INTEGRATED MODELING AND SIMULATION FOR CO_2 EOR AND CO_2 STORAGE IN THE ZAMA PINNACLE REEFS OF THE ALBERTA BASIN, CANADA

Guoxiang Liu, Jason R. Braunberger, Charles D. Gorecki, Panqing Gao, Wesley D. Peck, Edward N. Steadman, and John A. Harju

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, North Dakota 58202-9018

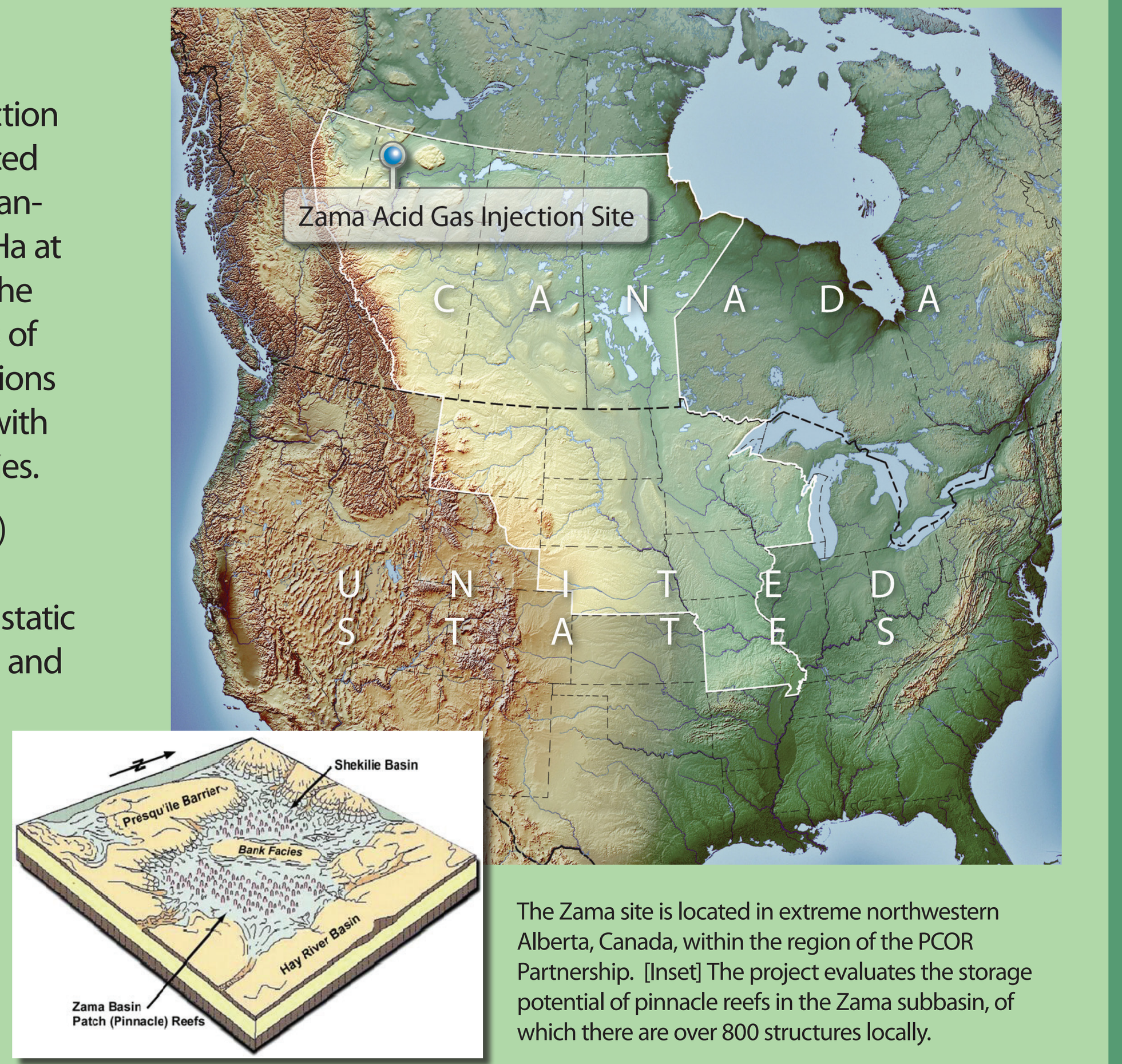
Abstract

The Zama oil field in northwestern Alberta, Canada, has been the site of acid gas injection (70% carbon dioxide [CO_2] and 30% hydrogen sulfide [H_2S]) for the purpose of enhanced oil recovery (EOR) and CO_2 storage since 2006. Oil and gas are produced from Devonian-aged pinnacle reefs encountered at an average depth of 1500 m and are typically 16 Ha at their base and 120 m tall. More than 700 of these reefs have been discovered within the Keg River Formation that have been sealed into "closed reservoirs" by tight anhydrites of the Muskeg Formation. Because of the size of each structure, the number of penetrations and portfolio of characterization data tend to be limited. The pinnacle reef reservoir with the most associated data, the Zama F Pool, was selected for detailed modeling activities.

The Energy & Environmental Research Center, through its Plains CO_2 Reduction (PCOR) Partnership, is working with Apache Canada Ltd. to validate the amount of CO_2 stored during the ongoing EOR operations in the Zama F Pool. This study provided detailed static geologic modeling and dynamic reservoir simulation to evaluate future EOR potential and CO_2 storage capacity as well as the long-term fate in this closed system.

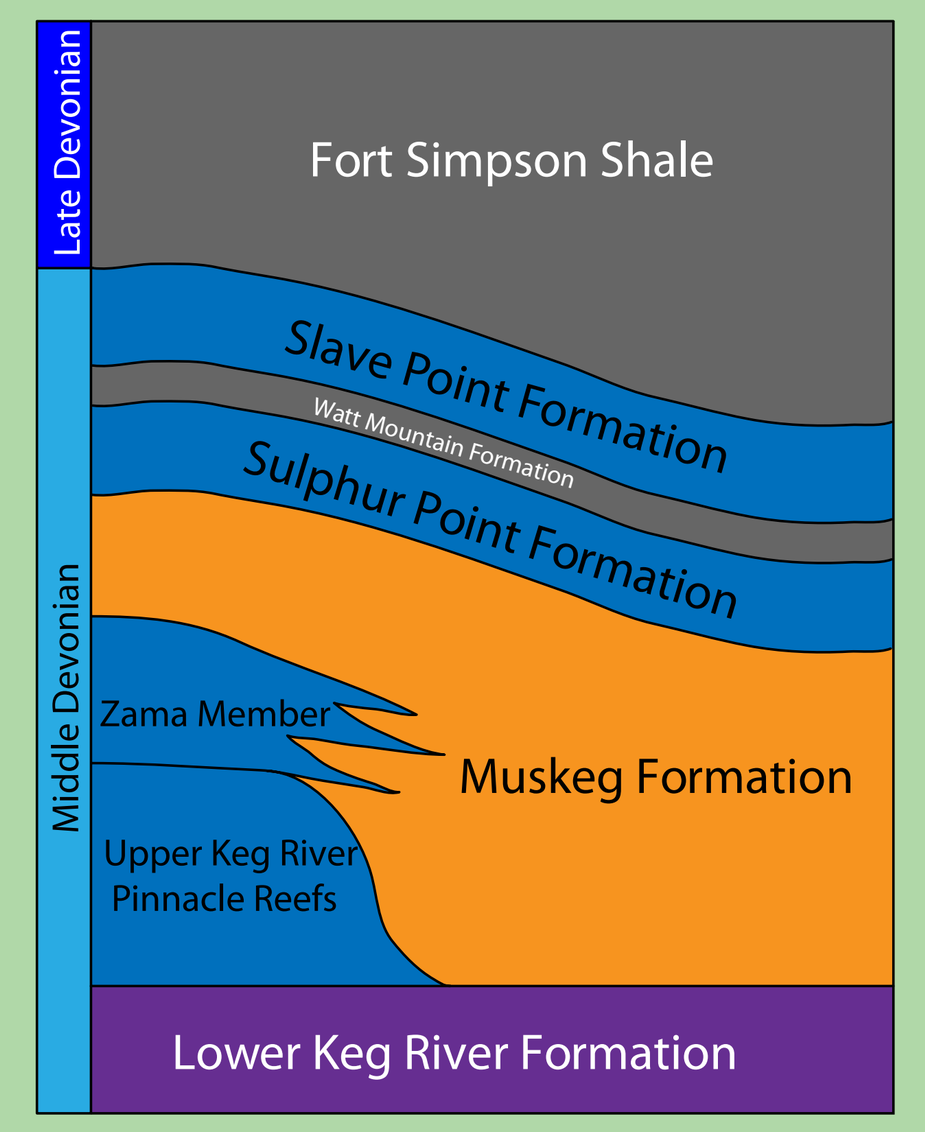
Predictive simulations explored the possibility of additional storage capacity gain by pressure management through water extraction from below the oil–water contact and optimization of the acid gas flood to maximize production.

Two simulation scenarios were produced, the first to maximize the storage volume of the Zama F Pool by exploring various water extraction scenarios and the second to optimize the EOR program.

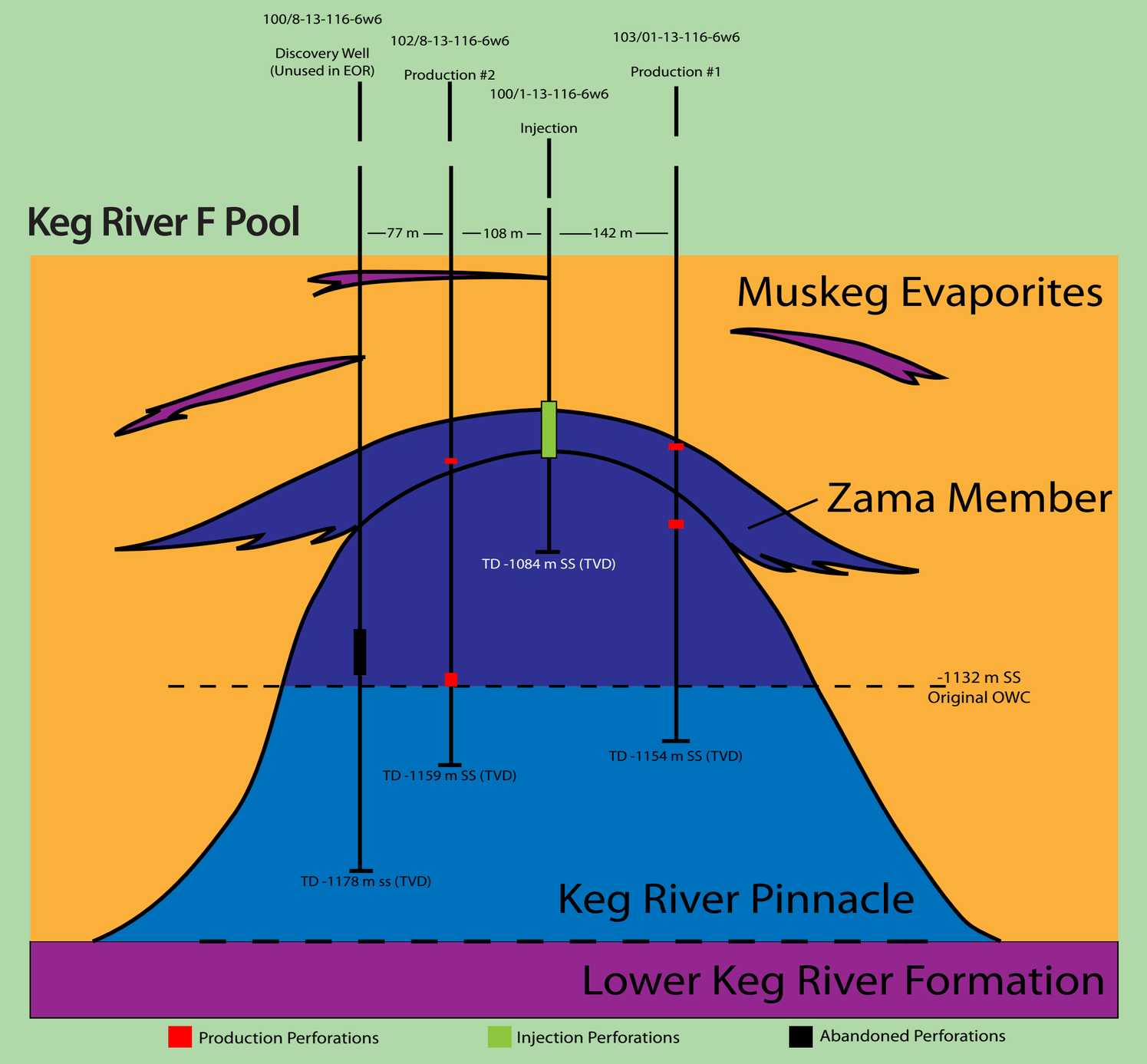


The Zama site is located in extreme northwestern Alberta, Canada, within the region of the PCOR Partnership. [Inset] The project evaluates the storage potential of pinnacle reefs in the Zama subbasin, of which there are over 800 structures locally.

Keg River F Pool Characteristics



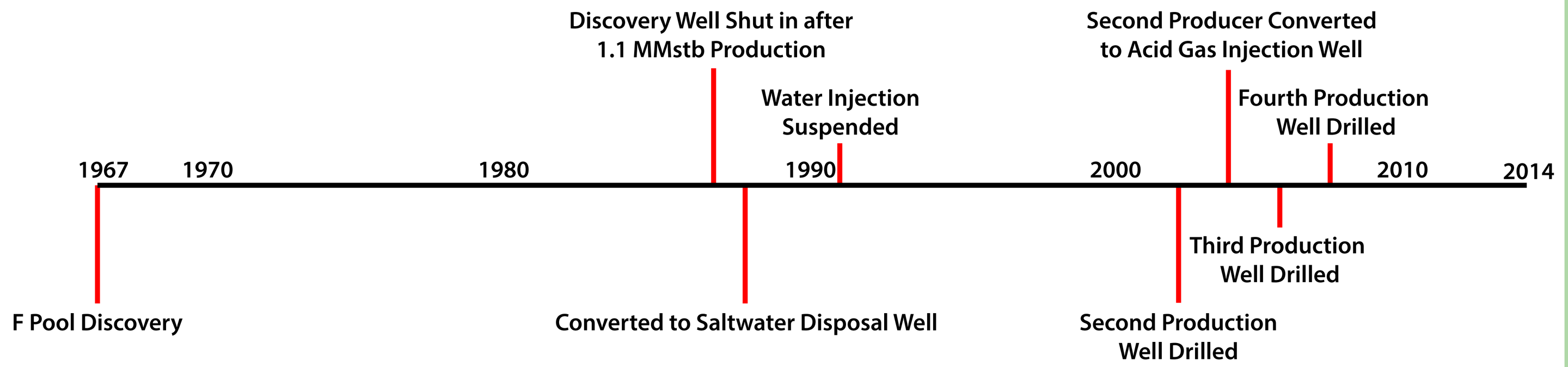
Partial stratigraphy of the Devonian succession in the Zama subbasin. This project focuses on acid gas EOR occurring in the Upper Keg River pinnacle reefs that for "closed" systems within the surrounding Muskeg evaporites.



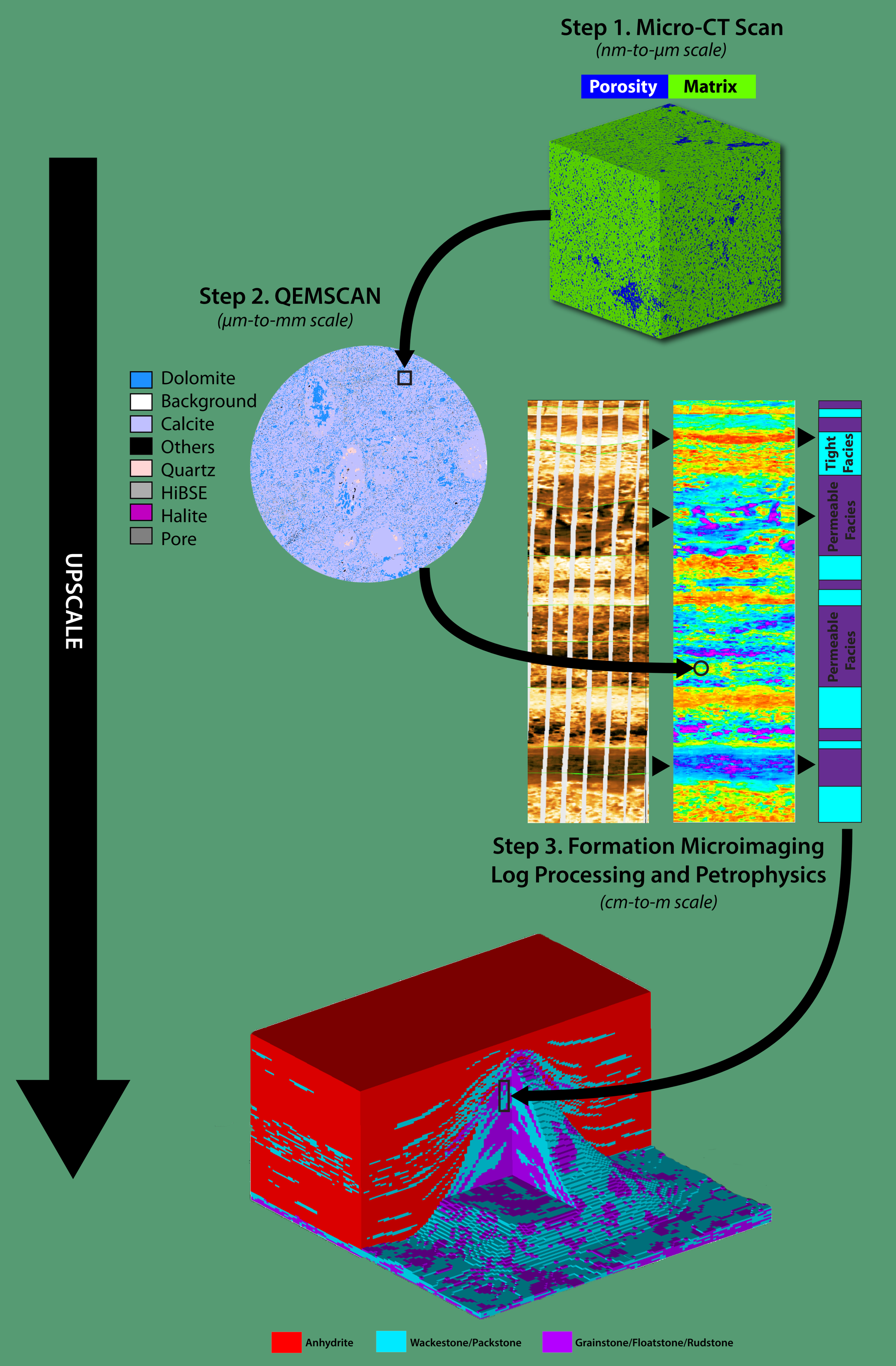
Schematic of F Pool installations. Acid gas is injected into the top of the structure, and oil is produced along the flanks.

F Pool Reservoir Characteristics

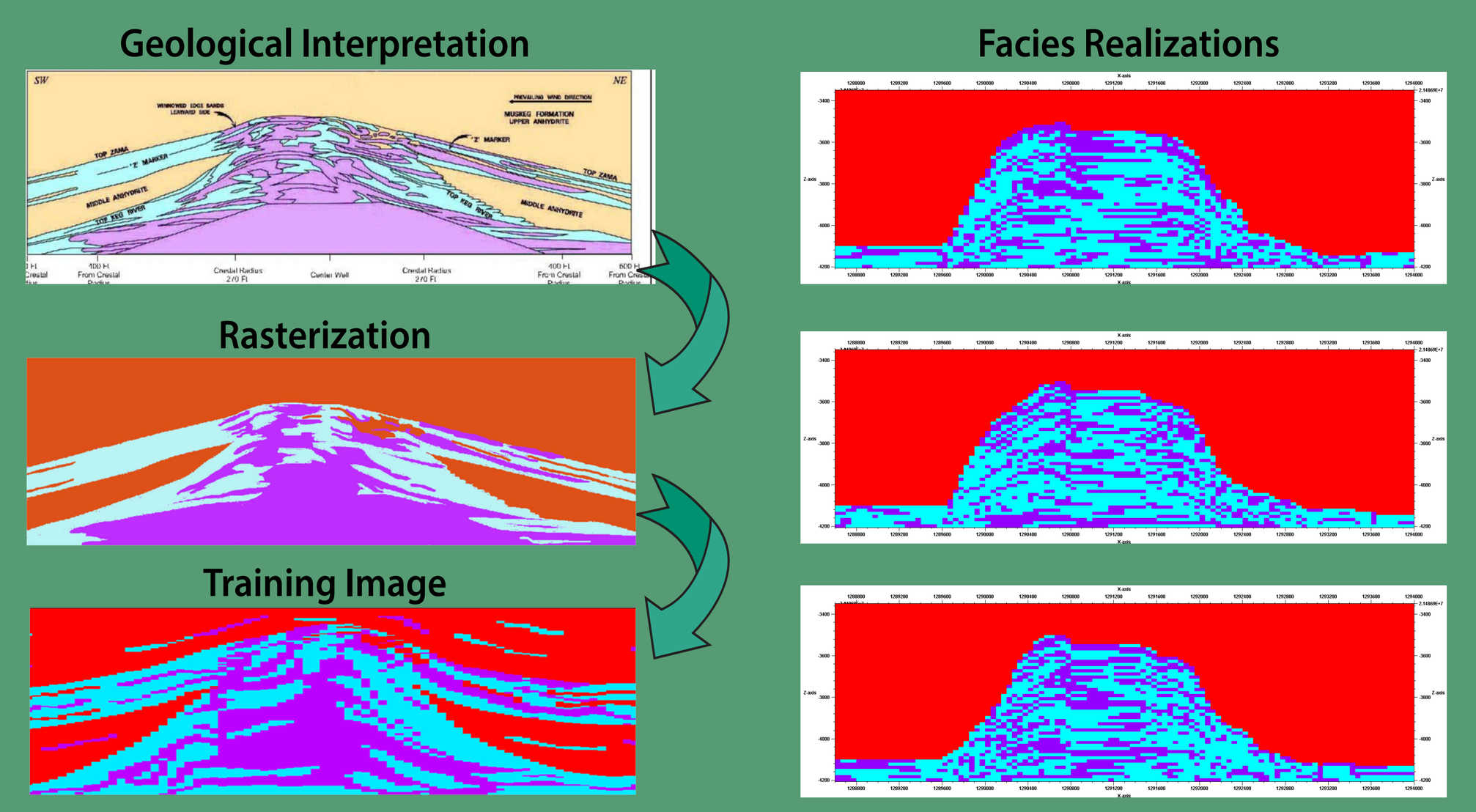
Discovered:	1967
Original oil in place (OOIP):	6.10 x 10^5 m^3 (3.93 MMstb)
Production:	1.71 x 10^5 m^3 (1.1 MMstb)
API Gravity:	35.2°
Porosity:	0.03 to 17%
Permeability:	<0.001 to >1000 mD
Res. Pressure:	14,445 kPa (2095 psi)
Res. Temperature:	71.1°C (160°F)
Gas-oil ratio:	52 m^3/m^3 (282 scf/bbl)
Acid gas injected:	121,200 tonnes (133,600 tons)



General Modeling Workflow

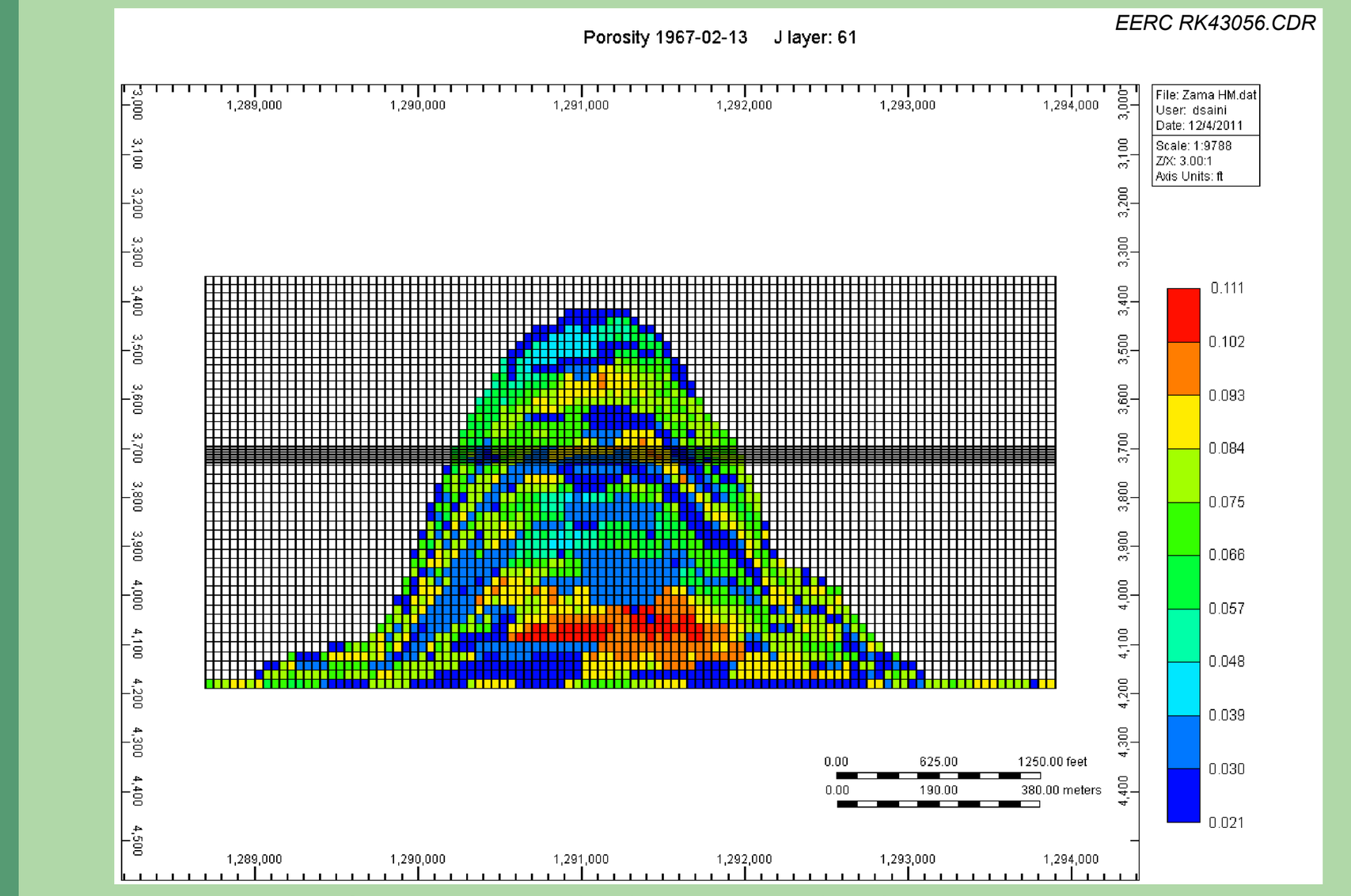


Step 4. Form Reservoir Model
(10s of m-to-km scale)

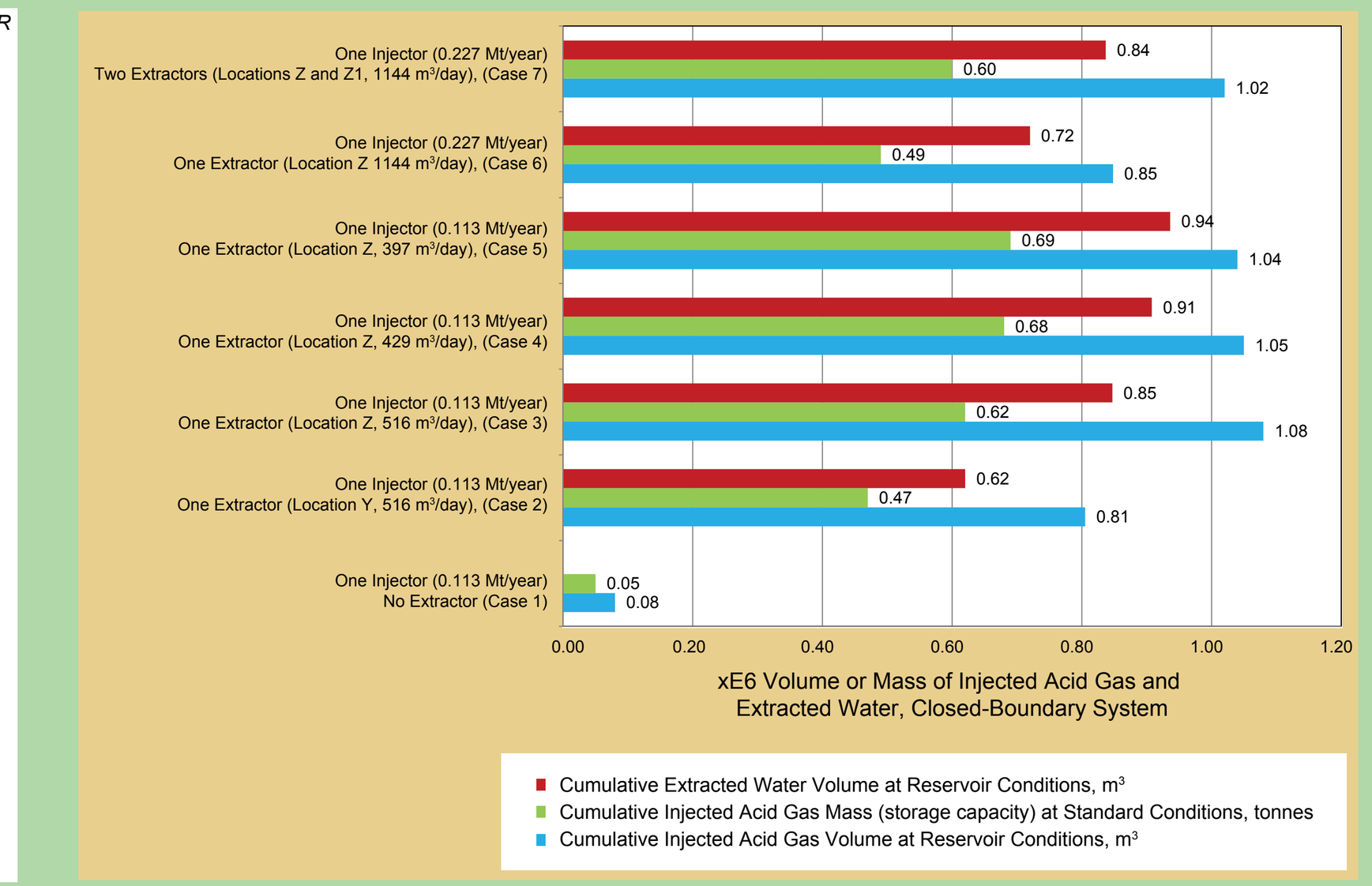


[Left] A geological interpretation of the F Pool was used to create training images in Schlumberger's Petrel. [Right] Three different outputs of the multiple-point statistics population using the training image.

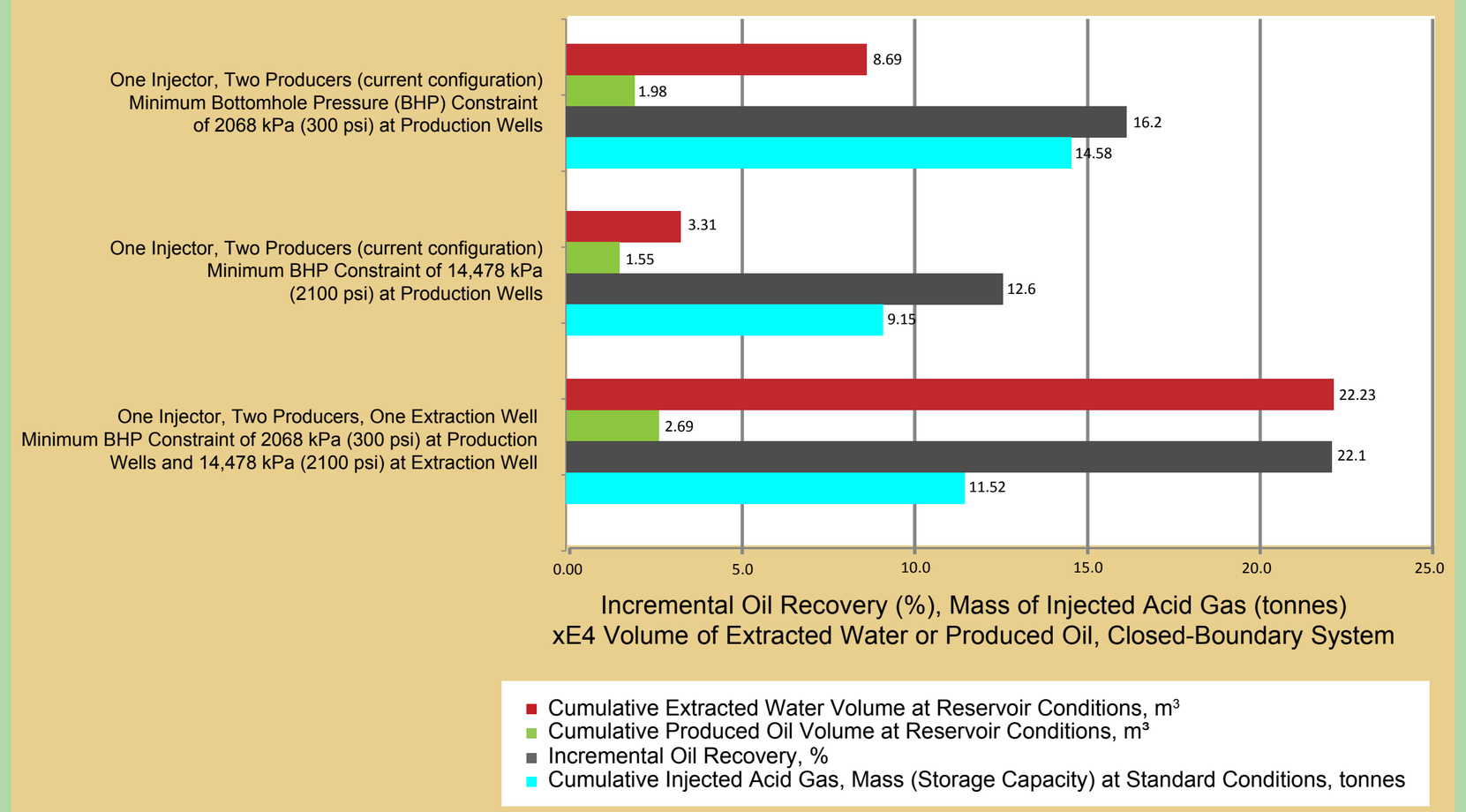
Scenario 1 – Storage Capacities with and Without Extraction

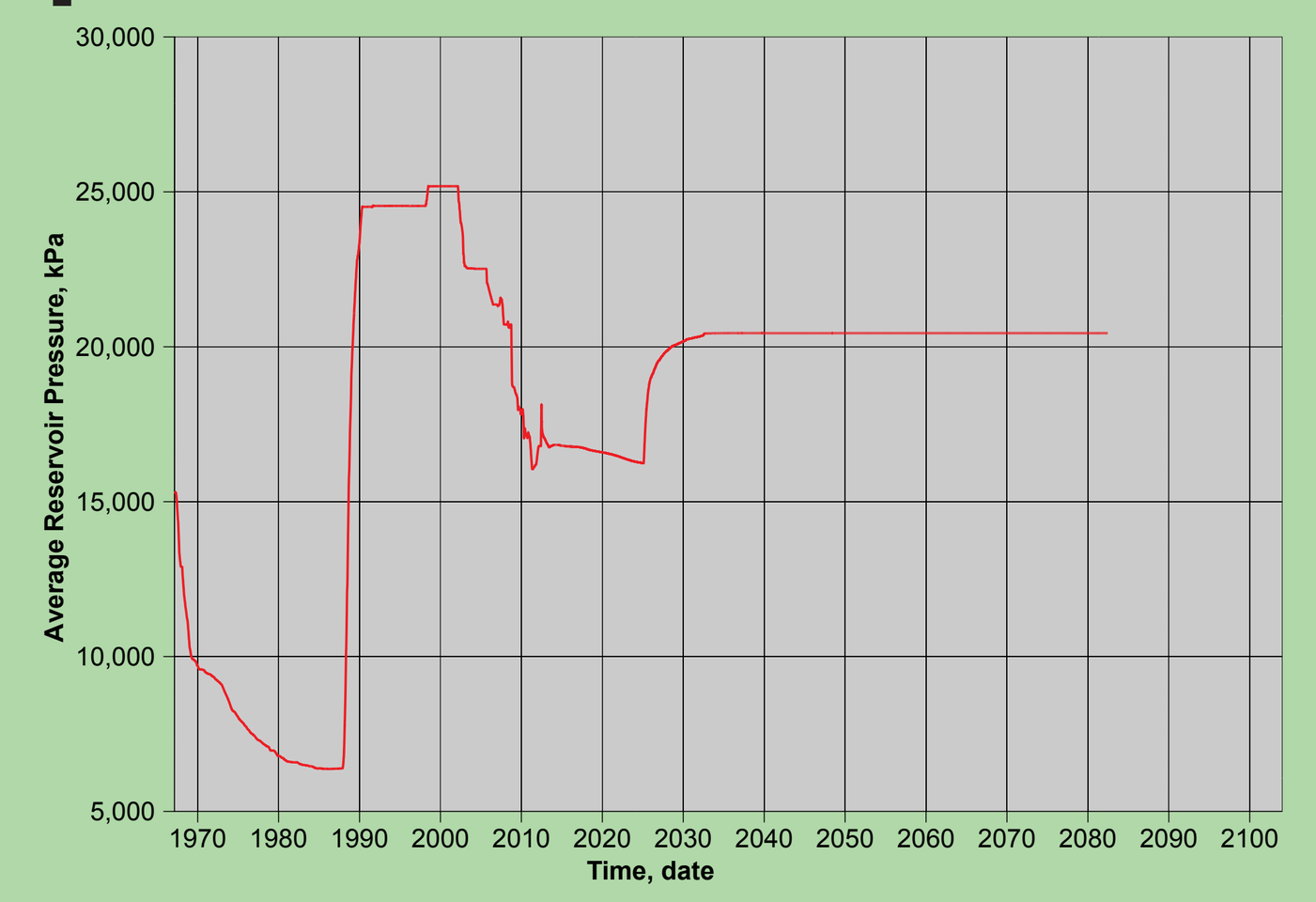


2-D slice of simulation model depicting modeled F Pool porosity.

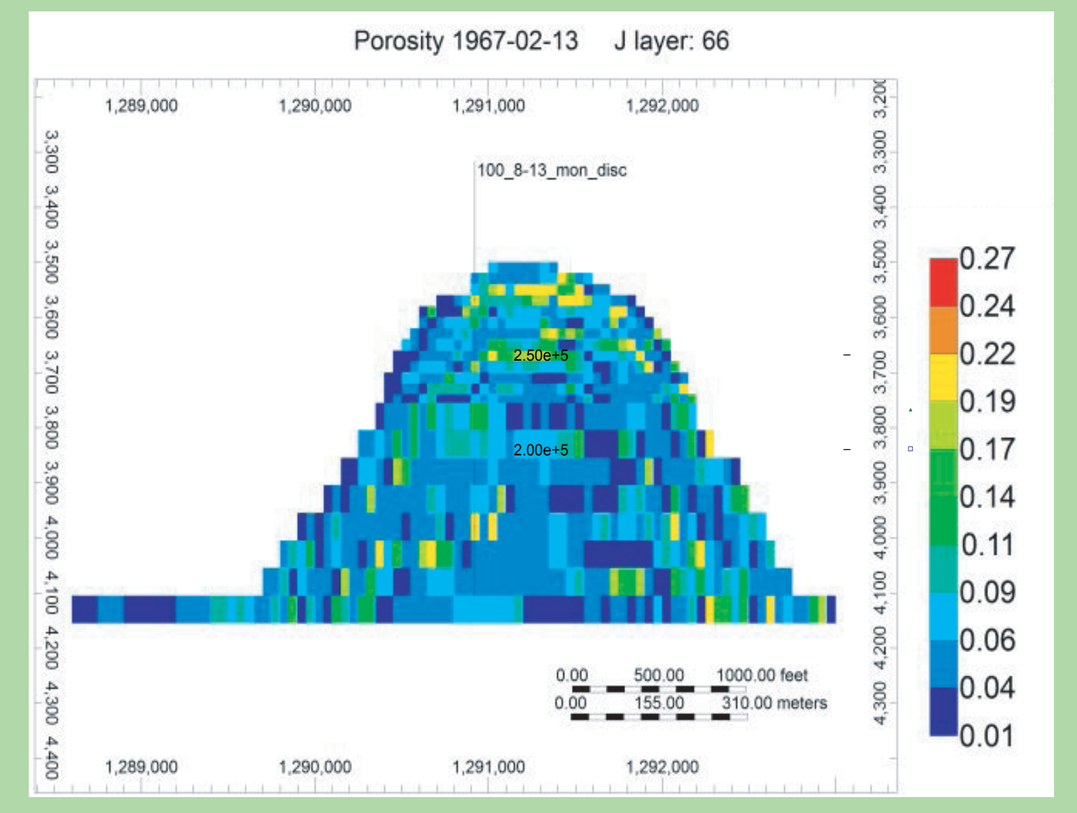


Scenario 2 – EOR Optimization

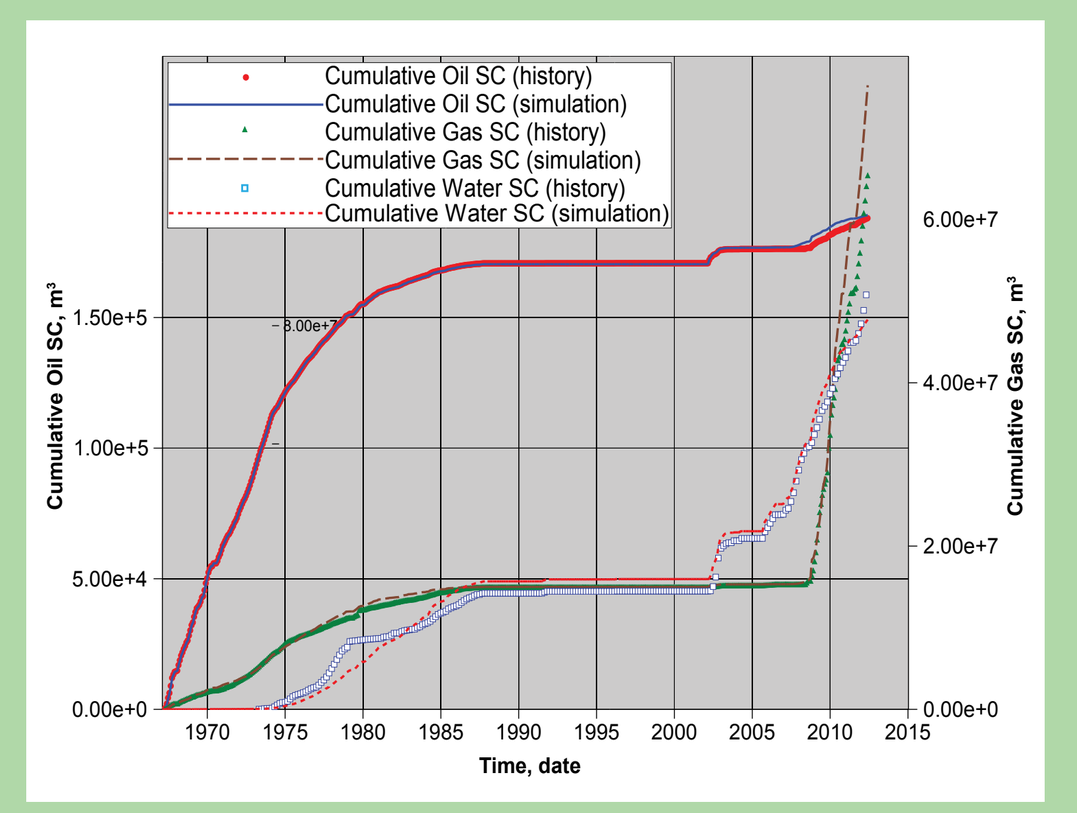




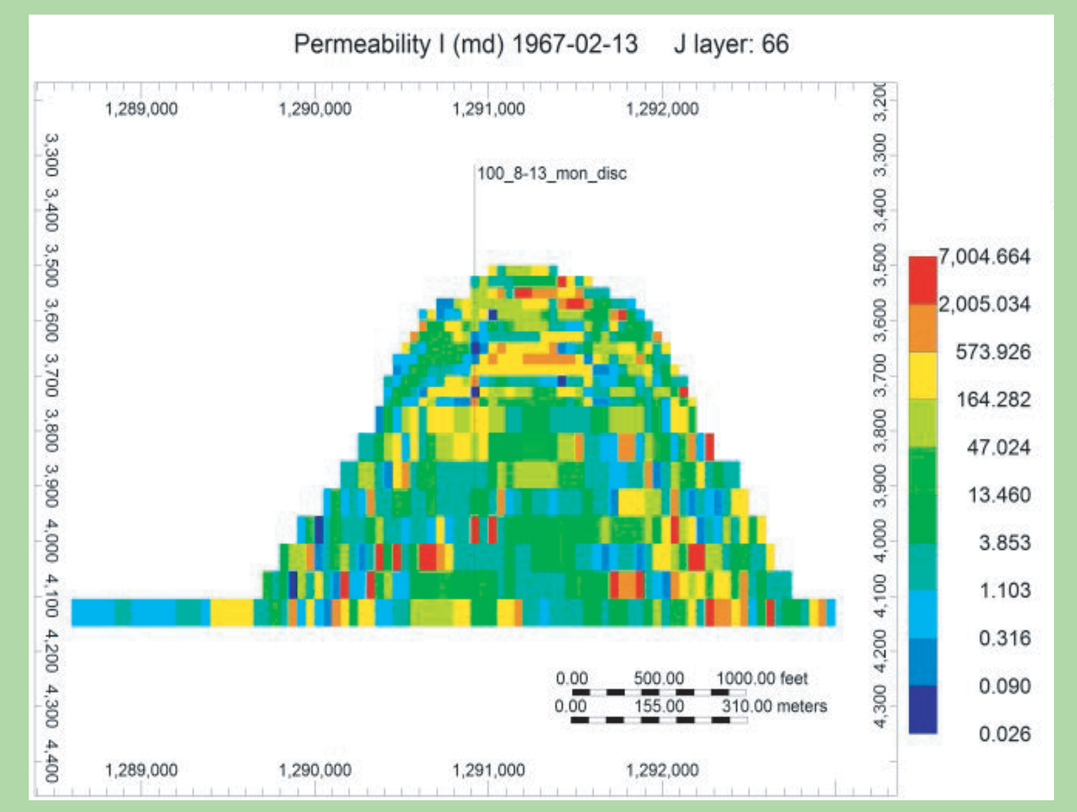
History match and predictive simulation of reservoir pressure. Final shut-in pressure is 20,400 kPa (2965 psi), significantly lower than the fracture extension pressure.



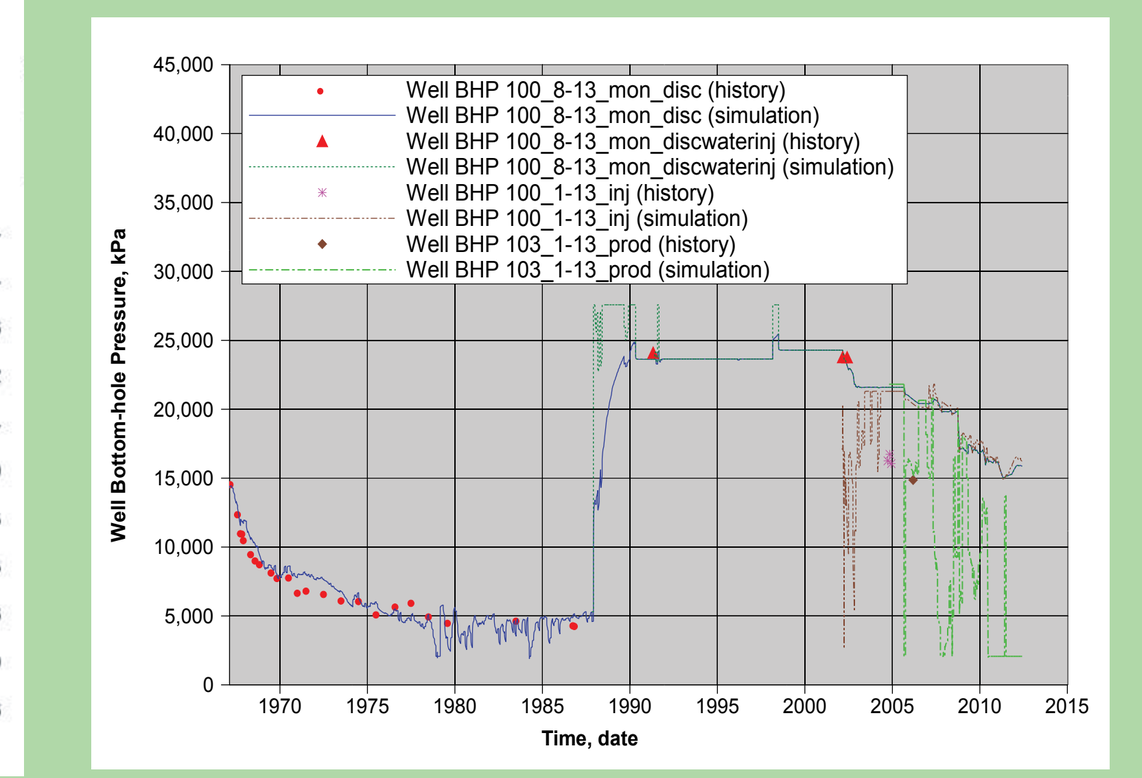
Reservoir model slice depicting porosity.



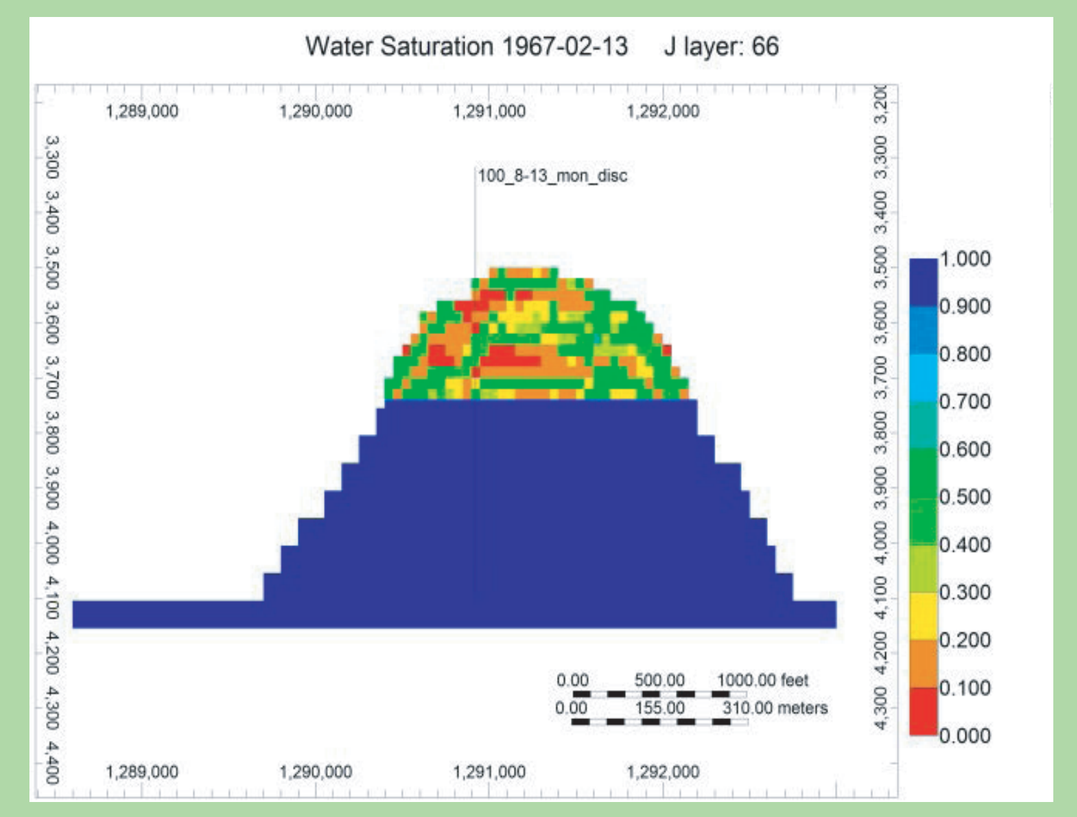
History match results for cumulative oil, water, and gas volumes.



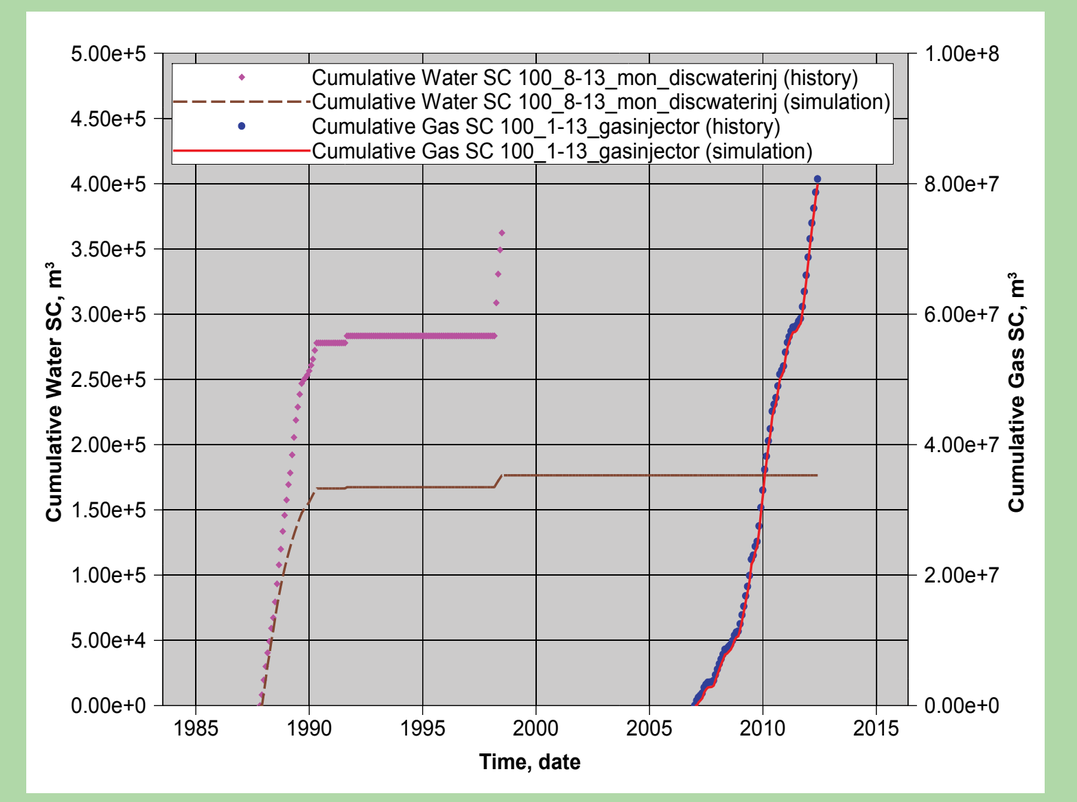
Reservoir model slice depicting permeability.



Actual and simulated well BHPs.



Reservoir model slice depicting water saturation.



History match results for cumulative volumes of injected acid gas and water.

Conclusions

- Water extraction from an underlying water zone (aquifer) can effectively be used for additional gain in both oil recovery and CO_2 storage capacity in a closed system like the Zama F Pool. Gains of over 1300% were simulated for the Zama F Pool for CO_2 storage capacity.
- A combination of top-down gas injection EOR coupled with bottom water extraction appears to provide a new way to increase overall recovery efficiency and storage capacity in such reservoirs. Incremental oil recovery increased 5% and storage capacity 480% in simulations using bottom structure water extraction.
- The predicted EOR potential for Zama pinnacle reefs through acid gas EOR predicts an additional 6.2% to 15.6% of the OOIP. The simulated CO_2 utilization results for modeled Zama pools averaged approximately 0.62 tonnes/bbl (11 MMscf/bbl).
- Storage capacity for several modeled pinnacles ranged from 0.18 to 1.22 Mt of CO_2, with the average storage capacity being nearly 0.4 Mt. Assuming the 840 other pinnacle reefs in the Zama Field have similar characteristics, the total storage capacity may be nearly 336 Mt of CO_2.
- This case study has implications for EOR opportunities in residual oil zones commonly found in pinnacle reef structures around the world.

PCOR Partnership 2003 – Present

5/14

Acknowledgments

This material is based upon work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory under Cooperative Agreement DE-FC26-05NT42592. Financial support from DOE to perform this work is greatly appreciated. The authors would like to thank Apache Canada Ltd. for providing necessary data to perform the work. The generous software support of Schlumberger and Computer Modelling Group Ltd. is gratefully acknowledged. The authors also thank former colleagues Mr. Damion Knudsen and Dr. Dayanand Saini for their work on this project.