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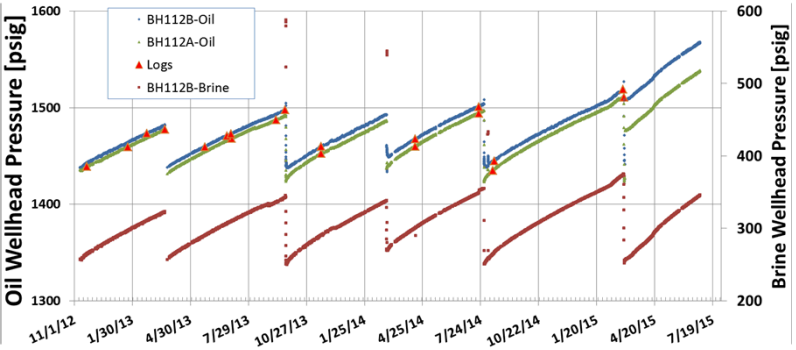

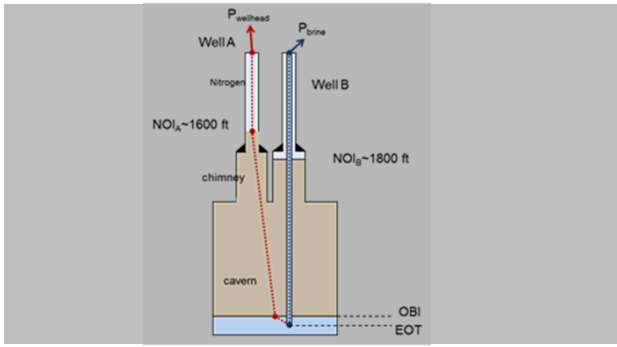

Modeling the behavior of caverns under nitrogen

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Galveston, Tx

U.S. DEPARTMENT OF ENERGY | National Nuclear Security Administration

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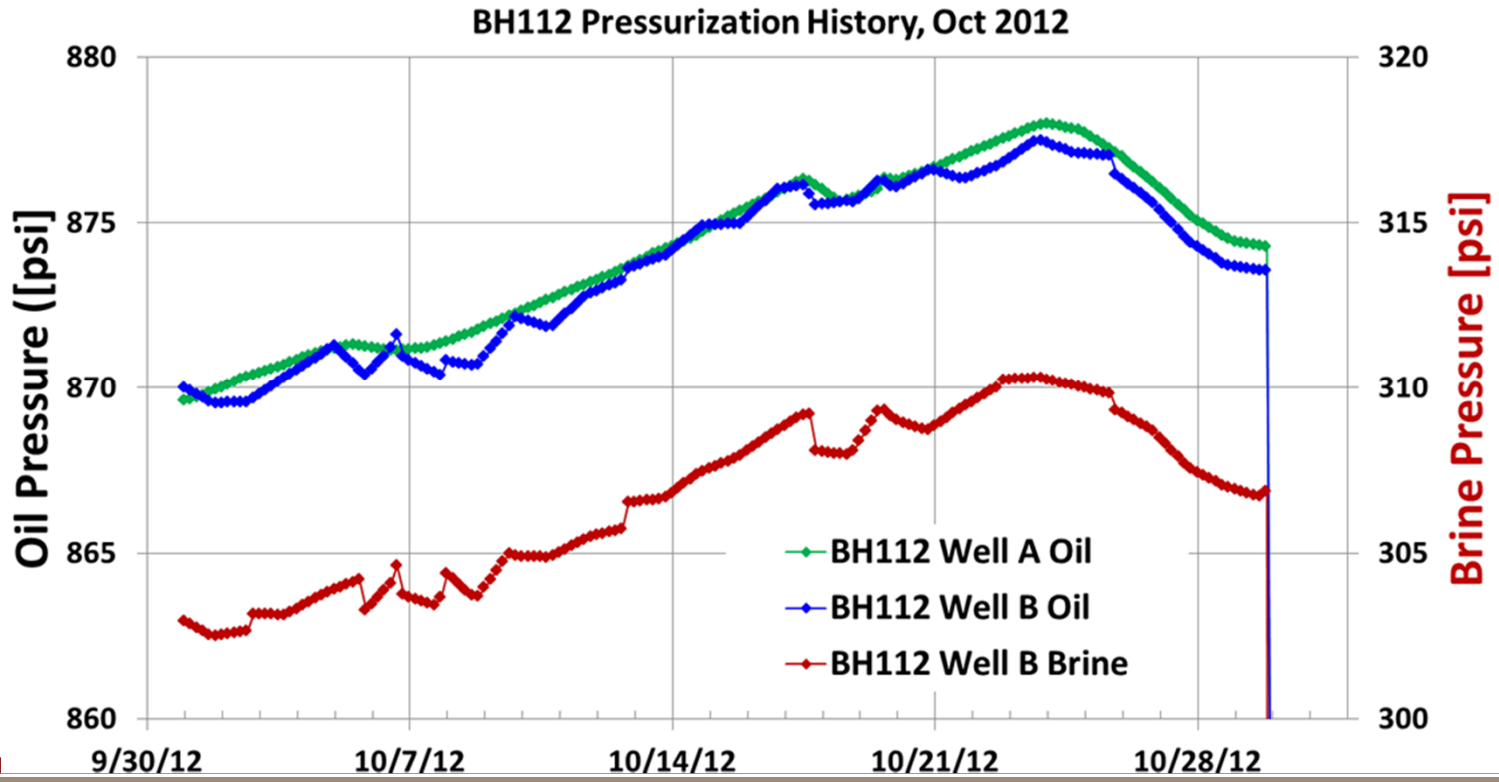
Outline

- Background
  - Why do we need a model?
  - 'Problem' description
- Hydrostatic Column Model (HCM)
  - Model description
  - Validation
  - Performance
- Discussion
  - Model predictions for original problem
  - Lesson learned
- Future direction

Background

- In Nov. 2012 two caverns at Big Hill site (BH 103, BH 112) were place under nitrogen after temporary flattening of pressurization rates. BH 107 followed in Dec. 2013.
- Caverns were closely monitor for several months.
- Steady, yet distinct, pressurization rates were found



Cavern Configurations

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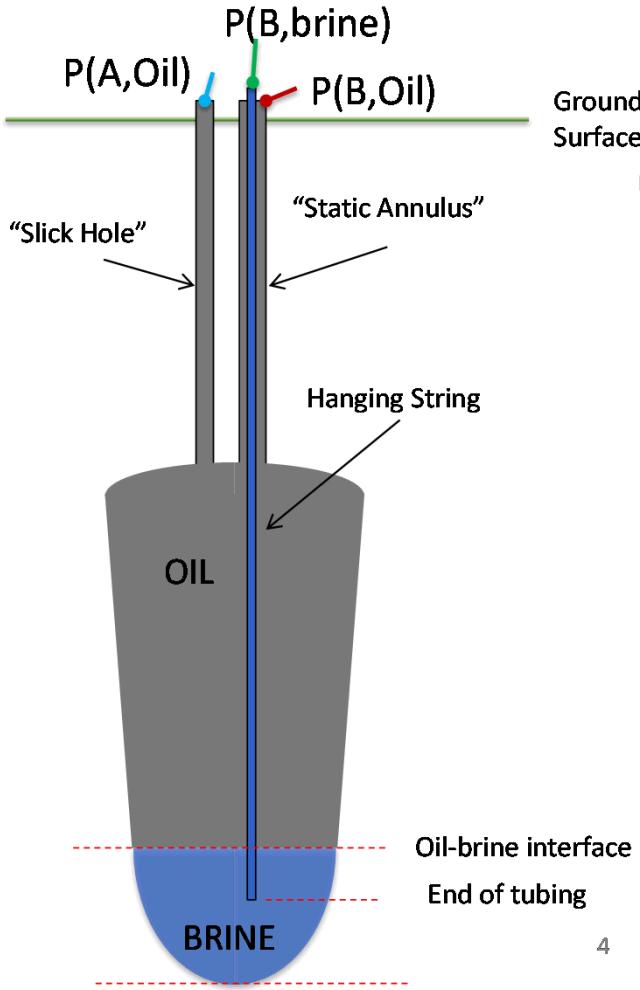
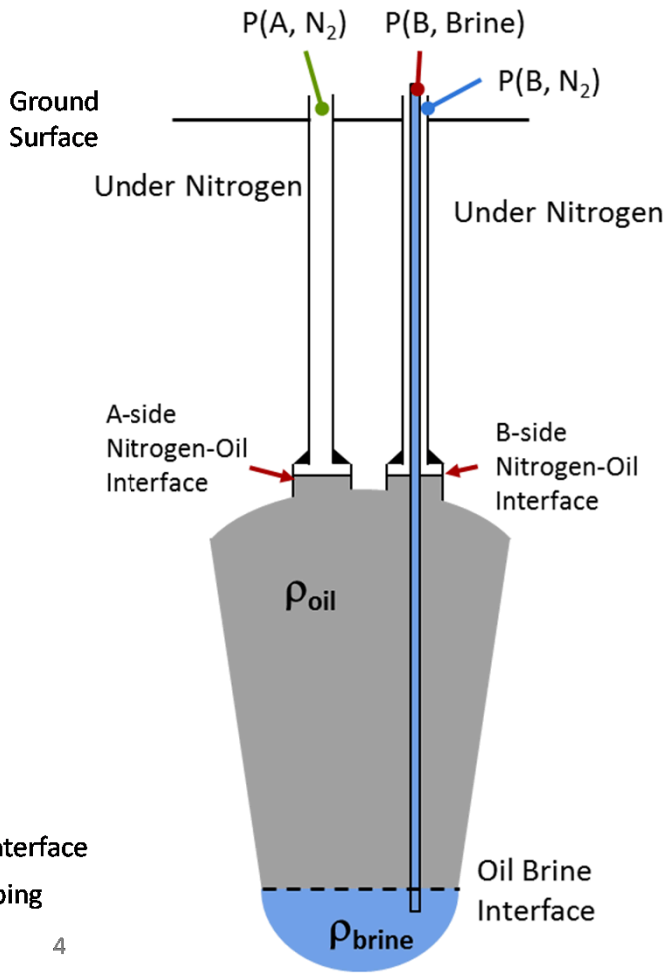
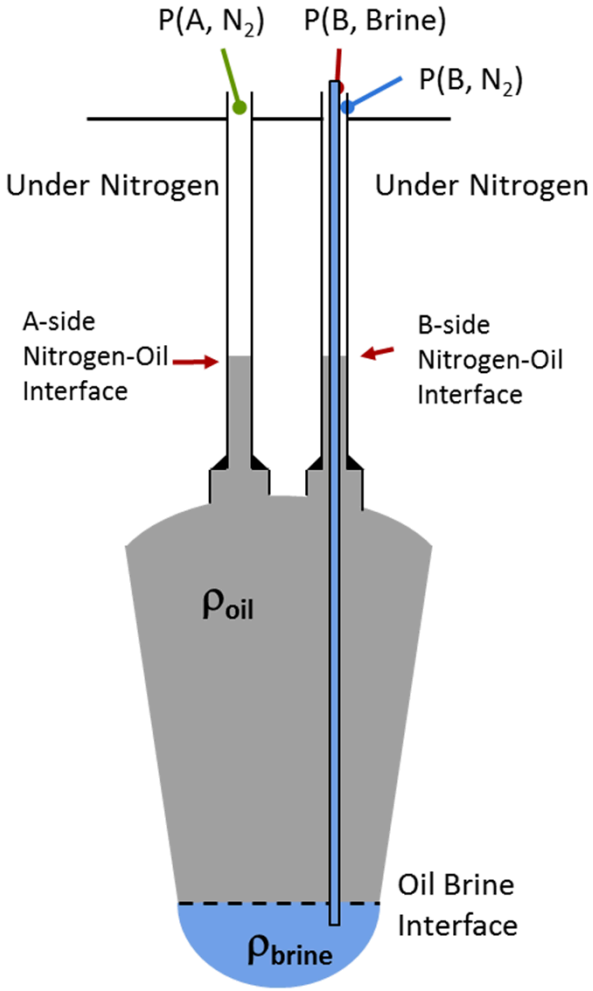
Normal Operating Configuration



MIT Configuration

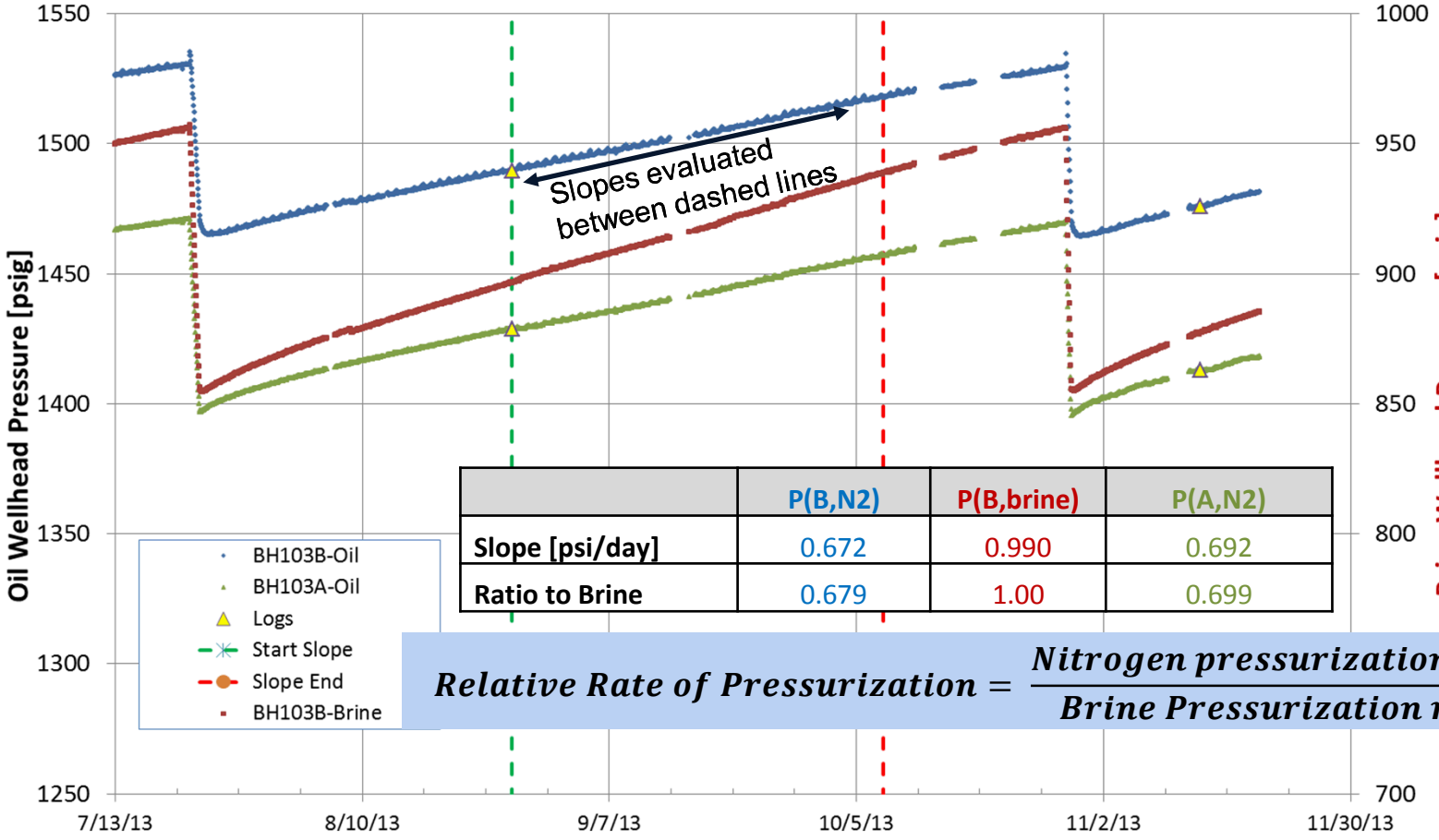


Nitrogen Monitoring Configuration

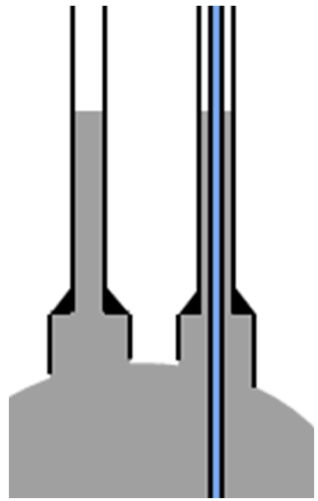


BH103 Under Nitrogen

- N_2 wellhead pressures were found to pressurize at the slower rate than brine
- Relative pressurization rates were found to be ~ 0.7 for both wells



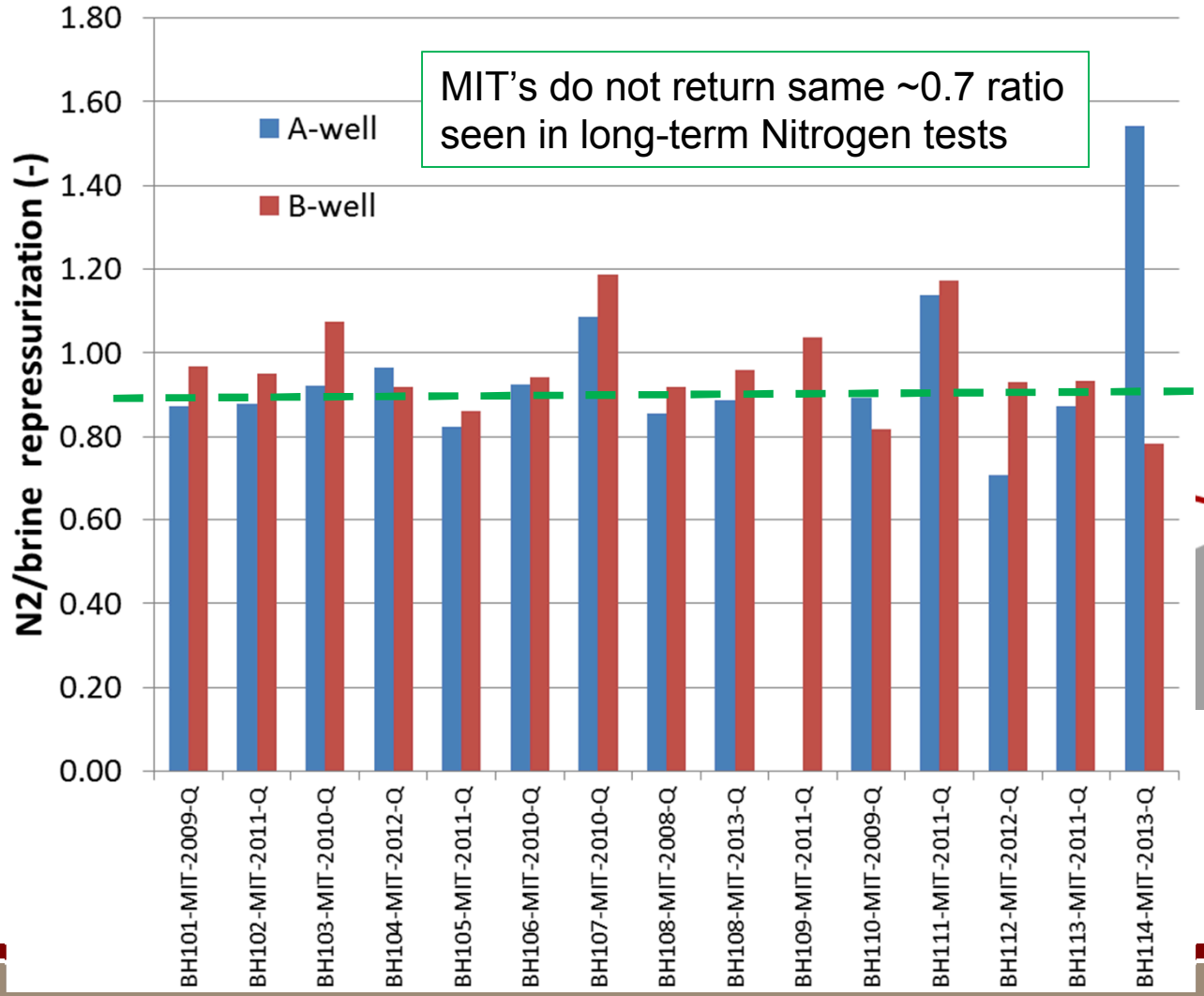
	P(B,N2)	P(B,brine)	P(A,N2)
Slope [psi/day]	0.672	0.990	0.692
Ratio to Brine	0.679	1.00	0.699



$$\textit{Relative Rate of Pressurization} = \frac{\textit{Nitrogen pressurization rate}}{\textit{Brine Pressurization rate}}$$

Big Hill MIT's in Aggregate

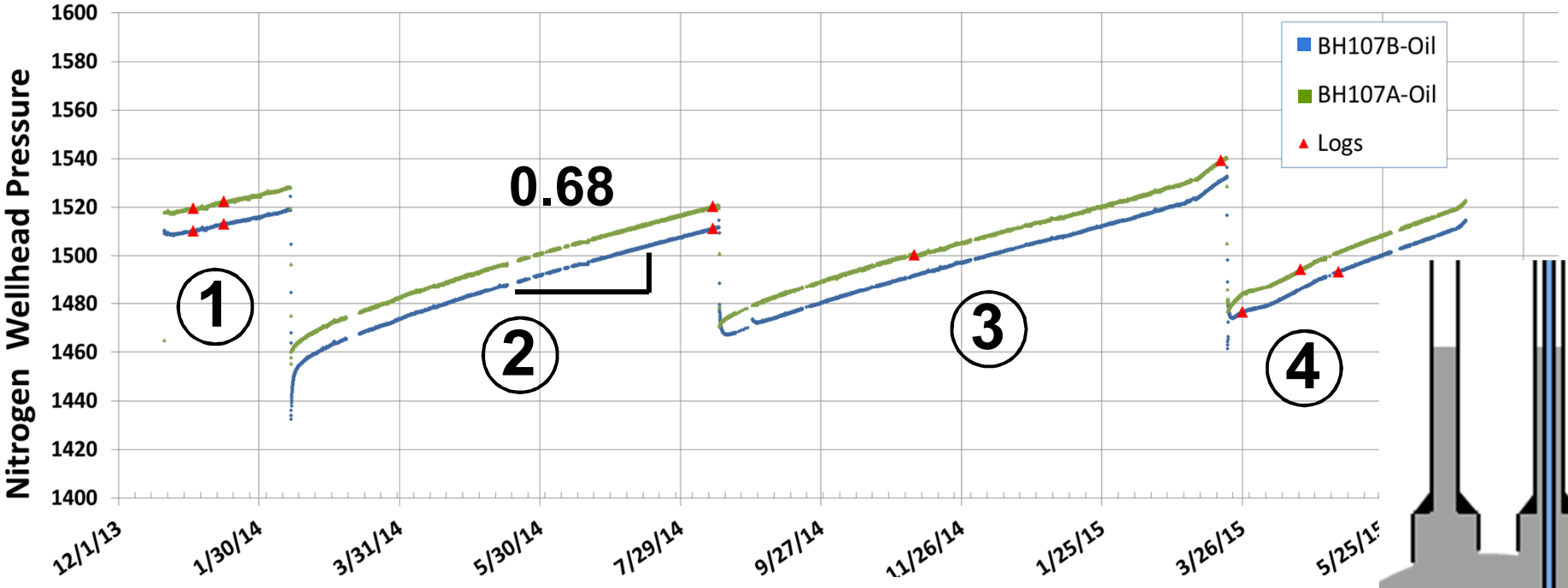
- Analysis of the relative pressurization rate during MITs for Big Hill site shows rates ~ 0.9



BH107 Pressure Analysis

- 1 ½ year under nitrogen monitoring
- Well A and B pressurize with a consistent relative rate of **0.68**

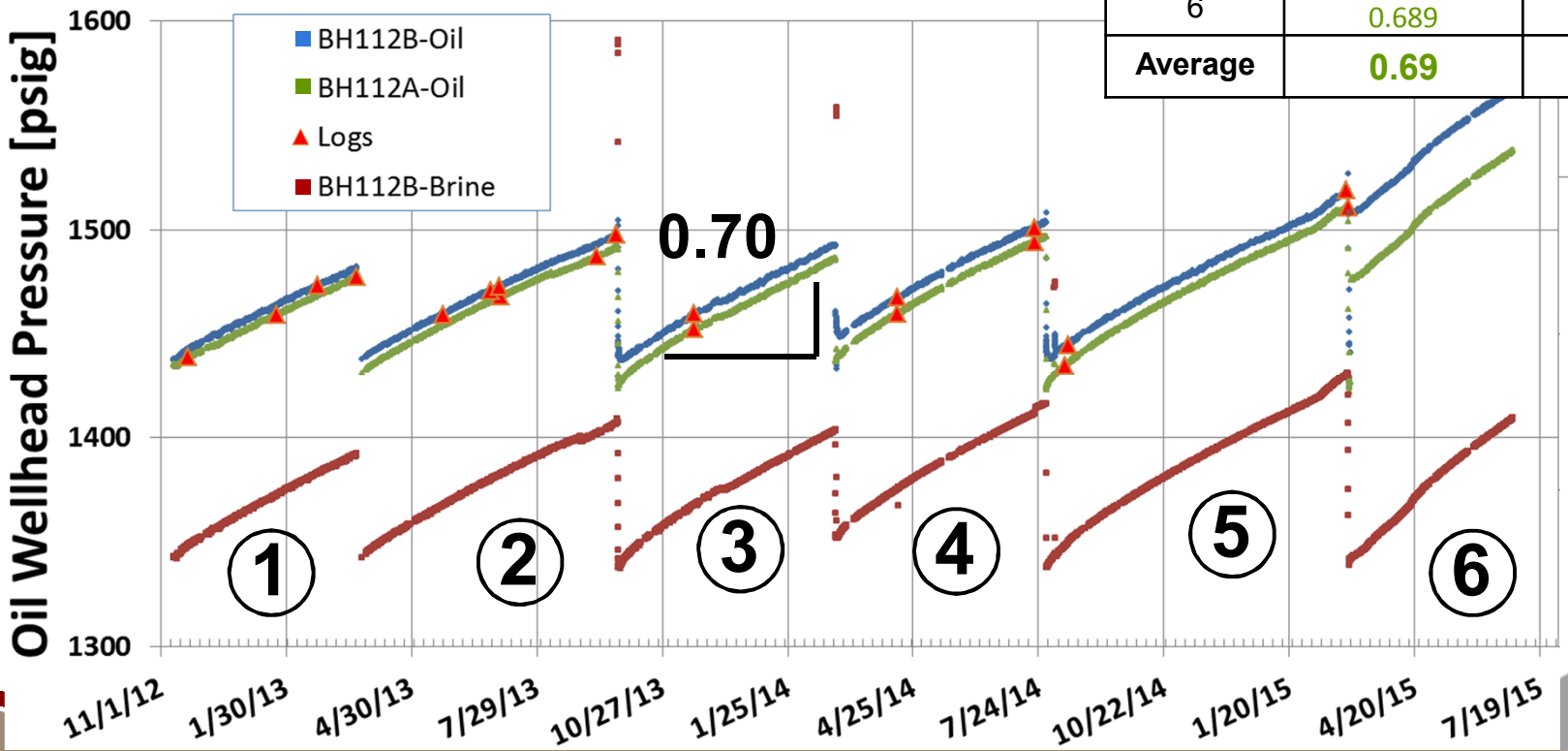
	BH107A	BH107B
Cycle	Relative rate	Relative rate
1	0.67	0.67
2	0.68	0.68
3	0.65	0.68
4	0.71	0.71
Average	**0.68**	**0.68**

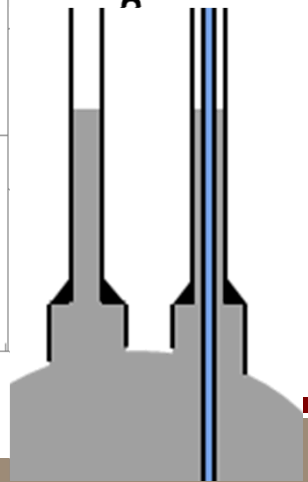


BH112 Pressure Analysis

- 2 ½ years under nitrogen monitoring
- Well A and B pressurize with a consistent relative rate of **~ 0.7**

	BH112A	BH112B
Cycle	Relative rate	Relative rate
1	0.662	0.668
2	0.694	0.696
3	0.697	0.691
4	0.710	0.699
5	0.713	0.695
6	0.689	0.724
Average	0.69	0.70

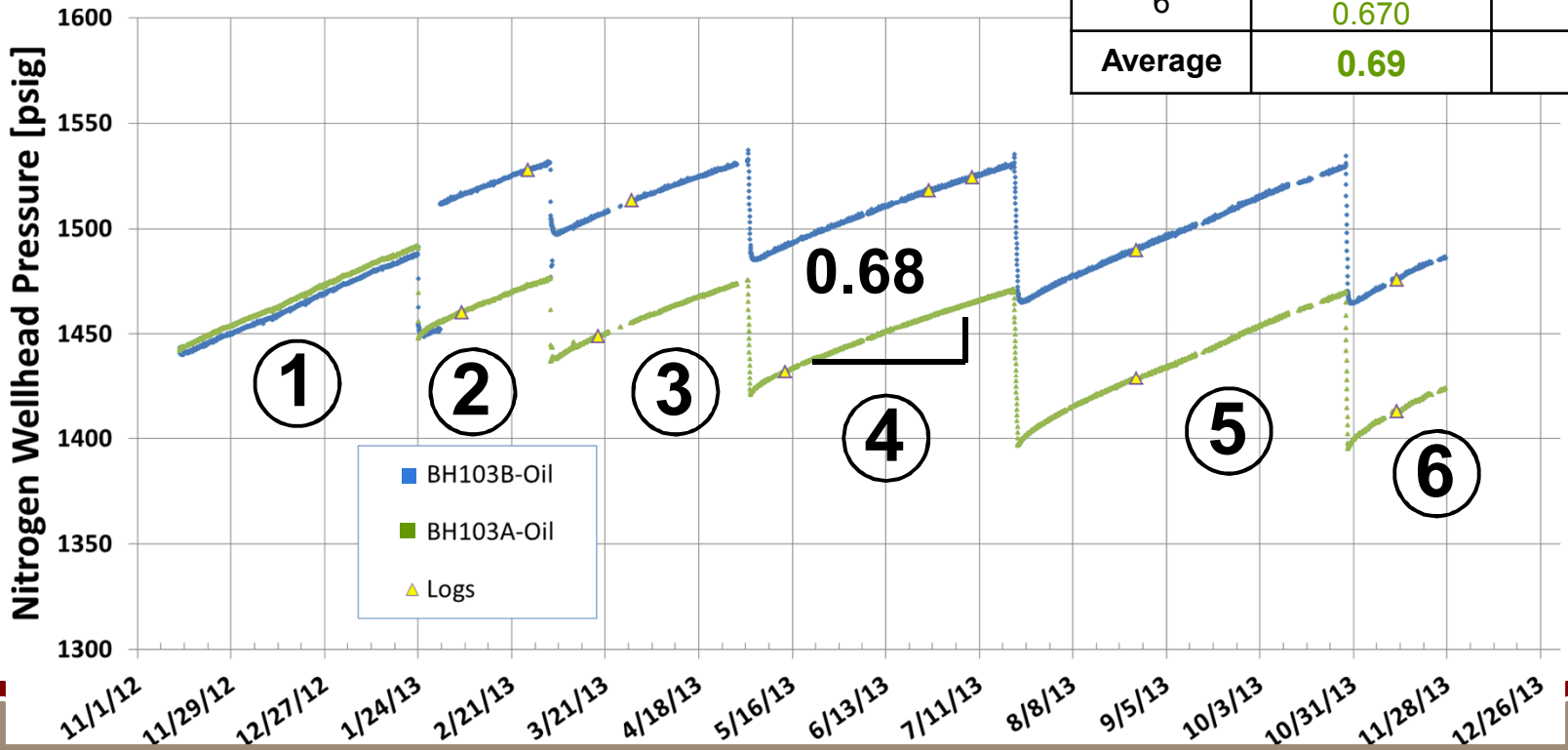


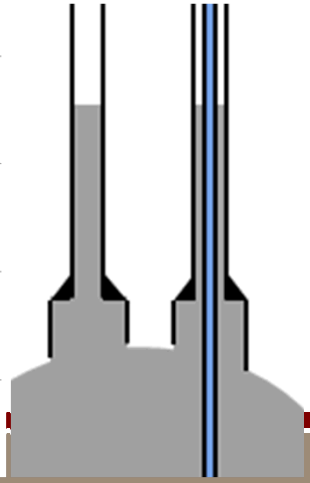


BH103 Pressure Analysis

- 1 year under nitrogen monitoring
- Well A and B pressurize with a consistent relative rate of **0.68**

	BH103A	BH103B
Cycle	Relative rate	Relative rate
1	0.702	0.697
2	0.693	0.665
3	0.717	0.686
4	0.678	0.678
5	0.689	0.666
6	0.670	0.662
Average	0.69	0.68





Hydrostatic Column Model

- Uses Gas law for nitrogen
- Liquid column with adjustments for pressure and temperature

Ideal Gas law

$$\rho_i = \frac{P_i}{RT_iZ}$$

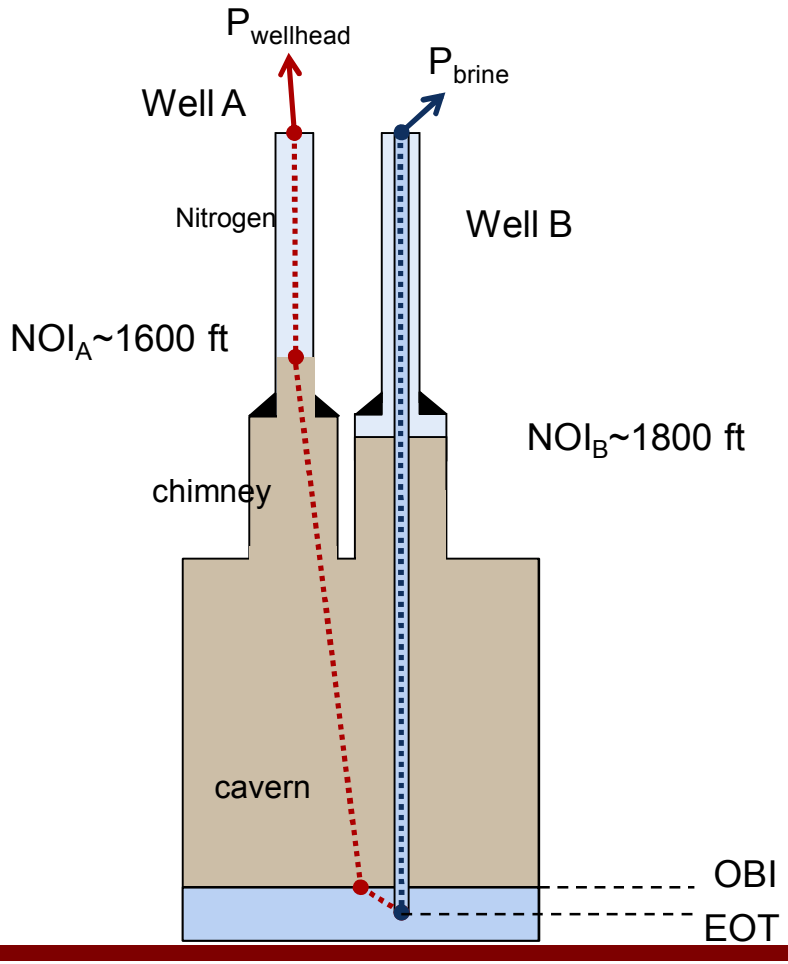
Liquids

$$P_{i+1} = P_i + \rho_i g(z_{i+1} - z_i)$$

$$\rho_i = \frac{\rho_o}{(1-(P_i - P_o)/E)\left(1+\beta(T_i - T_o)\right)}$$

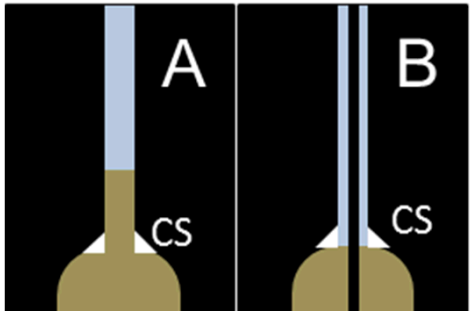
Pressure correction

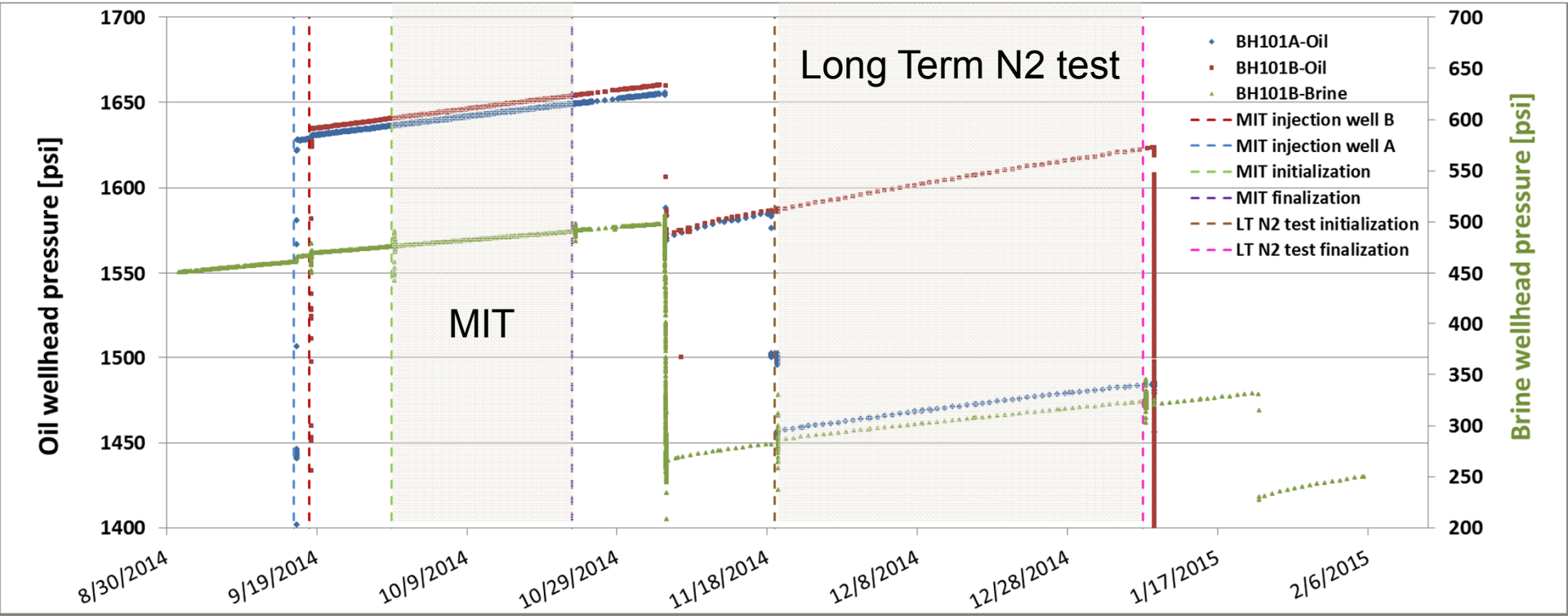
Temperature correction



BH101 history

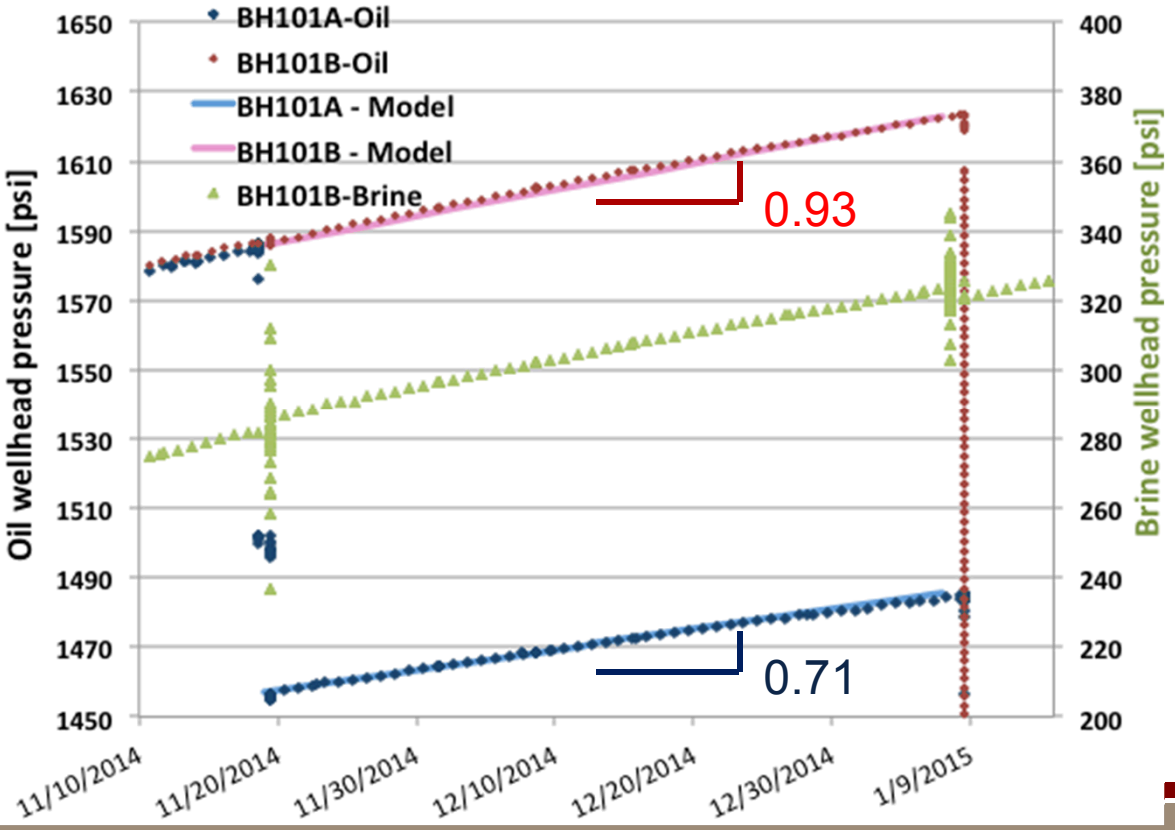
- BH101 was chosen as a control model experiment to validate the hydrostatic model predictions
- Passed MIT Oct 2014
- Long term Nitrogen test Nov 2014- Jan 2015

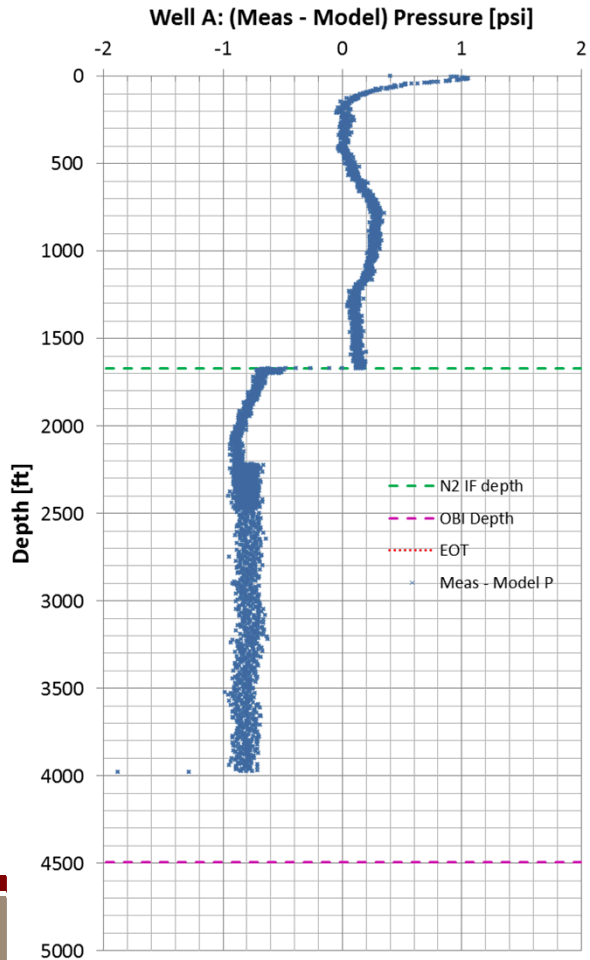




Model prediction vs. DCS data

- High resolution pressure logs were compared with model pressures as a function of depth
- Model Prediction matched pressure values as well as NOI locations for both wells.





Model analysis conclusions

- Factors that affect pressurization rates:
  - Well size (diameter)
  - Chimney size
  - Slick vs. hanging string
  - Location of interface (below or above CS)
- We can generalized that:

Mass of N_2 in the well

NOI is **below** casing shoe

Relative pressure rates **~ 1**
slick wells pressurizing slightly less than HS

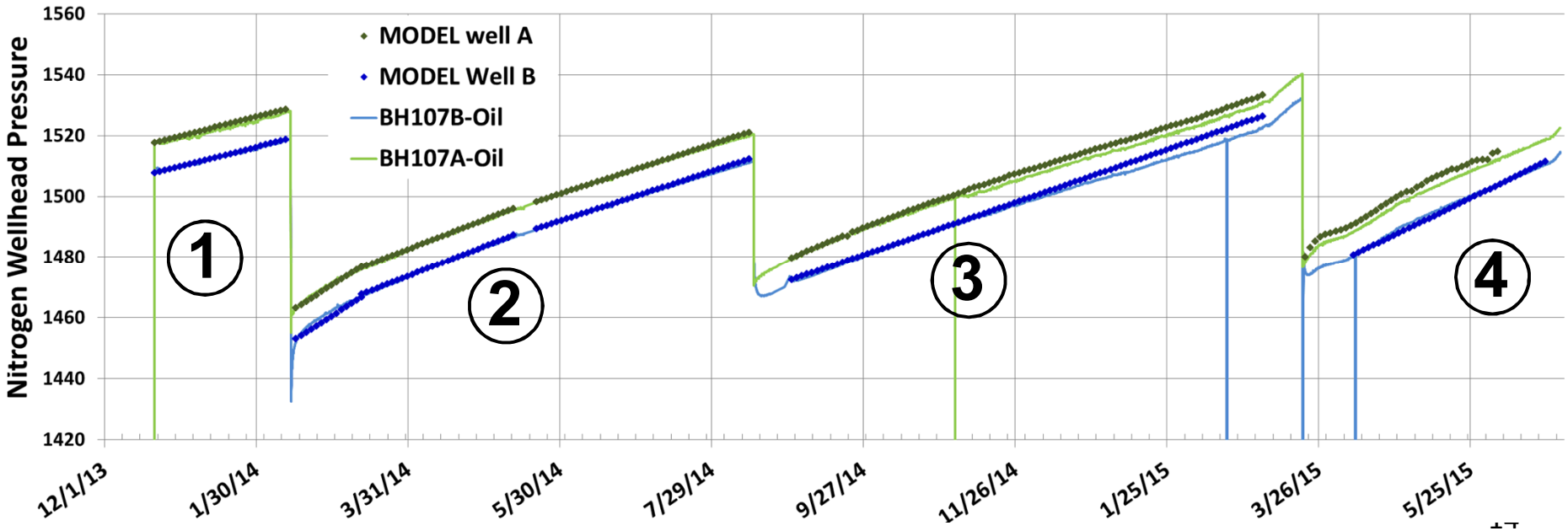
NOI is **above** casing shoe

Relative pressure rates < 1
(**~0.7** is a good number for BH caverns)

BH107 HCM Pressure Predictions

- Model predictions for **tight** system are consistent with pressure data

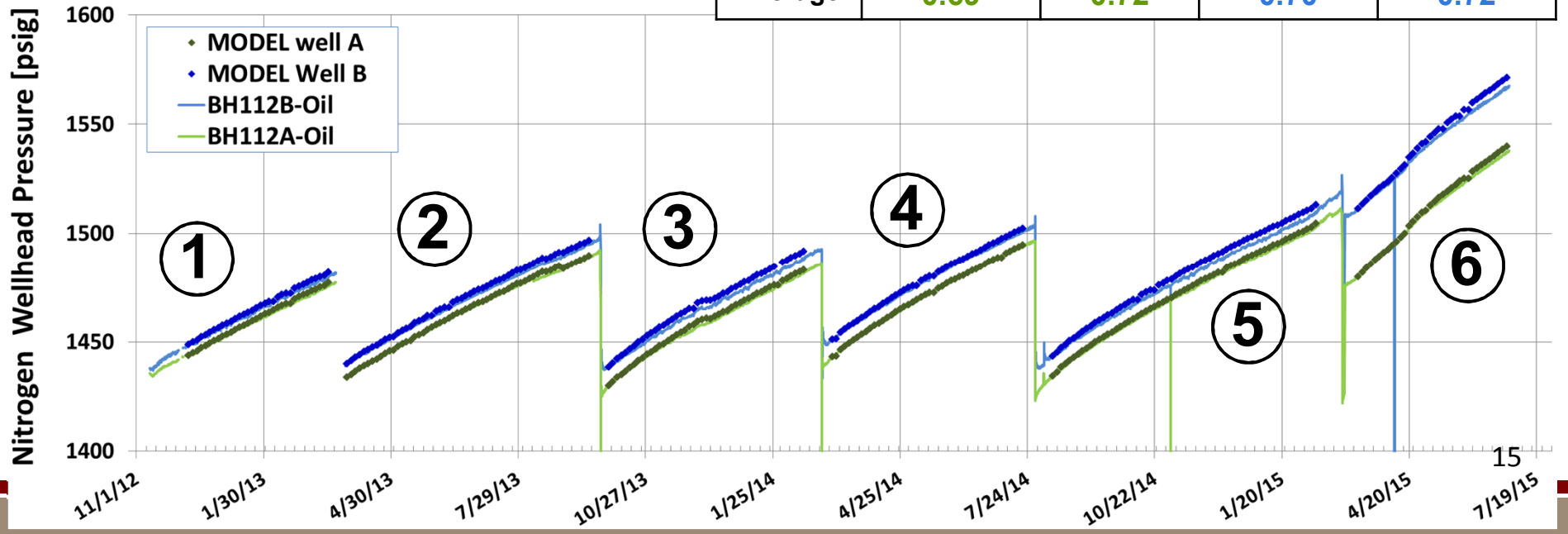
	BH107A Relative rate		BH107B Relative rate	
Cycle	DSC	Model	DSC	Model
1	0.669	0.710	0.669	0.712
2	0.687	0.704	0.685	0.705
3	0.680	0.707	0.653	0.708
4	0.699	0.706	0.711	0.707
Average	**0.68**	**0.71**	**0.68**	**0.71**



BH112 HCM Pressure Predictions

- Model predictions for tight system are consistent with pressure data

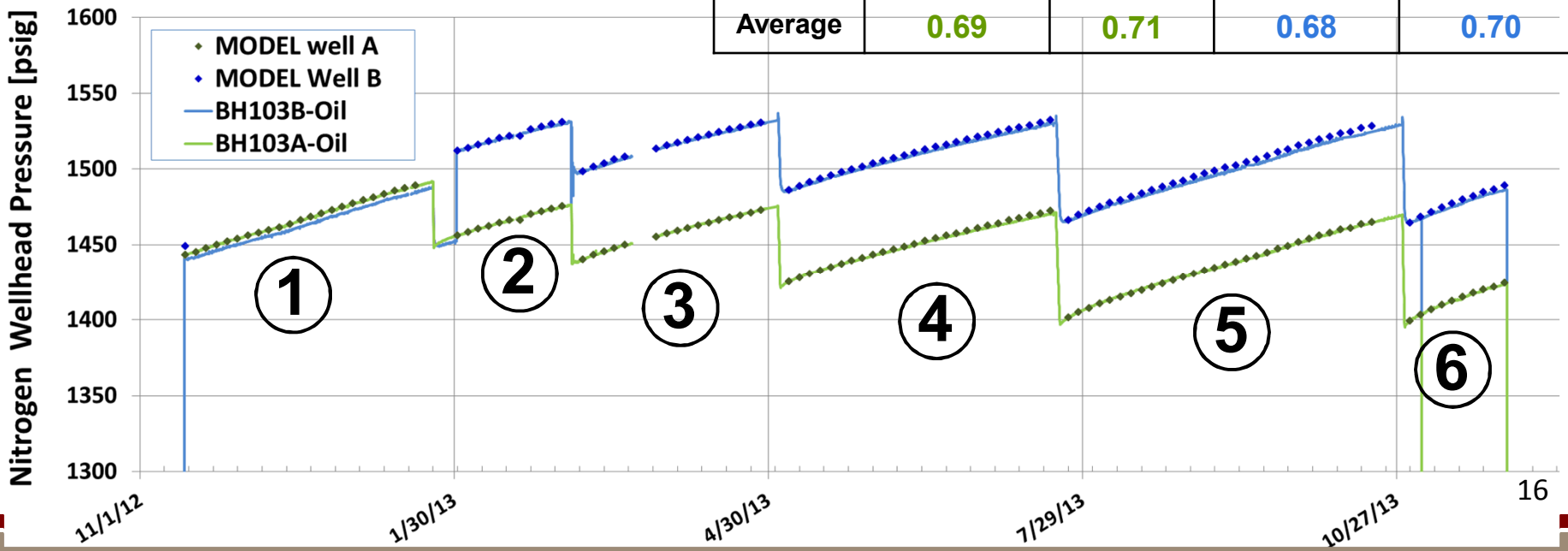
	BH107A Relative rate		BH107B Relative rate	
Cycle	DSC	Model	DSC	Model
1	0.662	0.714	0.668	0.710
2	0.694	0.721	0.696	0.726
3	0.697	0.713	0.691	0.710
4	0.710	0.716	0.699	0.712
5	0.713	0.716	0.695	0.712
6	0.689	0.725	0.724	0.727
Average	0.69	0.72	0.70	0.72



BH103 HCM Pressure Predictions

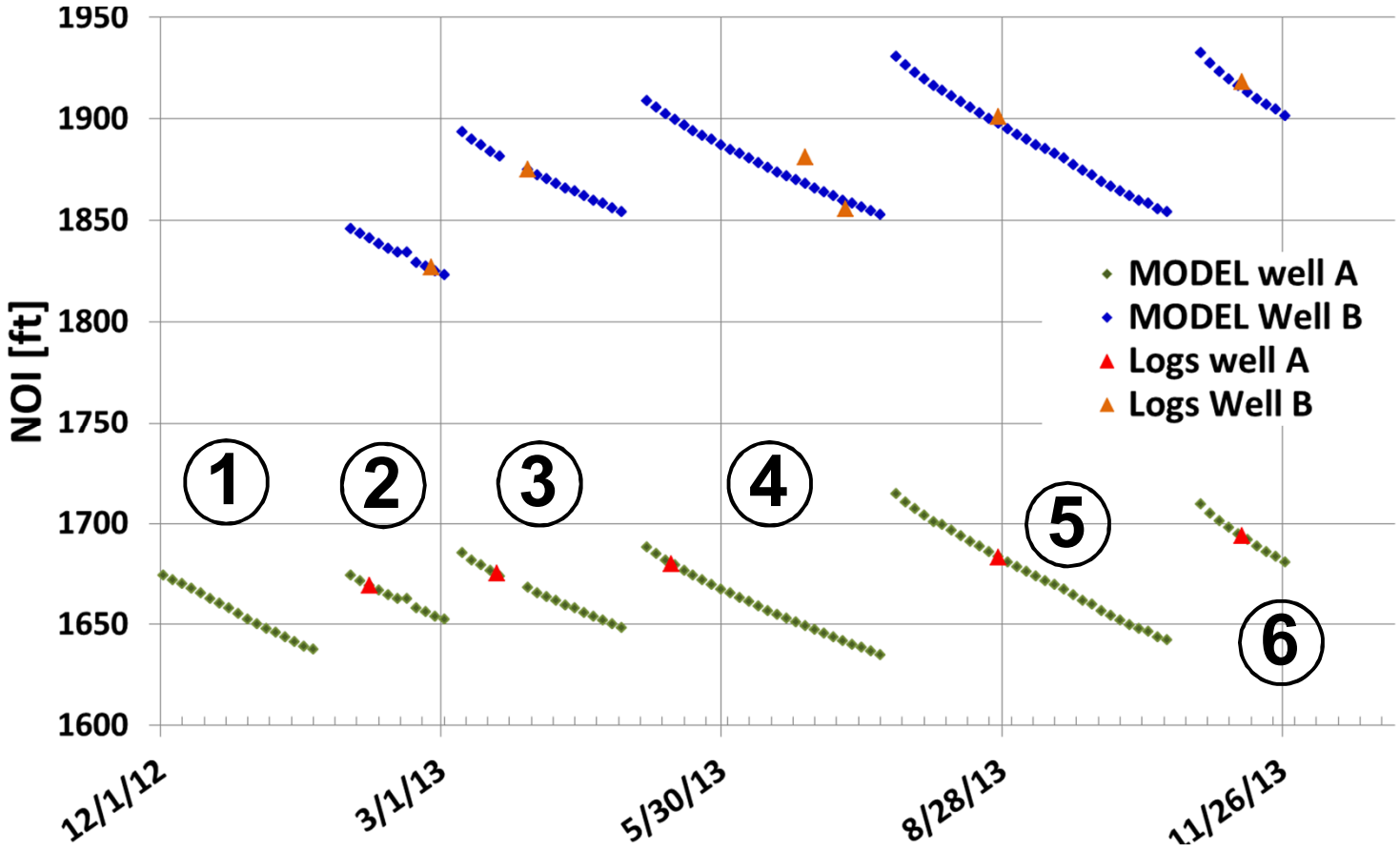
- Model predictions for **tight** system are consistent with pressure data

	BH103A Relative rate		BH103B Relative rate	
Cycle	DSC	Model	DSC	Model
1	0.702	0.716	0.697	
2	0.693	0.715	0.665	0.703
3	0.717	0.714	0.686	0.701
4	0.678	0.714	0.678	0.697
5	0.689	0.711	0.666	0.694
6	0.670	0.708	0.662	0.688
Average	0.69	0.71	0.68	0.70



BH103 HCM NOI predictions

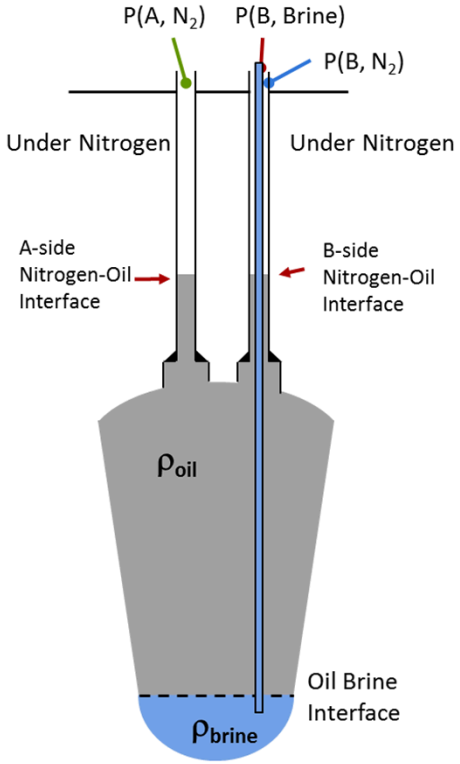
- Model predictions for NOI match interface logs measurements



Conclusions

The Hydrostatic Colum Model (HCM) has been developed to study the pressure behavior of N_2 capped cavern/wells.

- The relative rate of pressurization depends on
  - well configuration
  - pressure and location of the NOI and
  - varies from well to well.
- The relative pressurization of ~0.7 is the outcome of the monitoring configuration and NOT a leak



- For the case when the NOI in below the casing shoe the relative pressurization rate was found to be around 0.9 which is consistent with the historical data (MITs).

- **Big Hill caverns 103, 107, and 112 exhibited no evidence of active leaks of oil or nitrogen during the period December 2012 – June 2015**

Leak Prediction Module

A version 2 of the model is under development and it will be able to incorporate leak prediction capabilities

- Leak rates
- Leak locations
- Multiple leaks locations (shoe and/or collars)