A rock physics model for hydrates bearing sediments of near surface

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Summary

Gas hydrates presented as form of segregated bodies have been observed on shallow subsurface sediments. However, most gas hydrate physics models describe that hydrates occur in pore space in deep subsurface sediment. A new model considers gas hydrate as segregated bodies to derive elastic properties of hydrates bearing sediments and gas hydrate saturation. The predicted elastic properties based on the model are coincided with measurements of well logs in site 1327 of Integrated Ocean Drilling Program (IODP). The results show the model can be used to estimate gas hydrate saturation from seismic data of near surface.

Introduction

Gas hydrates are ice-like solid composed of gas molecules enclosed in cages of water molecules. They occur in marine sediments in deep water. The interval in which submarine gas hydrate is stable is mainly controlled by temperature and pressure, but the physical properties of deep marine sediments may also affect its formation and distribution.

Gas hydrates can be detected from seismic data by observations of features such as bottom-simulating reflectors, blanking zone, and amplitude variations of offset. Amount of gas hydrate in marine sediments are determined from seismic data, if the relationship of velocity and gas hydrate concentration is known. Several methods have been applied to predict the relationship. Physical-based effective medium model is considered to be an accurate prediction because internal structure of hydrated sediment is inferred. Ecker et al. (1998) suggested two models of hydrate morphology for deep subsurface sediments. One mode is hydrates cement the grains, the other model is small hydrate particles fill pore space. Dai et al. (2004) showed six models to describe microstructure of gas hydrate for both shallow and deep subsurface sediments. They realized the model of nodules for hydrated bearing sediments often exist in the shallow shaly sediments, but did not develop a method for rock properties of the sediments. In the paper, we work out a rock physics model based on effective medium theories for shallow subsurface sediments.

Gas Hydrate Distribution

Gas hydrates have been recovered from coring program and drilling program in many sites around the world. Some gas hydrates have been observed in pore space of coarser-grained sediments in relative deep section below seafloor; more gas hydrates have been observed as form of segregated bodies, such as lenses, nodules, and pellets, in fine-grained or coarser-grained sediments in relative shallow section below seafloor.

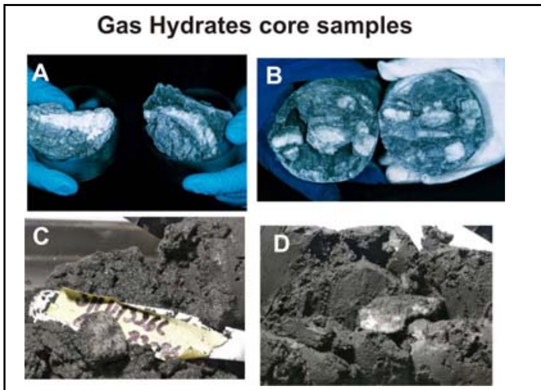

Figure 1: Images of segregated bodies of hydrate samples. A and B are collected in site 1244 of ODP leg 204. The images are from initial reports of the leg (Shipboard Scientific Party, 2002). C and D are collected in site 1326 of IODP leg 311. The images are from preliminary report of the leg (Expedition 311 Scientists, 2005).

Nine sites were drilling and cored in offshore Oregon during Ocean Drilling Program (ODP), Leg 204 in 2002. Gas hydrates samples were found in many sites. Figures 1A and 1B show gas hydrate samples recovered from a depth of about 80 meter below seafloor (mbsf) from site 1244. Infrared thermal scans of cores (IR) indicates lenses or nodules of gas hydrate are present between 40mbsf and 134 mbsf, gas hydrates are clusted at about 50-60 mbsf. These gas hydrates disseminate in silty and sandy turbidities interlaid with fine-grained hemipelagic clay.

Four sites were drilling and cored in the Northern Cascadia margin during IODP leg 311 in 2005. Gas hydrates were detected in the fine-grained sediment and coarse-grained sediment in the leg. The observation shows that gas hydrate mainly occurs with coarse-grained sands and silts. Locally high gas hydrate concentration was found in the leg. In the previous study about gas hydrate occurrence and formation, gas hydrate were expected to have highest concentrations near the base of the gas hydrate stability zone, however, the largest concentration of gas hydrate were observed in shallow section at the top of the gas hydrate occurrence zone in the leg. Figures 1C and 1D are gas hydrate samples found at about 50 mbsf from site 1326.

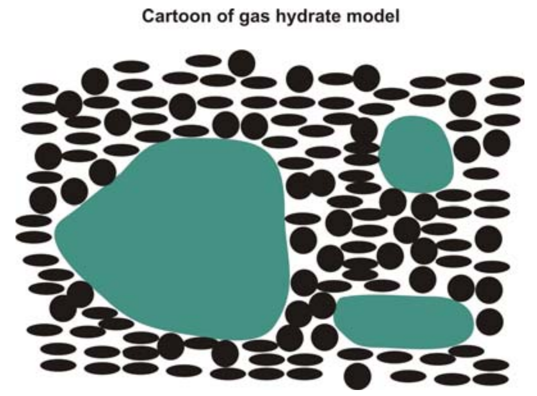

Figure 2: Proposed rock physical model for hydrate bearing sediments. Hydrates are represented in light green. Solid black circles represent sands and solid black ellipses represent clay.

Rock physics model of Gas Hydrate

Xu and White (1995) developed a shaly-sand model for predicting velocities from porosity and clay content. The compliances and densities of sand and clay minerals are first specified. These grains of clay and sand are mixed by clay content to form a dry solid rock. Bulk and shear moduli of the frame are computed using differential effective media theory. Finally, Gassmann's equations are applied to calculate bulk and shear modulus of the fluid-saturated rock.

Following Xu and White (1995), we assume that unconsolidated hydrates bearing sediments can be approximated by hydrate segregated bodies imbedded in matrix composed water, clays and sands. We first compute the effective elastic moduli of dry frame of clay-sand-water mixture using Kuster and Toksőz (1974) equations:

$$K_d - K_m = \frac{1}{3}(K' - Km)\frac{3K_d + 4\mu_m}{3K_m + 4\mu_m}\sum_{l=S,C}\varphi_l T_{iijj}(\alpha_l) \qquad (1)$$

and

$$\mu_d - \mu_m = \frac{(\mu' - \mu_m)}{5}\frac{6\mu_d(K_m + 2\mu_m) + \mu_m(9K_m + 8\mu_m)}{5\mu_m(3K_m + 4\mu_m)} \times \sum_{l=S,C}\varphi_l F(\alpha_l) \qquad (2)$$

Where

$$F(a) = T_{iijj}(\alpha) - \frac{T_{iijj}(\alpha)}{3} \qquad (3)$$

In the Kuster and Toksőz (1974) equations, K_d, K_m, and K' are the bulk moduli of dry frame, the rock matrix, and the pore inclusion material, respectively, and μ_d, μ_m, and μ' are shear moduli of dry frame, the rock matrix, and the pore inclusion material, respectively. φ_s is the porosity associated with sand pores; φ_c is the porosity associated with clay pores. They can be computed from porosity and clay content.

Differential effective medium method is applied to satisfy the Kuster and Toksőz (1974) conditions. After dry rock elastic moduli obtained, Gassmann's equations are used to calculate the fluid saturated bulk and shear modulus of the clay-sand-water mixture.

The hydrate is imaged as being imbedded in the homogeneous medium with same elastic moduli over the clay-sand-water mixture. Hydrate is assumed as playing one phase; clay-sand-water mixture is assumed as playing the other phase. We use Hashin-Shtrikman low bounds to compute elastic moduli of the hydrate-clay-sand-water mixture.

$$K^{HS} = K_1 + \frac{f2}{(K_2 - K_1)^{-1} + f_1(K_1 + \frac{4}{3}\mu_1)^{-1}} \qquad (4)$$

and

$$\mu^{HS} = \mu_1 + \frac{f2}{(\mu_2 - \mu_1)^{-1} + \frac{2f_1(K_1 + 2\mu_1)}{5\mu_1(K_1 + \frac{4}{3}\mu_1)}} \qquad (5)$$

where K_1, μ_1, and f_1 are the bulk moduli, shear moduli, and volume fractions of clay-sand-water mixture, respectively, and K_2, μ_2, and f_2 are the bulk moduli, shear moduli, and volume fractions of hydrate, respectively.

The compressional (P) wave velocity Vp and shear (S) wave velocity Vs are given by

$$V_p = \sqrt{\frac{K^{HS} + \frac{4}{3}\mu^{HS}}{\rho}} \qquad (6)$$

and

$$V_s = \sqrt{\frac{\mu^{HS}}{\rho}} \qquad (7)$$

A rock physics model for hydrates bearing sediments

Where ρ is density of rock.

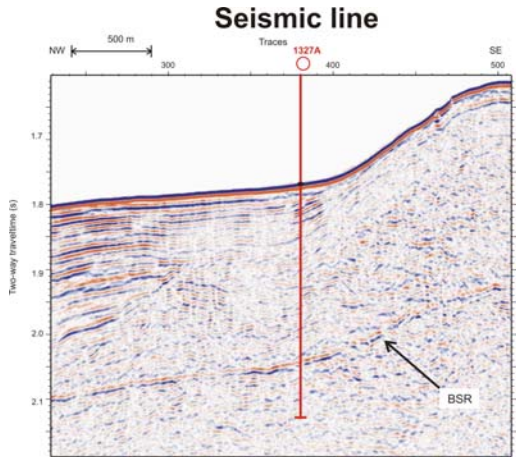

Figure 3: Seismic line cross well site 1327A. Clear BSR presented in the section indicates the base of hydrates stability zone. Seismic image is from preliminary report of the leg (Expedition 311 Scientists, 2005).

Application of Well Data

The goal of IODP leg 311 was to study gas hydrate occurrences. The water depth at site 1327 is about 1300m and the BSR is located at about 250 mbsf (Figure 3). Figure 4 show the porosity, Vp, Vs and water saturation in site 1327. Porosity is neutron porosity, water saturation were estimated from the measured resistivity log by Archie equation. The gas hydrate saturation can be derived from water saturation within the gas hydrate stability zone. Water saturation log shows a thick zone of high concentration gas hydrate.

Component	ρ, g/cm^3	K, MPa	G, MPa
sand	2.65	36	45
Clay	2.58	20.9	6.85
Hydrate	0.91	7.7	3.2

Table1. Elastic constants for components of sediment

We predicted Vp and Vs from porosity and water saturation logs based on the model described above. Physical constants used in the model show in Table1. Clay content is estimated from gamma-ray data of the site. In Figure 5, the red dash lines are estimated velocities from rock physics model. The predicted Vs have a good agreement with measurement of logs. The predicted Vp is under-estimated approximately 5% between 140 mbsf and 230 mbsf.

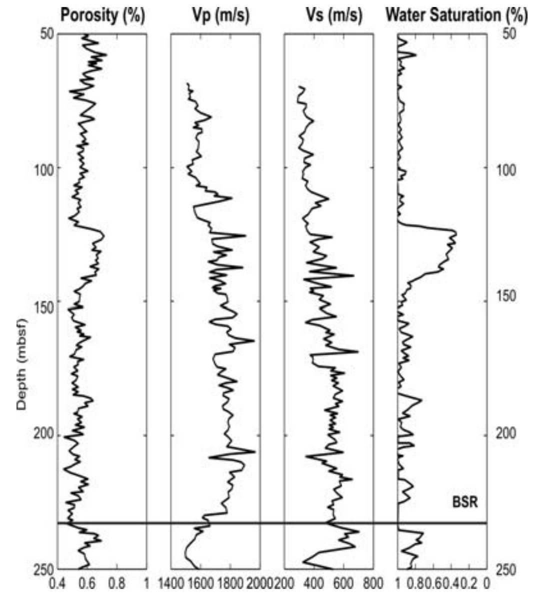

Figure 4: Well logs from site 1327. The solid line marks the depth of the BSR. The data are from IODP logging summaries of leg 311.

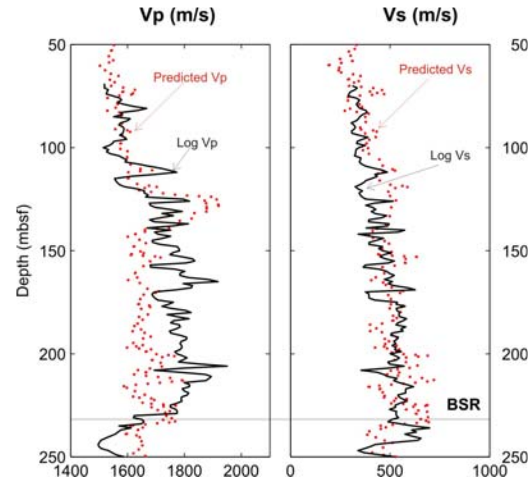

Figure 5: Predicted Vp and Vs from porosity and water saturation. Measurements of logs are also displayed for comparison.

Conclusions

A rock physics model of gas hydrate for shallow subsurface sediments has been derived. The predicted Vp and Vs coincide with results of measurements for well log data of IODP 311. The result indicates that the model presented here can be used to determine gas-hydrate saturation in porous media. Once the relationship between sediment parameters (porosity and water saturation) and seismic parameters (Vp. Vs and density) is built up, elastic inversion can be used for identification of gas hydrate from seismic data.

Acknowledgments

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EDITED REFERENCES

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