Understanding the Role of Natural Fractures and Faults as Potential Fluid Pathways Through the Colorado Shale

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The Primrose heavy oil reservoir produces in the order of 90,000 barrels a day of bitumen through high pressure cyclic steam injection from the Clearwater Formation. During 2013, a number of flow to surface (FTS) events were experienced where bitumen emulsion was found to have migrated upwards through several metres of Clearwater Capping Shale, the Grand Rapids Formation (~115 m) and the thick (~170 m) overlying Colorado Group shales, resulting in a surface expression. Following the discovery of these FTS events, an extensive phase of forensic investigation including drilling >50 deep delineation wells was carried out in order to attempt to understand the nature of the sub surface pathways. What became clear was that there were a myriad of potential candidates that could act as flow pathways including well bores, natural fractures, seismic scale tectonic faults, polygonal faults and induced hydraulic fractures, and that diagnosing the nature of the pathway was a complex undertaking. This papers presents and synthesizes various fracture data sets in order to highlight evidence that supports the roles of fractures and faults in the migration of bitumen emulsion. This analysis was supplemented by both Discrete Fracture Network (DFN) modelling as well as small scale coupled hydro-mechanical models to test important conceptual flow models.

A key observation has been the variability with depth of the dip of oil filled fractures identified from the drilling program within the Colorado Group. When the stress data are integrated with the orientation of oil filled fractures, there appears to be strong geomechanical control. Natural fractures within the Westgate, Fish Scales, and Belle Fourche formations are dominated by steeper dips, greater than 50 degrees. However, in the thrust fault stress regime of the lower Colorado Group, low angle fractures were primarily exploited by migrating hydrocarbons as the vertical stress is the minor principal stress and therefore lower angle fractures require the lowest pore pressure to overcome the closing normal stresses. This is consistent with an analysis of oil filled fractures within these formations. In the SWSPs and Niobrara Formations where a strike slip stress regime exists, it is sub vertical fractures that are primarily seen to be oil filled, consistent with that predicted from geomechanics and the orientation requiring the lowest pore pressure to overcome the closing stresses.

Discrete Element Model (DEM) geomechanical simulations indicate that the development of horizontal hydraulic fractures within the lower Colorado Group is consistent with available geomechanical and fracture observations. If such hydraulic fractures were allowed to extend into existing low angle structures (fractures or bedding plane partings), it is possible that a small subset of shallow dipping fractures could be hydraulically opened and that this could provide elevation gain for bitumen emulsion. Simulations of the interaction of hydraulic fractures with inclined natural fractures within the Westgate - Belle Fourche thrust fault stress regime show that it is possible for hydraulic fractures to interact with and be diverted by low angle structures. However the hydrodynamics of high viscosity systems (typical Primrose viscosities are in the order of ~30,000-70,000 cP) is such that it is difficult to divert viscous emulsions with no simulations with a fracture interception >18 deg dip angle being diverted.

Whilst larger seismic scale faults (tectonic or polygonal) may provide possible vertical conduits to flow, no evidence of their hydraulic significance has been identified. This is based upon the lack of oil shows and oil filled fractures being associated with seismic scale polygonal or regional faults; the limited correlation of any drilling losses with faults in the Colorado Group and FTS pathways do not appear to be diverted when intersected by faults within the system.