GEOMECHANICAL EVALUATION OF PRESSURE DRAWDOWN IN WESTLAKE CAVERN PPG 6 AT THE SULPHUR MINES SALT DOME, CALCASIEU PARISH, LOUISIANA

MINING & ENERGY

CAVERN GEOMECHANICS

RAPID CITY, SD, USA

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OUTLINE

- Introduction
- Technical Approach
  - 3D Numerical Model Overview
  - Key Assumptions
  - Modeled Cavern Pressure Conditions
- Modeling Results
- Conclusions

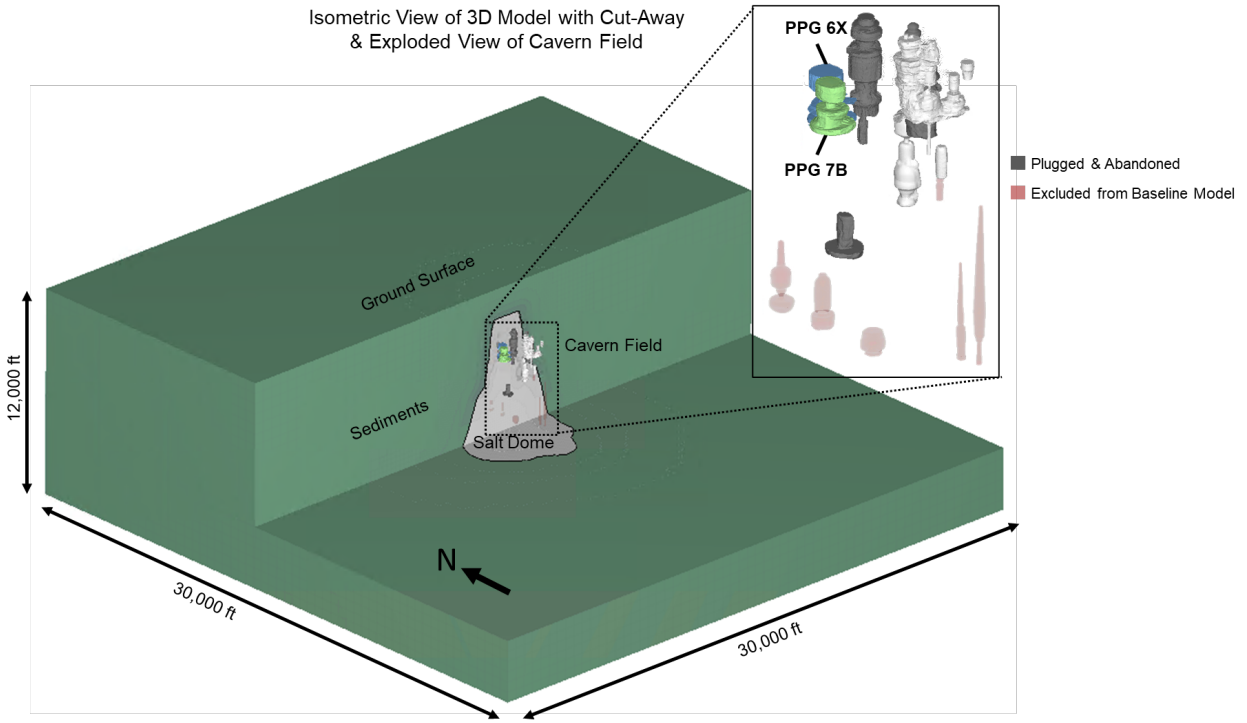
INTRODUCTION

- Lonquist is planning a work-over on the PPG 6X well to perform necessary maintenance. To perform the work-over maintenance, they plan to reduce the pressure in PPG 6 from its current, approximate 190 psi wellhead pressure to 0 psi wellhead pressure over a 7-day period, while maintaining PPG 7 at 80 psi wellhead pressure.

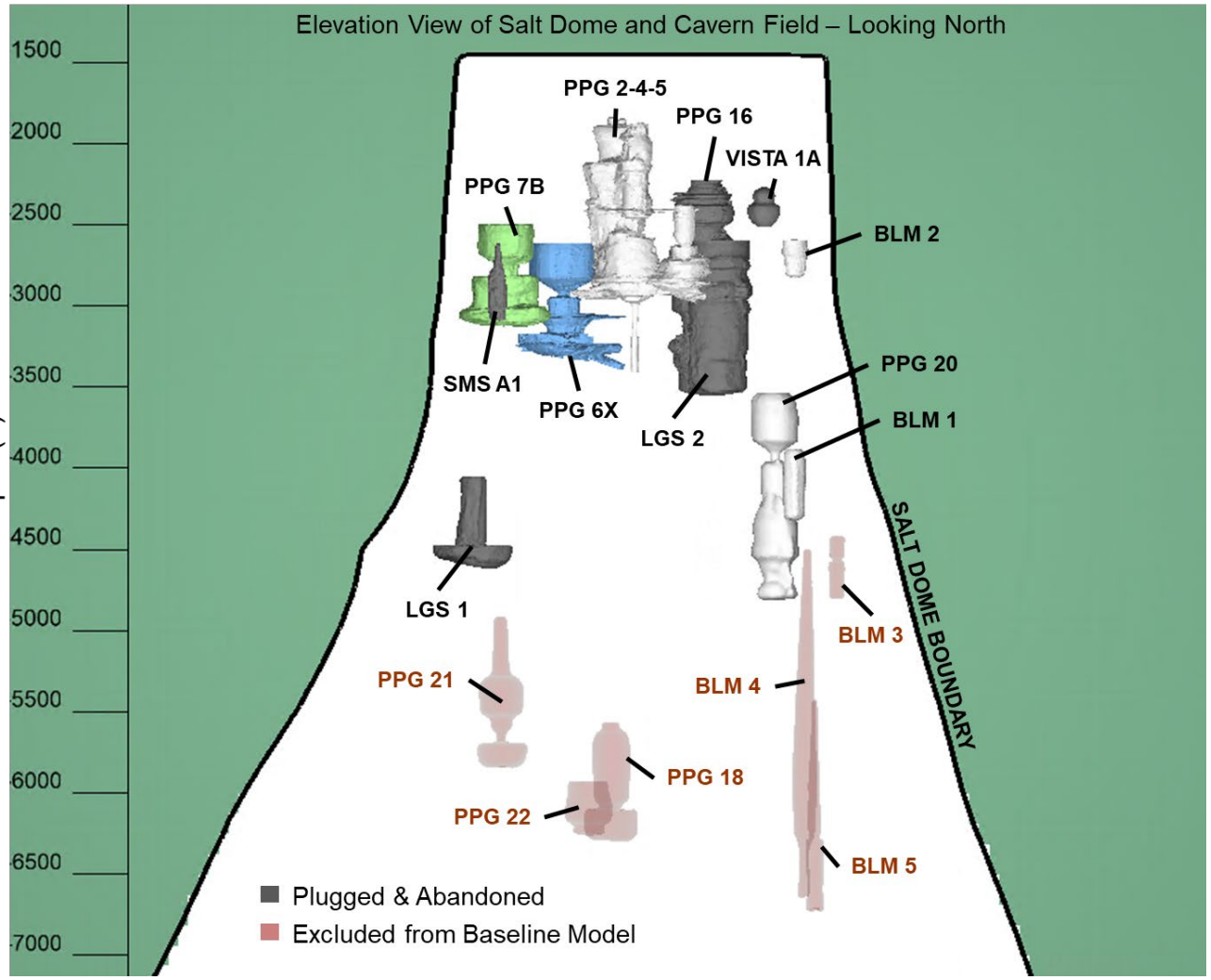
- RESPEC was requested to perform a geomechanical analysis to evaluate the planned pressure drawdown in PPG 6 and the resulting stress conditions to assess the stability of the caverns. RESPEC was also requested to evaluate the future stability of the caverns, assuming PPG 6 was held at a constant 0 psi wellhead pressure, and PPG 7 was held at a constant 80 psi wellhead pressure for the next 10 years.

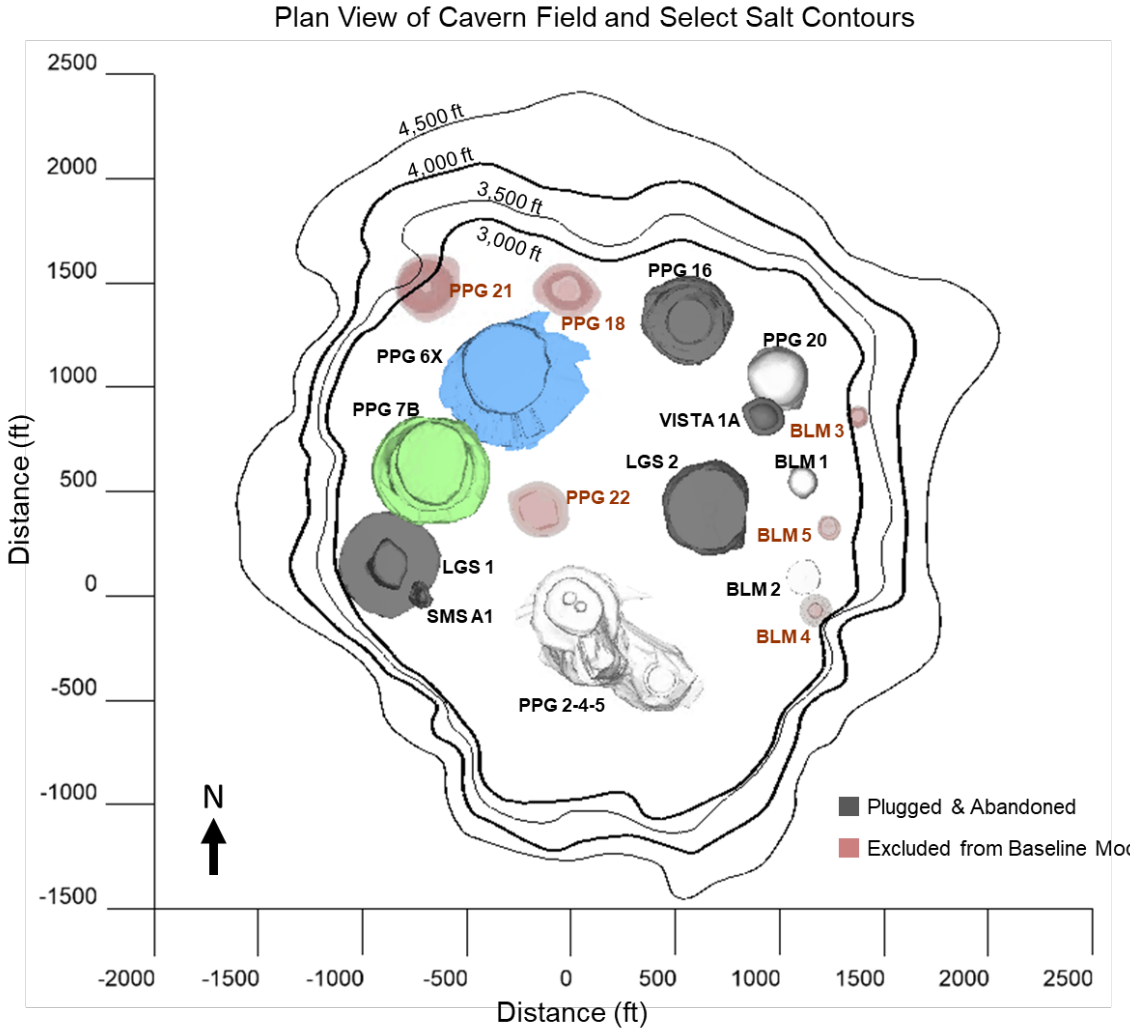
TECHNICAL APPROACH OVERVIEW

- This analysis employed the existing 3D geomechanical model that has been developed for the Sulphur Mines salt dome.
- Large-domain three-dimensional (3D) numerical model to predict the geomechanical response of the caverns to various operating conditions.
- Included Westlake Caverns PPG 6 and PPG 7 and the surrounding caverns within the area of influence.
- Approximated the historical cavern development and operations to estimate the stress state in the salt at present-day.
- The model-predicted stresses were post-analyzed to determine factor-of-safety (FS) values for salt dilation (or damage).



3D NUMERICAL MODEL OVERVIEW

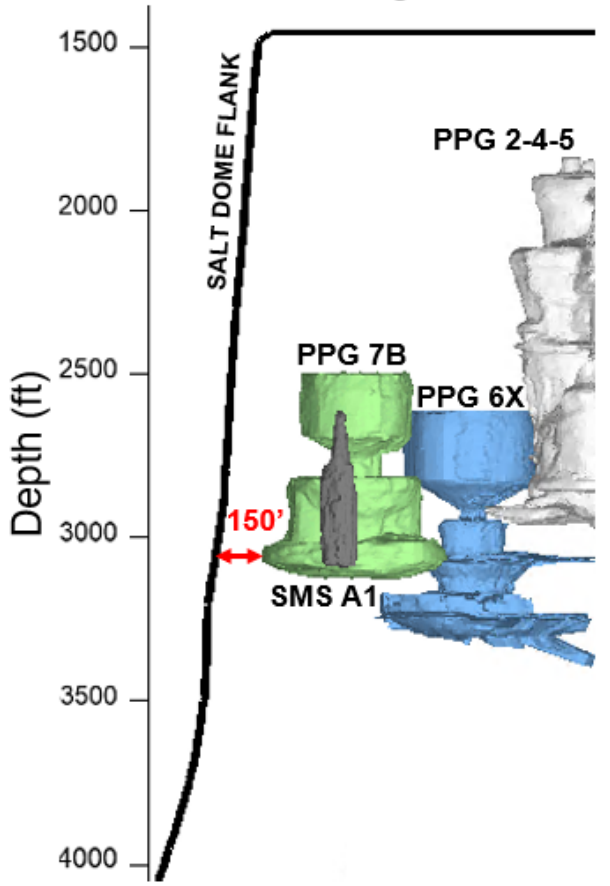




KEY ASSUMPTIONS

- The salt dome flank is approximately 150 feet from the perimeter of Cavern PPG 7.
- The web between Cavern PPG 7 and the dome flank consists entirely of rock salt, with homogenous strength and deformation properties.
- The rock salt between Cavern PPG 7 and the dome flank is perfectly bonded to the adjacent nonsalt rock formations.
- Mechanical properties of the salt surrounding Caverns PPG 6 & 7 can be accurately characterized by the RESPEC testing of salt core recovered from Well No. 22 [Arnold, 2015].
- The potential leak path from Cavern PPG 7 is undefined, and therefore, it is omitted from the model.
- The potential hydraulic connection between Caverns PPG 6 & 7 is undefined, and therefore, it is omitted from the model.
- Adjacent formation pressures are neglected in the model; therefore, they do not affect the stresses within the salt stock.
- Extensive sulphur mining in the caprock has significantly degraded the caprock stiffness and strength, therefore it is omitted from the model.

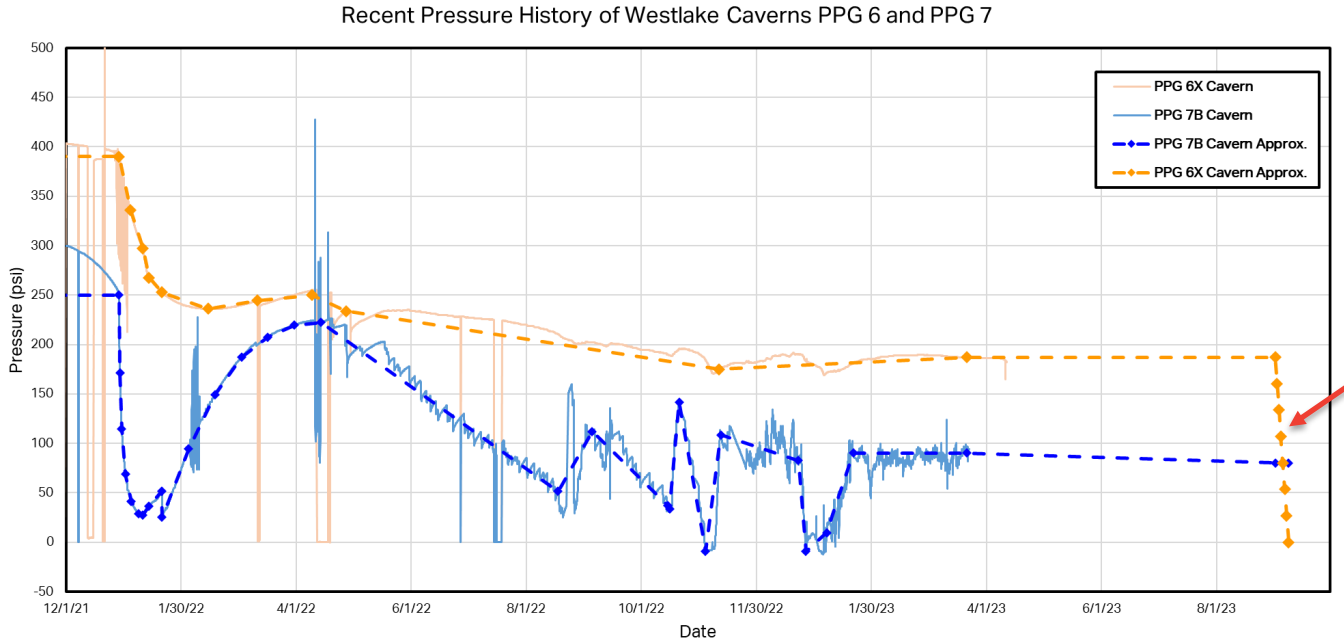
Cropped Elevation View of Salt Dome and Cavern Field – Looking North



Arnold, R. D., 2015. *Mechanical Properties Testing of Core From Axiall PPG Brine 22 Sulphur Mines Salt Dome, Calcasieu Parish, Louisiana,* RSI-2533, prepared by RESPEC, Rapid City, SD, for Lonquist & Co., LLC, Austin, TX.

CAVERN OPERATIONS

- Historical cavern operations (prior to 2021) were approximated in the model by simulating each cavern at a constant brine pressure gradient with minimal wellhead pressure.
- The caverns were modeled at static pressure conditions up until Jan 2021, at which time the pressures in PPG 6 and PPG 7 were adjusted to more closely approximate the recent pressure histories in these caverns up until March 2023.
- The cavern pressures were held constant from March 2023 through Aug 31, 2023, at which time a 7-day pressure drawdown was performed in PPG 6 to a wellhead pressure of 0 psi, while PPG 7 was held at a constant 80 psi wellhead pressure.



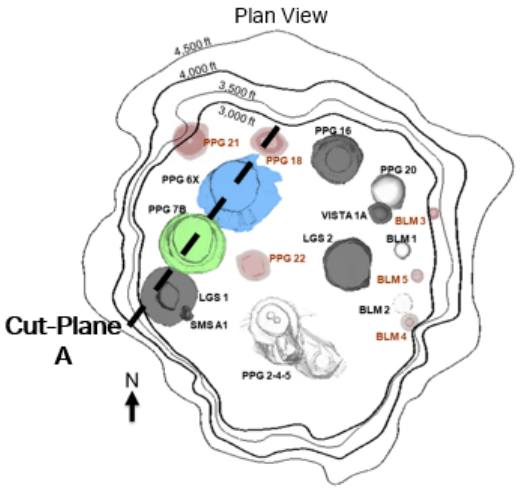
7 Day Pressure Drawdown in PPG 6 Starting on Sep 1, 2023

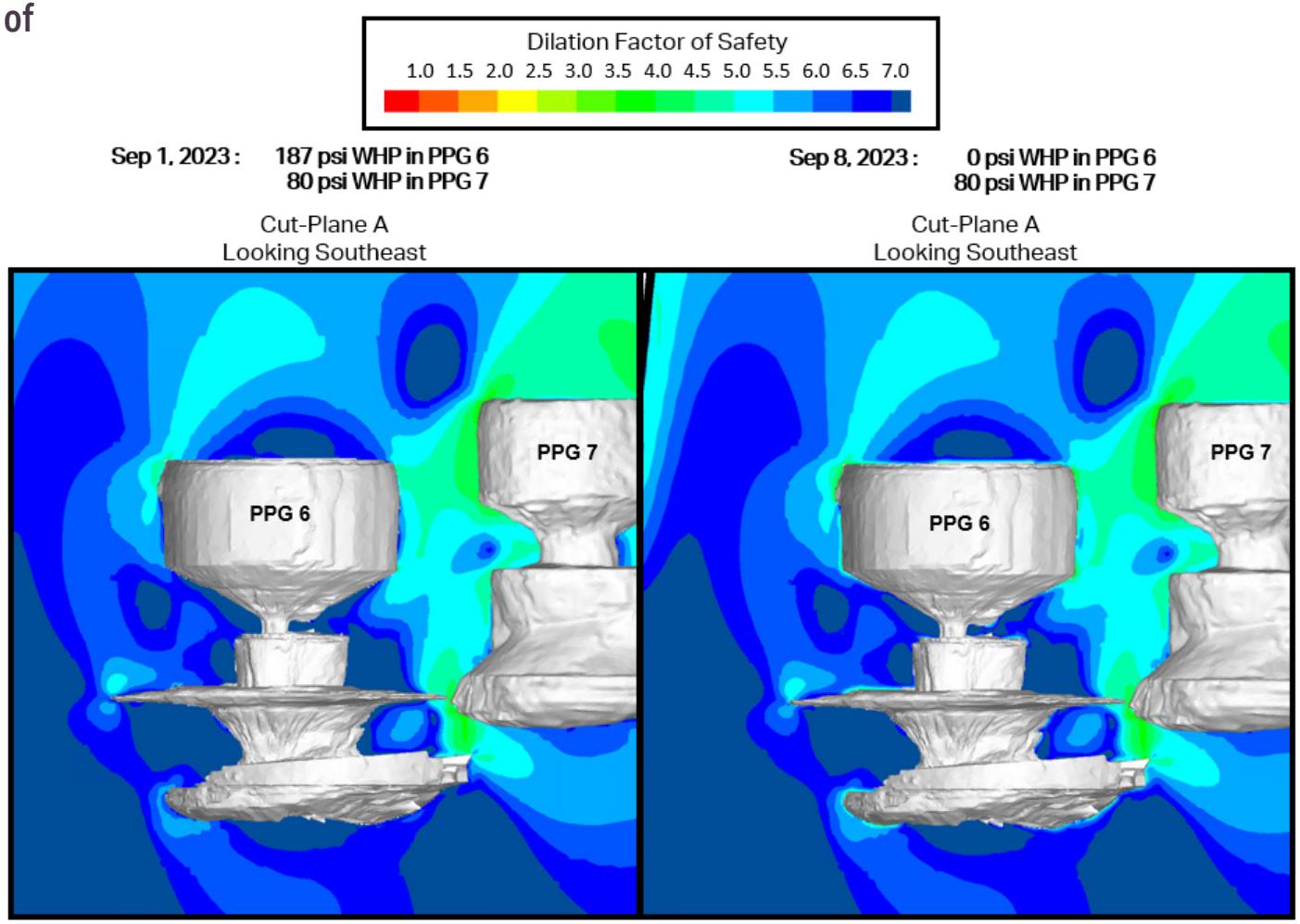
3D MODELING RESULTS FOR PRESSURE DRAWDOWN IN PPG 6

SALT DILATION FACTORS OF SAFETY IN THE SALT SURROUNDING PPG 6 AND PPG 7

PRESSURE DRAWDOWN IN PPG 6

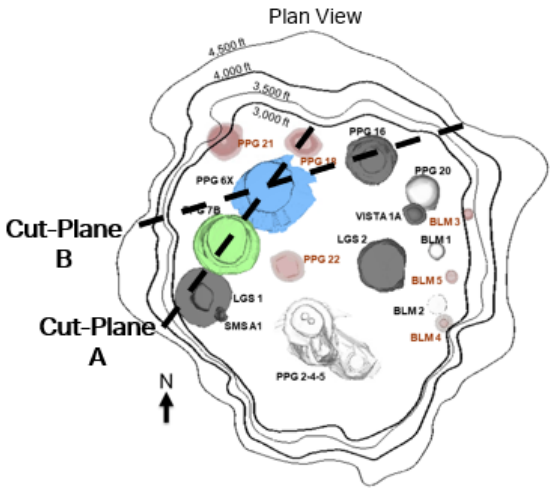
- 3D model predicts a slight reduction of FS values very near the cavern surface, within the range of 4.0 < FS < 7.0
- The contours presented on following slides are shown on the scale of 1.0-5.0 for consistency with previously provided modeling results



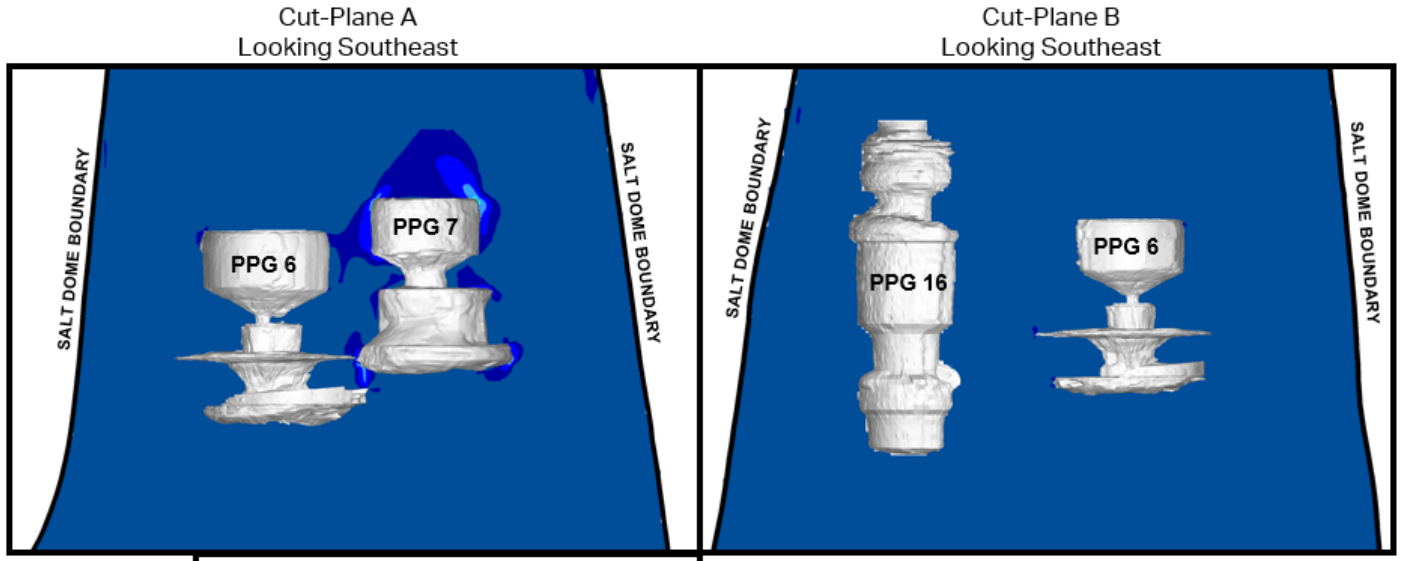


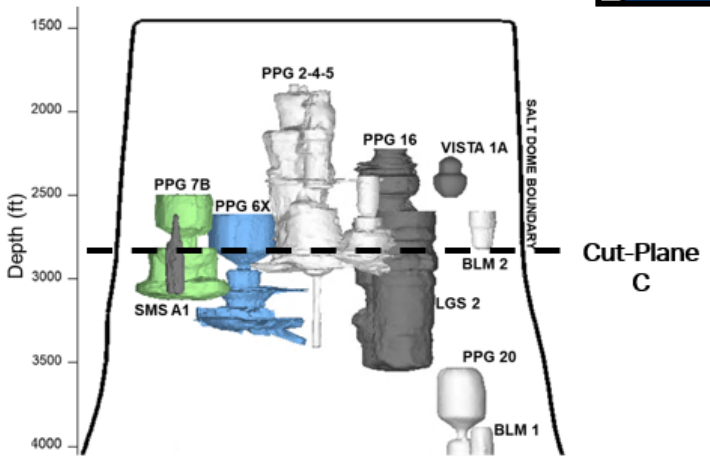
SEP 1, 2023 : PRIOR TO PRESSURE DRAWDOWN IN PPG 6

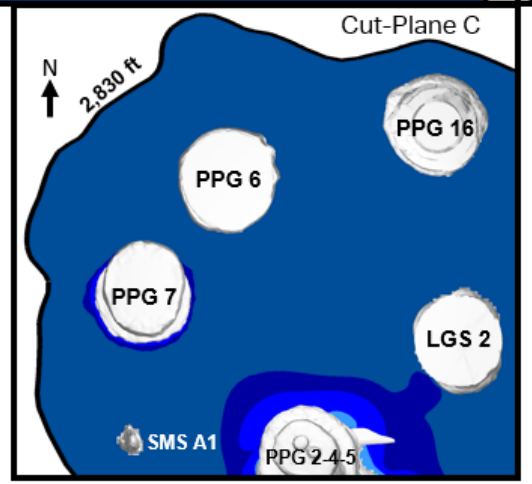
- Min. FS values of 3.0-3.5 at perimeter of PPG 7 roof
- Dilation FS values greater than 5.0 for much of the salt stock surrounding the caverns

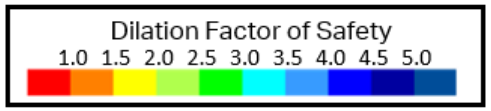


Sep 1, 2023 : 187 psi WHP in PPG 6
80 psi WHP in PPG 7





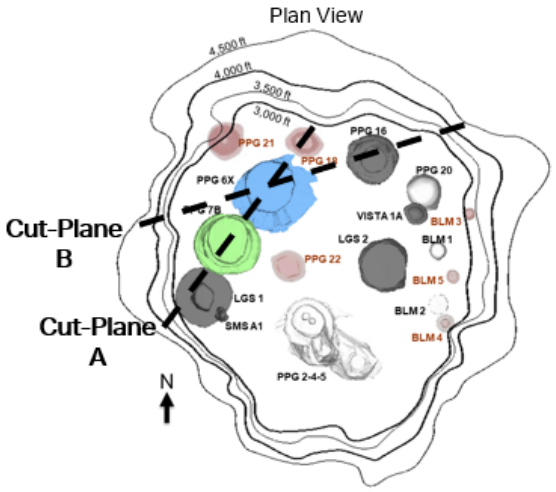




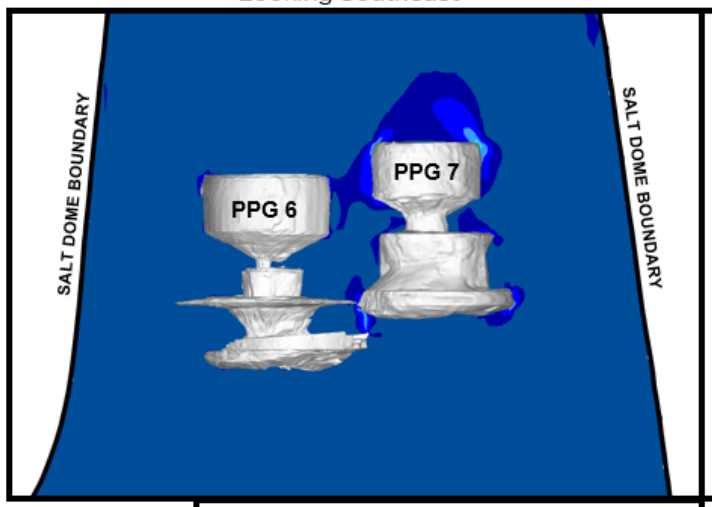
(Images Not-to-Scale)

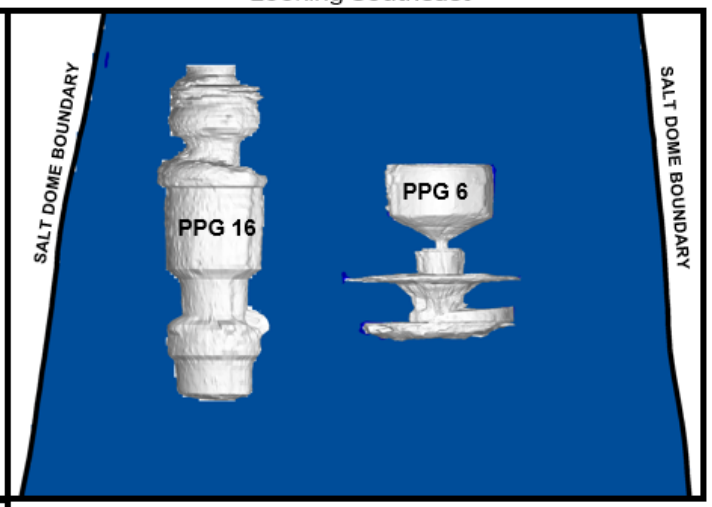
SEP 8, 2023 : AT END OF PRESSURE DRAWDOWN IN PPG 6

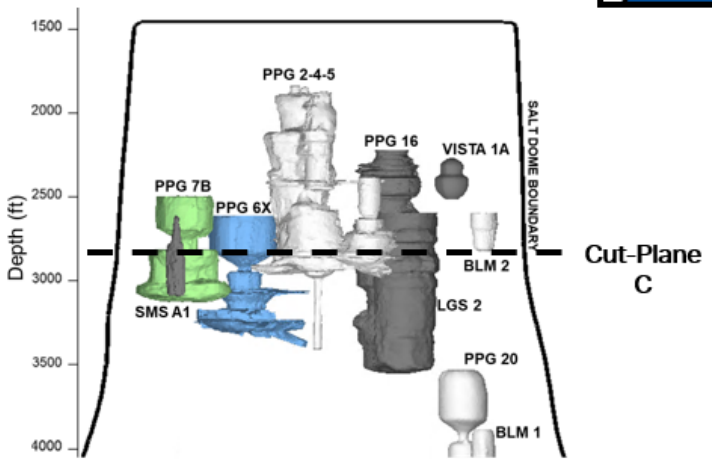
- A gradual pressure drawdown in PPG 6 has a very minor impact on the surrounding salt stock
- The model predicts very low risk of inducing dilatant stress states in the salt around PPG 6 & 7

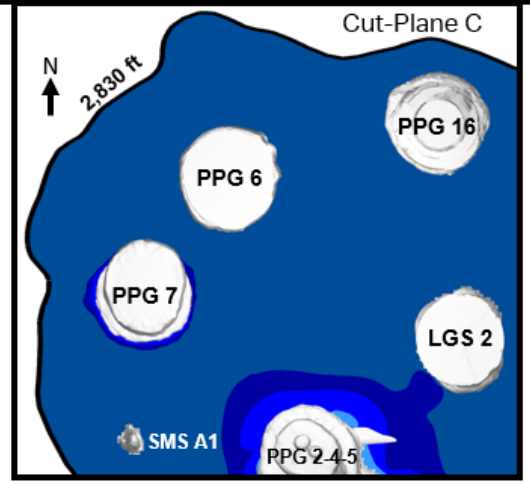


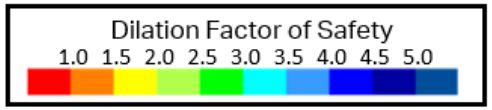
Sep 8, 2023 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7









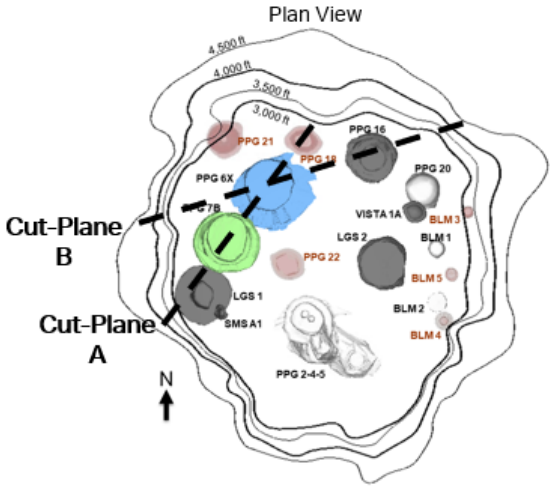


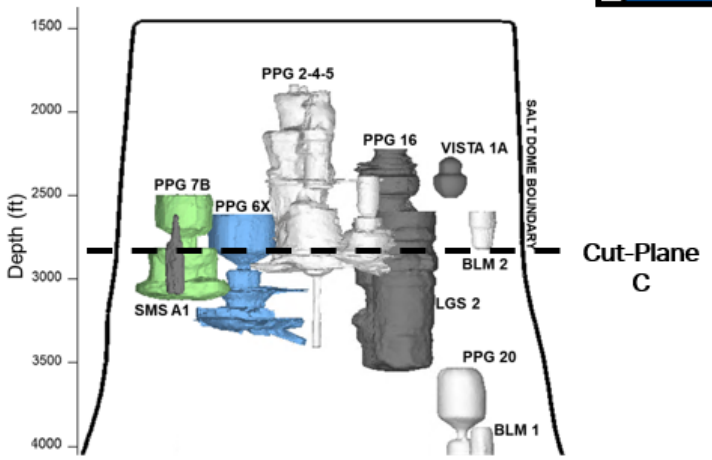
(Images Not-to-Scale)

Sustained Constant Pressure Conditions in PPG 6 & PPG 7 for the next 10 years

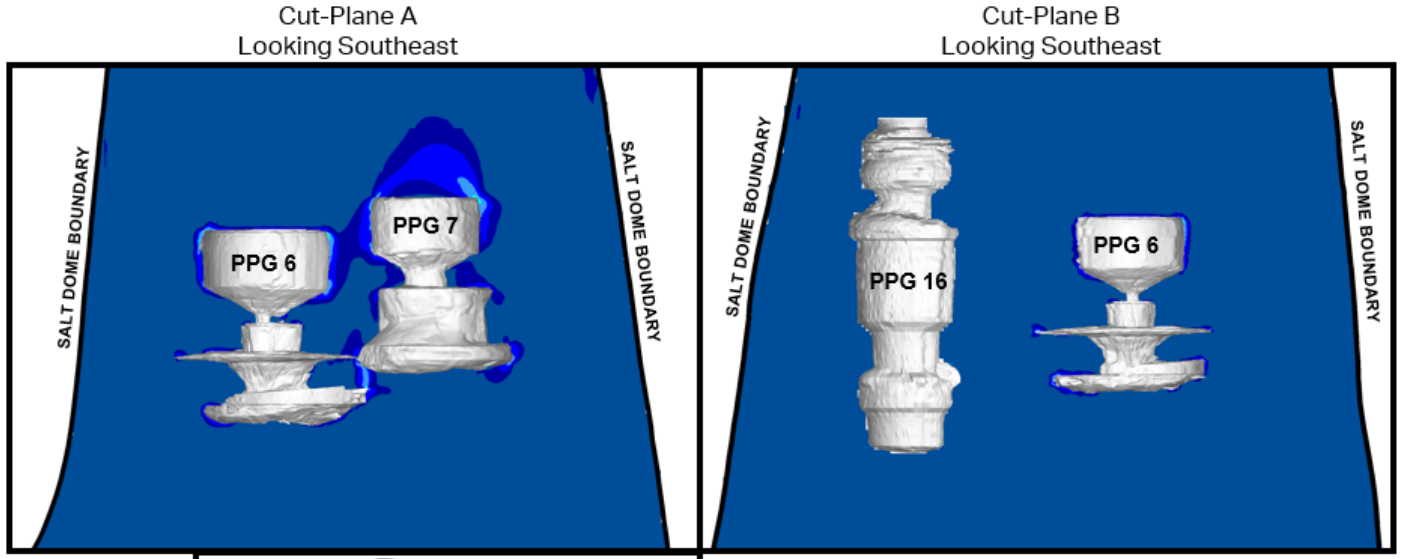
OCT 8, 2023 : AFTER 1 MONTH AT CONSTANT PRESSURES

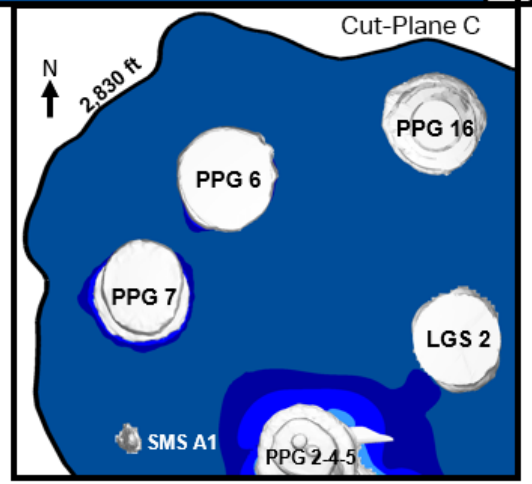
- Model predicts low risk of cavern or web instability in the near-term after reducing the pressure in PPG 6 to 0 psi wellhead pressure
- Min. FS values around the perimeter of the PPG 6 roof are similar to the PPG 7 roof conditions

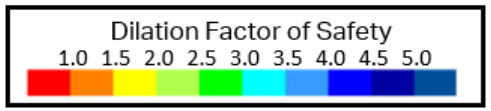




(1 Month) Oct 8, 2023 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7



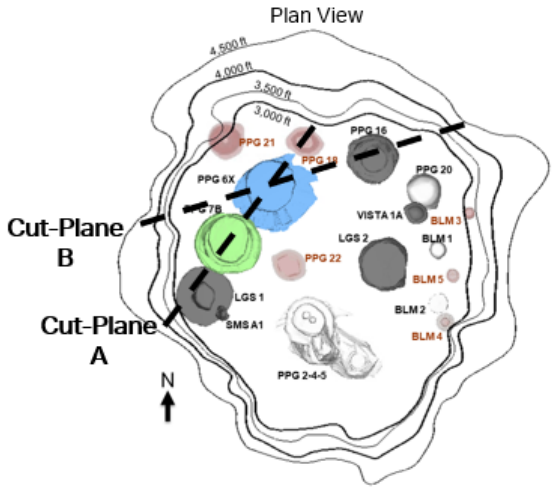




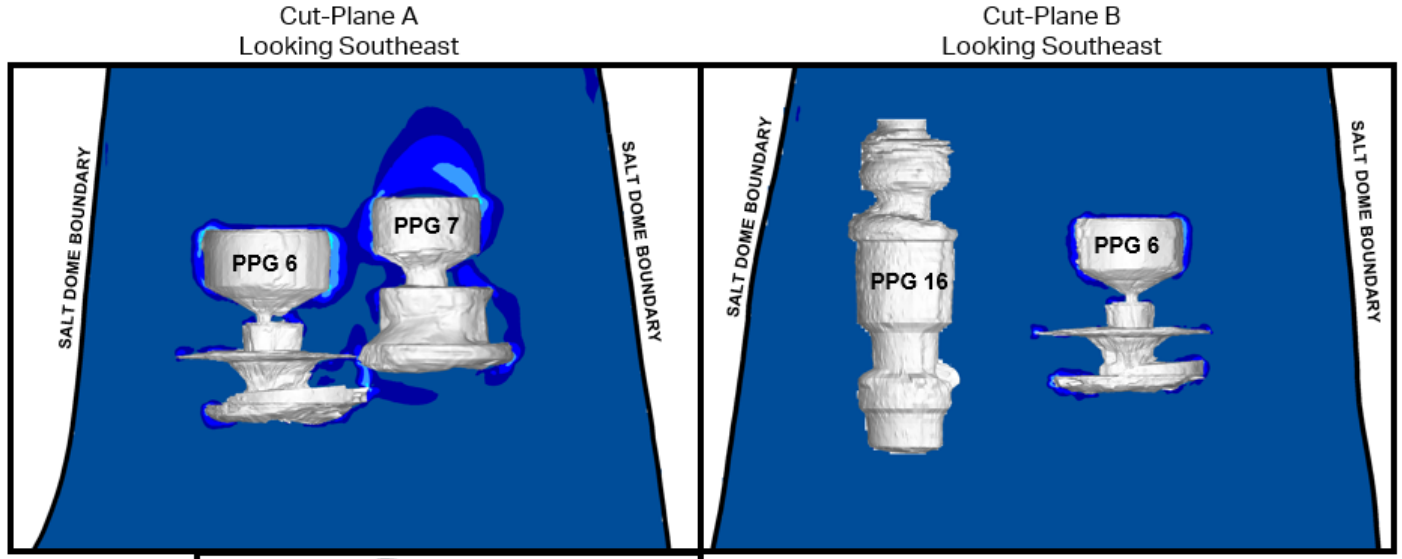
(Images Not-to-Scale)

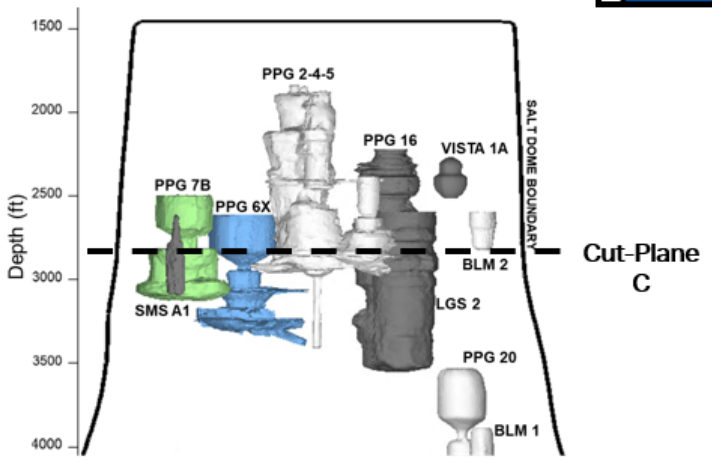
DEC 8, 2023 : AFTER 3 MONTHS AT CONSTANT PRESSURES

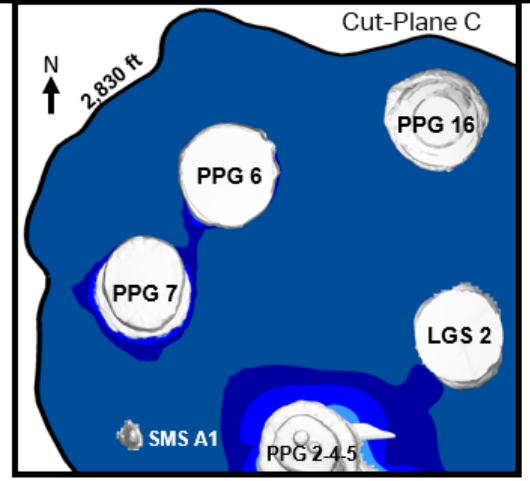
- After 3 months of future salt creep at constant pressures, the region of FS values between 3.0-4.0 around PPG 6 increases slightly

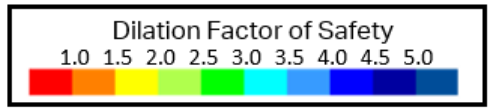


(3 Months) Dec 8, 2023 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7





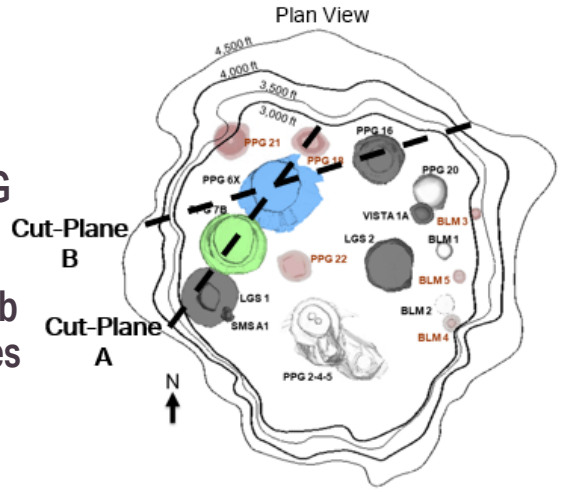




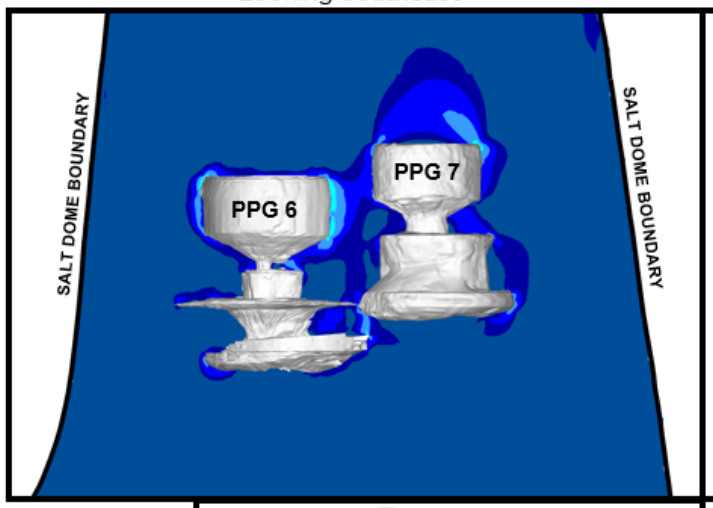
(Images Not-to-Scale)

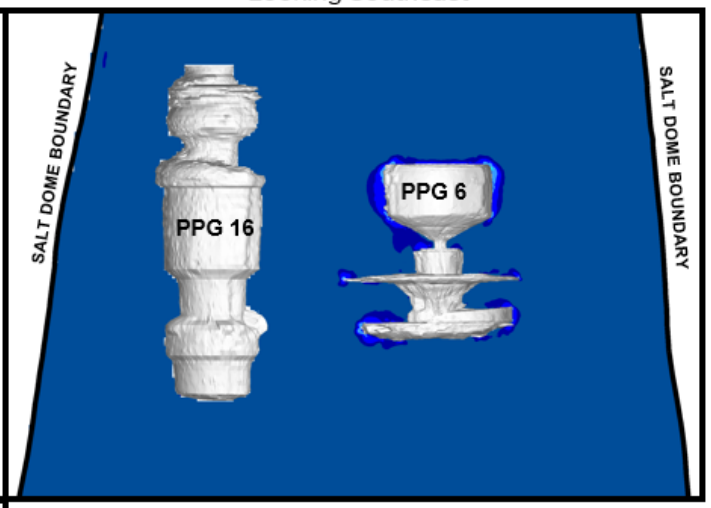
MAR 2024 : AFTER 6 MONTHS AT CONSTANT PRESSURES

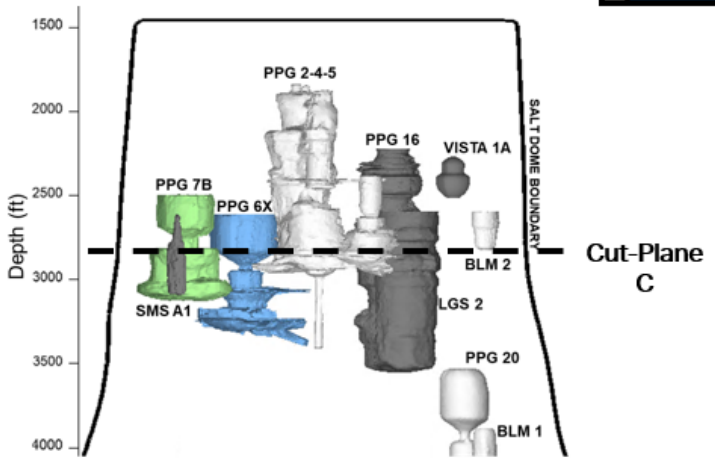
- After 6 months of future salt creep at constant pressures, the region of FS values between 3.0-4.0 around PPG 6 increases slightly
- The min. FS values in the web between PPG 6 & 7 decreases slightly, to values between 4.0-4.5

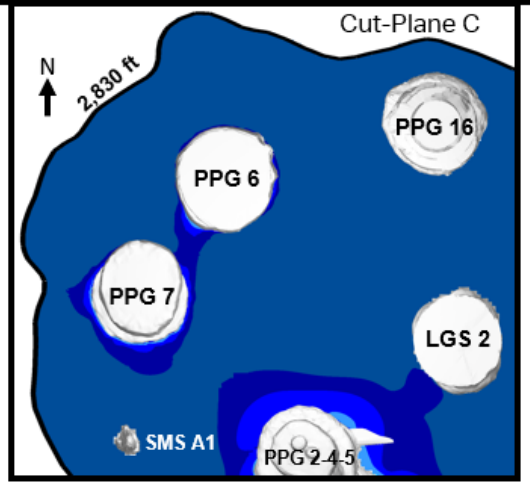


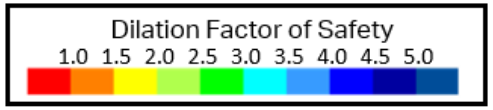
(6 Months) March 2024 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7







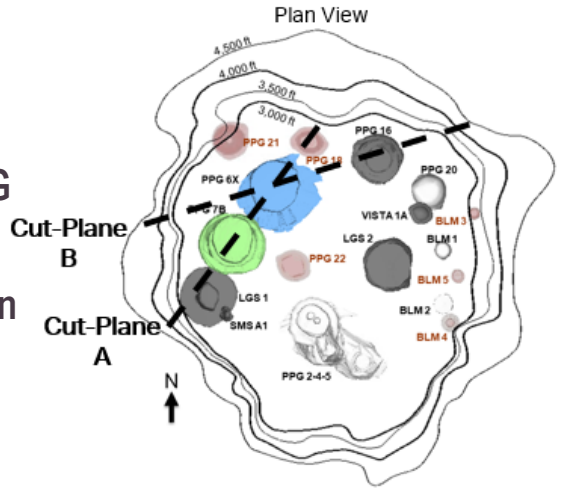


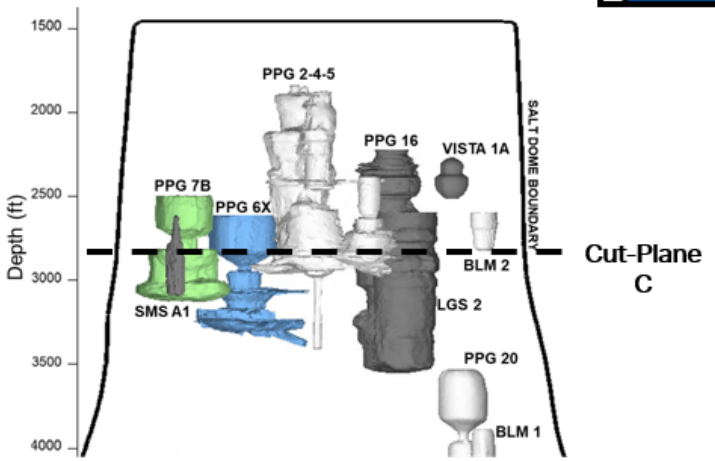


(Images Not-to-Scale)

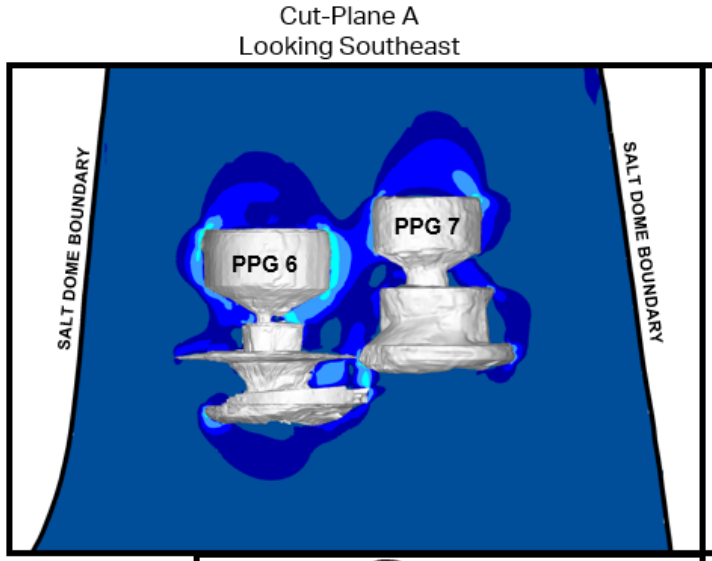
SEP 2024 : AFTER 1 YEAR AT CONSTANT PRESSURES

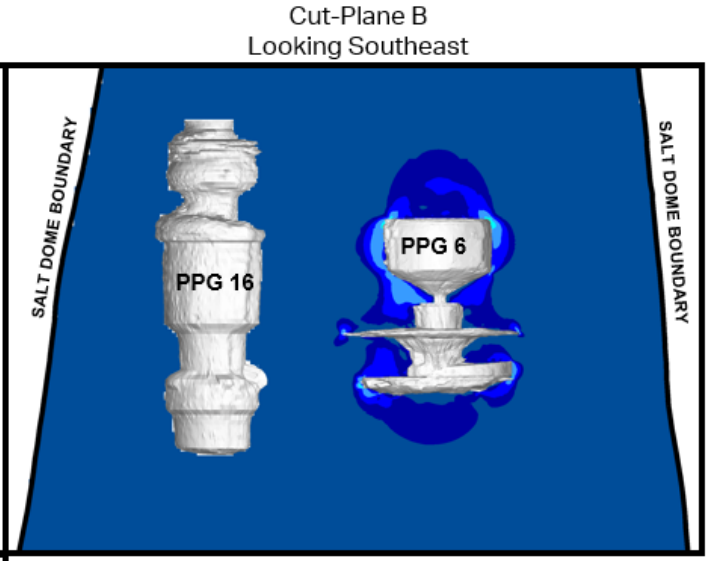
- After 1 year of future salt creep at constant pressures, the region of FS values between 3.0-4.0 around PPG 6 increases a little more
- FS values in the web between PPG 6 & 7 remain greater than 4.0

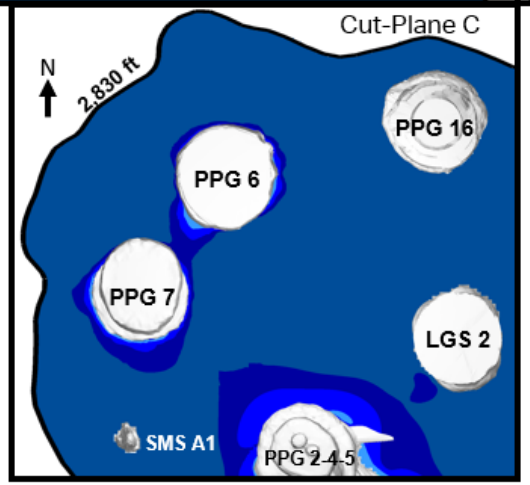


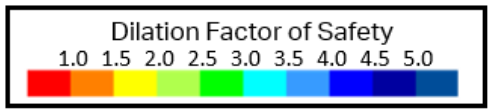


(1 Year) Sep 2024 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7





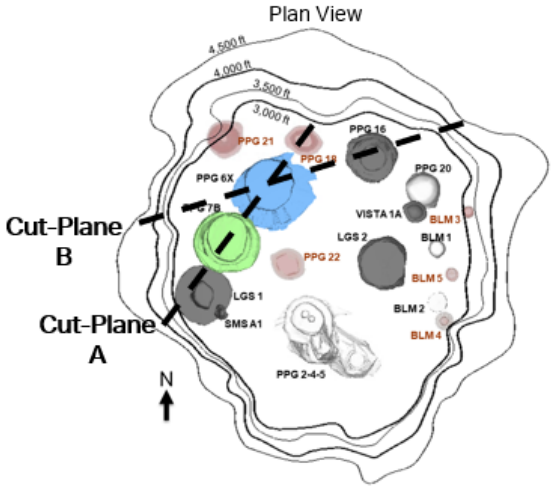




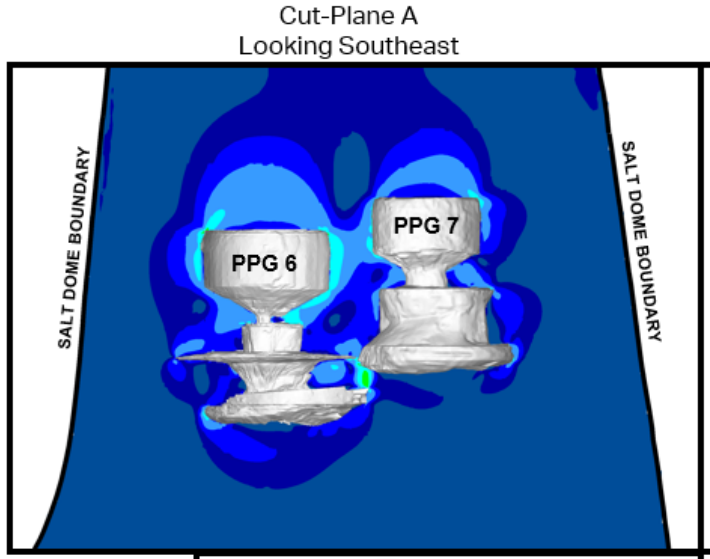
(Images Not-to-Scale)

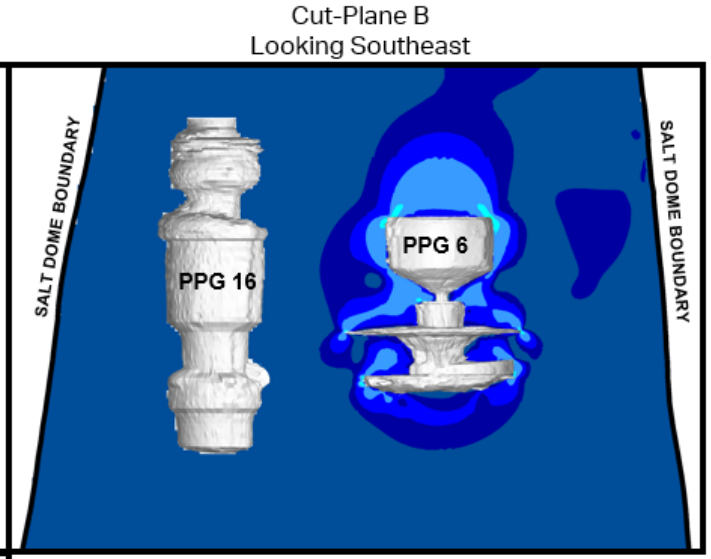
SEP 2028 : AFTER 5 YEARS AT CONSTANT PRESSURES

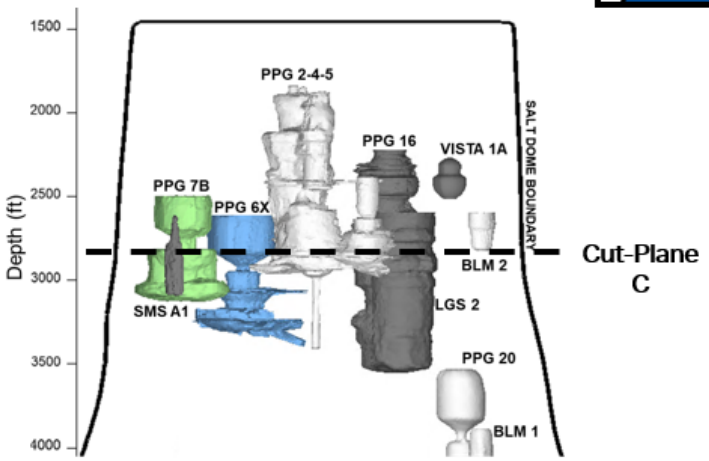
- After 5 years of future salt creep at constant pressures, FS values near the caverns remain greater than 3.0
- FS values in the web between PPG 6 & 7 decrease to values between 3.5-4.0
- FS values in other webs remain greater than 4.5+

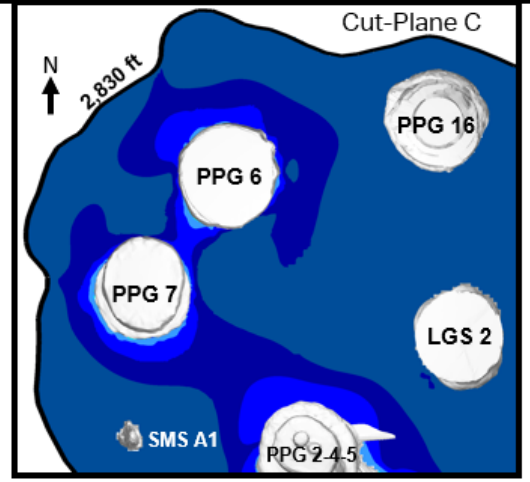


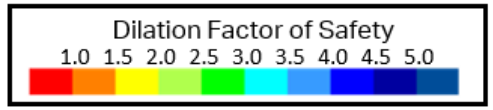
(5 Years) Sep 2028 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7







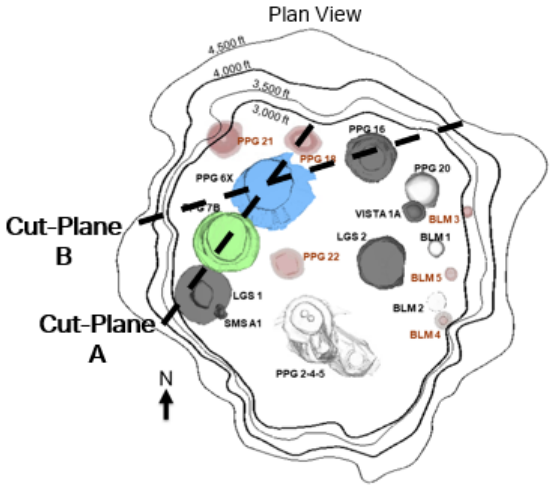




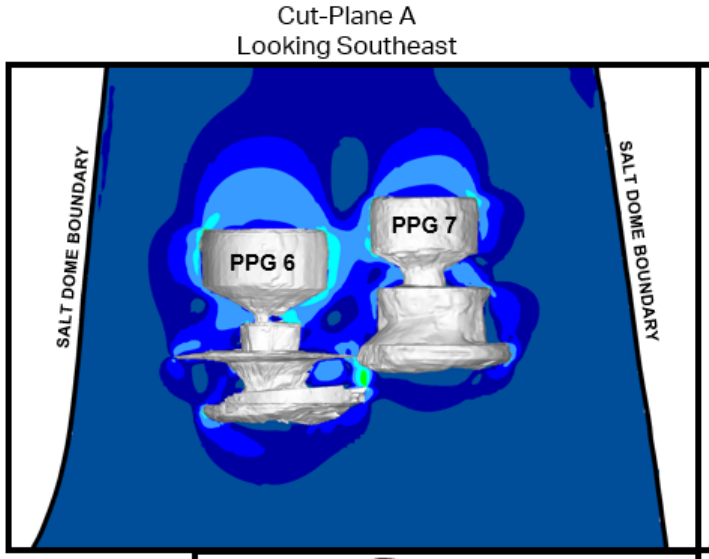
(Images Not-to-Scale)

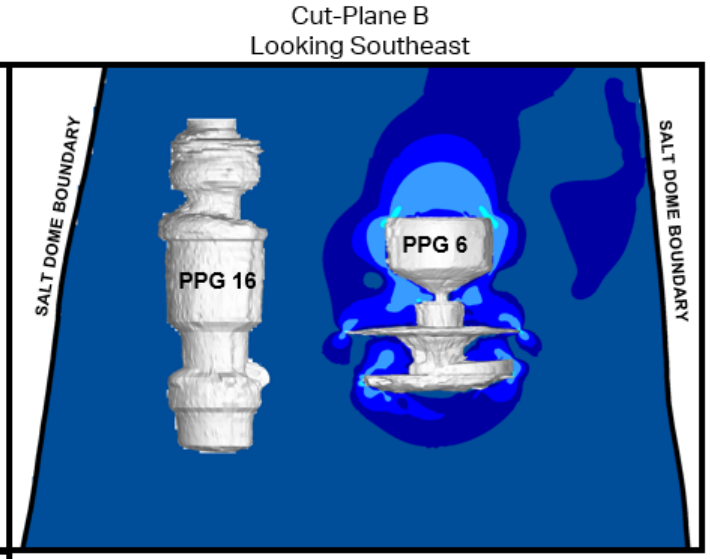
SEP 2033 : AFTER 10 YEARS AT CONSTANT PRESSURES

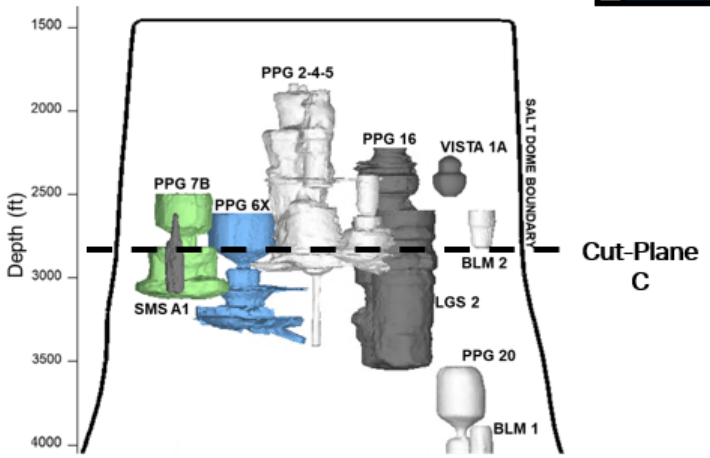
- Very small change in stresses between 5-10 years
- FS values near the caverns remain greater than 3.0
- FS values in the web between PPG 6 & 7 remain greater than 3.5
- FS values in other webs remain greater than 4.5+

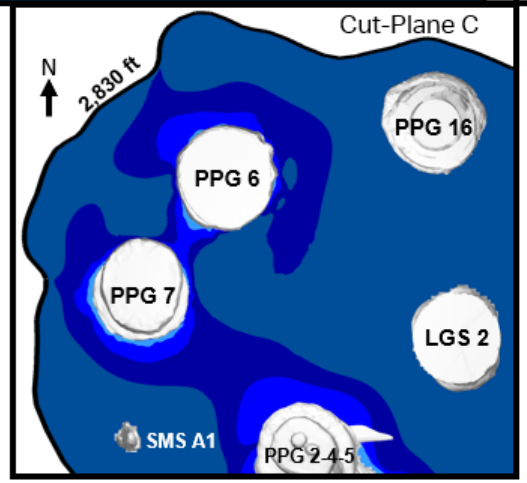


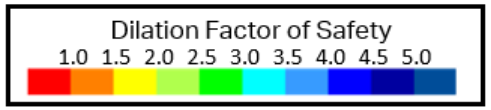
(10 Years) Sep 2033 : 0 psi WHP in PPG 6
80 psi WHP in PPG 7











(Images Not-to-Scale)

SUMMARY OF RESULTS & CONCLUSIONS

- The 3D model predicts very low risk of cavern or web instability immediately after reducing the wellhead pressure in PPG 6 from the current wellhead pressure of approximately190 psi down to 0 psi over a 7-day period.
  - A rapid depressurization of the cavern would be expected to have a more significant impact on the surrounding salt. The depressurization rate of the cavern should be controlled as much as possible to reduce the impact on the salt webs.

- The simulated future salt creep deformation with the caverns at constant pressure conditions causes a redistribution of the stresses, resulting in an evolution of the model-predicted salt damage FS values:
  - Within approximately 1-3 months, the FS values near the cavern surface are reduced to 3.0-4.0
  - Within approximately 6 months, the FS values in the web between PPG 6 & 7 are reduced to 4.0-4.5
  - Within approximately 5 years, the FS values in the web between PPG 6 & 7 are reduced to 3.5-4.0
  - Min. FS values near the caverns remain greater than 3.0 and greater than 3.5 in the web after 10 years

CONCLUSIONS – CONTINUED

- The modeling results and conclusions presented above were based on assuming that the salt properties in the webs can be accurately characterized by the salt from Well No. 22 [Arnold, 2015]. If the properties of the salt forming the webs differ significantly from the salt in Well No. 22 , the conclusions presented here may be impacted. Furthermore, if the contact between the salt web and the nonsalt formations outside of the dome is not perfectly bonded as assumed in this study, the conclusions presented here may be impacted.
- The historical sidewall spalling in PPG 7 evidenced by sonar surveys indicates that the salt in the web between PPG 6 and PPG 7 and the dome flank may exhibit lower strength than what was assumed in this study. It may also indicate that the salt web contact with the adjacent nonsalt formations is weaker than assumed, or that the distance from the dome flank is less than what was assumed in this study.
- Subsequent modeling efforts will investigate these assumptions and the sensitivity of the modeling results to a reasonable range of strength characteristics for the dome flank and adjacent rock formations.

Arnold, R. D., 2015. *Mechanical Properties Testing of Core From Axiall PPG Brine 22 Sulphur Mines Salt Dome, Calcasieu Parish, Louisiana,* RSI-2533, prepared by RESPEC, Rapid City, SD, for Lonquist & Co., LLC, Austin, TX.

GEOMECHANICAL EVALUATION OF PRESSURE DRAWDOWN IN WESTLAKE CAVERN PPG 6 AT THE SULPHUR MINES SALT DOME, CALCASIEU PARISH, LOUISIANA

MINING & ENERGY

CAVERN GEOMECHANICS

RAPID CITY, SD, USA

SEPTEMBER 7, 2023

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