Chapter 1

Conclusion

1.1 Seismic time-lapse monitoring of subsurface fluid-flow

Fluid flow plays many important roles in the Earth's crust, including: a resource of potable groundwater, a lubricant along earthquake fault surfaces, an exchange system with atmospheric fluids, and an association with natural energy resources such as geotherms, mineral deposits, and hydrocarbon reserves. To learn more about the role of fluids in crustal processes, remote sensing of fluid distribution and movement with time-lapse seismic monitoring data may prove to be an extremely useful technique. However, a good understanding of seismic time-lapse monitoring requires an integrated view of three traditionally separate disciplines: fluid flow, rock physics, and reflection seismology.

1.2 Main contributions of this thesis

In this thesis, I have explicitly developed the link between fluid flow, rock physics and seismic wave propagation. This was achieved in four main parts: mathematical aspects of seismic monitoring theory, feasibility analysis of monitoring fluid flow at a given site, data processing issues related to time-lapse seismic monitor data, and integrated interpretation of monitoring data combining fluid-flow, rock physics, seismic modeling and seismic analysis.

In Chapter 2, I derived mathematical relationships between fluid flow, rock physics, seismic modeling, seismic imaging and velocity analysis. These equations are useful to interrelate the physical properties of fluid flow, rock mechanics and seismic wave propagation.

In Chapter 3, I discussed the importance and methodology of performing a detailed feasibility analysis with a case study from the Troll Field, offshore Norway. I demonstrated that I could predict whether gas coning from a horizontal oil depletion well could be monitored from surface seismic data under realistic acquisition conditions using a pre-monitor engineering and petrophysical database. This model for feasibility analysis can be used in any general scenario of subsurface fluid-flow for predicting the physical time-lapse seismic response.

In Chapter 4, I discussed data processing issues related to time-lapse seismic monitoring with a case study of six 3-D seismic surveys recorded over a steam injection site at the Duri Field in Sumatra, Indonesia. I demonstrated the importance of experimental repeatability, and in careful model-based processing to allow valid comparisons among multiple time-lapse seismic data sets.

In Chapter 5, I discussed how to perform an integrated interpretation with a case study of the Duri 4-D data set by combining aspects of fluid-flow, rock physics, seismic modeling, velocity analysis, and seismic imaging. I demonstrated that it is possible with seismic time-lapse data to directly image fluid-flow fronts associated with saturation changes, thermal heating, and the presence of steam. Most surprisingly, I discovered that a pressure transient during fluid flow could be seismically imaged and mapped with time to estimate preferential permeability flowpaths and predict spatial fluid flow months in advance.