RELATIONSHIPS BETWEEN SEISMIC WAVE VELOCITIES, ELECTRIC RESISTIVITIES AND SATURATION RATIO OF METHANE HYDRATE USING CORE SAMPLES IN LABORATORY EXPERIMENTS

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ABSTRACT
It is important to clarify seismic wave velocities and electric resistivities of natural and artificial samples in relation to methane hydrate (MH) saturation ratio. Because those physical properties are useful not only to estimate amount of MH as a resource in situ prospecting but also to discuss the occurrence of natural MH. First, a laboratory experiment system was developed so that P- and S-wave velocities and electric resistivities were measured simultaneously under the condition of in situ pressure and temperature. Natural methane hydrate samples were prepared from the stored cores kept in liquid nitrogen at a low temperature. Artificial methane hydrate bearing sand samples were produced in the tri-axial cell of the experiment device. All core samples were saturated by brine just before the measurements. P- and S-wave velocities of the artificial methane hydrate samples increased with increased saturation of methane hydrate. These measurement results agreed well with those obtained by the previous study on the relationship between MH saturation and seismic wave velocities of the wireline logging around the Eastern Nankai Trough area offshore Japan. In addition, it was found that the relationship was explained by one of the rock physics models for the MH bearing sediments as the matrix-supporting model. Electric resistivities of the same samples as those used to measure the seismic velocities increased with increased MH saturation, though the resistivities run up as the saturation was more than 50 %. These also agreed well with those obtained from the wireline logging.

Keywords: methane hydrate, seismic wave velocity, electric resistivity

INTRODUCTION
In order to provide useful information to estimate the in situ status of methane hydrate, it is required to clarify the physical properties of sand samples containing methane hydrate, and to evaluate the relationship between hydrate saturation and seismic velocity and resistivity. First, we developed a laboratory experiment system that can generate artificial methane hydrate bearing sand samples. The system is also used to measure seismic velocity and electric resistivity under the condition of in situ pressure and temperature. Then, we measured seismic velocity and electric resistivity of both natural and artificial methane hydrate bearing samples by the developed system. Then the experiment results are compared with those obtained by well logging conducted around the Eastern Nankai Trough area offshore Japan. This paper describes the outline of the developed system, laboratory experiment procedures, and the experiment results.

LABORATORY EXPERIMENT SYSTEM
We, first, developed a laboratory measurement system for seismic velocity and electric resistivity of core samples containing methane hydrate under the condition of in situ pressure and temperature. Since the natural core samples that can be used for

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the experiments were not so many, we decided to generate artificial methane hydrate bearing sand samples in the laboratory. To do this, we developed new experiment facilities in Figure 1 and Figure 2 which have the following features:

- Size of core sample: 50 mm (diameter) x 100 mm (height)
- Confining pressure: 25 MPa (max)
- Pore pressure: 20 MPa (max)
- Controllable temperature: 0°C - 20°C

EXPERIMENT PROCEDURES

In this study, we measured physical properties of both natural and artificial samples. The natural methane hydrate samples used for the experiments were cored from the Eastern Nankai Trough area offshore Japan. The natural core samples were kept refrigerated and were saturated by water (brine) just before the measurement. The experimental procedures are shown in Figure 3, and follows.

1) A specimen of dry Toyoura sand is prepared so that the porosity becomes 41%. Since the methane hydrate saturation is roughly determined by the initial water content, the dry sand and predetermined amount of ion-exchanged water are blended well. This wet sample is put into a mold with a membrane inside, and compacted.

2) After the axis and lateral displacement sensors are set on the capped specimen, wiring and piping is done in the cell. Cooled cell fluid (silicon oil) is provided into the set up cell, and pressurize up to 0.5MPa of confining pressure. The temperature of the cell fluid is between -5 and 0 °C at this stage. The temperature of the specimen is adjusted by the cell fluid which is indirectly controlled by refrigerant circulation in the temperature conditioning cell covering the whole tri-axial cell.

3) In order to remove the air in the specimen, methane gas is insufflated from the bottom of the specimen and exhausted at the top of the specimen. The amount of the methane gas was about 4l, and the rate was 0.5l/min. In order to avoid the change in effective stress, which is the difference between confining pressure and pore pressure, during the insufflation procedure, the confining pressure is controlled so as to keep the effective stress 0.5MPa. Then, the methane gas pressure in the pore is increased up to 5MPa, while the effective pressure is kept at 0.5MPa. At the same time, methane gas is injected into the electric back pressure pump connect to the bottom of the specimen, and pressurized up to 5MPa. After the gas pressure in the pore becomes 5MPa, the pore pressure is controlled at 5MPa by the electric back pressure pump, and methane hydrate generation is started. The temperature of the specimen is controlled at 2°C. The status of methane hydrate in the specimen is monitored by the gas injection rate by the electric back pressure pump. When the gas injection rate becomes less than about 0.005cc/min, it is considered as the methane hydrate is generated.

4) Since the methane hydrate containing specimen generated by the above mentioned procedures is saturated with methane gas, we have to remove the gas and saturate the pore with water in order to reproduce in situ conditions of methane hydrate bearing sediments. To do this, brine (3.5% NaCl aqueous solution) is injected into the pore space of the specimen from the bottom of it. After injecting the brine, the specimen is controlled under the following conditions:

- Pore pressure: 10MPa
- Confining pressure: 11MPa
- Effective stress: 1.0MPa
- Specimen temperature: 10°C
5) After the measurements of seismic velocity and electric resistivity, the specimen is depressurized and the contained methane hydrate is dissociated. During the dissociation process, methane gas and water are produced from the specimen. Since the methane gas and water are just produced from methane hydrate as a phase change, we can figure out the methane hydrate saturation accurately by measuring the amount of produced gas and water.

EXPERIMENT RESULTS

Seismic wave velocity
Seismic velocity is determined by travel time of seismic wave between top and bottom of the core sample. Seismic wave is generated by a piezoelectric ceramics transducer at the core pedestal and received by a piezoelectric ceramics element at the core cap. A rectangle wave with 460V is input to the transducer to generate seismic wave. The received signal is transformed to voltage signal by a charge converter and amplified before storing in a wave data logger. To acquire high S/N waveform data, 64-time averaging measurement was conducted. The sampling time of A/D conversion was 0.1μs. To get an accurate travel time between source and receiver, the system delay time is subtracted from the first arrival time picked up from the waveform data. The velocity is calculated from the travel time and the core height.

Figure 4 shows the relationship between seismic wave velocities (Vp, Vs) and MH saturation for 5 natural cores and 18 artificial samples. Vp and Vs increase as methane hydrate saturation increases. The background plots in these figures are the results from the wireline logging at the 4 wells around the Eastern Nankai Trough area offshore Japan (Inamori et al., 2008). These relationships between seismic velocity and methane hydrate saturation suggest that the matrix-support model is reasonable among 4 types of rock physics models proposed by Helgerude (2001) as the models for the methane hydrate bearing sediments (Inamori et al., 2008). The plotted points obtained by the laboratory experiments in this study fall within the scattering range of those obtained by the well logging. In these figures, theoretical curves for different sand-shale ratio (Vsh) are also shown, as the matrix-support model is assumed. The results of the laboratory tests showed roughly the same tendency. The actual Vsh of the Toyoura sand used in the experiments is 0.01. It is interesting that the relationship between seismic velocity and methane hydrate saturation are explained by the matrix-support model, not only for the natural cores, but also for the artificial samples. Since the hydrate was generated using meniscus water between sand particles as mentioned before, we expected stronger particle association like cemented model. We think the process of water saturation after methane hydrate generation may affect the status of particle association.
Electric resistivity

Electric resistivity of core samples was measured by applying electric current between the top and bottom of the core. The applied current was ± 100 μA with 8 sec period. The voltage potential difference between 2 electrodes with 25mm separation on the side surface of the core was measured 500 times with 0.5 sec interval. The average of these measured values was used to calculate resistivity.

Figure 6 shows the relationship between resistivity and methane hydrate saturation for 4 natural cores and 14 artificial samples, which are parts of those used in velocity measurements. Resistivity increases as methane hydrate saturation increases. The background plots in these figures are the results from the wireline logging at the 4 wells around the Eastern Nankai Trough area offshore Japan (Inamori et al., 2008). The plotted points obtained by the laboratory experiments in this study fall within the scattering range of those obtained by the well logging. The red curve shows synthetic resistivity curve of Archie’s equation in which high resistivity sand and hydrate particles are assumed to be in the low resistivity brine (3.5% NaCl aqueous solution; resistivity 0.188Ωm). The results of logging and laboratory experiments showed the same trend compared to the synthetic curve.

Figure 6  The relationship between electric resistivity and MH saturation

CONCLUSIONS

We developed a laboratory experiment system so that we can generate artificial methane hydrate samples and measure seismic velocity and electric resistivity under the condition of in situ pressure and temperature. The relationships between seismic velocity or electric resistivity and methane hydrate saturation obtained by this study agreed well with those obtained from the well logging in the Eastern Nankai Trough area offshore Japan, though the number of samples was not many in this study. We think the necessity of physical property measurements in laboratory are expected to increase in the future.

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