtosis responses across the lithology in the region below the BSR, highlighted by the green box in Figure 9 .
- The low kurtosis region corresponds to the associated free trapped gas that accumulates below the BSR.
- This region follows an abrupt high positive kurtosis response that correlates to the well defined BSR observed in the seismic amplitude profile (Figure 7b).
- As we extend to the northwest, the positive response together with the low kurtosis values become less defined in the zone of the unclear BSR.
- The skewness attribute, has a similar trend to kurtosis, such that the BSR is defined by a maximum negative skewness overlaying a region of maximum positive skewness values.
- The trend is uniform as we extend further northwest, but terminates in a more chaotic region of located undefined BSR.
- Both cwt and cmp frequency results (Figure 14) clearly image the BSR in both the regions of its strong amplitude response and where its seismic amplitude is discontinuous. This is easily distinguishable in the higher frequencies, likely associated with the abrupt change in attenuation, likely from hydrate presence.

FUTURE WORK

- Intensive work in investigating the effects of the length of the sliding window and more effective the use of the Fast Fourier Transform are currently being analyzed.
- For more precise understanding of the attenuation effects, the phase and amplitude components of the frequency domain will be pivotal in observing how frequency correlates to the environments containing hydrates in the GHSZ and free gas both below and above the BSR, respectively.
- Skewness and kurtosis should allow us to identify the corresponding effects of both the phase and amplitude components of the waveform. Further understanding of how this will be accurately applied is needed.
- Application of the AASPI program q_estimation to perform seismic attenuation attributes of kurtosis and skewness on 2D seismic dataset. (See possible potential workflow results that can be calculated on 3D data, in the figure below)
- Tests on the software algorithm will be conducted to work on 2D data.
- Application of the q_estimation algorithm on the 2D seismic can determine how effective kurtosis and skewness calculations have when applying the cwt and cmp spectral decomposition methods.
- Importing two horizon surfaces in the software and generating spectral stratal slices of the volume's magnitude and phase components from their frequency, q_estimation will calculate the following seismic attenuations attributes. In this case kurtosis and skewness.

AKNOWLEDGEMENTS

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