Challenges in Pore Pressure Prediction for Unconventional Petroleum Systems

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ABSTRACT

Formation pore pressure prediction is essential for executing a safe drilling program. For unconventional resources, pore pressure has also a significant impact on our ability to artificially fracture shale formations and to achieve successful completion. In addition over pressure increases the production drive of liquid hydrocarbon, and favors higher production rates. Our reservoir engineering models suggest that an increase of pore pressure gradient by 0.04 psi/ft will lead to increase in production rate by 150%, and ultimate recoverable volumes by 73%. Thus accurate pore pressure prediction can enable us a much better resource play economic forecasting, especially in current low commodity price environment.

There are commonly three ways to predict formation pore pressure, seismic method (inversion of interval velocity derived from stacking velocities), petrophysical calculation (the integration of resistivity, sonic and density data to measure porosity and to associate it with vertical effective stress), and basin modeling (finite element simulation from physical/chemical equations that relate to all possible mechanisms of pore pressure generation).

However pore pressure prediction in shale systems is hampered by the lack of "true" pressure values inside shale formations. Due to extremely low permeability in the resource play shales, direct pore pressure measurements with wireline tools for conventional reservoirs do not work. Pressure data in unconventional plays are generally inferred from mud weights and drilling events, instantaneous shut-in pressure (ISIP) during the pad stage, electric Submersible Pump (ESP) pressure gradient estimates or diagnostic fracture injection test interpretations (DFIT). If good quality data are available, these can be used to calibrate pore pressure prediction.

Pore pressure encountered in onshore shale systems can range from significant over pressure, which in many basins is due to uplift and erosion of overburden rocks, to under pressure, where subsurface strata are hydraulically connected via outcropping to high altitude surfaces.

Generation of subsurface abnormal pressure can be one or a combination of several mechanisms: shale rock under-compaction (disequilibrium compaction), lateral compression, aqua thermal expansion, mineral transformation, hydrocarbon generation, cementation, centroid effect, hydrocarbon buoyancy, etc. Pore pressure prediction from basin modeling approach depends on the good understanding of physical principle of each process, and our ability to decide which of these processes play a more dominant role than the others. This presentation will describe our experience when using different modeling tools to reconstruct formation pore pressure. Many times default shale compaction curves, while being very effective in over pressure generation for offshore Tertiary basins, are inadequate to cause large magnitude over pressure in unconventional shales, because these curves are probably representing much higher permeability than those observed in these shales. The contributions from hydrocarbon generation and aquathermal effect are often needed, and significant, for additional over pressure

generation. Chemical compaction via quartz/carbonate cementation provides an alternative or addition to simulate pore pressure transition. The presentation will also discuss the impact of complex burial/uplift history to overburden and pore pressure evolution in shale systems.

The fact that some high abnormal pressures have existed for tens to hundreds of million years after original shale deposition and after hydrocarbon generation has baffled geologists as to how these over pressure systems were formed and persisted in geologic history. These observations and the way we understand them will also have implications on the interpretation of inter-connectivity of subsurface pore systems, and on the hydrocarbon charge and migration in and out of unconventional shales.