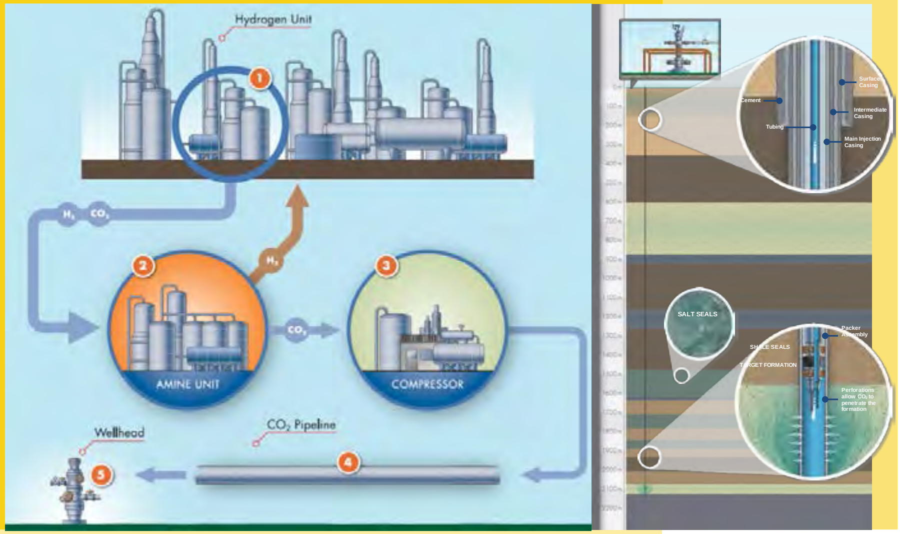
QUEST CCS PROJECT

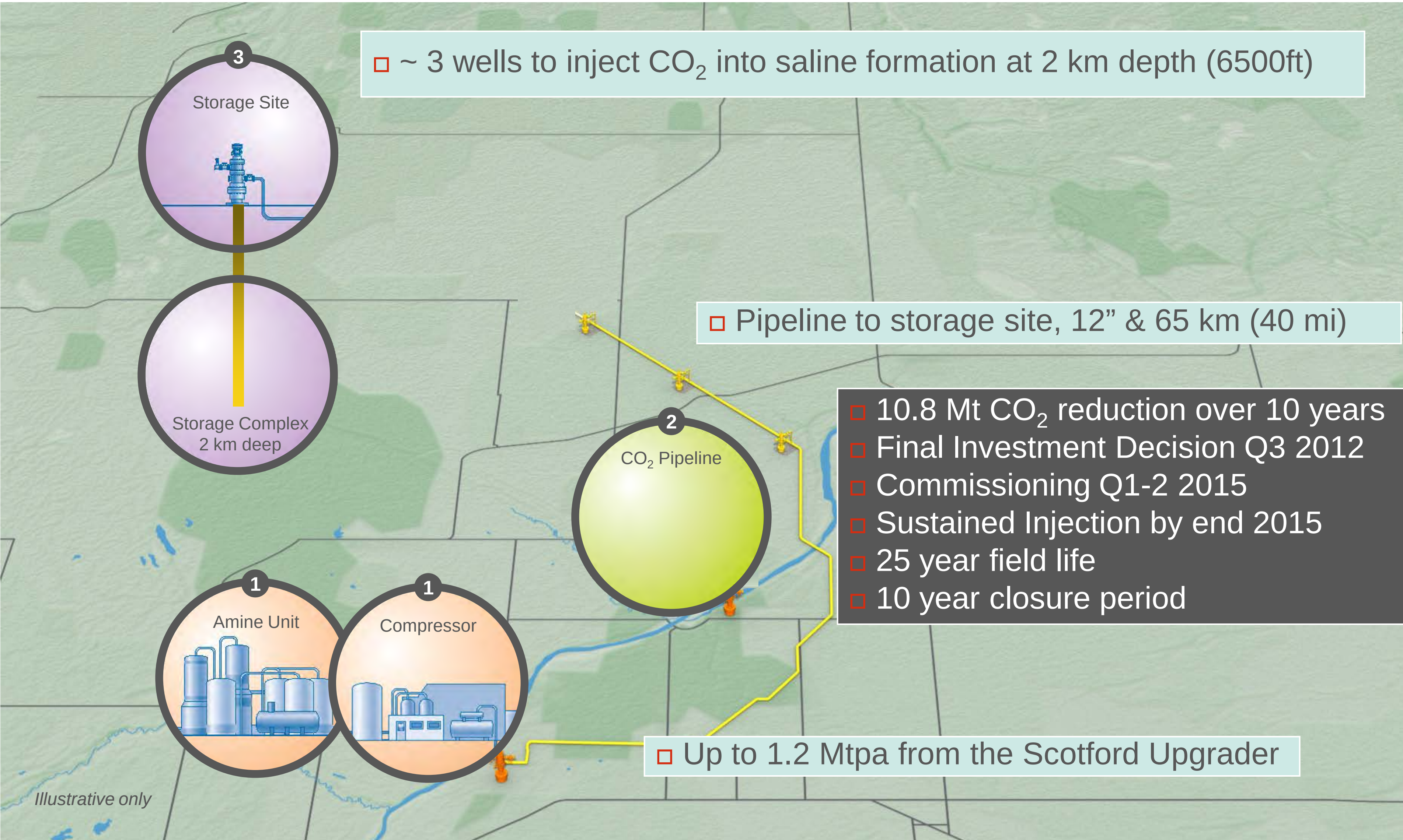
CSLF – Rome

April 2013



Sean McFadden– Quest Sequestration Manager

QUEST - Integrated CCS Project



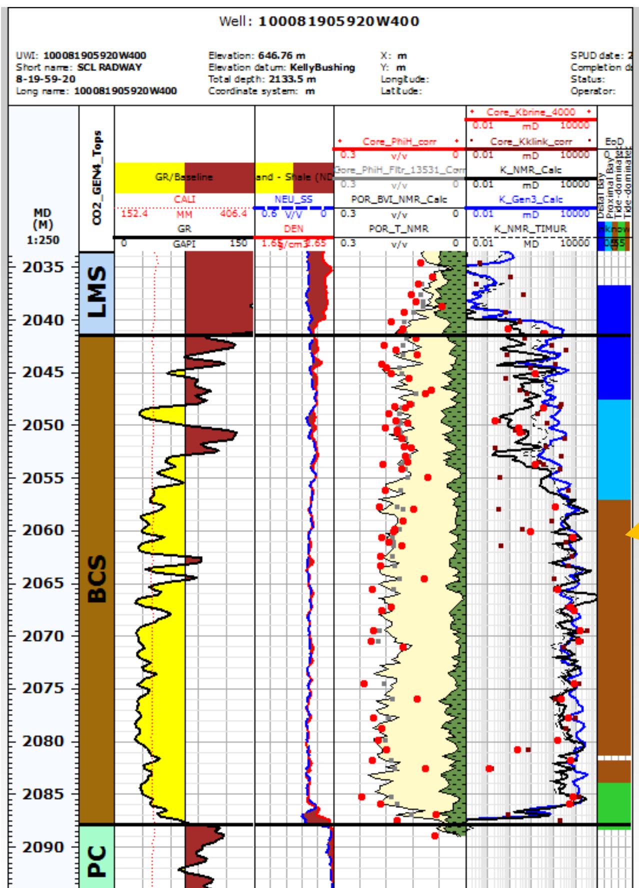
- ~ 3 wells to inject CO_2 into saline formation at 2 km depth (6500ft)
- Pipeline to storage site, 12" & 65 km (40 mi)
- 10.8 Mt CO_2 reduction over 10 years
- Final Investment Decision Q3 2012
- Commissioning Q1-2 2015
- Sustained Injection by end 2015
- 25 year field life
- 10 year closure period
- Up to 1.2 Mtpa from the Scotford Upgrader

QUEST - Storage Complex and MMV Interval

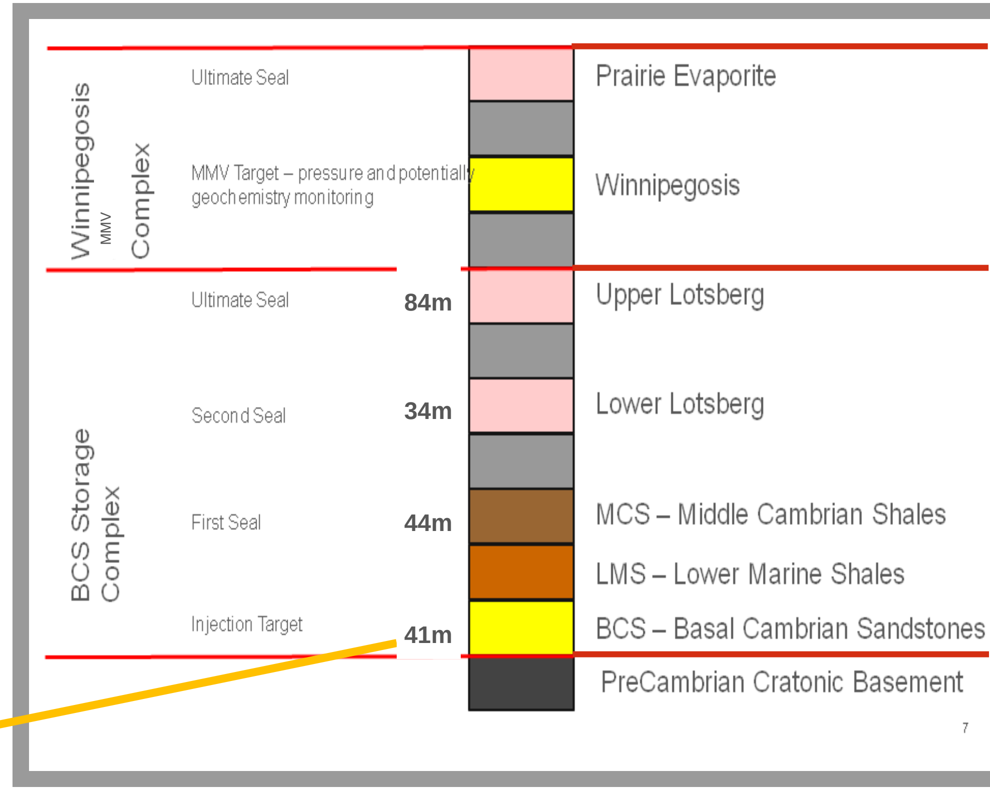
Basal Cambrian Sand

- Deep saline aquifer (~2km). Well below potable water zones (<200m)

8-19 well results



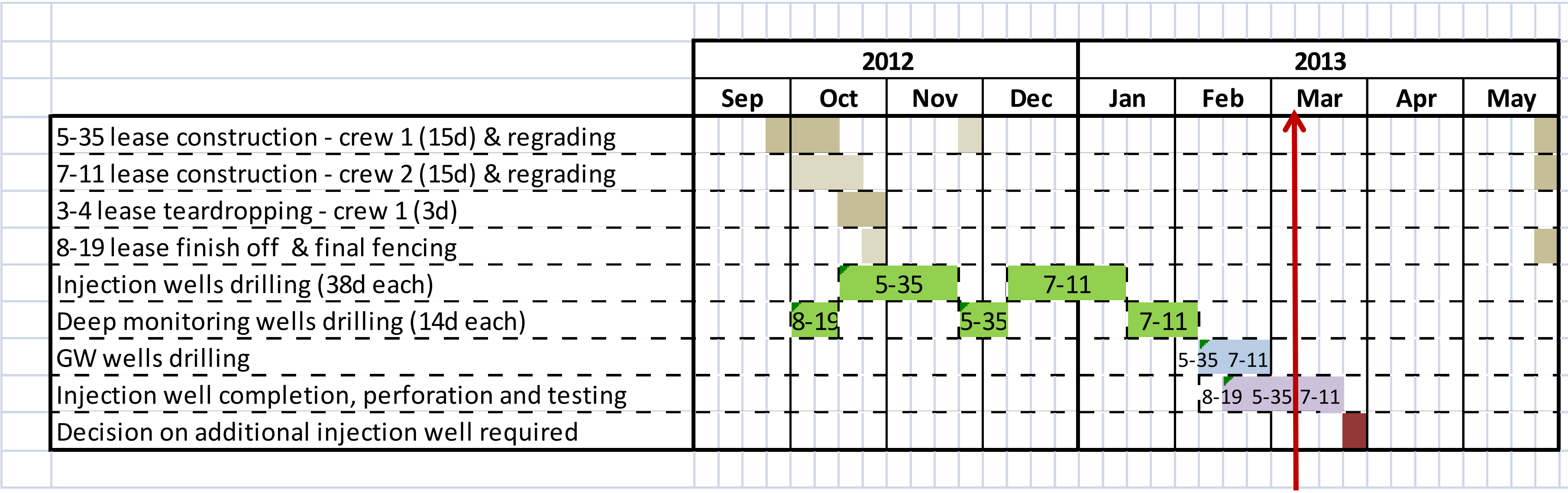
Por	K
16%	300mD



Multiple Seals

- Winnipegosis - Planned MMV pressure monitoring zone
- Upper Lotsberg – Salt - Ultimate Seal
- Lower Lotsberg - Salt - Second Seal
- MCS - Shale layer - First Seal

QUEST - 2012/13 Drilling Schedule



- Drilled 2 additional injection wells in 2012 (5-35 and 7-11 Locations)
- Drilled 3 Deep Monitoring wells – One on each injection well pad
- Drilled 4 additional Ground Water monitoring wells
- Tested the 5-35 well – similar injectivity to the 8-19 well
- **Next steps**
- Install final completion and execute test in IW 7-11

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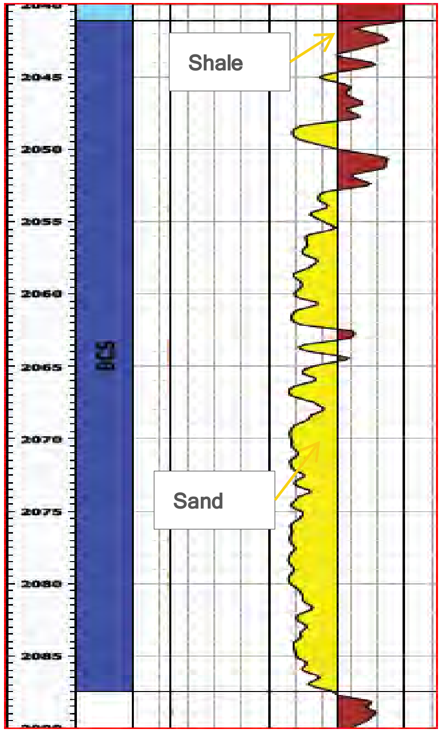
QUEST - Storage Complex- BCS Reservoir

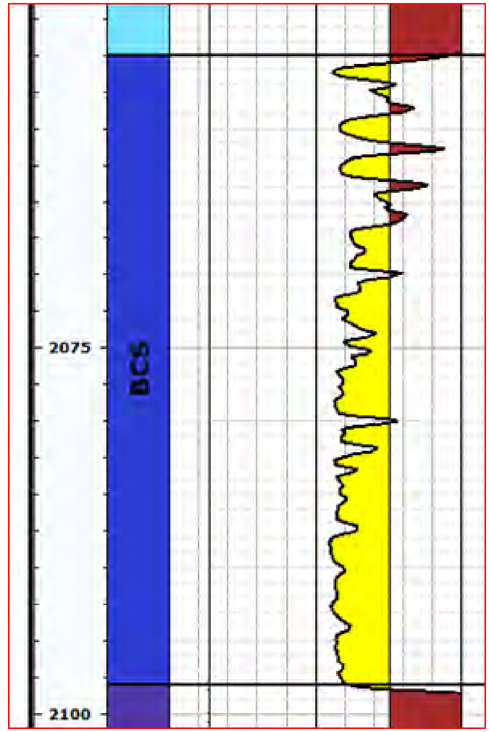
IW- 8-19 (Gamma Ray Log)



Net Sand - 38.7m

Porosity – 17.1 %

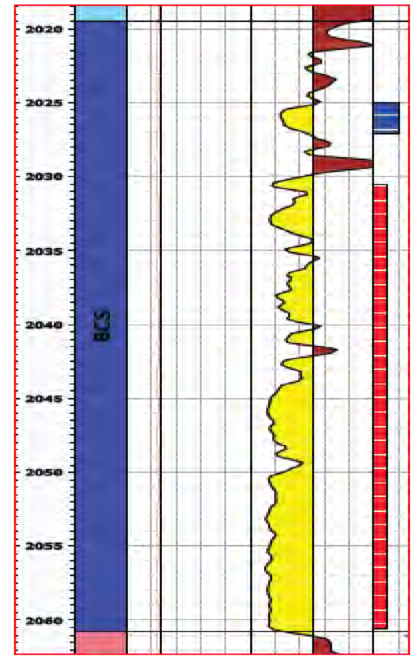
IW- 5-35 (Gamma Ray Log)



Net Sand - 42.1m

Porosity – 16.3 %

IW - 7-11 (Gamma Ray Log)

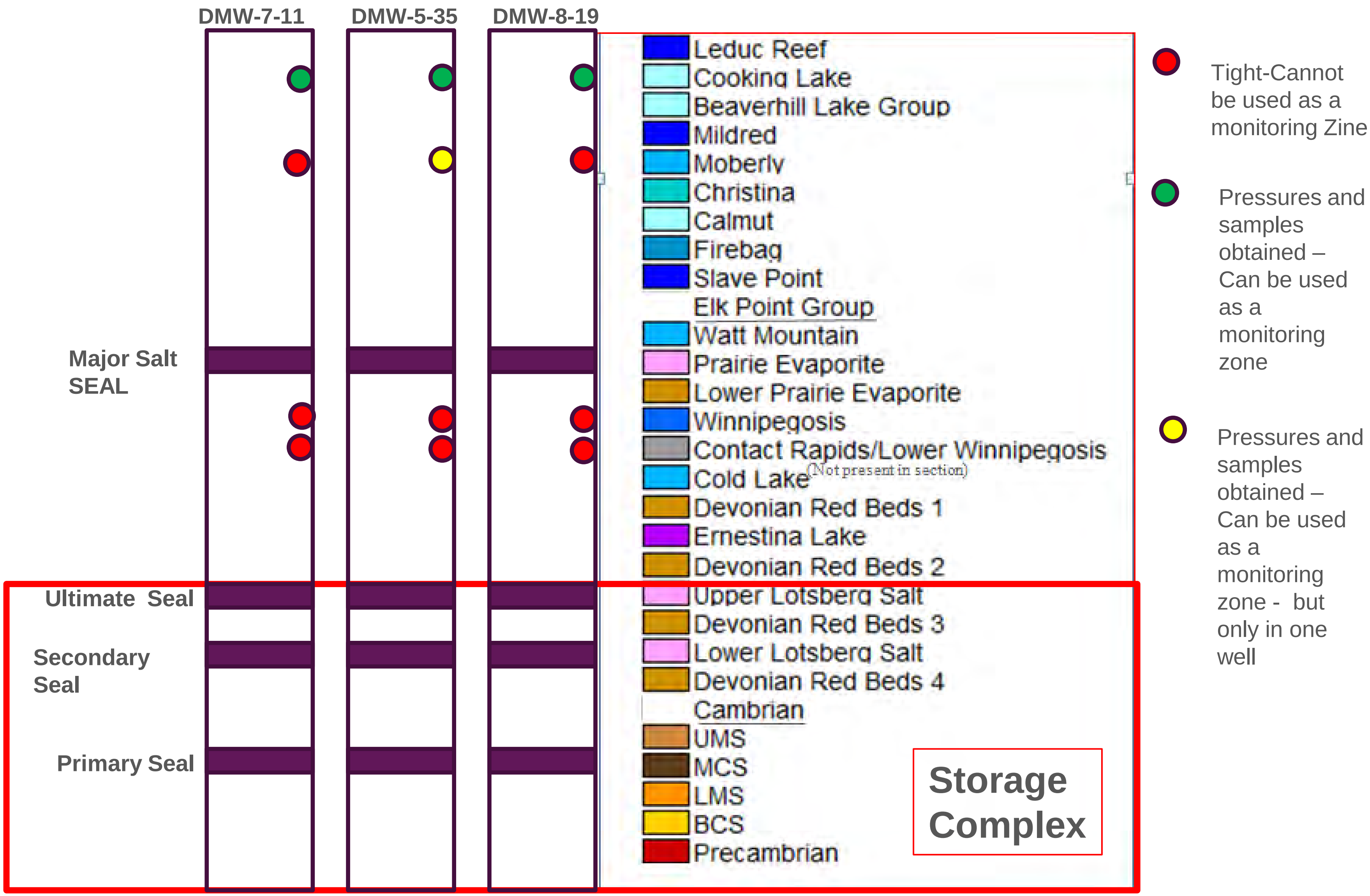


Net Sand - 37.8m

Porosity – 17.4 %

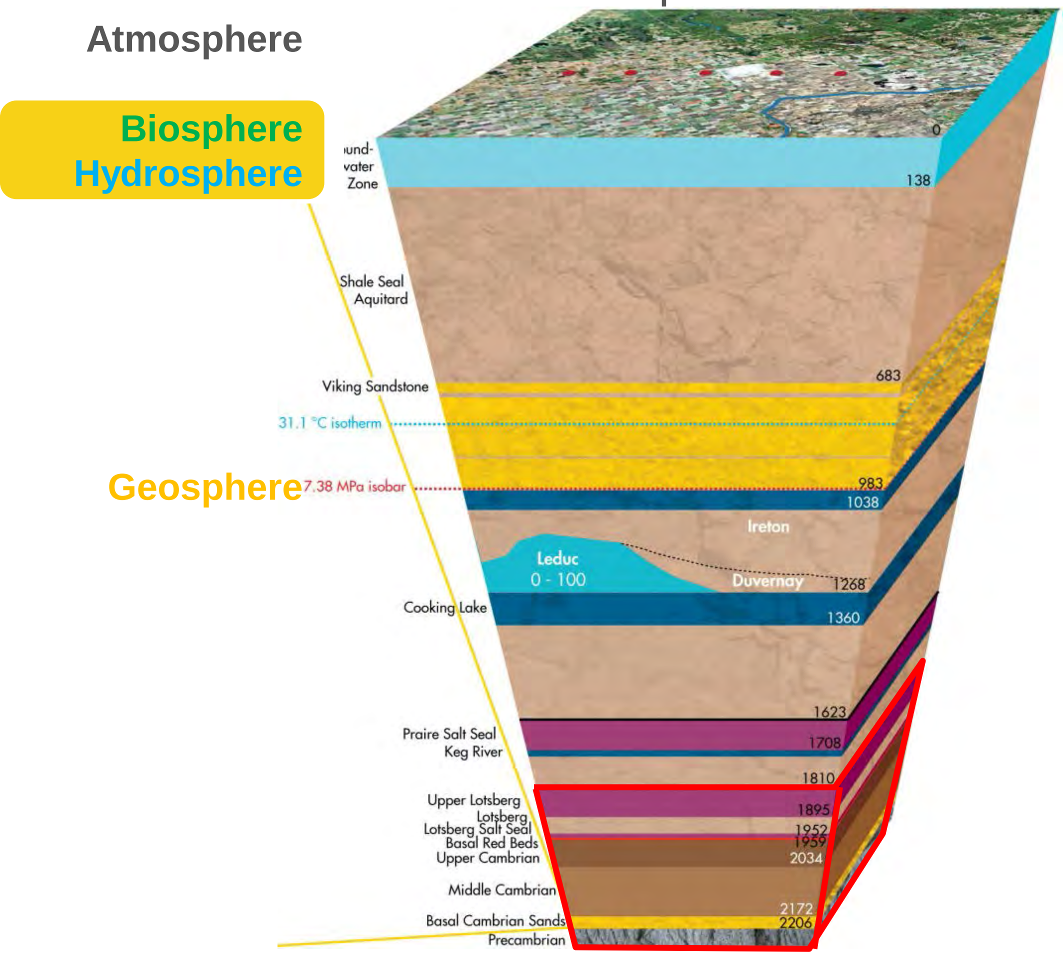
Based on simple Vsh cut off = 0.35 and Porosity Cut Off =0.1

QUEST – Pressure Monitoring Interval

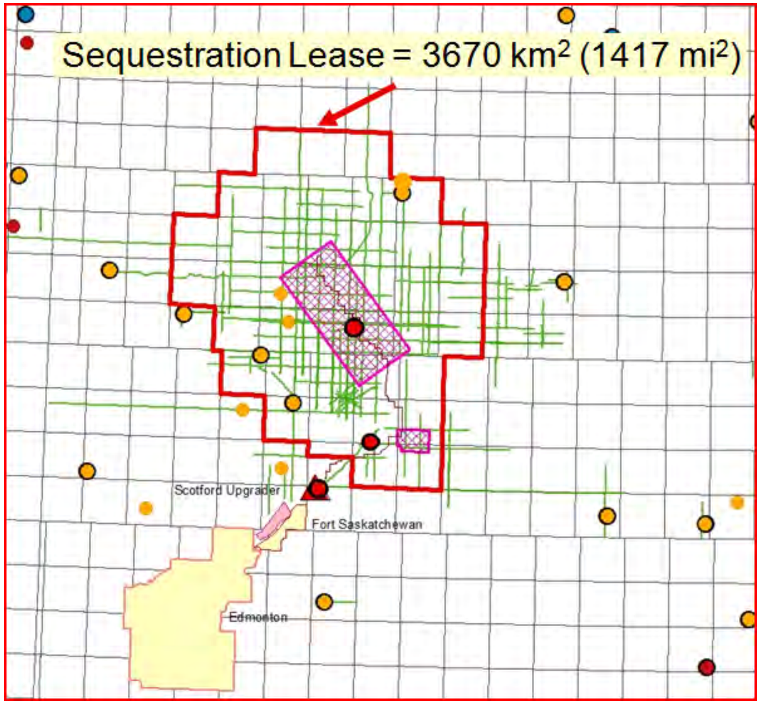


MMV - Domains and Area

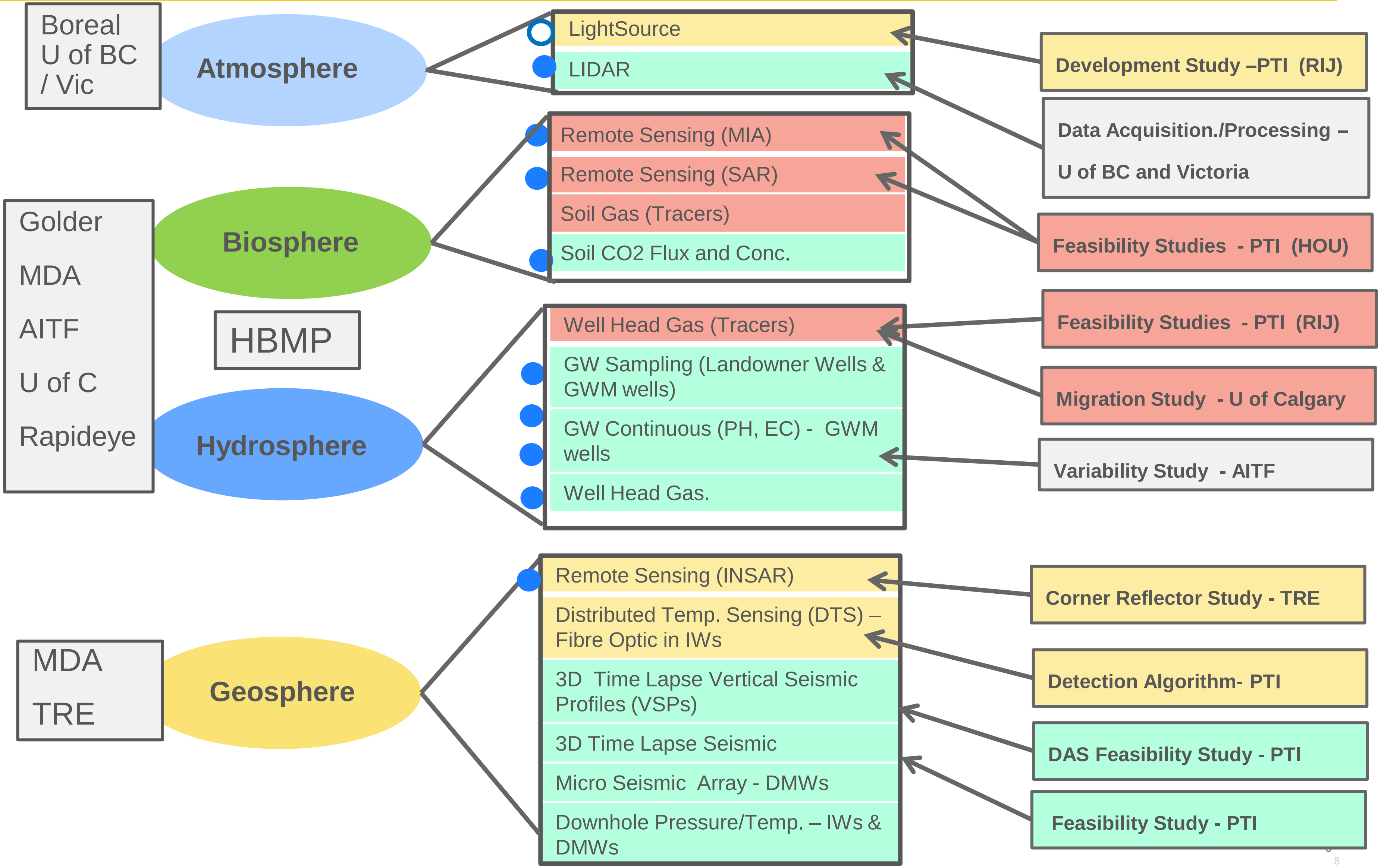
Depth Extent



Areal Extent



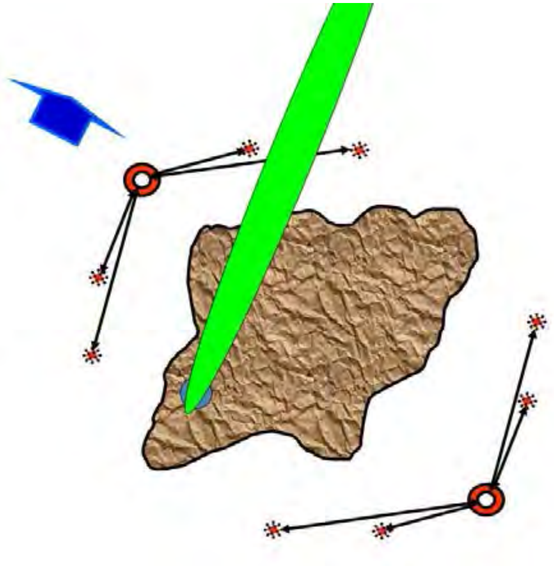
MMV / Technologies / Studies / Contracts



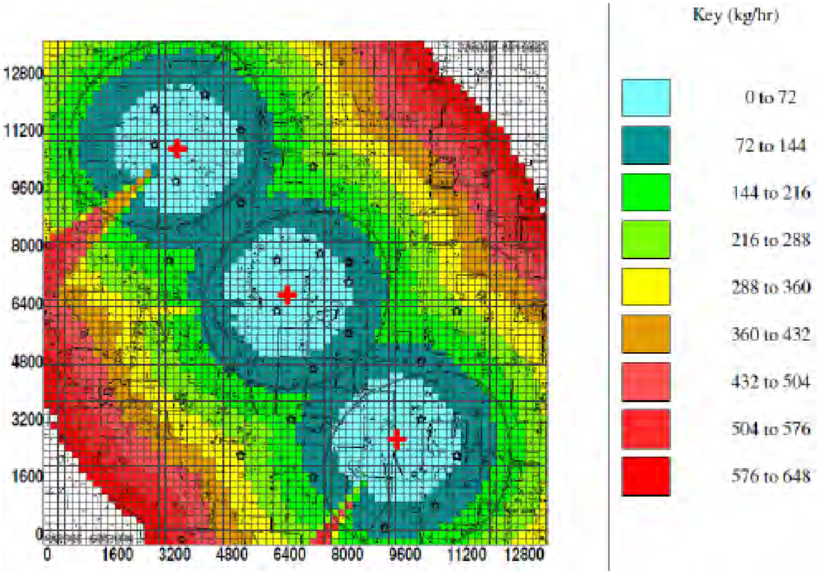
ATMOSPHERE: “LightSource” - Remote Gas Flux Monitoring (RGMF)

Open-Path Sensor

Imaging Capability



Expected Detection Performance



- ➢ Data accumulates for different wind directions, speeds and Turbulence intensities
- ➢ As data grows, fewer source patterns can satisfy data constraints.
- ➢ Evaluate numerous candidate source arrangements to find best fit to data.

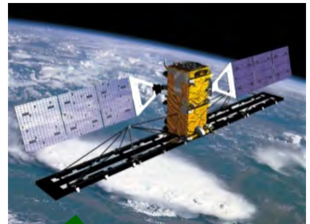
BIOSPHERE: Remote Sensing (RS)

- **RADAR**
  - Increased soil salinity above background scatter for BCS brine detection
  - RADARSAT2
- **OPTICAL (Multispectral)**
  - Measure and monitor spectral properties of light reflected by vegetation to measures plant stress to confirm the absence of Quest CO_2 or BCS brine in the biosphere.
  - Baseline with RAPIDEYE

BIOSPHERE: Remote Sensing (RADAR amplitude)

Active System

Transmits a C –Band RADAR signal – 5.6 cm



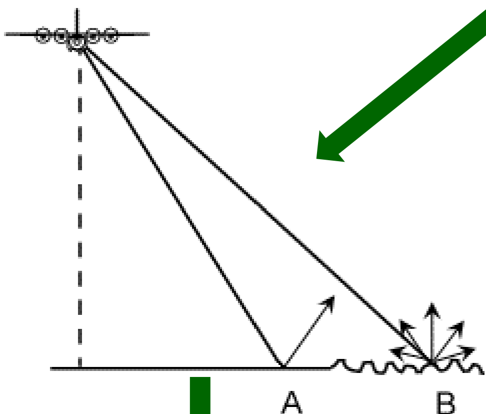
RADARSAT-2 Satellite
The Canadian Space Agency and MacDonald, Dettwiler and Associates Ltd. (MDA)

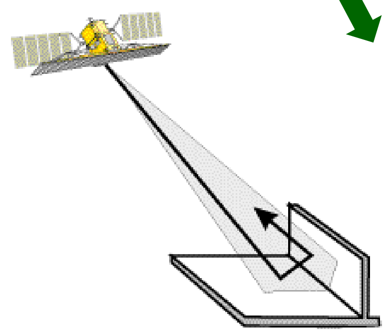
Launched – 2006

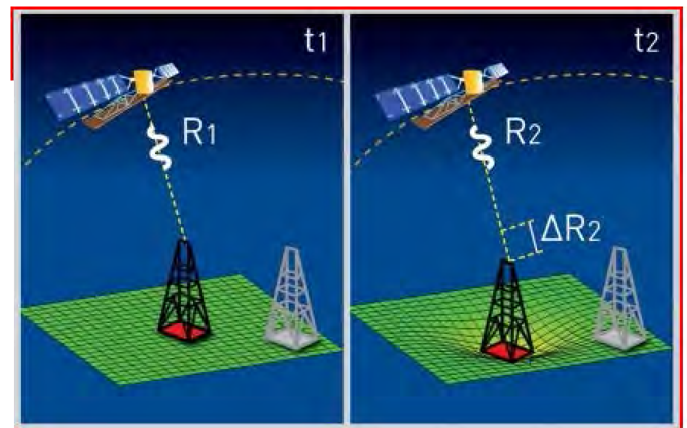
Orbit – 798 Km

SAR (Amplitude)

InSAR (Phase)

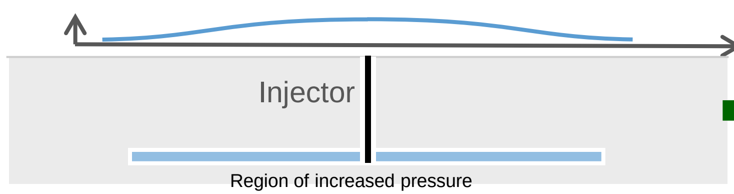






Dielectric Constant
Roughness

Soil Salinity

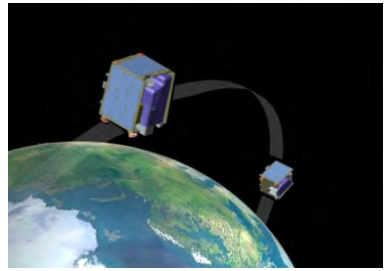


Surface Deformation

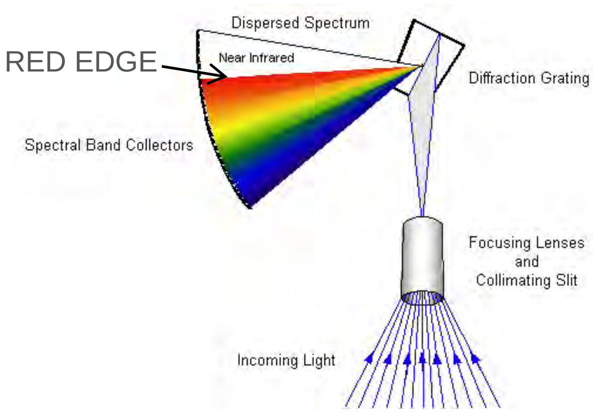
BIOSPHERE: Remote Sensing (Multi-Spectral)

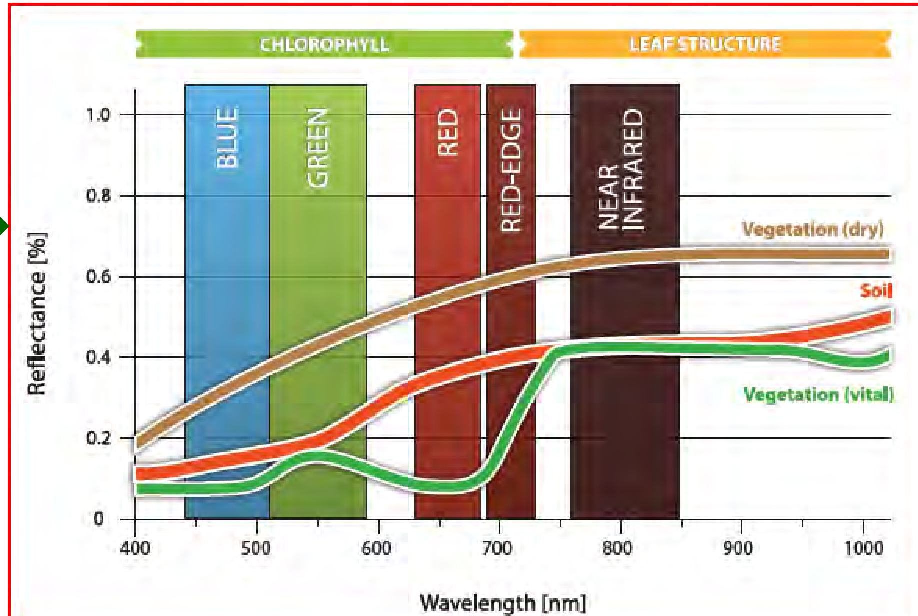
Passive System

Reflected Visible/Near Infrared Spectrum



RapidEye Constellation
Owner – Rapideye
Designed and launched by MDA
5 Satellite Constellation
5m Resolution





NDVI – Normalised Difference Vegetation Index

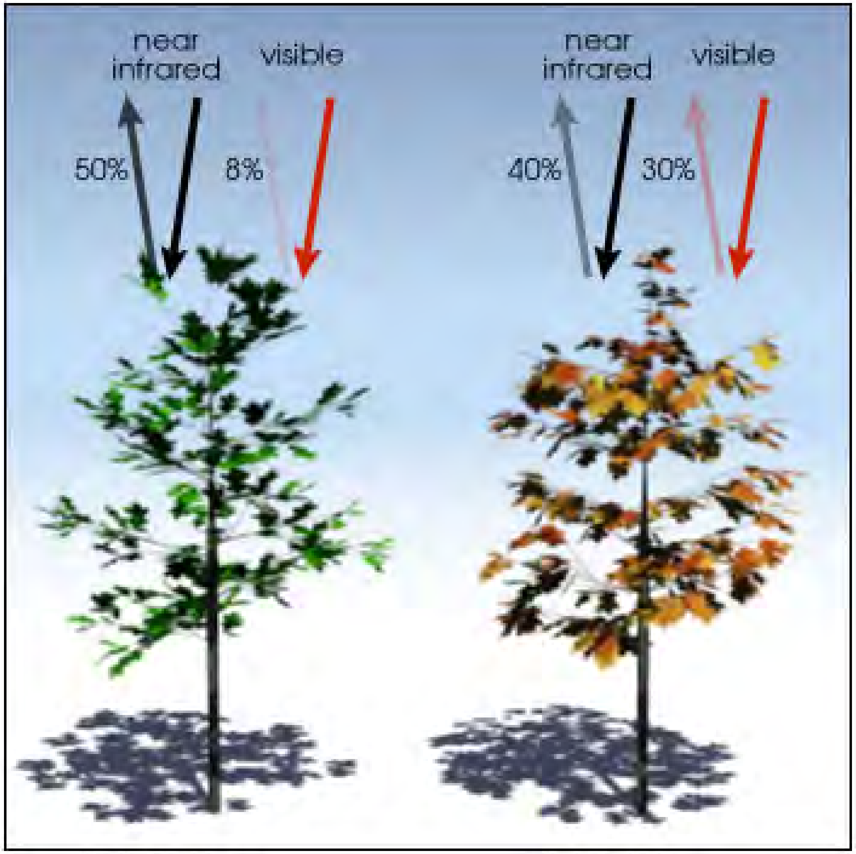
BIOSPHERE: Remote Sensing (Multi-Spectral) - NDVI

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)}$$

NIR- Near Infra Red Reflectance

VIS - Visible (Red) Reflectance

NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation (left) absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation (right) reflects more visible light and less near-infrared light.



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

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BIOSPHERE: RS Calibration (Ground Measurements)

GOLDER

(Data Collection)

Dielectric Constant

EM-38

Surveys

NDVI

Vegetation

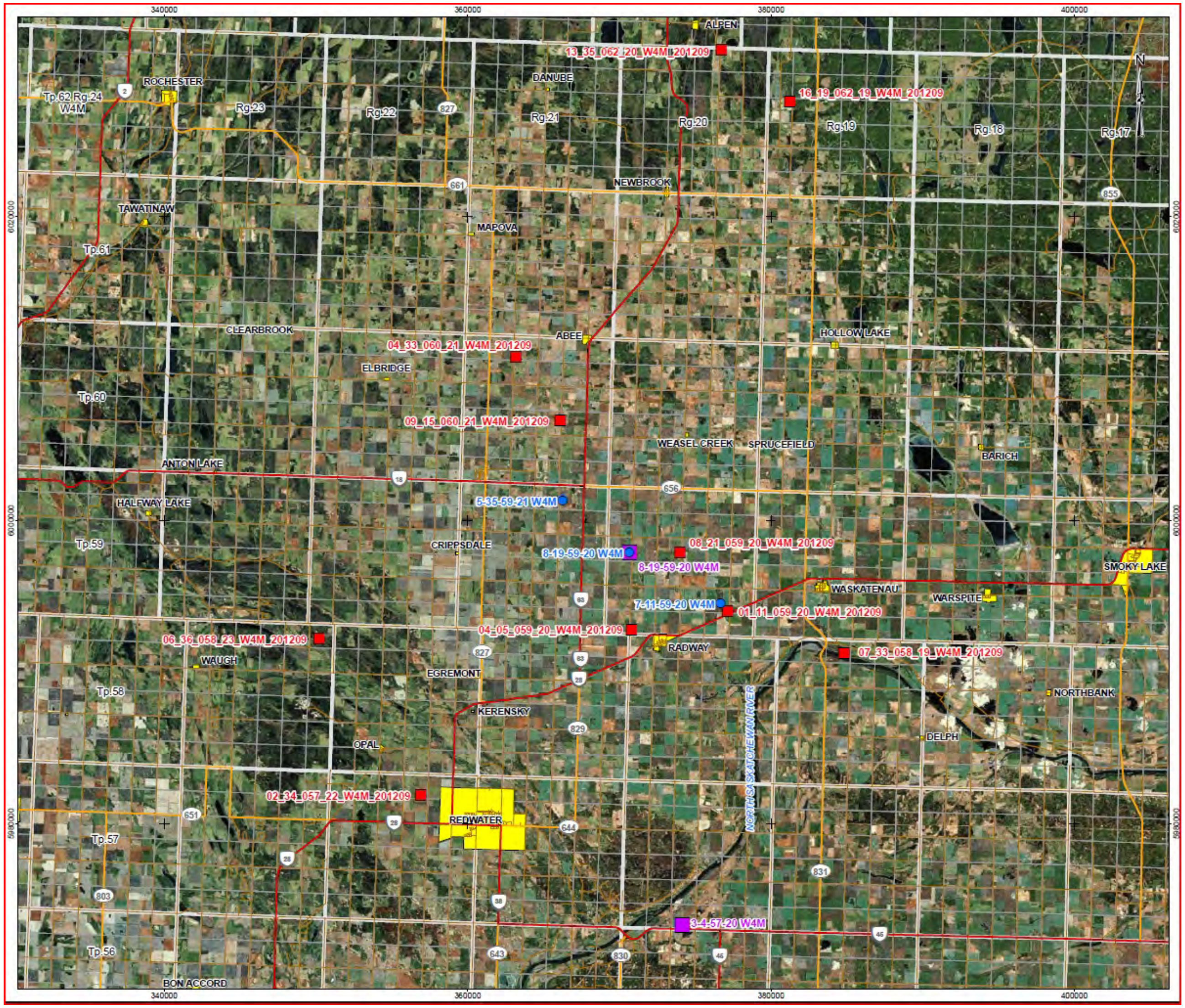
Spectroscopy

+ Physical Data on Vegetation Cover, Type & Health

BIOSPHERE: RS Calibration - Soil and Vegetation Plots (2012)

LEGEND

- GEOTEXTILE TARGET LOCATION
- INJECTION WELL
- VEGETATION PLOT
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- LOCAL ROAD
- POPULATED PLACE



BIOSPHERE / HYD Tracer Selection

	Reactivity	Partitioning	Low Detection Limit	Low Environmental Impact	Low Cost	Other	Comment
$\delta^{13}C$	☹	😐	😐	☺	☺		Useful but not for liability
^{14}C	☹	😐	😐	☺	☺	Radioactive, public perception ☹	Inexpensive
Xe	☺	😐	☺	☺	☹	Mostly research, partitioning behavior not fully known	Prohibitively expensive
Kr	☺	😐	☺	☺	☹?		Prohibitively expensive????
^{3}He	☺	😐	😐	☺	☹	High atmospheric content ☹	Procurement and analysis issues
^{36}Ar	☺	😐	😐	☺	☹	High atmospheric content ☹	Amount needed is not feasible.
^{22}Ne	☺	😐	😐	☺	☹		Amount needed is not feasible.
PFC	☺	☺	☺	☹	☺		GHG, but amount added very small
SF_6	☺	☺	☹	☹	☺	Most potent GGH. Banned in Europe as tracer ☹	Large quantities needed. Potent GHG. Do not use.
CD_4	☺	😐	☺	☺	☹	Under development.	Expensive, mostly scientific (Otway)

Gas Tracer Comparison
(based on Mackie, 2007; Stalker et al., 2009)

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BIOSPHERE / HYD Tracers -

	Project	Tracers use	Type of tracers	Objective
Commercial Scale (> 100,000 tonnes CO_2/year	Sleipner, N Sea, Norway	No		
	Weyburn, Canada	Yes	$\delta^{13}C$, $\delta^{18}O$	Reservoir plume migration
	In Salah, Algeria	Yes	PFC	Reservoir plume migration
	Gorgon	No	-	
Pilot Scale (<10,000 tons CO_2/year)	Frio, Texas, USA	Yes	SF_6, PFC, Kr	Reservoir plume migration
	CO2 Sink, Germany	Yes	Xe & Kr	Reservoir plume migration
	Otway, SW Australia	Yes	SF_6, Kr, CD_4	Reservoir plume migration
	BP Miller field EOR	Yes	?	Reservoir plume migration
	K12-B N. Sea, Dutch Sector	Yes	PFC	Reservoir plume migration

Tracers have been widely used for plume migration monitoring in the reservoir. Most applications were once-off deployment.

No examples of continuous tracer injection for "tagging" the CO_2.

If Quest deploys an artificial tracer throughout the life of the project, it will be setting new ground.

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BIOSPHERE / HYD: Soil Gas - Artificial tracer - PFC

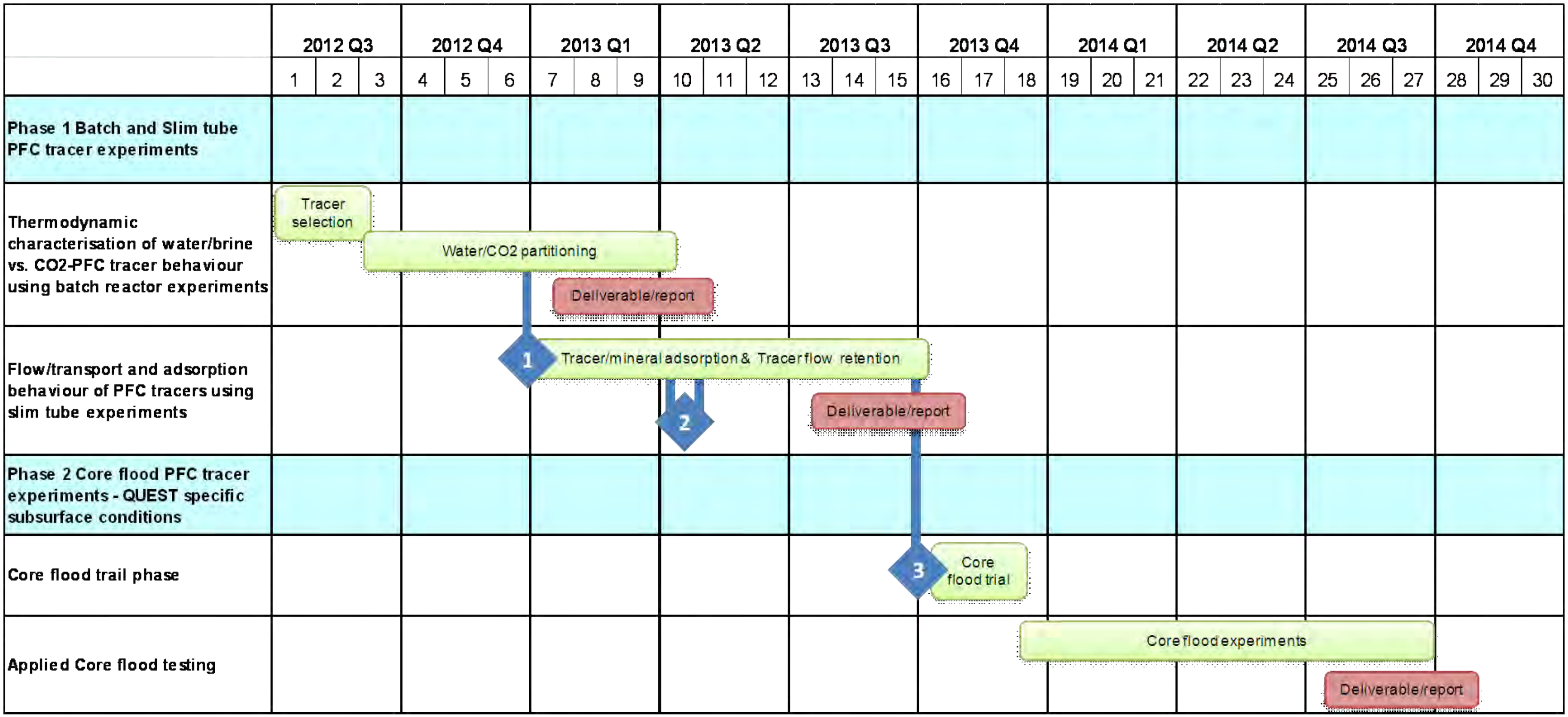
- PFC - perfluorocarbons
- Artificial tracer compound(s) added to injected CO_2
- **No baseline or characterisation required**
- **Feasibility study to evaluate use (PTI + CSIRO)**

Examples of sampling devices:

Cylinders for well sampling

CATS tube for environmental sampling

BIOSPHERE / HYD: Soil Gas - Artificial tracer – PFC Feasibility Study



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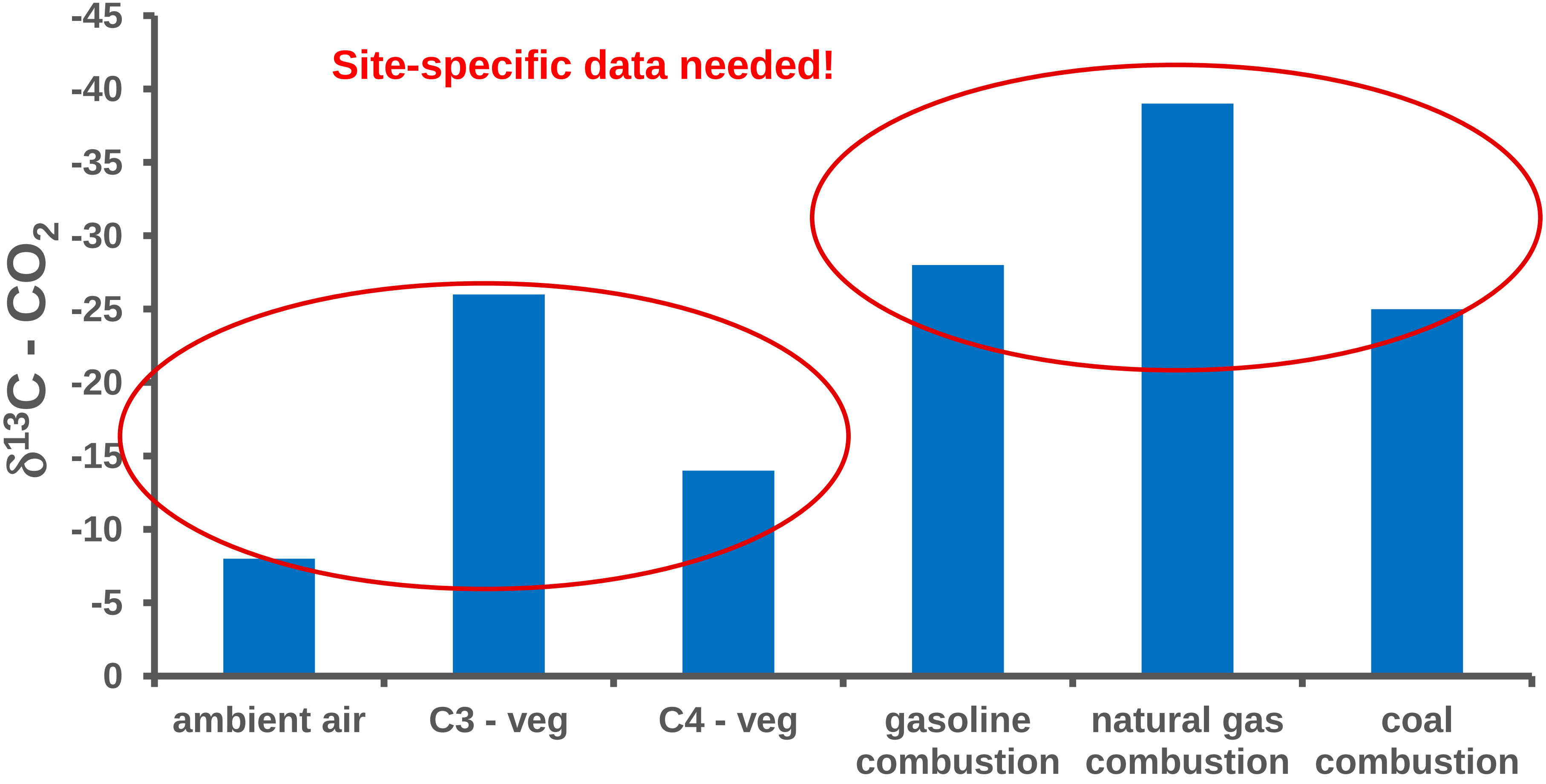
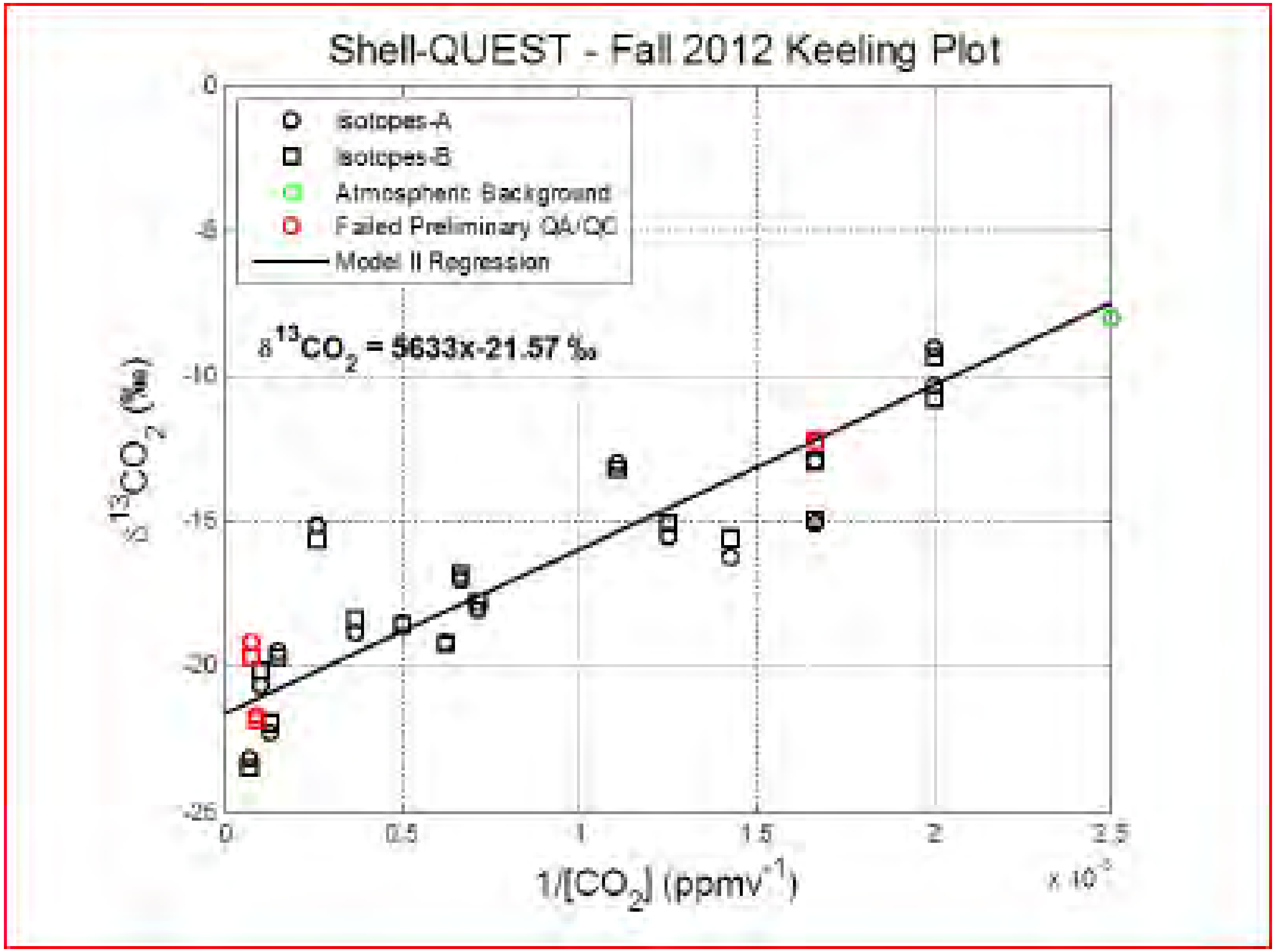
BIOSPHERE / HYD. : - Natural Tracer - $\delta^{13}C$

Isotopic Analysis - concept



data from literature: general & Widory and Javoy (2003)

BIOSPHERE / HYD. : QUEST 2012 Soil Gas Sampling Natural Tracer - $\delta^{13}C$

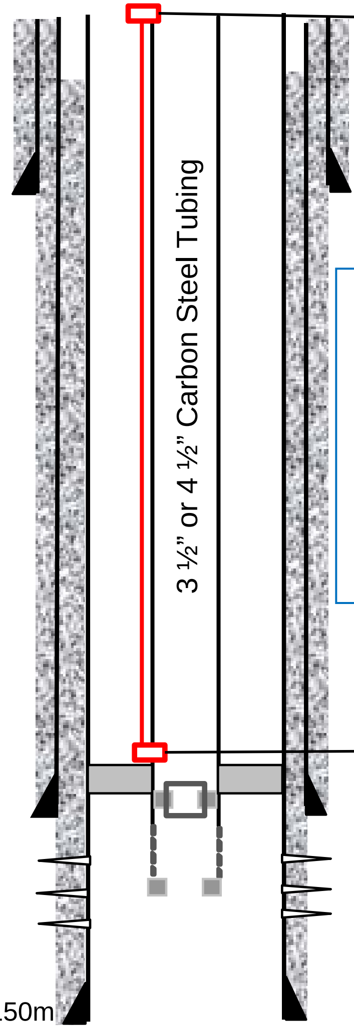


$\delta^{13}C$ data collected during the 2012 soil gas sampling campaign – Sept 2012

GEOSPHERE: In Well Monitoring

Down Hole Pressure Monitoring – Injection Zone

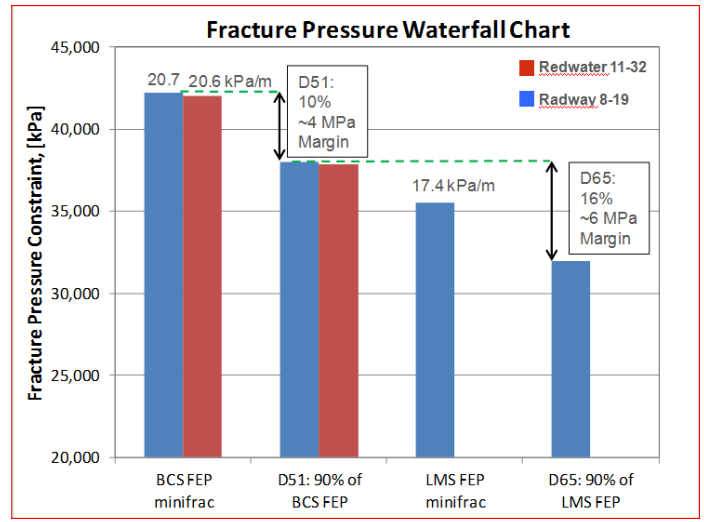
INJECTION WELL



Tubing Head Pressure (THP) → Scotford Control Room — **12 Mpa**

Objective

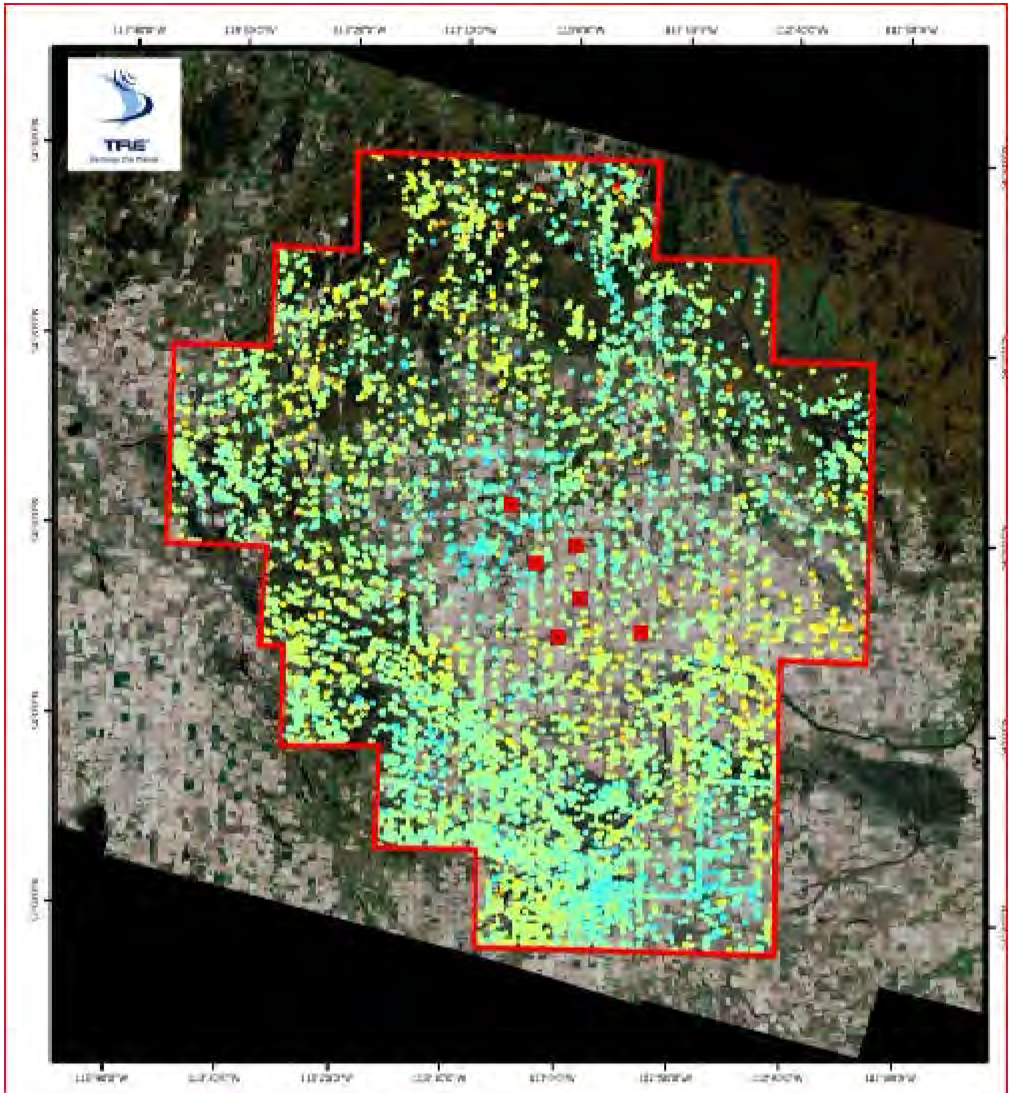
Prevent the BHP from exceeding the Formation Fracture Pressure



Bottom Hole Pressure (BHP) → Calgary Office — **28 Mpa**

Normal Operating pressure ➡ 22- 23 Mpa

GEOSPHERE - INSAR Feasibility Study



InSAR -Reflection Points across the QUEST lease area.

The results of the InSAR analysis over the Quest Project site on data acquired between June 2011 and December 2012 by the RADARSAT-2 (RSAT2) satellite **demonstrate that it is possible to monitor a large agricultural and vegetated landscape with advanced InSAR Techniques**

An average density of 10.64 reflector points per square kilometre was obtained from the SqueeSAR processing and in the vicinity of the injectors varies between 6.98 and 12.03 points per square kilometre **which supports the feasibility of using INSAR without the need for corner reflectors**

Ground displacement over the site is mainly limited to a few millimetres and is within a range that can be linked to seasonal fluctuations.

The precision of the ground deformation measurements is currently close to 2 millimetres per year and based on the characteristics of the SAR imagery acquired to date . TRE estimates that millimetric precision will be attained after 32 months of image acquisitions.

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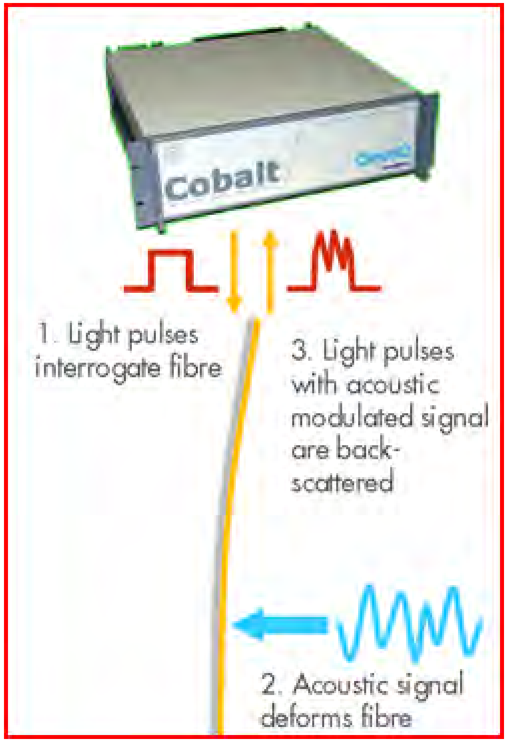
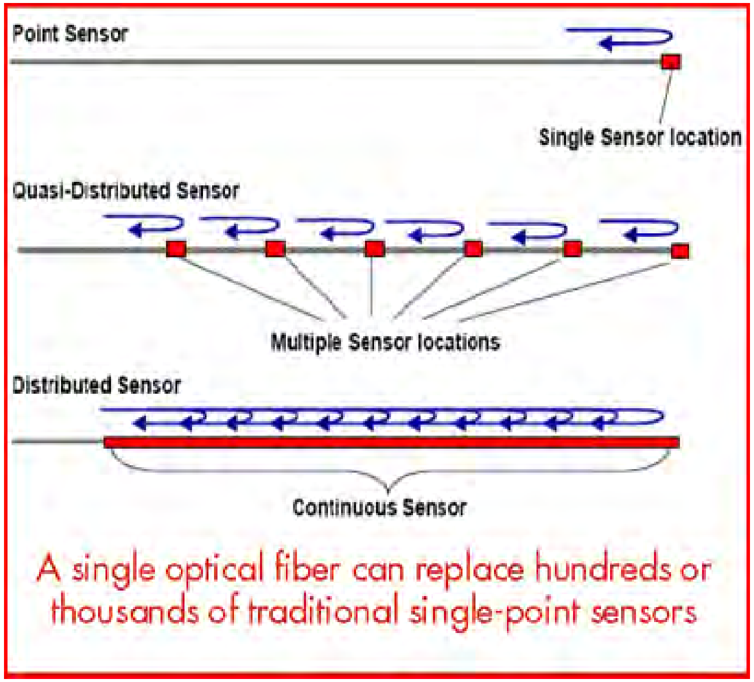
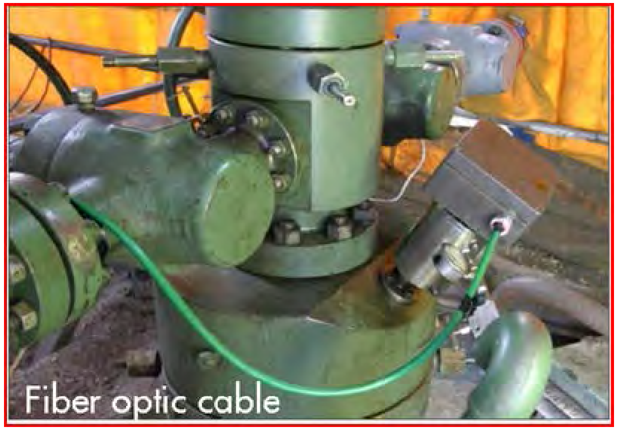
GEOSPHERE: In Well Monitoring
Fibre Optics (DTS & DAS)







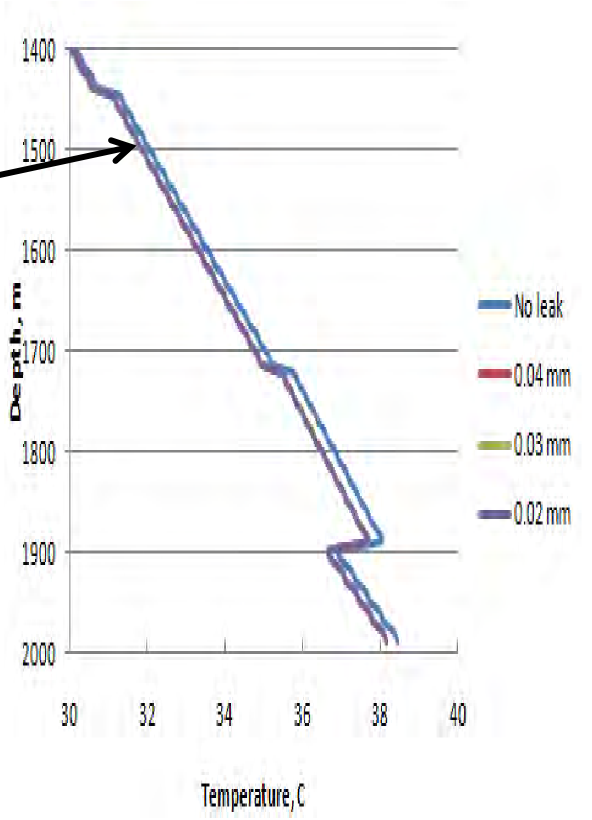
DTS - Distributed Temperature System

DAS - Distributed Acoustic System

GEOSPHERE: In Well Monitoring
Distributed Temperature Sensing (DTS)

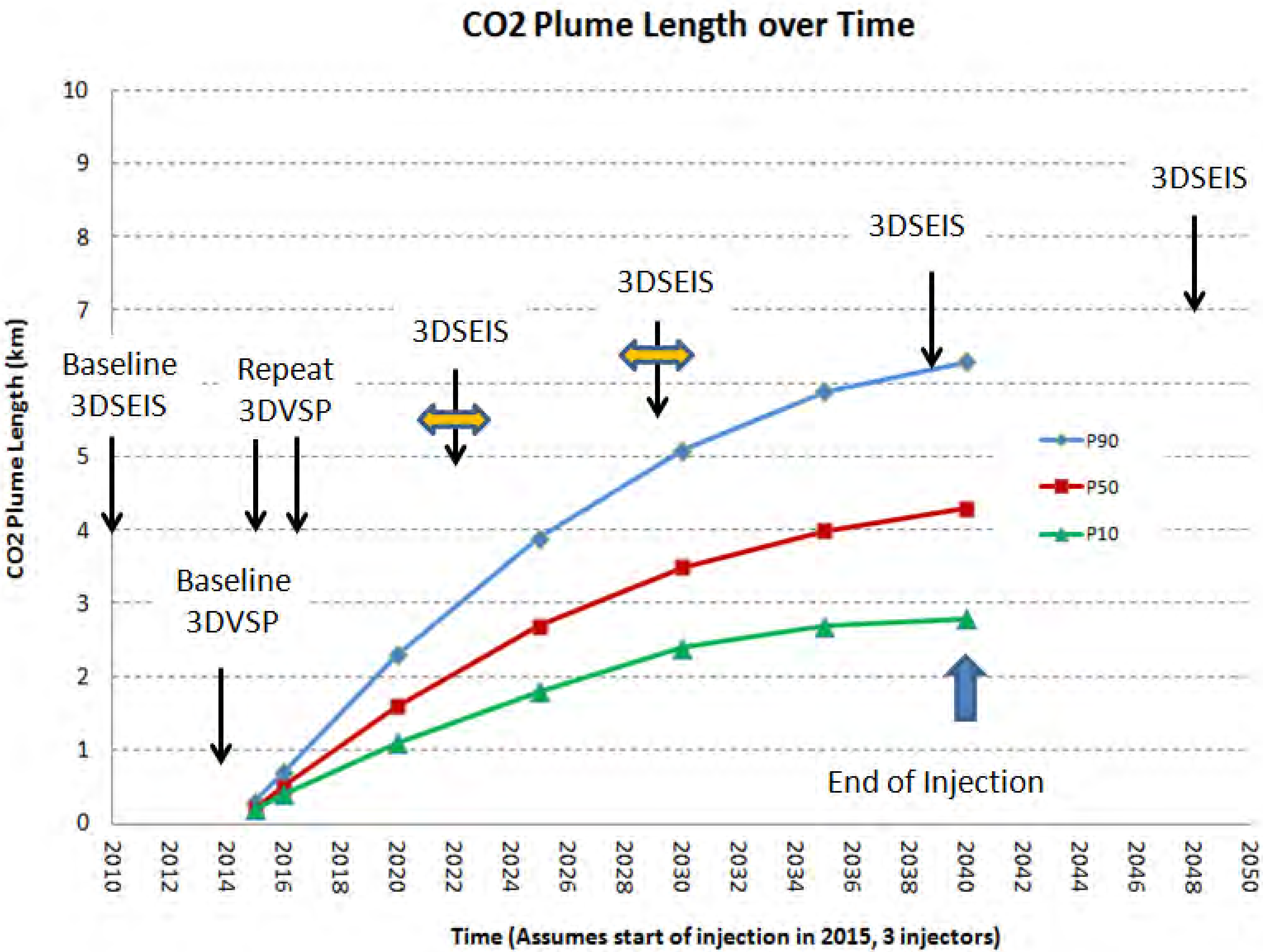
Continuous Detection - With well flowing

Example :
Modelled temperature anomaly after 10 hours of leakage outside casing for an assumed leak path (0.02 – 0.04 mm) and all the way to surface



More difficult detection process due to shifts in the baseline measurement – developing software to automate this detection process.

GEOSPHERE: In Well Monitoring VSPs using DAS



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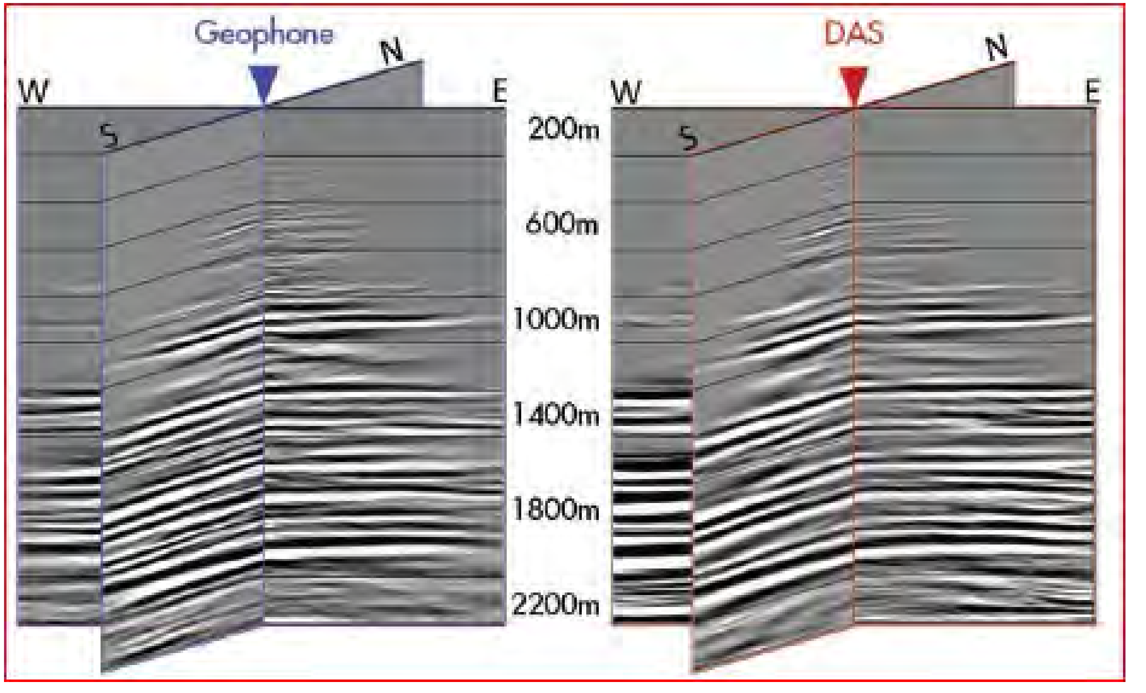
GEOSPHERE: In Well Monitoring
DAS Test Results

- The signal to noise ratio is lower for the DAS data versus the geophone data.
- The frequency spectra for geophone and DAS are comparable, but the geophone data have slightly higher frequency content.



DAS can replace Geophones for time lapse VSP monitoring

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BACK UP

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MMV Baselining- Status

- **Ground water sampling**
  - First campaign was completed by Golder in Oct /Nov. 2012
  - Report of 2012 activities was submitted by Golder in January 2013
  - Analysis Results available in March 2013
- **Remote Sensing /Soil Gas**
  - First Remote Sensing calibration campaign completed in Sept / Oct 2012 using 10 calibration plots
  - Soil Gas Measurements carried out on the same plots
- **Project GW Monitoring Wells**
  - Drilled the 4 additional Project ground water monitoring wells at the 5-35 and 7-11 locations.
  - 5 Ground Water wells existing at the 8-19 location
  - Continuous Measurements to start in March 2013

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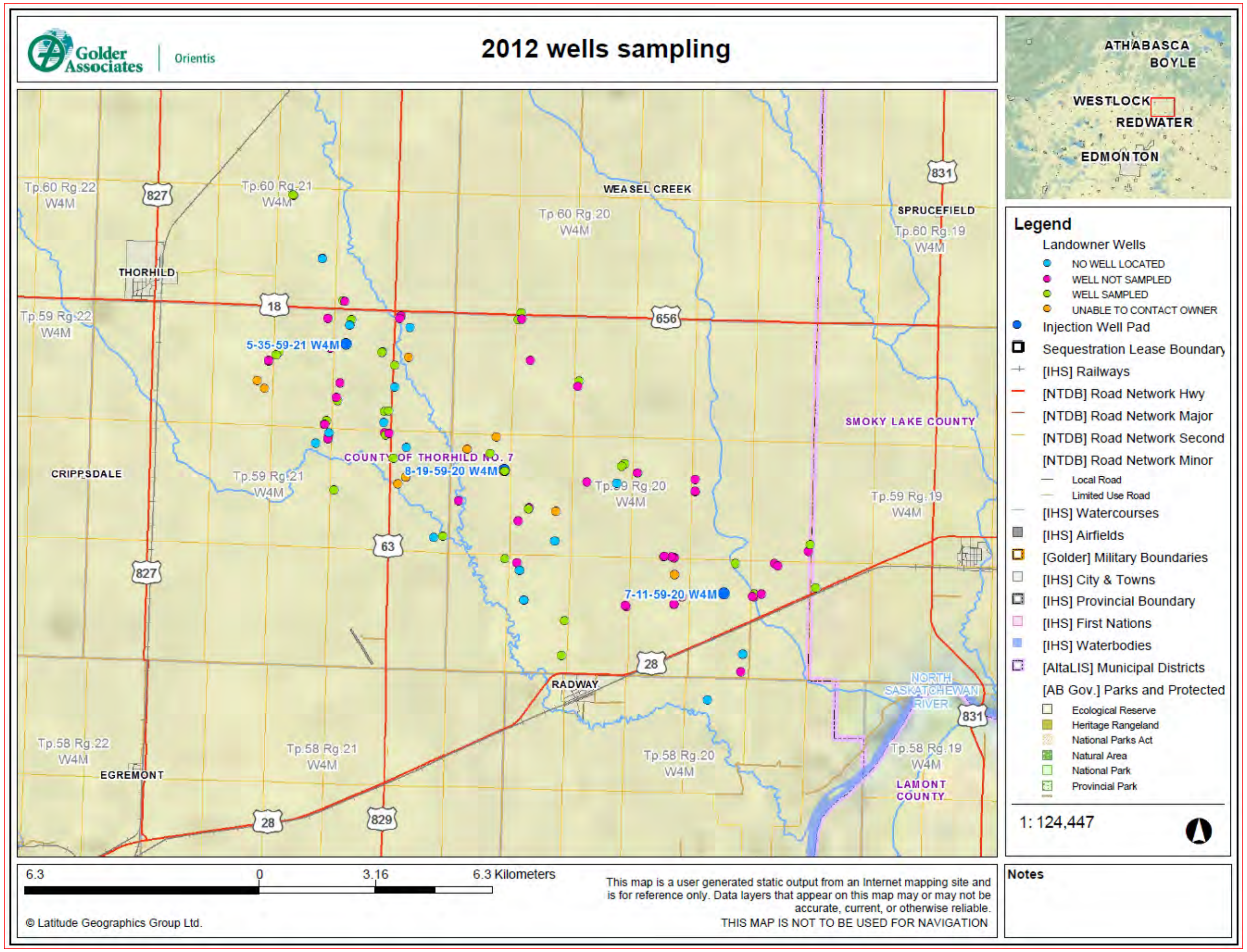
HYDROSPHERE: 2) Landowner & Project GW Well Sampling (2012 /2013 Sampling)

- **Q4 2012 campaign:**
  - 198 landowner wells identified,
  - ~ 130 permission to visit/sample
  - Sampled 53 wells
  - Results available – individual landowner will receive report
  - Issues identified:
    - GW wells access/condition – planned spatial coverage
    - Collection of well headspace gas samples
- **2013 campaign:**
  - Quarterly sampling frequency
  - Modified sampling method for well headspace gas
  - First QTR campaign underway. (complete missing wells around injection wells.



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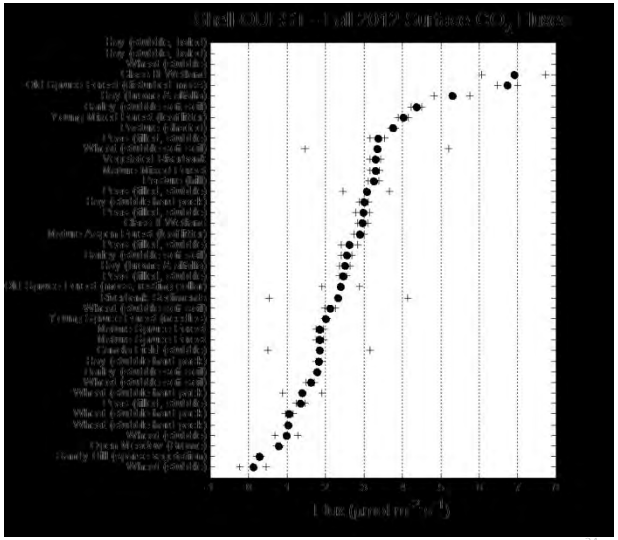
Soil gas / flux - Sampling update

- **Q4 2012 campaign**
  - 10 transient plots & 2 injection well pads visited
  - Soil gas depths:
    - @ injection well pads: 100, 150, and 200 cm
    - @ transient plots: 150 cm
  - Soil flux taken at 3 or > sites per @ plots and injection pads
  - Final results available mid-March 2013
  - issues identified : probe installation @ 200 cm
- **2013 campaigns**
  - 3 to 4 sampling events
  - modified sampling depth for soil gas:

(50, 100, 150 cm)

Plot ranking Fall 2012 CO2 fluxes from highest to lowest



MMV Feasibility Studies – Status

LightSource （RGFM）

- Work continues on developing the processing algorithms based on data acquired in 2011 at the 8-19 location.
- Collaborating with University Of Victoria on atmospheric CO_2 flux （eddy covariance） data from 8-19 location

Tracer Feasibility Studies

- The report entitled "PFC Tracers – Suitability for MMV Techniques" was received in Jan 2013
- Commonwealth Scientific and Industrial Research Organisation （CSIRO） commenced work on batch experiments to test partitioning behaviour.
- Next step – Slim Tube experiments to test Adsorpsion
- Contract awarded to the University Of Calgary to Study CO_2 Isotopic Fractionation

INSAR

- MDA continuing to acquire data
- TRE carried out their proprietary SqueeSAR processing and completed a feasibility report in Jan 2013.
  - Report supports the feasibility using InSAR for surface deformation monitoring without the need for manufactured reflectors （"corner reflectors"）

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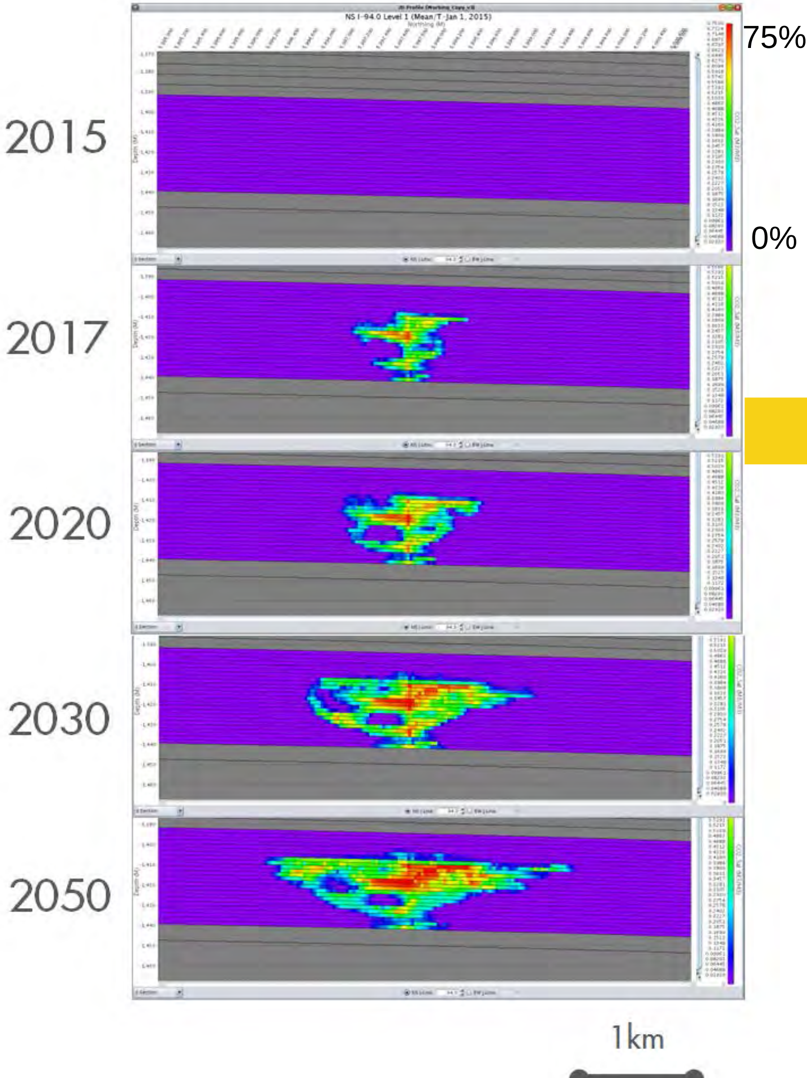
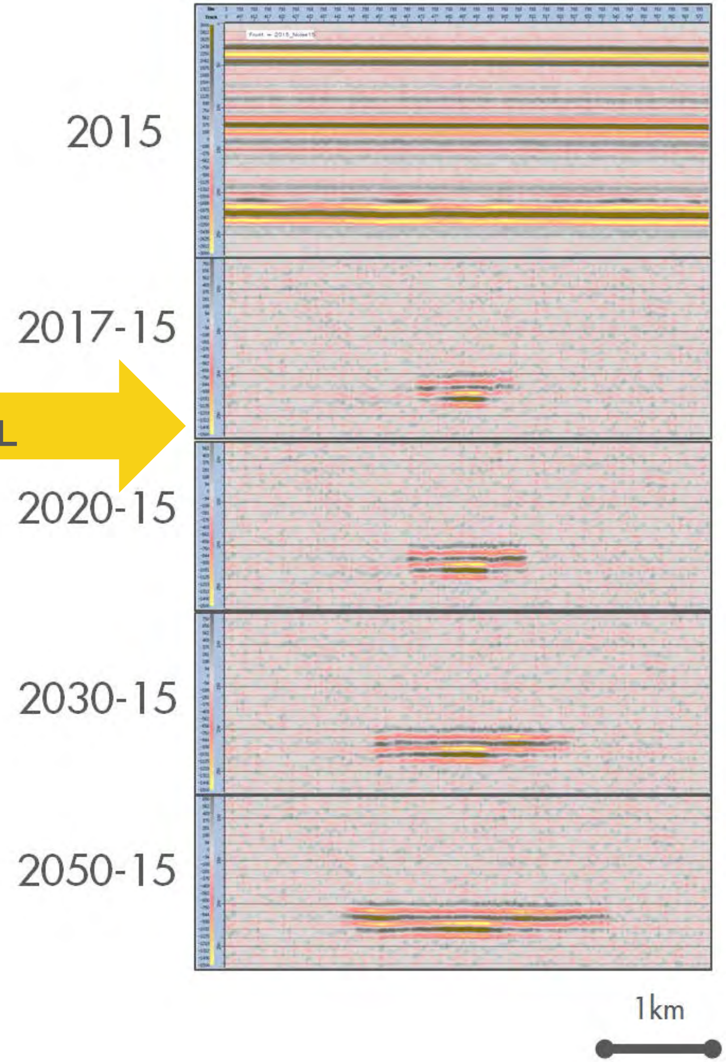
GEOSPHERE: 3D Time-Lapse Seismic
Feasibility



CO2 Saturation through time

MODEL

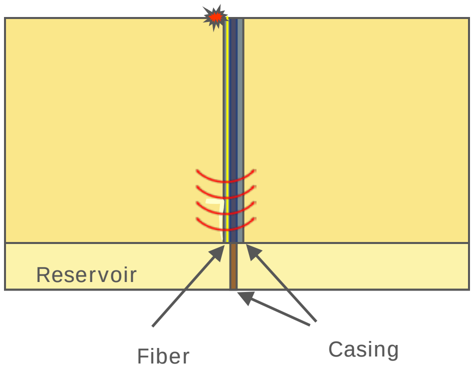


Time-lapse seismic signature through time

GEOSPHERE: In Well Monitoring
Vertical Seismic Profile

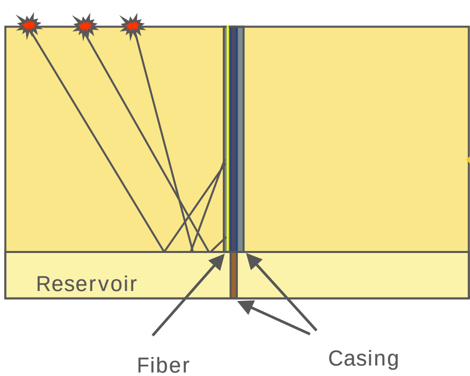
Zero-Offset Source for CO2 Leak Detection

Velocity change in overlying formations

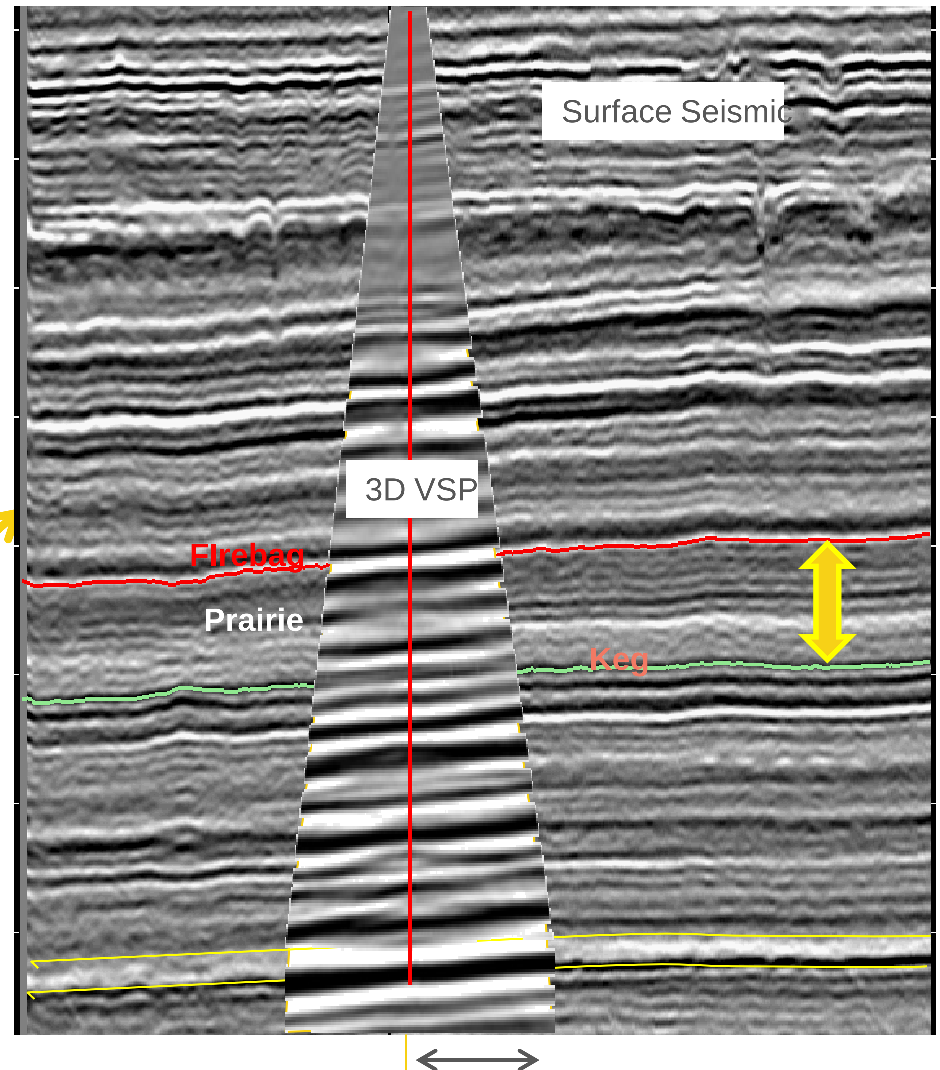


Offset Sources for Plume (conformance) Monitoring and

CO2 Leak Detection



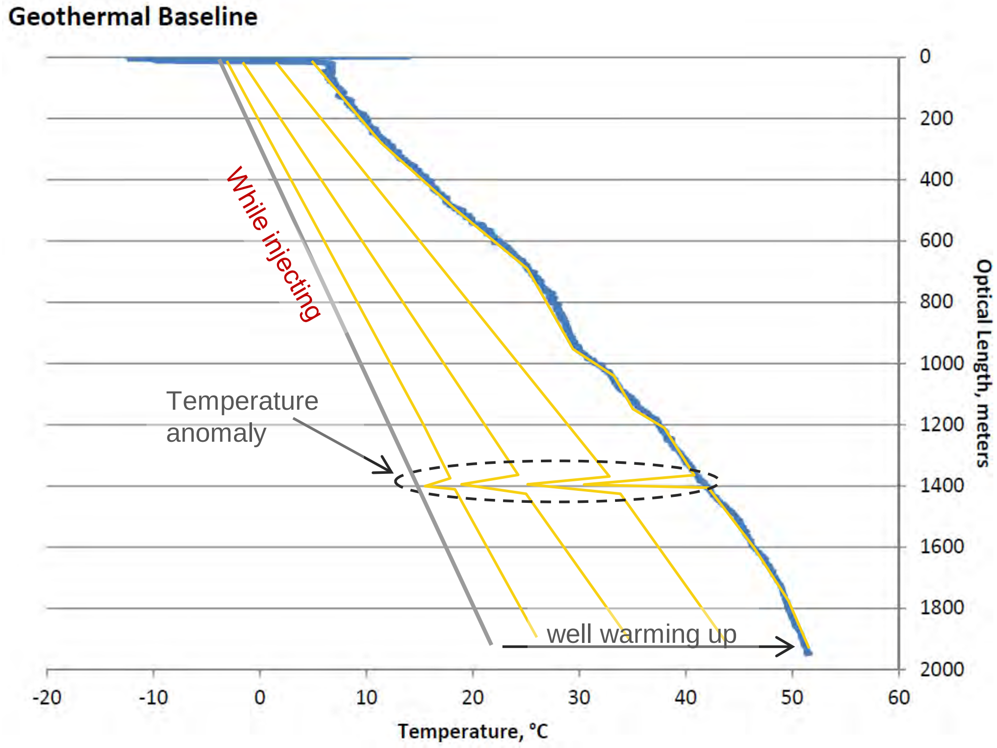
Time Lapse 3D Vertical Seismic Profile (3D - VSP)



GEOSPHERE: In Well Monitoring
Distributed Temperature Sensing (DTS)

Objective
Determine CO2 leaks outside casing via a poor or compromised cement bond

1) **On Demand Application - With well shut in**



Since the injected CO2 is significantly colder than the formation, if the hydraulic isolation has been compromised, a DTS measurement while shut-in will detect a temperature anomaly in the receiving formation,

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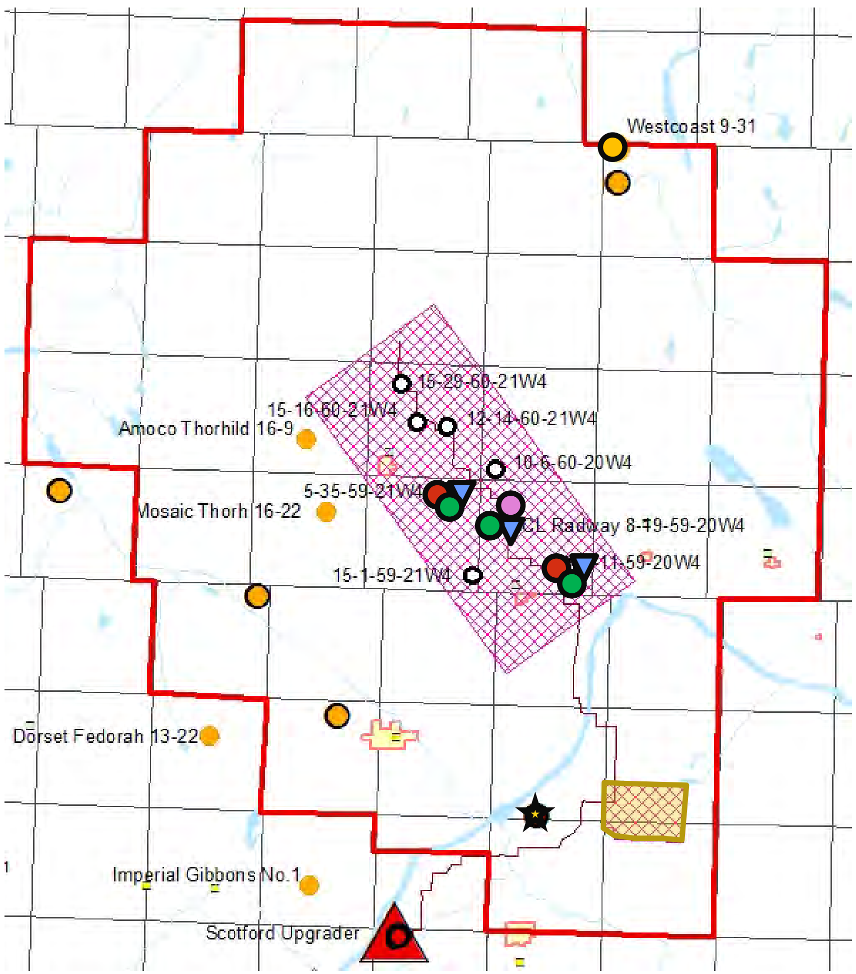
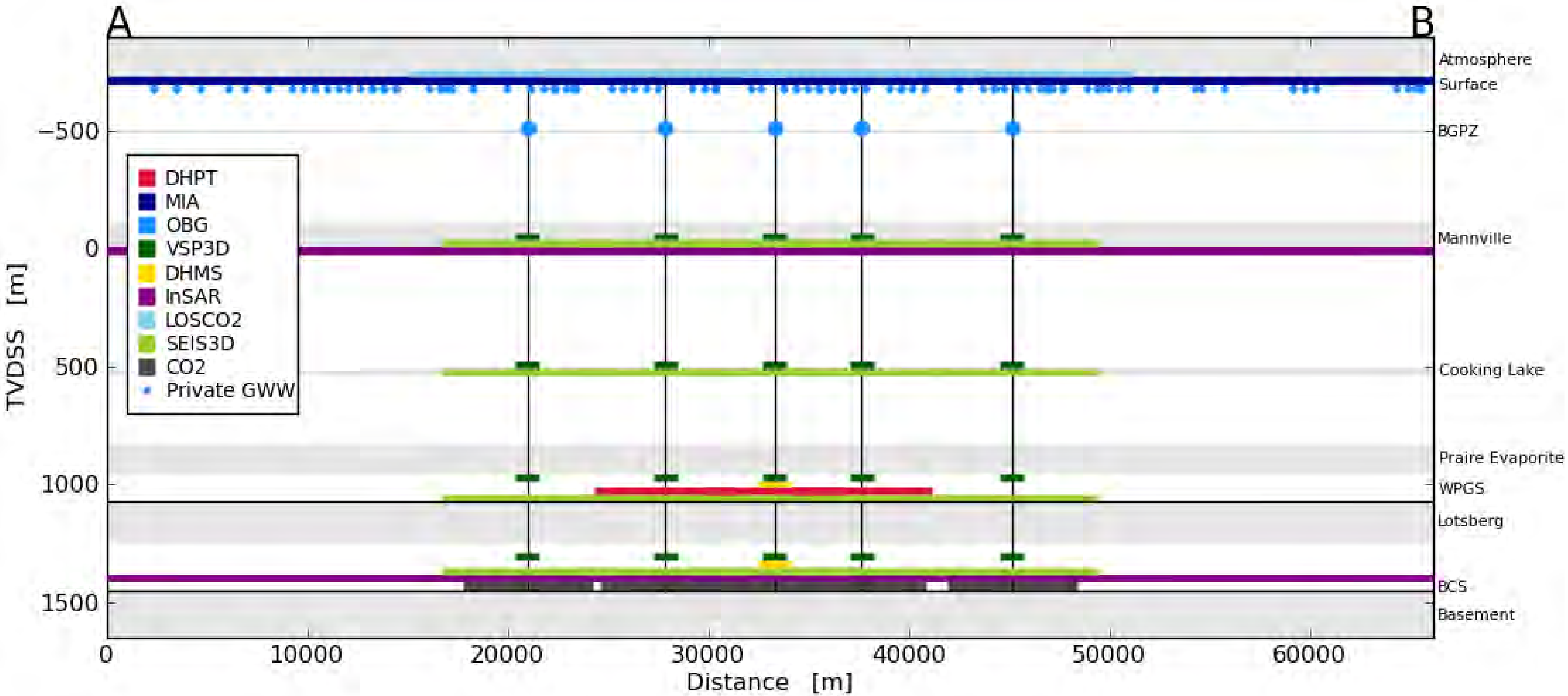
MMV - Monitoring Well Locations

(3 Inj. Well Case)



- Legacy wells penetrating BCS
- Injection wells (3 well case)
- Injection wells (>3 well case)
- GW monitoring wells
- Deep monitoring wells (DHPT)
- Deep monitoring well (DHPT, DHMS)
- BCS monitoring well (DHPT)
- Time-lapse seismic baseline
- Sequestration Lease Area

MMV Plan –Spatial Coverage



Legend

DHPT: Down-hole pressure temperature
MIA: Multi-spectral image analysis
OBG: Groundwater observation well
VSP3D: Time-lapse 3D vertical seismic profiles
DHMS: Down-hole microseismic monitoring
InSAR: Interferometric Synthetic Aperture Radar
LOSCO2: Optical path remote gas flux mapping
SEIS3D: Time-lapse 3D surface seismic
CO2: Maximum expected CO_2 plume
Private GWW: Landowner groundwater wells

MMV - Risk Based Approach