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Tailoring the Solution – To What Objective

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SUMMARY

In order to optimally utilize repeat 4D Time-lapse seismic data for the purpose of seismic reservoir monitoring, it is necessary to first fully understand the acoustic and elastic response to both reservoir and field-wide changes. This is a complex interaction. It incorporates not only the reservoir dynamics component - which encompasses fluid properties, fluid flow characteristics, field performance history and pressure distributions and profiles over time, but also all the changes in stress induced by the pressure changes during production. It is those changes in stress that induce strains/deformations not only within the reservoir but also around it. Understanding the reservoir dynamics is not possible from studying the individual geologic, reservoir simulation and reservoir geomechanical models in isolation – it requires them all to be fully integrated into a full-field coupled Dynamic Integrated Earth Model (DIEM). Only by fully understanding the mechanisms that produce the 4D signal via a DIEM can we hope to design an acquisition configuration in order to measure the 4D response at time intervals necessary, within the survey specific coherent and incoherent noise conditions, to be used for pro-active closed loop seismic reservoir monitoring and management.

Introduction

In order to optimally utilize repeat 4D Time-lapse seismic data for the purpose of seismic reservoir monitoring, it is necessary to first fully understand the acoustic and elastic response to both reservoir and field-wide changes. This is a complex interaction. It incorporates not only the reservoir dynamics component - which encompasses fluid properties, fluid flow characteristics, field performance history and pressure distributions and profiles over time, but also all the changes in stress induced by the pressure changes during production. It is those changes in stress that induce strains/deformations not only within the reservoir but also around it. This energy is manifested in various guises, sometimes as top reservoir seal compaction and top surface subsidence or as fault and fracture re-activation which may lead to dynamic permeability changes or fracturing during operations. Understanding the reservoir dynamics is not possible from studying the individual geologic, reservoir simulation and reservoir geomechanical models in isolation – it requires them all to be fully integrated into a full-field coupled Dynamic Integrated Earth Model (DIEM).

The closed loop seismic reservoir monitoring workflow

A closed loop seismic reservoir monitoring workflow is a two-pass process, figure 1. The first pass starts from the DIEM and progresses through a rock physics conversion to a fully 3D acoustic or elastic geophysical model to surface. The sensitivity of the 4D signal to simulated reservoir changes as a function of future-time is analyzed to assess the validity, frequency and design of seismic baseline and monitor acquisition. Assuming there is detectable 4D signal; the second-pass starts from the repeat seismic acquisition and processing and progresses through the inverse process to the reservoir simulation. At each step, analysis and reconciliation takes place between the measured and modeled 4D response, ending the process with an update of the DIEM to reconcile the difference between the predicted synthetic 4D seismic data and the measured 4D seismic data.

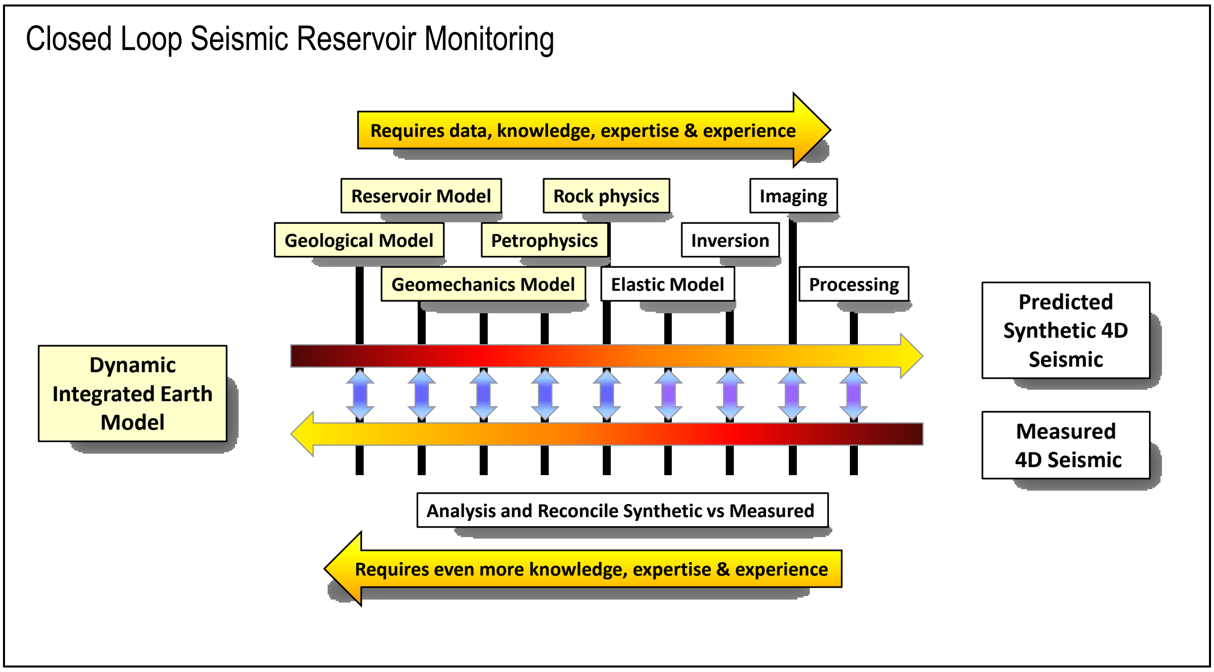

Figure 1 *The Closed Loop Seismic Reservoir Monitoring Workflow.*

Tailoring the solution – to what objective?

The closed-loop seismic reservoir monitoring workflow has the potential to optimally manage reservoir production, and to accurately predict future reservoir behavior. However, this is conditional upon there being a 4D response to hydrocarbon production, and that 4D response is detectable at the required time intervals for proactive reservoir management. It is safe to assume that all producing reservoirs will produce a 4D response of some form and magnitude, even though some will be very small. The question then reduces to how we measure the 4D response at the required time intervals in order to address the particular reservoir management objective, for example the mapping of injected water, Gas or CO_2 or identifying the location bypassed or mobilized hydrocarbons.

The author will present and elaborate upon details of the "Dynamic Integrated Earth Model to Predicted Synthetic 4D Seismic" leg of the closed-loop seismic reservoir monitoring workflow. With the objectives of determining:

- The nature, magnitude and distribution of a 4D Response
- If the 4D response is detectable using the base-line acquisition geometry with the inherent survey area specific coherent and incoherent noise characteristics,
    - If so over what time interval.

And if the base-line geometry is unable to measure the 4D response at the desired time interval tailor an appropriate solution and derive:

- The necessary acquisition geometry to measure the 4D response, at the required time intervals to optimally manage the reservoir with the inherent survey area specific coherent and incoherent noise characteristics

Conclusion

Historically survey design for 4D time-lapse monitoring has involved relatively simplistic and often noise free modelling which can lead to disappointment if the derived survey designs do not met expectations when deployed in the field. In order to derive a high fidelity acquisition geometry, with a high probability of measuring the 4D response at the required time intervals to optimally manage the reservoir a far more sophisticated workflow needs to be employed.
This workflow comprises three equally important components:

- Understanding the reservoir dynamics – this requires an integrated full-field coupled Dynamic Integrated Earth Model from which accurate reservoir simulations can be made.
- These simulations are used to generate time-stamped 3D elastic models of Vp, Vs, density and anisotropic elastic properties via a calibrated petro-elastic model (PEM).
- Which in turn are used by a range of sophisticated 1D, 2D and 3D acoustic and elastic forward modelling and imaging algorithms to accurately predict the 4D signal in the presence of the inherent survey area specific coherent and incoherent noise characteristics

Only by fully understanding the mechanisms that produce the 4D signal can we hope to design an acquisition configuration to measure it at time intervals necessary for pro-active closed loop seismic reservoir monitoring and management.