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Up-to-date examples of quantitative reservoir monitoring using time-lapse seismic in the oil industry.

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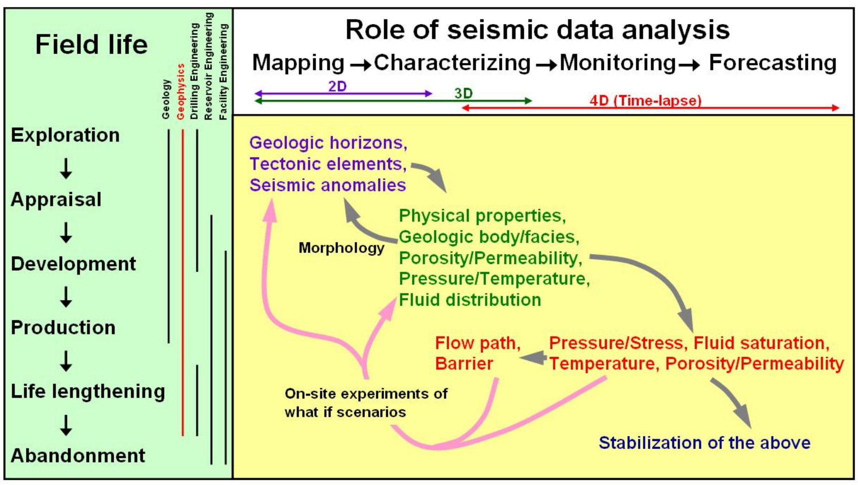
Reflection seismology has been playing a significant role for **mapping** subsurface structures for a long time. In the late 1970s, 3D seismic became a practical tool, accordingly seismic data began to be used for **characterizing** reservoirs by obtaining morphological information of sedimentary bodies and/or understanding the distribution of seismic anomalies related to hydrocarbon saturation. Furthermore, on the analysis side, (1) computation of various attributes and the multi-trials of forward/stochastic modeling due to the drastic advances of the capability of computers, and (2) progress of rock physics: quantitative understandings of the relations between rock/fluid properties and pressure/temperature conditions, enabled us to perform quantitative AVO/Inversion analysis with better precision and accuracy. Particularly, seismic inversion provides absolute values of the interval properties in subsurface. In addition, rock physics theories predict quantitative changes of seismic responses in what if scenarios such as changing in lithology, the volume of cement, and fluid saturation. Eventually, seismic expands its role to reservoir **monitoring** and **forecasting** nowadays. In other words, reflection seismology evolved to a tool providing the fundamental data during the whole life of oil and gas fields (Figure 1). Moreover, time-lapse seismic (4D seismic) feedbacks the important knowledge of the quantitative difference induced by a change in pore pressure/fluid through on-site experiments, which is beneficial for exploration and appraisal in the next phase.

In this paper, I introduce three latest case studies of time-lapse seismic application from North Sea. (1) Valhall oil field has Cretaceous chalk reservoir, which shows a pressure depletion induced by the production. The compaction of the reservoir is detected by travel-time difference in time-lapse seismic. Joint venture buried permanent receivers and recorded 3D seismic six times from 2003 to 2005. At first, the time-shift maps of five-period demonstrated inconsistent movements and even multiple reflections exhibited different travel times depending on the vintage. Eventually, they identified that the reason of the complications is the seasonal variation of sea-water velocity and presented the comparison before and after the calibration (Hatchell *et al.* 2007). (2) South Arne field in Danish North Sea is producing oil/gas from a chalk reservoir. Recent study revealed that time shifts are observed not only in the reservoir interval but also for overburden formations. Herwanger *et al.* 2007 integrated Geomechanical modeling to understand distribution of stress states. As a result, they determined extensional regime above and below the reservoir due to the compaction of the reservoir, consequently travel-time delay should occur even outside the reservoir. Moreover, at the top of reservoir, the model demonstrates extension in vertical direction but contraction in the horizontal direction. Therefore, they predict mitigation of time delay for far-stack seismic. Actual time-lapse data validate their predictions, so the Geomechanical model. (3) Gullfaks oil field has started production in 1986 from a Jurassic sandstone reservoir. Qualitative detection of remaining-oil distribution by comparing impedance volumes from time-lapse seismic has been applied, however, quantitative information of fluid saturation is required as the field life towards tail end. Statoil developed <u>4D simultaneous seismic inversion</u>, which simultaneously solves two set of angle stacks at a time. In addition, they invented <u>stochastic rock physics inversion</u> to determine a change in reservoir pressure and fluid replacements separately using the location shift in the Vp/Vs to P-Impedance cross-plot. The new method analyzes fluid saturation properly. The resultant change in reservoir pressure still needs improvements (El Ouair and Stronen 2006).



4D seismic brings benefits on (1) revenue improvement, (2) cost reduction, (3) environmental protection by efficient production, and (4) knowledge accumulation.