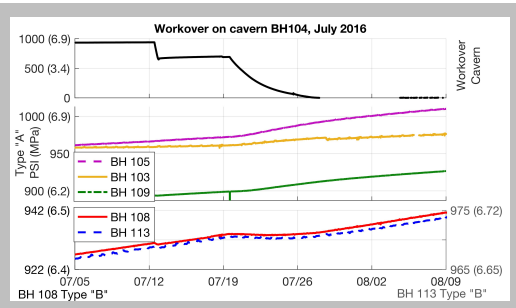
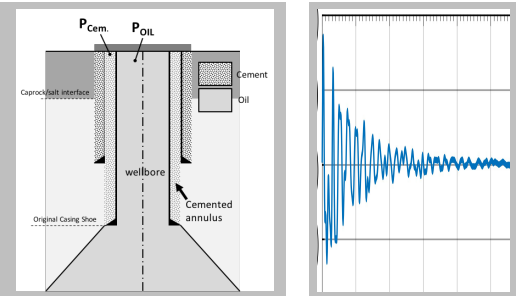


Pressure Trend Analyses for Geophysical and Integrity Investigations



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Introduction

- The U.S. Strategic Petroleum Reserve (SPR) stores emergency supplies of crude oil owned by the U.S. Government.
 - SPR contains ~693 MMbbls ($110 \times 10^6 \text{ m}^3$) of crude oil
 - Stored in 60 solution mined caverns located in four different salt domes on the Louisiana and Texas coasts
 - Filled to maximum capacity of 727 MMbbls ($115 \times 10^6 \text{ m}^3$) in 2009
- The U.S. Department of Energy (DOE) runs and oversees the SPR for the U.S. government from New Orleans, Louisiana
 - Fluor Federal Petroleum Operations (FFPO) is the Management and Operations (M&O) contractor for SPR
 - Sandia National Laboratories (SNL) is the DOE laboratory tasked to provide geotechnical and scientific support for SPR, and provides advice on cavern integrity, among other tasks

Introduction

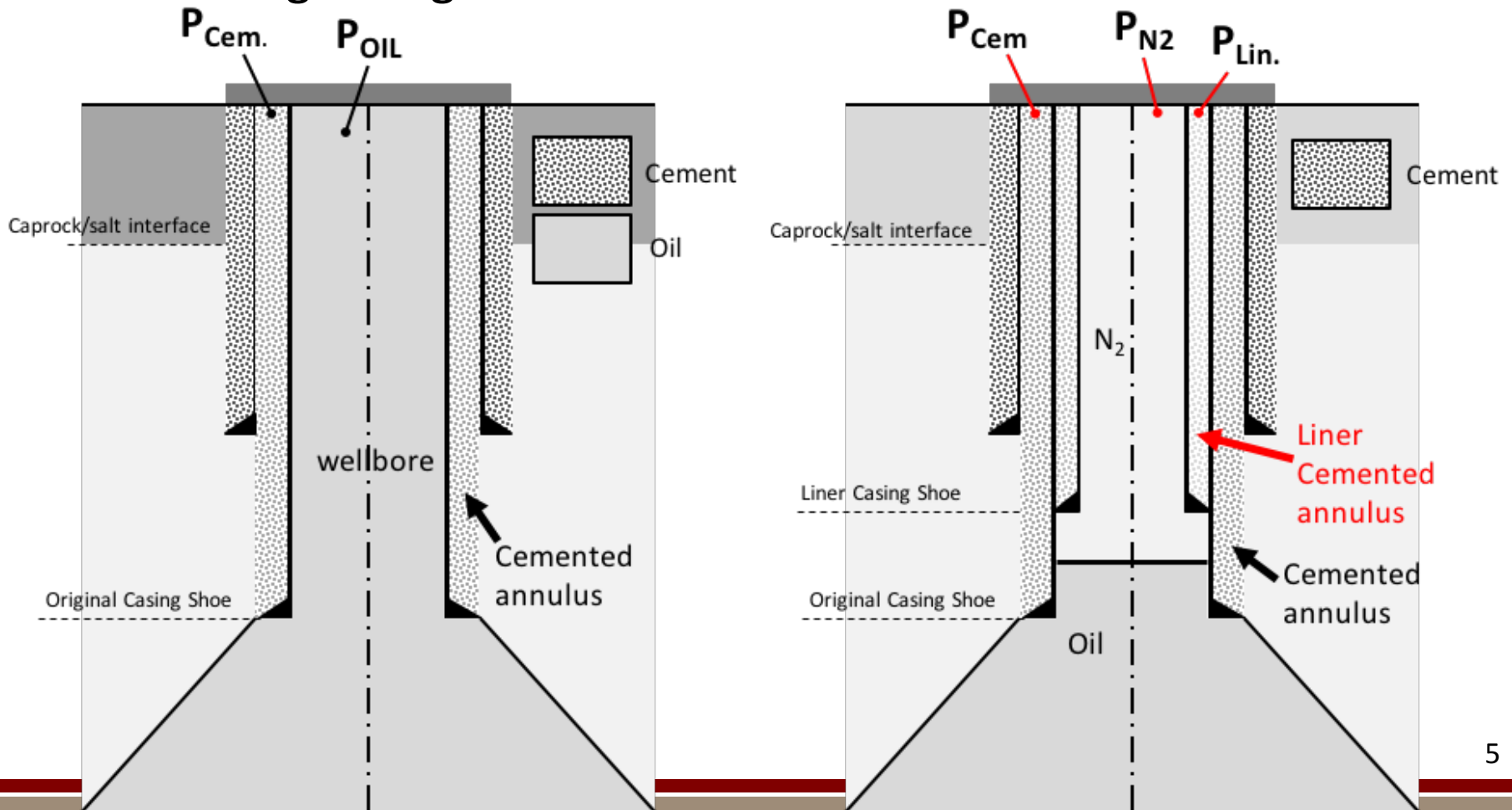
- Well and cavern integrity is an issue of significant concern for cavern operators
 - No one wants another incident like the Napoleonville collapse/Bayou Corne sinkhole
 - No one wants to deal with the environmental impact of leaking caverns, nor with the fines
 - No one wants to lose product
- Analysis of pressure trends can provide insight into geophysical behavior and well and cavern integrity, including
 - Salt falls
 - Neighboring cavern depressurization/repressurization effects
 - Well-bore to annulus flow paths
- SNL developed a tool to aid in these analyses

Outline

- Application of pressure versus time analysis at longer time scales
 - A. Casing pressure flow paths and seal-tite application
 - B. Workover effects on neighboring cavern pressurization rates
 - C. Salt fall detection

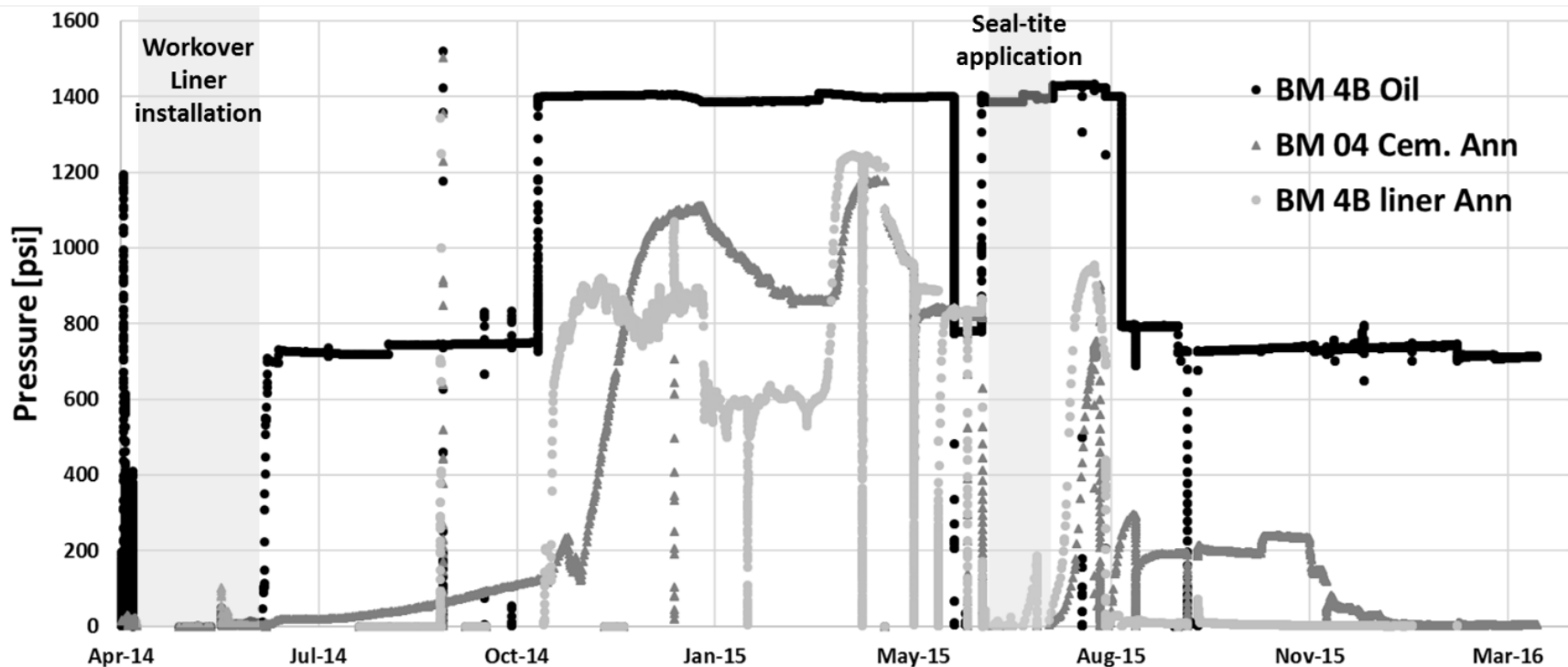
SPR Well Configurations

- SPR caverns generally have two wells with one of the following configurations



Cemented Annulus Analysis

- After liner installation cemented annulus pressure rises rapidly with nitrogen injection
- After seal-tite application pressure returns to zero after a few weeks bleeding off trapped gasses (from application)



Cemented Annulus Analysis

- Long term pressure trends are necessary to see if annular pressures are rising slowly or sharply
- Analysis of annular pressures important when looking at success of sealant and remediation activities
- We has seen a successful application of seal-tite to well BM-4B – annular pressure is still at effective zero pressure

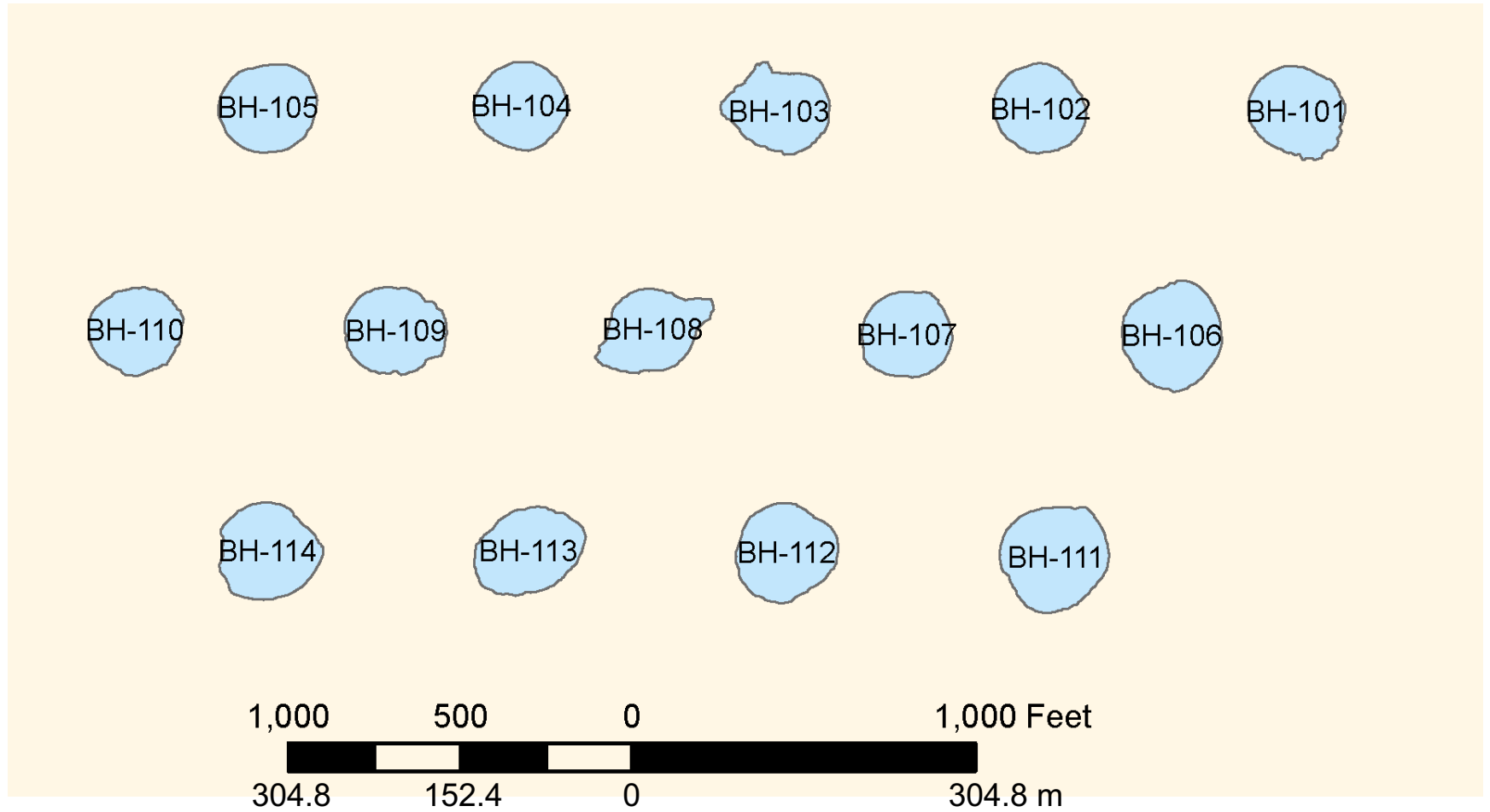
Neighboring Cavern Effects

- During cavern lifecycle many depressurization and pressurization events occur, usually for well maintenance or repair activities

- Depressurizing one cavern can have significant effects of neighboring caverns
 1. Pressure changes will propagate through the salt radially
 2. Changes in vertical pressure affect the overburden and caprock pressure across the dome

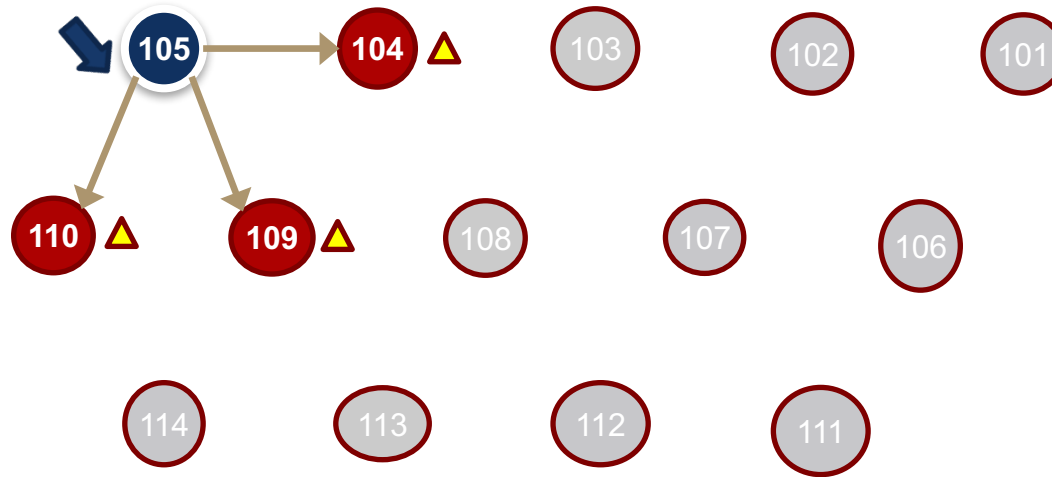
- A study was performed looking at neighboring cavern effects at the SPR Big Hill site (TX, USA)

Big Hill Site: 14 caverns



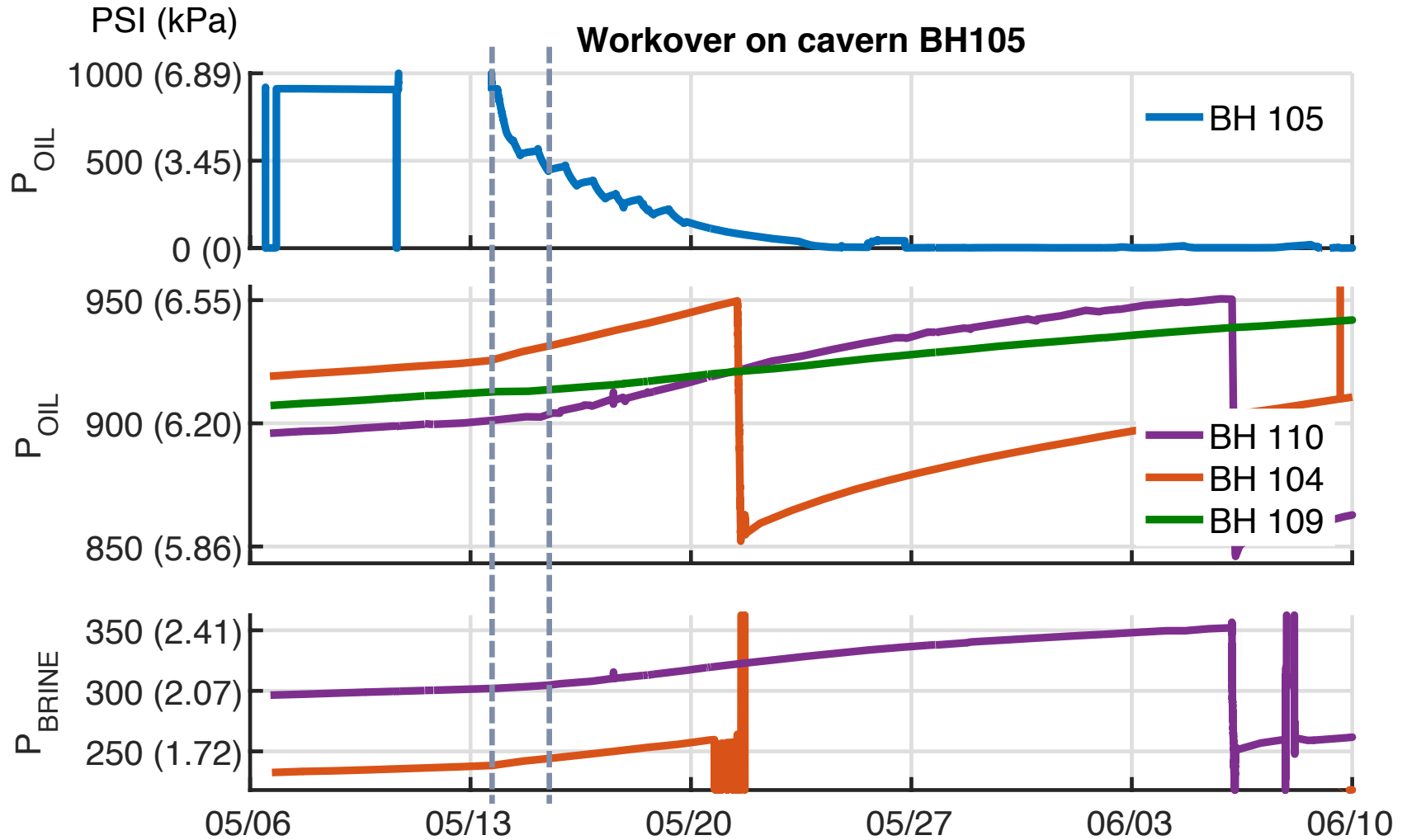
Single Cavern Depressurization

- Cavern 105 depressurized for 49 days for well workover



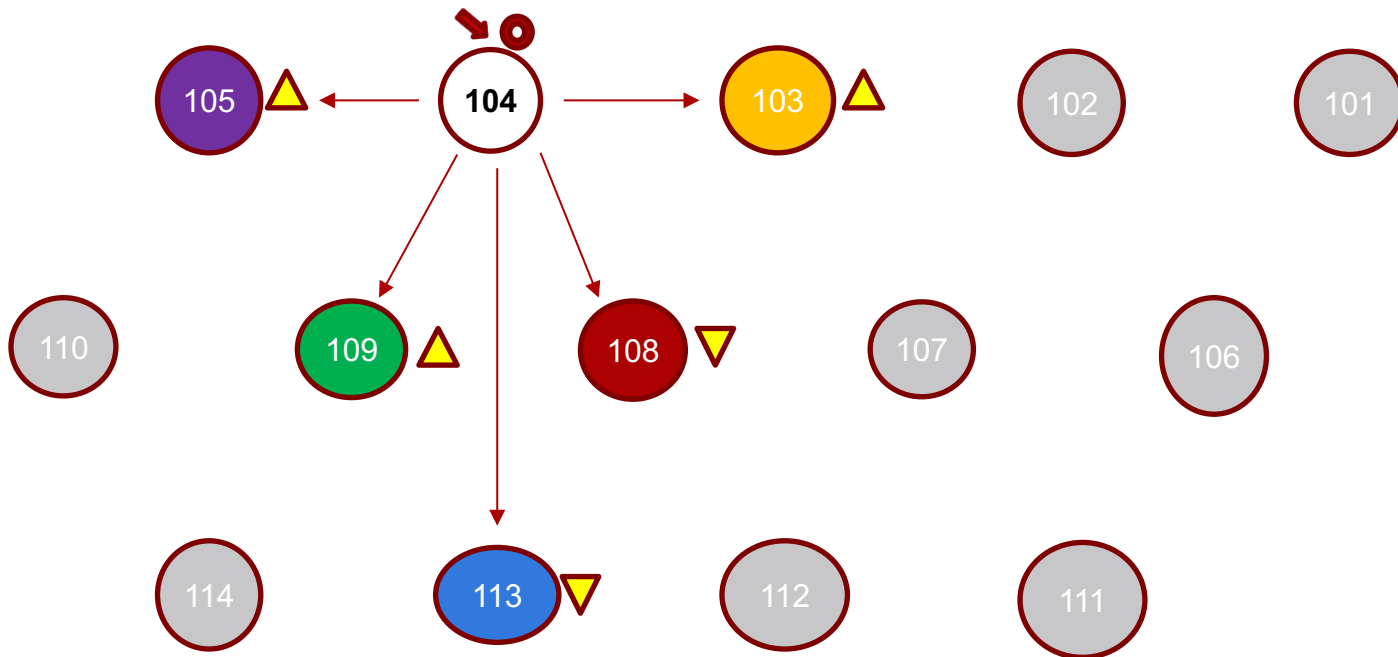
- Pressurization rate (dP/dt) **increased** in neighbor caverns as pressure decreased in 105

Single Cavern Depressurization

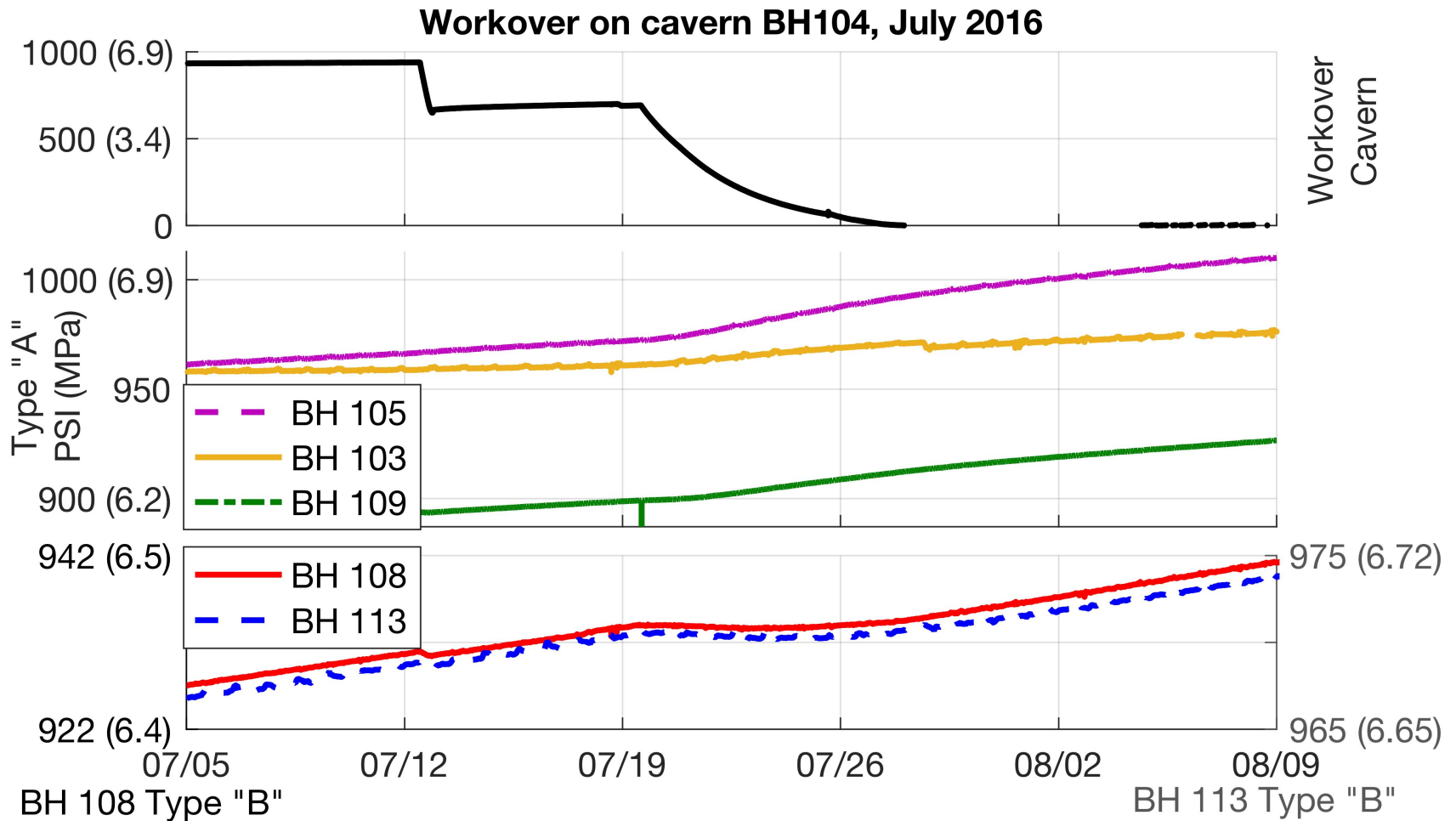


Differing Behavior

- Depressurization at Cavern 104 resulted in 3 wells showing typical behavior, and two wells showing a different behavior
- New behavior shows pressure **decreasing in sync** with the pressure drops in the cavern undergoing workover

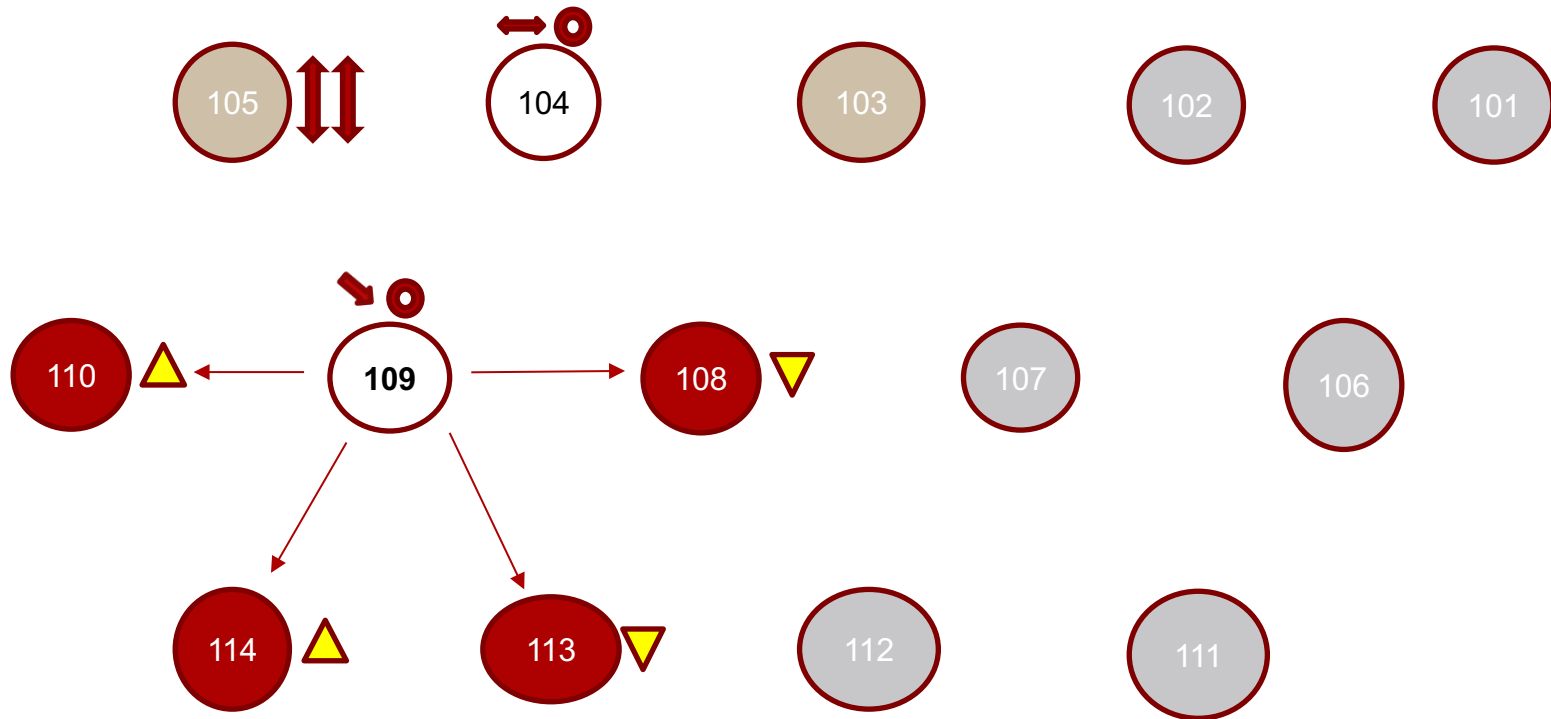


Differing Behavior

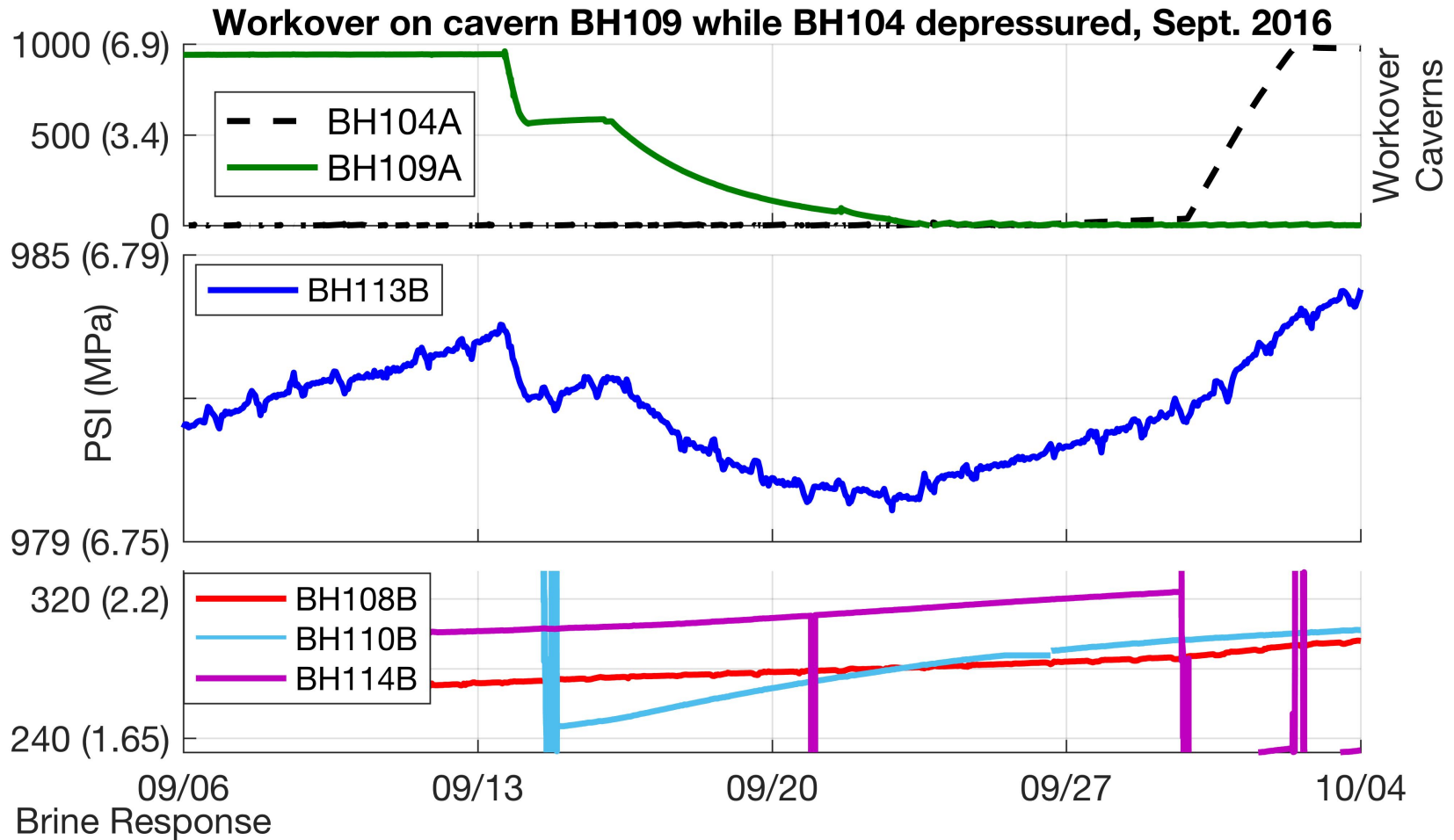


Simultaneous Depressurization

- Depressurization of Cavern 104 was followed by depressurization of Cavern 109 with an overlap
- Same two caverns (108 and 113) show the “new” behavior



Simultaneous Depressurization



Implications

- Two identified behaviors:
 - A. Pressurization rate (dP/dt) increase during neighbor depressurization
 - B. Pressure changes that follow track (at a fractional amount) the pressures in the neighboring, depressurizing cavern

- Behavior is location dependent
 - All caverns that demonstrate behavior B also demonstrate behavior A, depending on which neighbor is depressurized
 - Some caverns only demonstrate behavior A
 - Behavior B occurs in multiple places across the site

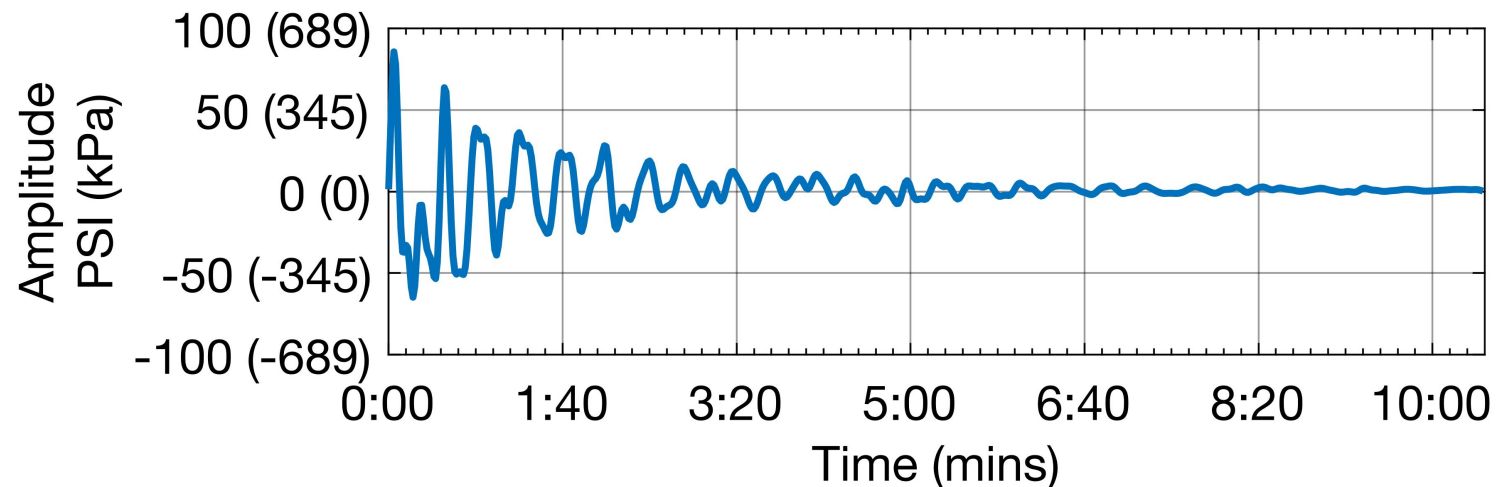
- Behavior B was only identified as a normal response because analysis of long-term pressure trends was available

Salt Fall Detection

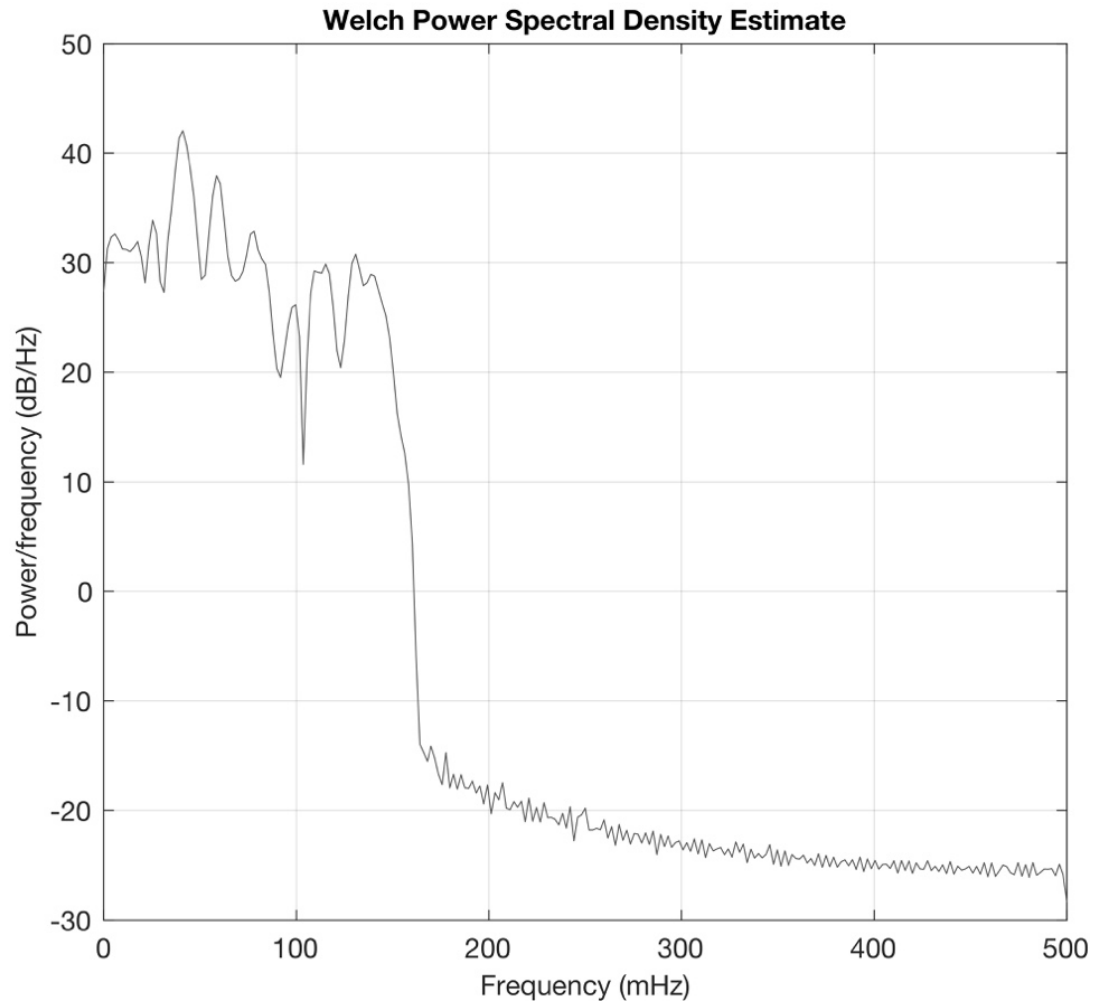
- Salt falls within a cavern can damage hanging strings, change cavern geometry and characteristics, and have implications for cavern integrity
- Detecting salt falls can be done in several ways
 - Being on the pad and hearing/feeling the fall (or use geophones)
 - Seeing cavern shape change on a sonar
 - Having the string break
 - Processing well head pressures for a signature signal
- FFPO developed an algorithm for the SPR SCADA setup that can flag salt falls based on pressure signatures

Salt Fall Detection

- A series of known salt fall events were used to develop the algorithm
- Events with similar signatures, such as fluid movements or logging, are excluded using other information from SCADA
- Example shows deviation from starting pressure



Signal Analysis



Salt Fall Detection

- Salt fall pressure waves tend to last five to ten minutes
- Falls causing string failures have clear and characteristic increase in pressure as oil replaces brine in the remaining string
 - May be possible to anticipate depth of break, and therefore minimum height of the fall from this curve?
- We believe that with modeling it may be possible to relate pressure signal to the size of the fall
 - An example fall with good SONARs before and after would be needed to validate the model empirically

Summary & Conclusions

- We have developed a tool to study cavern pressure history as a function of time, both at the day-to-day scale and multi-year historical time scale
- We have looked at successful application of Seal-Tite to a well
- We have previewed an upcoming report on neighboring cavern workover effects
 - Able to find two different behaviors
- We have shown that detecting salt falls can be done through the DCS/SCADA system with appropriate rules