SAND2023-05669C

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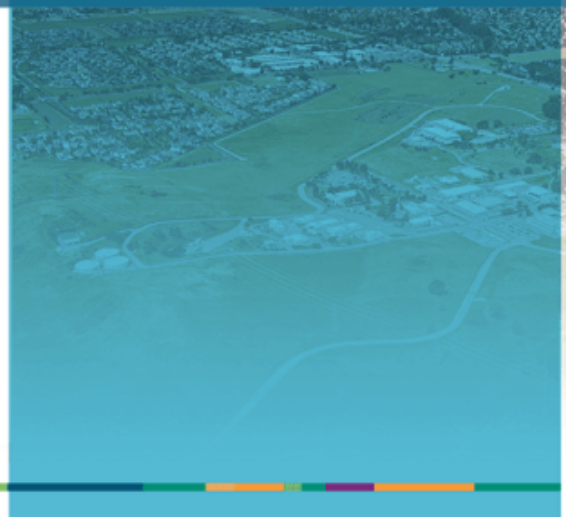
Evolution of Geomechanics for Underground Storage within Salt



Byoung Yoon Park, Ph.D.

57th U.S. Rock Mechanics / Geomechanics Symposium

25-28 June 2023, Atlanta, Georgia

U.S. DEPARTMENT OF ENERGY | NNSA

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Presentation Overview

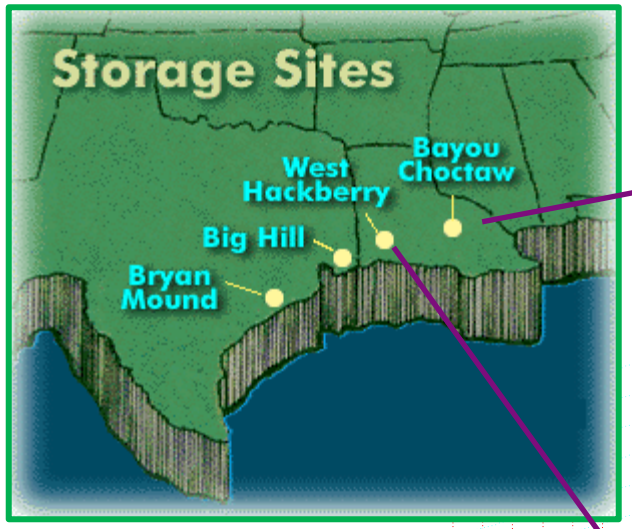
- Introduction
- 1980s-1990s – The Early Days
- 2002-2007 – Maybe we need some geomechanics modeling?
- 2007-2012 – Maybe we need some site-specific geomechanics models?
- 2012-2018 – Evolution of models to respond to observations at the SPR sites
- 2018-2023 – Improved understanding of salt dome mechanics
- 2023 and beyond – Where do you go from here?

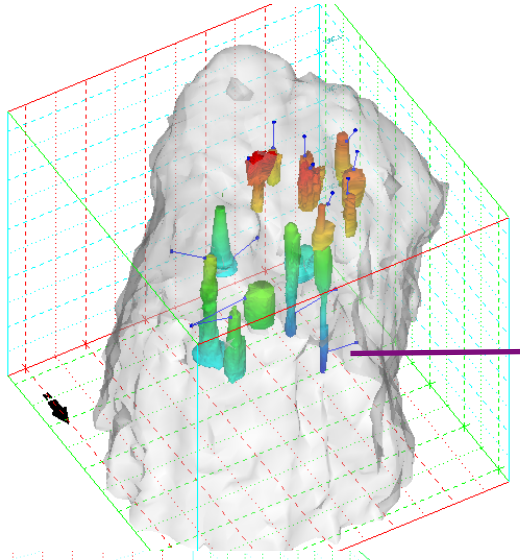
History

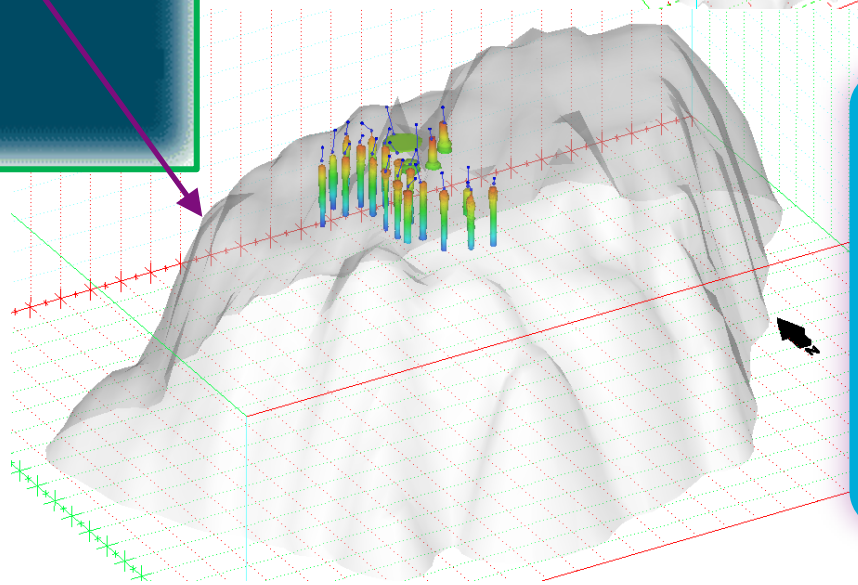
- Sandia has served as the geotechnical advisor to the U.S. Strategic Petroleum Reserve (SPR) since 1979.
- The reserve is an emergency stockpile of crude oil that can be tapped into to mitigate a disruption in supply that could impact the nation's economy.
- It was established in 1977 after the Arab embargo that caused a disruption in oil being shipped to the U.S. for over 6 months.
- The U.S. is part of the IEA, which is an international coalition of 30 countries that support energy supply security – respond together to global distribution in oil supply.

U.S. Strategic Petroleum Reserve

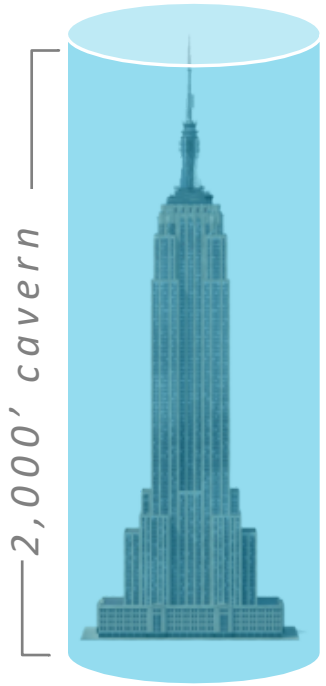
Established 1977 after OPEC oil embargo







Salt Domes



Empire State Building

- 60 caverns
- 714 MMB capacity

Presidential Order

1991 – Operation Desert Storm – 17.3 MMB
2005 – Hurricane Katrina – 20.8 MMB
2011 – Middle East unrest - 30 MMB (IEA)
2022 – Russia's invasion of Ukraine – 30 MMB (IEA)
2022 – Putin's energy price hike – 180 MMB

Why do we model salt creep in geomechanical models?

- Salt deforms until equivalent stress conditions since cavern internal pressure is not equal to in-situ pressure in salt (called salt creep).
- Salt creep causes storage caverns to deform inward, thus losing volume.
- Loss of volume affects salt above, around caverns, putting stresses and strains on borehole casings.
- Accurate evaluation of salt creep behavior drives decisions about cavern operations.

1980s-1990s – Computational Analyses

2D axisymmetric

- Evaluated cavern integrity, closure, roof shapes

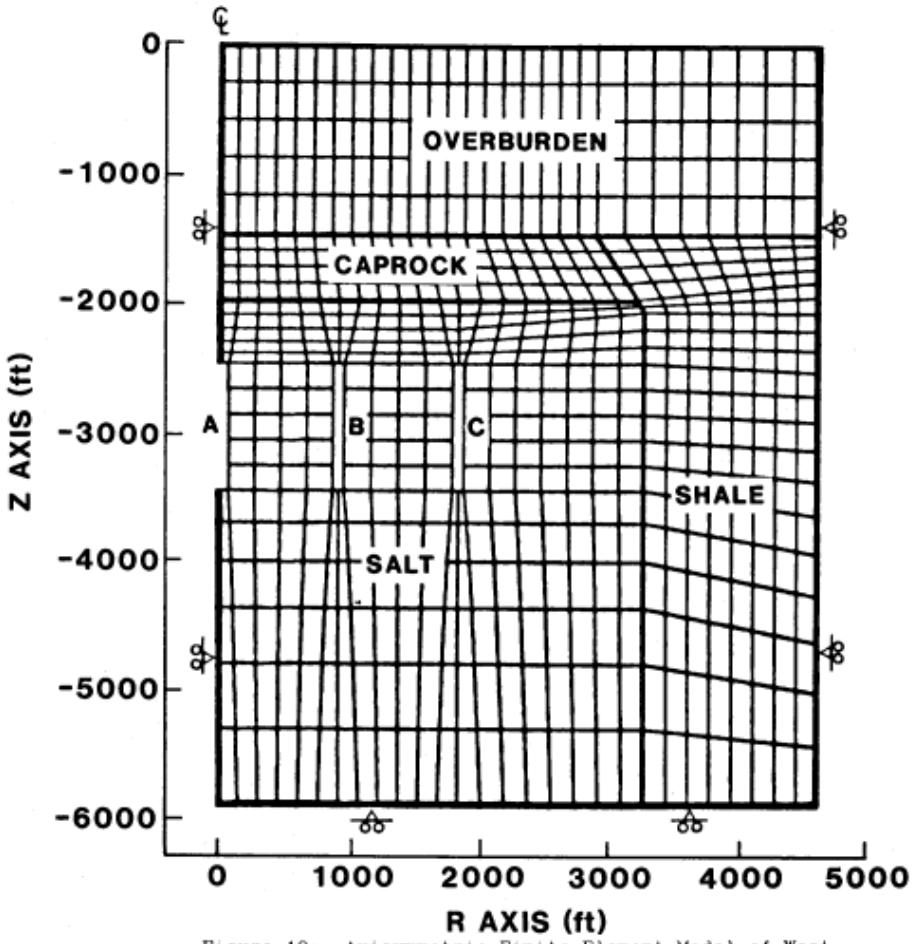
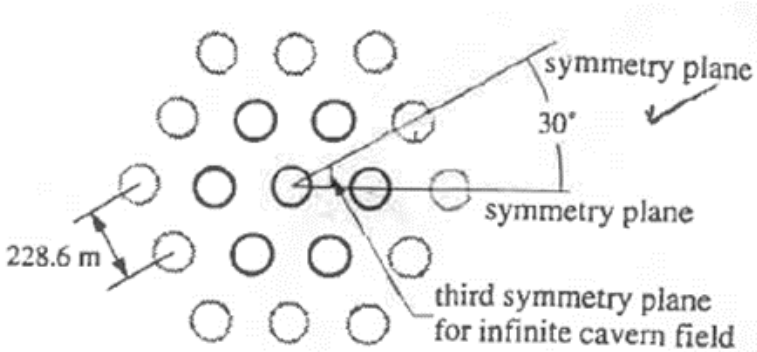


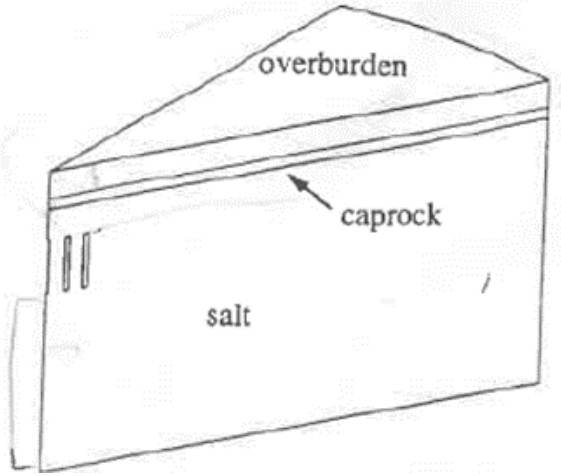
Figure 10: Axisymmetric Finite Element Model of West Hackberry Salt Dome.

30° wedge

- **Power-law creep model**
- Evaluated volume loss, strains on caverns



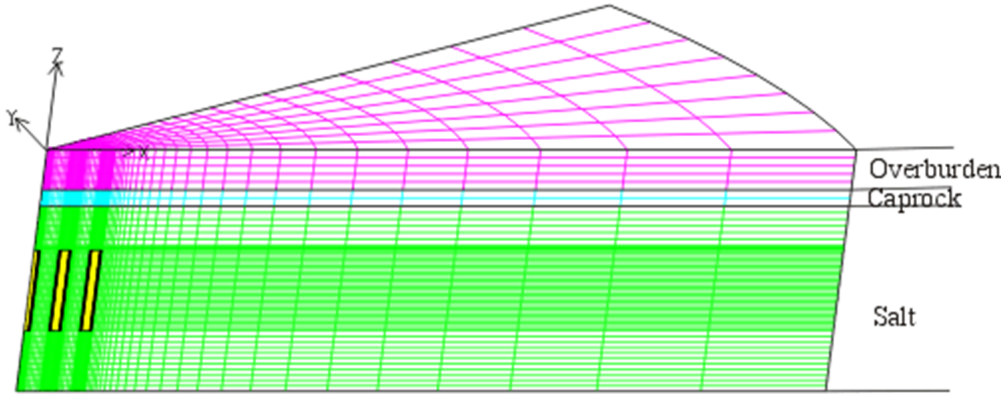
(a) typical SPR cavern spacing

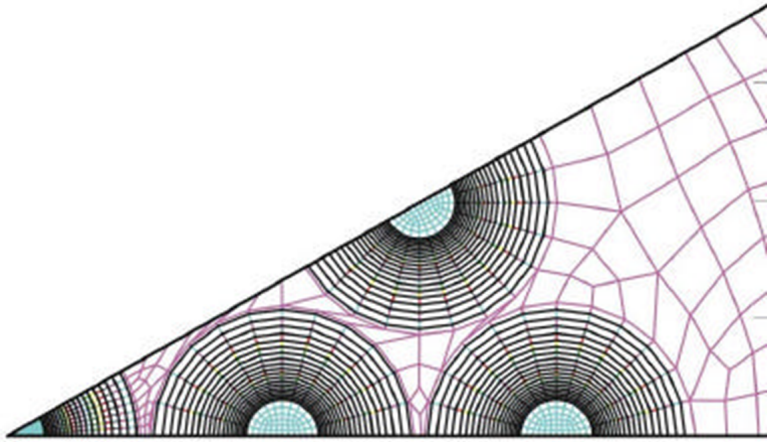


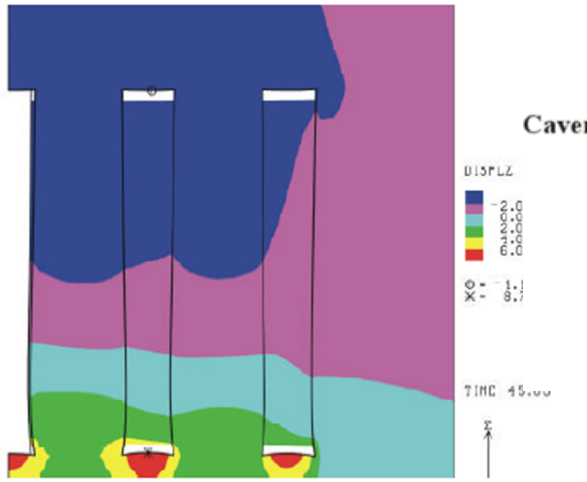
2002-2007 – Maybe we need some geomechanics modeling?

30° wedge generic model

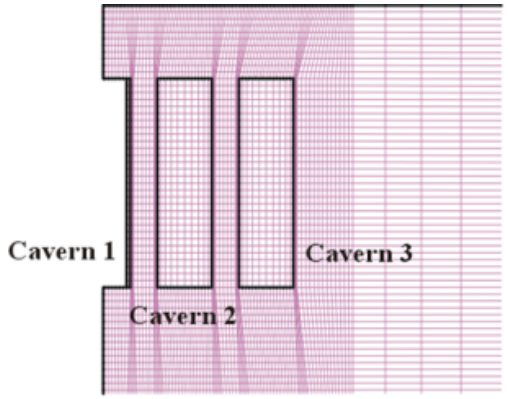
- **Power-law creep model**
- Estimate of maximum number of drawdowns



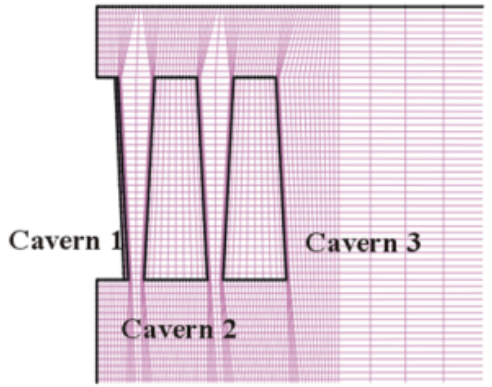




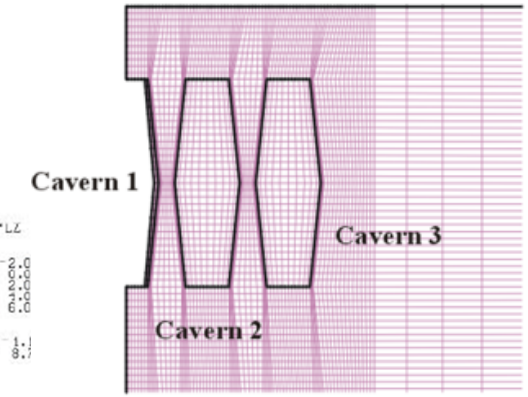
- Evaluate effects of different cavern shapes



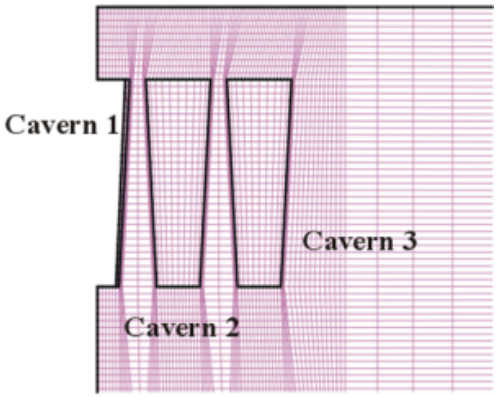
Cylindrical caverns



Enlarged bottom caverns



Enlarged middle caverns

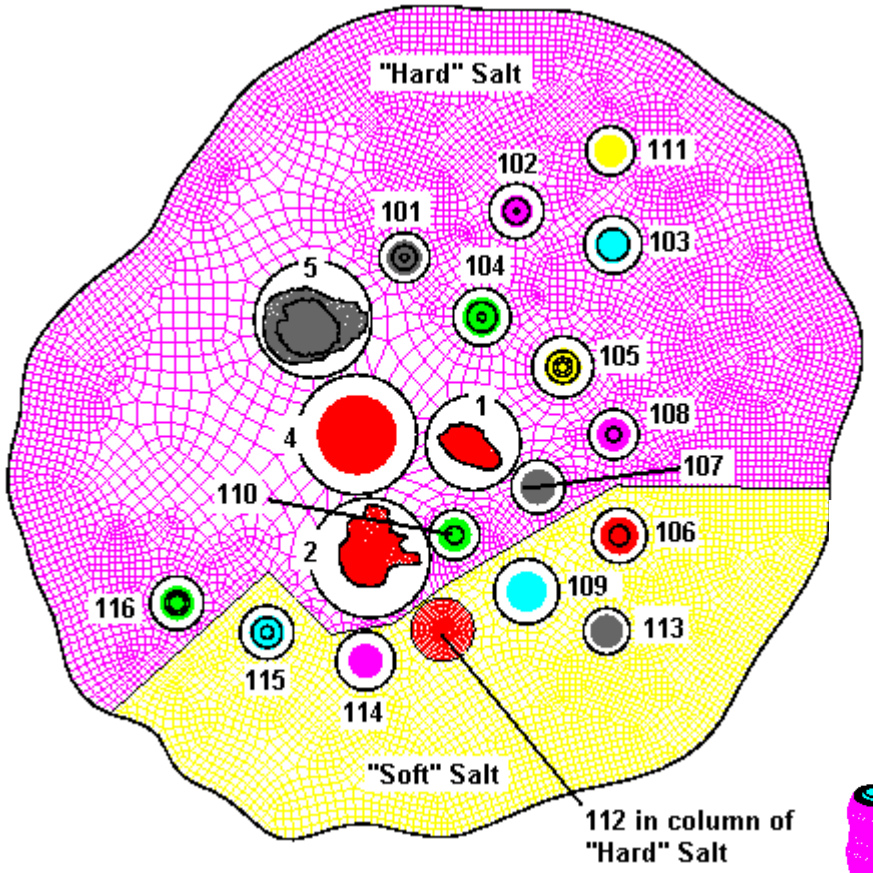


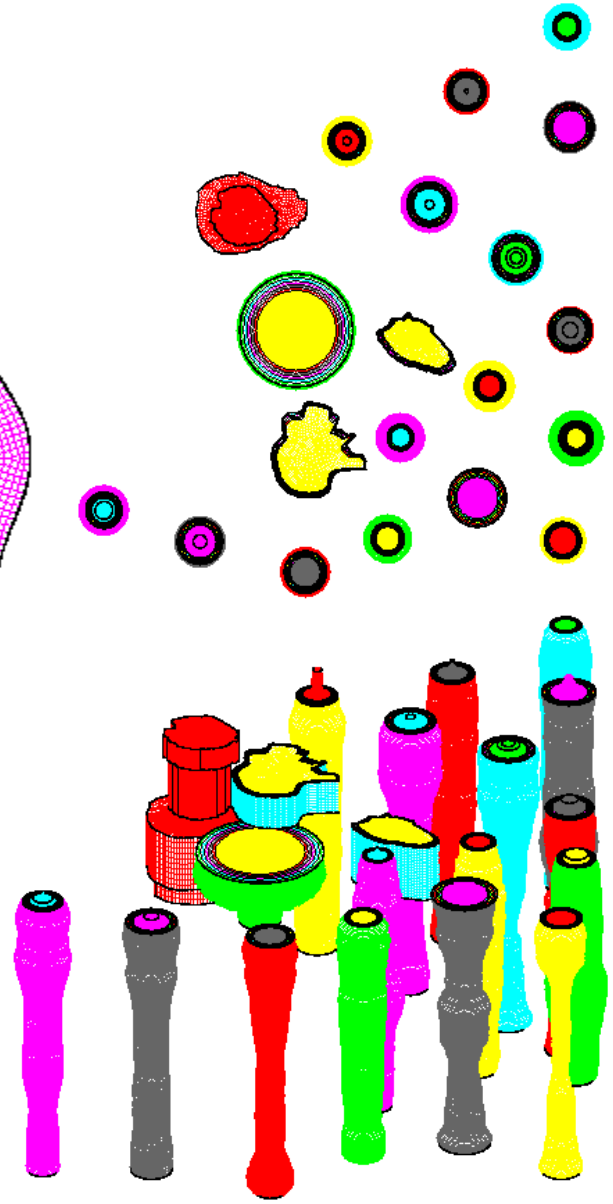
Enlarged top caverns

2007-2012 – Maybe we need some site-specific geomechanics models?

Full dome finite element model

- **Power-law creep model**
- Axisymmetric caverns – simple cylinders
- “hard salt” and “soft salt” designations
- Identify potential integrity problems
- Drawdown availability
- Evaluate potential strains on casings

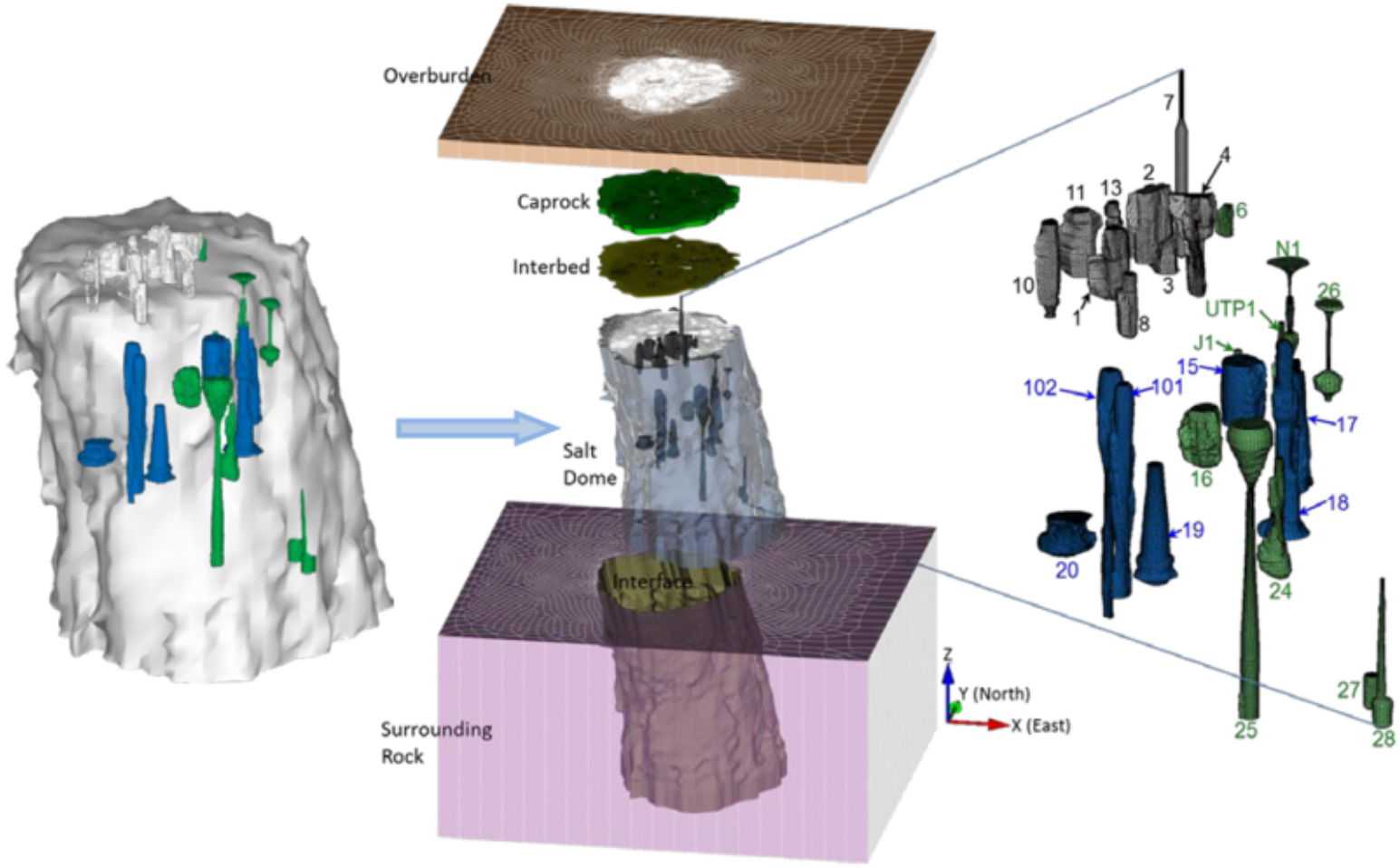




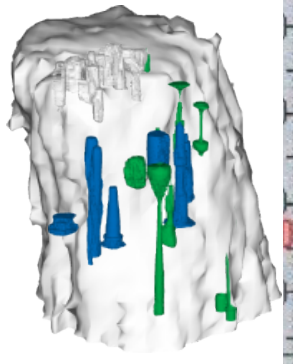
2012-2018 – Evolution of models to respond to observations at SPR sites

Full dome finite element model

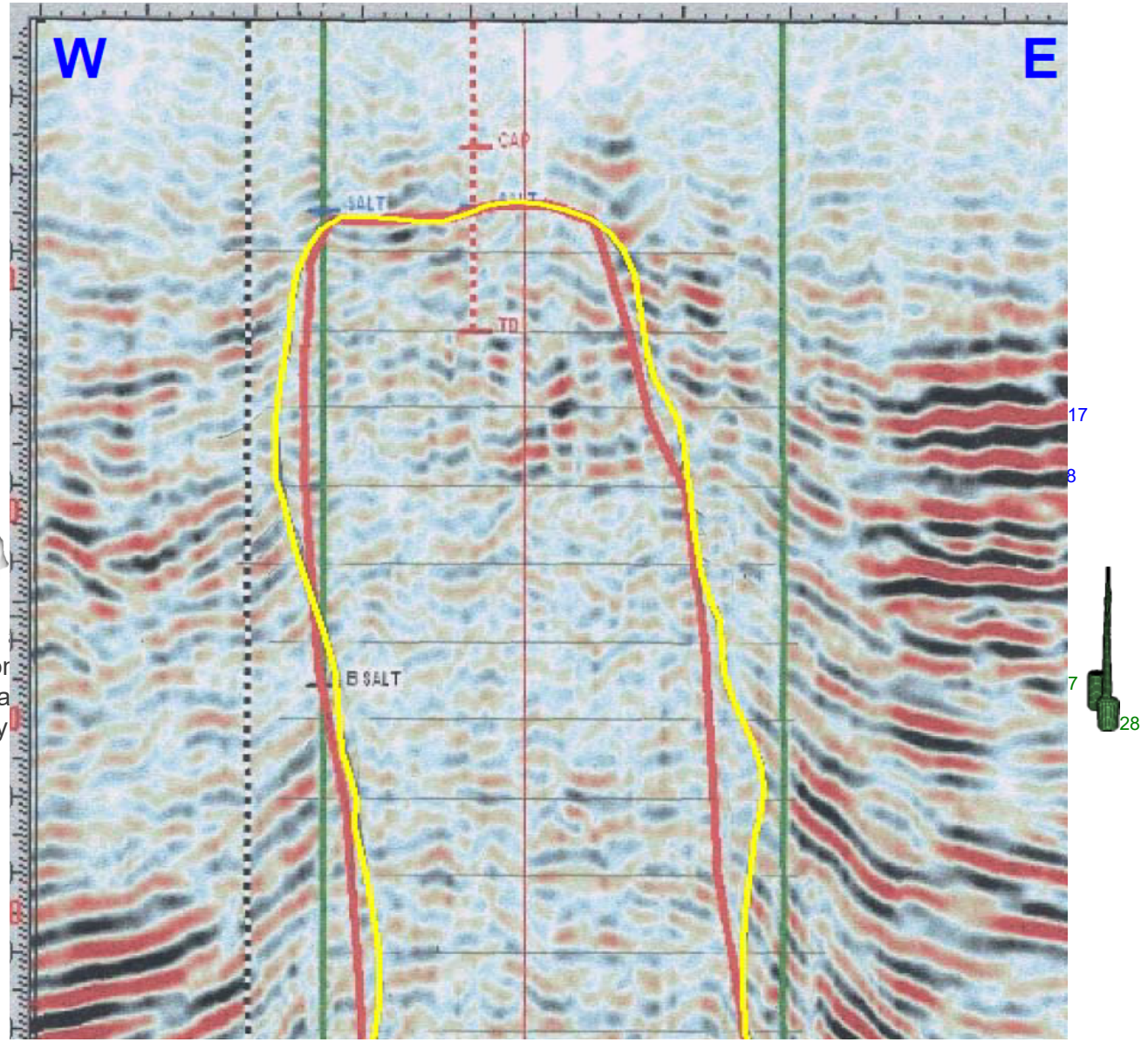
- Change salt model from power law creep to **full M-D model**
- Change computational tool from JAS3D to Sierra/Adagio
- Creation of cavern meshes based on sonar geometries (patented meshing method)



FE Model Capturing Realistic Geometries



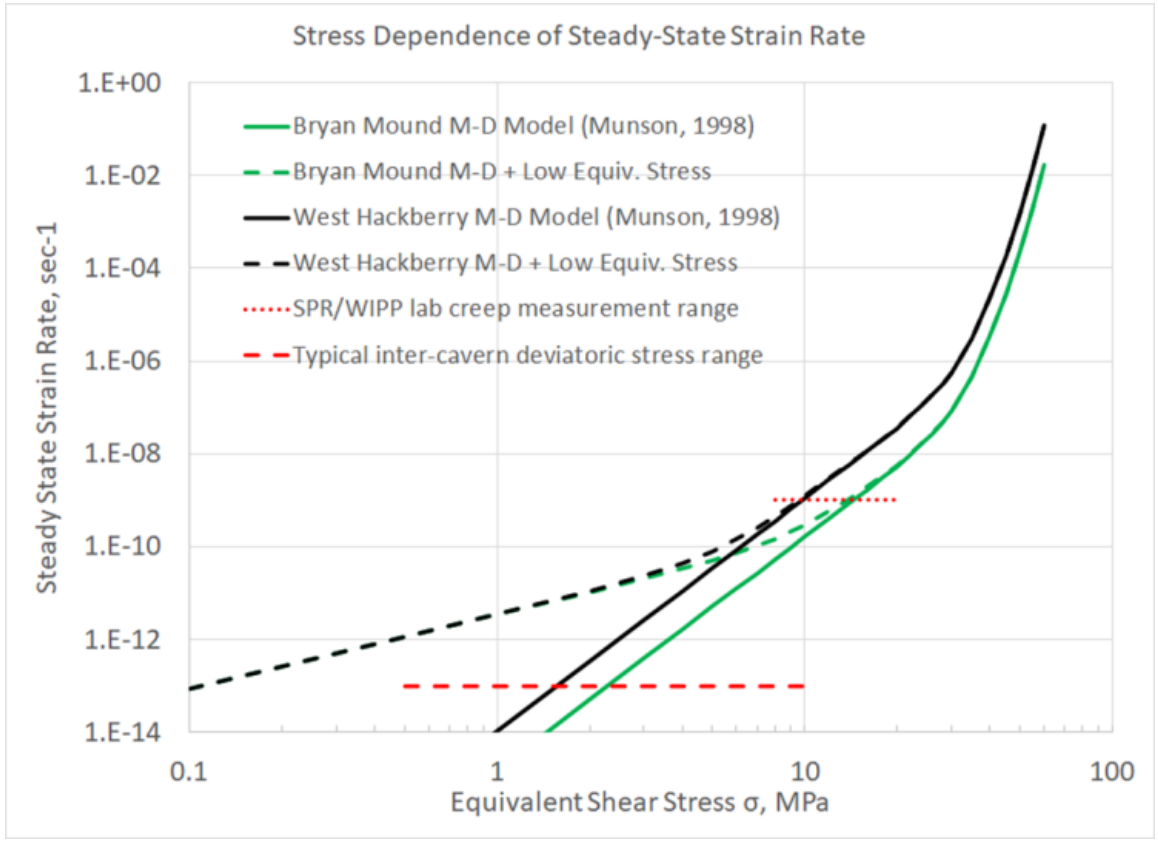
Images of salt dome caverns obtained fror the seismic and sona surveys, respectively



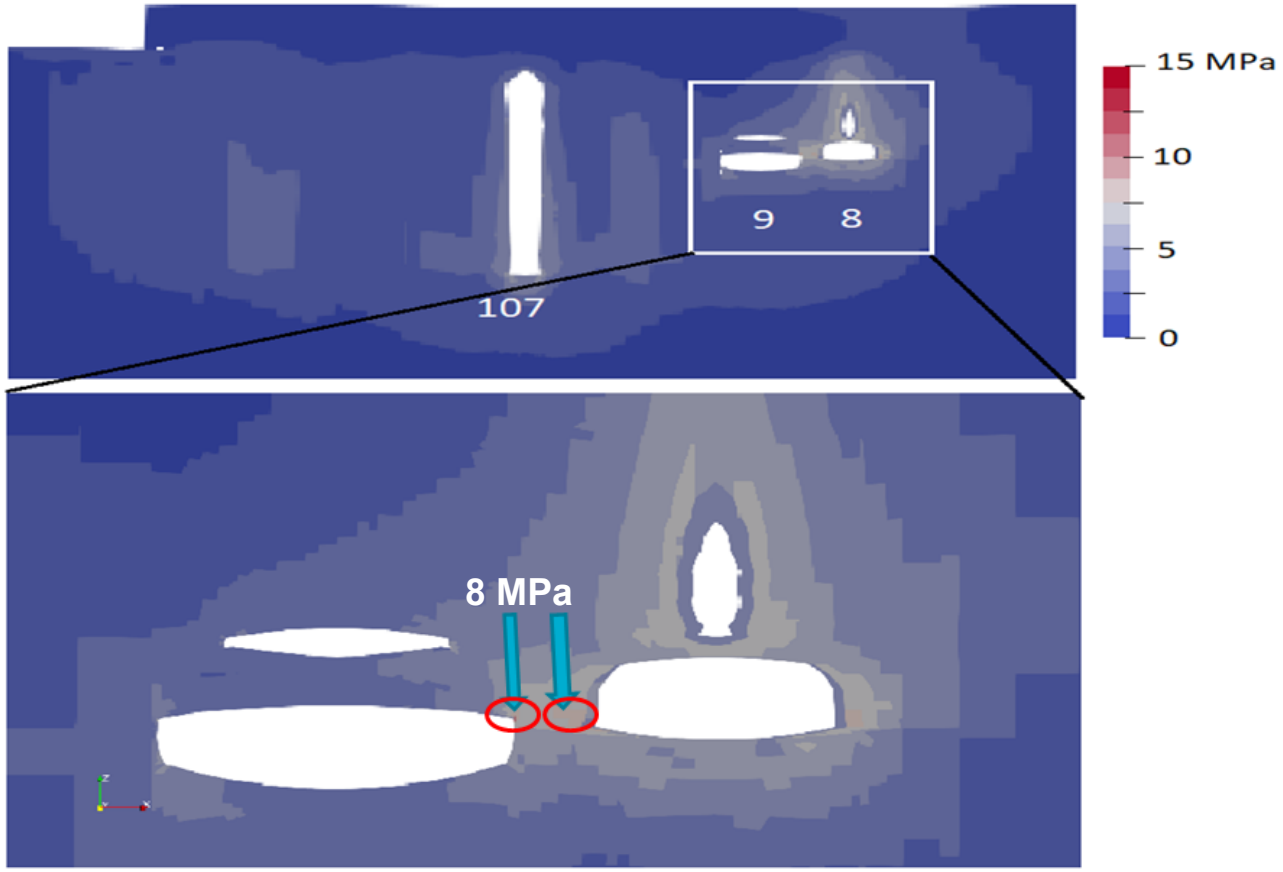
- 3D seismic survey result in Bayou Choctaw - yellow curve indicates the dome boundary
- 3D salt dome seismic image
- U.S. Strategic Petroleum Reserve stores crude oil in the seven blue caverns
- Green shows privately owned caverns, and grey depicts abandoned caverns

2018-2023 – Improved understanding of salt dome mechanics

- **Add low stress creep to M-D model (M-D viscoplastic)**
- Most creep tests at > 8 MPa; but small volume of salt dome affected
- But, most creep occurs < 8 MPa over large volume



- Evaluate damaged caprock
- Incorporate friction model at salt-caprock interaction

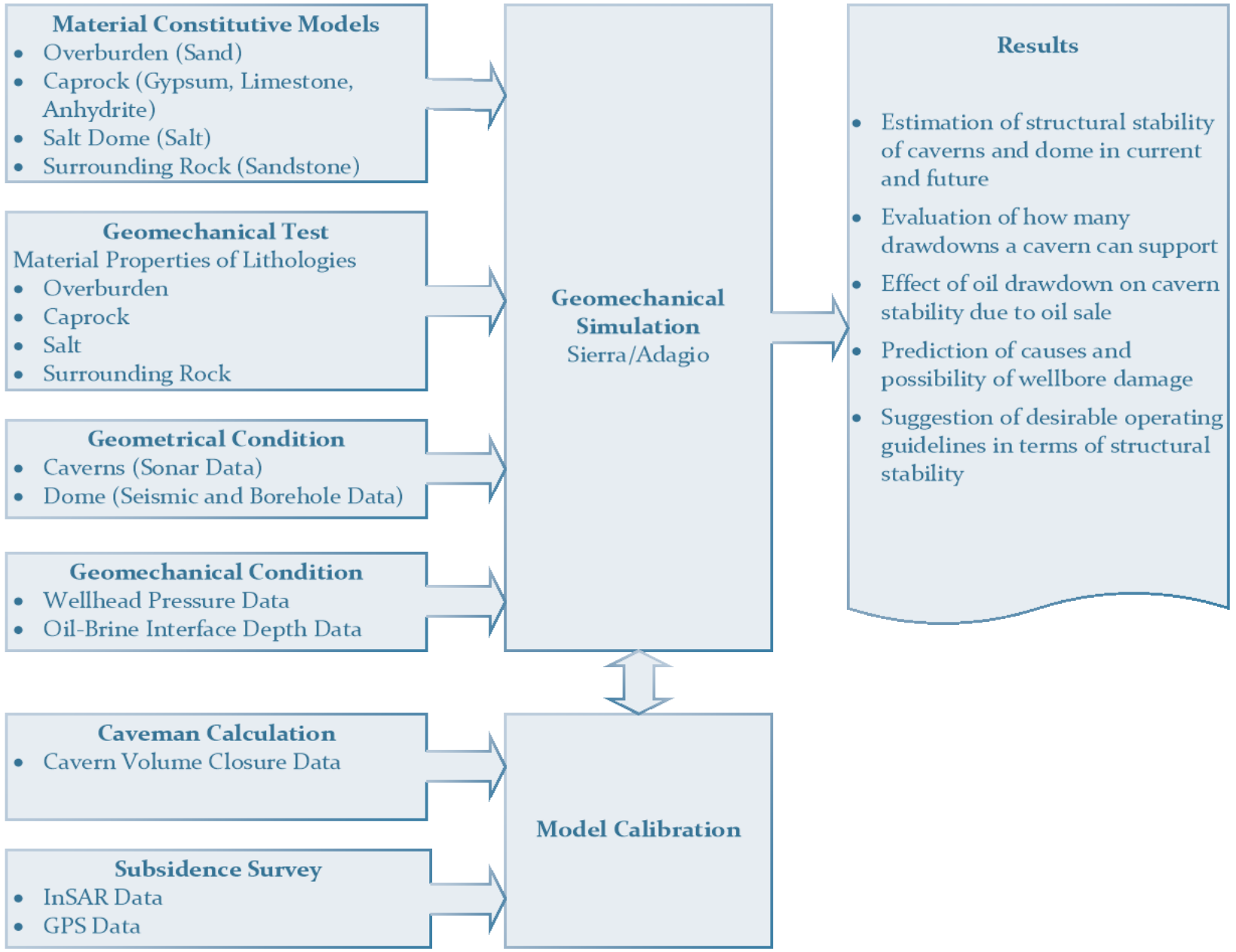


Geomechanical Simulation Workflow

Workflow includes:

- Input from geomechanics team
- Solid State Mechanics model
- High performance computing power

The parameter values of the **MD creep** or **MD viscoplastic salt constitutive model** are determined through the model calibration for each site.



2023 and beyond – Where do you go from here?

- New salt viscoplastic model – reverse creep, eventually also damage/healing
- Improved understanding of effect of stress changes on salt fatigue, salt falls
- Explicit inclusion of wellbore casings (in site-scale and/or borehole-scale models)
- Coordination with new site data – fiber optic strain, microseismic, characterization of salt/caprock interface
- Geomechanical evaluation of partial drawdown leach due to oil sale
- New salt constitutive model based on geomechanical testing of frequent loading-unloading for salt rocks
- Estimation of structural stability of cavern in current and future
- Suggestion of desirable operating guidelines in terms of structural stability