EVALUATION OF SOLITARY WAVES AS A MECHANISM FOR OIL TRANSPORT IN ELASTIC POROUS MEDIA: A CASE STUDY OF THE SOUTH EUGENE ISLAND FIELD, GULF OF MEXICO BASIN

Ajit Joshi

Dr. Martin Appold, Thesis Supervisor

ABSTRACT

Hydrocarbons in shallow (< 1 km depth) Pleistocene sand reservoirs of the Eugene Island 330 field in the northern Gulf of Mexico basin are thought to have originated from Early Tertiary source sediments at depths of about 4.5 km. Despite the low permeability of the intervening sediments, hydrocarbons appear to have moved rapidly through these sediments, which are hypothesized to have occurred as solitary waves, i.e. discrete pressure pulses, along the Red growth fault system. The purpose of the present research was to evaluate the mechanics of solitary wave formation and movement during sedimentation, diagenesis, and source rock maturation in the Eugene Island hydrocarbon field. A detailed two-dimensional model coupling sedimentation, compaction, hydrocarbon generation, heat transport, and multi-phase fluid flow predicted overpressures of 52 MPa by the present day in the hydrocarbon source sediments, with most of the overpressure caused by compaction disequilibrium and the remainder by hydrocarbon generation. Movement along the Red growth fault was rapid enough to cause a pressure decrease of several MPa from the upthrown block to the downthrown block, consistent with field observations. The average pressure generation rate at the

base of the Red fault during the period of hydrocarbon formation was predicted to be about 10^{-6} Pa/s. Based on the likely values of fault permeability and the calculated magnitude of the pressure gradients generated by the compaction-dominated flow regime, flow velocities on the order of 10^{-6} m/Myr would be expected, which is far too low for hydrocarbons to ascend kilometer-scale distances and accumulate in shallow Pleistocene reservoirs within the 3.6 million year lifespan of the minibasin.

To evaluate solitary wave behavior, a separate one-dimensional model was constructed that used the pressure generation rate determined from the two-dimensional basin model and solved the continuity equation for a single fluid phase consisting of oil using an implicit finite difference method over a five kilometer vertical profile. The calculations showed that solitary waves were only able to form and migrate over a narrow permeability range of about 10^{-25} to 10^{-24} m^2. Within this permeability range, solitary waves could reach velocities on the order of 10^{-3} m/yr. For permeabilities greater than 10^{-24} m^2, fluid pressures diffuse too rapidly from the source region for a coherent wave to form. For permeabilities lower than 10^{-25} m^2, the solitary wave grows to large amplitude but is effectively immobile over million year time scales. Solitary wave formation and propagation required high initial fluid pressures in the range of about 91-93% of lithostatic pressure. When fluid pressure lay outside of this range, then because of the sensitivity of permeability to effective stress, permeability lay outside of the 10^{-25} to 10^{-24} m^2 range such that solitary waves either did not form or formed but did not move significantly from their source location. As solitary waves ascend, their velocity increases while their amplitude diminishes and they leave behind a wake of slightly elevated fluid pressures (typically 1-2 MPa above the initial background values) that increases the permeability enough to prevent further solitary waves from forming. Thus, for time spans on the order of the 3.6 million year history of Eugene Island, solitary waves would not form in succession, which limits their hydrocarbon transport efficacy. Solitary waves were only able to ascend 1-2 kilometers from their source regions before their amplitudes diminished to background fluid pressure and porosity values. As they ascend their velocity increases from order 0.1 mm/year to order 1 mm/year. Wave volume was found to increase during the early stages of ascent, peaking after a travel distance of about 0.5 to 1 km at a pore volume of about order 10^5 m^3. Thus, solitary waves are unlikely to have charged the shallow Pleistocene reservoirs at Eugene Island with oil, though it is possible that solitary waves could be important agents of oil transport in other locations where the reservoirs are more proximal to the source rocks.