Geology, Heterogeneity, Steam-Rock Interaction Studies of the First Eocene Carbonate Reservoir Steamflood Pilots: Impact on Understanding Fluid Flow*

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Abstract

The Paleocene/Eocene age First Eocene dolomite reservoir is a candidate for continuous steamflooding due to its large resource base and low estimated primary recovery. There are currently two steamflood pilot projects in operation to evaluate reservoir response to steam injection: a 1.25-acre, single pattern pilot (SST) and a 40-acre, 16 pattern pilot (LSP) are in progress. The densely sampled pilot's provide a unique opportunity to assess reservoir heterogeneity and its impact on steamflooding. At the SST, an interval with abundant tidal flat cycle caps characterized by muddy, finely crystalline dolomites may be responsible for the observed vertical barrier to steam migration. Detailed studies, including routine core analyses, micro-permeameter measurements, quantitative mineralogical studies, micro-CT scans, and MICP were used to quantitatively characterize the permeability heterogeneity and its impact on recovery forecasts derived from ultra fine-scaled dynamic models.

Geological data obtained from the LSP suggest that similar vertical barriers may exist in the pilot area. Early steamflooding results show multiple thermal "events" (most likely baffles rather than barriers) in the lowermost flooded zone. The early LSP data from this zone allows inferences to be made regarding the occurrence and distribution of lateral high permeability "connections" between injectors and producers. While the rapid temperature response observed in a few wells may reflect local fractures or karst zones, numerical simulation using very fine grids (1.25 m areal cell size) shows that some of the LSP wells will experience relatively short breakthrough times without the need for fracture or karst-like zones. Over time, injection of high temperature, high pH fluids may complexly affect the fluid flow field, the thermal field, and the fluid/rock interactions near well, and in the reservoir. This in turn could affect storage capacity, production, and injectivity.

Two-dimensional (2D) reactive transport models (RTM) were run to simulate high pH, steam injection into the First Eocene dolomite reservoir for a continuous injection period of 6 months to a year, with the objective to understand changes in mineralogy, coupled with porosity change and potential scaling issues. Initial results predict precipitation of calcite and brucite, dissolution of dolomite, and conversion of gypsum to anhydrite. Sensitivity studies are currently ongoing involving steam quality, rock surface area, reaction rates, and mineralogy of evaporites.

References Cited

Meddaugh, W.S., W.T. Osterloh, S.F. Hoadley, N. Toomey, N. Champenoy, S. Bachtel, D.E. Rowan, J. Brown, F.M. Al-Dhafeeri, and A.R. Deemer, 2011, Impact of Reservoir Heterogeneity on Steamflooding, Wafra First Eocene Reservoir, Partitioned Zone (PZ), Saudi Arabia and Kuwait: SPE Heavy Oil Conference and Exhibition, 12-14 December 2011, Kuwait city, Kuwait, SPE 150606, 19 p..

Osterloh, W.T., W.S. Meddaugh, and D. Mims, 2011, Probabilistic Thermal Simulation of the 1st Eocene Large Scale Pilot (LSP) Steamflood, Partitioned Zone (PZ), Saudi Arabia and Kuwait: SPE Heavy Oil Conference and Exhibition, 12-14 December 2011, Kuwait city, Kuwait, SPE 150580, 23 p.

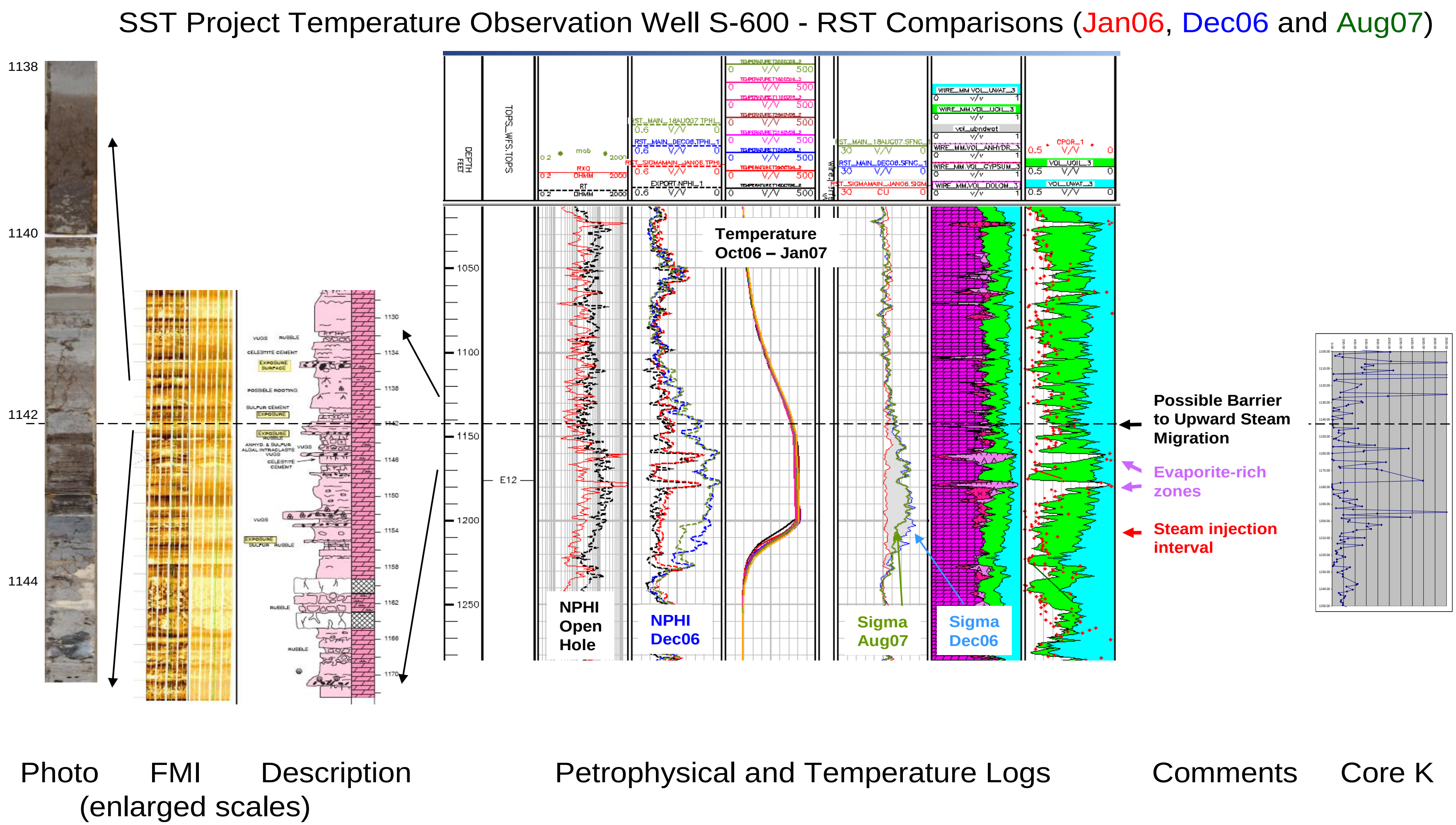


Figure 1. Summary of selected temperature observation well data along with petrophysical logs, core description, FMI log, core photographs, and core permeability data for the zone near the observed barrier to vertical steam migration just above the EOC600 evaporite. Note the tracks at far left are at an expanded scale relative to the main part of the figure. Note also the vertical variability of core plug permeability shown at the far right. Example from the Small Scale Test (SST) steamflood pilot (after Meddaugh et al., 2011).

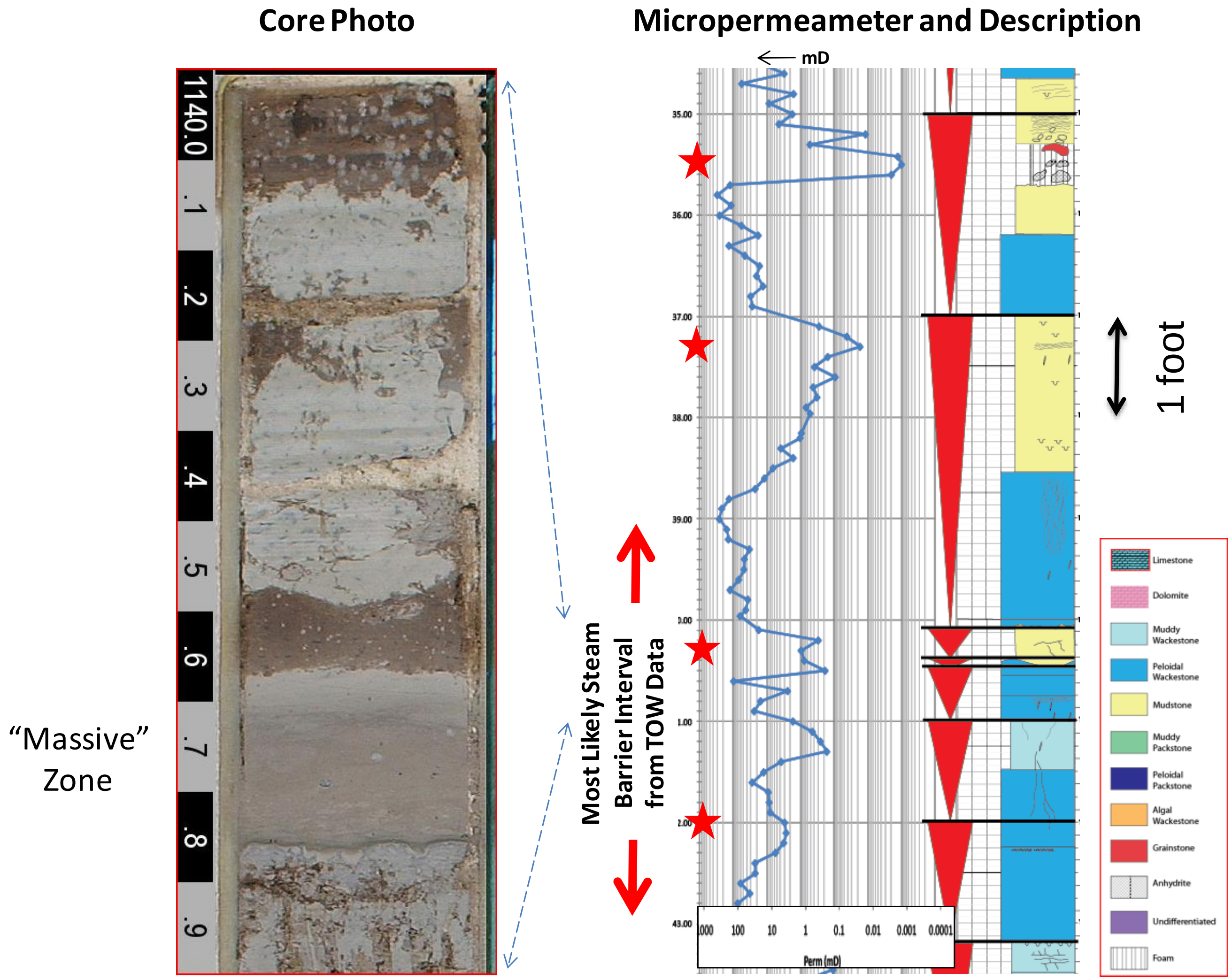


Figure 2. Based on the TOW data the most likely depth of the steam barrier is 1142±3 feet MD. However, as the TOW does not sufficiently resolve the vertical location of the steam barrier, micropermeameter data was collected every 0.1 foot and an ultra-detailed core description was completed over interval. This work is summarized above. Stars highlight the generally very low permeability at cycle tops. There is a cycle top at 1142 feet MD, but it has numerous small fractures and does not visually look like it would be a barrier to steam. Within the interval from 1140-1141 feet MD there is a “massive” competent unit (about 0.2 feet thick) of packstone and mudstone with no fractures. This is more likely the vertical barrier to steam. A post-steam core (planned for mid-2012) is required for verification (after Meddaugh et al., 2011).

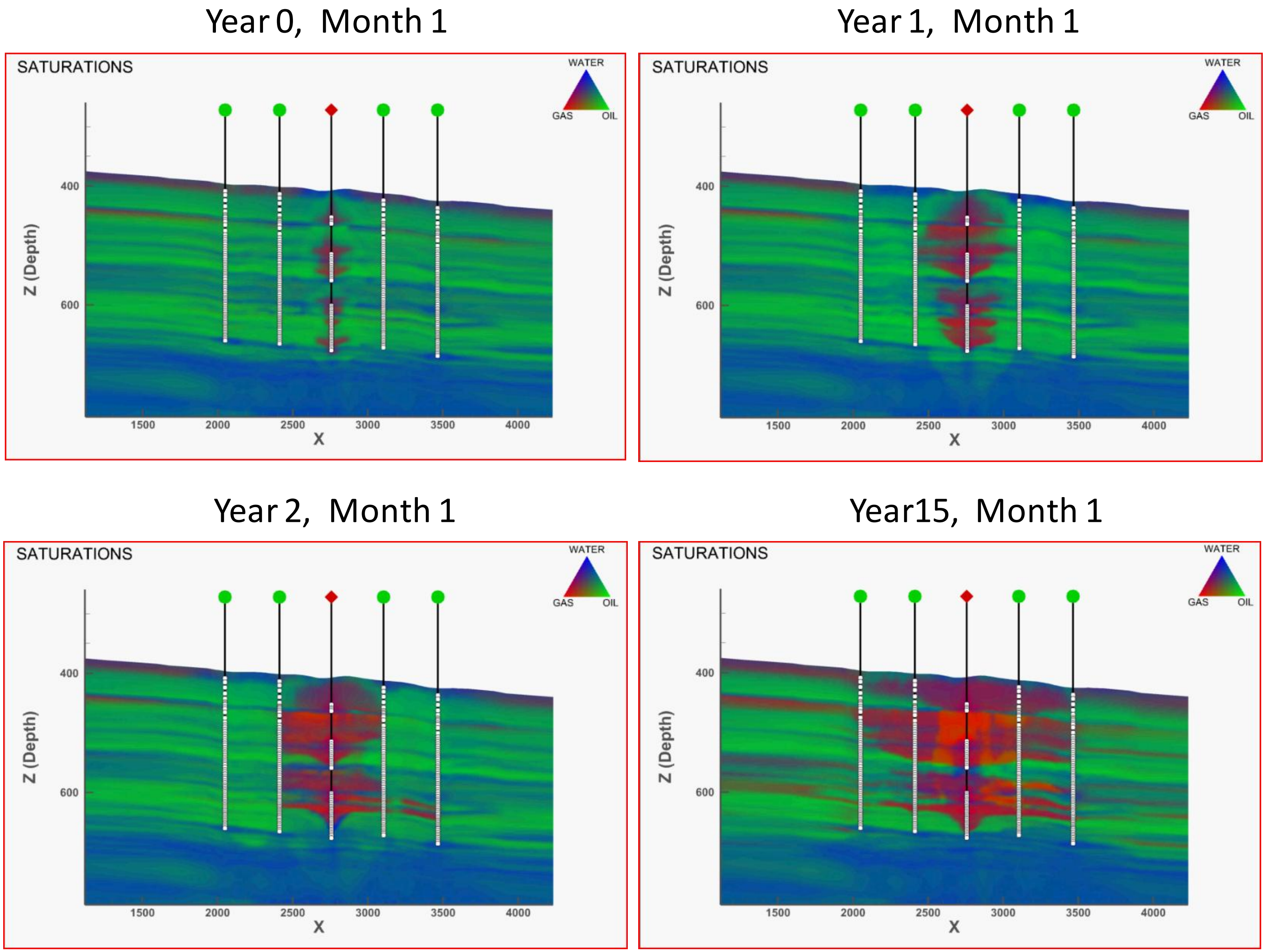


Figure 3. "Time slices" from LSP area thermal simulation model showing change in saturation over time. Central injector is completed in all three steam zones. Producers completed through entire interval. Even though vertical and lateral heterogeneity yields a "messy" sweep of the reservoir, continuous steam injection does yield reasonable overall recovery (after Meddaugh et al., 2011).

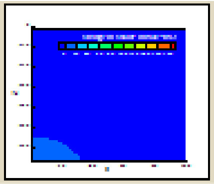
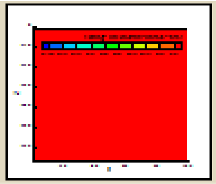
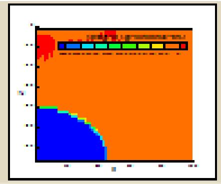
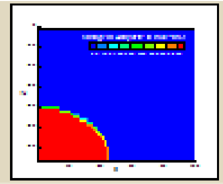
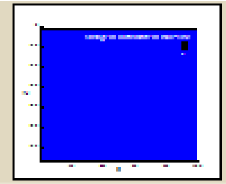
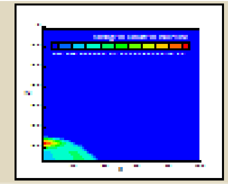
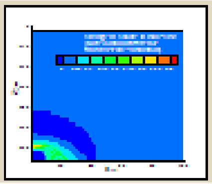
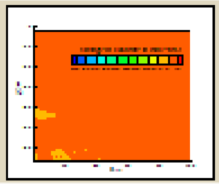
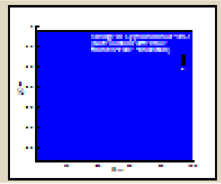
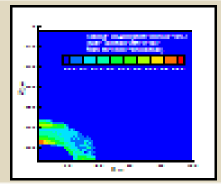
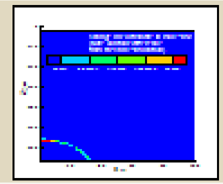
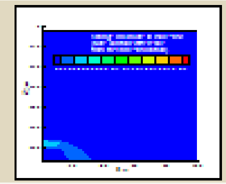
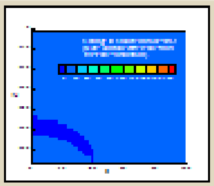
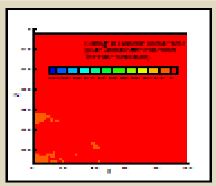
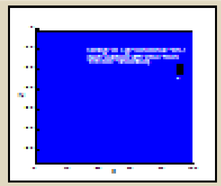
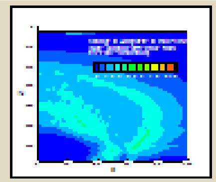
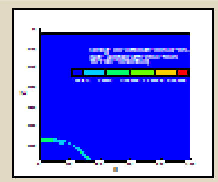
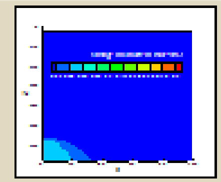
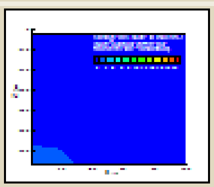
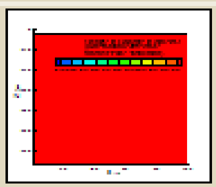
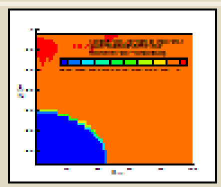
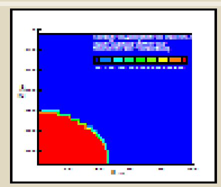
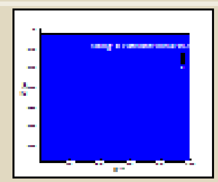
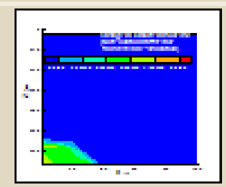
Results	Calcite	Dolomite	Gypsum	Anhydrite	Portlandite	Brucite
Baseline - 95% dolomite, 5% gypsum reservoir; high pH, high T injection						
100% Dolomite reservoir, no evaporite; high pH, high T injection						
95% Dolomite, 5% Anhydrite reservoir; high pH, high T injection						
Neutral pH - 95% dolomite, 5% gypsum reservoir; neutral pH, high T injection						

Figure 4. Summary of some preliminary RTM runs showing impact of steam injection under varying conditions (quality, rock mineralogy).