S31A-0583 0830h POSTER

Seismic Characterization of Fractured Reservoirs

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We present rock physics analyses for the San Andres carbonate reservoir in the Yates Field, with the objective of understanding how reservoir heterogeneities and fractures impact the seismic response. Statistical fracture modeling and Monte Carlo simulation for the P-P reflectivity of the reservoir rock help to quantify the uncertainty in the seismic response due to natural variability. We also derive expressions for far-offset elastic impedance in anisotropic media obtained by integrating the reflectivity and show how anisotropic elastic impedance (AEI) may be used for fracture characterization. Yates field is located in the Central Basin Platform of the Permian Basin in Western Texas. In spite of the high density of wells, there is still significant uncertainty regarding the existence and orientation of fractures. The main structural characteristic is a regional orthogonal fracture system, with approximately vertical dips. The San Andres formation, the main producing interval in Yates Field, is mostly a dolomitized limestone exhibiting different facies, represented by interbedded grainstones, packstones, wackstones, and mudstones. From rock physics analysis of well logs and core information, we show that different depositional environments and their associated facies have seismically distinguishable elastic signatures. We also discovered a correlation between fracture occurrence and the depositional environments. Majority of the fractures are associated with low energy, subtidal environment. This important result can play a significant role in seismic fracture delineation. For the Amplitude Variation with Offset and Azimuth (AVOZ) analysis we consider the interface between the cap rock (Grayburg formation), and the underlying San Andres reservoir rock, modeled with vertical fracture sets. We use stochastic simulations for fracture and background rock properties to assess the variability in the seismic response. Aligned fractures generate an azimuthally anisotropic medium from which we compute statistical distributions of P-P reflectivity, and AEI, as a function of incidence angle and azimuth. The modeling concludes that oil and brine saturated fractures have stronger azimuthal signature at smaller angles of incidence than gas filled fractures while gas filled fractures are most easily distinguishable from unfractured rocks.

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Preliminary Fracture Model for The SE Geysers Geothermal Reservoir

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In this study we combine interpretation of steam entry points, seismicity, shear-wave splitting, geology, and rock physics to develop a fracture model for the Southeast Geysers reservoir in an attempt to improve understanding of the permeability and steam flow within the reservoir. The Geysers is a dry steam field located approximately 140 km NNW of San Francisco, in Sonoma and Lake Counties in northern California. We developed this model by utilizing three-dimensional coordinates of wellbores and observations of steam entries encountered during drilling in conjunction with the locations of microearthquakes, the orientations of fractures from shear-wave splitting, geologic interpretation, and the result of rock physics interpretations. We utilize earthVision5.1TM visualization software in analyzing this data.

We are interested in analyzing the fault, fractures, or fracture sets that appear to have the major control over fluid flow at reservoir depths. Faults offsetting the reservoir graywacke and felsite are generally identified by indirect methods. Fault detection within the reservoir rocks is difficult because the geology is relatively homogeneous and lacks marker horizons. Most high-angle faults mapped at the surface are truncated above the reservoir by thrust faults, and do not project to zones of high permeability within the reservoir. Thus, we utilize steam entry points along with geological formation topography to assist in the identification of faults at depth.

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Strong reflectors observed in geothermal fields

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Since geothermal fields are highly fractured and form complex structures, the results of seismic reflection surveys are often poor because of attenuation, scattering, and absorption of seismic waves. In this situation, it is important to improve the S/N ratio. By applying diffraction stacking to the seismic reflection data obtained in the geothermal field, we obtained strong and continuous reflectors with a higher S/N ratio than conventional CMP method. The cause of strong reflectors in geothermal fields is controversial. Strong reflectors acts as a decoupling plane in the upper continental crust; it developed as a consequence of the extensional tectonics and high heat flow. Such strong reflectors correspond to a level of fractured rocks, saturated with hydrothermal fluids and minerals. Such a condition could cause a strong contrast in acoustic impedance. The strong reflectors may be related to thermal structure such as a rheological boundary (brittle-ductile boundary) that separates a brittle upper part from a ductile lower part. We compare the seismic section with both the hypocenter distribution of microearthquakes and isotherm lines obtained from deep boreholes. A high seismicity zone lies over the strong reflector, indicating that a brittle zone lies above the strong reflector. And also, the strong reflector coincides with the 350 C.

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Frequency-Dependent Azimuthal Anisotropy of Seismic Reflectivity From a Layer With Discrete Fractures

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Fractures in sedimentary rock can have a significant impact on the production of fluids and gas in the subsurface. These fractures often are regularly-spaced and near-vertical, with a preferred orientation due to the regional stresses that lead to their formation. The conventional approach for characterizing fractured rock using seismic waves treats the fractured rock as an equivalent homogeneous, transversely isotropic medium with the elastic symmetry axis aligned in the fracture-normal direction. This effective medium approach neglects scattering off and wave channeling along discrete fractures.

We examine the effects of a layer containing a single set of vertical periodic or semi-periodic fractures on the scattering of elastic waves. A numerical technique developed by Hennion et al.(1990) is used to compute frequency-domain responses which subsequently are used to compute seismograms in the time domain. This is a hybrid technique between finite element and plane wave solutions to simulate the three-dimensional scattering of elastic waves. Each fracture is modeled explicitly, so that the model can simulate both discrete arrivals of scattered waves from individual fractures and multiply scattered waves among them. Using this technique, we examine both AVA (amplitude versus azimuth) and AVO (amplitude versus offset) responses of a fractured reservoir as a function of wave frequency and fracture properties. Our preliminary results show distinct features developing in the seismograms as the wavelength approaches the fracture spacing. Furthermore, reflected waves measured in the fracture-normal and fracture-parallel directions in azimuth exhibited clear differences in their spectral characteristics. These characteristics may provide additional information that can be used to estimate fracture orientation and spacing.

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Seismic Detection of Gas in a Partially Saturated Fracture

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A strategy for reducing carbon dioxide (CO2) emissions into the atmosphere from power plants burning fossil fuel is to capture CO2 and sequester it in subsurface reservoirs. Candidate sites for geological sequestration differ in lithology and structure, but fractures are common to all. An issue that arises for long-term subsurface sequestration of CO2 is whether seismic methods be used to monitor the injection process once underway or after completion to determine leaks. We performed a laboratory investigation to determine the ability of seismic methods to detect the presence of gas in a fracture.

Seismic measurements were made on cylindrical samples of limestone and granite measuring 150 mm in diameter and ranging in height from 57 mm to 77 mm. For each rock type, an intact sample and a sample with an induced fracture were studied. Plane-wave water-coupled 1 MHz piezo-electric transducers were used to send and receive compressional waves that propagated through a sample. Measurements of the transmitted compressional wave (at normal incidence) were acquired initially when the samples were water-saturated, and then while air was pumped in to displace the water. A wavelet analysis was performed to examine the change in amplitude and arrival time of the dominant energy as a function of frequency. The results of the wavelet analysis were used to examine the change in the normal fracture specific stiffness as a function time, i.e., as function of air injection into the sample.

When a fracture was saturated with water, the fracture specific stiffness was independent of the frequency of the signal. When air was injected into the sample, the amplitude of the signal was reduced, and the attenuation in the transmitted amplitude now varied as a function of frequency. The normal fracture specific stiffness in this case was found to be frequency dependent, in which the fracture appeared to be stiffer at higher frequencies (1 MHz) than at low frequencies (200 kHz) by almost an order of magnitude. The frequency-dependent fracture specific stiffness is proposed to be a consequence of the spatial heterogeneity in fracture geometry highlighted by the impedance contrast caused by the air. When the fracture is fully saturated with water, the local heterogeneity in the fracture stiffness is masked by the low impedance contrast of the fluid.

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Rock Physics Interpretation of P-wave Q and Velocity Structure, Geology, Fluids and Fractures at the Southeast Portion of The Geysers Geothermal Reservoir

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We examine how quantitative rock physics models, such as effective medium theories, can improve the interpretation of seismic parameters and material and fluid properties at The Geysers. We use effective medium theories to estimate effects of fractures on velocities for The Geysers rocks. We compare theoretical velocity estimates to laboratory measurements from the literature and our seismic velocity values from 1992 earthquake data. We approximate the reservoir as being homogeneous in mineral composition, with a constant density of fractures whose total void ratio is

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