論 文 の 内 容 の 要 旨

論文題目　Rock physics study on the frequency dependence of seismic attenuation in methane hydrate-bearing sediments
（メタンハイドレート賦存層における地震波減衰の周波数依存性に関する岩石物理学的研究）

氏　名　　詹 林森

Methane hydrates (MH) are well known to have an influential effect on the physical properties of MH-bearing sediments such as velocity and attenuation. Geophysical techniques such as VSP (Vertical Seismic Profiling) and well logging have been widely used for mapping and quantifying hydrate for MH-bearing sediments. Ultrasonic measurements for synthetic or core MH samples can provide insight on the exploration of MH-bearing sediments, and partially frozen system is considered to be an effective substitution for synthetic or core MH samples.

Most sonic logging data acquired in MH-bearing zones have shown an increasing velocity of compressional (P-) and shear (S-) waves accompanied by high attenuation of P- and S-waves. In addition to field data, ultrasonic experimental investigations also showed simultaneous high velocity and high attenuation of ultrasonic P- and S- waves near the freezing point of brine in partially frozen systems. More controversially, no significant or significant attenuation was observed at seismic frequencies in MH-bearing sediments of various geological environments. Intuitively, one would expect that the higher velocity would be corresponding to the lower attenuation. Unexpectedly, significantly large attenuation was observed at sonic frequencies in MH-bearing sediments and at ultrasonic frequencies for partially frozen systems. Due to the lack of understanding on how MH affects the physical properties of MH-bearing sediments, using geophysical methods to accurately identify and quantify the extent of MH-bearing sediments is remain challenging and unreliable.

The combined use of various measurement methods at different frequencies such as sonic, VSP, and ultrasonic transmission measurements provides an opportunity to examine the frequency-dependent attenuation in MH-bearing sediments. For a more detailed understanding of the rock physical mechanisms responsible for the attenuation at different frequencies (VSP, sonic, and ultrasonic frequencies), different rock physics models are adopted to predict the P- and S-wave velocities and attenuations at MH-bearing sediments and partially frozen systems, and then the predicted values by rock physics modeling are compared with those derived from field sonic logging, VSP, and ultrasonic measurement data. In this study, two different rock physics models that have recently been developed to consider the squirt flow in porous/microporous hydrate and the interaction between sand and hydrate grains in MH-bearing sediments are applied. Also, an effective medium model is applied to partially frozen brine and a three-phase extension of Biot model is applied to partially frozen unconsolidated sands.

By matching the predicted and measured values, the input parameters of the rock physics models are adjusted, (1) such as hydrate morphologies, water inclusion concentration, water inclusion aspect ratio, and initial sand sediment and hydrate permeability for MH-bearing sediments, (2) such as average pore radius of porous ice, viscosity and density of brine, and freezing point for partially frozen systems. I find influential input parameters for different rock physics models, and carefully make a definition for these parameters, and then provide a good agreement between measured and predicted values. Finally, for field data, I infer that this frequency-dependent P-wave attenuation may be due to the squirt flow caused by the combined effect of the degree of hydrate saturation and two permeable systems (one is between sand grains and the other is between hydrate grains), or due to the squirt flow caused by fluid inclusions with different aspect ratios in a microporous hydrate. Furthermore, the similar frequency-dependent S-wave attenuation is predicted by rock physical modeling, and I infer that both the Biot flow and friction between hydrate and sand grains dominate S-wave attenuation at seismic frequencies, whereas friction alone is dominant at sonic logging frequencies.

In ultrasonic transmission measurements, for partially frozen brine, my rock physical study indicates that squirt flow caused by unfrozen brine inclusions in porous ice could be responsible for high P-wave attenuation around the freezing point. Decreasing P-wave attenuation below the freezing point can be explained by the gradual decrease of squirt flow due to the gradual depletion of unfrozen brine. For partially frozen unconsolidated sands, based on the rock physical study I infer that squirt flow between ice grains is a dominant factor for P-wave attenuation around the freezing point. With decreasing temperature below the freezing point, the friction between ice and sand grains becomes more dominant for P-wave attenuation. The increasing friction between ice and sand grains caused by ice formation is possibly responsible for increasing S-wave attenuation at decreasing temperatures. Then, further generation of ice with further cooling reduces the elastic contrast between ice and sand grains, hindering their relative motion and thus reducing the P- and S-wave attenuations.

The laboratory measurement results at ultrasonic frequencies and field data at seismic and well logging frequencies for MH-bearing sediments are separately discussed due to different performances of physical properties at different frequencies. This study tries to elucidate the underlying attenuation mechanisms responsible for P- and S-wave attenuations at various frequencies. This study also provides a geophysical basis for identifying the occurrence of MH and characterizing the amount of MH using P- and S-wave attenuations at various frequencies, and then the physical properties of MH-bearing sediments inferred from rock physics modeling are beneficial for field production monitoring of MH-bearing sediments.