TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

Estimating Across-Fault Leakage Rates and their Financial Implications for CCS with Application to Offshore Gulf of Mexico

Marco Andrés Guirola

MSc. Thesis

Supervisor: Dr. Alexander P. Bump

ENERGY AND EARTH RESOURCES GRADUATE PROGRAM

multidisciplinary studies for interdisciplinary solutions

FAULT UNCERTAINTY

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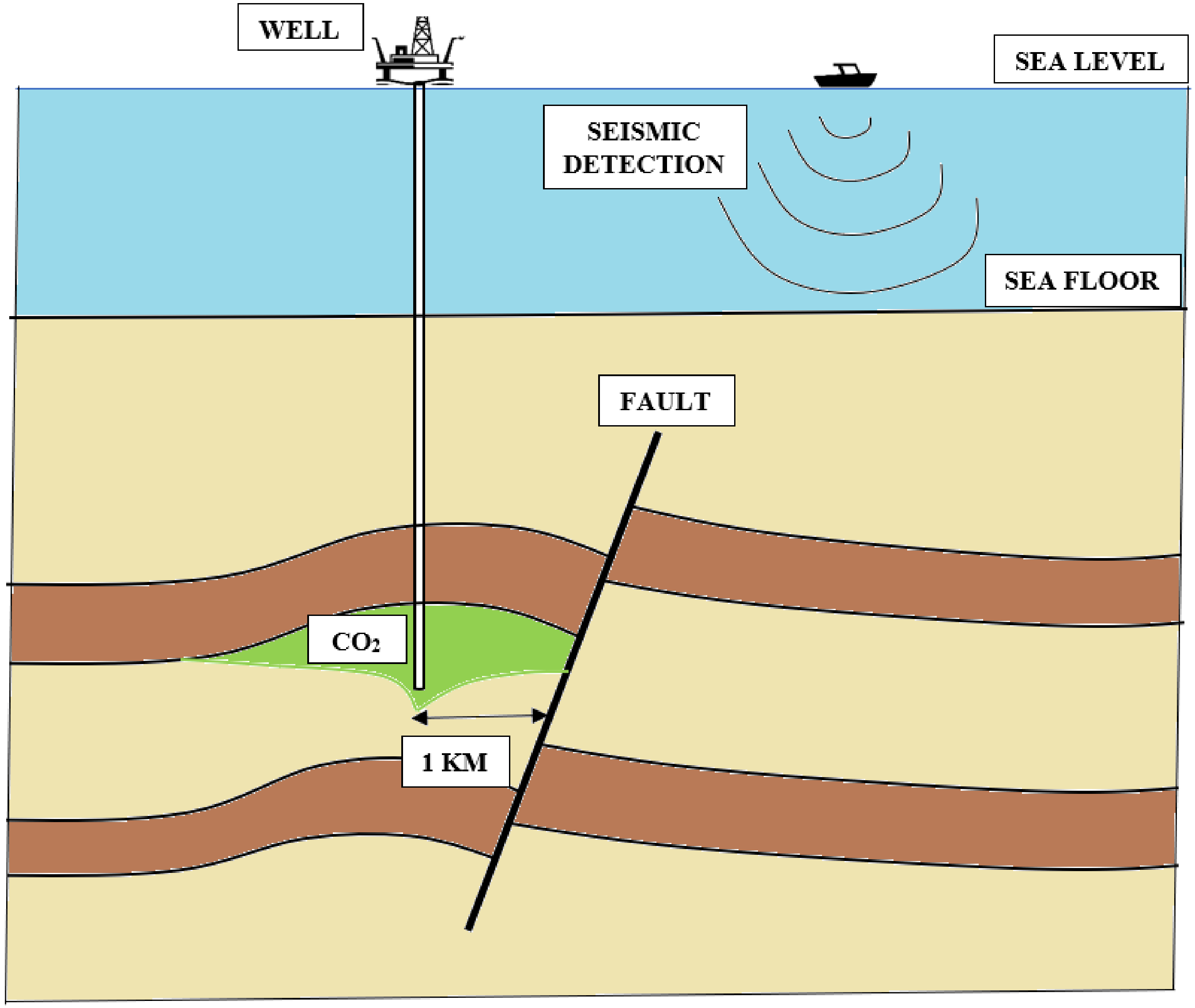

* Oil rig art from http://www.clipartbest.com/clipart-LiK5nKeXT and http://clipart-library.com/clipart/oil-rig-clipart_10.htm

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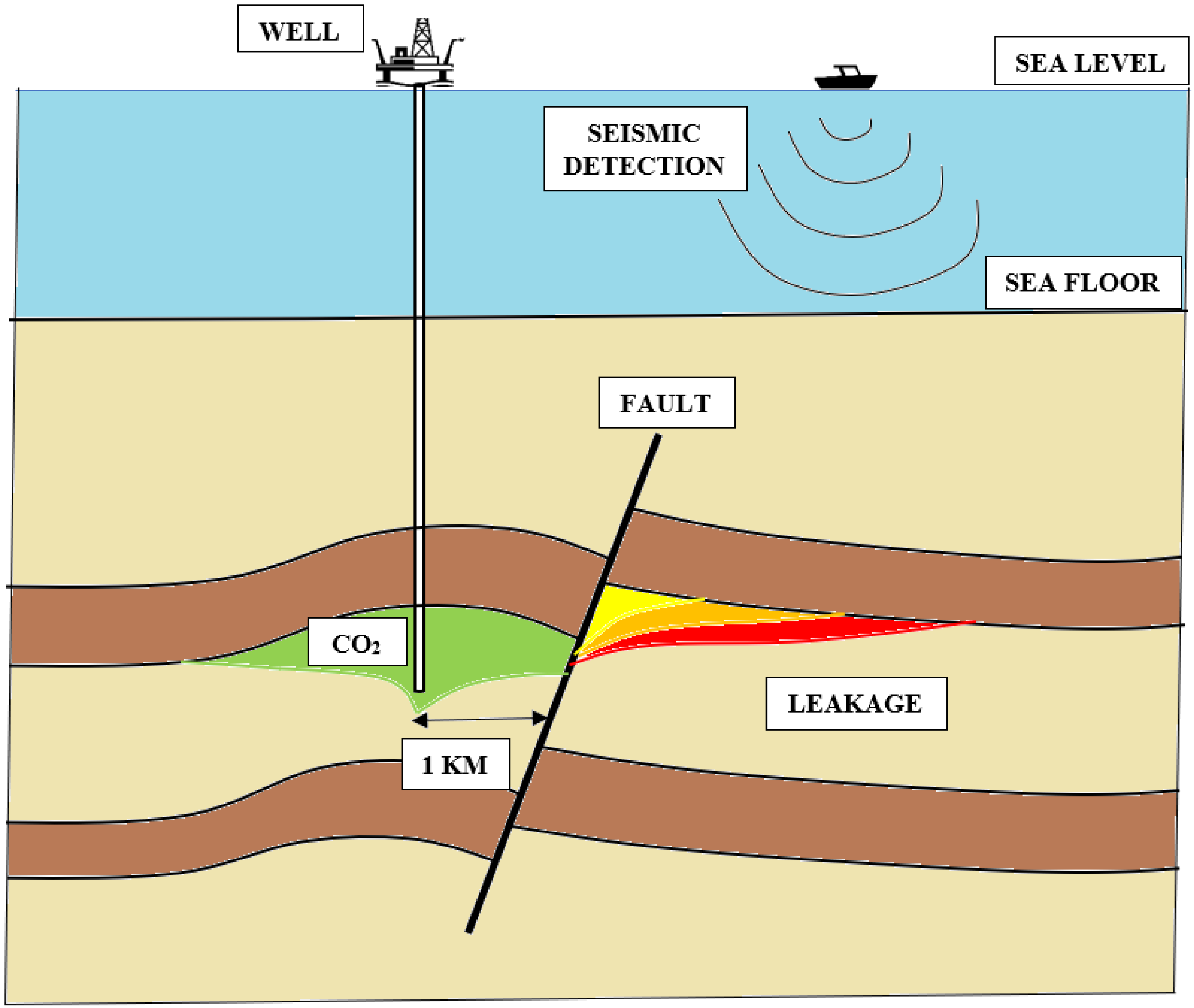

Leak size determines if and when we detect leakage

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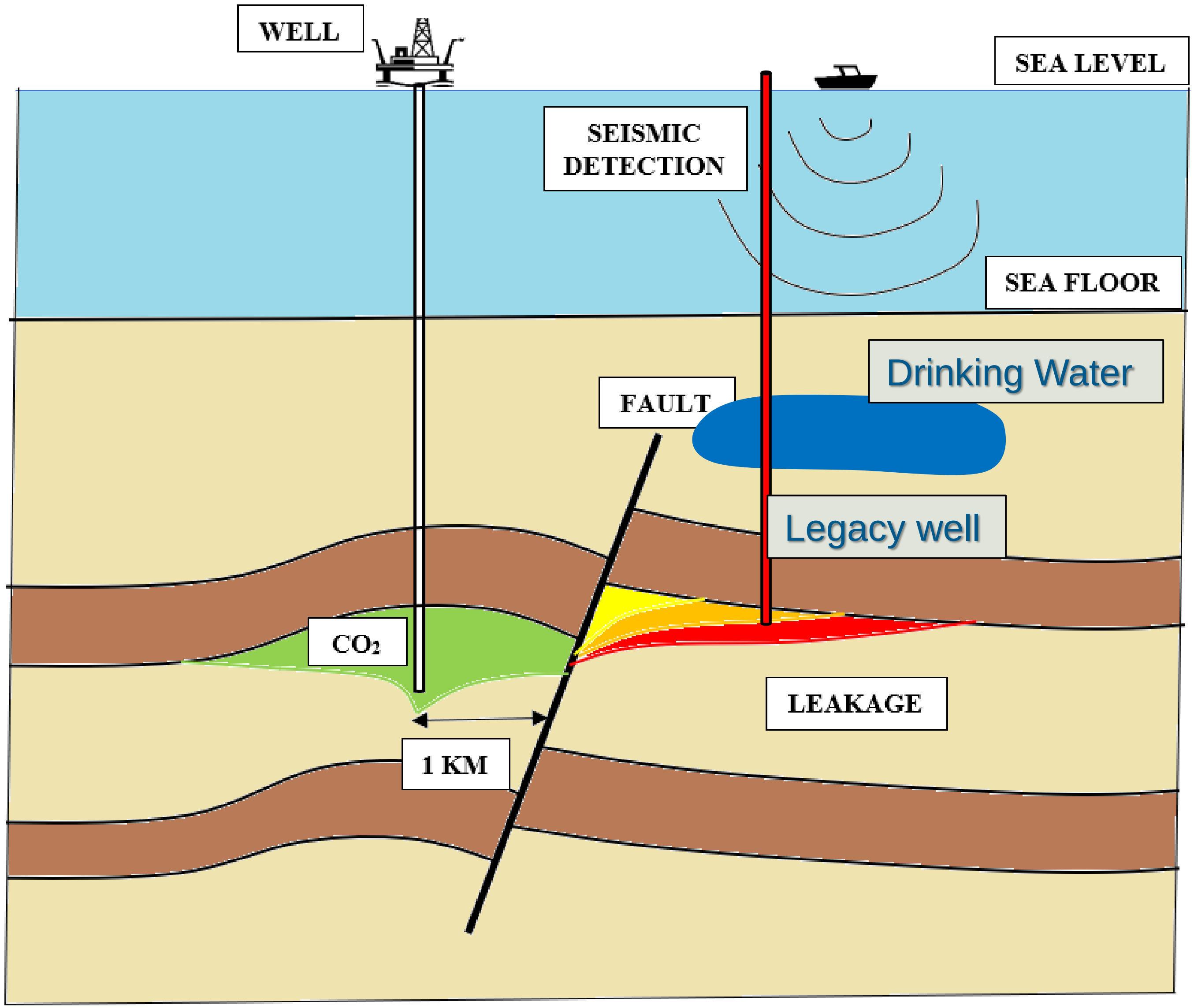

Leak size determines if and when we detect leakage

- Liability
- Purchase additional acreage to monitor, maybe remediate = cost

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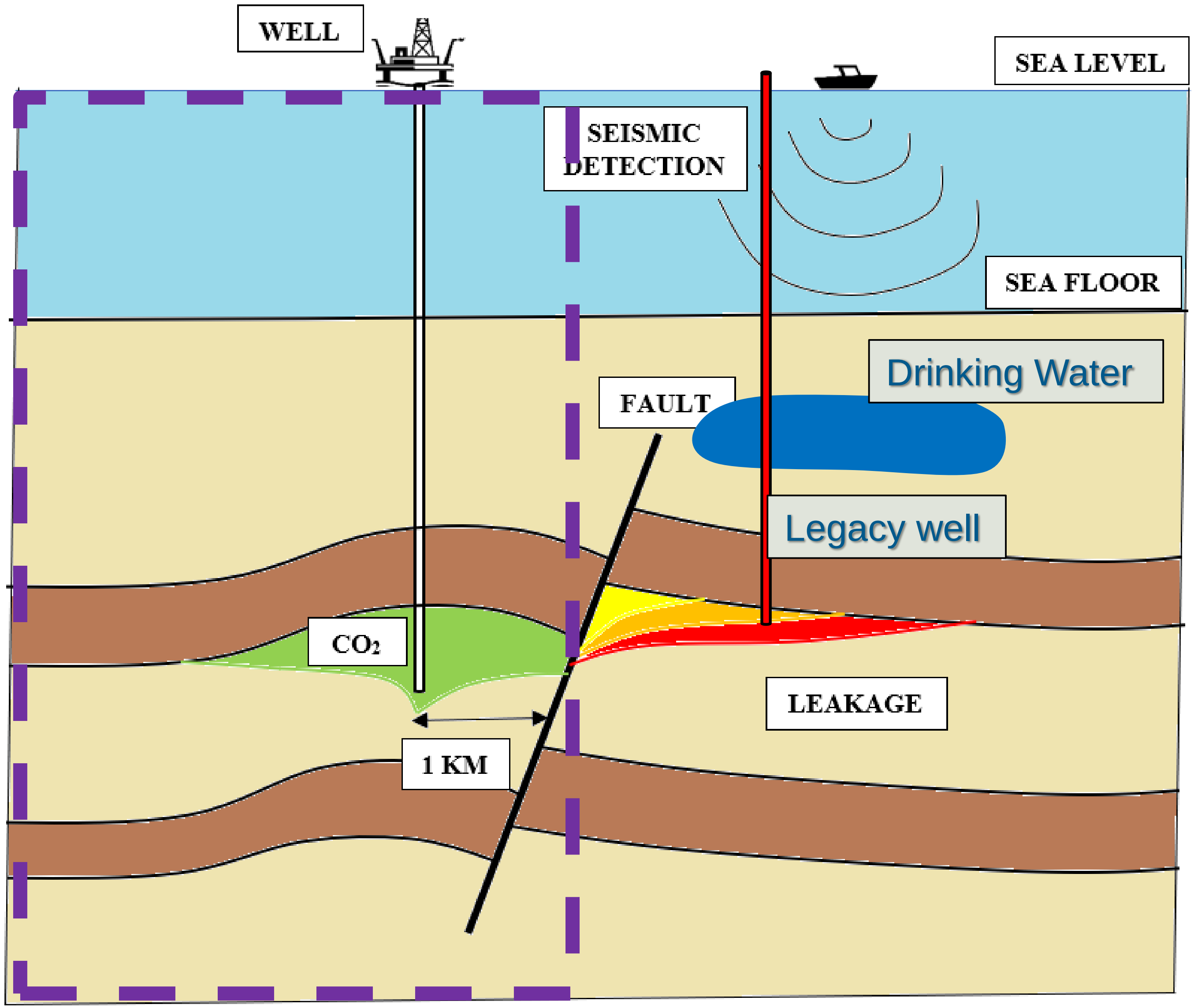

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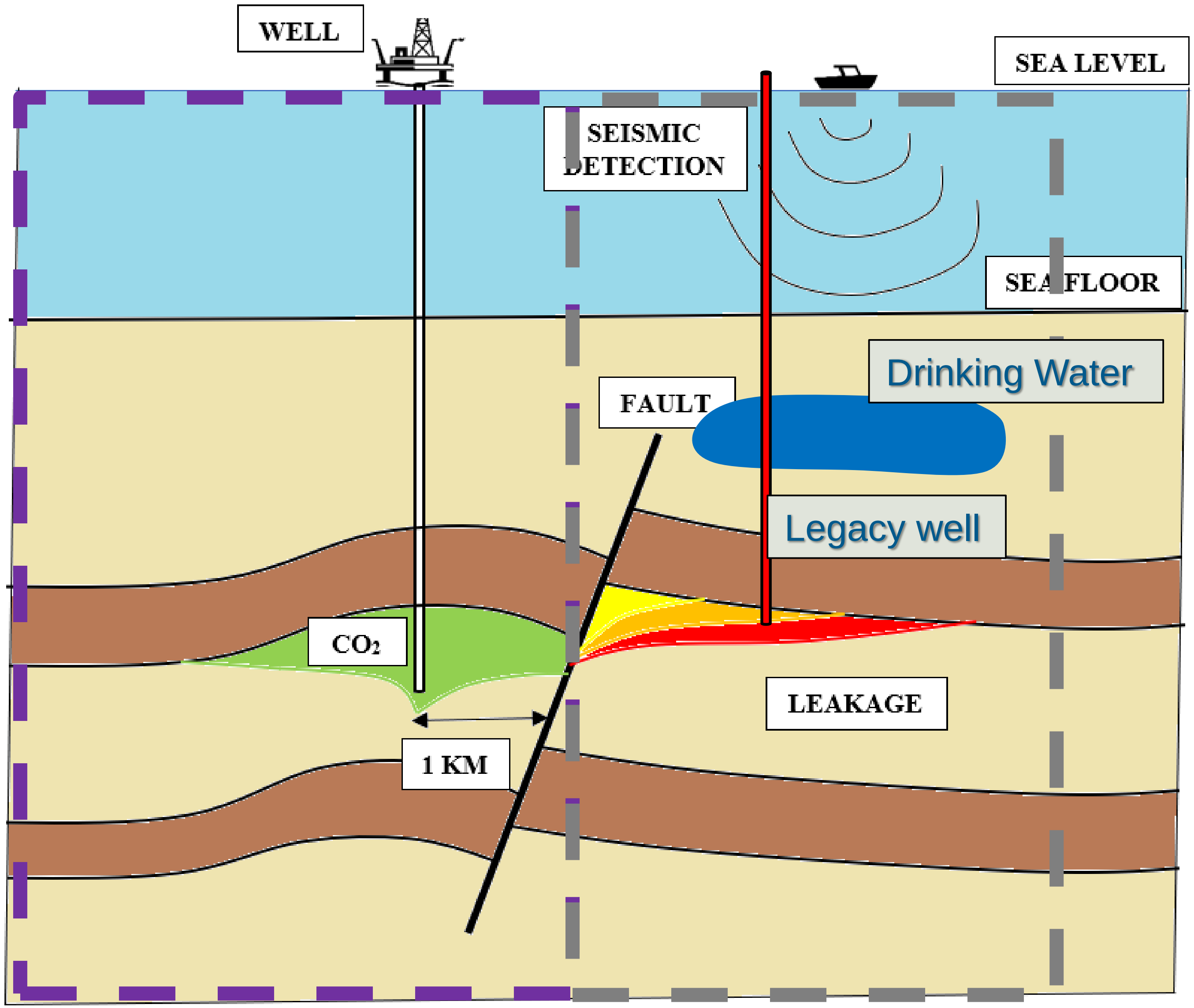

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Leak size = financial responsibility

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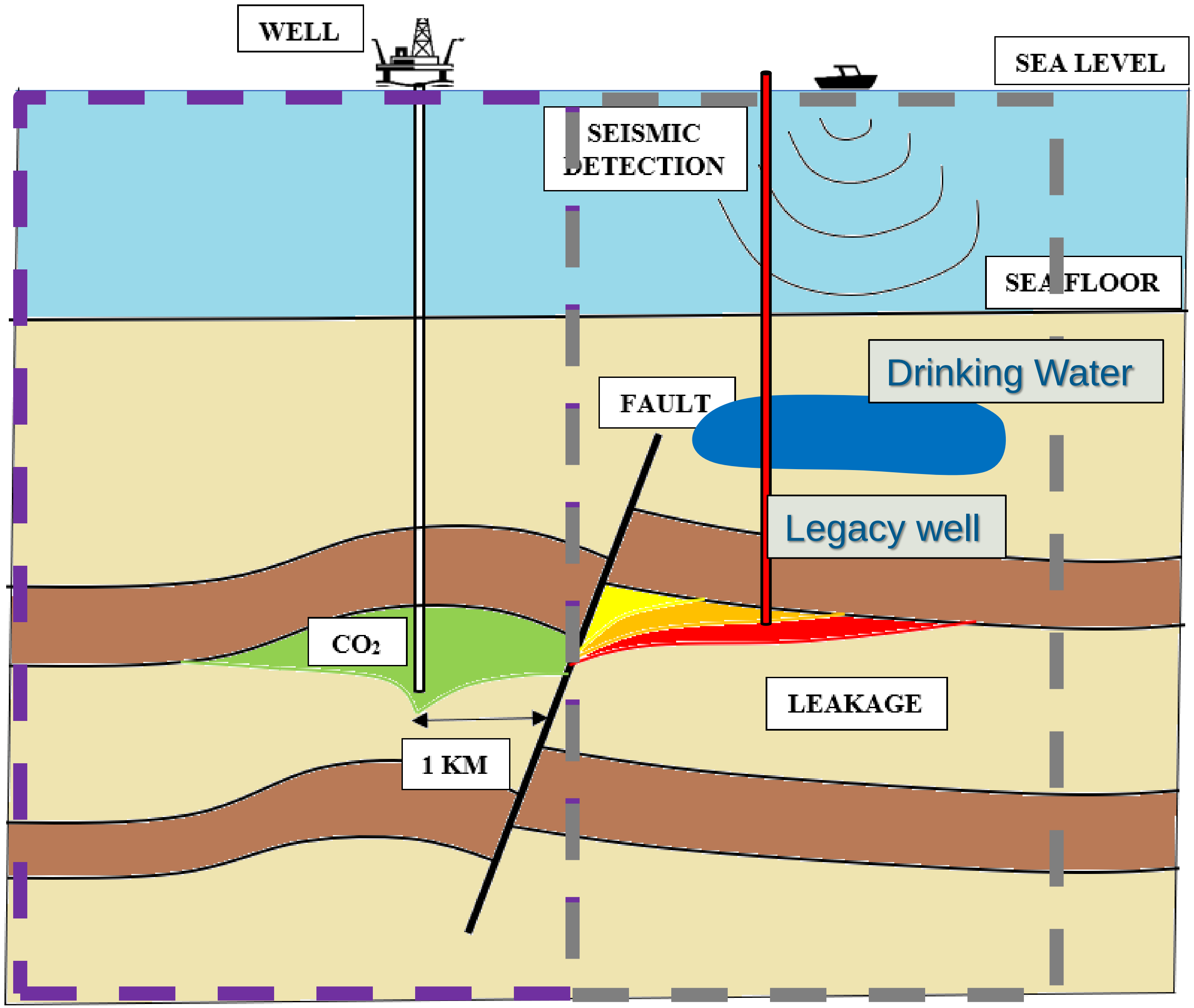

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Seal ⟷ Leak

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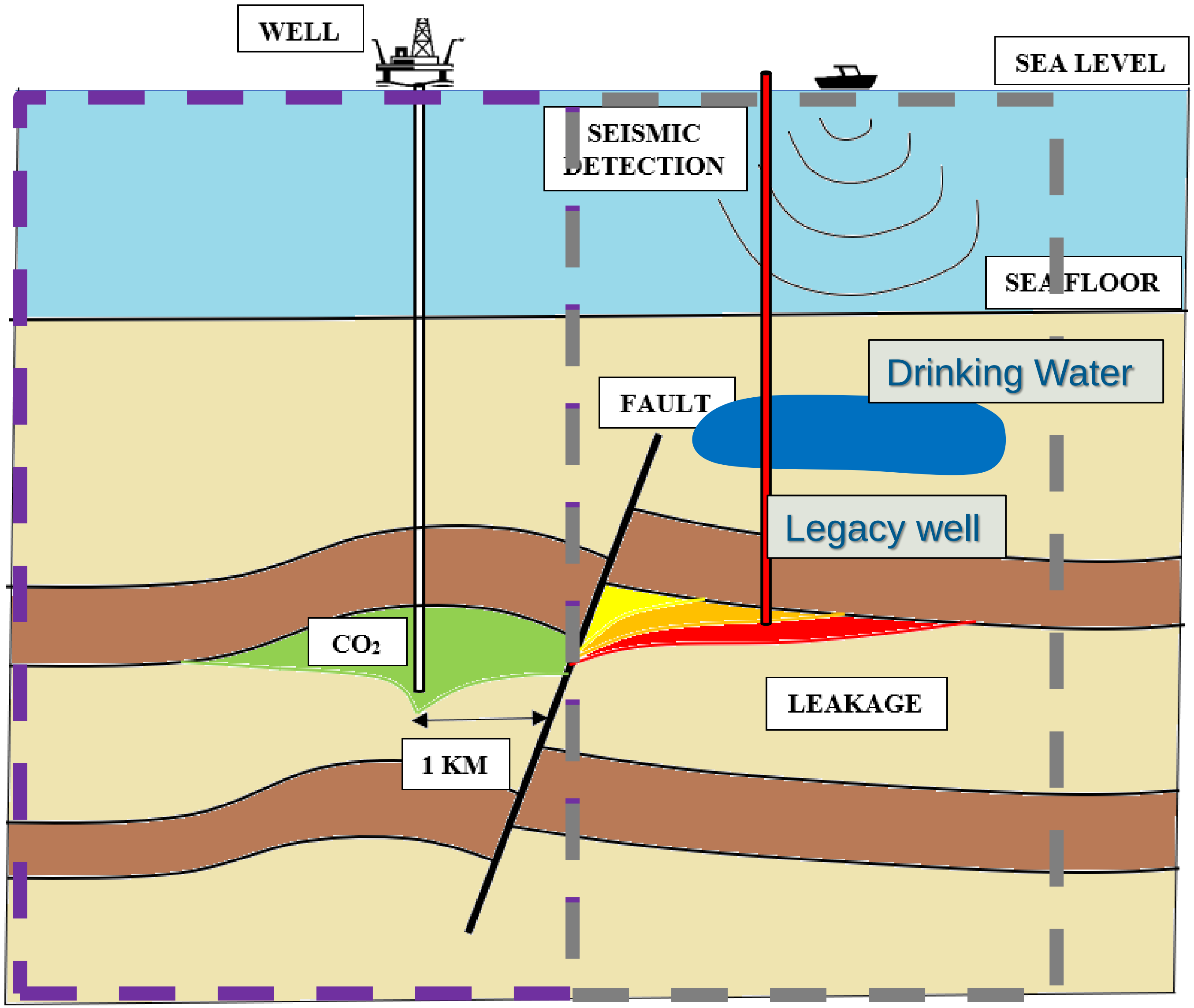

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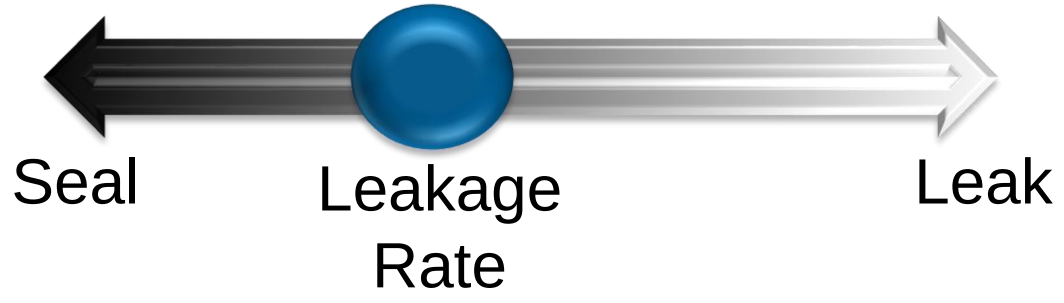

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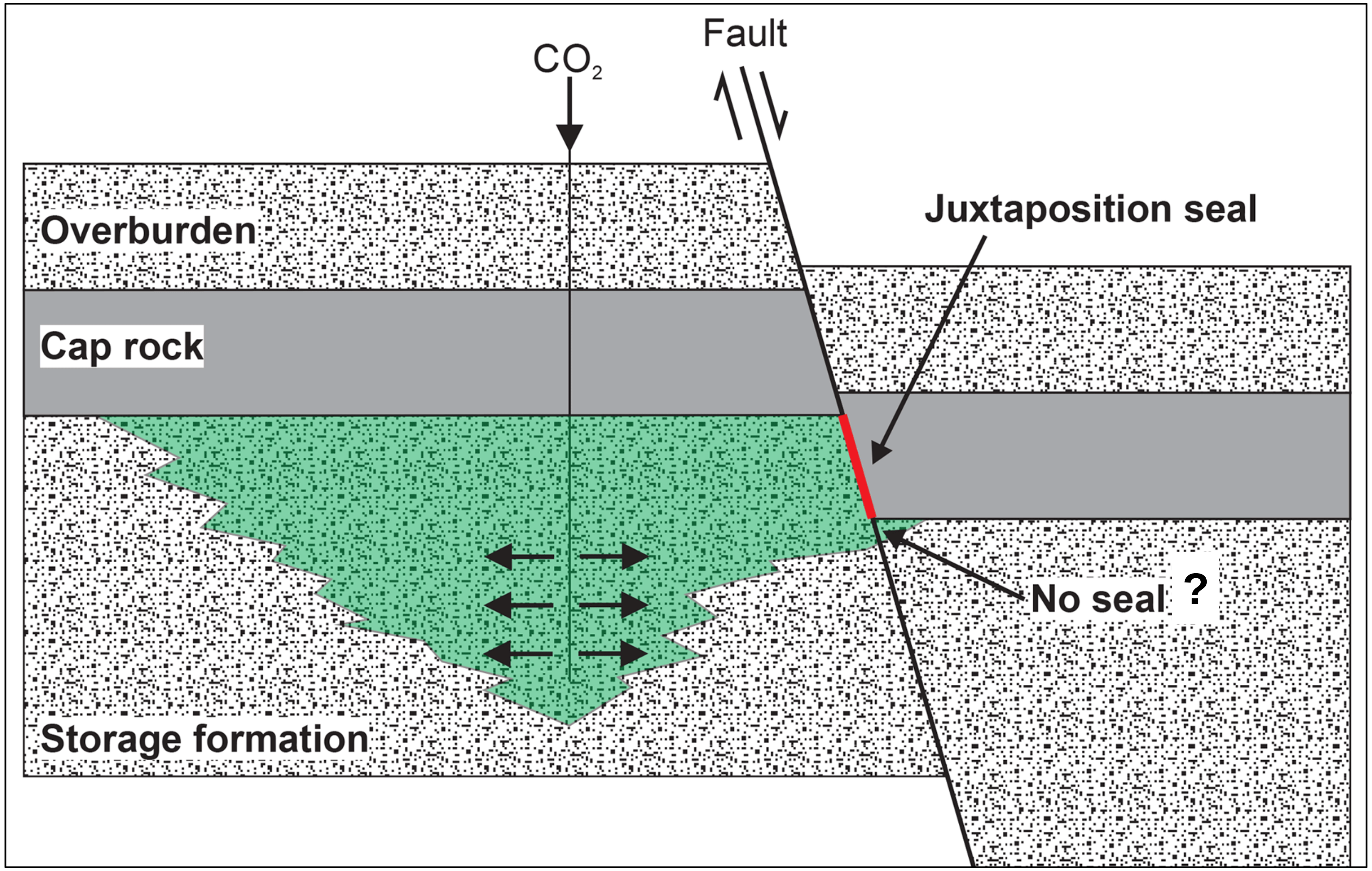
PETROLEUM FAULT SEAL ANALYSIS

Tool for assessing sealing potential

1. Juxtaposition sealing



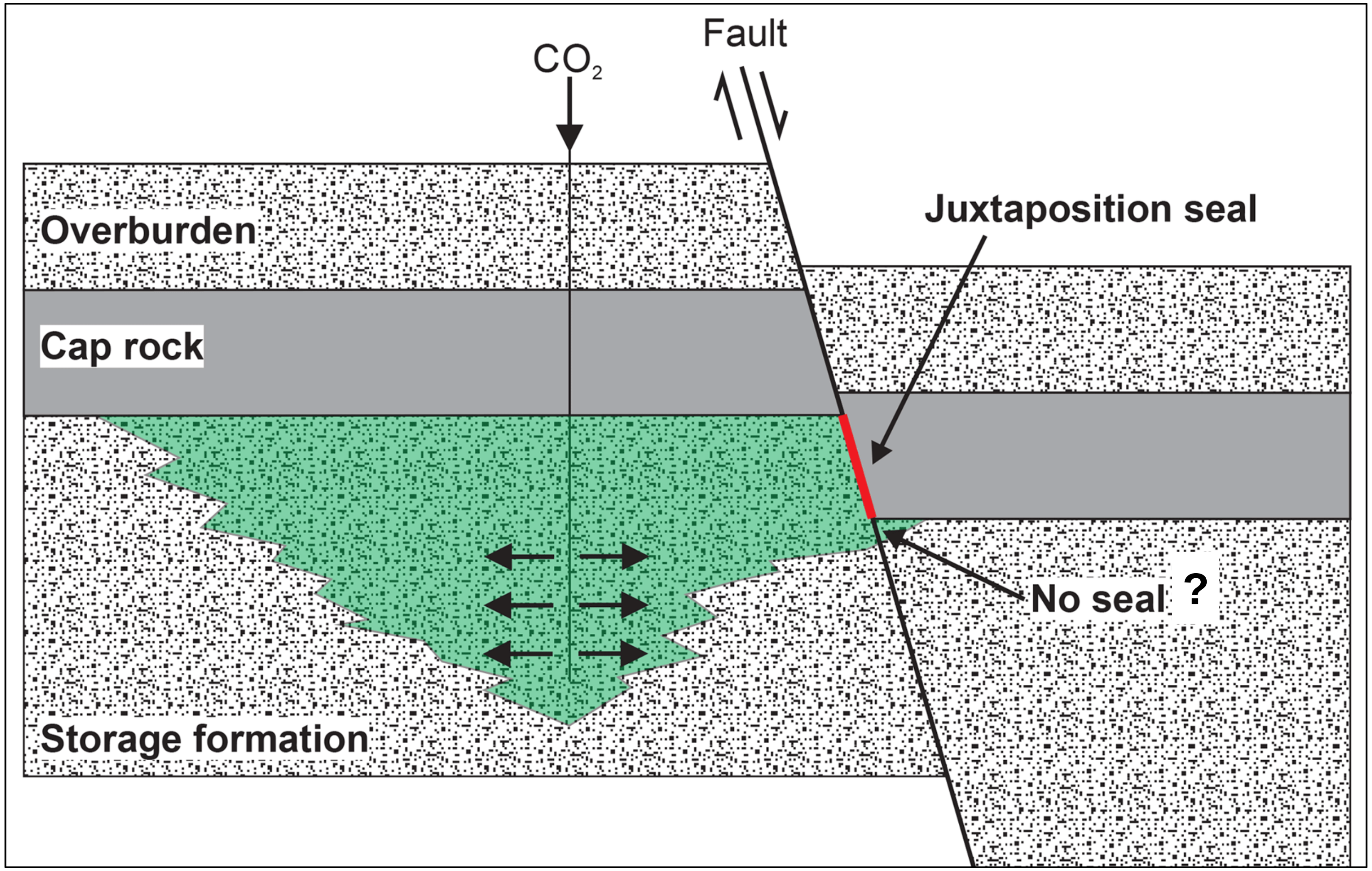
Miocic et al., 2019

PETROLEUM FAULT SEAL ANALYSIS

Tool for assessing sealing potential

2. Fault-rock sealing

   SGR (shale gouge ratio)



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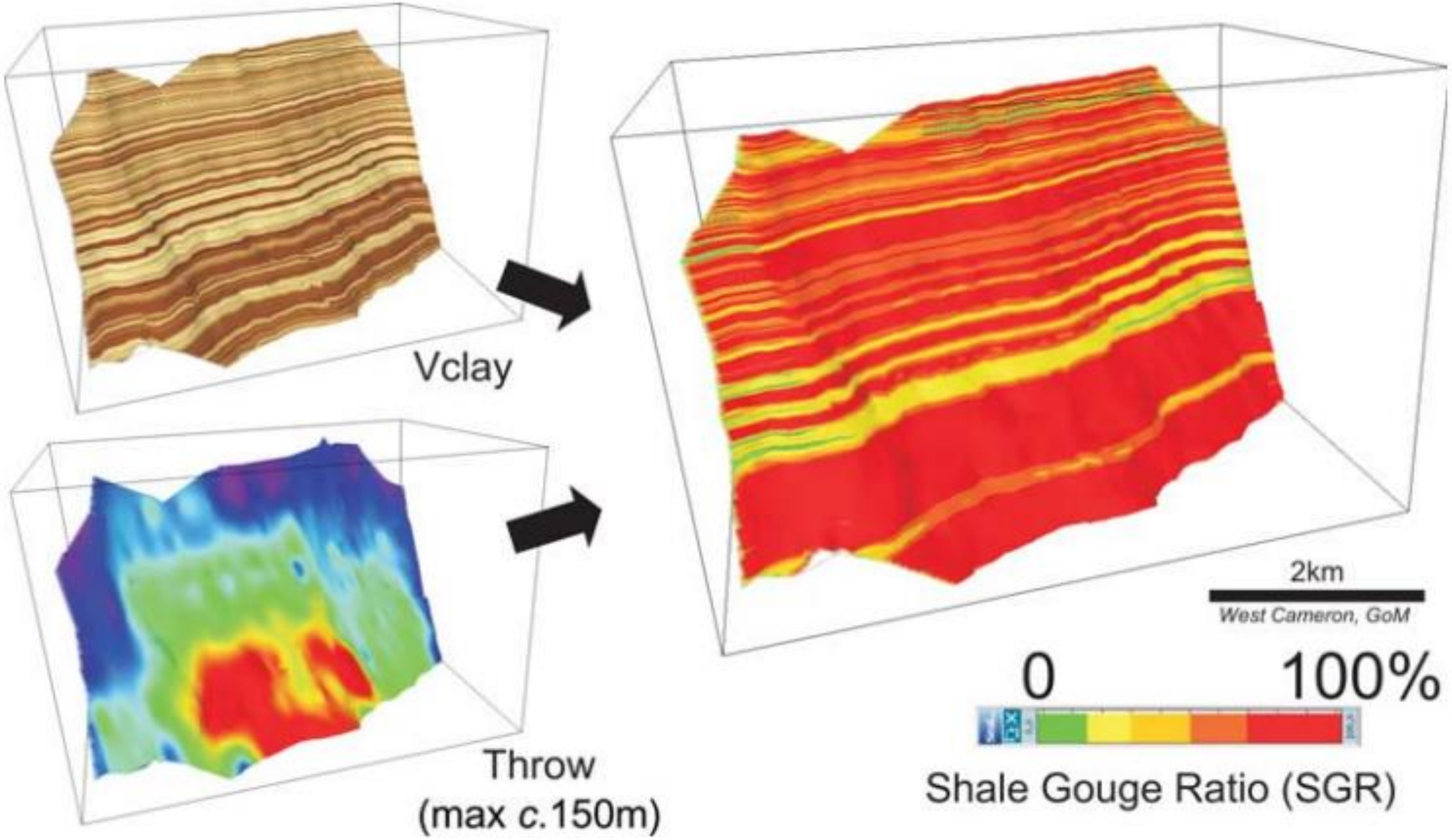


Yielding et al., 2010

PETROLEUM FAULT SEAL ANALYSIS

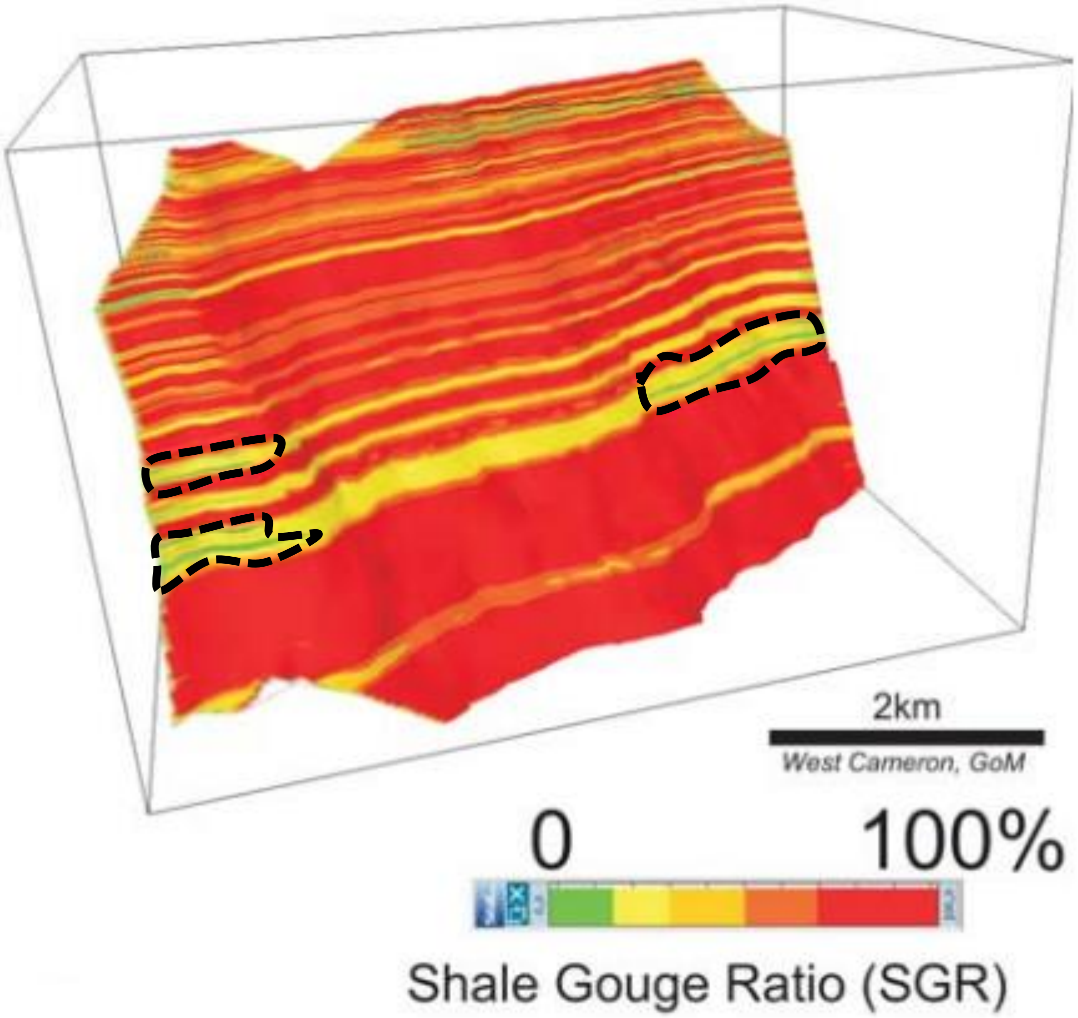
ENERGY AND EARTH RESOURCES GRADUATE PROGRAM

Tool for assessing sealing potential

2. Fault-rock sealing

SGR (shale gouge ratio)

We have found areas with the highest leakage potential!



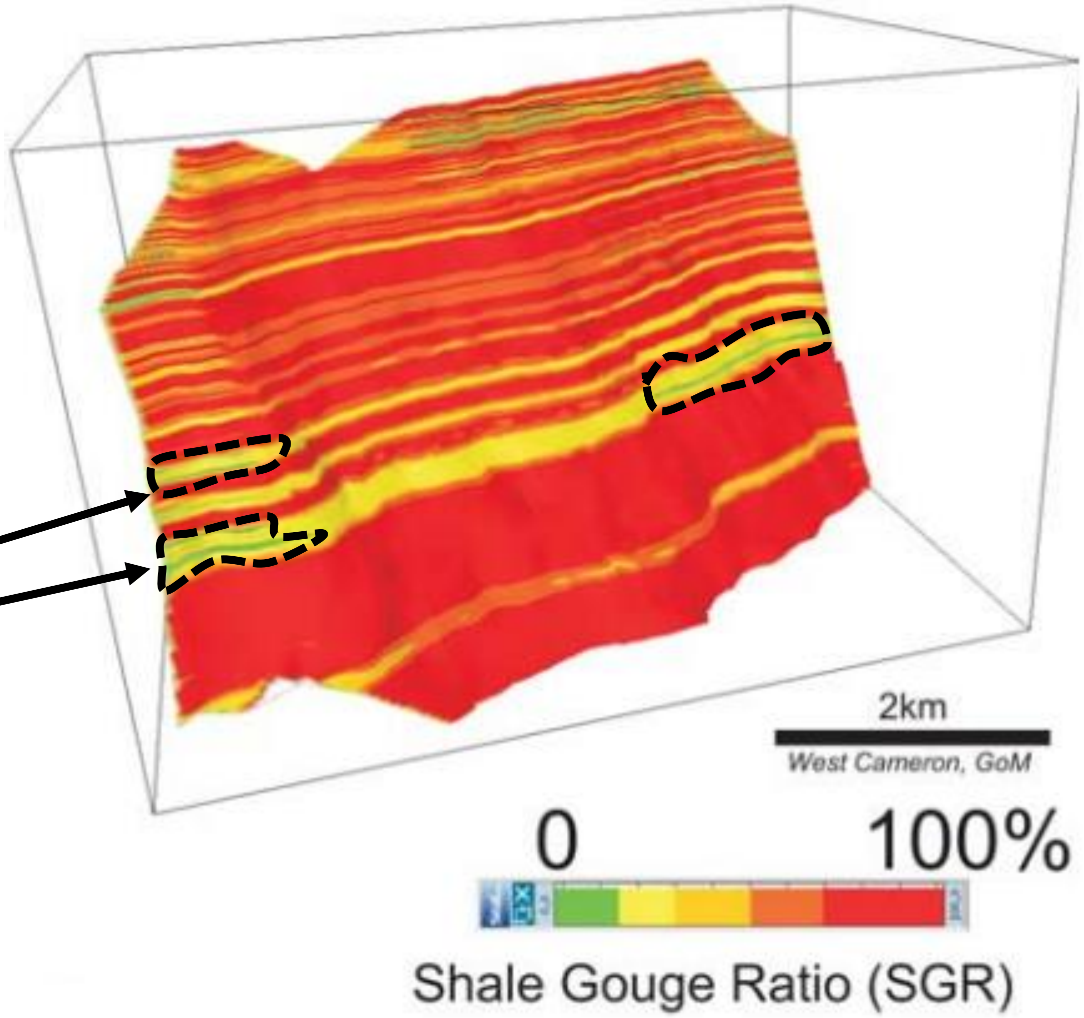
Yielding et al., 2010

DARCY'S LAW

Flow of fluid through a porous medium driven by a pressure gradient

$$Q = \frac{-kA\Delta P}{\mu L}$$

- Single-phase flow of supercritical CO_2 across the fault
- A = area of flux
- Q = leakage rate



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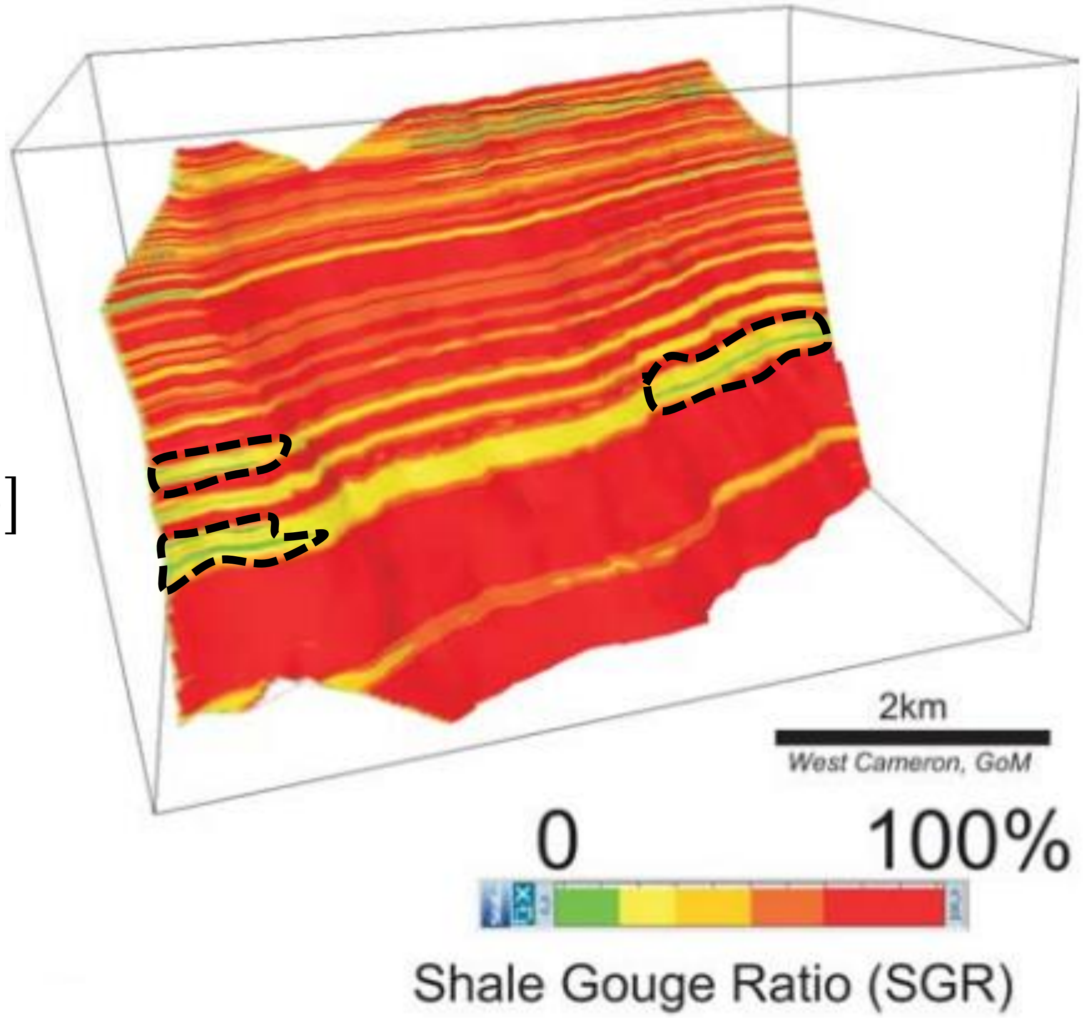
$$Q = \frac{-kA\Delta P}{\mu L}$$

- k

Sperrevick et al. (2002)

$$k = a_1 \times \exp\left[-\left(a_2 SGR + a_3 Z_{max} + \left(a_4 Z_f - a_5\right)(1 - SGR)^7\right)\right]$$



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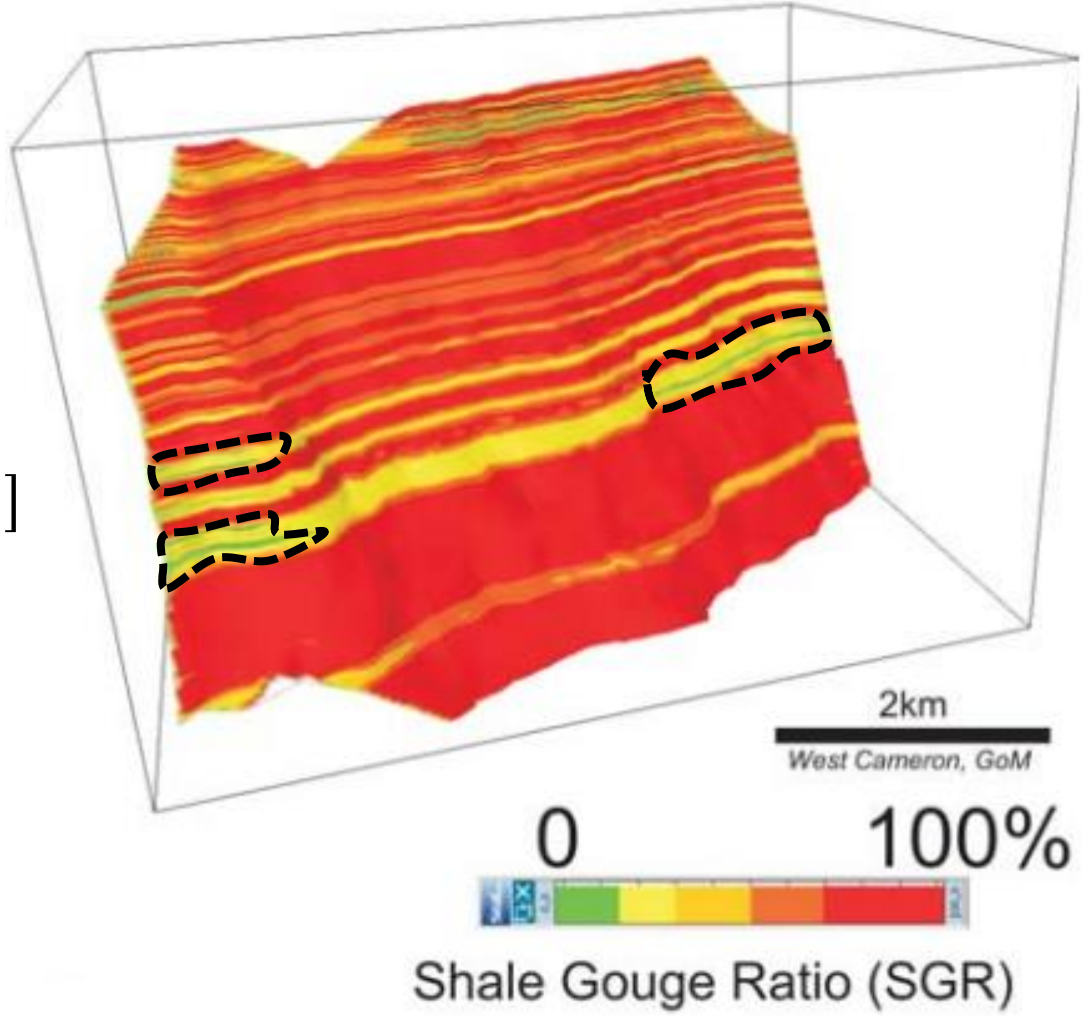
- ΔP

De Simone and Krevor (2021)

$$\Delta P = f(r, t)$$



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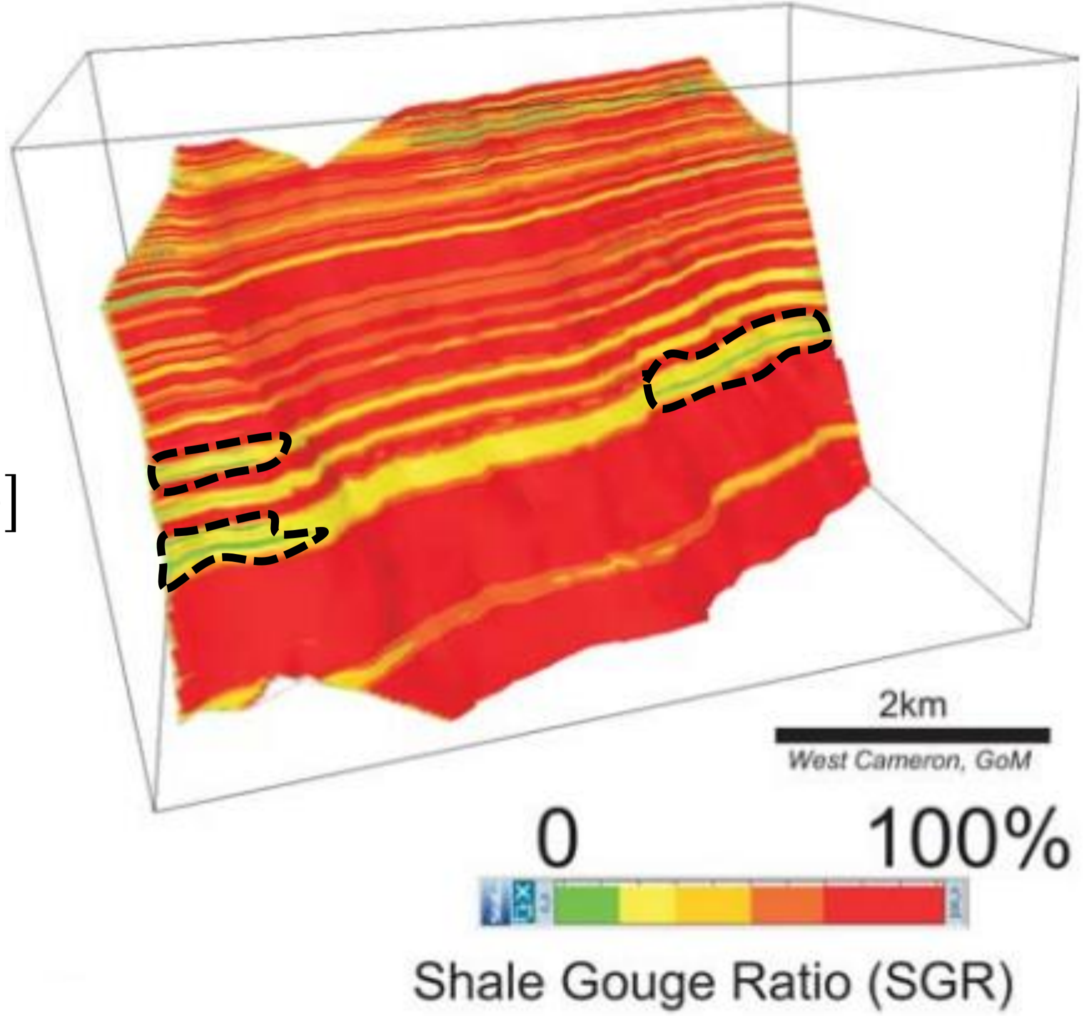
- μ_{CO2}

Ouyang (2011)

$$\mu \propto Temperature\ and\ Pressure$$



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$$\Delta P = f(r,t)$$

- μ_{CO2}

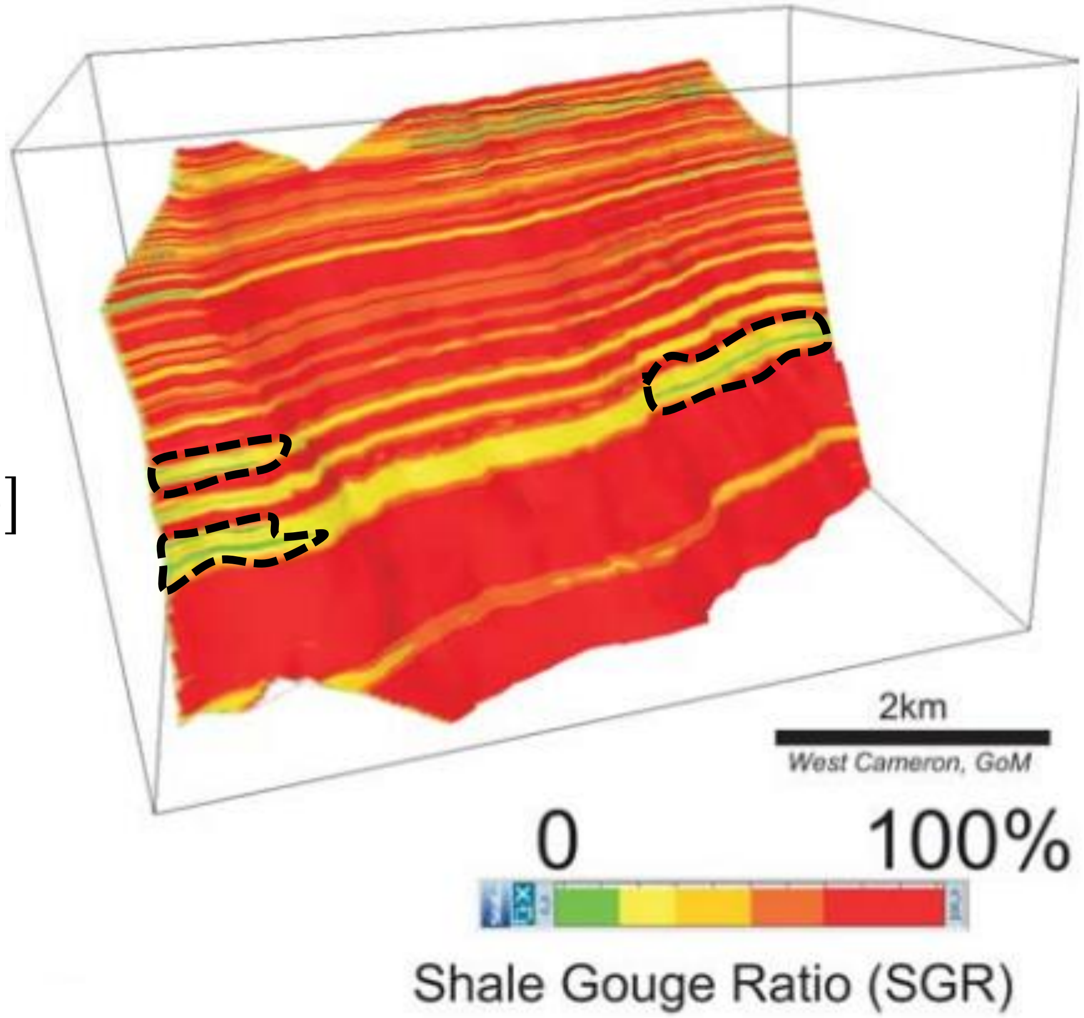
Ouyang (2011)

$$\mu \propto Temperature\ and\ Pressure$$

- L

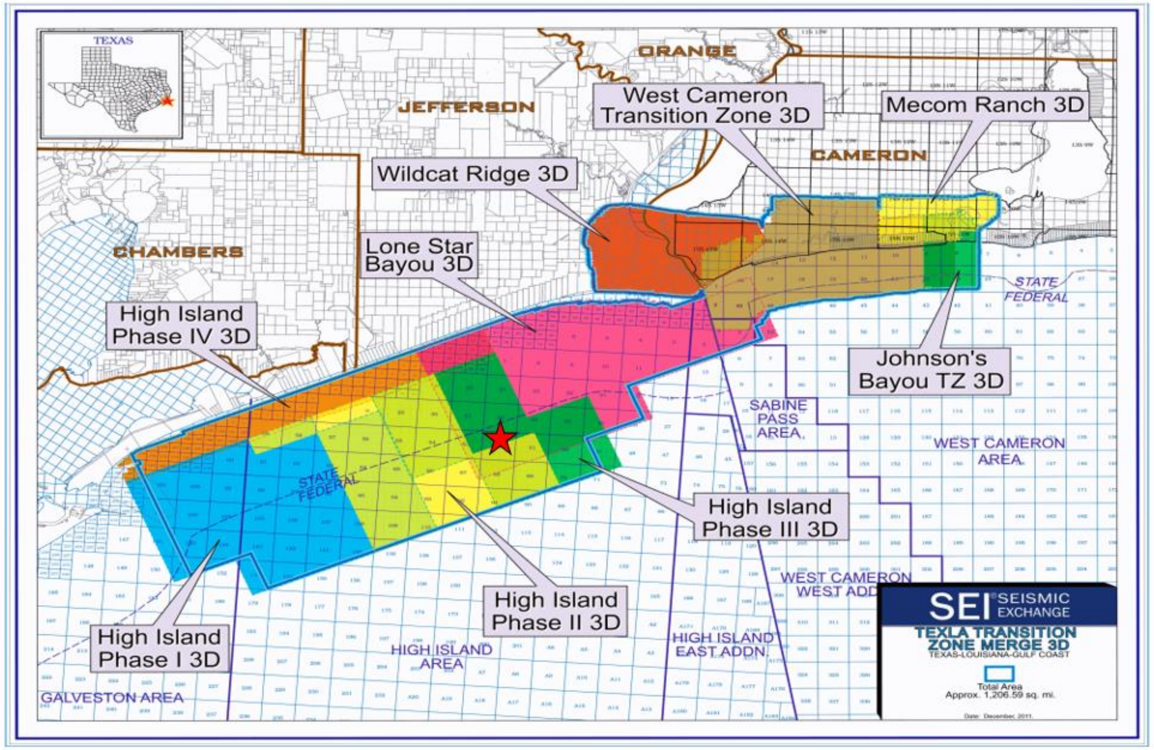
Torabi et al. (2019)

$$L = 0.06D^{0.64}$$



Yielding et al., 2010

Offshore Gulf of Mexico Application



DeAngelo et al., 2019

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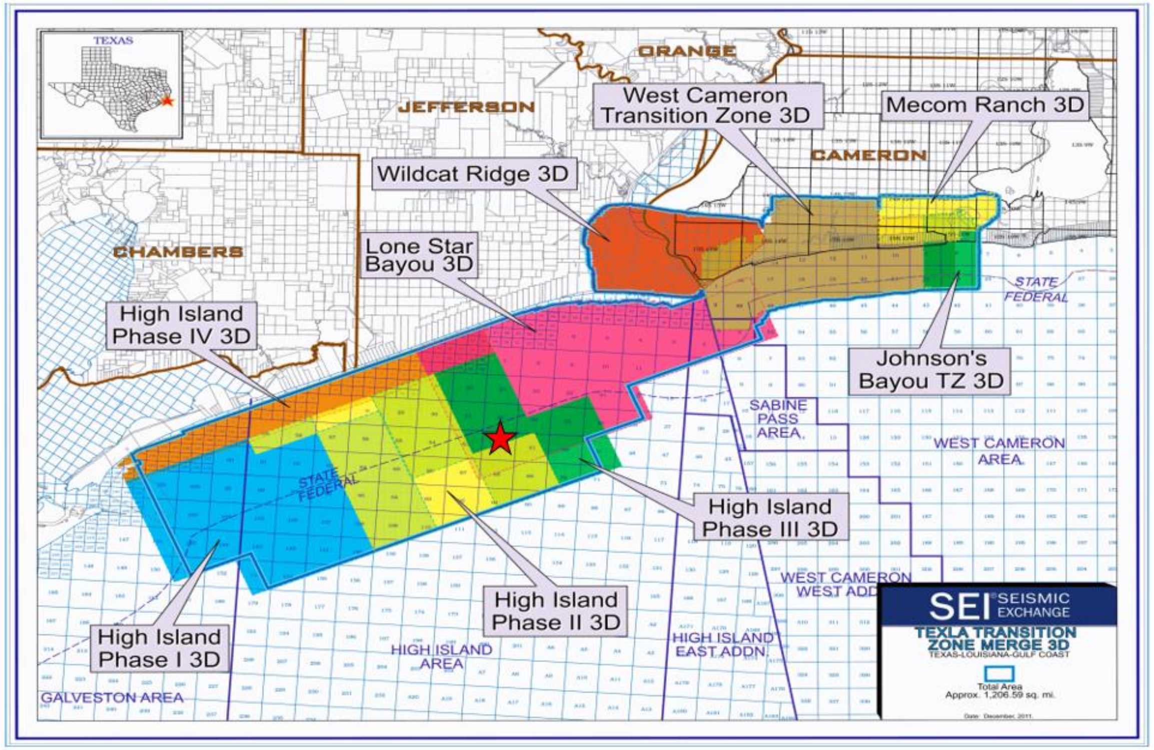

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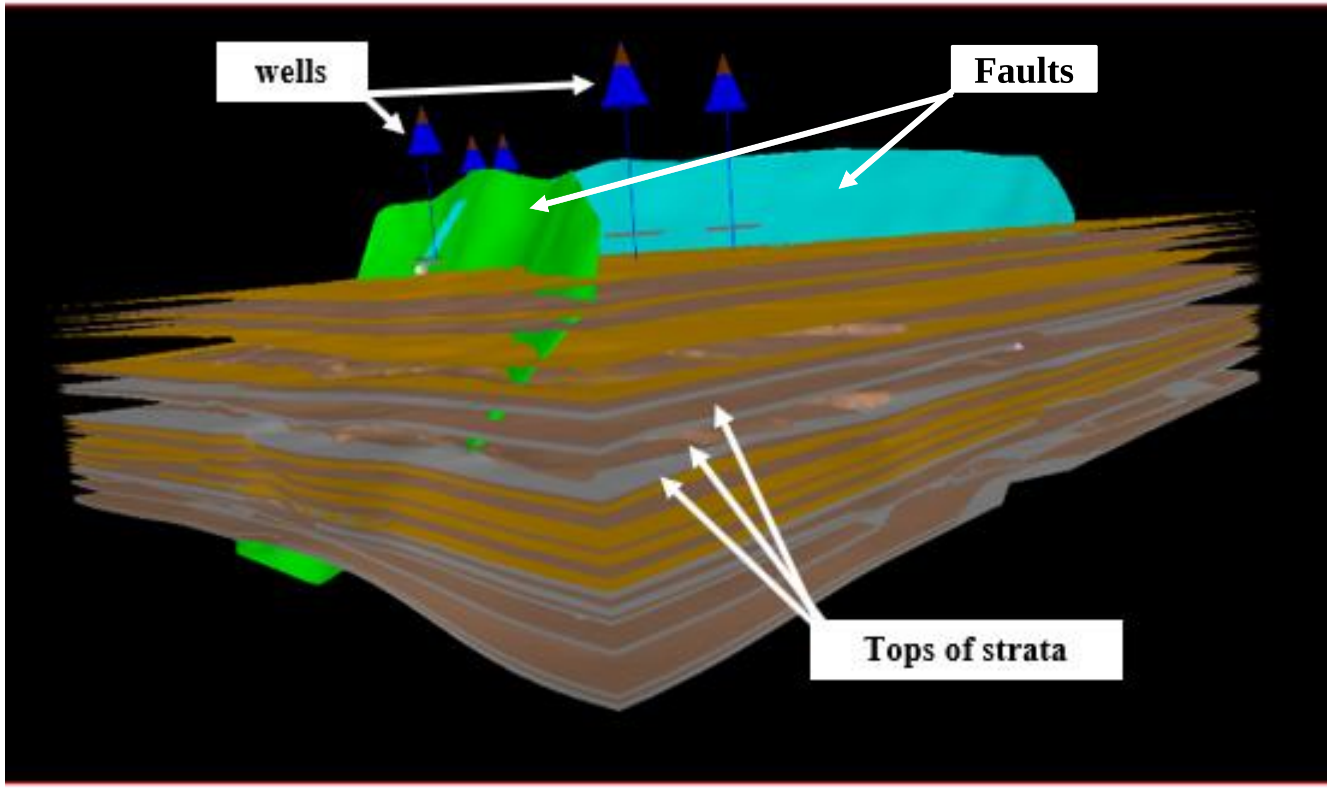

multidisciplinary studies for interdisciplinary solutions

Offshore Gulf of Mexico Application

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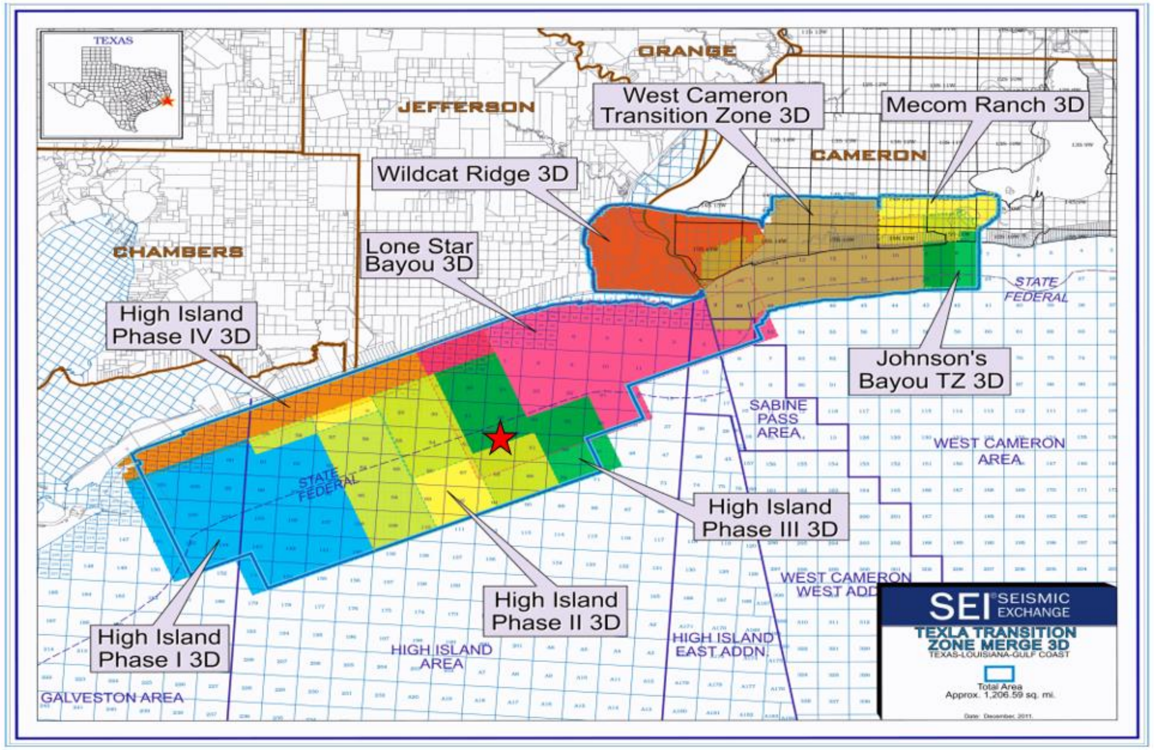

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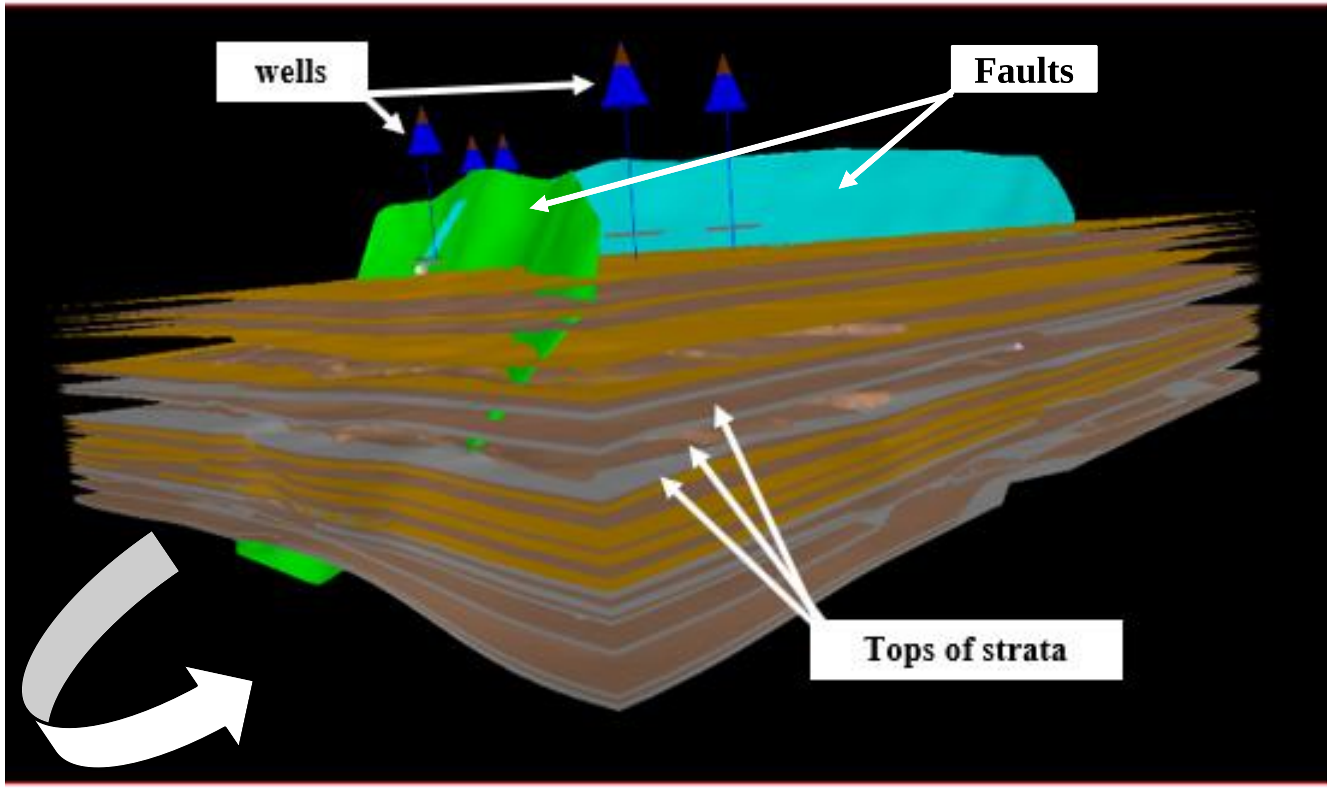
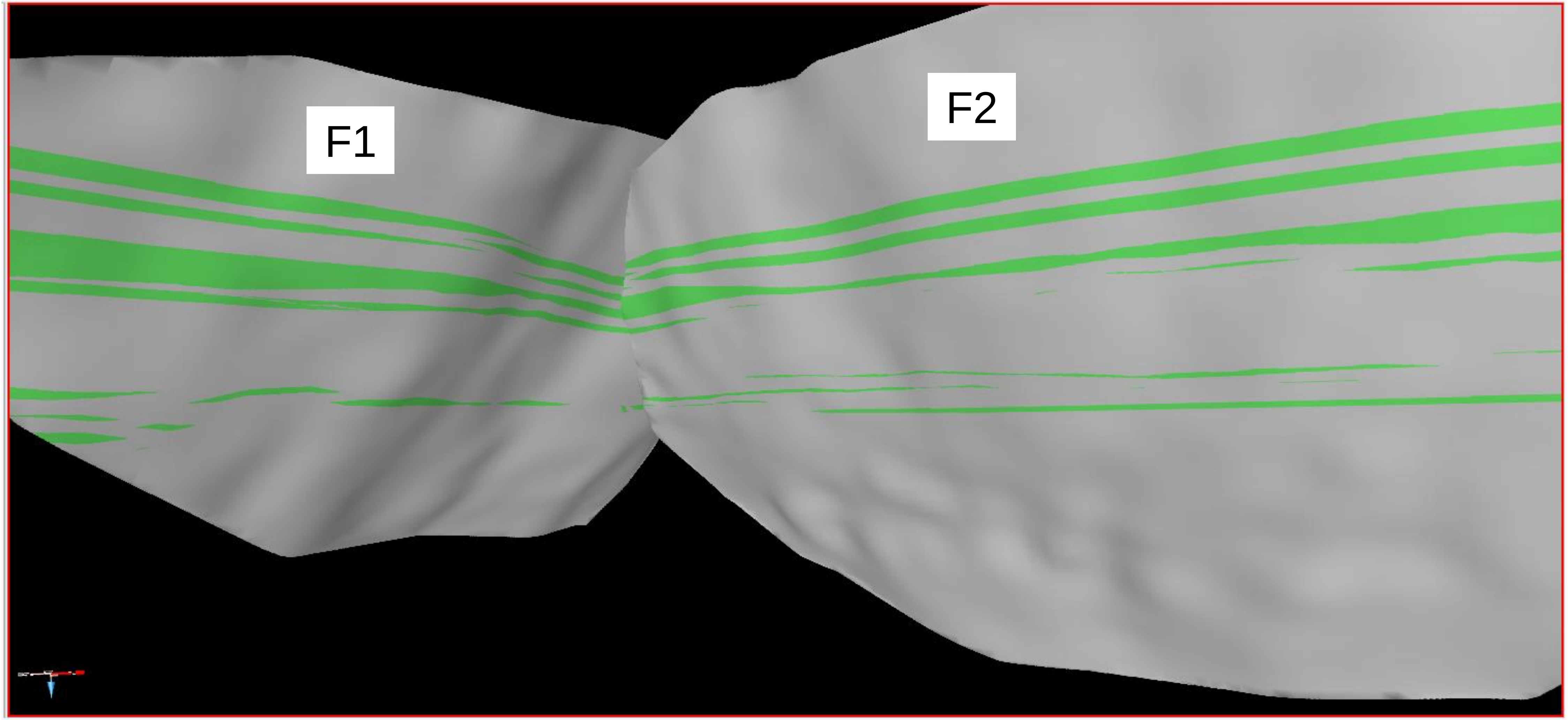
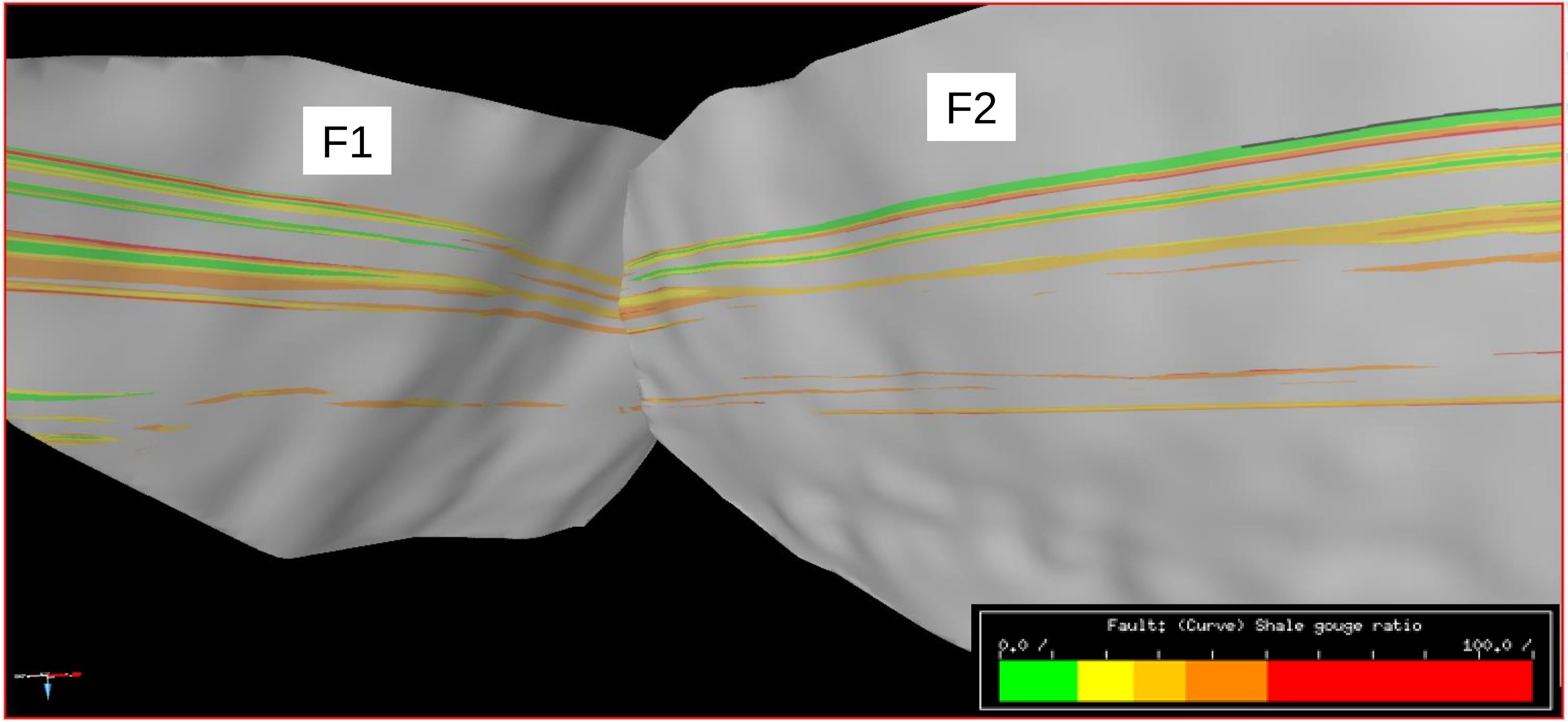


multidisciplinary studies for interdisciplinary solutions

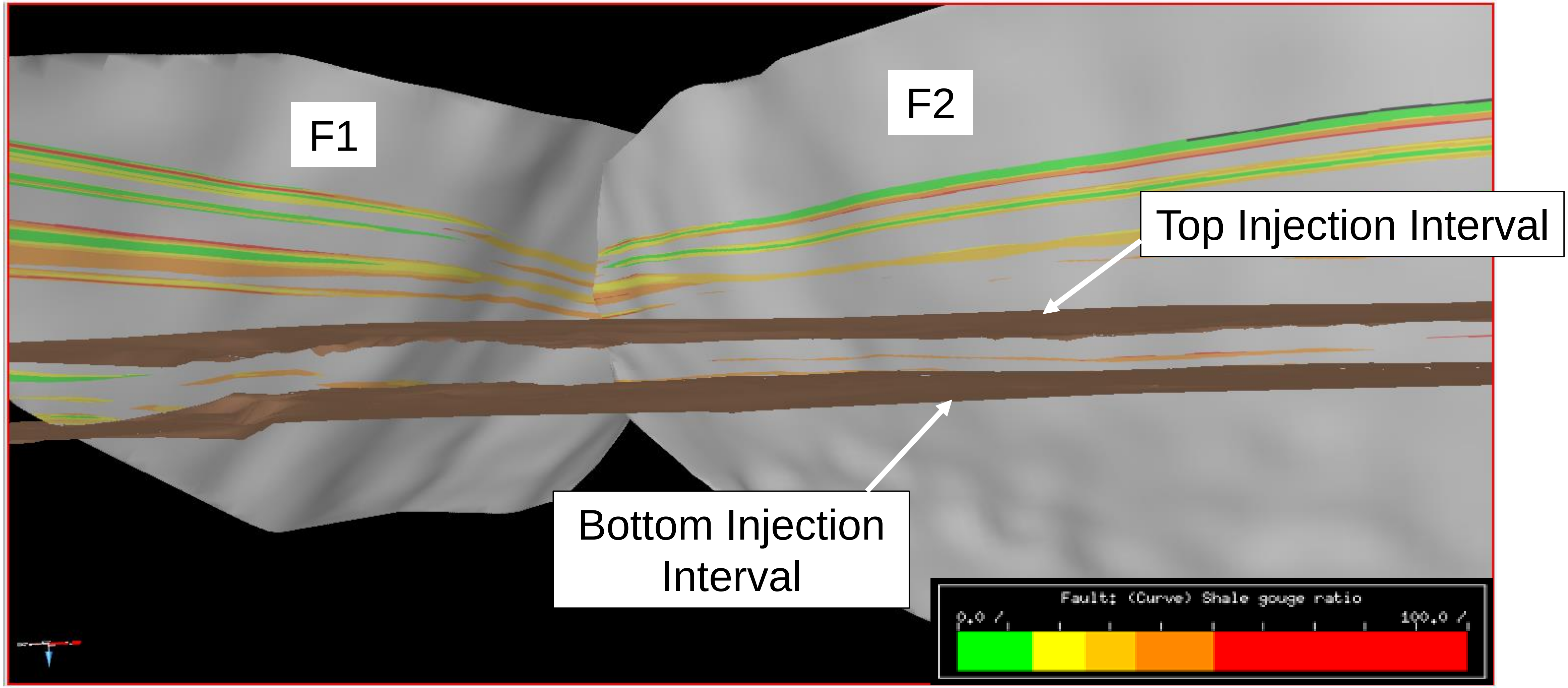
Reservoir-Reservoir Areas – No Seal



SGR in Reservoir-Reservoir Areas



Juxtaposition – No-Seal Areas



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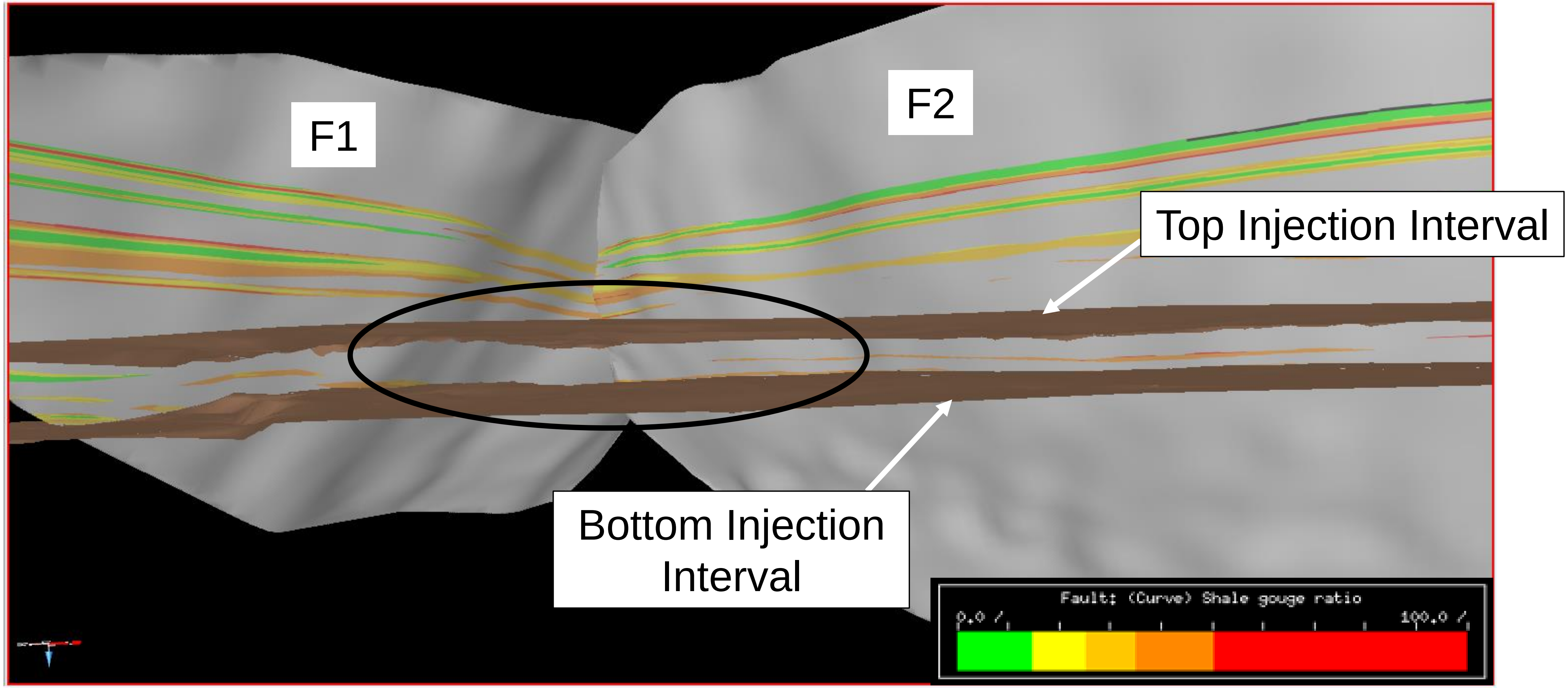

Areas of highest leakage potential

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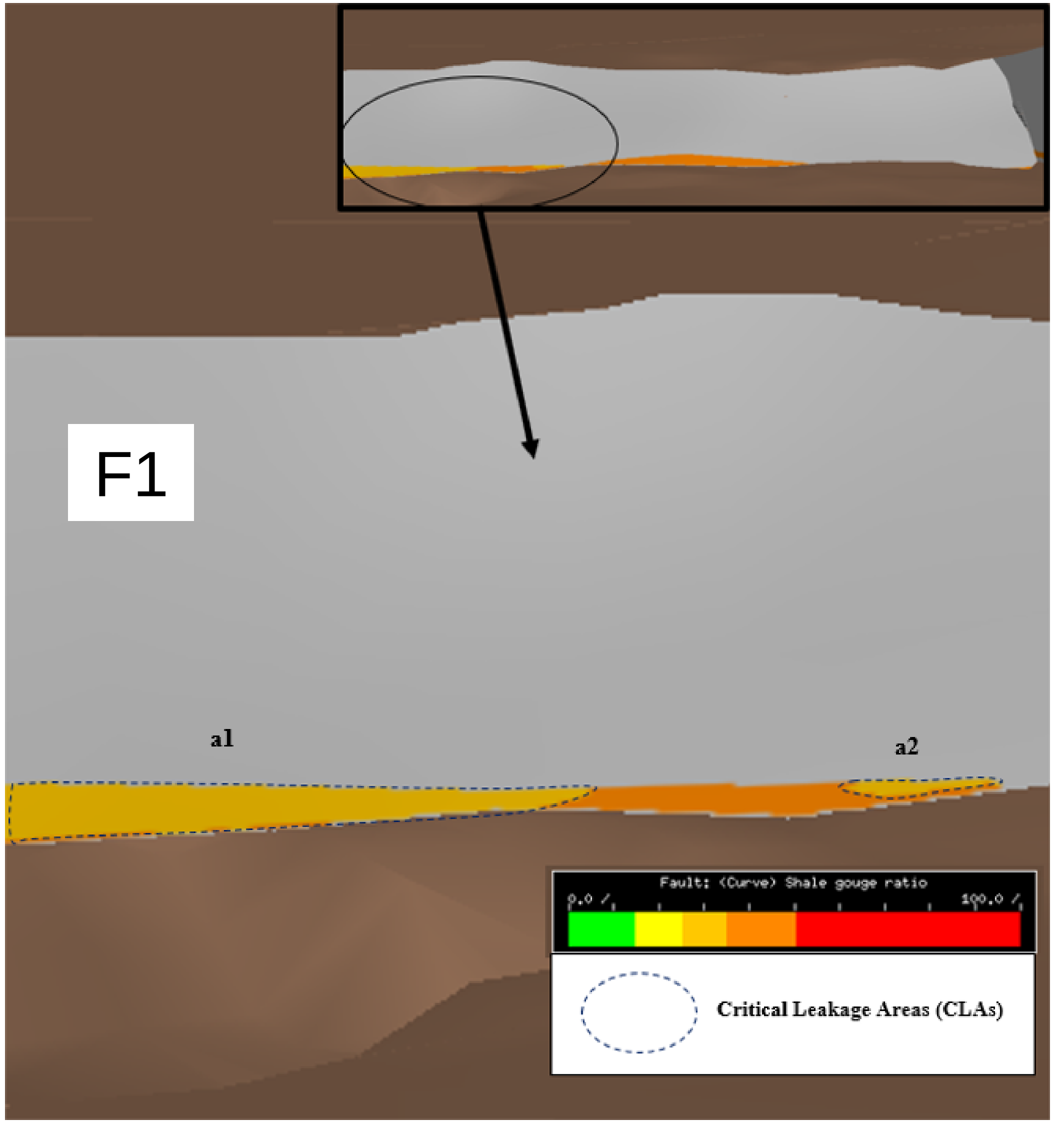

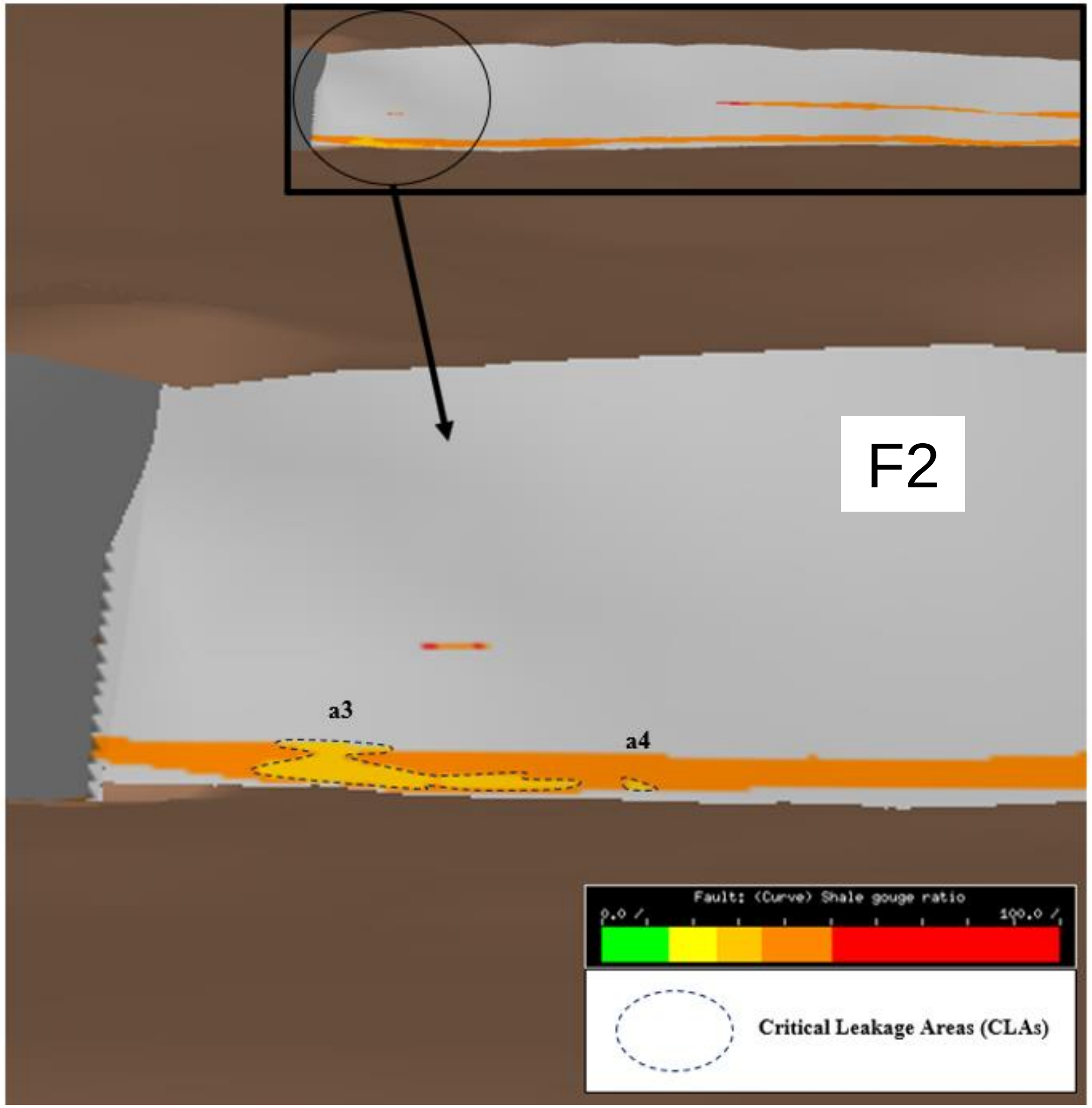

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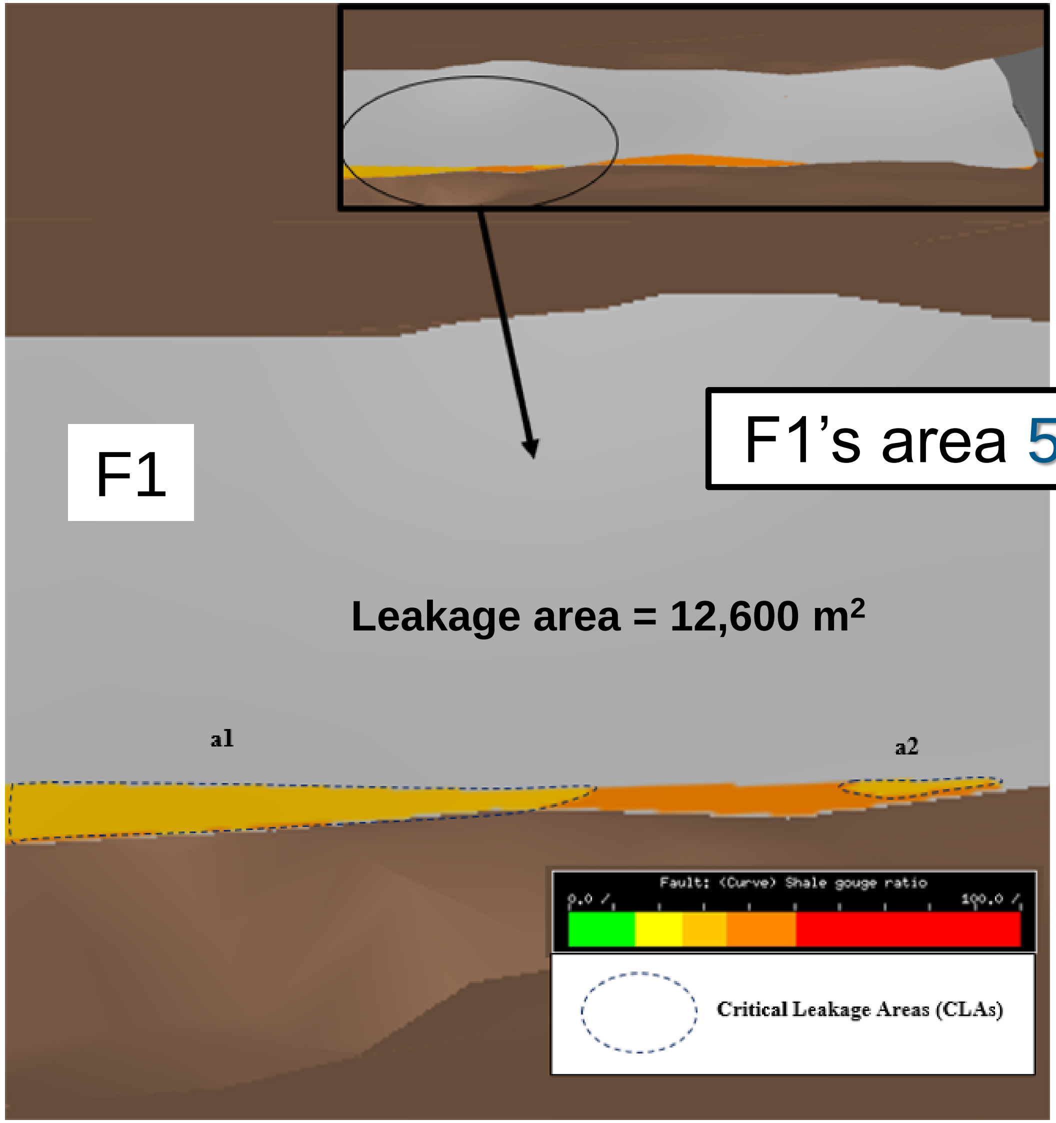
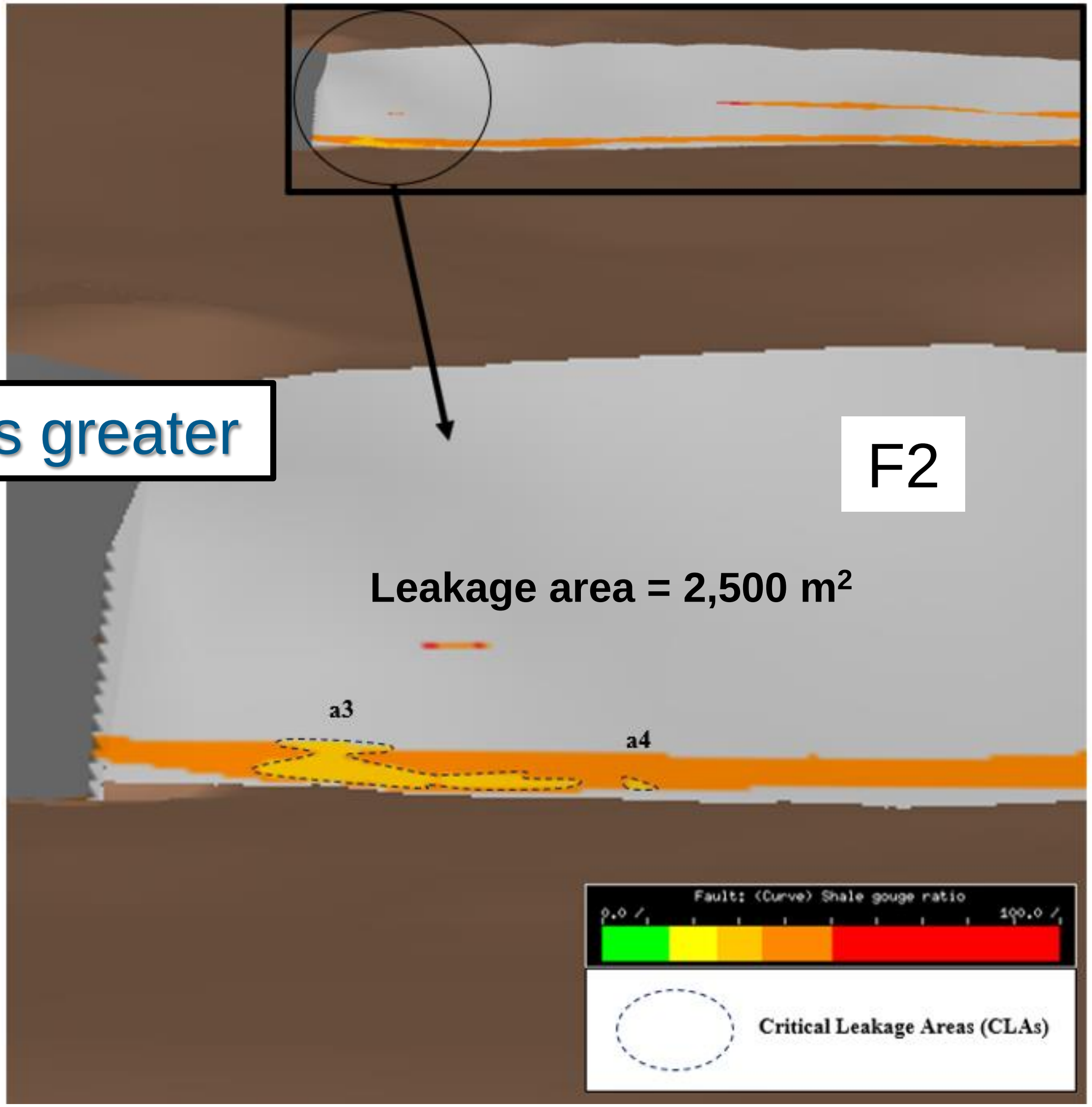


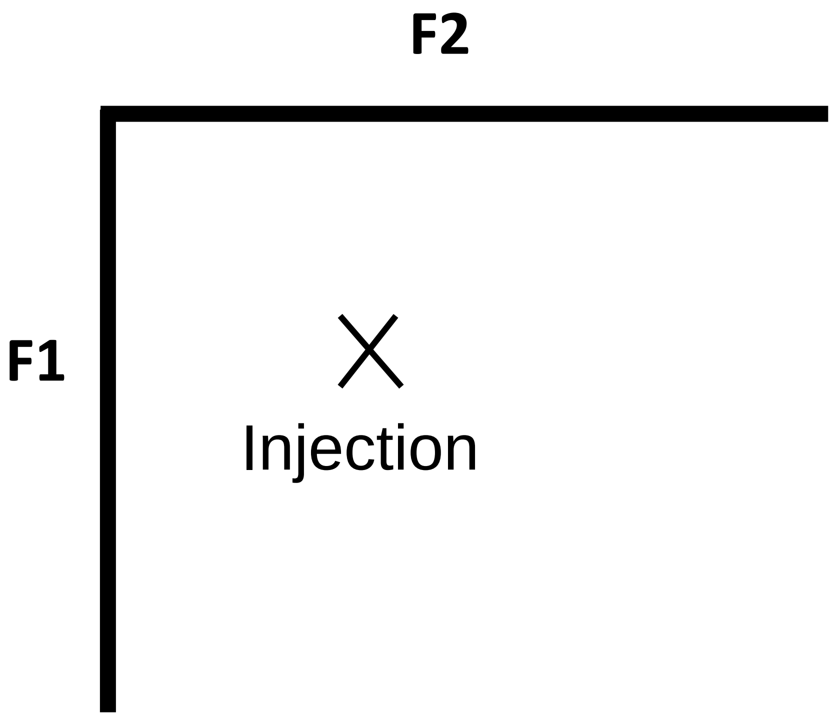
F1's area 5 times greater



Reservoir Boundary Conditions

ΔP in Darcy Equation = pore water pressure increase

- Constant injection rate: 0.7 $MtCO_2$/yr. (single well)
- For **40 years**
- Typical GoM reservoir properties

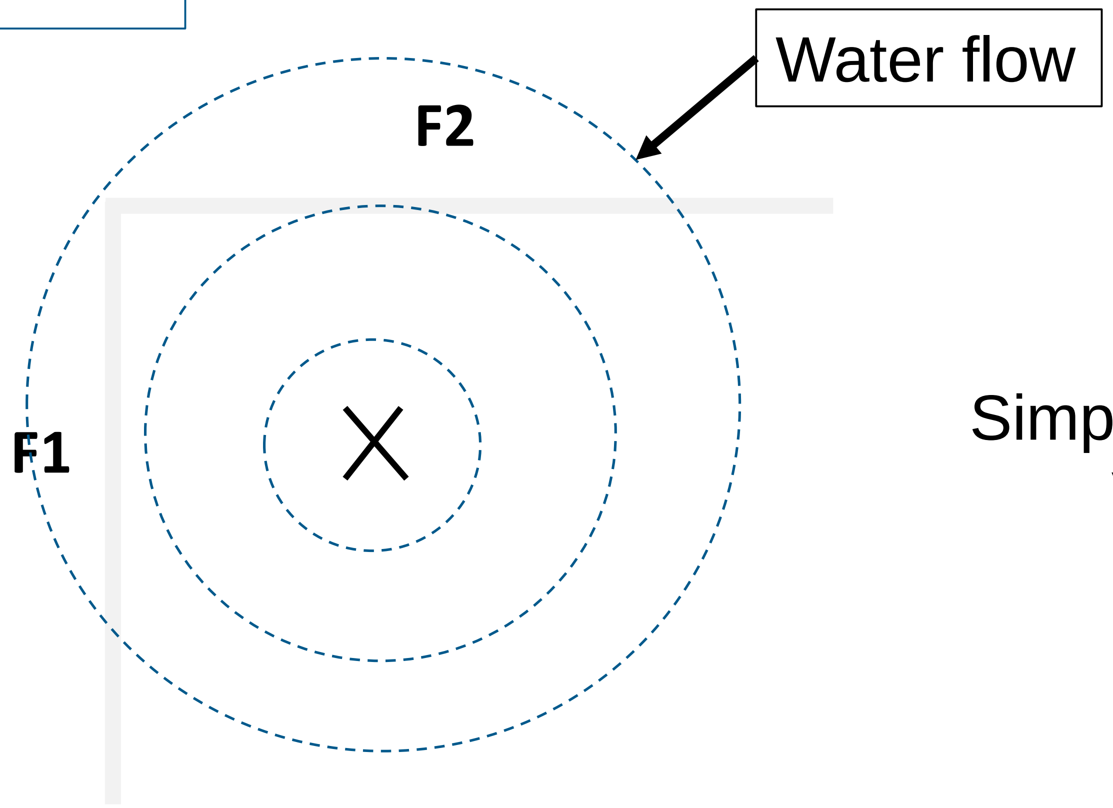


Simplified Map View

Reservoir Boundary Conditions

ΔP in Darcy Equation = pore water pressure increase

OPEN boundaries



Simplified Map View

Reservoir Boundary Conditions

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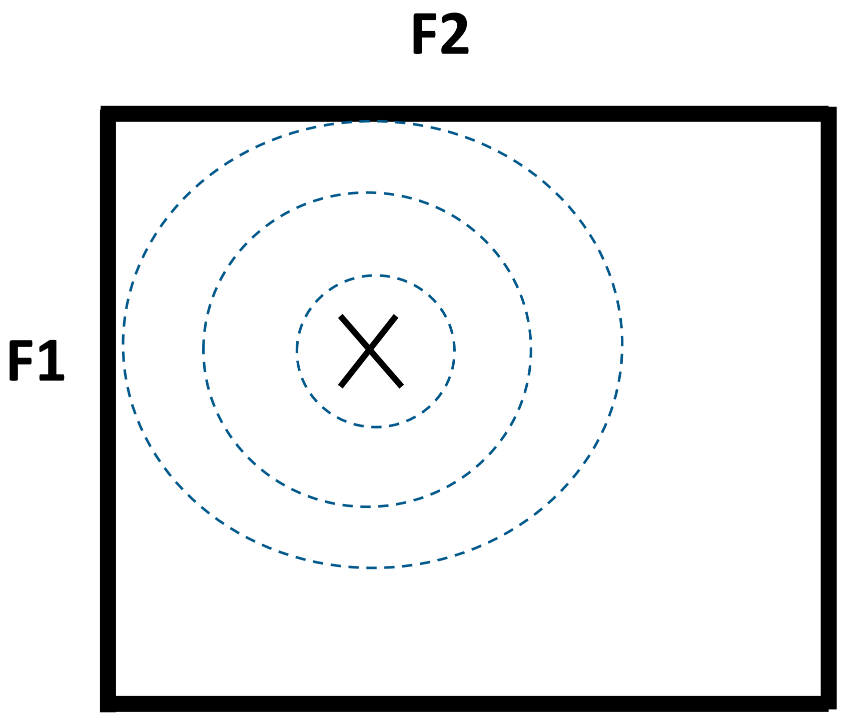
CLOSED boundaries



Simplified Map View

Reservoir Boundary Conditions

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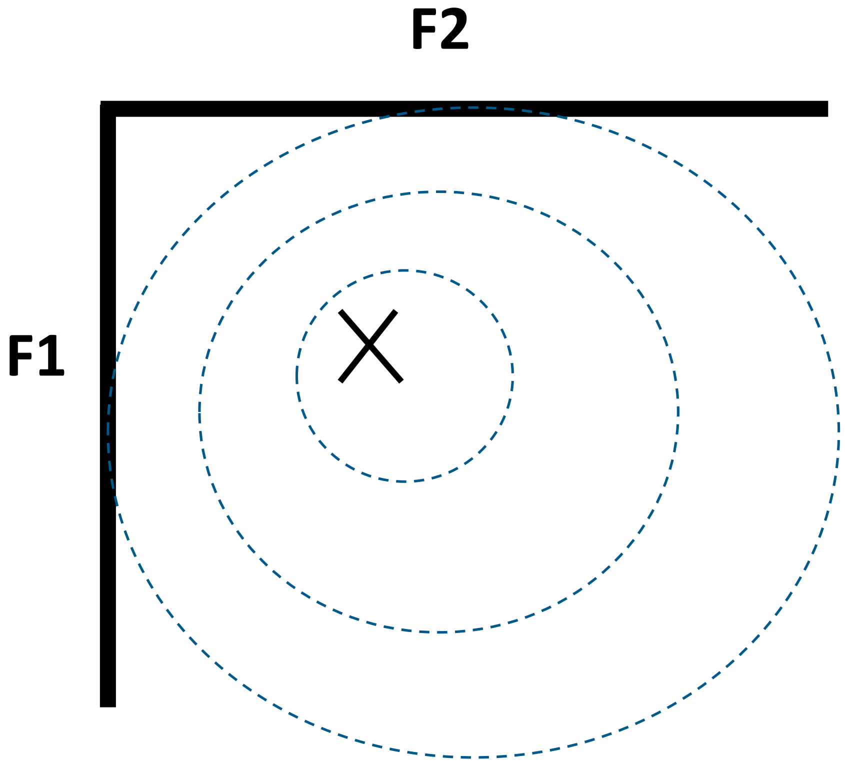
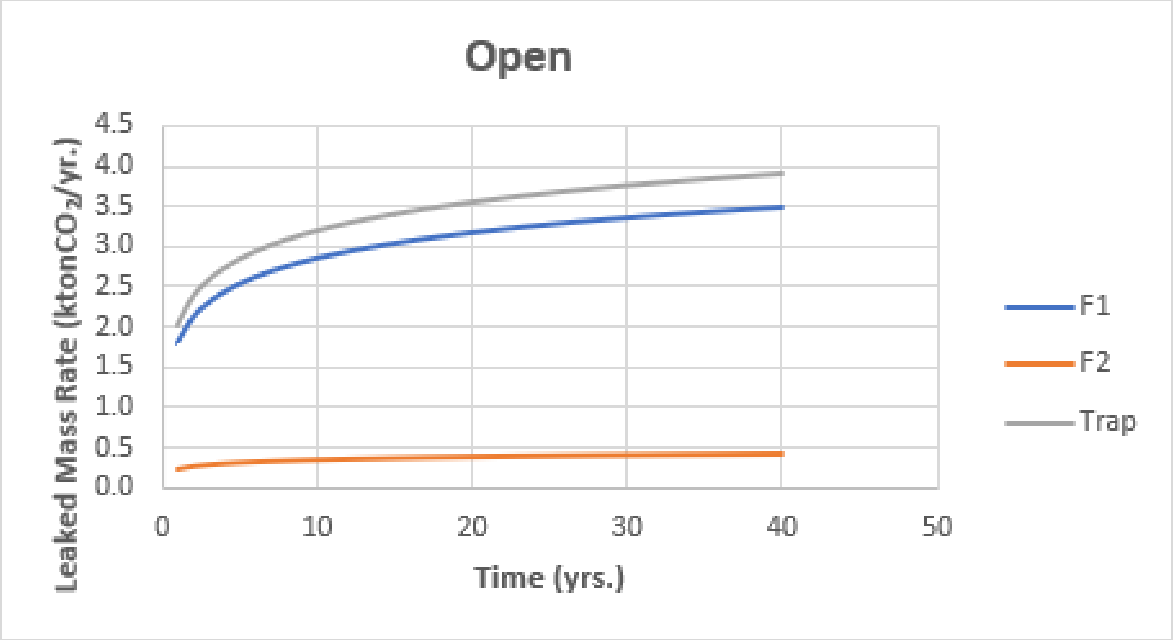
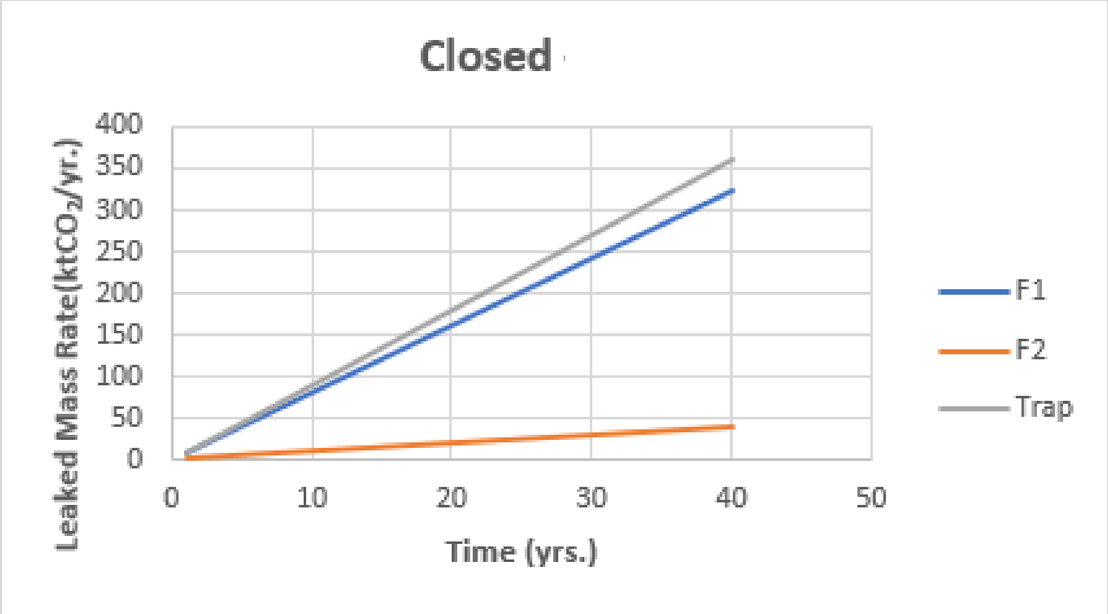
SEMI-CLOSED boundaries

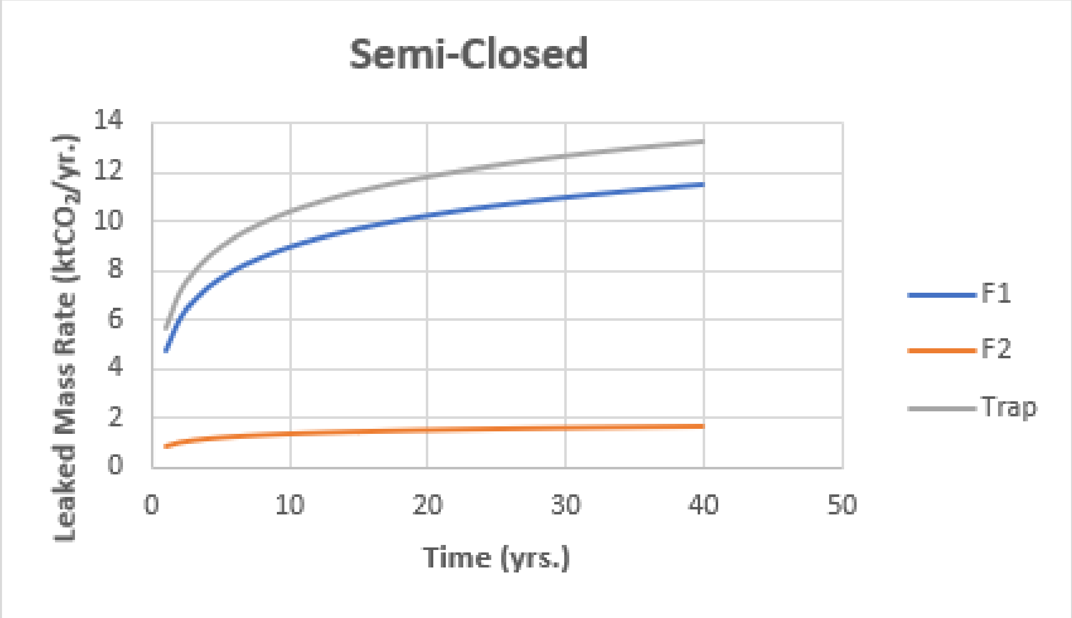


Simplified Map View

RESULTS


Open
Leaked Mass Rate (ktonCO$_2$/yr.)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
Time (yrs.)
F1
F2
Trap


Closed
Leaked Mass Rate(ktCO$_2$/yr.)
400
350
300
250
200
150
100
50
0
0
10
20
30
40
50
Time (yrs.)
F1
F2
Trap


Semi-Closed
Leaked Mass Rate (ktCO$_2$/yr.)
14
12
10
8
6
4
2
0
0
10
20
30
40
50
Time (yrs.)
F1
F2
Trap

Average yearly leakage rates – faults combined

Boundary Conditions	Fault-to-Well Distance (m)		
	100	1,000	2,000
Open	4.25	3.43	2.72
Closed	186.05	185.22	184.51
Semi-Closed	13.15	11.23	9.54

Average yearly leakage rates – faults combined

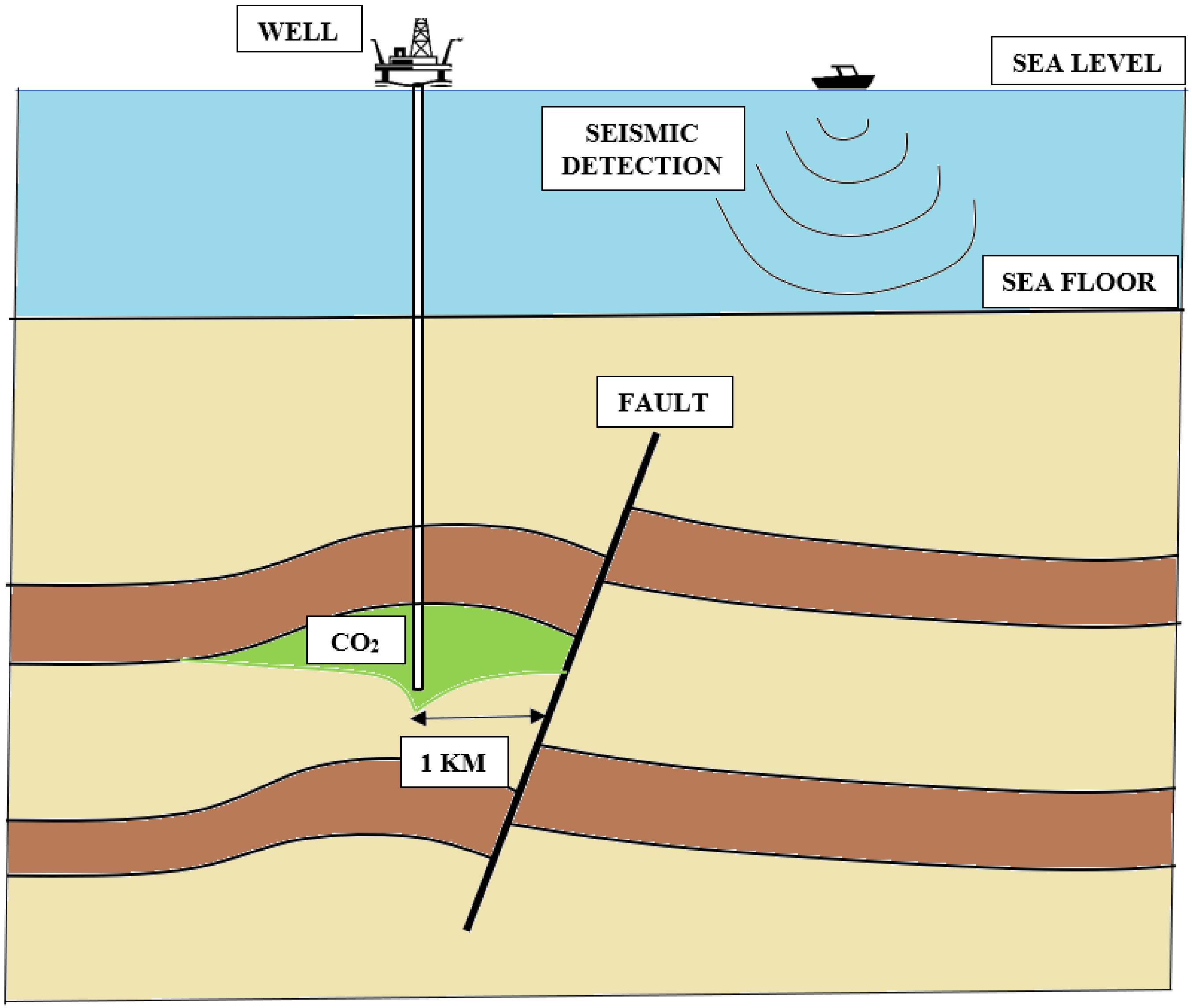
Boundary Conditions	*Fault-to-Well Distance (m)*		
	100	*1,000*	*2,000*
Open	4.25	3.43	2.72
Closed	186.05	185.22	184.51
Semi-Closed	13.15	11.23	9.54

- Monte Carlo Simulations
  - Leaks 372 to 570 ktCO_2 (90% confidence) ~ 1.6% (of total injected)

- F1 leaks 6 to 9 times more CO_2 than F2

- Pressure and area matter!

DISCOUNTED-CASHFLOW VALUATION

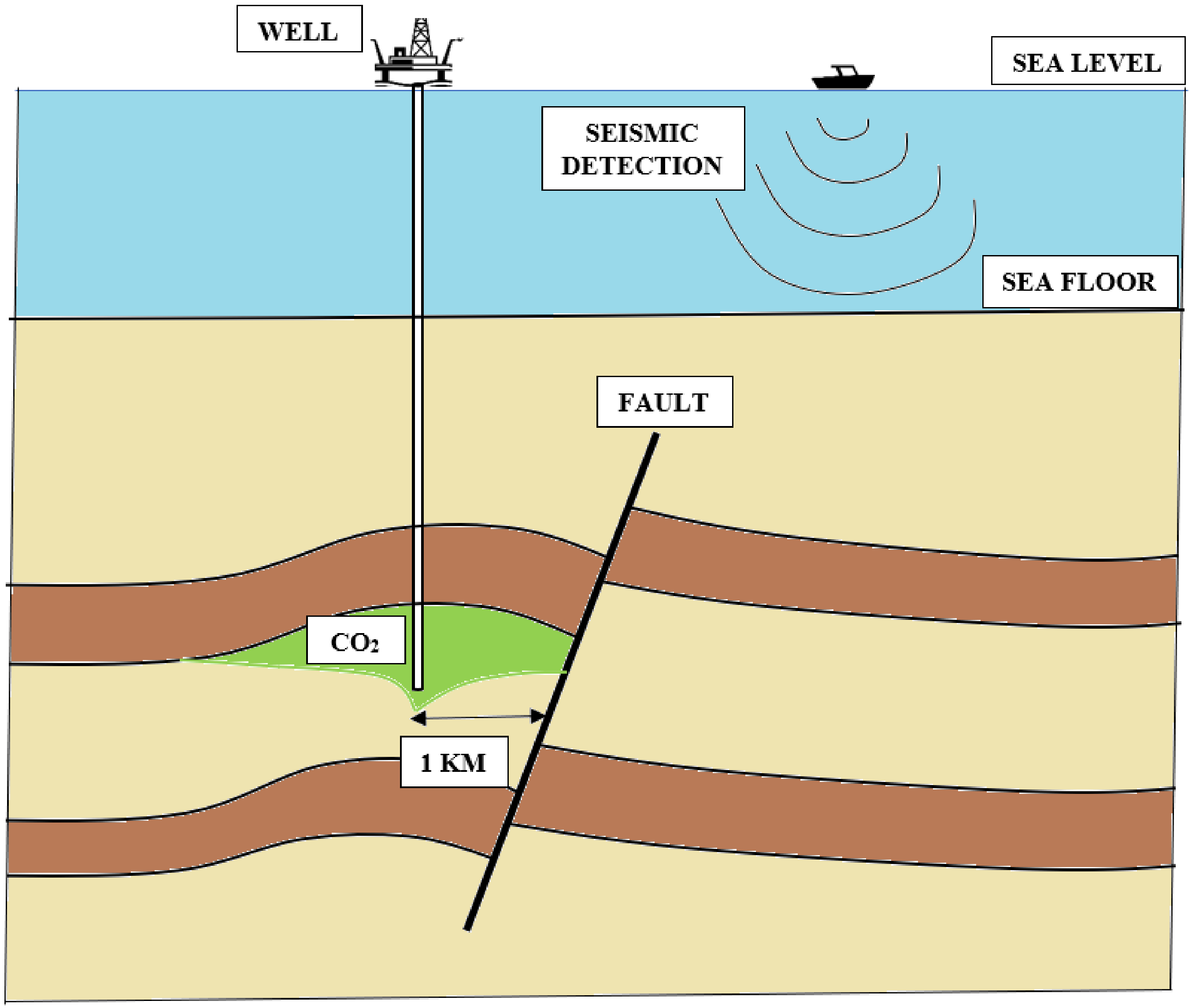


- Revenue = carbon credits
- Estimated CAPEX-OPEX
- Leakage cost = credits forgone + financial liability
- Seismic detection threshold = 10 ktCO_2
- Seismic shot at 3-year intervals

* *Boat and oil rig art from http://www.clipartbest.com/clipart-LiK5nKeXT and http://clipart-library.com/clipart/oil-rig-clipart_10.htm*

DISCOUNTED-CASHFLOW VALUATION

ENERGY AND EARTH RESOURCES GRADUATE PROGRAM



Scenario 1: No-Leakage

No carbon credits forgone, no financial liability

NPV = $63 M

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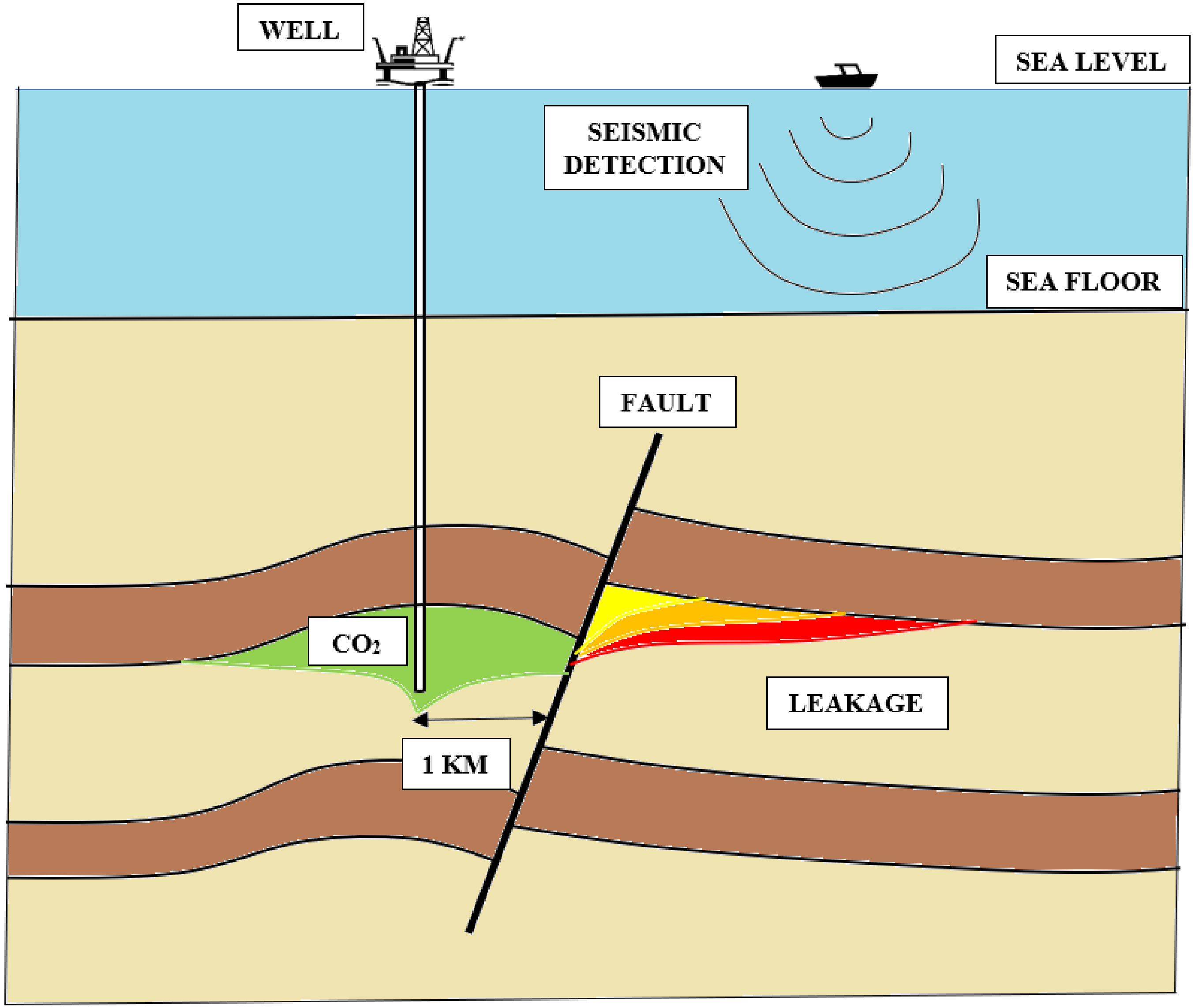
DISCOUNTED-CASHFLOW VALUATION

ENERGY AND EARTH RESOURCES GRADUATE PROGRAM



Scenario 2: Estimated Leakage Rates

- Undetectable
- Detectable, no seismic
- Detected

Detected in Year 3 (red), 20.5 ktCO2 credits forgone, Pay $6 M liability in Year 3

NPV = $52 M

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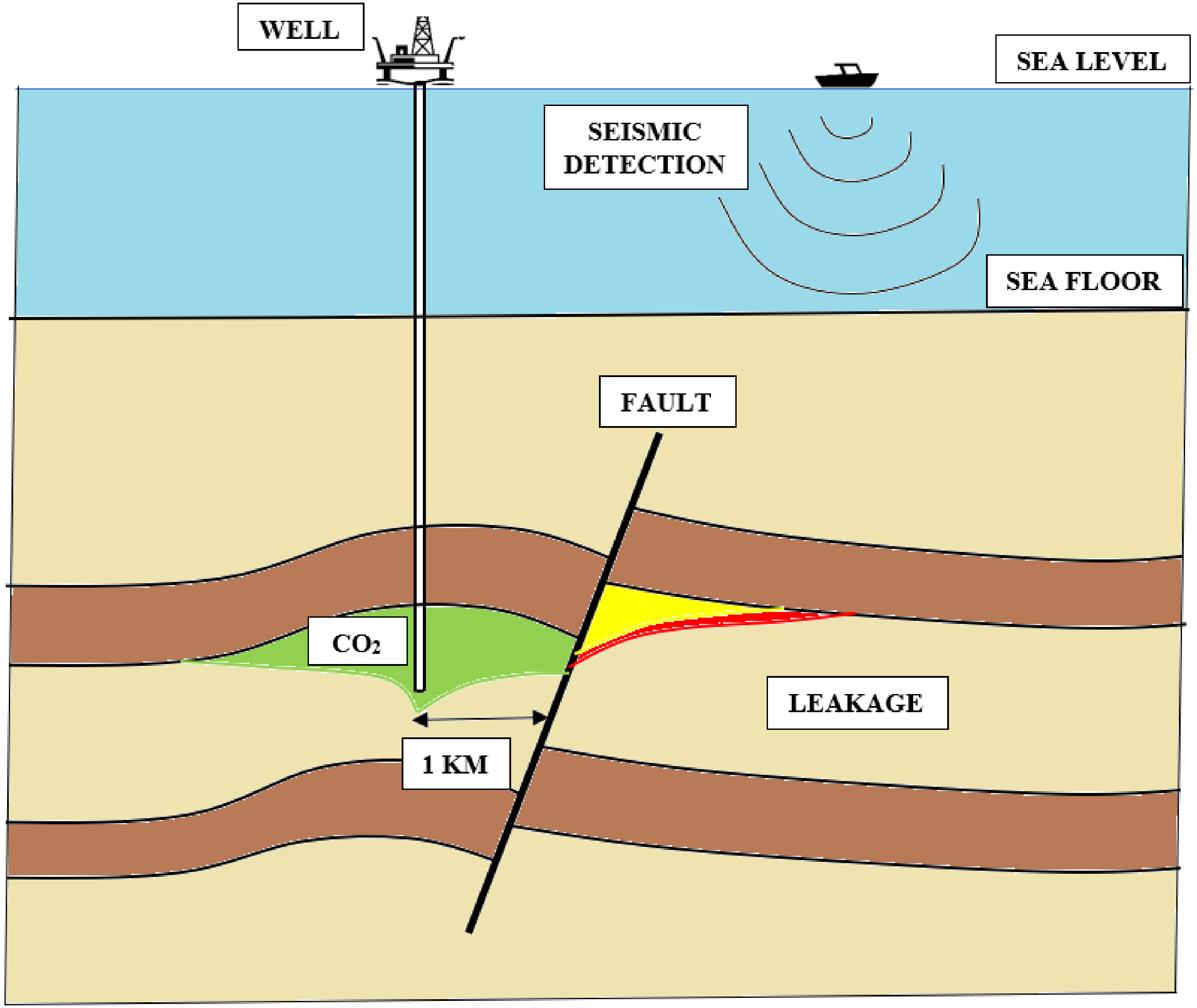
DISCOUNTED-CASHFLOW VALUATION



Scenario 3: Probability-Based Leakage Rates

Undetectable

Detected

Detected in Year 12 (red), 10.8 ktCO2 credits forgone, Pay $6 M liability in Year 12

NPV = $55 M

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MAIN TAKEAWAYS

ENERGY AND EARTH RESOURCES GRADUATE PROGRAM

- NPV of project can fluctuate significantly depending on leakage rates

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- Fault attributes favor slow leakage rates in our GoM example and potentially analogous reservoirs

MAIN TAKEAWAYS

- NPV of project can fluctuate significantly depending on leakage rates
- Reservoir pressure management is key
- Accurate leakage area size requires accurate seismic and log interpretation
- Fault attributes favor slow leakage rates in our GoM example and potentially analogous reservoirs
- Fraction of leaked CO_2 represents a conservative estimate in our GoM example

ACKNOWLEDGMENTS

- Dr. Bump and Dr. Hovorka (supervisor and co-supervisor), and Dr. Hennings and Dr. Hahn (readers) for their guidance
- Energy and Earth Resources (EER) Graduate Program for their funding
- Department of Energy (DOE) for their funding
- Gulf Coast Carbon Center (GCCC) and the Bureau of Economic Geology (BEG) for their expertise and equipment

US DOE NETL

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