Part I: Field-Based Observations for CO_2 Geological Storage from 6 Years of CO_2 Injection at Aquistore

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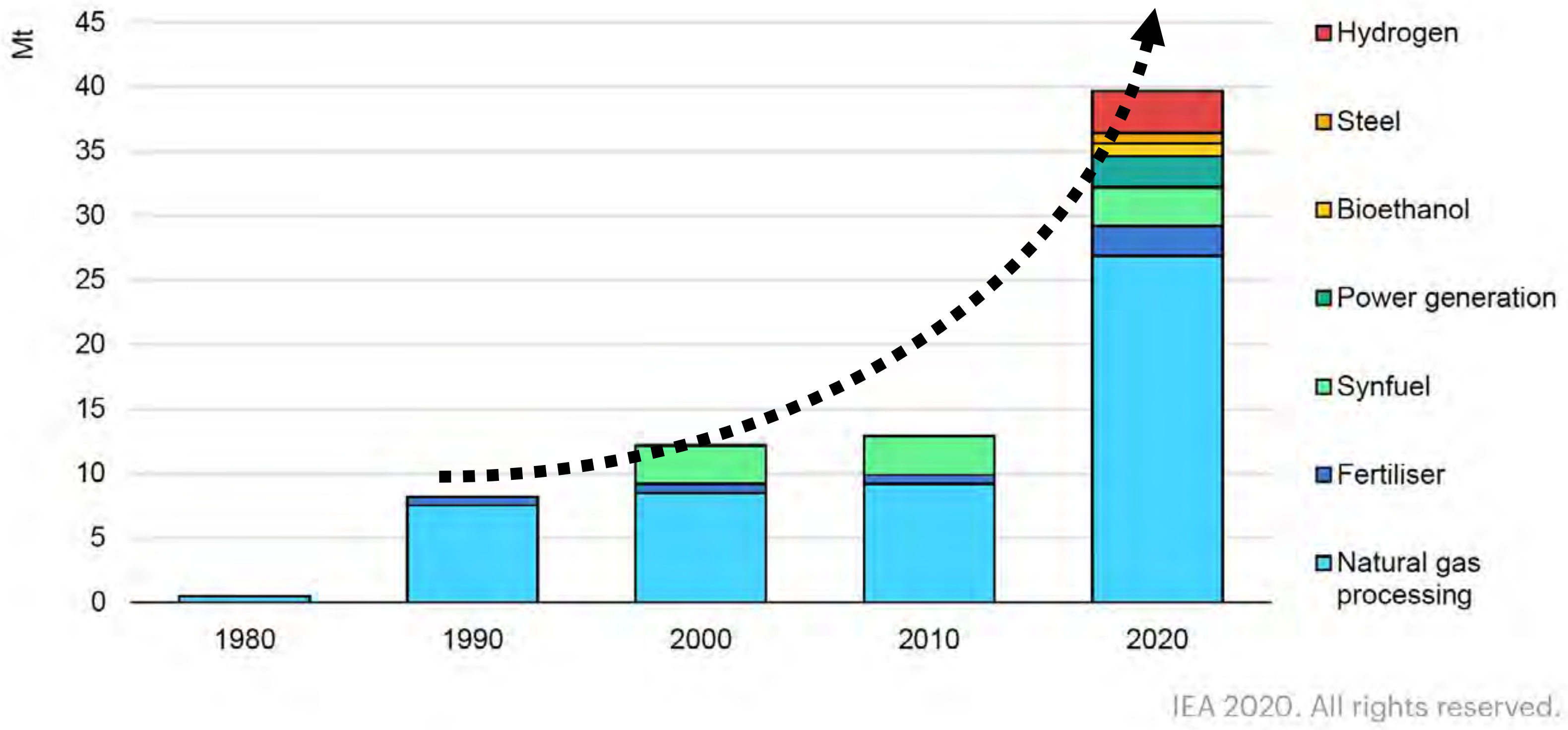
Outline

- Fundamental Requirements for CO_2 Storage and MMV
- Introduction to Aquistore Project
- CO2 Injection
- Time-Lapse Pressure Monitoring Dynamics
- Well Cementing Dynamics
- Surface and Subsurface Gas Measurement
- Well Dynamics
- Salt Precipitation
- Seismic Monitoring
- Dynamic Reservoir Modeling
- Summary

CCUS

Global CO_2 capture capacity at large-scale facilities by source



SaskPower CCS facility achieves 4 million tonnes of CO2 captured

Estevan Mercury
MARCH 31, 2021 01:38 PM

SaskPower's Carbon Capture and Storage (CCS) facility at Boundary Dam Power Station near Estevan has captured more than four million tonnes of carbon dioxide (CO2) since operations began in 2014.

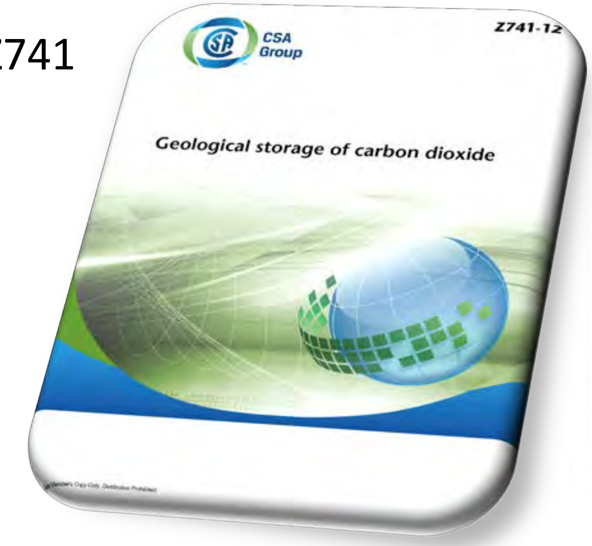
Fundamental Requirements for CO_2 Storage

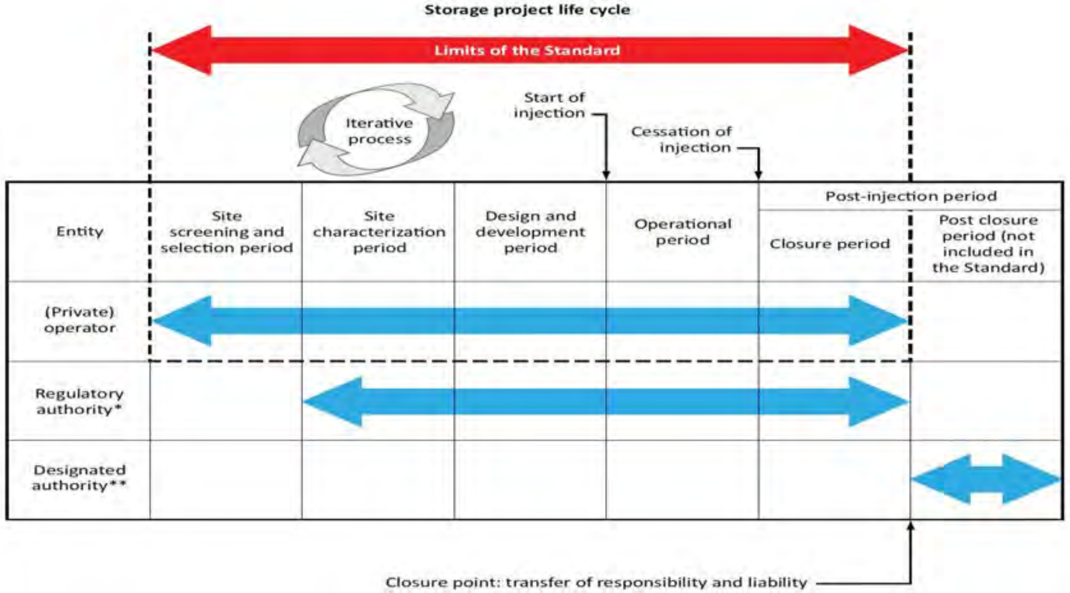
A geological site suitable for CO_2 storage must have:

- sufficient **injectivity** to receive CO_2 at the rate at which it is to be supplied
- secure **containment (and conformance)** of the CO_2 for the long-term
- sufficient **capacity** to store the delivered CO_2 over the lifetime of injection operations

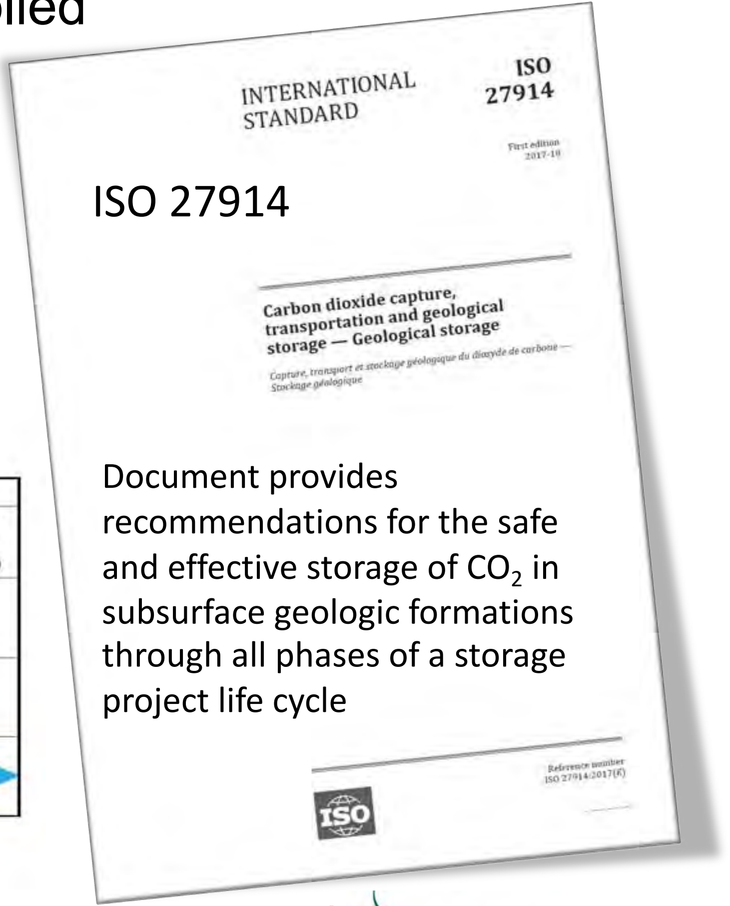
ISO/TC 265

CSA Z741





ISO 27914



Document provides recommendations for the safe and effective storage of CO_2 in subsurface geologic formations through all phases of a storage project life cycle

Measurement, Monitoring and Verification (MMV)

- Project operators **shall** develop and implement an MMV program suited to their operation be designed to serve the following objectives:
  - (a) to protect health, safety, and the environment throughout the project life cycle by ***detecting early warning signs of significant irregularities or unexpected movement of CO_2 or formation fluid***
    - (i) through gathering information on the effectiveness of containment of CO_2 throughout the project life cycle; and
    - (ii) by providing sufficient evidence that the CO_2 has not moved beyond the storage complex, including leakage to a shallow subsurface zone or to the atmosphere
  - (b) to support risk management throughout the project life cycle
  - (c) to provide adequate information for decision support within the project, communication with regulatory authorities and with other stakeholders, including the local community or local landowners as appropriate

Planning for MMV at Aquistore…

ptrc

AQUISTORE

Deep Saline CO_2 Storage Project

Work Program

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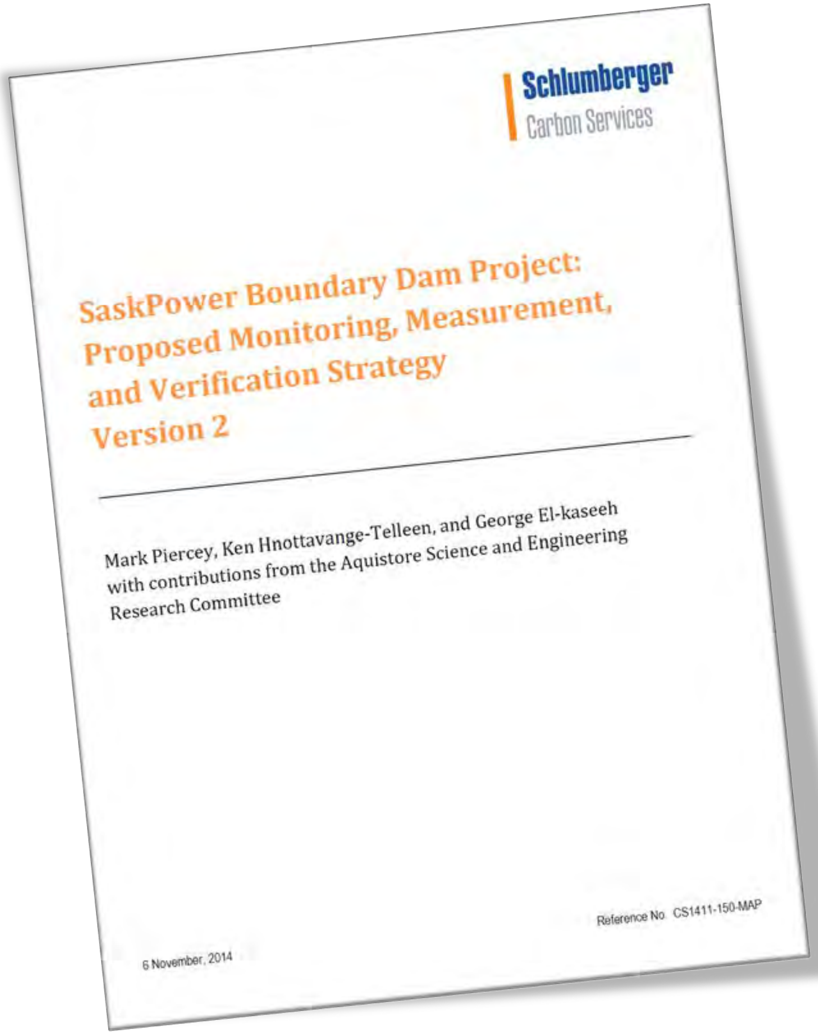
Executive Summary

Introduction

Project Description
Operations
Site Selection
Site Location
Preliminary simulation results
Research and Monitoring Program
Project Schedule

Fundamental Requirements for CO_2 Storage
Injectivity
Capacity
Containment

Project Work Plan by Task



Schlumberger
Carbon Services

SaskPower Boundary Dam Project: Proposed Monitoring, Measurement, and Verification Strategy
Version 2

Mark Piercey, Ken Hnottavange-Telleen, and George El-kaseeh with contributions from the Aquistore Science and Engineering Research Committee

6 November, 2014

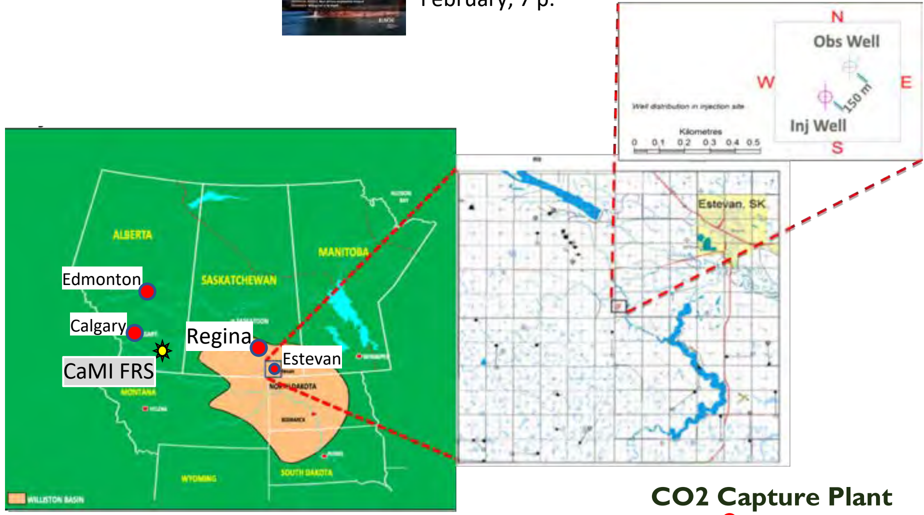
Reference No. CS1411-150-MAP

(1) Plume/Containment Monitoring
(2) Public Assurance
(3) Research Objectives

Aquistore - CO_2 Storage in Saskatchewan

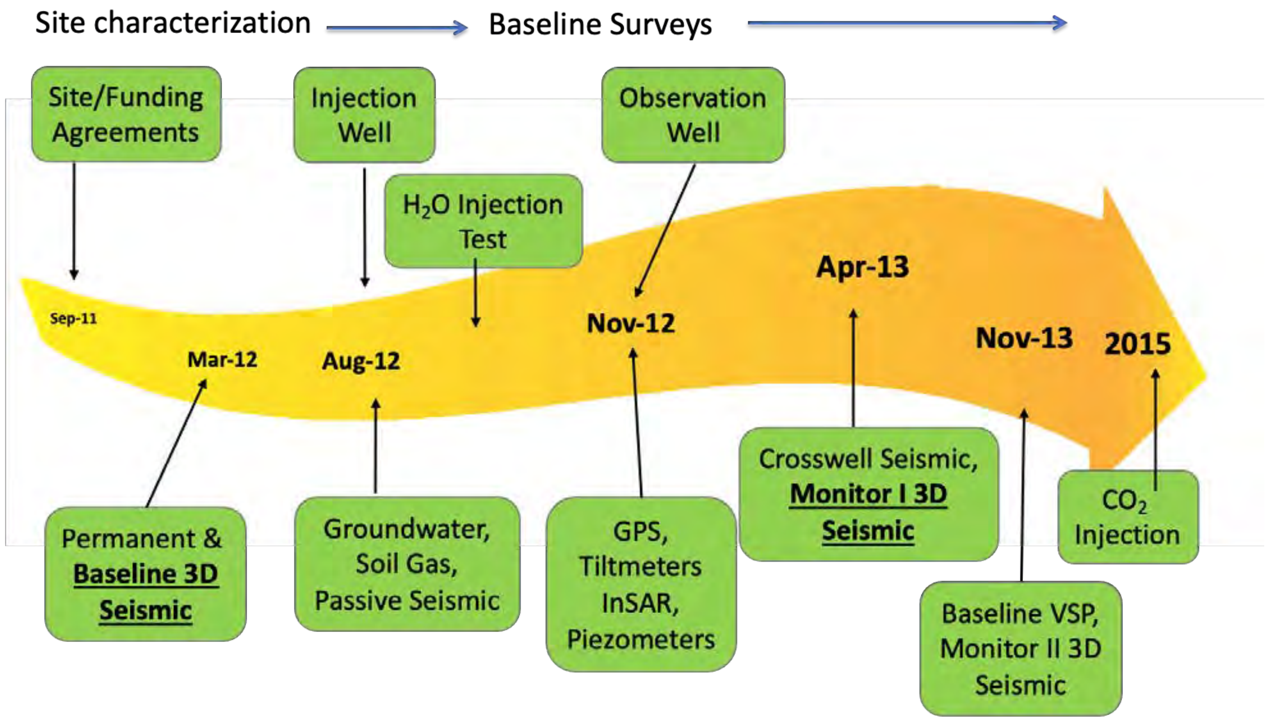
Movahedzadeh, Rangriz Shokri, Chalaturnyk, Nickel and Sacuta, 2021. Measurement, monitoring, verification and modelling at the Aquistore CO_2 storage site. First Break, Vol. 39, February, 7 p.

- SaskPower owner and operator of the wells and Aquistore, an independent CO_2 Monitoring and Storage research project managed through PTRC with guidance provided by a Science and Engineering Research Committee
- Injection commenced April 16, 2015 and a ribbon cutting ceremony May 20, 2015. Over 370,000 tonnes of CO_2 injected to date.
- Testing and comparing proven and novel measurement, monitoring and verification technologies for efficiency and economics.
- CO_2 injection well with confirmed acceptance of up to 2400 tonnes/day and one observation well 150m away from injection well.
- Aquistore has and will continue to contribute significant evidence-based knowledge in support of safe and effective implementation of the geological storage of CO_2 in association with coal-fired power generation and that **MMV technologies can be effectively deployed in commercial projects to demonstrate injectivity, conformance and containment performance metrics under complex and dynamic operating conditions.**



CO2 Capture Plant

MMV Program at Aquistore



30 MONITORING TECHNOLOGIES DEPLOYED

Surface-based:

- **Regional 3D seismic survey**
  - **Geological characterization**
  - **Baseline & time-lapse**
- **Permanent seismic array**
  - **Time-lapse imaging**
- **Electrical/electromagnetic**
- **Gravity**

Plume

- **Passive seismic (broadband & short period array)**
- **InSAR**
- **GPS**
- **Tiltmeters**

Deformation

- **Groundwater & soil gas monitoring**
- **Carbon isotope profile**

Leakage

Down-hole

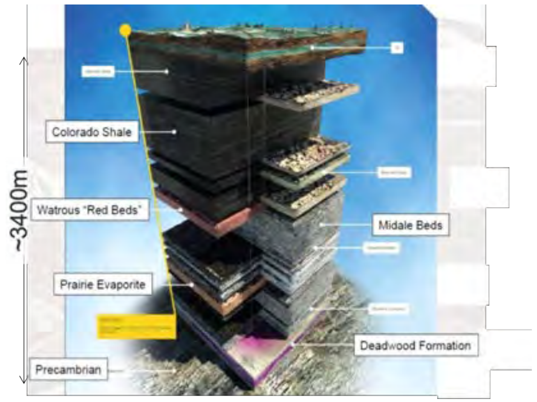
- **Cross-well seismic & VSP**
- **Cross-well & surface-to-downhole electrical monitoring**
- **Real-time P & T**
- **Passive seismic**
- **Fluid sampling**
- **Time-lapse logging**
- **Distributed Acoustic/ Temperature Sensors (DAS/ DTS)**
- **Heater cable**
- **Gravity**

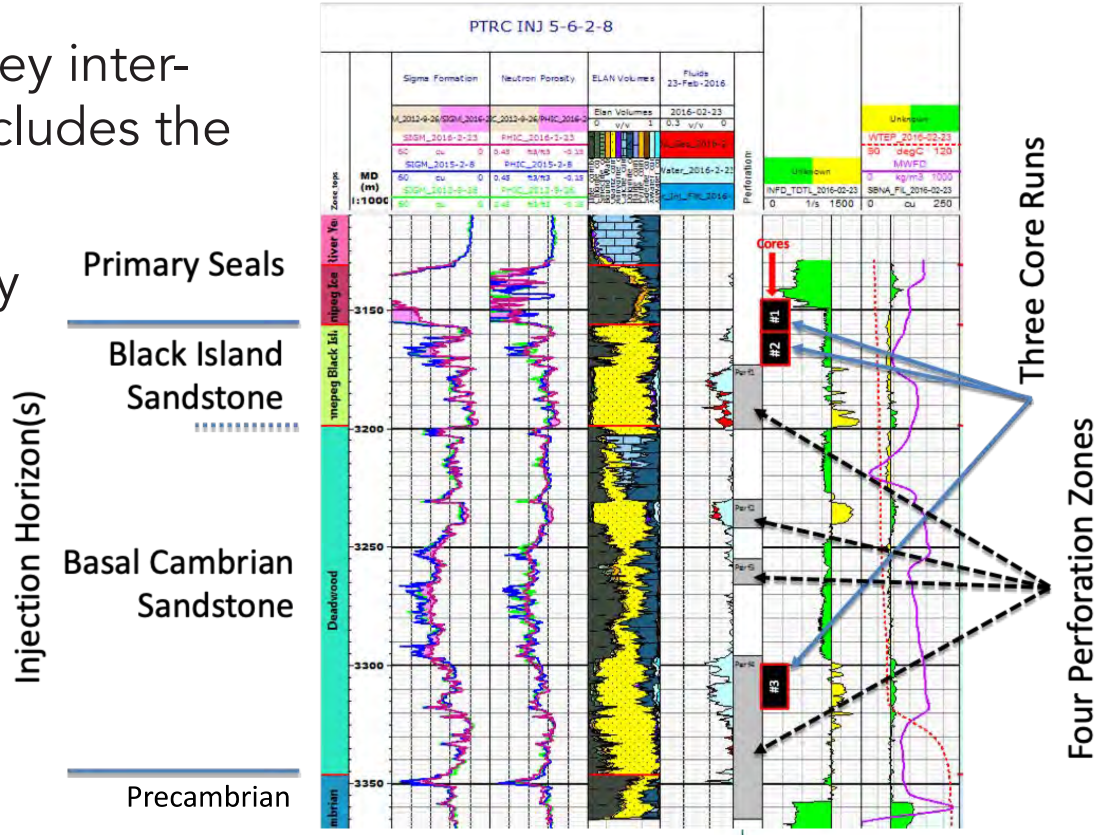
In Situ

Site Configuration

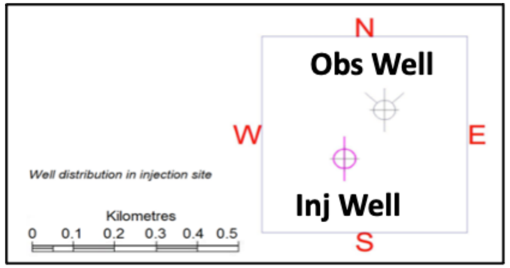
Geological Setting

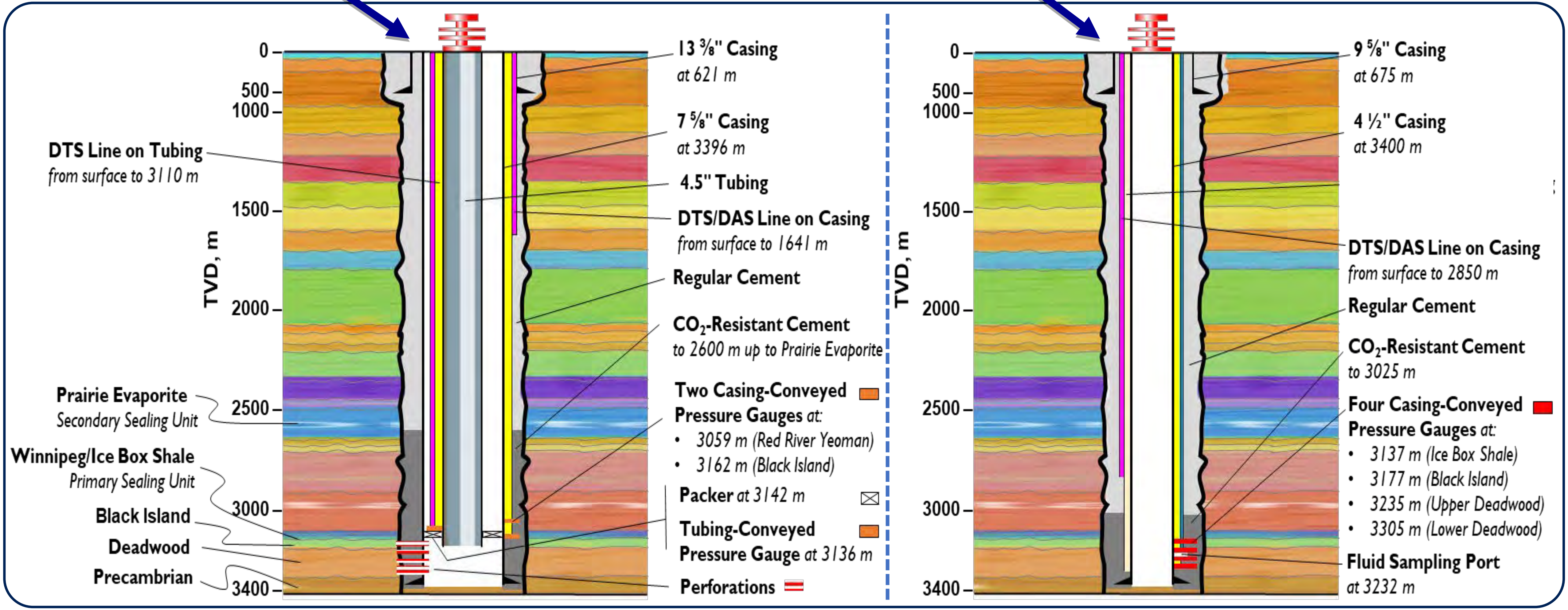
- Storage reservoir is 200 m thick and extends from 3130 m to 3350 m depth at the injection well and comprises the Deadwood and Winnipeg formations.
- The Deadwood Formation is sandstone with silty-to-shaley inter-beds. It is overlain by the Winnipeg Formation, which includes the Icebox (shale) and Black Island (sandstone).
- The Icebox constitutes a shale caprock and is the primary seal to the reservoir. A secondary storage seal is provided by the Prairie Evaporite Formation which is a ~150 m thick evaporitic unit that resides ~500 m above the reservoir.
- The injection well has been perforated over four intervals: one in the Black Island, two in the upper and one in the lower Deadwood interval.





CO_2 Injection Well and Observation Well



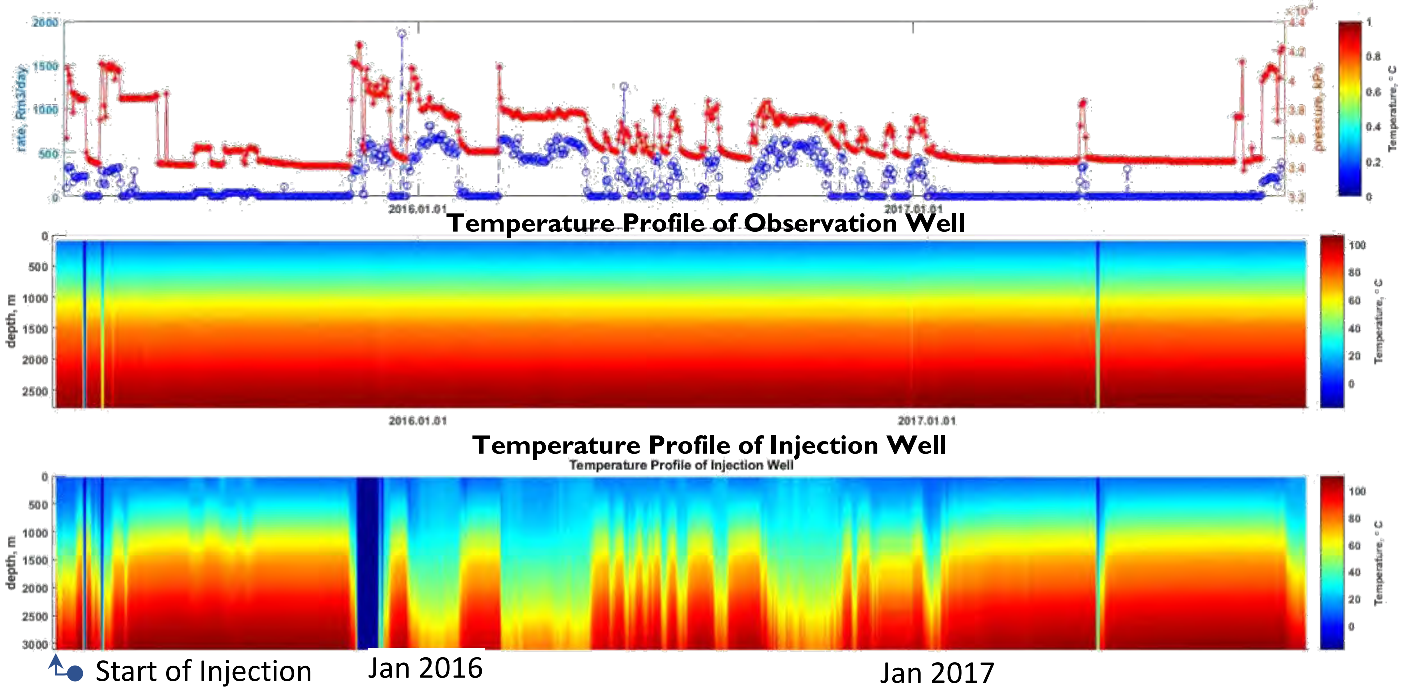


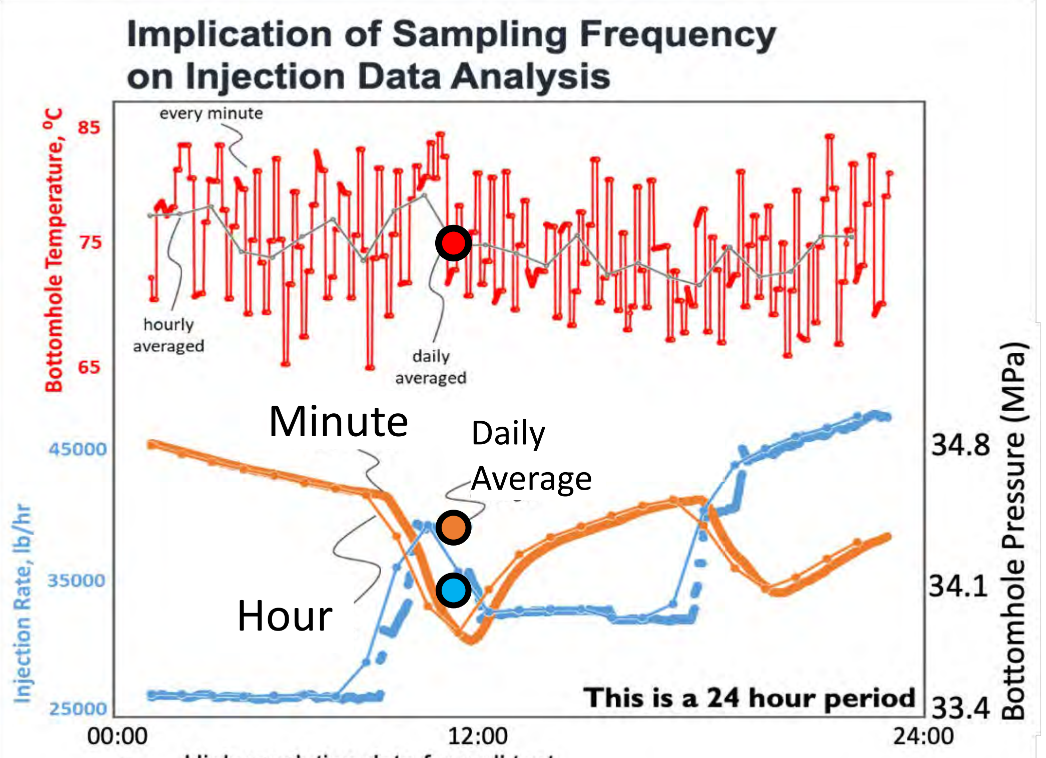
DTS lines are located along the length of the ***tubing of injection well***, and the ***casing of the observation well*** *(~spaced every 100 m)*.
DTS lines do NOT cover the targeted CO2 storage interval. NOT capable of profiling the injection flowrate in the 4 perfed zones.

CO_2 Injection

CO_2 Injection

Multiple ***non-isothermal transient periods*** of relatively high injection rates followed by periods of limited injection.



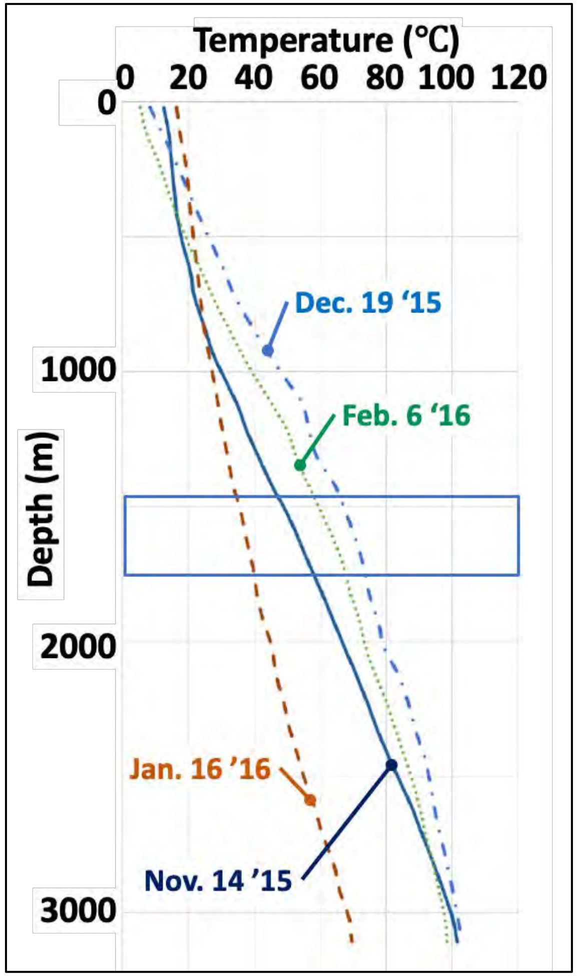


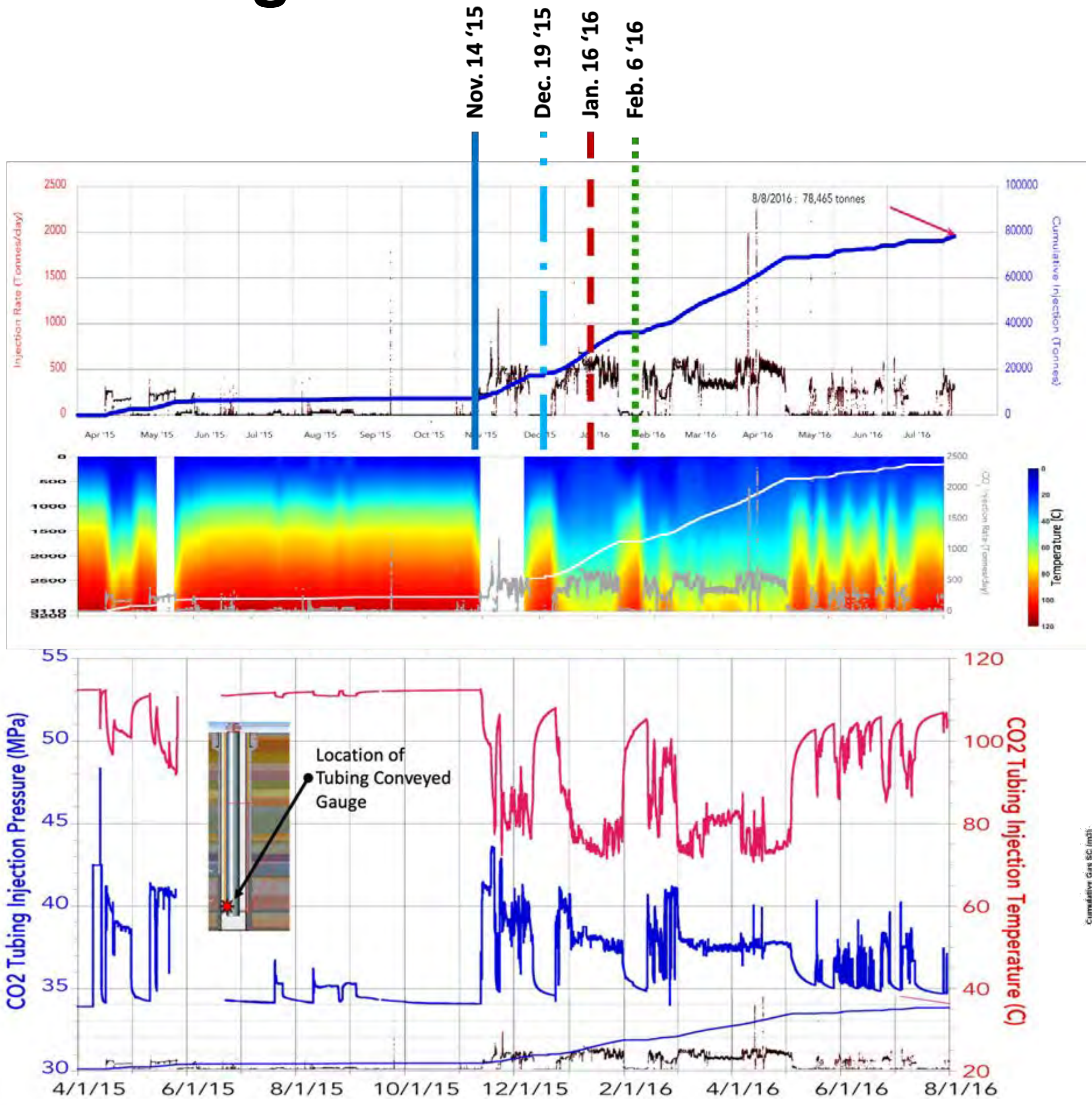
- High resolution data for well test
- Low resolution data for history matching, reservoir simulation

Thermal map shows ***rapid heating & cooling*** of the wellbore with injection

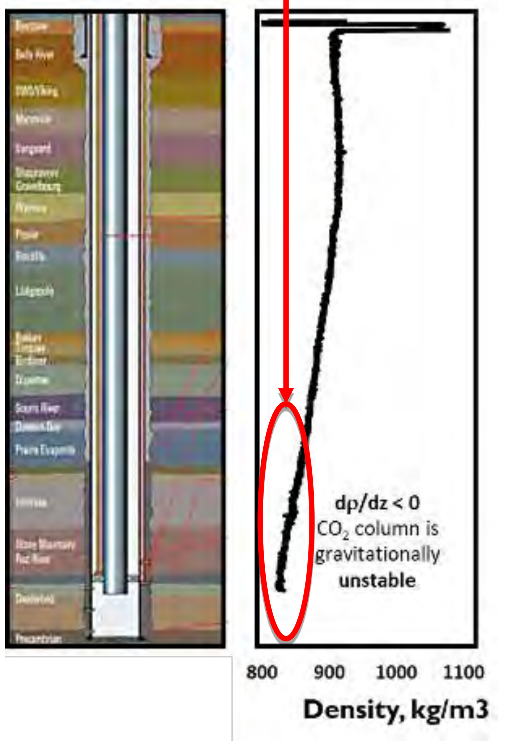
Temperature is monitored along ***Inj*** and ***Obs wells*** (DTS).

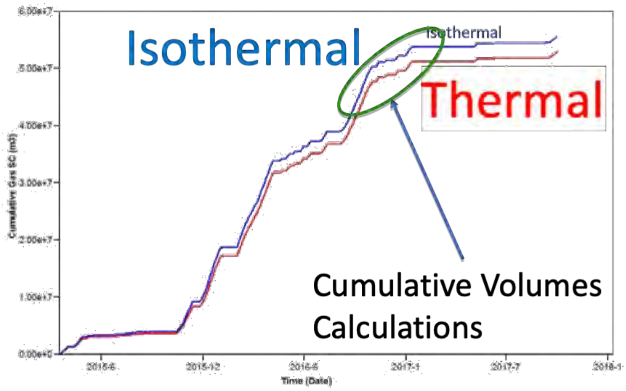
Dynamic Responses during CO_2 Injection





Density Instability





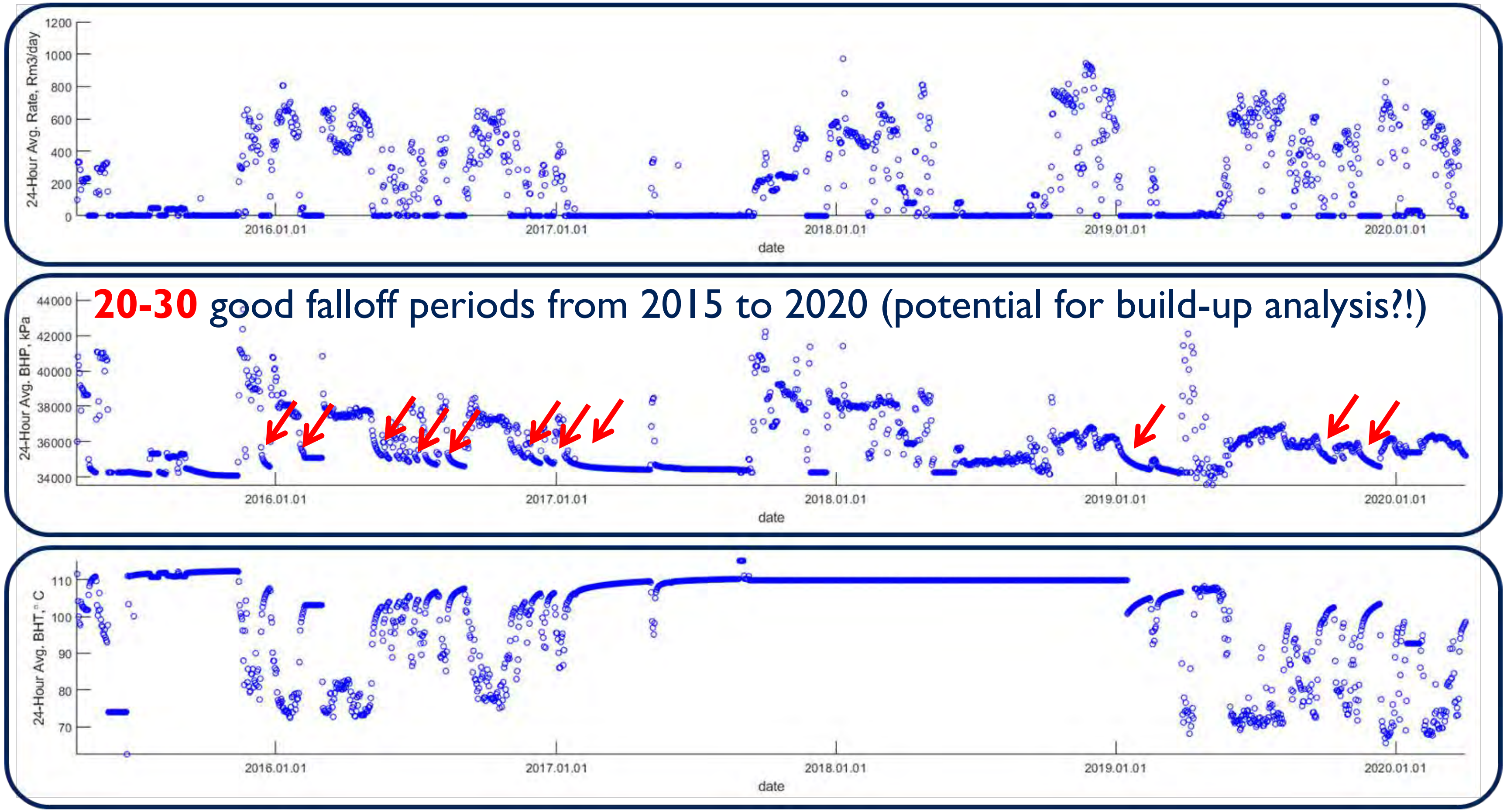
Time Lapse Pressure Transient Dynamics

Time-lapse Pressure Transient Analysis at Aquistore

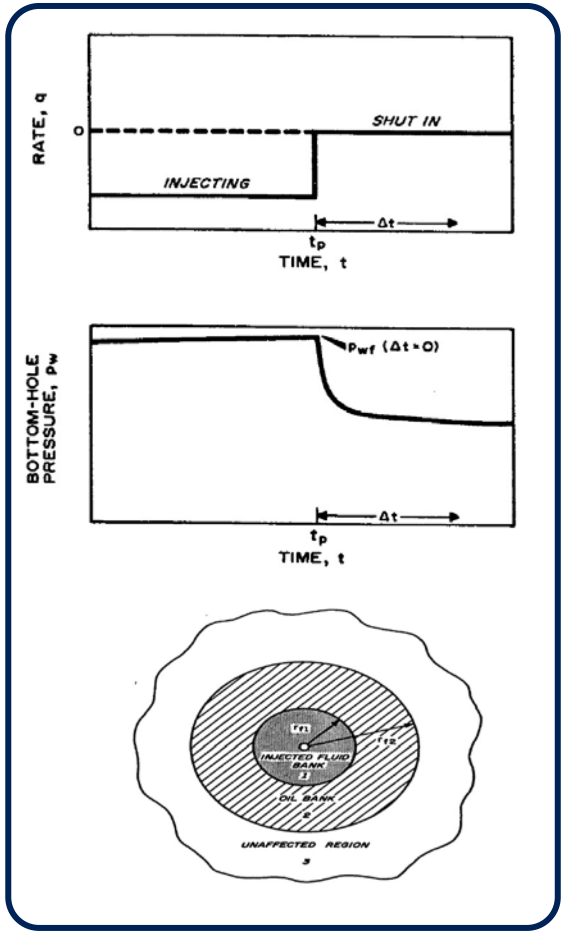
Rate

Pressure

Temperature

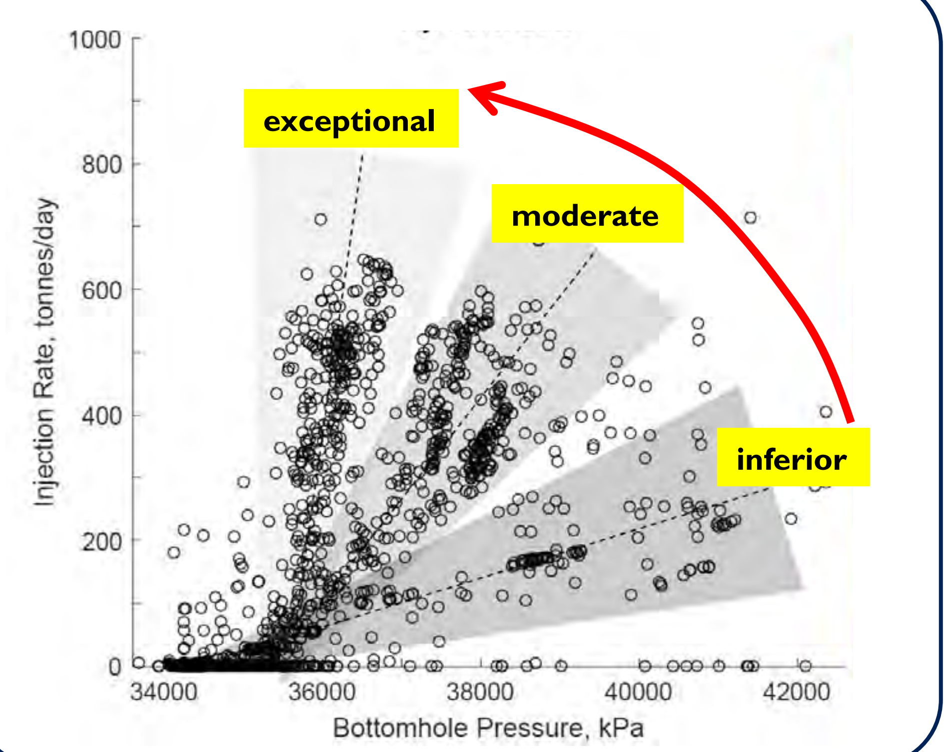


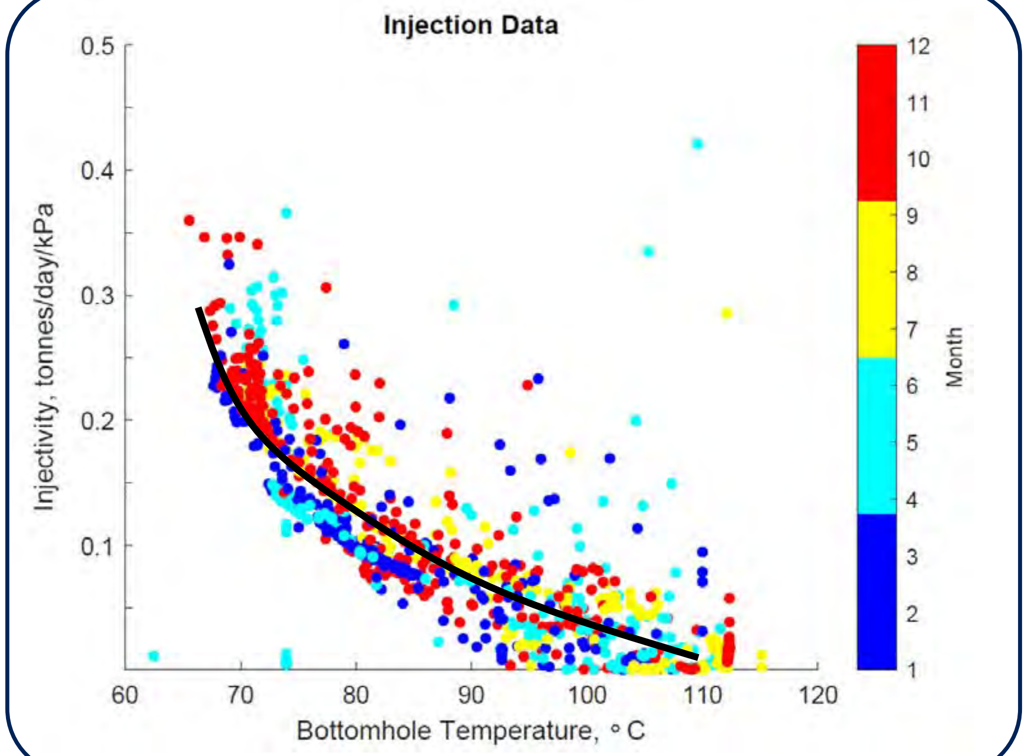
20-30 good falloff periods from 2015 to 2020 (potential for build-up analysis?!)



John Lee (1982) Well Testing

Temporal Evolution of Non-Isothermal (..cold) CO_2 Injectivity at Aquistore





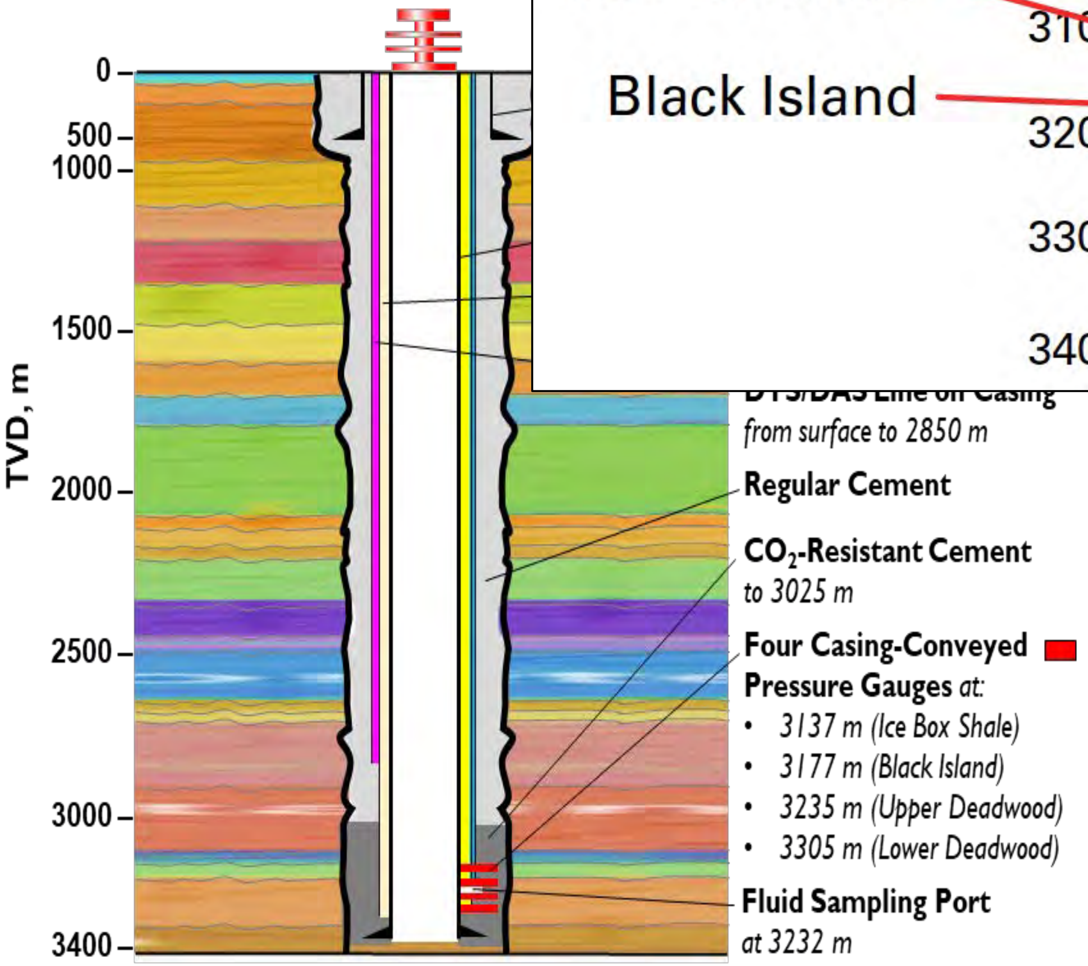
Injectivity data could be grouped into **3 clusters** with distinct injectivity status (**~10,000% increase**).

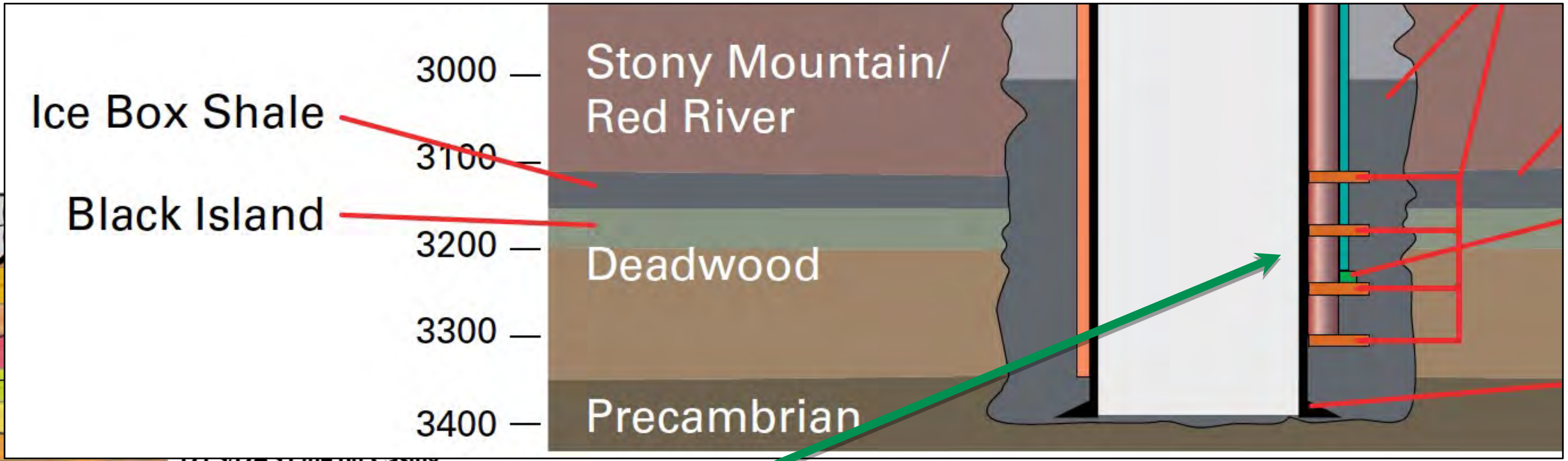
No seasonal variation in injectivity

Injectivity ***correlates negatively*** with ***BHT***.

Cementing Dynamics

Observation Well – Dynamics during Cementing

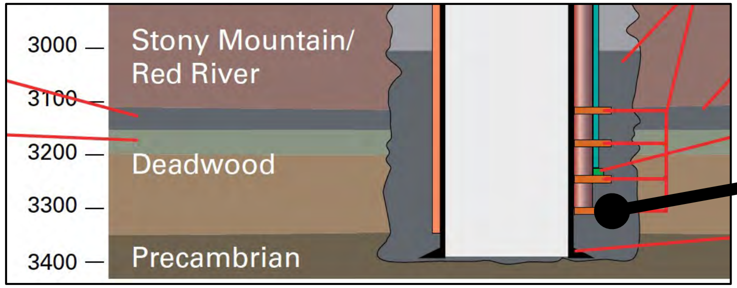


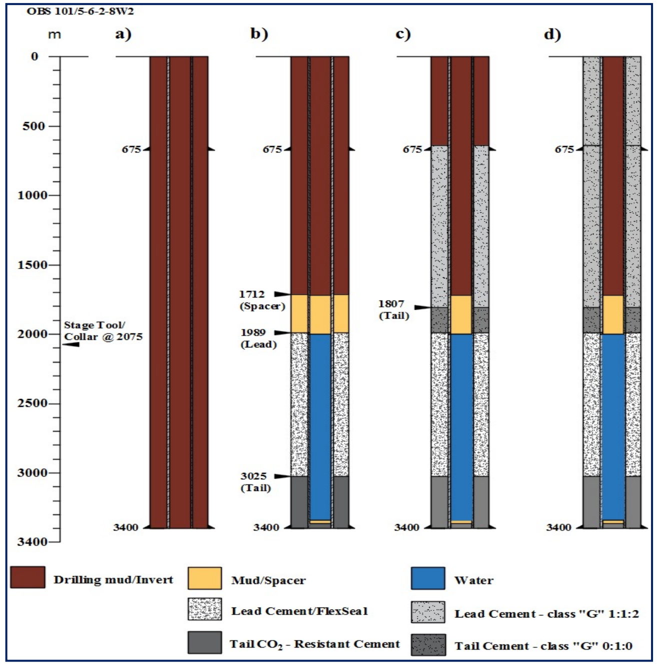


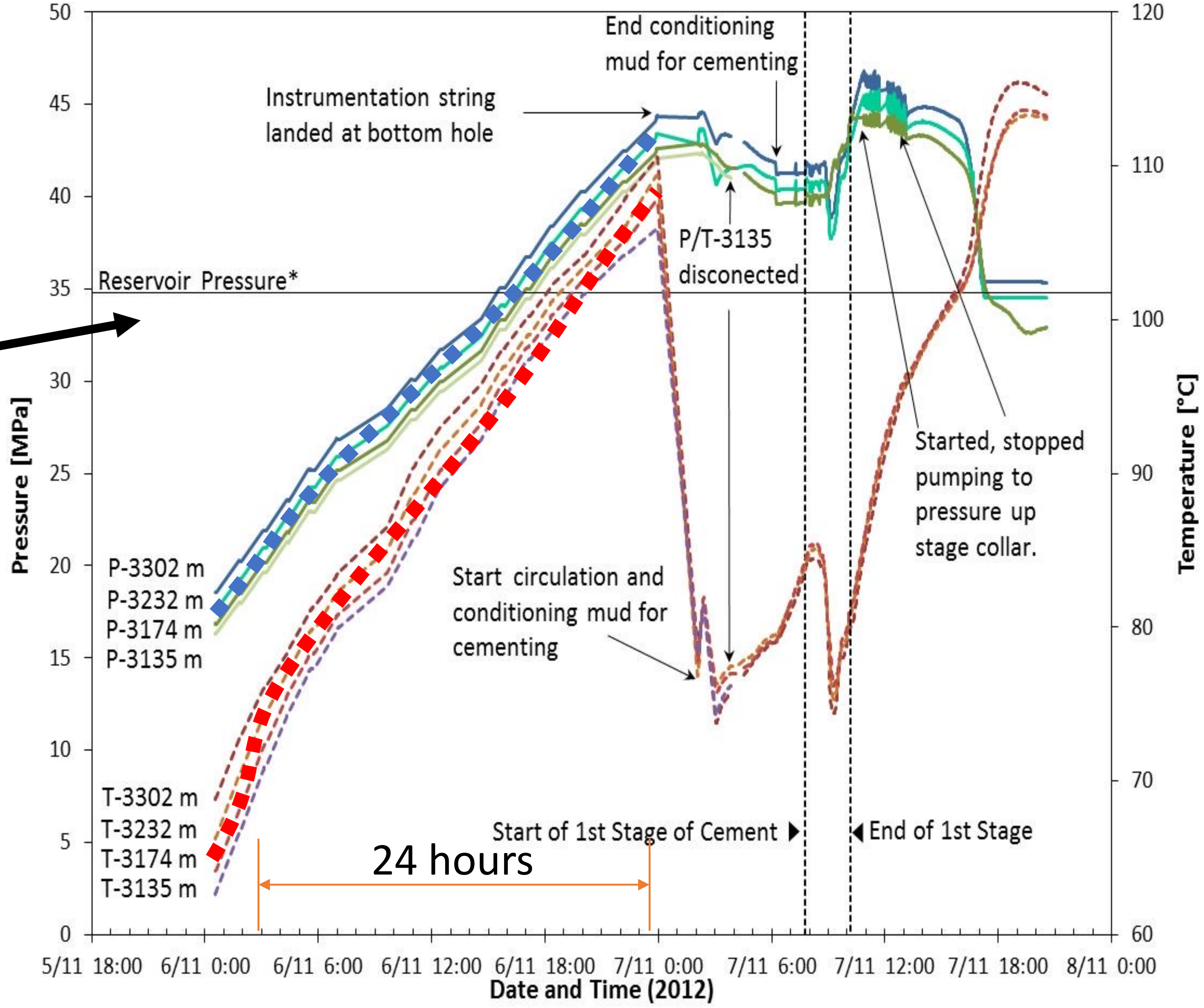
4 Casing-Conveyed Pressure Gauges

1. 3137m (Ice Box Shale)
2. 3177m (Black Island)
3. 3235m (Upper Deadwood)
4. 3305m (Lower Deadwood)

Cementing Dynamics



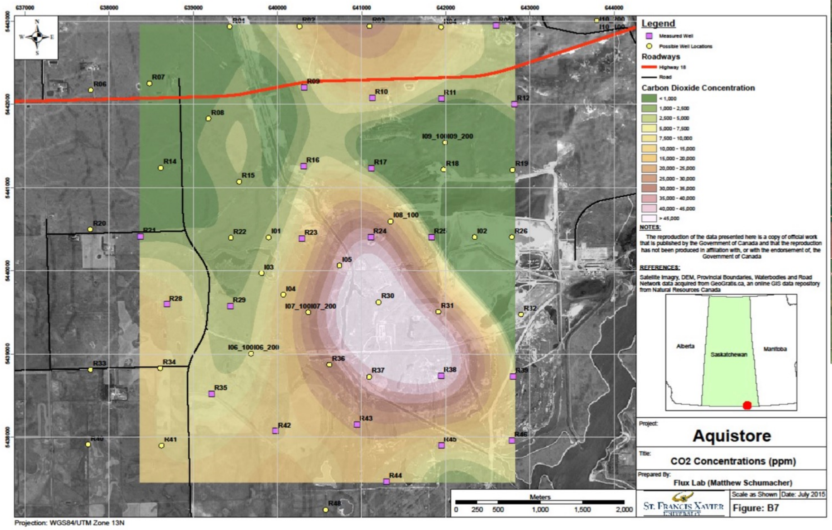


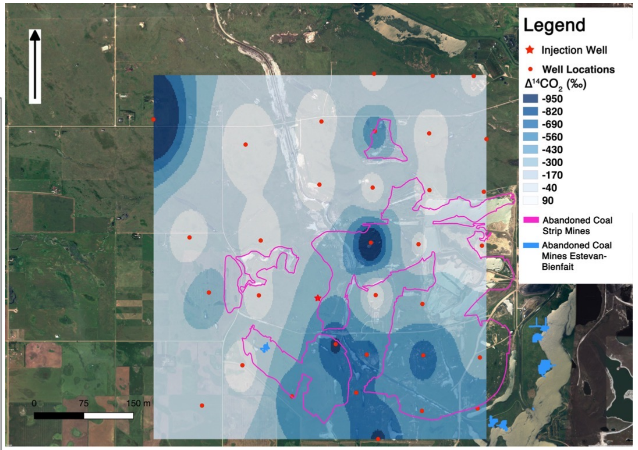


Surface and Subsurface Gas Measurement

Gas Measurements: Surface and Subsurface

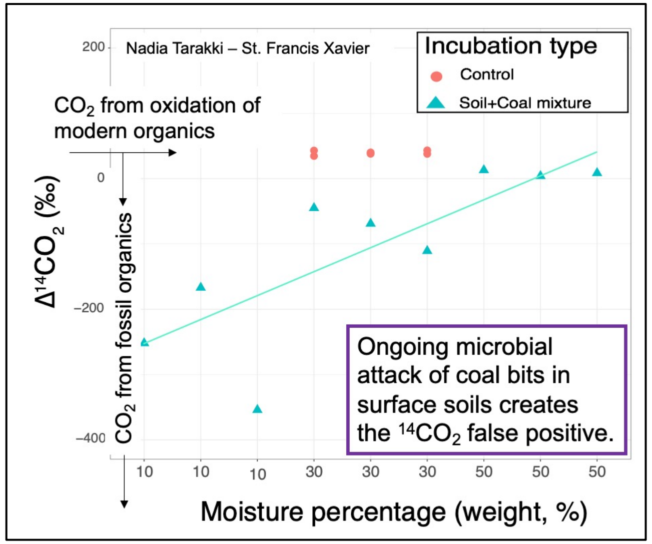
- Surface





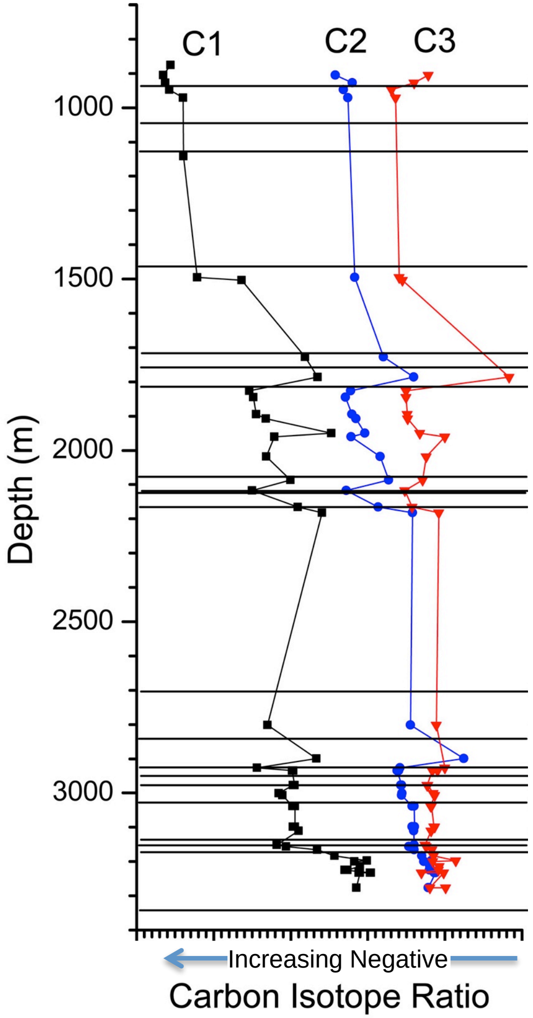
Interpretation:

1. Soils on this 49 km² grid will respire about 70,000 tons/yr CO_2 naturally across the seasons. So there is the potential for significant buildup of CO_2.
2. The soils in this region are hard, tight, cemented, and compact, and significant accumulation of naturally produced-CO_2 in SK is well documented.
3. Soil wetness (low points, wet seasons) enhance CO_2 storage by limiting outward diffusion.



D. Risk, St. F.X. - FluxLab

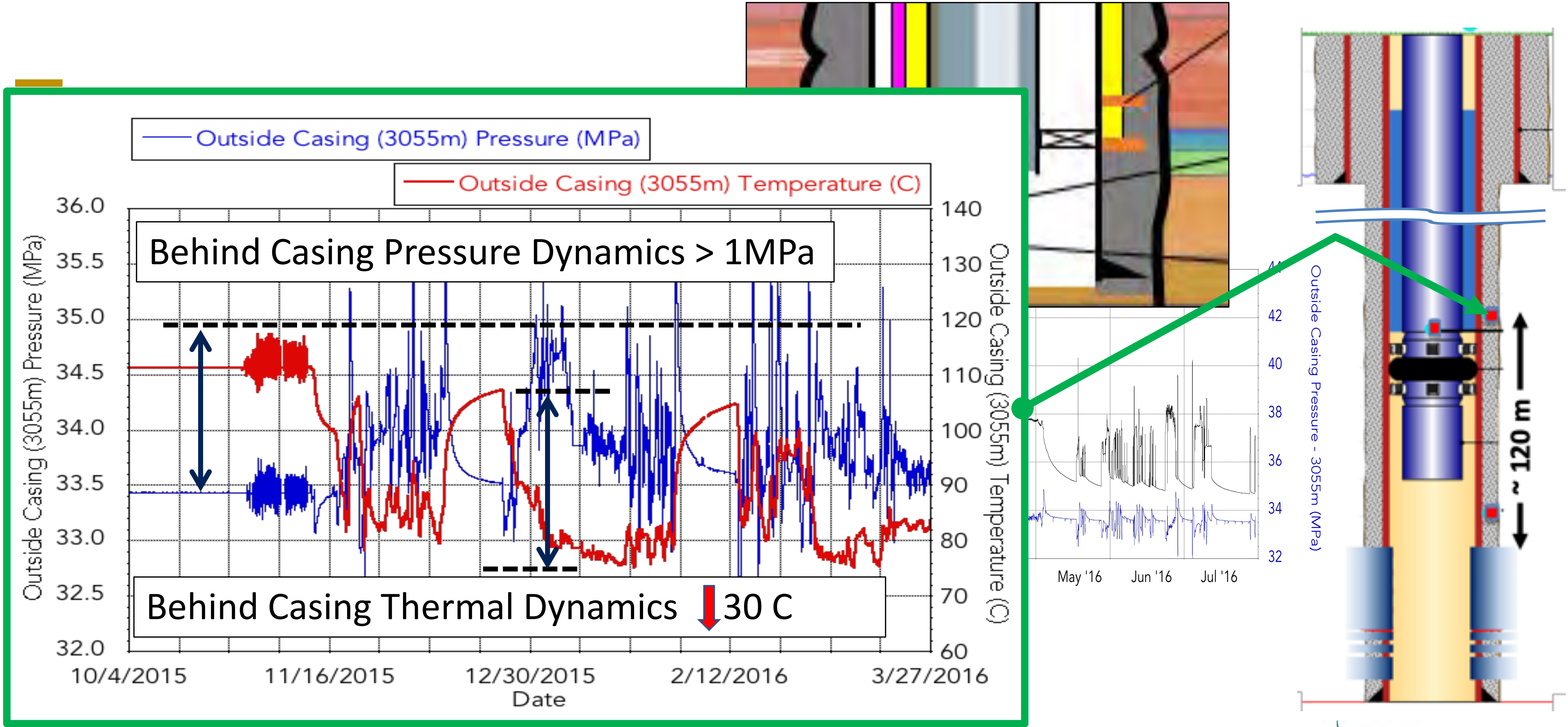
- Subsurface

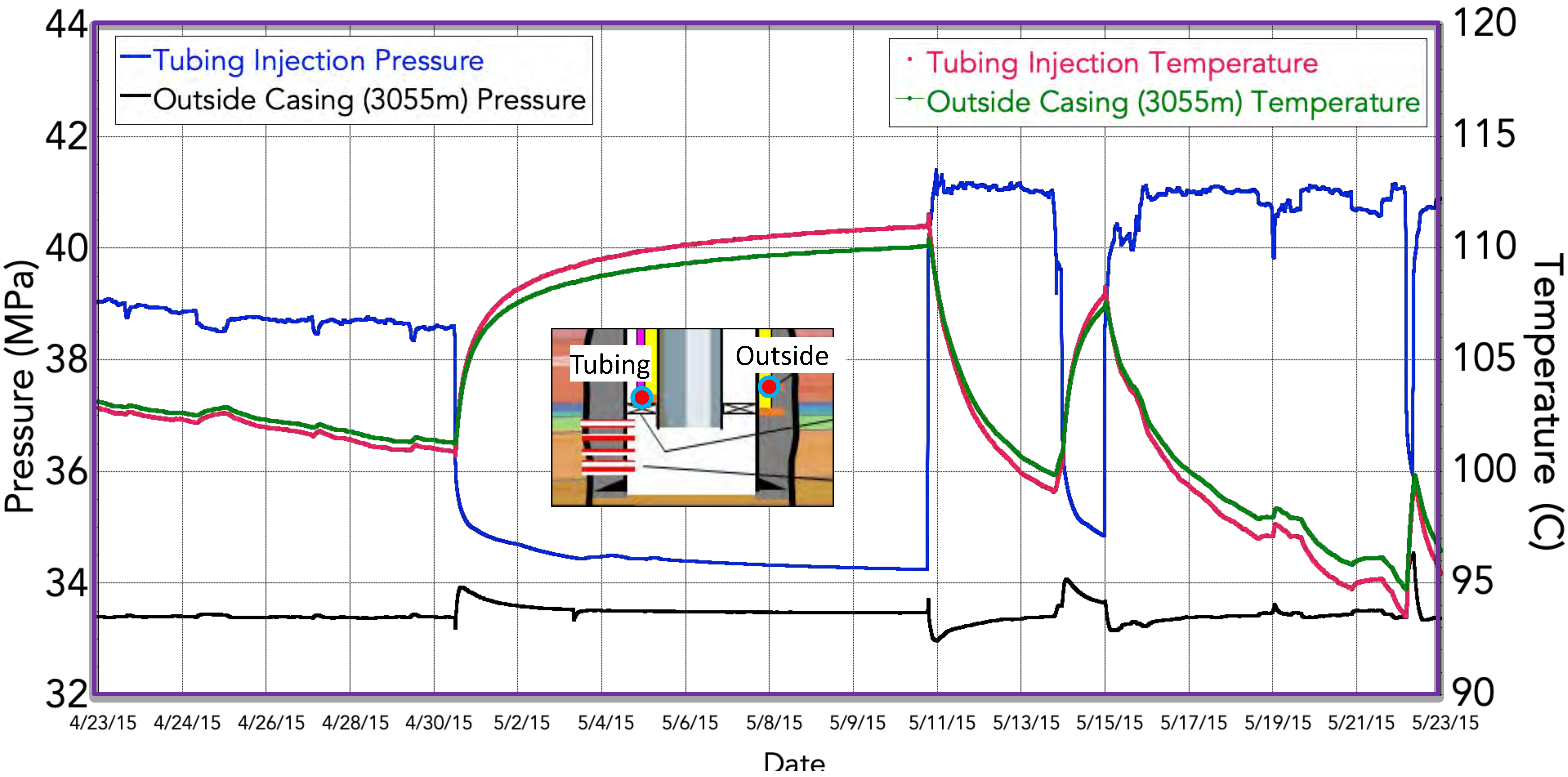


- Sample the gases contained in drilling fluids
- Compound-specific isotopes of $\delta^{13}C$ in gases show patterns as a function of depth (kerogen, maturity, mixing, alteration, etc)
- Gas samples (e.g, SCVF, soil gas, etc) can then be fingerprinted

Well Integrity Dynamics

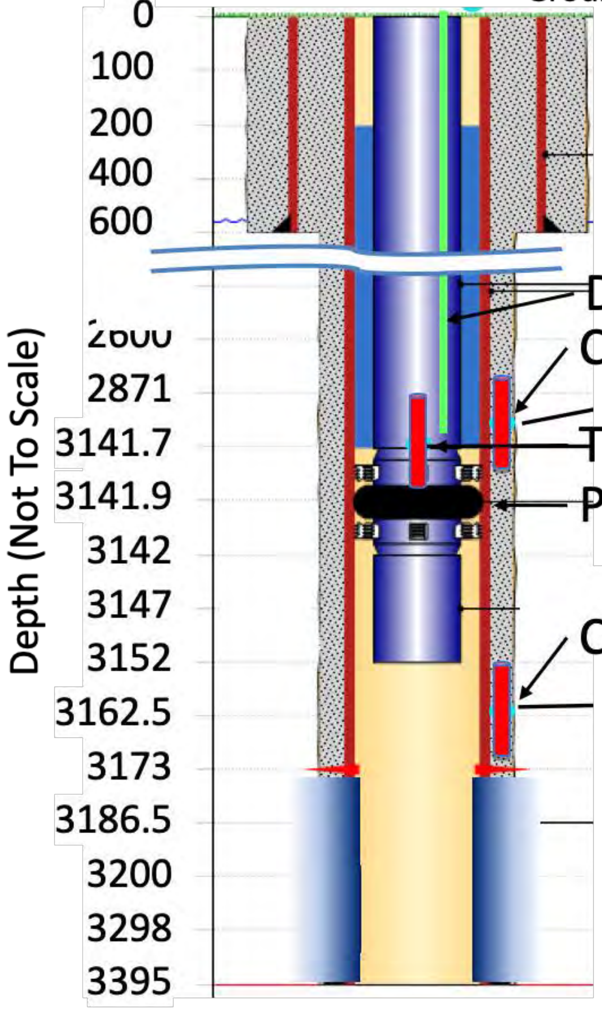
Response of Casing Conveyed Sensors to CO_2 Injection





Tubing Injection Pressure
Outside Casing (3055m) Pressure
Tubing Injection Temperature
Outside Casing (3055m) Temperature
Tubing
Outside
Pressure (MPa)
Temperature (C)
Date
44
42
40
38
36
34
32
120
115
110
105
100
95
90
4/23/15
4/24/15
4/26/15
4/28/15
4/30/15
5/2/15
5/4/15
5/6/15
5/8/15
5/9/15
5/11/15
5/13/15
5/15/15
5/17/15
5/19/15
5/21/15
5/23/15

Metallurgy and Corrosion - CO_2 Injection Well



Gauge Mandrel for Tubing Conveyed Gauge

DTS

Casing Conveyed Sensor (3055 m)

Tubing Conveyed Sensor (3136 m)

Packer (3141.7 – 3142.0)

Casing Conveyed Sensor (3162 m)

Turn-Around Sub for DTS

4 ½" Tubing
(114.3mm, 17.26 kg/m, L-80, QB2)

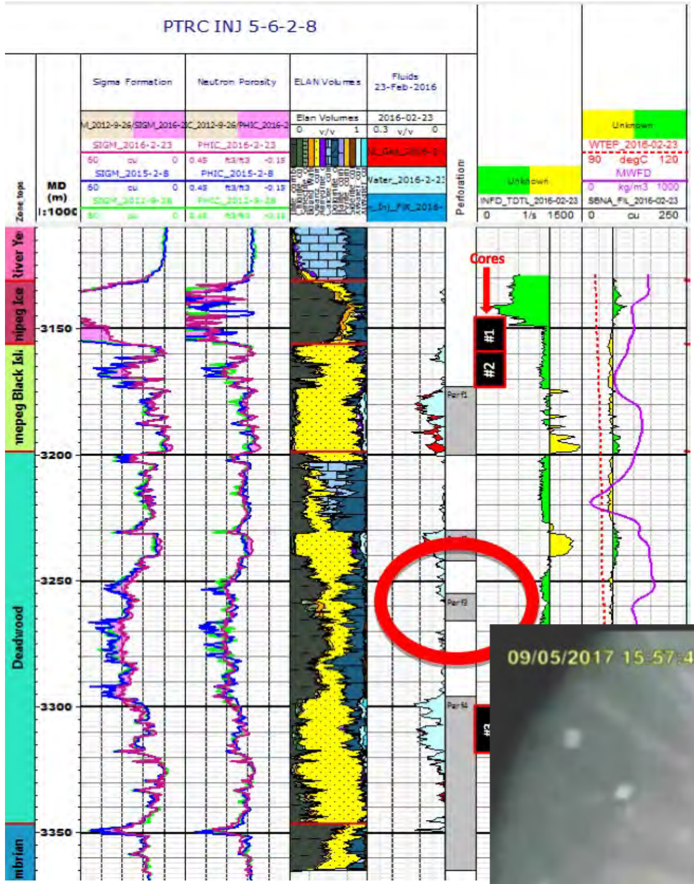
Salt Precipitation Dynamics

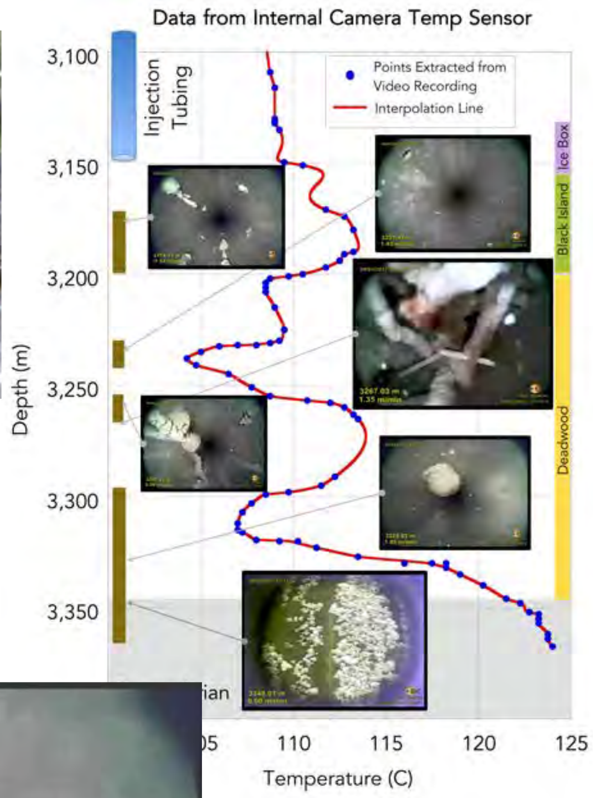
Salt Precipitation

Brine Chemistry:

- Highly saline, Na, Ca, Cl dominated
- The water is likely saturated with respect to halite, calcite and anhydrite

Solution		Precipitates			
	g/L		mmoles/L	g/L	cc/L
Na^+	87.7	Halite	3815.0	222.95	102.7
K^+	4.96	Sylvite	124.0	9.24	4.6
Ca^{2+}	32.5	$CaCl_2{\cdot}2H_2O$	809.3	118.98	64.3
Mg^+	1.70	$MgCl_2{\cdot}6H_2O$	70.0	14.23	9.1
Cl^-	203.0	Anhydrite	1.6	0.22	0.1
SO_4^{2-}	0.15	Calcite	0.4	0.04	<0.1
HCO_3^-	0.05	Total			180.9
Br^-	0.71				





Lower Deadwood
3255m – 3266m

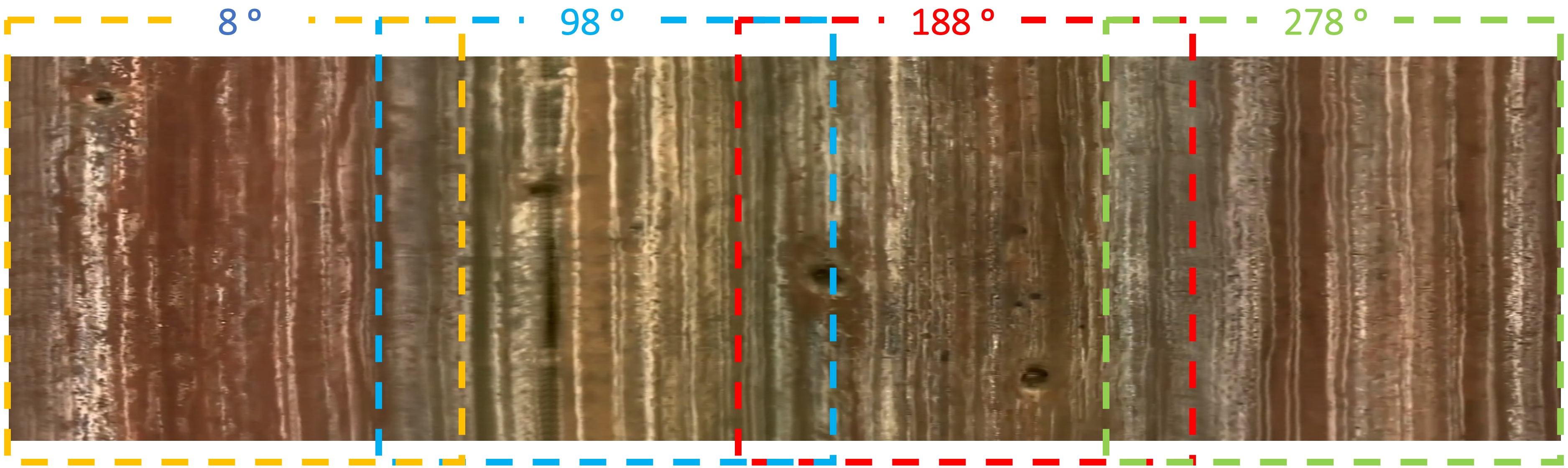
Talman, Rangriz Shokri, Chalaturnyk and Nickel, 2020. Salt Precipitation at an Active CO2 Injection Site. In Wu, John J. Carroll, Mingqiang Hao and Weiyao Zhu (eds.) Gas Injection into Geological Formations and Related Topics, Scrivener Publishing LLC, pp. 183-200.

Virtual Flowmeter Log from Downhole Camera Videos

Correcting for

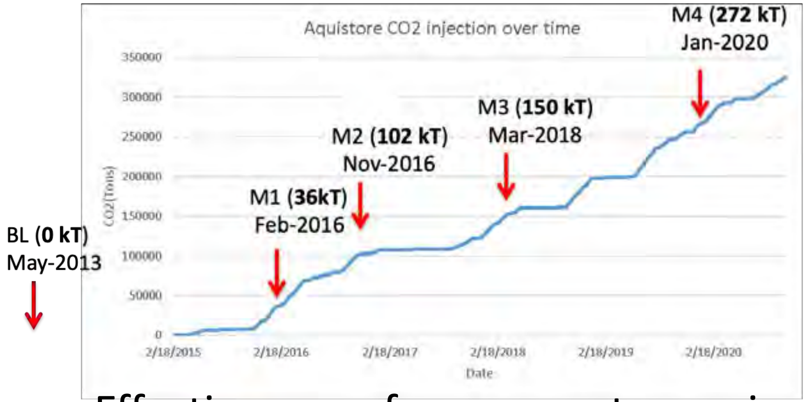
- image distortion
- image overlap
- image orientation

results in:
"*stitched images*" of wellbore profile



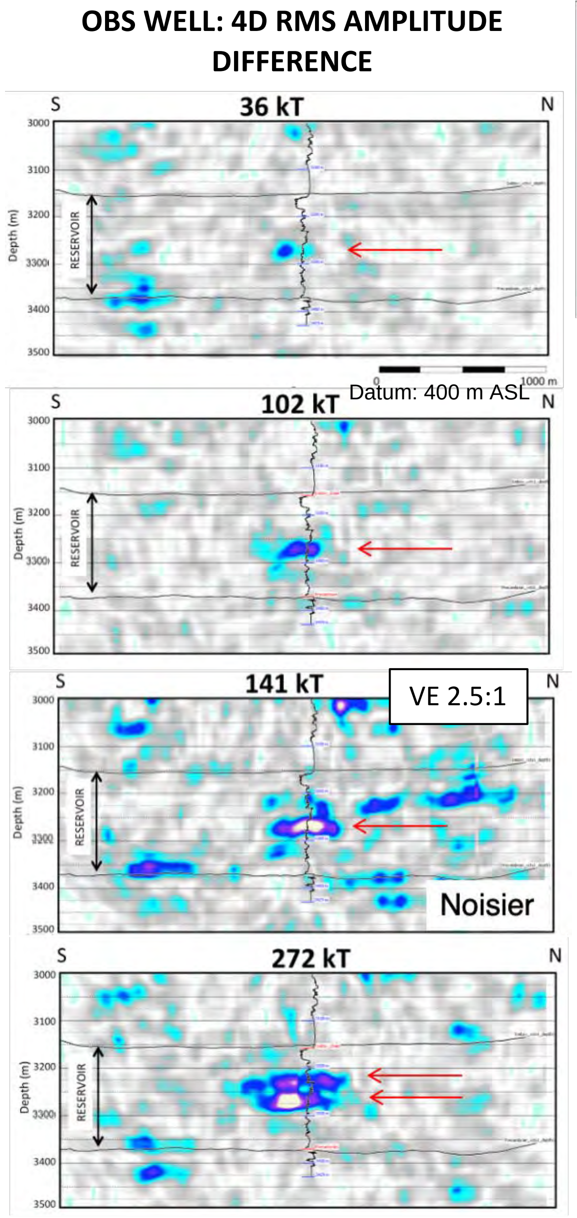
Seismic Monitoring

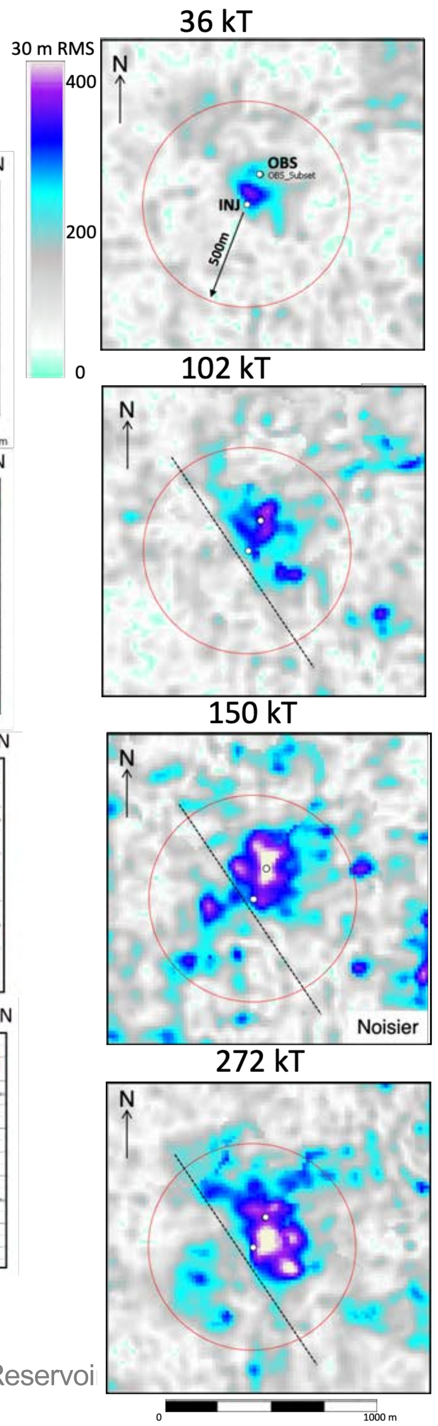
Time Lapse Seismic Monitoring

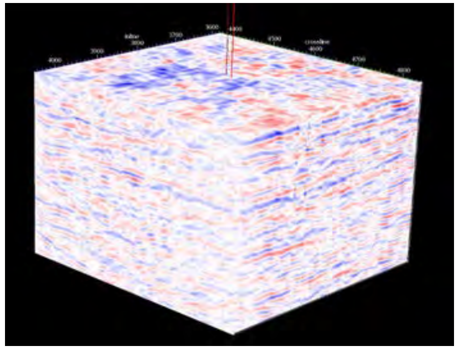


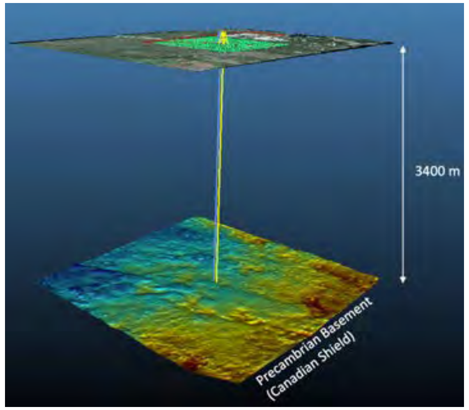
Currently: >370 kT

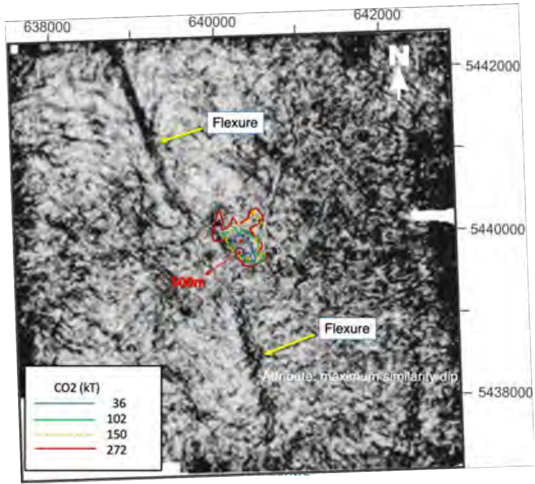
- Effectiveness of permanent array is demonstrated -still operational after 8.5 years.
- Alternative DAS fibre configurations show potential for surface data acquisition.
- No induced seismicity over 5-1/2 years of injection.
- CO_2 plume is contained within the reservoir.
- Constrains vertical distribution of CO_2 in the reservoir
- Strong influence of reservoir structure is observed.



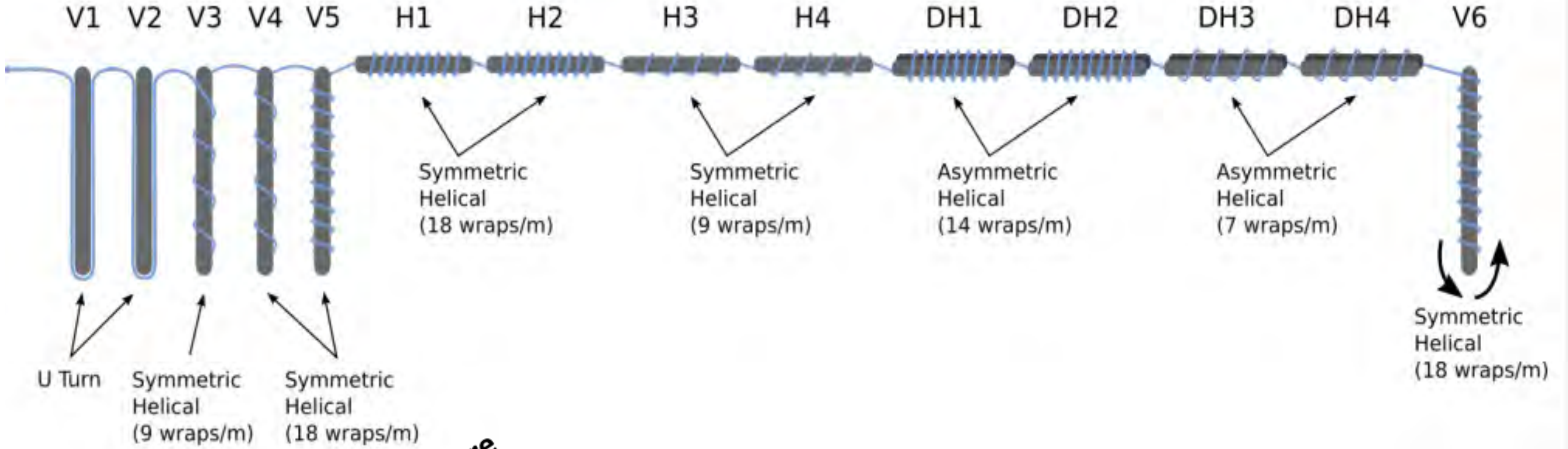


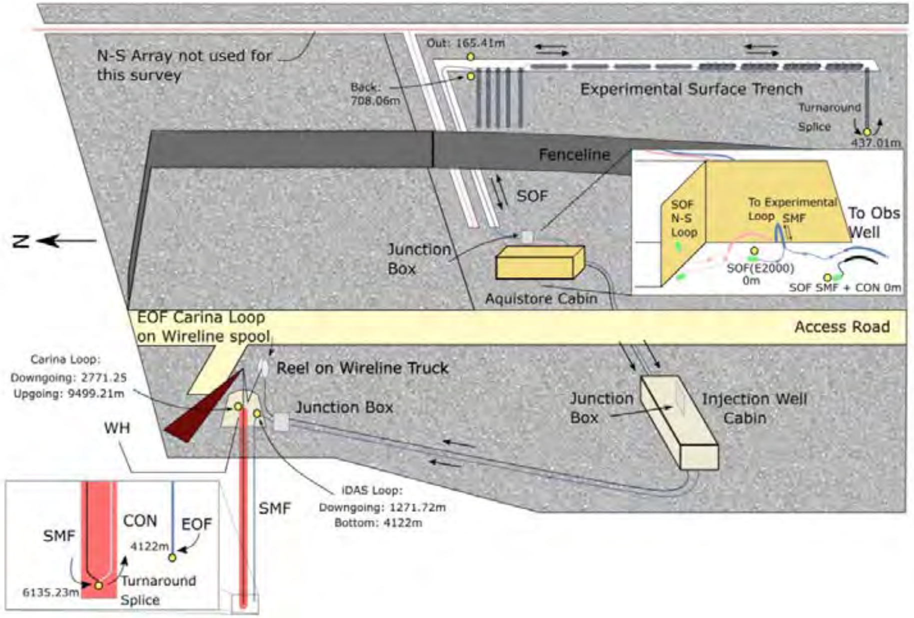


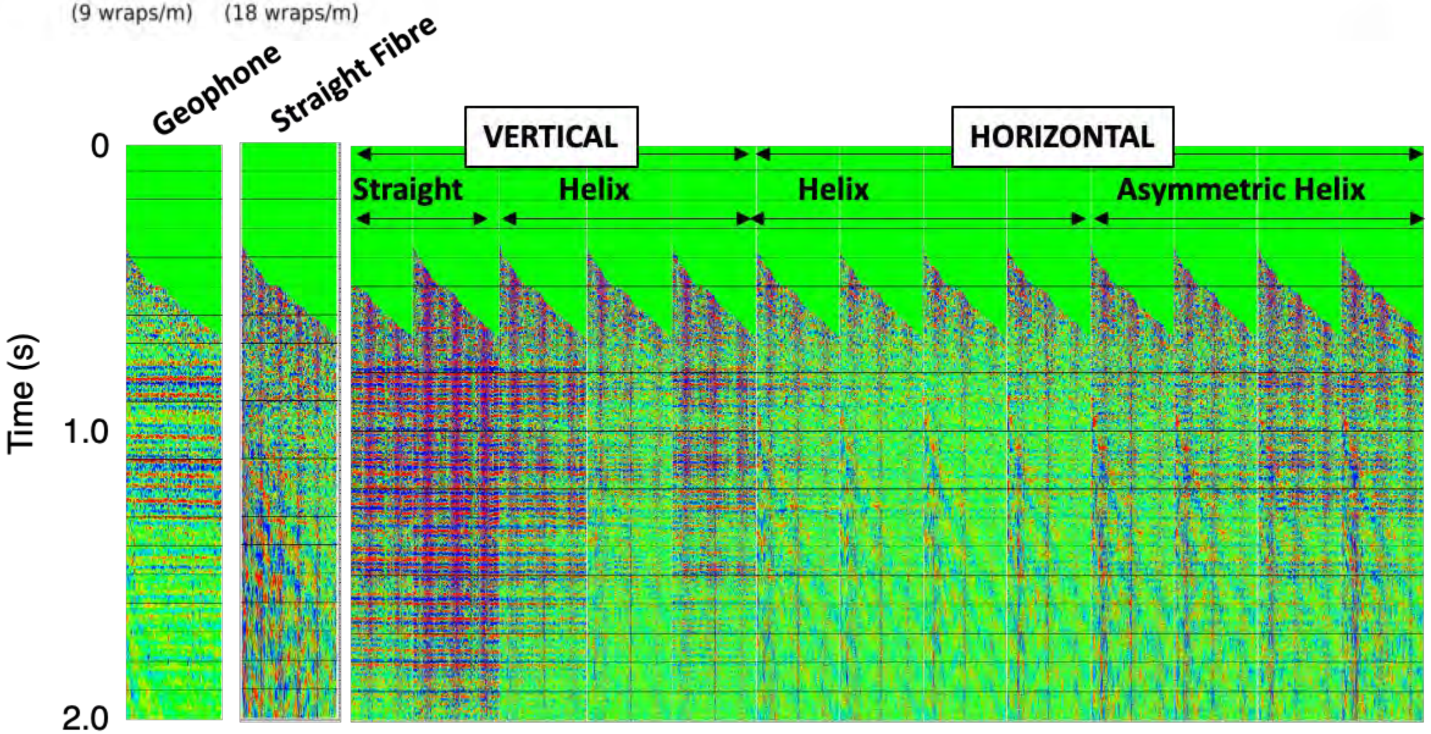




Experimental DAS Configurations (Fibre Optics)



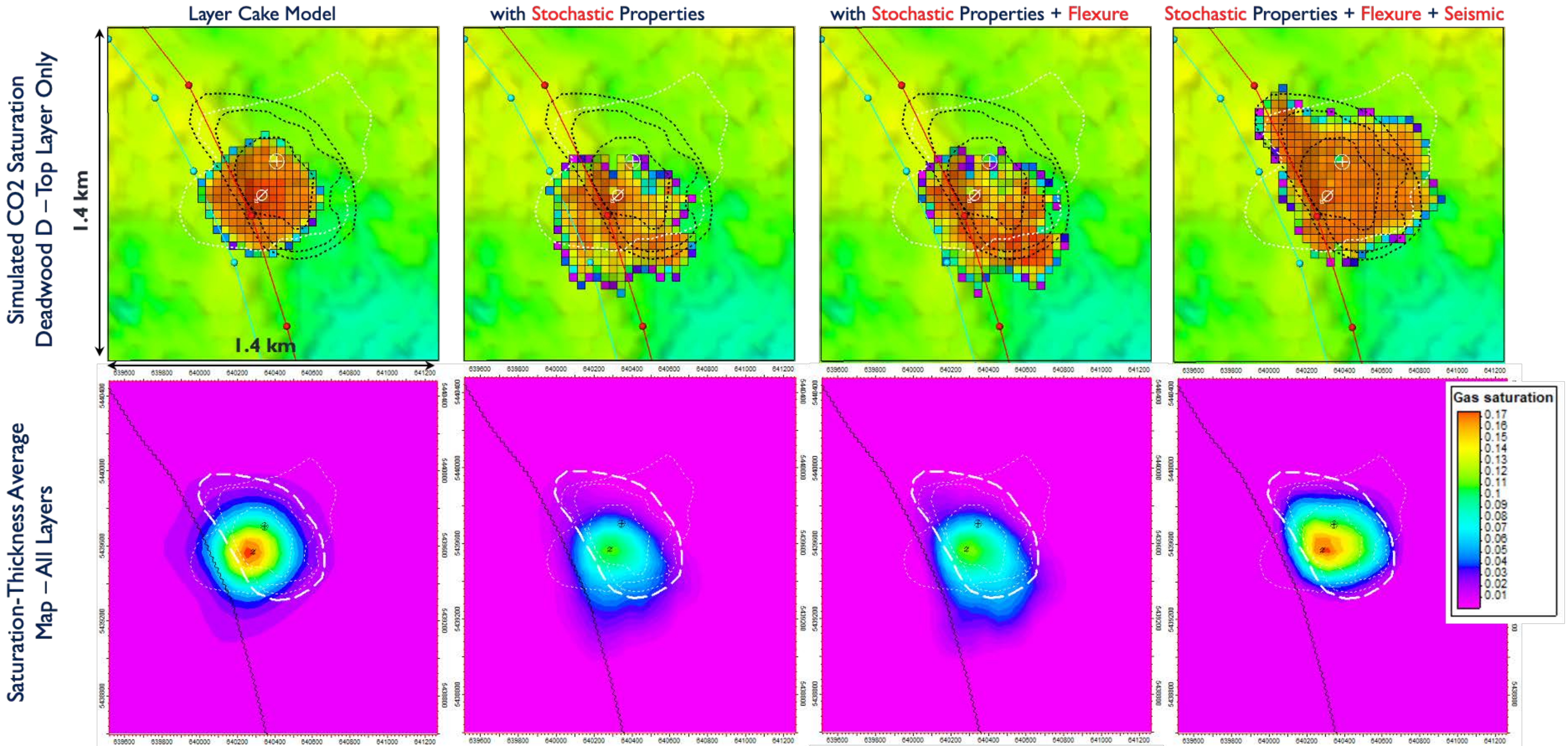




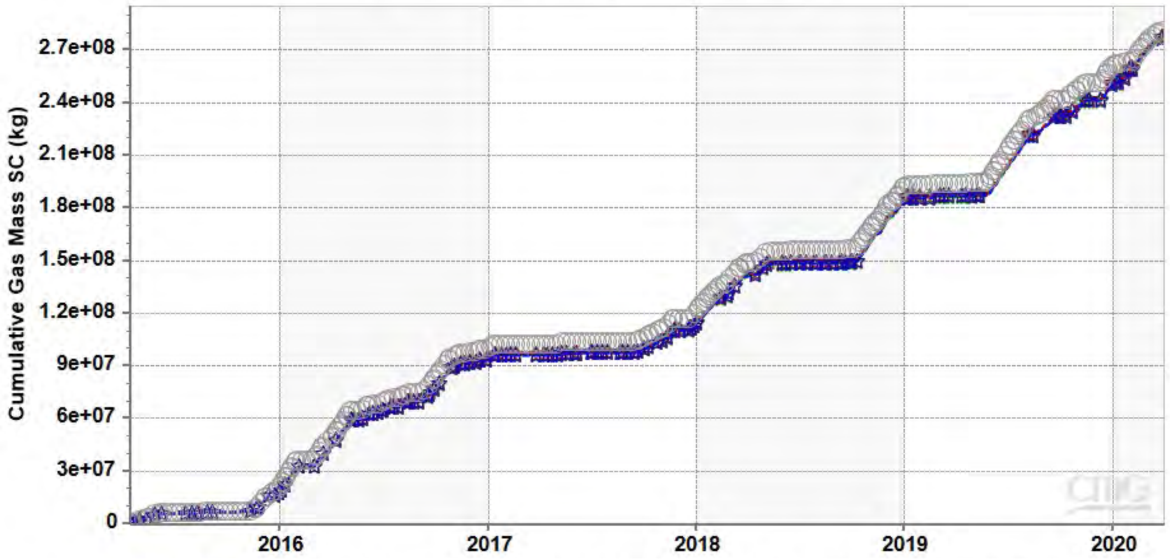
Constant Amplitude Scaling

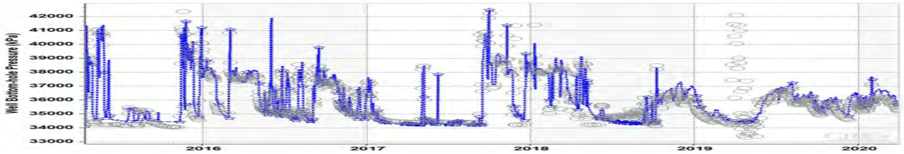
Dynamic Reservoir Modeling

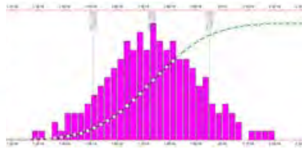
Different History Matched Realizations of CO_2 Plume

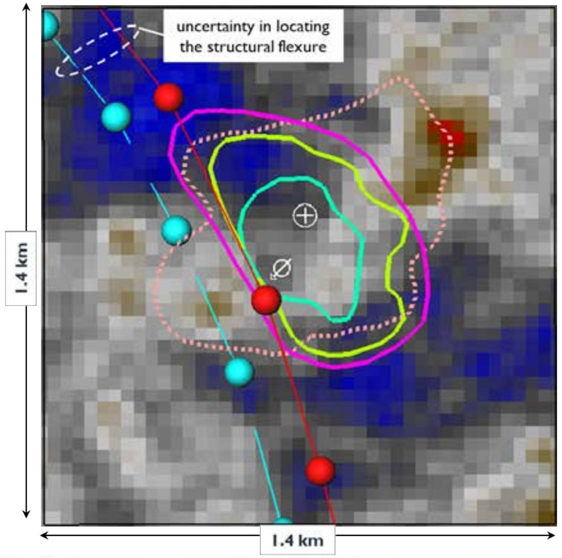


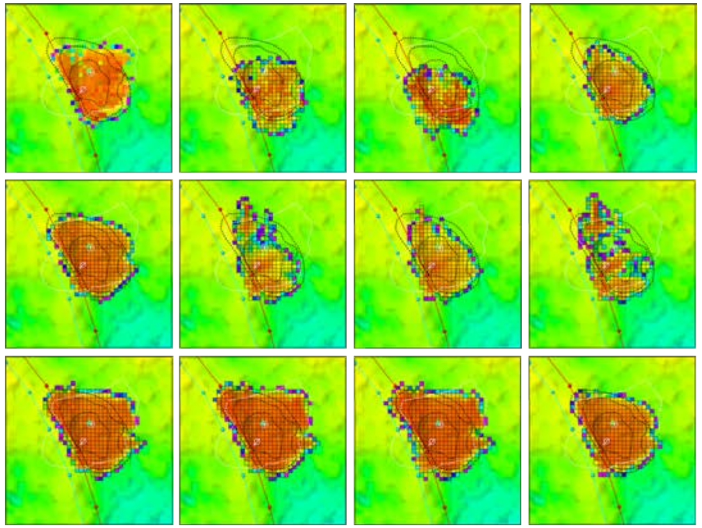
Different History Matched Realizations of CO_2 Plume

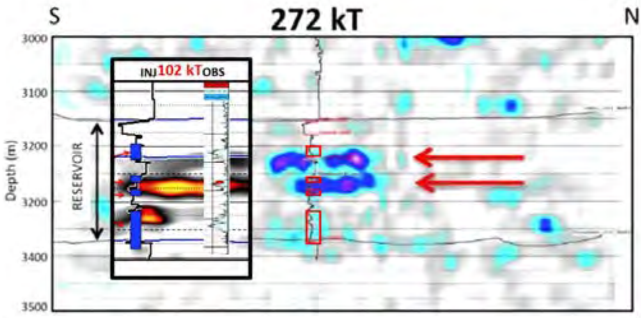


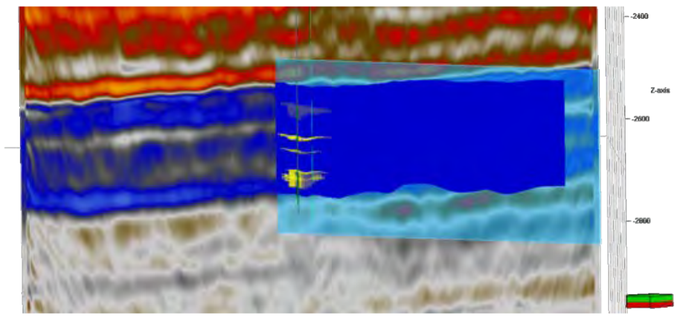








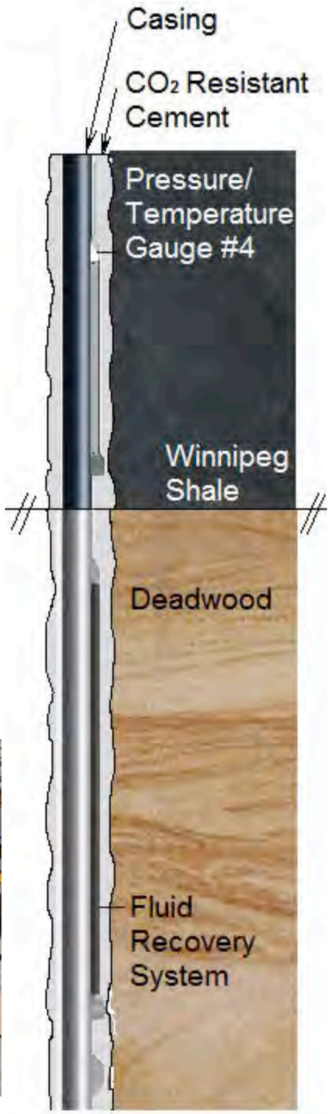


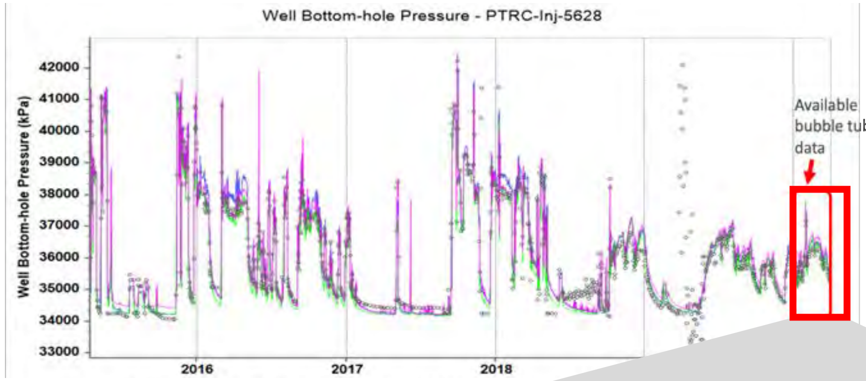


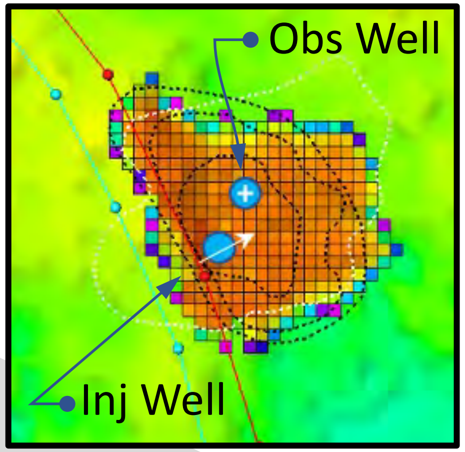
- All realizations match reported field data!
- Very similar history matches on injection rate data, but with very different petrophysical property distribution.
- There is a need to constrain the simulation with time-lapse seismic surveys.

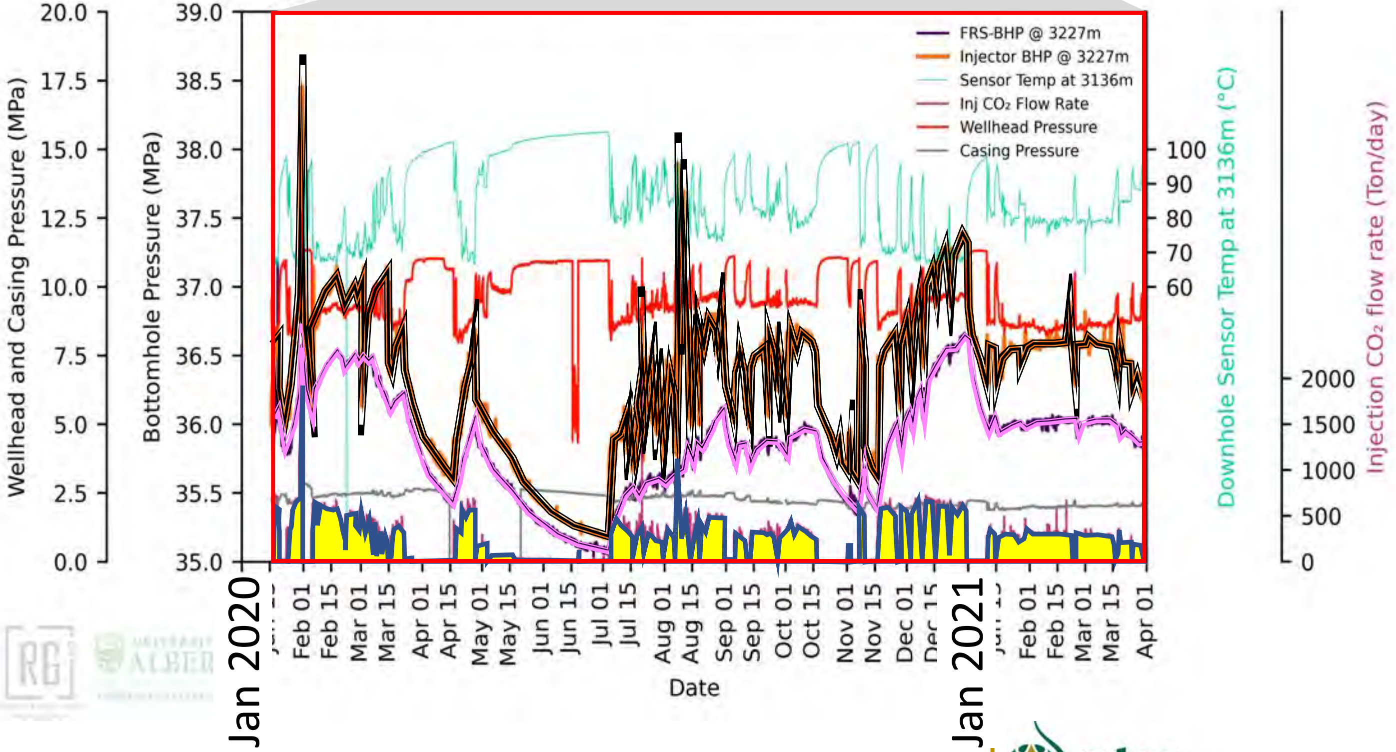
Additional Constraint: Observation Well BHP using Bubble Tube

- Loss of casing conveyed gauges in Obs Well meant no BHP data away from injection well
- Convert casing conveyed fluid recovery system (which did not fail) to automated bubble tube system for BHP at Obs Well









MMV and CO_2 Storage

Know what you're looking for !

Sometimes it really does make sense to just get started !

A geological site suitable for the CO_2 storage must have:

- sufficient **injectivity** to receive CO_2 at the rate at which it is to be supplied
- secure **containment (and conformance)** of the CO_2 for the long-term
- sufficient **capacity** to store the delivered CO_2 over the lifetime of injection operations

Field-Based Observations for CO_2 Geological Storage from 6 Years of Dynamic CO_2 Injection at the Aquistore CO_2 Storage Site

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