AN INTEGRATED EARTH MODELING APPROACH TO SIMULATING FAULT FLOW BEHAVIOR

"HOT OFF THE PRESS"

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Faults play a significant role in defining connected fluid volumes in many hydrocarbon reservoirs. Faults can act as flow barriers by offsetting permeable strata and by causing the development of low permeability gouge within the fault zone. Conversely, faults act as flow conduits if continuous fracture and joint networks develop within the fault zone. Although the impact of faults on reservoir production has long been recognized, fault property characterization has traditionally played a secondary role to stratigraphic characterization in the earth modeling workflow. While detailed 3D reservoir characterization is now routine, it is still not standard practice to model faults with spatially-varying flow properties, despite the increasing availability of computational tools to assist in these calculations.

We present a methodology for the estimation of 3D fault properties as part of an integrated earth modeling workflow using Gocad® as the modeling platform. We also present a case study illustrating advantages and ongoing limitations to this method as a predictive tool. In our approach, fault properties are derived from the faulted stratigraphic grid and associated reservoir properties, thereby making full use of the detailed stratigraphic and fault geometry information captured in the earth model. As part of this workflow, faults in the stratigraphic grid must be modeled with split-node grid cells. This enables the cross-fault juxtaposition relationships to be accurately represented by the grid cell geometry. For a simulation model, the grid volume is populated with reservoir flow properties such as porosity and directional permeabilities. In addition, the fault characterization approach requires that the model be populated with a Vshale property. Ideally, the Vshale property is conditioned both to seismic data and well control to capture 3D variability, although alternative approaches may be required when seismic data is poor or where well control is limited. The fault geometry and Vshale attribute are then used together to estimate the impact of fault gouge on fluid communication for each cross-fault grid connection in the model. To do this, fault slip distributions over each split-node fault are translated into an estimate of fault zone thickness using an empirical correlation. The Vshale attribute is used to calculate a Shale Gouge Ratio. Shale Gouge Ratio is in turn translated into a fault zone permeability estimate using an empirical correlation. From these fault property estimates, transmissibilities at each non-neighbor connection are adjusted for estimated fault gouge in a manner consistent with the 3D geologic model. One advantage of this approach is that it provides geologically consistent and reproducible fault transmissibility estimates. These values are typically intermediate between the two geologic extremes most often tested in flow simulations: the totally open fault scenario and the totally sealing fault scenario.

To examine the effectiveness of this fault characterization approach, we present results from a full-field simulation case study where faulting was considered a key parameter required for achieving a history match. The field has 35 years of production history with 27 producing wells. The simulation study was designed to determine the extent and source of communication between two main reservoir sands, which are separated by an approximately 10-foot-thick shale. A combination of structural closure and faulting has segmented the two main reservoir sands into several compartments. Production data suggests that faults vary from totally sealed to open with minimal restriction.

In the case study, the earth model and simulation grid were built in Gocad® using sloping faults. These faults compartmentalize the two reservoir sands into eight separate equilibrium regions with five different original oil-water contacts. A geostatistical model of the reservoir was built with the grid oriented parallel to the major fault trend. The grid includes split-node geometry to represent twenty-six named faults. A majority of the fault seal calibration was achieved using fault property predictions from the tool described above. However, despite the use of this tool, adjustment of fault zone properties at a cellular level was still required to achieve acceptable history matches for all of the producing wells in the reservoir interval. In a sense, history matching represents the integration of production data into the process of fault zone characterization.

The case study illustrates that the flow behavior of many faults may be adequately characterized by relatively simple fault prediction methods at the resolution of a reservoir simulation model. However, the predictive capability of the approach remains limited by the accuracy of the fault framework model used to build the faulted stratigraphic grid and on the accuracy of the Vshale volume near the modeled faults. Complex fault zone development that reflects complex variations in strain history, mineralogy, state of lithification, and other geohistory factors is also not easily modeled quantitatively in a standard earth modeling workflow. These current technology limitations explain why additional calibration of the predicted fault flow properties is still required to achieve individual well history matches. Despite these limitations, the use of model-consistent fault zone properties in reservoir simulation appears to be a promising improvement to the history matching process.