FLUID SUBSTITUTION AND SEISMIC MODELLING IN A SANDSTONE AQUIFER

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Outline

- Objectives
- Area of Study and Stratigraphy
- Fluid Substitution
- Data and Methodology
- Results and Conclusions

Objectives

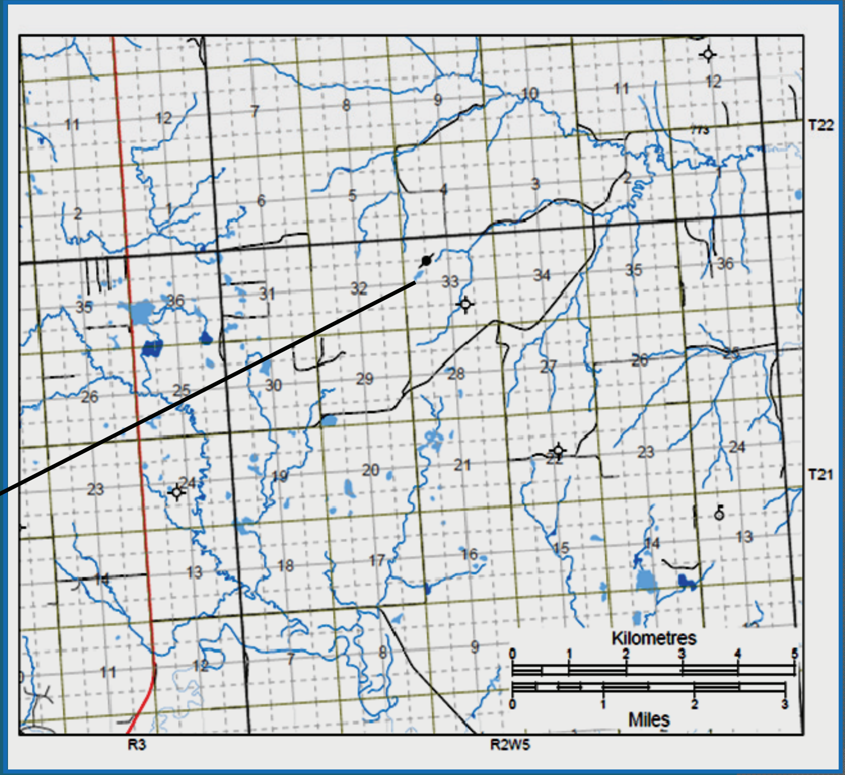
- To evaluate the Paskapoo Formation as a potential CO_2 geological storage site.

- To apply fluid substitution and seismic modelling in order to identify and analyze the effects of CO_2 on rock properties and seismic patterns.

Area of Study

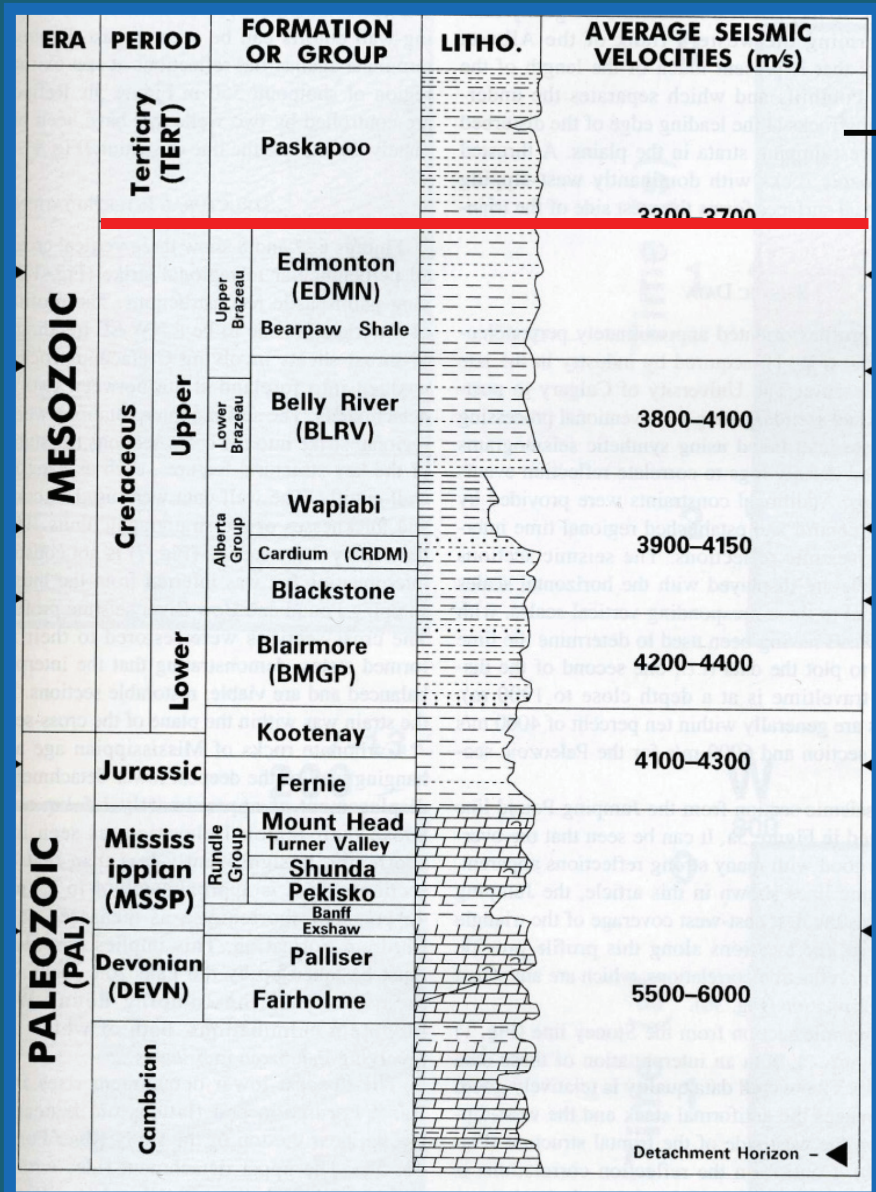
Rocky Mountains Foothills, 20 kilometres Southwest of Calgary

(Bachu et al., 2000)



Wellbore Data: MILLAR 12-33-21-2W5

Stratigraphy



Lawton et al., 1996

Paskapoo Fm:

- Composed of mudstone, siltstone and sandstone, with subordinate limestone and coal.
Foreland Deposits
- Important ground water reservoir target
- High porosity coarse-grained sandstone channels

Fluid Substitution

Gassmann equation

K= Bulk Modulus $K = \frac{\delta\varepsilon}{\delta\sigma}$ → Stress increment → Volume strain

K_{sat}= Saturated Rock Bulk Modulus →

$$K_{sat} = K* \frac{\left(1 - \frac{K*}{K_o}\right)^2}{\frac{\varphi}{K_{fl}} + \frac{1-\varphi}{K_o} - \frac{K*}{K_o^2}}$$

Matrix Properties

- K_0= Matrix Bulk Modulus
- ρ_0= Matrix Density

Fluid Properties

- K_{fl}= Fluid Bulk Modulus
- ρ_{fl}= Fluid Density

Rock Properties

- K_{100sat}= Rock Bulk Modulus 100% water sat
- K*= Dry Rock Bulk Modulus
- G= Shear Modulus
- ρ_b= Bulk Density
- ϕ= Porosity

$$\varphi = \frac{\rho_0 - \rho_b}{\rho_0 - \rho_{fl}}.$$

Fluid Substitution

Gassmann equation

Constantes during substitution:
φ, G, ρ_0, K_0, K*

Variables during substitution:
K_{fl}, ρ_{fl}, ρ_b,

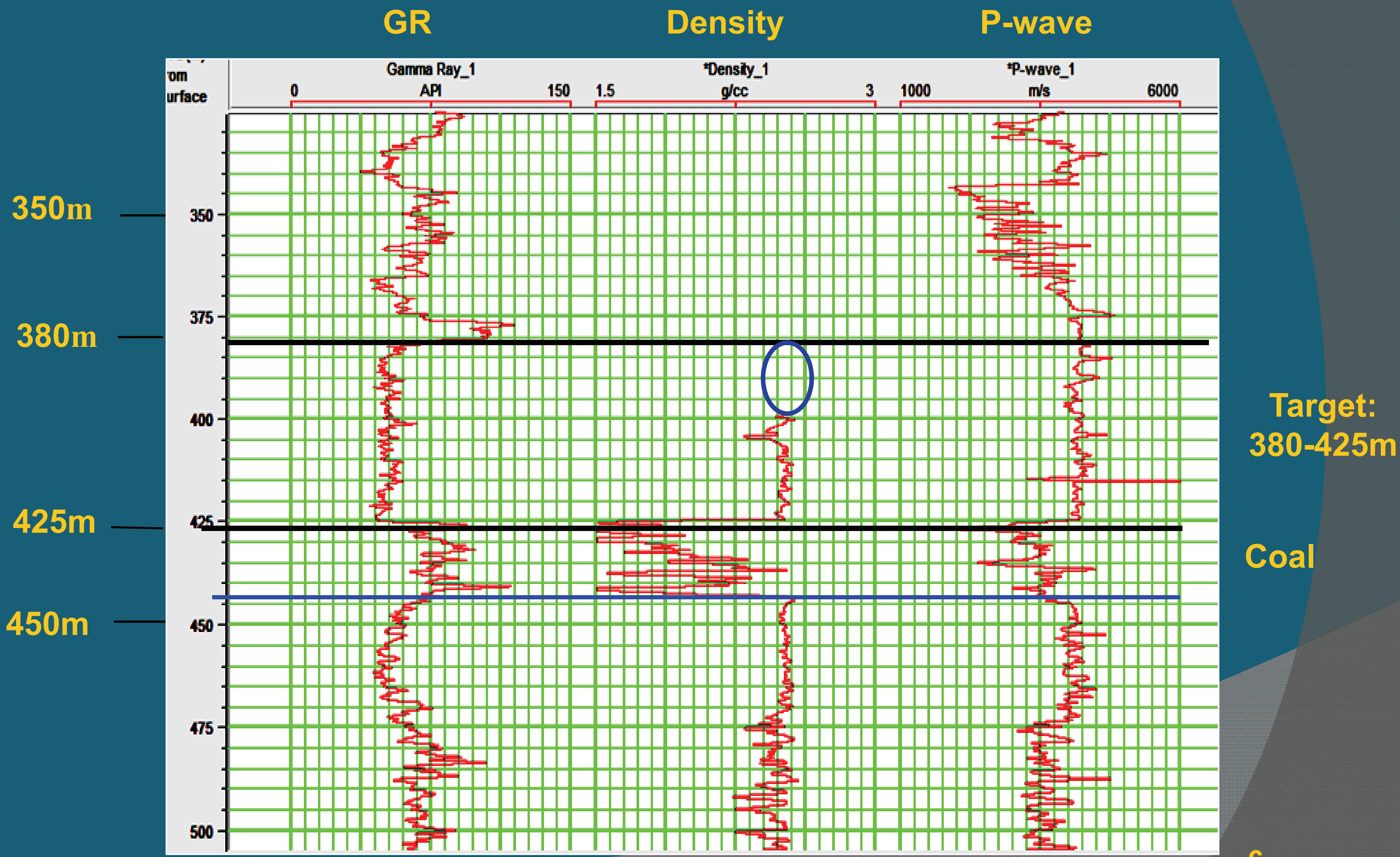
$$K_{sat} = K* \frac{(1-\frac{K*}{K_o})^2}{\frac{\varphi}{K_{fl}} + \frac{1-\varphi}{K_o} - \frac{K*}{K_o{}^2}}$$

$$Vp = \sqrt{\frac{Ksat + \frac{4G}{3}}{\rho b}}$$

$$V_s = \sqrt{\frac{G}{\rho_b}}$$

Data

Wellbore data: MILLAR 12-33-21-2W5



Methodology

Fluid substitution using Gassmann's equation and synthetic seismogram generation.

Seismic Modelling :

- 2D geological model
- Ray-tracing and synthetic seismogram generation
- Processing of the seismic sections
- Comparison between different seismic sections
- Recognition of differences in seismic pattern and AVO analysis

Results

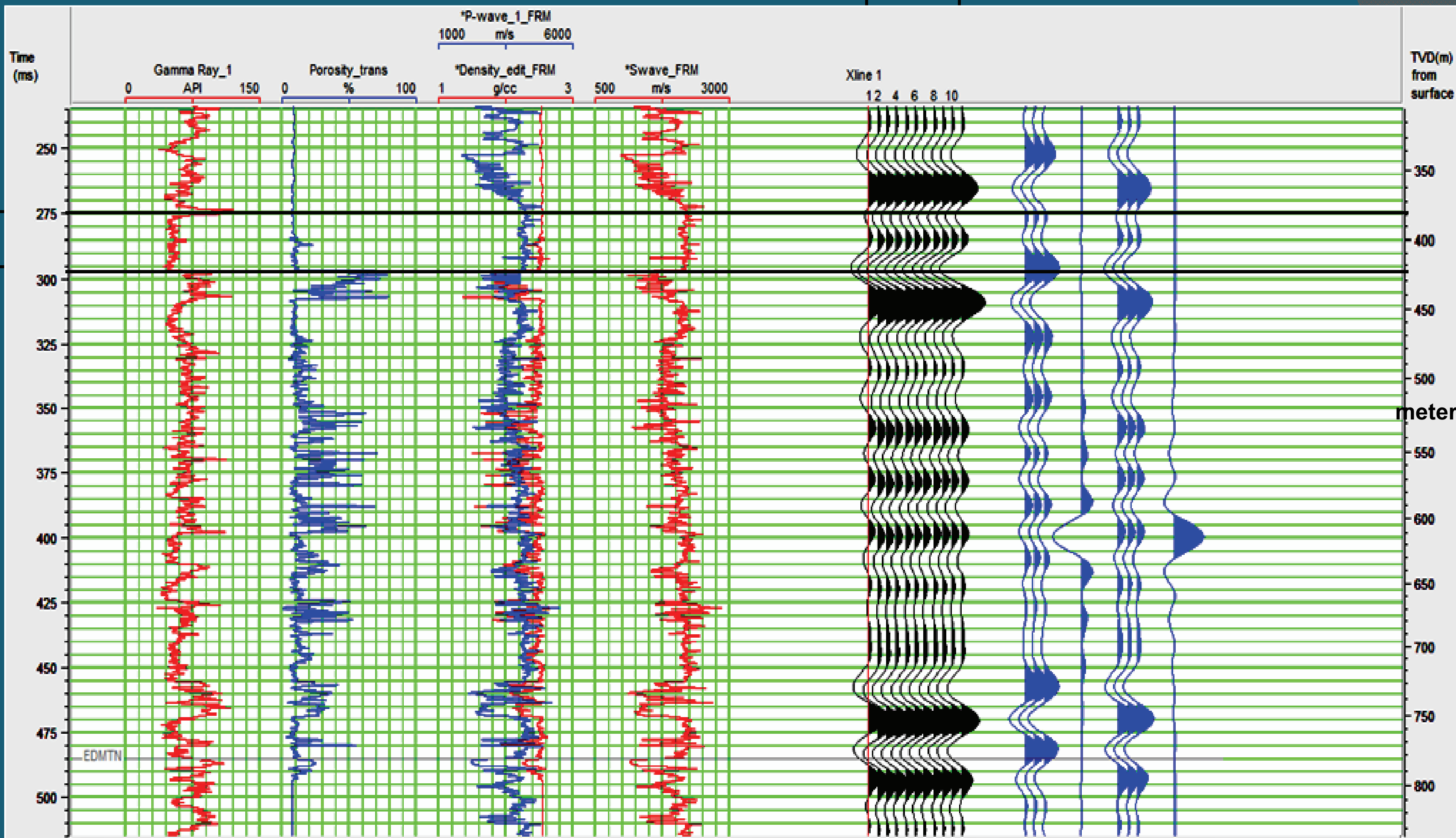
Logs and synthetic traces

Vp (m/s)

GR (API) Φ (%) ρ(gr/cc) Vs (m/s) 0% 100%

380(m)

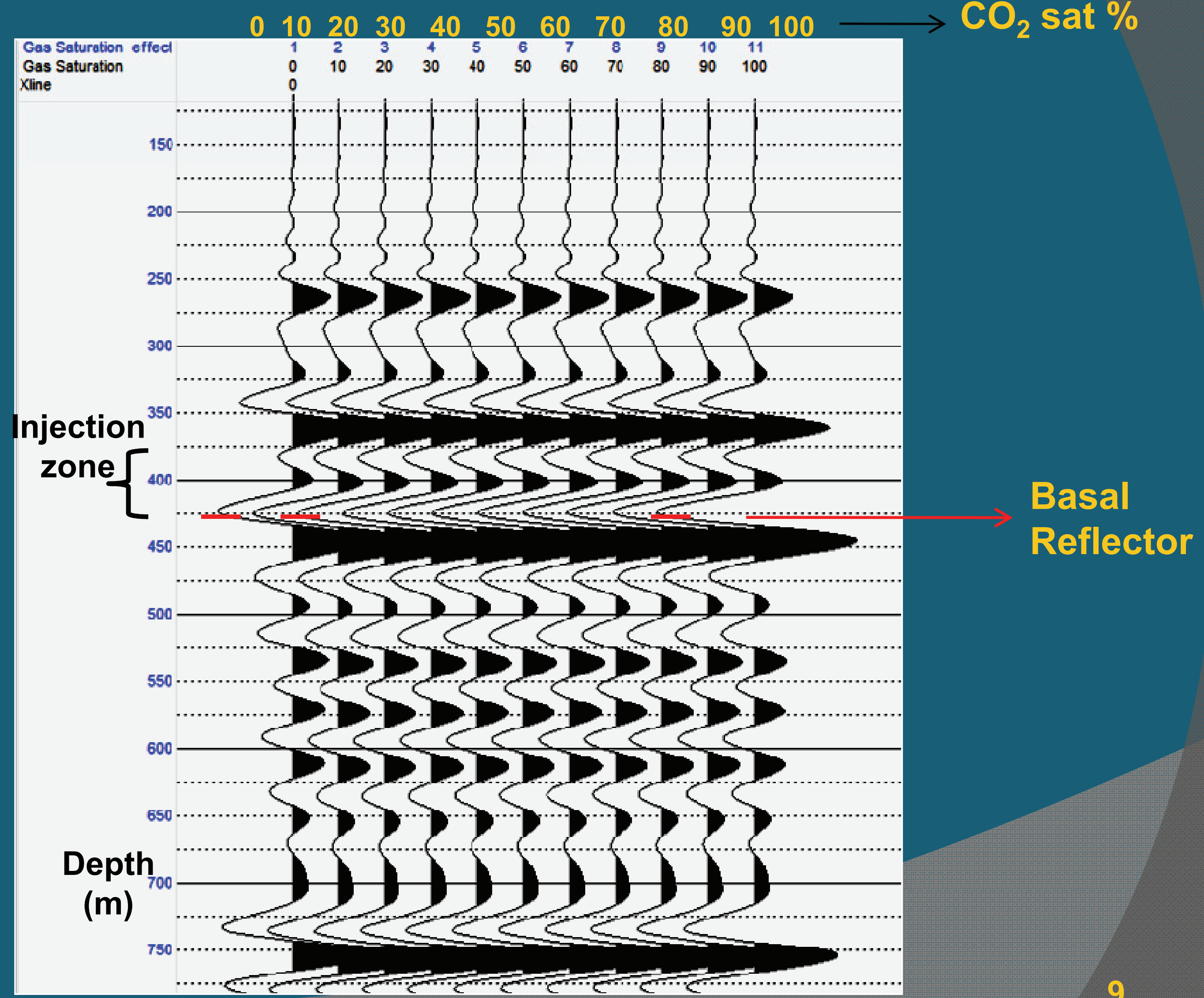
425(m)



meters

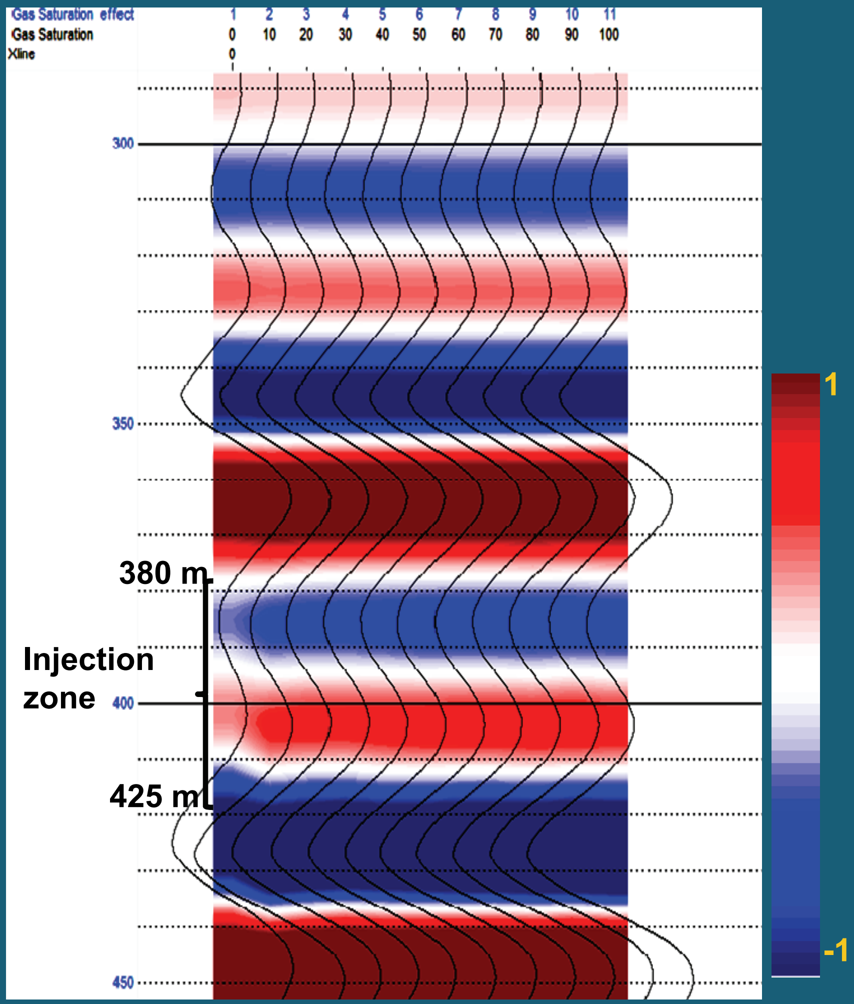
Results

Synthetic Traces. CO_2 Saturation

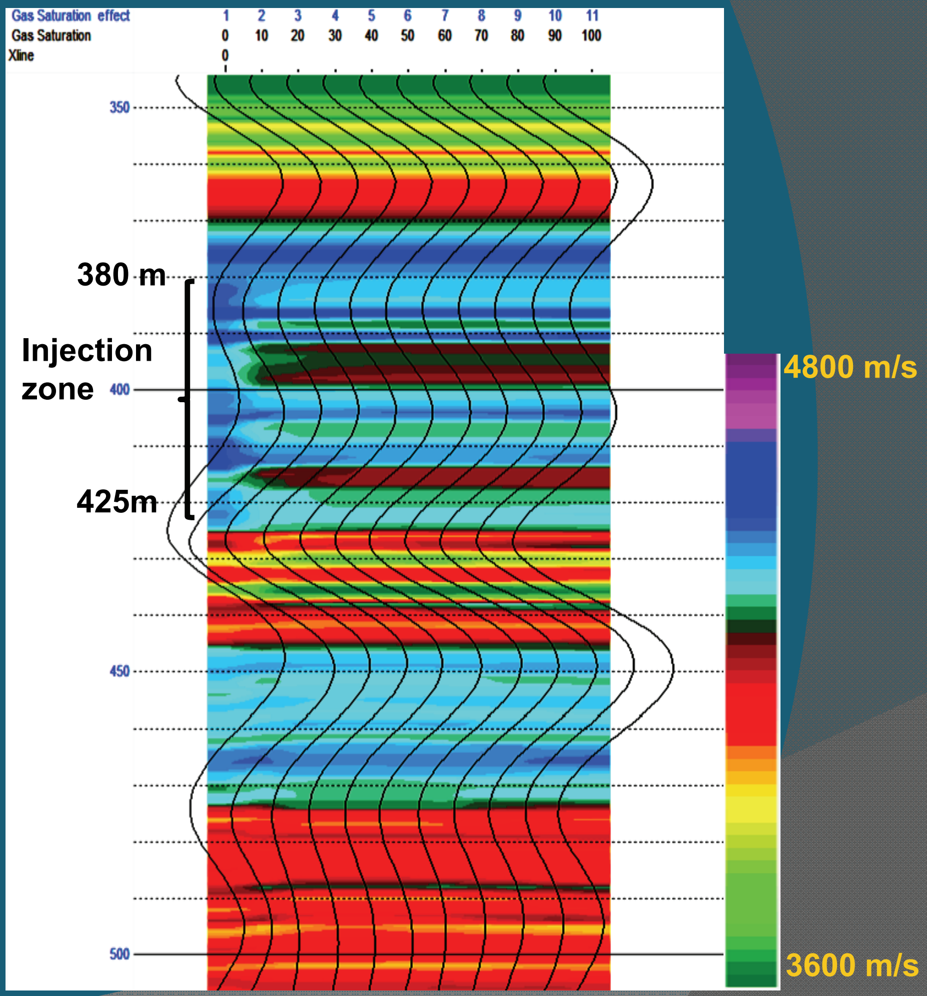


Results

Amplitude variations

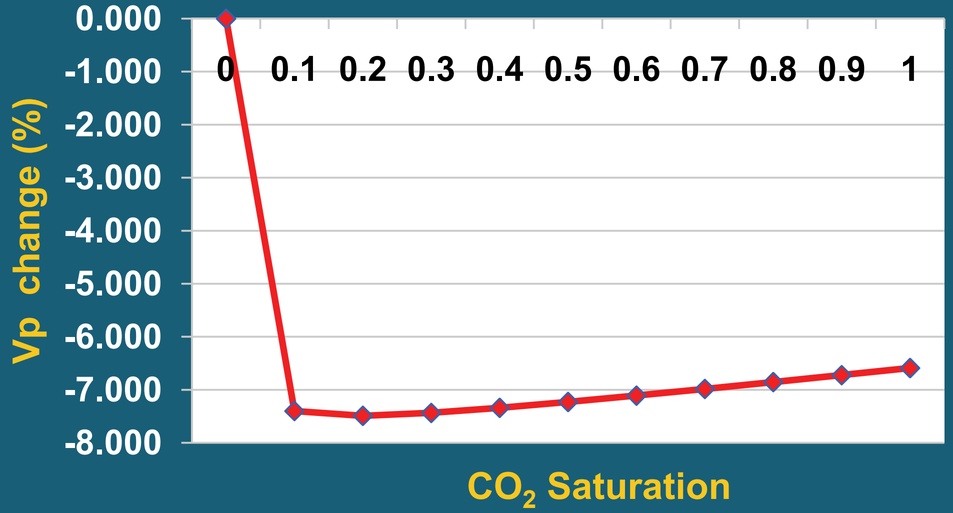


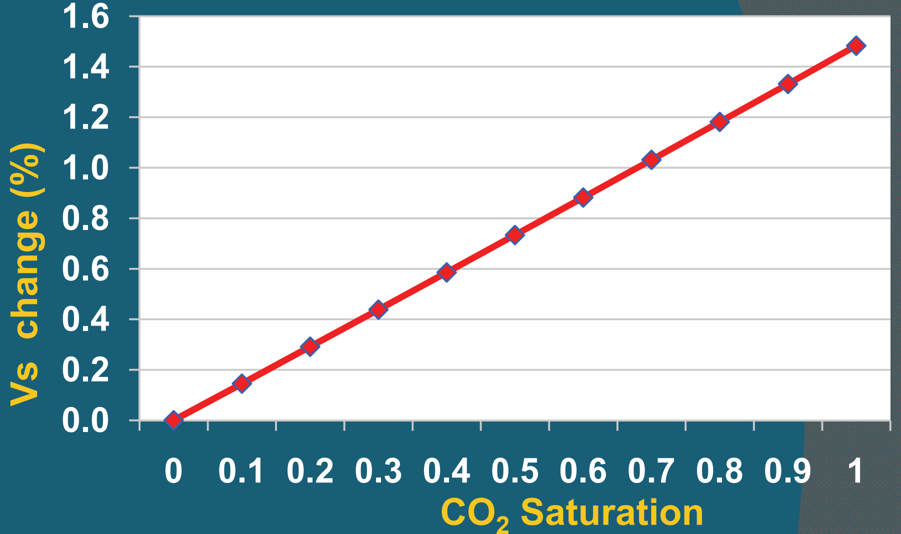
Velocity variations

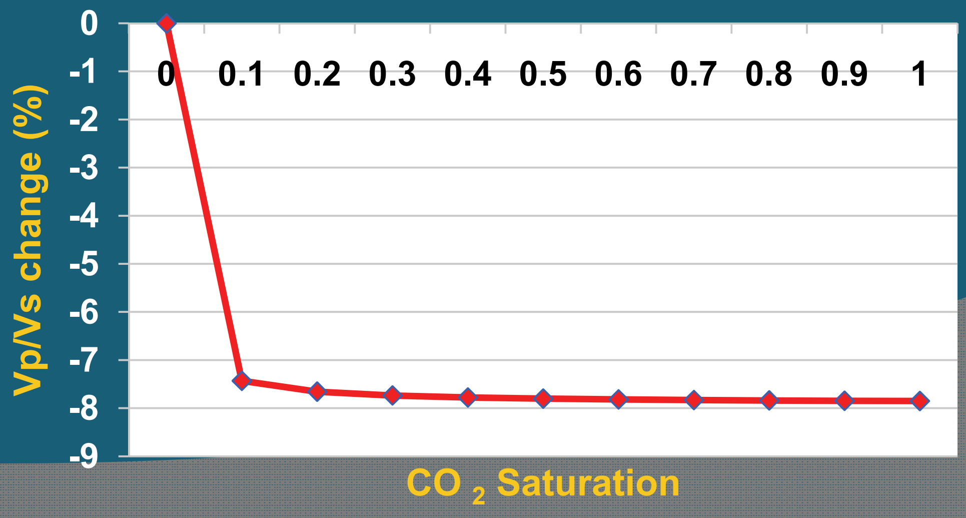


Results

V_P and V_S changes



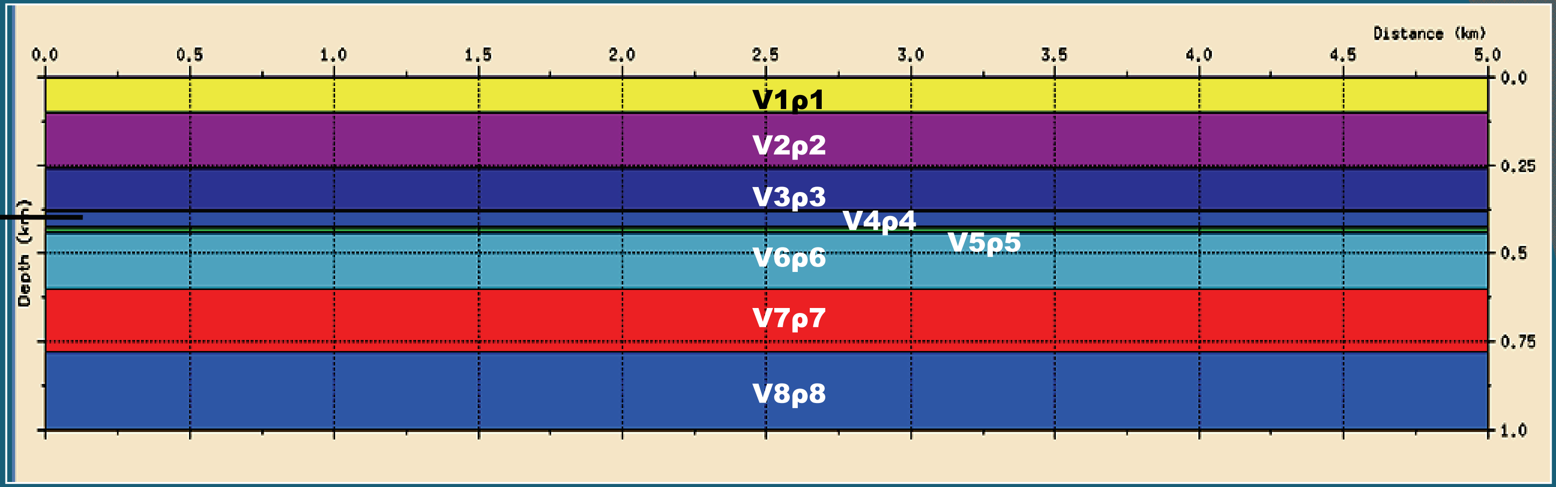




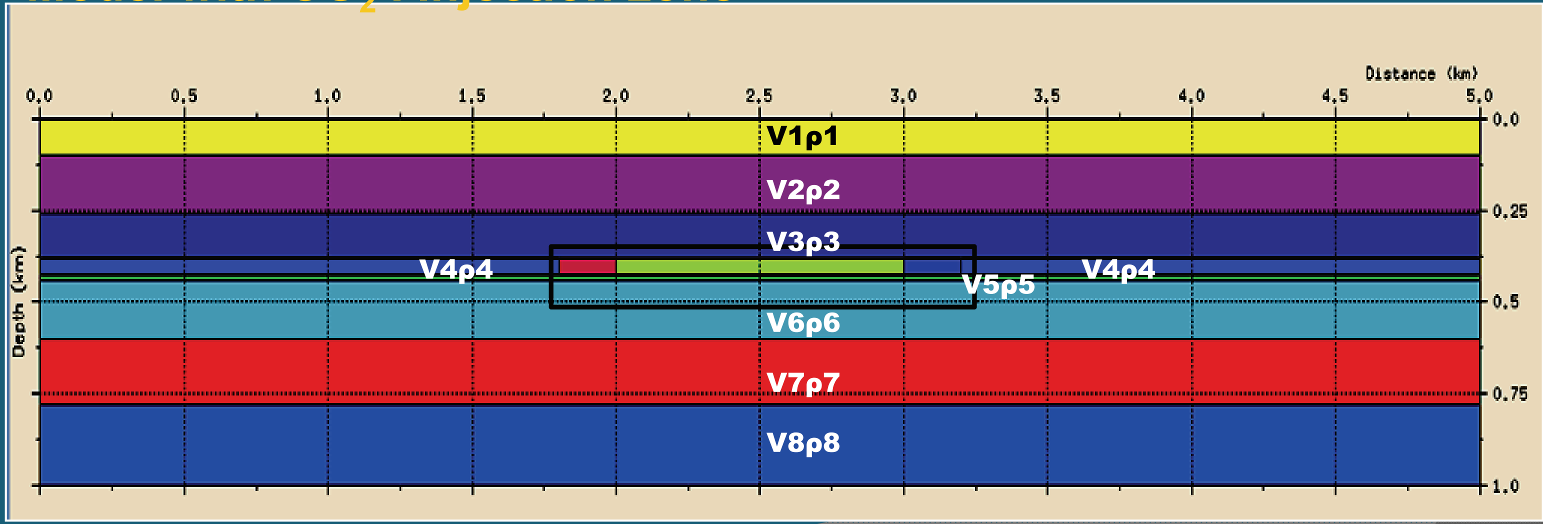
Geological model

Initial model

Target



Model with CO_2 . Injection zone



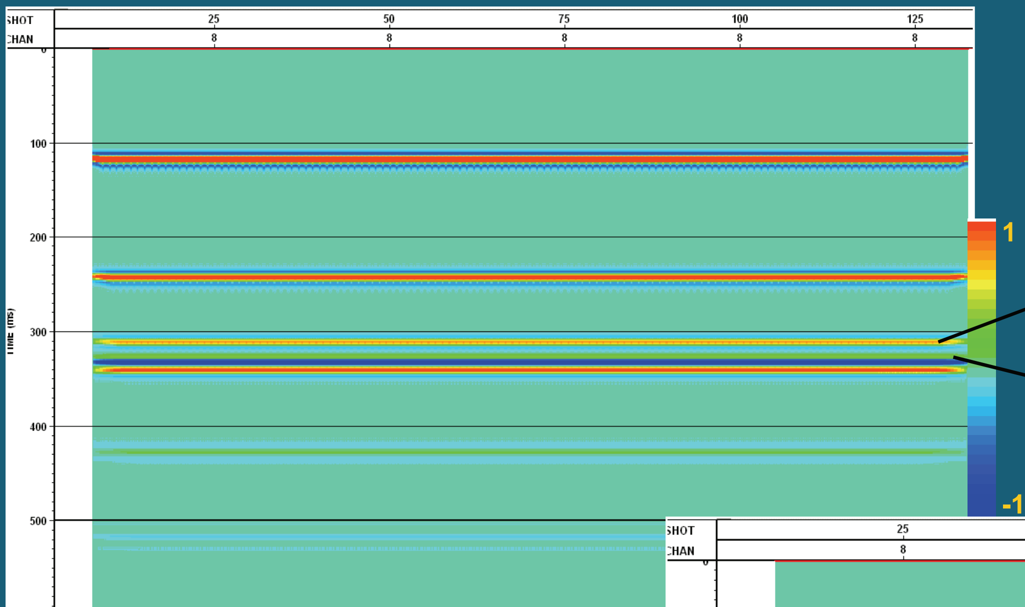
Results

Seismic modelling

SHOT

Time (ms)

300



CDP stack:
Initial model

Top reflector

Basal reflector

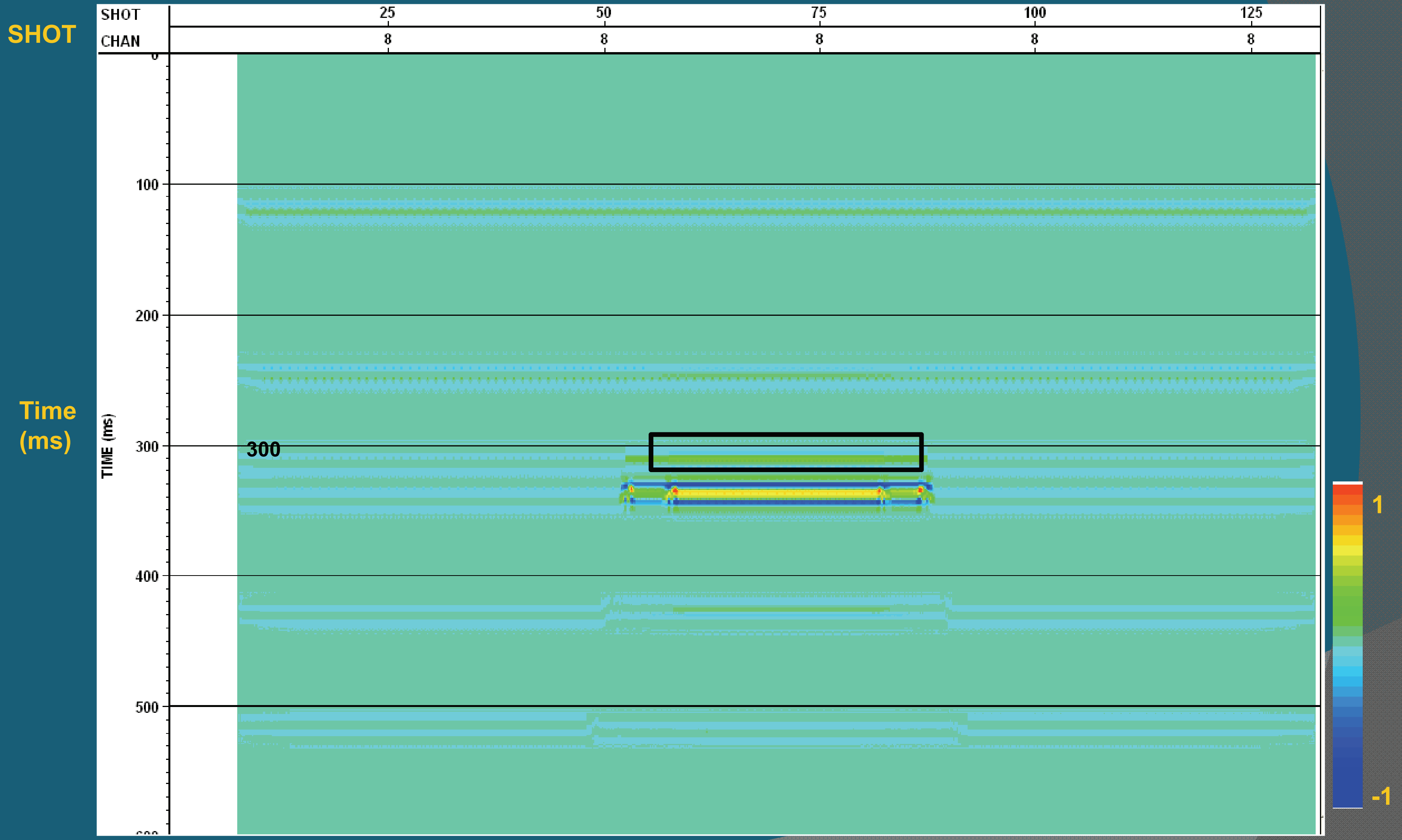
CDP stack:
After CO_2 injection

Time (ms)

300

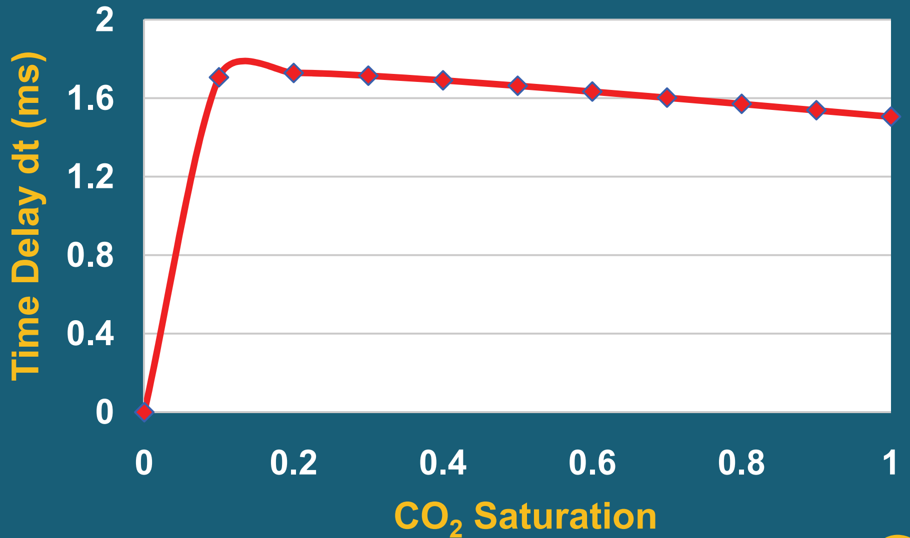
Results

Difference between sections



Results

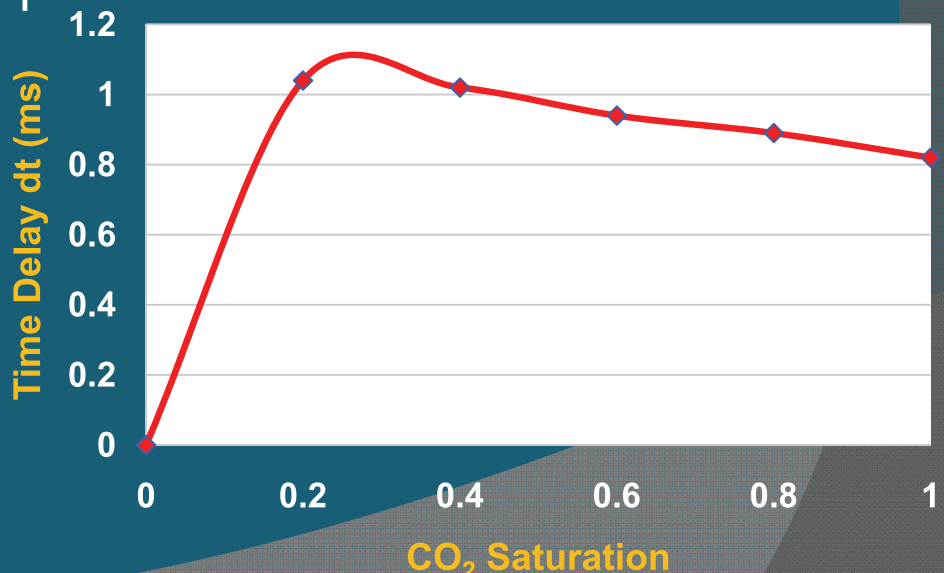
Time delay (basal reflector) vs. CO_2 saturation



Theoretical calculation:

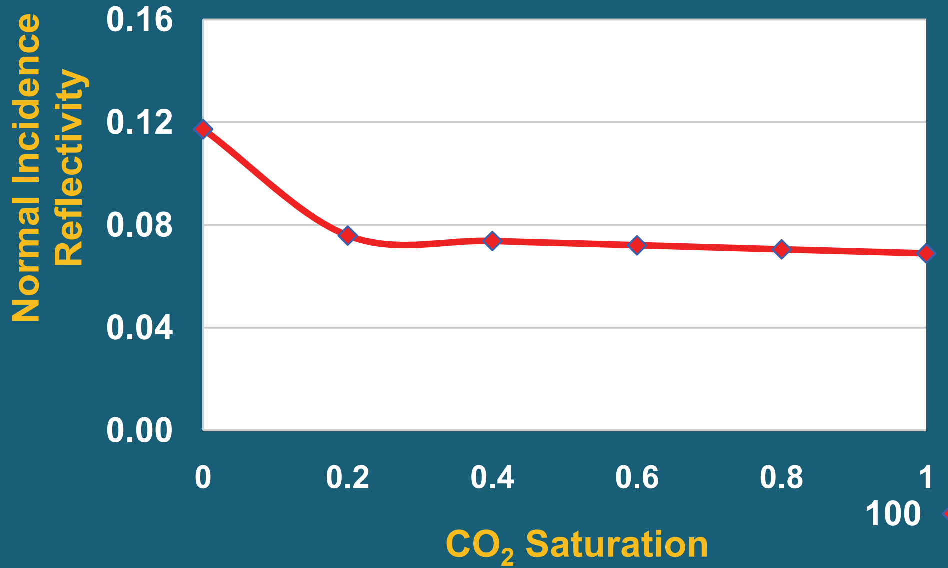
$$\Delta T = T_2 - T_1 = 2H\,(1/V_2 - 1/V_1)$$

Measured from the section



Results

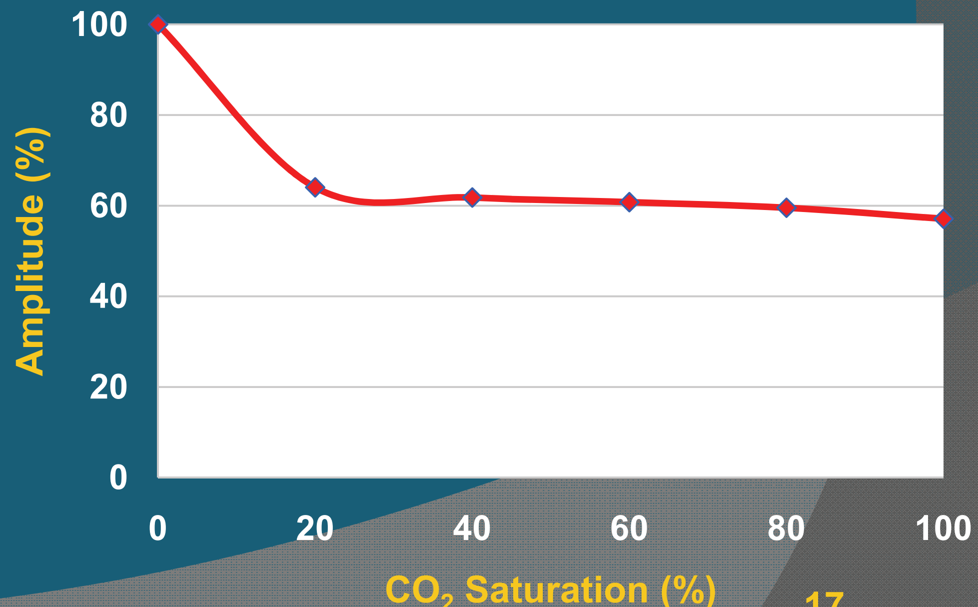
Amplitude (top reflector) vs. CO_2 saturation



Theoretical calculation:

$$R_{ij} = (\rho_j V_j - \rho_i V_i)/((\rho_j V_j + \rho_i V_i)$$

Measured from the section



Results

AVO: Shuey's approximation

$$R_{pp} = A + B\sin^2\theta_i + C(\tan^2\theta_i - \sin^2\theta_i)$$

R_{pp}= P-wave Reflectivity

A= First Coefficient, normal Incidence Reflectivity

B = Second Coefficient, small angle (<30 degrees)

C = Third Coefficient, larger angle (>30 degrees)

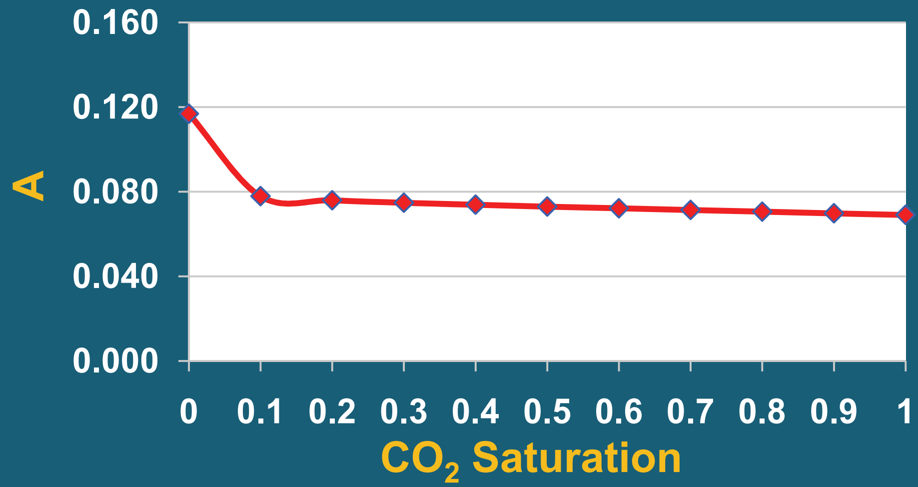
Θ = Angle of Incidence

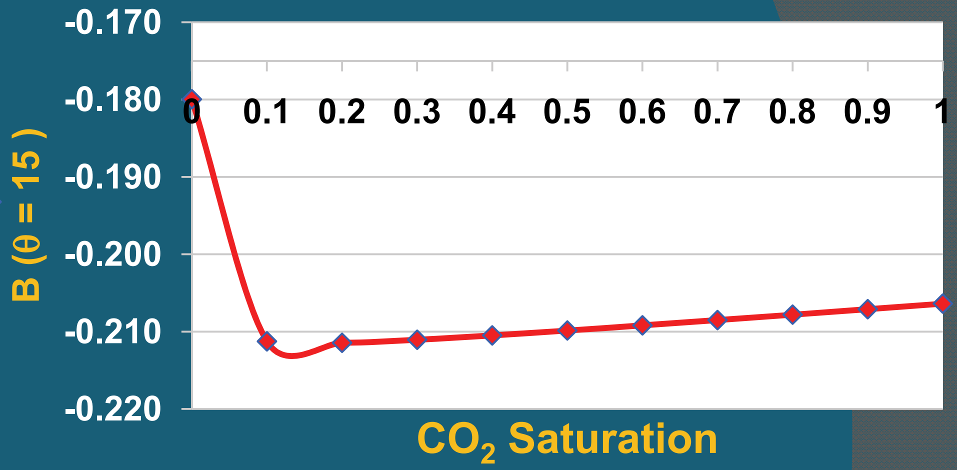
$$R_{pp} = A + B\sin^2\theta_i$$

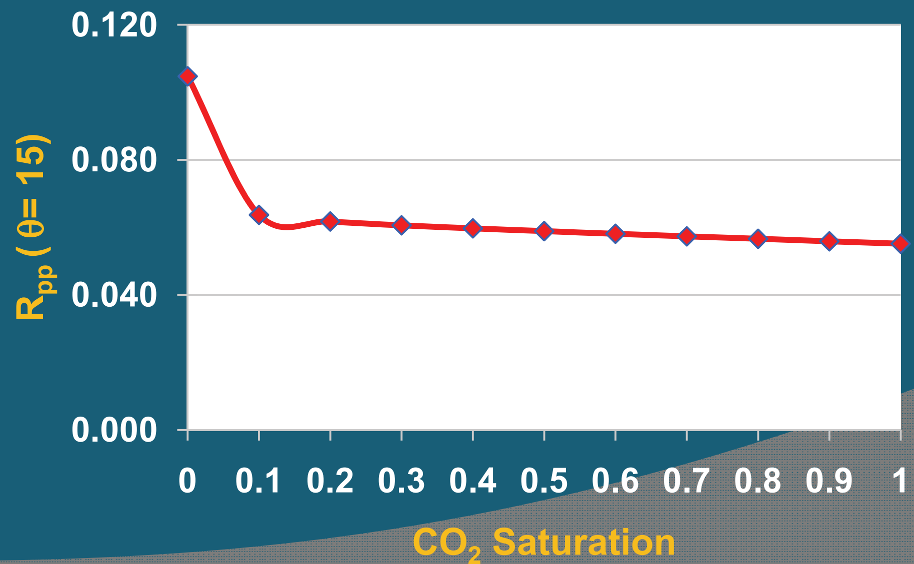
Results

AVO: Shuey's approximation

Having an angle of Incidence, θ = 15 degrees







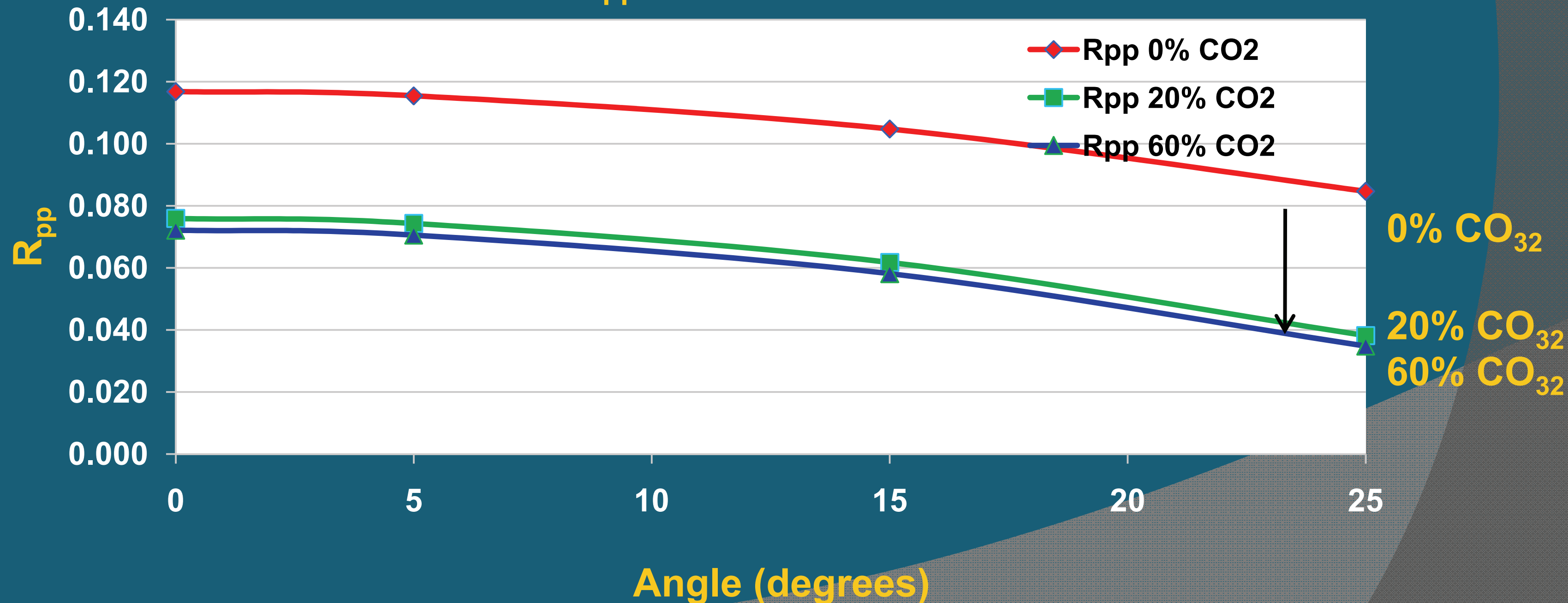
Results

AVO: Shuey's approximation

AVA (Amplitude Vs. Angle)

Angle (Degrees)	Rpp(0% CO_2)	Rpp(20% CO_2)	Rpp(60% CO_2)
0	0.117	0.0759	0.0721
5	0.115	0.0743	0.0706
15	0.105	0.0618	0.0581
25	0.085	0.0382	0.0348

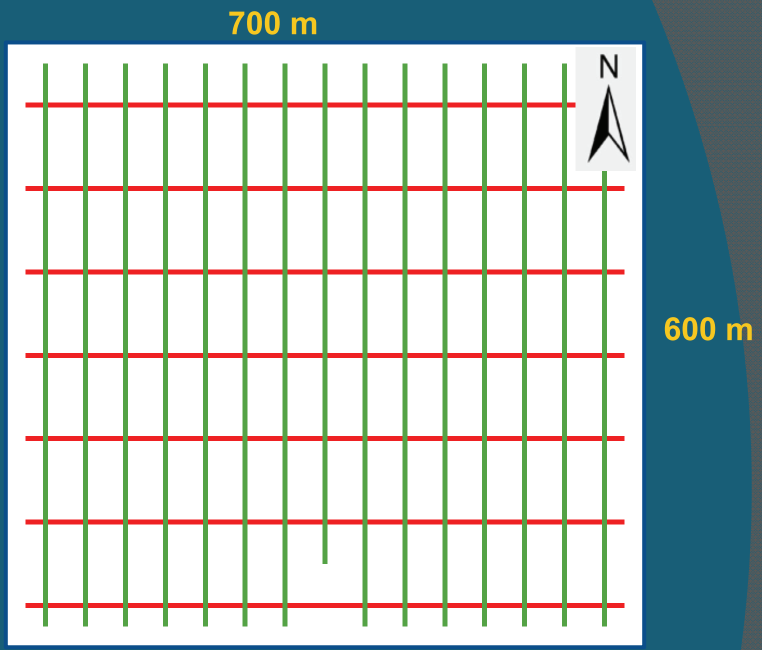
R_{pp} Vs Angle



Recent Progress

Field acquisition

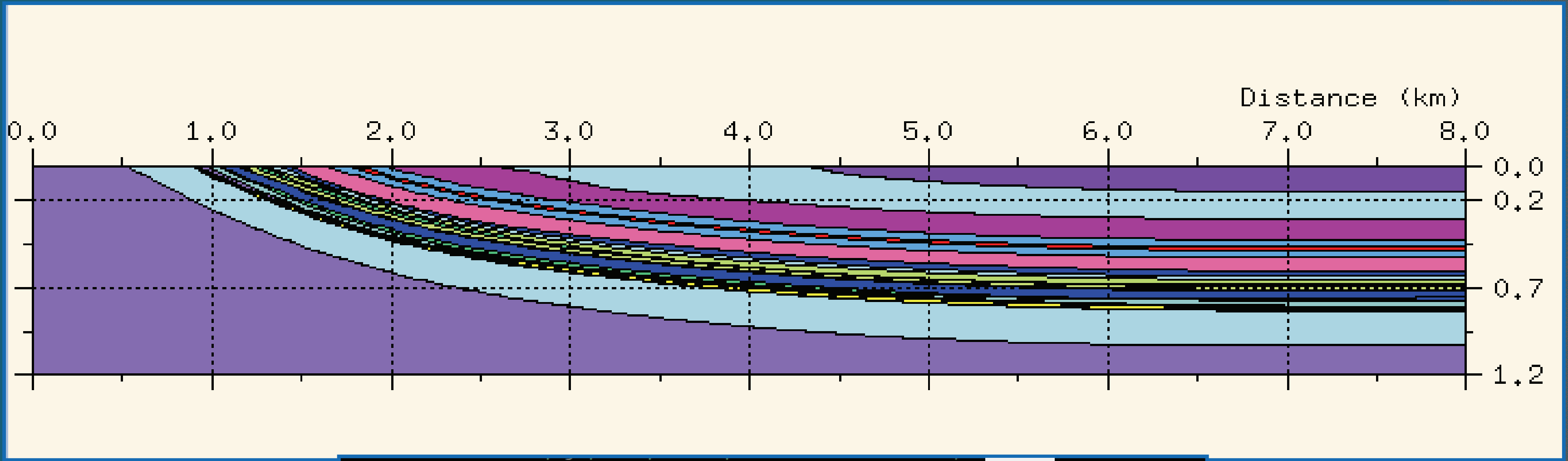
May, 2010: 3D 3C Seismic Survey
(15 receivers lines and 7 source lines)

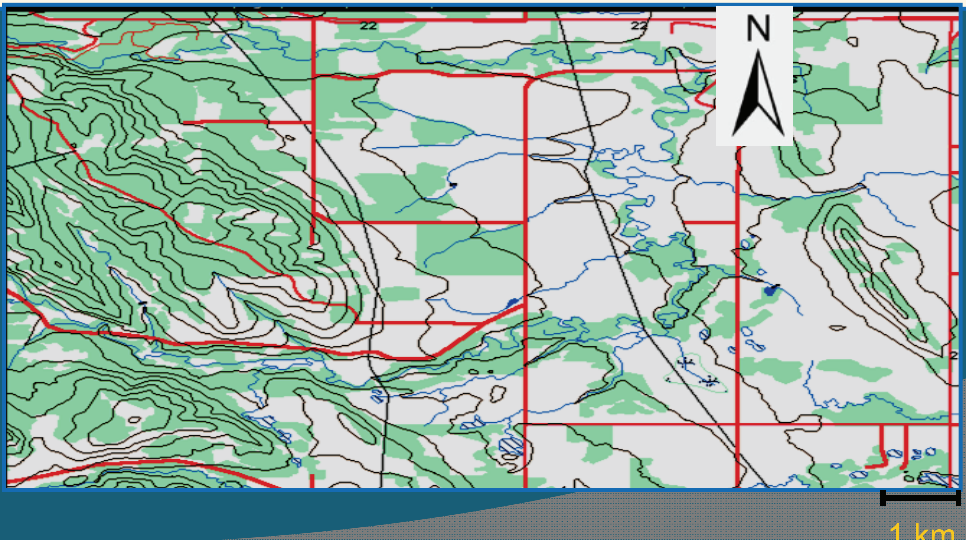


August, 2010: 2D Seismic Survey
(One 2.5 km Line)

Recent Progress

Extended geological model





Conclusions

- Paskapoo Formation has suitable qualities for a test CO_2 geological storage site.
- Gassmann theory is a practical and useful tool in fluid substitution models.
- There is a recognizable difference in rock properties and seismic response due to CO_2:

  1) P-wave velocity drops ~7% from 0% to 20% CO_2 saturation

Conclusions

2) S-wave velocity increase is directly proportional to CO_2 saturation (average V_s increase 0.8 %).

3) V_p / V_s shows a decrease of 8%

4) Time delay of the bottom reflector is ~ 1.6 ms

5) AVO gradient will decrease with CO_2 saturation, particularly between 0% and 20 % CO_2 saturation.

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