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# Modeling Overburden Stress Change Due to Compaction of Stacked Reservoirs and Application of Model Results in 4D-Seismic and Infill Drilling

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## Abstract

A compacting reservoir remains physically connected to the rock surrounding it. Therefore, as the reservoir deforms and compacts, stresses will change and reorient themselves in the reservoir *as well as* in the overburden, underburden and sideburden, and there will be deformation in these rocks too. It is a well known and extensively described physiological phenomenon that stresses and strains induce changes in seismic velocity. Thus, reservoir deformation induces changes in velocity affecting the seismic wave throughout the basin. For certain combinations of velocity change and overburden thickness, vertical integration of the local traveltime changes may lead to timeshifts of several milliseconds, which can be measured in well-repeated seismic surveys. Timeshift technology has an interesting application in reservoir monitoring: Maps of timeshifts could indicate the areal distribution of reservoir compaction and thus reveal the areal distribution of depletion. Timeshift analysis then has the potential to help determine compartmentalization, locate bypassed oil in undrained compartments, identify new drilling targets and sidetracks, avoid expensive infill wells, and eventually decide when to abandon a field. Promising patterns of timeshifts of up to 15 milliseconds have already been observed in several fields.

We simulated the geomechanical effects of the depletion of stacked oil-saturated reservoir sands. The calculated deformation and stress changes were used to calculate timeshifts as a function of production. Reasonable agreement was obtained between calculated and measured timeshifts. However, the fact that the measured timeshifts resulted from stress perturbation due to the *combined effect* of several stacked reservoirs complicates their interpretation: It requires a good (i.e. field-data-proven) static and dynamic model for all sands to correctly model their effect on the overall timeshift signal. Only then can the remaining difference between synthetic and field-observed timeshifts be used to monitor and interpret the production performance of a target "problem reservoir" within the stacked pay. Our models also suggest that stress changes in rocks overlying compacting reservoirs are complex and anisotropic, and dependent on proximity and structure of the relatively stiff formations. When these are present, the 3D-variation in stress state, and not the 1D-variation, should be used to compute and analyse timeshifts in 4D-seismic data.

## Introduction

Production-induced depletion of hydrocarbon reservoirs leads to deformation, compaction, displacements, and stress change in the reservoir as well as in the surrounding rock (Teufel et al. 1991, Kenter et al. 1998, Hettema et al. 2000, Schutjens et al. 2004, 2005). Such stress changes affect the acoustic wave velocity and bulk density (Holt et al. 2004, Macbeth et al. 2004, Sayers 2006a). This has two implications: It changes the contrast in acoustic impedance between reservoir and overburden, resulting in seismic amplitude changes at the top of the compacting reservoir (Landrø and Stammeijer, 2004). Secondly, it changes the travel-time of seismic reflection waves, leading to arrival-time delays (timeshifts) of seismic data gathered in the repeat survey compared to data gathered in the base survey (Kenter et al. 2004, Stammeijer et al. 2004, Hatchell and Bourne 2005, Staples et al. 2007). Maps of timeshifts can then indicate the areal distribution of reservoir compaction and thus reveal the areal distribution of depletion. This could help to determine compartmentalization, locate bypassed oil in undrained compartments, identify drilling targets and sidetracks, and avoid expensive infill wells. These interesting geophysical applications of reservoir mechanics justify the question how accurate such geomechanical models really are. What is their sensitivity is to the (natural) variation in input parameters like geological structure and sedimentological detail, depletion