Q estimation in hydrate bearing sediments at Joetsu Knoll - Japan Sea

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Abstract

In this work a single channel seismic line surveyed in Joetsu Basin in Japan Sea, a known site of gas hydrate (GH) occurrence, was used to calibrate zones of high and low absorption related to hydrates. Adopting the premises of normal ray (seismic) incidence and flat ocean bottom, with the support of viscoelastic seismic modeling, it was possible to differ zones of high and low absorption in a qualitative fashion. In such analysis high absorption zones coincides with the occurrence of BSR (bottom simulating reflectors) pointing out to the fact that attenuation is stronger in hydrate zones than in neighboring domains without GH. Quantitative analysis using the same premises and averaging the power spectra through windowed fourier transform, reveals a Q_{avg} ranging from 50 to 60 for hydrate bearing sediments and Q_{avg} higher than 100 for the domain without hydrate.

Introduction

The Earth as a whole, rocks and sediments, works as a high cut filter. Q factor is a parameter that describes the absorption characteristics of a media. Usually, this parameter is more easily estimated through direct wave as in VSP survey. Estimation of Q in seismic reflection data is more complex because, usually, the wave trajectory is not known until data is processed. Constrains and premises should be used to allow the estimation of Q.

Nevertheless, anomalous or out of trend Q behavior in reflection data could be suitable to estimate other properties: helping to delineate the extension of lithologies and; for mapping the limits of hydrocarbon bearing rocks. Calibrations, although, are needed and Q estimation should be studied in known areas in order to support interpretation of frontier or unknown areas.

Joetsu Knoll is a known gas hydrate site in Joetsu Basin in Japan Sea (Figure 1). Multidisciplinary works have been conducted (eg. Freire et al., 2008) and direct - sampling (piston core) - and indirect evidence - BSR occurrence - of gas hydrate have been reported. In this paper we aim to determine the anomalous Q behavior of hydrate zone qualitatively and quantitatively, assuming some premises.

Seismic data characteristics

The seismic line subjected to the study was acquired in 2007 by the of R/V Natsushima vessel, of JAMSTEC, in Japan Sea following NE direction according to the Joetsu Knoll structure.

The acquisition device SCS (Single Channel Seismic) is composed of one source, an airgun, towed 30m far from the vessel and a small streamer with 48 hydrofones with minimum offset of 136,5m and receiver spacing of 1m. This streamer constitutes just one channel - one seismic trace.

The vessel velocity during acquisition was 3.1 knots with shot interval of 5s (one shot at each 8,3m) and a recording length of 4.0s, with 1 ms sampling interval. The dominant frequency of the pre-processed data dominant frequency is **125** hz.

Hydrate Q behavior

Methane hydrate is a mixture of methane and water that is frozen into a crystalline structure forming a cage-like lattice which traps high concentrations of methane molecules. Hydrate solid state turns rock or sediment stiffer than the same one containing only free gas which lead us to think they have higher Q. However the facts are persistent, says Dvorkin and Uden (2004), which cite examples of large attenuation in sediments with gas hydrates at different geographical locations [Outer Blake Ridge (US coast), Malik (Canada), Nankai Trough (offshore Japan)], at different depositional environments and at different frequency ranges.

Therefore, despite the solid domain involving soft sediments, the GH bearing sediments have low Q.

Spectral decomposition

Usually, higher energies tend to locate at low frequencies bandwidth, and the energy becomes smaller as frequency increases. This behavior is due to the fact that the earth acts as a high-cut filter for seismic waves. With a simple Fourier Transform it is not possible to map spectrum variation with time or depth. It is needed methods that allow mapping spectral variation with recording time, such as wavelet transform, s-transform and windowed Fourier Transform. In this work we use windowed Fourier Transform due both to it's easy implementation and to the high frequency content of the data which avoids the window size limitation of this method. The window is defined as a Gaussian function.

The equation that describes windowed FT is:

$$U(t,f)=\int a(t).g(t-\tau).e^{2\pi.f.t}dt \quad ,(1)$$

Where trace a(t) is the trace, g(t-τ) the moving gaussian window and U(t,f) is a matrix showing power spectrum in a time (t) vs. frequency (f) plane.

Synthetic example

A viscoelastic modeling method based in Carcione (1993) and Robertsson et al. (1994) was used to build synthetic 2D seismic data embodying Q characteristic of rocks. The used model is a layer cake composed of 6 layers. The third layer (green in figure 2a) has a Q parameter for P wave (Qp) of 16 and the remaining layers a Qp of 100. The seismic section (figure 2b) was obtained by shooting all the sources together located at the top of the model equally spaced, creating a plane wave front. Receivers are located in source locations also in the top of the model.

Spectral decomposition through gaussian windowed fourier transform was performed on the central trace of the synthetic seismic section. Figure 2c displays the power spectrum along time in order to show the maximum frequency (brown area) at each time. A dashed red line is traced from top to bottom to highlight the trend of Qp=100. After crossing the third layer there is a shift, explained by the lower Qp of this layer.

The observed results in this synthetic example are used to support the premises applied in real seismic absorption analysis.

Premises and constraint

It was already mentioned that the single channel device is composed of 48 (1x1 m) receivers delivering just one trace response. Considering the center of this array as the receiver *locus*, the offset in each shot is 160,5 m. For a water depth of 1000 m (usually it is larger than this), the incidence angle, in a flat ocean bottom, is equal to 85,4 degrees. With the inherent imprecision of the data this incidence angle is considered vertical in our analysis. The second premise is to consider a flat ocean bottom.

With those premises we are assuming that source and receiver are in the same position and ray trajectory is vertical with normal incidence.

Spectral decomposition for a single channel seismic dataset

It was already mentioned the seismic line was chosen due to known occurrence of hydrates: aBSR is easily mapped in it about 0.2 s under the sea bottom surface. This interface works as the contact between layer 3 and 4 in synthetic model. Traces were selected at intervals of 100 (traces) from trace 100 to 2900. Each trace, a(t), was subjected to the process described by equation 1 and the gaussian function, g(t-τ), has a window of 0,05 s

The upper part of figure 3 (3a) shows the power spectrum panels obtained with gaussian windowed fourier transform of each transformed trace. They are sorted in the same order as the seismic section below (figure 3b). All traces show power spectrum decreases with depth, but not in the same way.

A qualitative analysis indicates greater absorption along the traces that cut the BSR denoted by the shorter extension of power spectrum with time. Otherwise, the domain without BSR, areas where we interpret there are no GH, there are longer extension of power spectra.

This qualitative observation supports previous works of low Q characteristic of hydrate bearing sediments. However, how could we quantify it?

The technique of spectral ratio used to estimate Q from power spectrum at different positions is commonly used, usually delivering good results mainly for VSP data, but also for reflection data, under some constraints. In this work this last technique was tried with the raw and migrated data (Stolt migration), however the results were not conclusive.

Alternatively we perform an average of the windowed power spectrum of each trace obtained with spectral decomposition around a frequency f_m:

$$U^*(t,n,f_m) = \frac{\int_{f_0}^{fn} U(t,n,f)df}{f_n - f_0} \qquad ,(2)$$

where U* is the average spectra of each trace and n is the channel or trace number; $f_m=(f_o+f_n)/2$; f_0 and f_n are respectively lower and upper chosen frequency; U(t,n,f) is calculated with equation 1 for each trace n.

In function U* it was picked the maximum amplitude of each trace, in a position inside the interval where hydrates could appear. From the picked peak, after suitable normalization, for each trace, it was performed an exponential regression and the fitting coefficient was used to calculate an average Q. Table 1 shows the results for some traces with a frequency f_m= 200 hz.

Clearly Q_{avg} is ranging from 50 and 60 in hydrate zone and it is higher than 100 in zones without hydrate. These values have comparable Q for rocks and sediments reported in the literature (Winker & Nur, 1979). Traces 400 and 2200 represent transition from hydrate and non-hydrate zone.

trace	Exponent	Q
200	5.3	118
400	7.0	90
600	11.1	57
800	12.8	49
1000	11.6	54
1200	10.6	59
1400	9.5	66
1600	10.8	58
1800	11.3	56
2000	10.6	60
2200	7.7	82
2400	5.2	120

Table 1: Q_{avg} for each trace and the corresponding computed exponent obtained with curve fitting

Conclusions

In this work spectral decomposition was performed in order to, initially, qualitatively evaluate attenuation for a known hydrate bearing sediment. The power spectra, under the premises of normal incidence ray and flat interfaces reveal that the hydrate zones impose more absorption than the neighboring domains without it.

An experimental test was conducted in order to estimate an average Q around a single frequency. Despite not being exactly an interval Q, it is representative for the absorption behavior of stratigraphic interval under analysis and the values are comparable with observed Q in rocks and sediments.

Further studies will be conducted in the remaining area of Japan sea in order to calibrate the presented technique in other seismic lines acquired by SCS.

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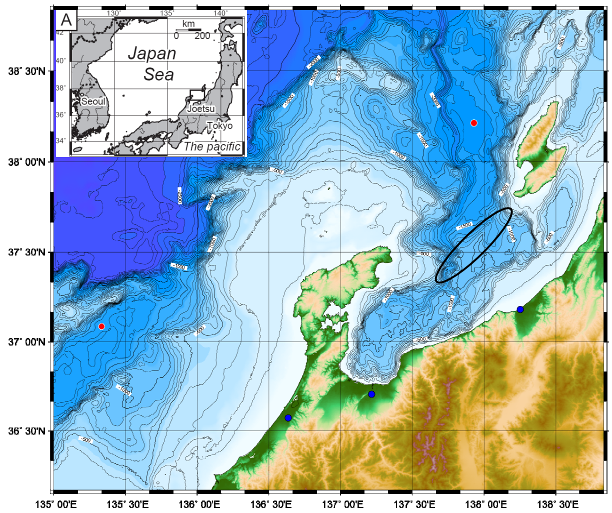
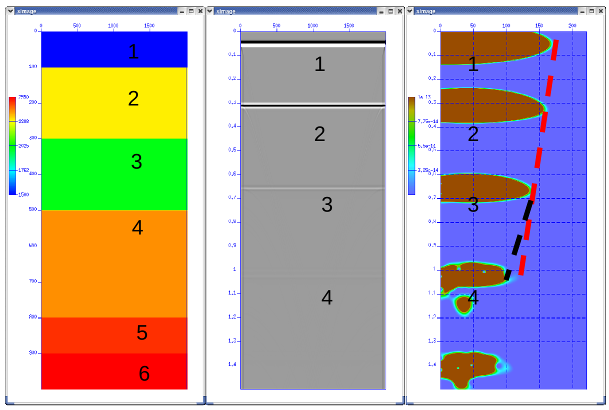
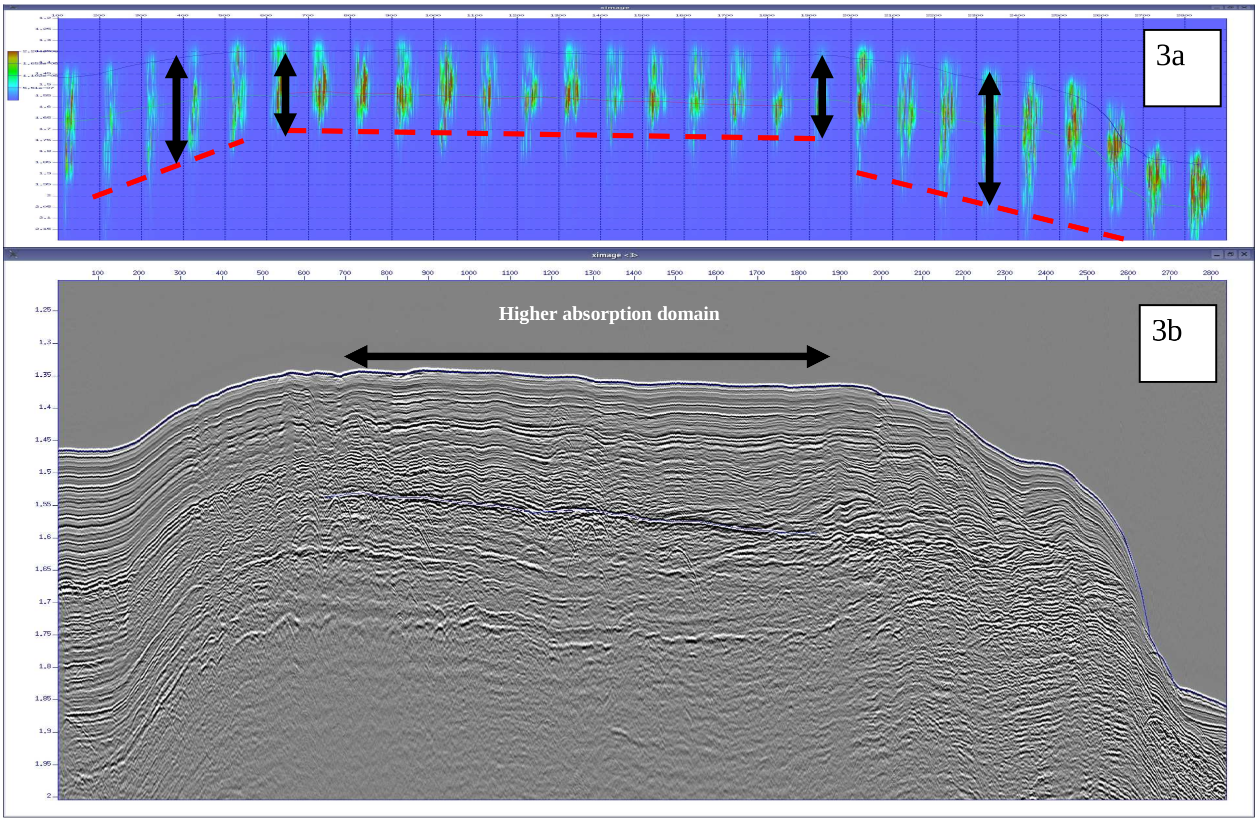


Figure 1: Area of study. Joetsu Knoll is marked by an ellipse.



2a 2b 2c

Figure 2: Velocity model with 6 layers (2a) in depth with layer 3 (green) containing a Qp=16 and all other layers have Qp=100; (2b) Seismic section corresponding to model 2a in time and; (2c) Matrix of Windowed Fourier transform performed in central trace of seismic section 2b. In 2c dashed red line shows the trend of high Qp of layers 1 and 2 and the black dashed line highlights the shift caused by low Qp in layer 3.



Figures 3 – (3a)Spectral decomposition of every 100 traces between traces 100 to 2900 in Joetsu Knoll. The extension of the black arrows is proportional to the Q factor. (3b) Seismic section SCS along Joetsu Knoll. BSR is mapped about 0.2 s under sea bottom.