Seismogenic faults monitoring from time-lapse seismic survey: Development of a rock physics model via core-log-seismic integration

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Abstract: Monitoring dynamic activities of seismogenic faults (e.g., mega-splay fault in the Nankai Trough) from time-lapse seismic survey is important for earthquake disaster prevention. To monitor the seismogenic faults from seismic approaches, we need to develop a rock physics model around the seismogenic fault using core-log-seismic data. Now we do not have an appropriate rock physics model for the seismogenic fault. Furthermore, although we obtain many kinds of geophysical/geological data from the drilling campaign, we usually use core-log-seismic data separately. To integrate core-log-seismic data, the construction of rock physics model for the seismogenic fault is also necessary. From the scale difference in core-log-seismic integration, we could estimate fracture-scale or fracture-intensity. Furthermore if we use information of shear-wave splitting, there is a possibility to monitor dynamic stress change before large earthquake.

Fault monitoring via time-lapse seismic survey

Seismic data has a potential to estimate two-dimensional (2D) or three-dimensional (3D) underground physical properties as well as stress state (e.g., effective stress and pore pressure). Furthermore if we operate time-lapse seismic survey using borehole seismometers and active-sources, we can monitor the underground properties from the tomography-derived velocity, reflection strength, quality-factor, shear-wave splitting, and etc. By integrating borehole data to the seismic reflection data, furthermore, quantitative estimation of 2-D or 3-D underground properties as well as stress state is possible.

When we integrate core-log-seismic data in order to monitor seismogenic fault quantitatively, we need to develop a rock physics model for the seismogenic fault. The rock physics model is constructed using the following velocities: (1) laboratory-derived velocities (Vp, Vs, and anisotropy), (2) logging velocities (Vp, Vs, and anisotropy), and (3) velocities derived from zero-offset & offset VSP.

Furthermore if we focus on the shear-wave splitting caused by stress-aligned cracks, there is a possibility to monitor dynamic stress change before large earthquake (Crampin, 2001). Crampin (2001) suggests that time and magnitude of future earthquakes can be estimated by analyzing shear-wave splitting in controlled-source cross-well seismology between three boreholes.

Development of rock physics model

To estimate underground properties as well as stress state (e.g., pore pressure) from seismic data, we usually use seismic velocity. Many models have been proposed that attempt to establish a link between formation parameters and seismic velocities [e.g., *Mavko et al.*, 1998]. The relationship between effective stress and seismic velocity depends on many parameters: pore volume, pore shape, mineral texture, and mineral composition. Therefore, although total porosity (pore volume) is one of the most important parameters of those that constrain velocities, pore shape (e.g., crack or void) also significantly influences seismic velocity [*Tsuji and Iturrino*, 2008b]. Because thin cracks with small pore volume can significantly decrease velocities [*Kuster and Toksoz*, 1974], we need to consider pore features other than total porosity.

To construct velocity–stress relationships that can be used to predict pore pressures (effective stress) and monitor the seismogenic thrust, therefore, we need to consider pore geometries (e.g., aspect ratio). Tsuji et al. [2008a] tried to develop a theoretical method for predicting effective stress and pore pressure based on rock physics theory and applied it to reveal the pore pressure (effective stress) distribution within the Nankai accretionary prism. In the method, we introduced an application of the aspect ratio spectrum of pore space [e.g., *Toksoz et al.*, 1976; *Cheng and Toksoz*, 1979] and Differential Effective Medium (DEM) theory [e.g., *Berryman*, 1992] to predict effective stress and pore pressure from seismic velocity. However we can apply this method (inclusion model) only for the consolidated rocks. For unconsolidated shallow sedimentary sequences, we need to use a grain-contact model because seismic velocities increase with effective stress as a result of the strengthening of grain contacts as effective stress increases [*Dvorkin and Nur*, 1996]. Since we do not have an intermediate model which connects between crack (inclusion) model and grain model, we should develop it or clarify its constraints (e.g., applicable porosity range for crack-based model and grain-based model). When we monitor the dynamic stress change from shear-wave splitting (*Crampin*, 2001), the crack should be aligned in the rock physics model.

Scaling in Core-Log-Seismic Integration

Scale (frequency) difference often becomes a problem when we integrate between core data, logging data, and seismic data. Acoustic properties (e.g., velocities, quality factor, and anisotropy) of discrete samples measured in laboratory are usually different from low-frequency seismic data as well as VSP data. One of the reasons is that discrete samples do not have large-scale fractures and heterogeneities. In the core-log-seismic integration, therefore, we need to reveal the acoustic properties parameterized by scale using rock physics model. If the frequency-dependent mechanisms (e.g., fluid-solid interaction) are revealed, there is a possibility that we can use the scaling difference for the estimation of fracture-scale and fracture-intensity.

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