AVO Analysis to Gas Hydrates BSR in the Continental Shelf of the Canadian Beaufort Sea

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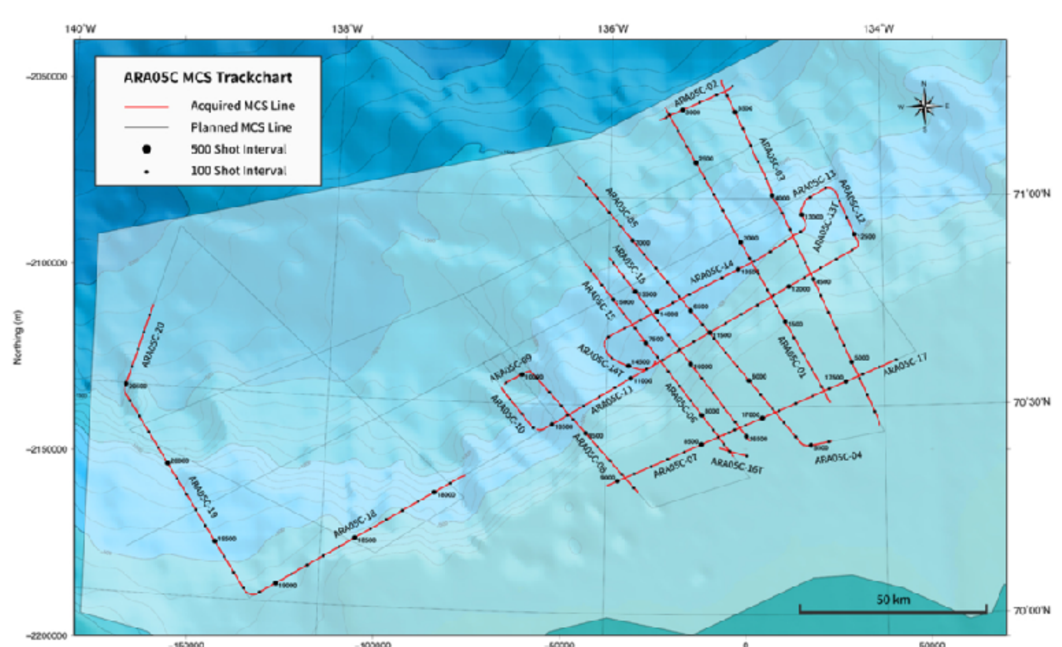
Introduction

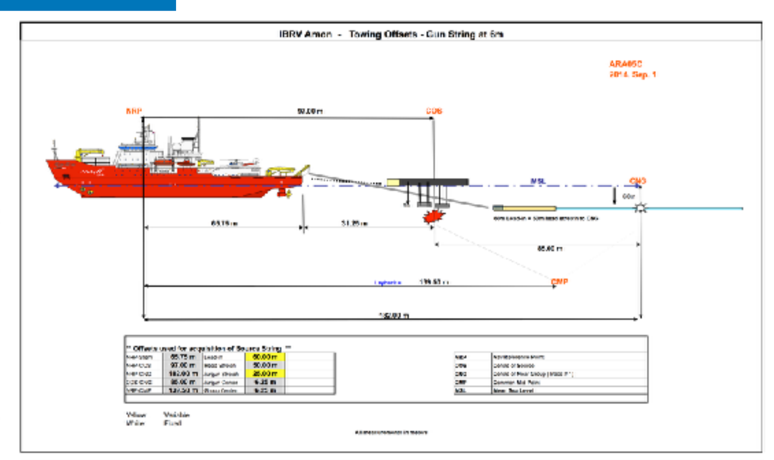
Gas hydrates are ice-crystalline solid counting gas molecules entrapped within rigid cage of water molecule. Gas hydrates can be existed in the permafrost area on the polar region or marine environments under low temperature (<15°) and high pressure condition (>5MPa) known as the gas hydrates stability zone (GHSZ).

Expedition ARA05C (2014. 08. 26 ~ 2014. 09.19) was carried out to understand degrading permafrost, gas hydrates, fluid flow, and seismic stratigraphy of the continental shelf of the Canadian Beaufort sea. During the expedition, multi-channel seismic survey was conducted along 998 L-km with 19,962 shots. A gun array with 8 air guns and 120 channel streamer (1.5 km length) was used. In this continental shelf, the bottom simulating reflector (BSR) was reported recently (Riedel et al., 2017).

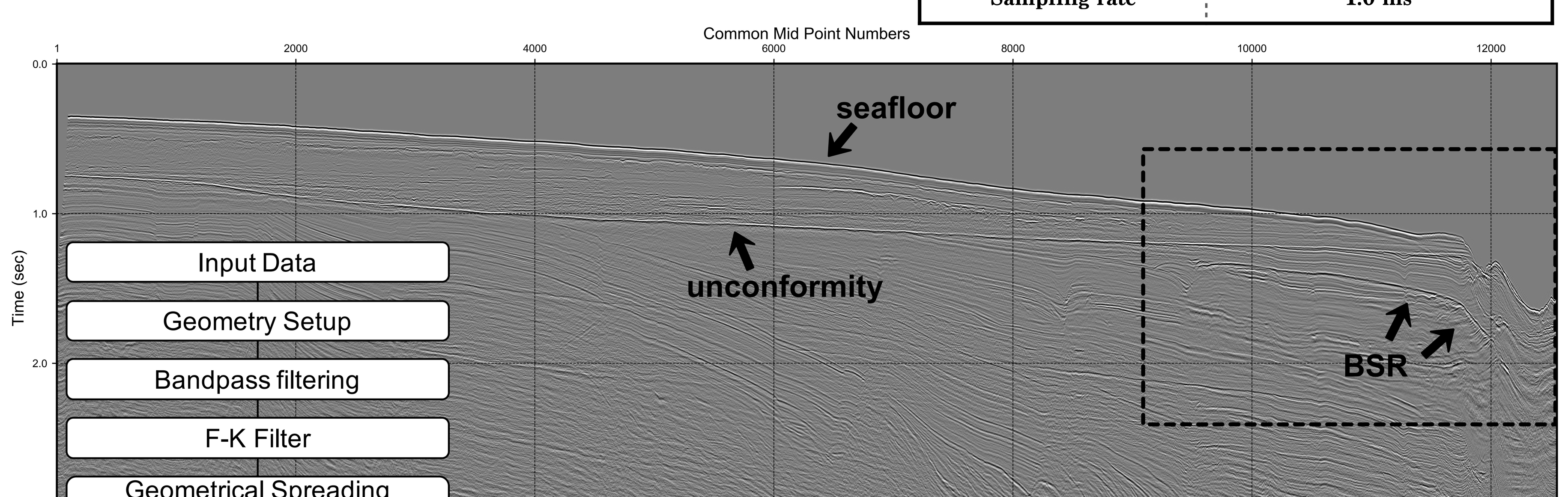
In this study, we applied Amplitude versus Offset analysis (AVO analysis) to gas hydrates BSR in continental shelf, in order to identify the distribution of gas hydrates and free gas and AVO characteristics of BSR. For the study, data processing was conducted in Line 19 to Line 20. To get acoustic impedance, migrated section was applied model-based inversion. Finally, AVO attribute analysis and AVO gradient analysis were conducted. As a result, we verify the distribution and characteristic of gas-saturated sediments below BSR.

Seismic survey & Data processing





Shot interval	50.0 m
No. channel	120 ch with 12.5 m interval
Source / streamer depth	6.0 m / 6.0 m
Recording length	10.0 sec
Sampling rate	1.0 ms

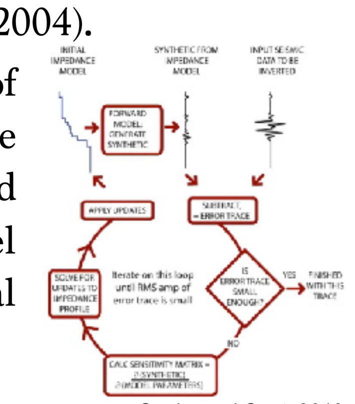


Multi-channel seismic data acquired from the continental shelf of the Canadian Beaufort sea (ARA05C-19 to ARA05C-20) was processed to migration section. Seismic processing was applied to standard processing steps using VISTA 2D/3D software. Final seismic migration section shows the geophysical structure in study area. BSR was observed between CMP 9000 - 12500 in the outer continental shelf (Riedel et al., 2017).

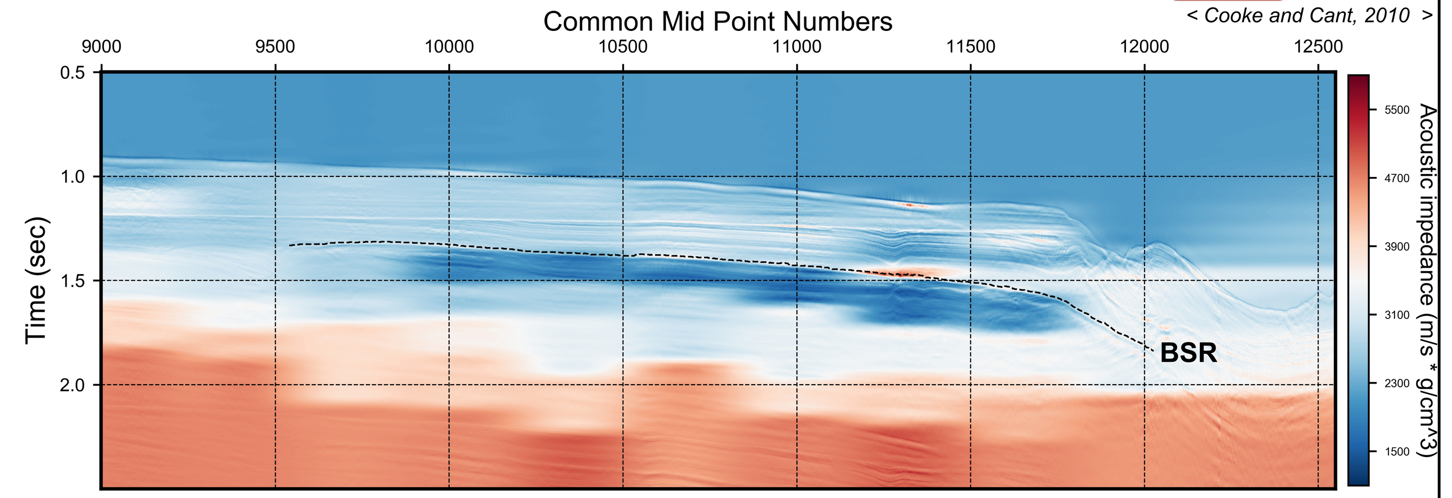
Acoustic impedance inversion

In this study, we applied the model-based acoustic impedance inversion to post-stack time migration data to identify the distribution of free gas area. In case of sediments containing free gas, low acoustic impedance and Poisson's ratio should be appeared (Hato et al, 2004; Lu and McMechan, 2004).

The model-based inversion was iteratively procedure of minimizing the misfit function between synthetic trace (convolution of reflectivity layer model and wavelet) and observed data. Initial low-frequency p-wave velocity model was obtained from seismic velocity analysis, and initial density model was calculated to Gardner's relationship.



< Cooke and Cant, 2010 >



Inverted model shows the low impedance area between CMP 9800 - 11800, thickness are 0.2 ms below BSR. It is assumes that gas-saturated sediments is distributed in the low impedance area.

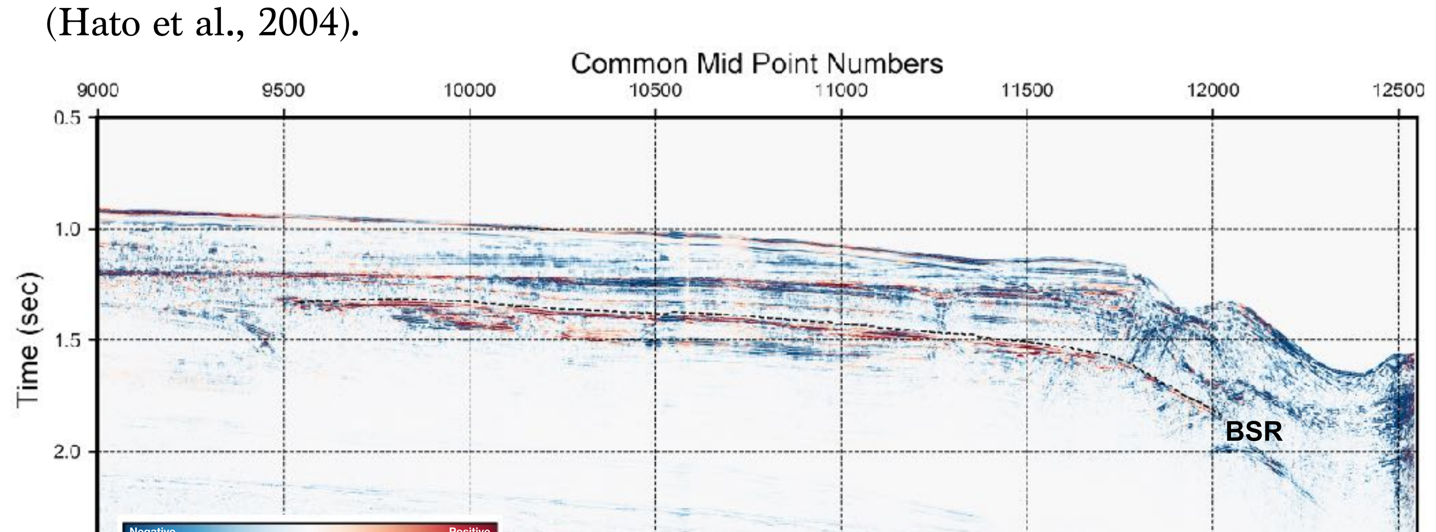
AVO attribute analysis

In order to analyze the AVO characteristic in BSR, we applied the AVO attribute analysis. In the Aki-Richard equations, P-term means a zero-offset change in acoustic impedance, and G-term is related to the Poisson's ratio or Vp/Vs ratio.

< Aki-Richard equation >

$$R(\theta) = \underbrace{\frac{1}{2}\left[\frac{\Delta v_p}{v_p} + \frac{\Delta \rho}{\rho}\right]}_{\textbf{P (intercept)}} + \underbrace{\frac{1}{2}\left[\frac{\Delta v_s}{v_p} - 2\left(\frac{v_s}{v_p}\right)\right]\left[2\frac{\Delta v_s}{v_s} + \frac{\Delta \rho}{\rho}\right] sin^2(\theta)}_{\textbf{G (gradient)}}$$

In this study, we applied to the production of P and G (P*G attribute). P*G attribute is known to always positive valued when the top of gas-saturated layer (Hato et al., 2004).

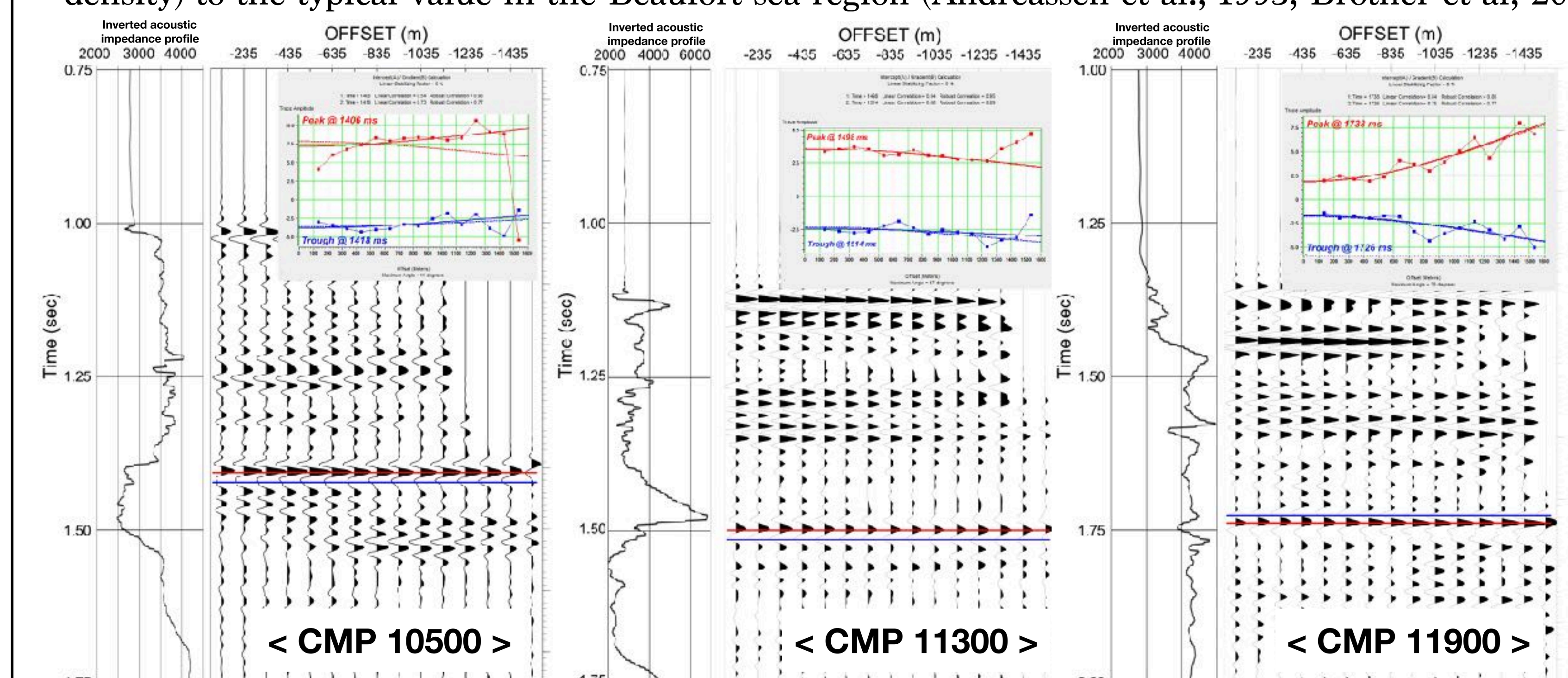


We display the calculated P*G attribute section. As a result, positive value(red color) is appeared along the BSR. This event is thought to be a top of the gas-saturated sediment. The upper boundary of low impedance area is consistence with positive value, considered the top of gas-saturated layer, according BSR.

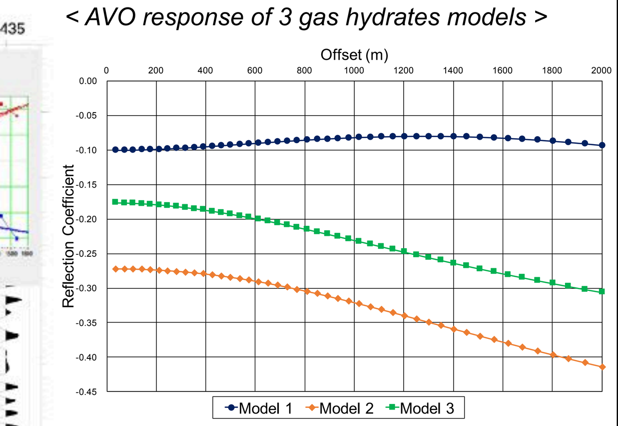
AVO analysis to gas hydrates BSR

For identification of gas hydrates BSR, we applied the AVO gradient analysis at three positions (CMP 10500, CMP 11300 and CMP 11900). AVO analysis is need to careful seismic processing for the preservation of the relative amplitude so as to recognize amplitude variation with offsets (Yilmaz, 2001). In this study, we applied standard and simple processing sequence to avoid distortion of amplitudes by some processing algorithms. A bandpass filter in range of 3-5-100-120 Hz was applied, and geometric spreading correction using exponential gain control and offset scaling were conducted. AVO gradient analysis was carried out to next steps; 1) sorting the NMO gather to CMP domain, 2) picking the peak and trough amplitude along the constant BSR times, 3) plotting the picked amplitude variation with offsets.

To compare with the AVO gradient analysis results, we calculated the AVO response from 3 gas hydrates models using Zoeppritz equations. **Model 1 is a hydrates only model, Model 2 is a hydrate-gas model, and Model 3 is a gas only models.** Due to the lack of the gas hydrates and rock properties in study area, we selected the rock properties (p-wave velocity, s-wave velocity, density) to the typical value in the Beaufort sea region (Andreassen et al., 1995; Brother et al, 2005).



< AVO response of 3 gas hydrates models >



		Vp (m/s)	Vs (m/s)	Rho (g/cm³)
Model 1	above BSR	2500	928	1.86
	below BSR	2000	475	1.90
Model 2	above BSR	2500	928	1.86
	below BSR	1400	850	1.90
Model 3	above BSR	2000	475	1.90
	below BSR	1400	850	1.90

- CMP 10500 is located in the continental shelf area. Inversion results shows the increment of amplitude with increasing offsets. To compare the AVO trends of gas hydrates models, it is similar to model 2 (hydrate-gas model). The acoustic impedance inversion results show the low impedance trends below BSR.
- In CMP 11300, gradient analysis result show the decreasing amplitude trends up to 1200 m offsets. This results is similar to model 1 (hydrates only model). Considering the acoustic impedance inversion results, it is seems that sediments of high concentration gas hydrates are distributed.
- Gradient analysis results at CMP 11900, located in outer continental shelf, shows the AVO trends in model 3 (gas only model).

Summary

- We applied AVO analysis to gas hydrates BSR in the continental shelf of the Canadian Beaufort Sea
- The results of acoustic impedance inversion shows the low impedance area, caused by sediments containing free gas, below BSR. This result is consistence with top of gas-saturated sediments from P*G attribute section.
- AVO gradient analysis was conducted at the three locations. At two locations (CMP 10500, CMP 11900), results of gradient analysis was considered to be the gas saturated model (model 2 and model 3). AVO response at CMP 11300 was similar to AVO trends in model 1 (hydrates only model).
- We plan to use the full waveform inversion method in elastic media to obtain the insufficient rock properties (p-wave velocity, s-wave velocity and density) and to compare the AVO analysis results.

Acknowledgements

We express great thanks to members of ARA05C expedition and crews of IBRV ARAON for data acquisition in the Arctic sea. This work was supported by the project entitled "Investigation of submarine resource environment and seabed methane release in the Arctic (KOPRI, PM17050)" was funded by the Ministry of Ocean and Fisheries(MOF), Korea.