WS07

4D seismic coda waves

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Summary

Time-lapse seismic imaging of the earth's interior, and quantitative estimation of time-varying changes in rock and fluid properties, has produced many spectacular results over the past 30 years; however, we are still making many approximations, and extracting only a small percentage of the information available in the full time-lapse seismic wavefields. I will present advanced concepts in full wavefield imaging and inversion (including 4D RTM and 4D FWI) to enhance 4D seismic reservoir monitoring.

Introduction

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Abstract

4D seismic reservoir monitoring works well when the rock and fluid physics properties, and also the changes in reservoir variables (fluid content, pore pressure, stress, strain, temperature etc.), are optimal. In this 4D seismic "sweet spot", time-lapse changes in rocks, fluids and other reservoir variables are readily detected, imaged and interpreted in high-quality repeatable time-lapse seismic data sets. Examples include sandstone reservoirs that are not strongly cemented, which undergo significant fluid and/or pressure changes during production or injection. In these cases, to first order, the 4D seismic data response looks like a simple set of reflection hyperbolas in the seismic difference shot gathers, and is thus amenable to 4D imaging and inversion methods based on ray theory, or one-way wave equations.

In contrast, using current best practices, the 4D seismic method does not work well when reservoir rock and fluid properties are sub-optimal, for example: hard reservoir rocks like cemented sandstones or carbonates, small fluid compressibility or pore pressure changes as in gas depletion reservoirs, etc. In these cases, the 4D signal is often too weak to detect in realistic levels of 4D noise. At the other extreme, very strong changes in reservoir properties, such as gas/steam/CO2 injection in soft sands, create 4D seismic wavefield responses that are easy to detect above 4D noise levels, but are extremely complex due to strong scattering. In both cases, when the 4D primary response is very weak, and when the 4D scattered response is very strong, 4D seismic imaging and inversion methods based on ray theory and one-way wave propagation break down. I will show that in such cases there is significant energy in the "4D coda" (full time-lapse scattered wavefield), but extracting useful information from these complex 4D seismic responses is challenging and requires full wavefield methods such as 4D RTM and 4D FWI.