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Non-linear elastic wavefield inversion of VSP data and rock physics model building

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1. Introduction

Elastic wave velocity is the basic physical quantity for solid and fluid identification in the exploration of hydrocarbon and others. Non-linear elastic wavefield inversion is an iterative computational attempt to provide elastic wave velocity estimates under the condition that synthetic traces most closely resemble observed traces. Standard velocity analysis methods based on the image enhancing criterion have limited resolution and accuracy by their nature. There are many examples that show the benefit of the estimates of the elastic wave velocity. I take examples for the application of the wave field inversion for gas and gas hydrates estimates. Both of them made use of VSP surveys. Resolution gaps may exist between wireline logging data and seismic data as the source frequencies are kHz order and 20-200Hz respectively. In current cases, VSP data provided high resolution elastic wave velocity in major gas hydrate saturated zones and could be used for estimates of gas hydrate. VSP data could reconstruct velocity data in the missing logging data intervals by assuming gas saturation that was consistent with inversion results in Nankai trough data.

2. Implementation of non-linear elastic wavefield inversion and rock physics model

Since horizontally layered model bounded by free surface and half-space was a good approximation in the current cases, wavefield syntheses used reflectivity method in the cylindrical coordinate system, transforming horizontal coordinates and time into wavenumber, azimuthal order and frequency. We can account for the correct 3-D geometrical spreading for point source without amplitude and phase correction usually done for 2-D formulation. VSP wavefiled inversion is driven to minimize the misfit function between upgoing waves and synthetic traces in the frequency-depth domain.

Rock physics model is built as follows. As effective elastic modulus of dry rock frame, Hertz-Mindlin contact theory is applied at the state of critical porosity and in the range of zero to critical porosity and that of critical to full porosity, modified Hashin-Strikman lower and upper bound between each end material is applied. Elastic moduli of mixture of solid grain and gas hydrate are computed by Hill average and those of fluid saturated rock are computed by Gassmann's equation.

3. Inversion analysis and estimates of gas and gas hydrate

Mallik 2L-38 well was drilled in 1998 as the first well dedicated to the gas hydrate study in permafrost. VSPs were conducted in vertical and horizontal source motions at rig-site and offset points. P-source sweep frequency is 10-200Hz and the frequency band to be inverted is taken as 45-130Hz. Initial model was used by the traveltime inversion of the first-breaks of downgoing wave by the conjugate gradient scheme and/or GA. Other approaches to build initial model were examined but it was the most efficient in limited number of iterations. Matching between calibrated sonic and inversion results are excellent with higher resolution in gas hydrate saturated zones. As any reflections reflected below TD of VSP well can be observed, structures below the TD can be estimated by analyzing shallower receiver traces (look-ahead capability). It was simulated by using shallower receiver data to examine the effectiveness of the inversion method. Proposed rock physics model was successfully used for gas hydrate saturation estimates combined with log data analysis.

In 1999 to 2000 of MITI drilling campaign, VSPs were gathered in three wells. Sonic data at several intervals were missing due to high attenuation of the first-breaks. Missing log data were estimated and recovered by VSP inversion. By means of the proposed rock physics model, gas saturation was estimated. Using surface seismic data, inversion was done. Source frequency bands were similar each other, but VSP inversion result showed higher resolution with better fidelity.