Multidisciplinary data integration: A case study from a heavy oil reservoir

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Summary

We analyze monitoring data over a heavy-oil steam injection field, including time-lapse 2D reflection seismic data, microseismic data, production data, and tiltmeter recordings. During cyclic steam stimulation, the reservoir-caprock system undergoes multiple changes due to imposed high pressures and temperatures, including dilation, compaction, and alterations of rock physics properties. We find that microseismic activity is more likely to occur in the overburden due to stress-induced failure in brittle rocks, whereas seismic reflection data highlight the changes at the reservoir level, predominantly because of temperature-induced viscosity changes in the in situ heavy oils. A joint interpretation of multiple datasets thus provides a more complete picture of the reservoir-caprock response to steam injection and production.

Introduction

Thermal heavy oil extraction techniques involve high temperatures and pressures to produce heavy oil. During thermal recovery, the temperature can rise to 350^{o}C, and the reservoir undergoes complex mechanisms absent in conventional reservoirs (Shafiei & Dusseault, 2013). In addition to thermal conduction and convection, the reservoir also experiences geomechanical changes. Elevated temperature and pressures alter the subsurface stresses, causing shear failure of rock within and surrounding the steam front. The steam also introduces volumetric changes at the reservoir level, and its impact may also propagate to the surface resulting in surface heaves. These changes make it difficult to understand how steam moves inside the reservoir, which adds uncertainty to the understanding of steam recovery processes.

Valuable information on unconventional reservoirs can be obtained by various geodetic and seismic techniques used in the industry e.g., seismic reflection surveying, microseismic monitoring, tiltmeter, and interferometric radar (InSAR). Unfortunately, few case histories exist integrating various geophysical datasets to monitor the spatial and temporal evolution of the steam front during heavy oil extraction. We analyze and integrate multidisciplinary geophysical data to investigate and better understand the impact of steam injection and oil production on the reservoir-caprock system.

Results

Microseismic events were located during four steam-injection/production cycles. Figure 1 shows the microseismic locations, both in map view, East-West cross-section, and histogram, summarizing the event count per cycle. The histogram of event count per cycle indicates that most of the microseismicity was triggered during the first cycle, and less events were recorded during cycles 2, 3 & 4. A large number of events is concentrated in the NE portion of the pad, forming a NE-SW trend close to the monitoring well. The majority of these events are clustered in the overburden (Wilrich and Falher Member); solely a few events occur inside the reservoir portion (Bluesky Formation). 70% of events are recorded during the first injection cycle. The microseismic activity recorded after the first cycle is more scattered (Figure 1).

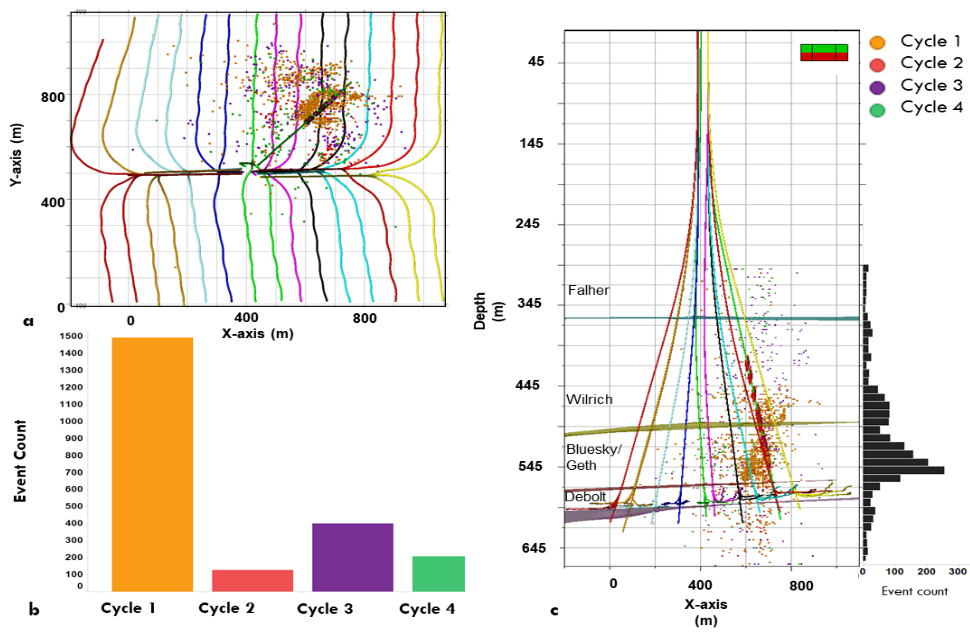

Figure 1: a) A map view of microseismic event location over the pad, b) Histogram of event count for each injection cycle, and c) Cross-section view and depth histogram of microseismic event distribution across the pad, horizontal colored lines indicate geological formations of interest, e.g., Falher Member, Wilrich Member, Bluesky, and Debolt Formations are shown as blue, yellow, red and purple colors, respectively. Microseismic events are colored based on their time of occurrence. Events that occurred during cycles 1, 2, 3, and 4 are colored as solid yellow, red, purple, and green circles, respectively.

The time-lapse reflection seismic data show travel time shifts and amplitude anomalies within the reservoir interval. Two isolated amplitude anomalies are found within the reservoir, at respectively the Eastern and Western portions, but at different depths. The isochron difference map of the reservoir also shows time thickening at the center of the pad (Figure 2). These delays are due to decreased P-wave velocities due to steam injection and/or increased reservoir thickness because of thermal expansion. Both the amplitude changes and the isochrone map indicate a non-homogenous steam distribution inside the reservoir. This is further supported by comparing the isochrone difference map and two temperature logs (Figure 2).

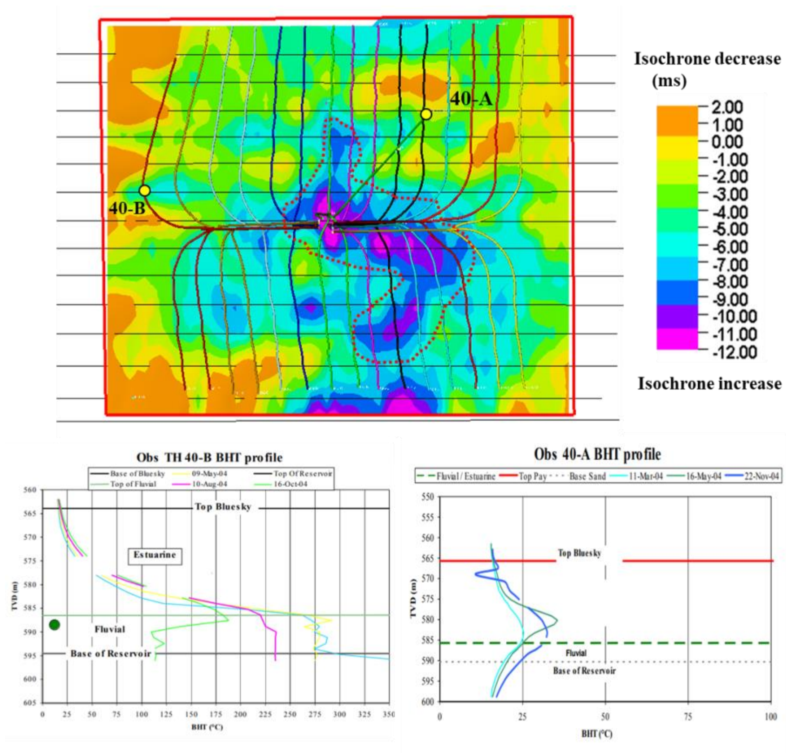

Figure 2: Isochrone difference map for the reservoir (top) and temperature profiles from two observation wells at the pad.

Discussion

Significant work has been done by Maron et al. (2005) to investigate and understand the steam movement and associated geomechanical processes in and around the reservoir. According to Maron's model, steam transfer into the unproduced reservoir occurs under fracturing conditions, which would be supported by the presence of microseismicity inside the reservoir during steam injection. Conversely, we find that most microseismic activity occurs in the caprock, and very limited microseismicity is triggered in the reservoir.

Computation of the brittleness index based on logs shows that the overburden is more brittle than the reservoir. Furthermore, the conceptual model of Dusseault & Collins (2010) argues that stiffer rock ahead of the heated zone is subjected to increased stresses and eventually will be forced into its yielding condition. Thus, rock in advance of the propagating steam front may shear at low confining stresses. This also creates a large concentration of stresses between the reservoir and overlying impermeable non-expanding caprock. As a result, effective stresses decrease in the caprock, causing shear failure, resulting in microseismic activity. Their conceptual model is supported by our observed microseismic location patterns.

Conclusion

Analysis of single datasets can produce misleading interpretations. Solely using the microseismic data in our case study could have been interpreted as steam or reservoir fluids leaking into the overburden, thereby compromising caprock integrity. Similarly, the time-lapse reflection data only highlight steam-assisted changes within the reservoir zone but fail to show the impact of steam injection and hydrocarbon extraction on the surrounding rocks, e.g., small-scale fracturing in the overburden, responsible for triggering of microseismicity. Multidisciplinary data are needed to link geomechanical changes with the geophysical observables to ground truth and calibrate any proposed models. Steam injection not only changes the physical properties (velocity, density, volume) of the reservoir but also affects its geomechanical properties (stresses and rock strength) and those of the surrounding rock. We find that reflection seismic data highlight changes occurring at the reservoir interval, whereas microseismic data reveal the changes in the caprock. A complete picture of subsurface changes requires integrating multiple geophysical datasets.

Acknowledgment

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References

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