Time-shift and AI difference cross-plot: pressure depletion and saturation change trends

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Introduction

The most widespread rock physics templates relate elastic properties, e.g. acoustic impedance and Poisson's ratio to different diagenetic, pressure or saturation trends [1]. Once we have generated impedance cubes from seismic, we can use templates to identify trends in data and classify results. In 4D applications, however, we mostly deal with amplitude differences and time-shifts, which we relate to acoustic impedance and velocity [2]. The question is if cross-plots between time-shifts and relative acoustic impedance changes display trends and clusters, which we can relate to production effects in the reservoir.

In Brage, a mature field in the Norwegian North Sea, we have observed discrepancies between time-shifts (positive) and relative amplitude differences (negative) in parts of the field over several monitors. We usually dismiss these discrepancies as estimation errors, which is always at least partially true. However, rock physics analysis of the trends in cross-plots of time-shift (DT) vs normalized acoustic impedance change (RAID) show that we can attribute these to combined pressure and saturation changes. We have used the insight from the cross-plot in classification of three different targets in Fensfjord reservoir in Brage.

Methods

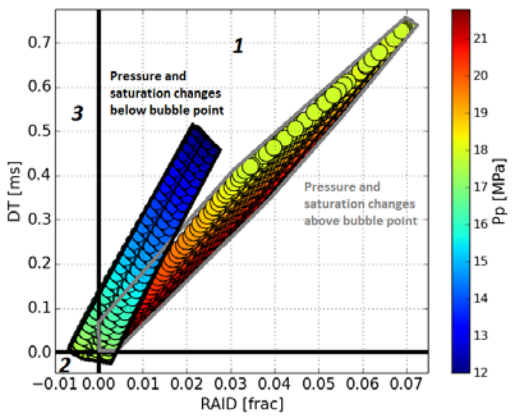
We perform a fluid substitution for Fensfjord reservoir in 31/4-3 well in Brage in a production consistent manner. By that, we mean that all reservoir and fluid changes are included simultaneously and consistently to mimic reservoir conditions according to the production history. With poor aquifer and lack of pressure support from the injection wells, the initial reservoir pressure (21.8 MPa) in Fensfjord drops very quickly below the bobble-point (17.8 MPa) after production start and continues to reach very low values (12 MPa). In addition, dry core measurements indicate a significant pressure sensitivity of the dry rock frame. Pore pressure is therefore a significant driving mechanism for elastic changes.

During fluid substitution, as the pore pressure is changed, we calculate GOR for oil using PVT measurements; we change oil properties according to Batzle-Wang and modify dry rock frame velocities using velocity-pressure relationship derived from the dry core measurements. We gradually introduce gas into the homogeneous fluid mixture as the pressure drops below bubble-point. For each pressure point, we allow oil saturation to vary within realistic ranges for Fensfjord reservoir. From velocity and density change, we calculate relative acoustic impedance difference $RAID = (AI_M - AI_B)/AI_B$ and time-shift $DT = 2z\,(V_M - V_B)/V_M V_B$. Here, AI_M and V_M are acoustic impedance and P-wave velocity of the reservoir in monitor survey, while AI_B and V_B are the same properties in the base survey. We denote reservoir thickness by z.

Results

The cross-plot in Figure 1. shows two different clusters of data with corresponding trends. One trend is driven by the pressure changes above the bubble point. As the pressure drops below bubble point, a new pressure trend is created. Separation between these trends will depend on the amount of gas introduced in the fluid mixture. Oil saturation changes create deviations from the trends, which also will depend on the pore pressure.

Figure 1: Relative acoustic impedance difference vs. time-shift – trends and quadrants



Discussion and conclusions

We have calculated amplitude differences and time-shifts for a base-monitor pair, cross-plotted them and compared them to the classification scheme suggested in the Figure 1. In the first quadrant (positive DT and $RAID$), we identify areas with strong water flooding; in the second quadrant, (negative DT and $RAID$), we identify areas with large amounts of associated or injected gas; in the third quadrant (positive DT and negative $RAID$), we identify an area where we believe that pressure drop has released small amounts of associated gas while oil saturation is close to the initial. We plan to drill a well in the area later this year. Cross-plotting DT vs. $RAID$ reveals trends which are related to pressure and saturation changes in the reservoir. We show that we can use these to detect potential targets in Fensfjord reservoir in the Brage field.

References

[1] Ødegaard, E. and Avseth P.,2003, Interpretation of elastic inversion results using rock physics templates. EAGE Ann.Mtg. Extended Abstracts

[2] Stammeier, J.G.F. and Hatchell P.J., 2014. Standards in 4D feasibility and interpretation. The Leading Edge. 33(2),134-140