QUANTITATIVE RESERVOIR CHARACTERIZATION USING HIGH-RESOLUTION SEISMIC VELOCITY STRUCTURE AND ROCK PHYSICS MODEL

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論 文 名　：QUANTITATIVE RESERVOIR CHARACTERIZATION USING HIGH-RESOLUTION SEISMIC VELOCITY STRUCTURE AND ROCK PHYSICS MODEL
（高解像度弾性波速度と岩石物理学モデルを用いた資源貯留層の定量評価）

区　　分　：甲

論 文 内 容 の 要 旨

The accurate identification of geological structures (e.g., faults and gas chimneys) and rock properties is required in oil/gas exploration and development. Three- or four-dimensional seismic reflection survey are commonly conducted to image geological structure, estimate physical/hydraulic properties and identify dynamic behaviors of the oil/gas reservoirs. Enhancing the geological information using the seismic data contributes to reduce risks during reservoir exploration, especially in new areas with lack of wells. Furthermore, mapping of the distribution of gas hydrate and free gas in deep water sediment of the plate convergent margin is important for both in evaluation of potential hydrocarbon resources and prevention of submarine geo-hazards. In addition, the quantitative reservoir characterization is important in environmental problem. One of the potential solutions to reduce the amount of emitted CO_2 into atmosphere is to store CO_2 in the geological formations. The CO_2 geological storage can be conducted in the geological formation that has been focusing on oil and gas exploration and development.

Several subsurface characterization techniques have been developed for exploration in reservoirs, including the analysis of seismic data combined with rock physics model. In this study, I used and advanced these methodologies to elucidate the distribution of gas hydrate and free gas in the Sanriku-Oki forearc basin, northeast Japan. To quantify seismic data (i.e., hydraulic and elastic property estimation), furthermore, I developed a new rock physics method to estimate pore geometry and grain elastic moduli. This thesis was divided into four chapters as summarized below.

Chapter 1 describes the background, motivation and objective of this study. Then, I introduce the previous/ongoing studies about seismic data interpretation and rock physics models for reservoir characterization.

In Chapter 2, automated velocity analysis was applied to a 3D seismic data volume in order to obtain a high-resolution seismic velocity model that I used to investigate the influence of fluid behavior on the subsurface distribution of gas hydrate in the Sanriku-Oki forearc basin, northeastern Japan. I identified free-gas accumulations as zones of low P-wave velocity separated from overlying high-velocity gas hydrates by the clear seismic boundary of the Bottom-Simulating Reflector (BSR). Then, the conductive modeling was used to map upward heat flow in our study area from the depth of the BSR derived from the high-resolution velocity model. The BSR-derived heat flow demonstrated that upward fluid flux has a considerable influence on the distributions of both gas hydrate and free gas. The areas of high heat flow (representing fluid flow) corresponded to underlying permeable geological features such as gas chimneys, faults, and the edges of porous slumps, suggesting that these features provide fluid migration pathways from Eocene to Oligocene source rocks to free-gas and gas-hydrate accumulations in overlying sedimentary rocks. The techniques I have employed can contribute to the quantification of gas-hydrate and free-gas resources in similar deep-water reservoirs off the eastern continental margin of Japan and at tectonically similar plate subduction margins in other regions.

In Chapter 3, a grid-search inversion method was proposed to estimate pore geometry and grain elastic moduli from observed velocity–porosity relationships. This approach could be useful to predict hydraulic properties from seismic velocity. In the inversion, laboratory-derived velocity–porosity relationships were compared with the theoretical relationship calculated from crack aspect ratio and grain elastic moduli via the Differential Effective Medium (DEM) model. Compared with existing approaches to estimate elastic moduli and pore geometry, our approach is easy to apply because it can be applied to physical properties measured at atmospheric pressure without changing pressure. I tested the proposed inversion method using synthetic data, and successfully estimated the grain elastic moduli and crack aspect ratio. I also applied the proposed inversion method to *P*-wave velocity and porosity measured in the laboratory on various rock samples acquired at the hydrothermal field and plate-spreading center, and found that the velocity–porosity relationship derived from DEM theory for the inverted model parameters agreed with the laboratory data. Using the proposed method, the average pore aspect ratio and grain elastic moduli for basaltic and hydrothermal ore deposit samples were estimated. Furthermore, the Root Mean Square Error distribution obtained in the grid-search inversion enables us to evaluate the uncertainty of the estimated values.

Chapter 4 summarized new findings and new approaches in this dissertation. High-resolution seismic velocity models and heat flow prediction provided the key information to understand gas hydrate and free gas related to fluid flow in the Sanriku-Oki forearc basin, controlled by complex structural features (i.e. faults, chimneys, and edge of slumps) from deep source rock to shallow reservoirs. Furthermore, grid-search inversion was used to identify the pore geometry and grain elastic moduli using velocity-porosity relationship from discrete samples of hydrothermal ore deposit, which could be used to estimate hydraulic property of reservoir rocks from seismic velocity. The methodologies developed in this study could be combined for quantitative reservoir characterization.