Feasibility assessment of carbon sequestration in the Grand Banks, offshore Newfoundland, Canada

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Abstract
EGU26-770

1 Introduction

- The Grand Banks is a structurally complex segment of the North Atlantic rift system, characterized by extensional faults, halokinesis, and heterogeneous rift basins.
- Despite advantageous geological formations, proximity to major CO_2 sources, and existing offshore infrastructure, the Grand Banks remains underexplored for Carbon Capture and Storage (CCS).
- Uncertainties in structural framework, fault architecture, and seismic history limit geological modelling needed for storage assessment.

Research Question

Are there potential sites for secure CCS integration within offshore Grand Banks, Newfoundland based on its geological and structural framework?

Objectives

- Investigate structural relationships between fault networks, salt structures, and stratigraphic sequences
- Characterize the tectono-structural evolution of the Grand Banks
- Construct and interpret the regional structural framework and basin architecture
- Identify candidate CCS sites, optimal injection locations, and safe injection thresholds to minimize induced seismicity risk

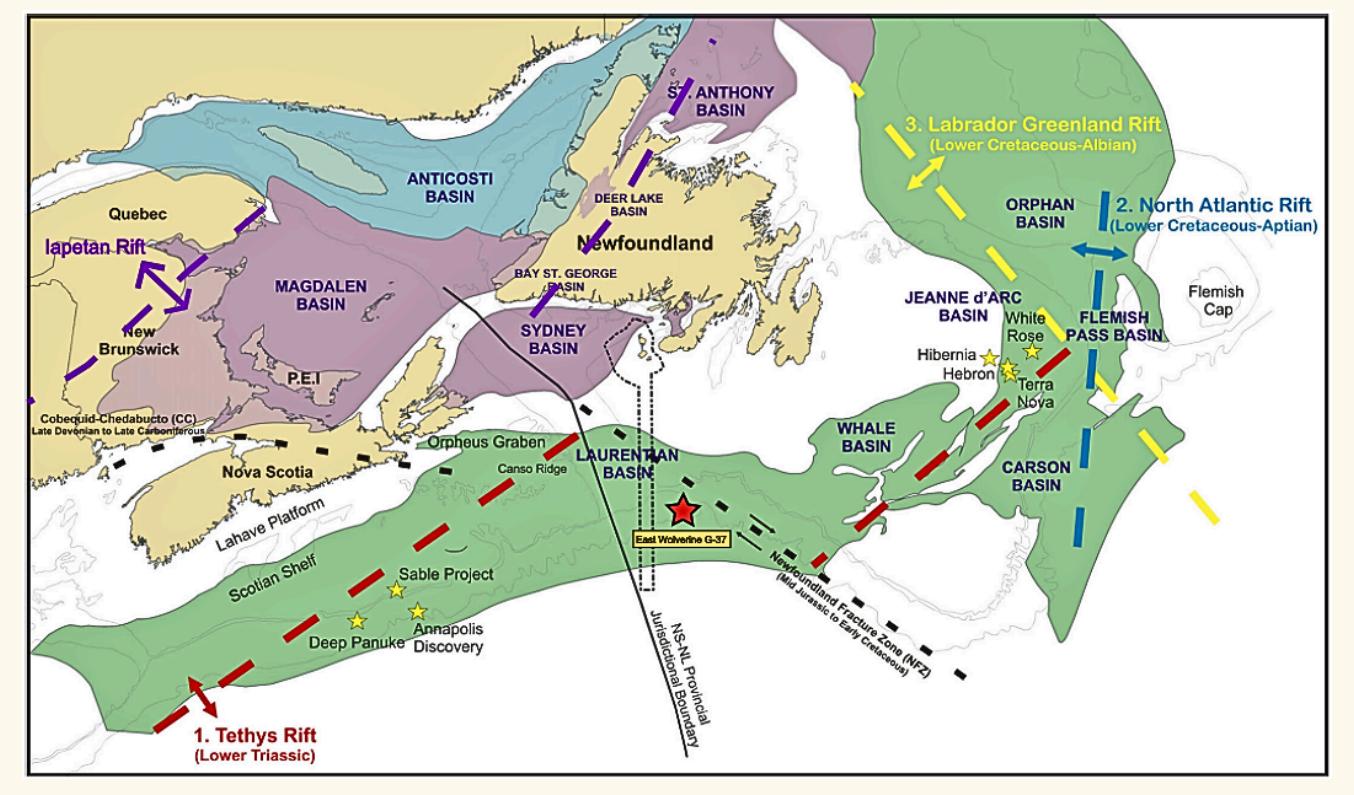

ST. ANTHONY BASIN
3. Labrador Greenland Rift (Lower Cretaceous-Albian)
ANTICOSTI BASIN
DEER LAKE BASIN
Quebec
Iapetan Rift
Newfoundland
ORPHAN BASIN
2. North Atlantic Rift (Lower Cretaceous-Aptian)
MAGDALEN BASIN
BAY ST. GEORGE BASIN
JEANNE d'ARC BASIN
New Brunswick
SYDNEY BASIN
Flemish Cap
PEI
Hibernia
Hebron
White Rose
FLEMISH PASS BASIN
Terra Nova
Cobequid-Chedabucto (CC)
Orpheus Graben
Nova Scotia
Canso Ridge
LAURENTIAN BASIN
WHALE BASIN
CARSON BASIN
Lahave Platform
Scotian Shelf
East Wolverine G-37
Sable Project
Deep Panuke
Annapolis Discovery
1. Tethys Rift (Lower Triassic)
NS-NL Provincial Jurisdictional Boundary

Figure 1. Tectonic elements of Canadian Atlantic Margin adapted from C-NLOPB (2012)[1].

2 Study Region and Geological Background

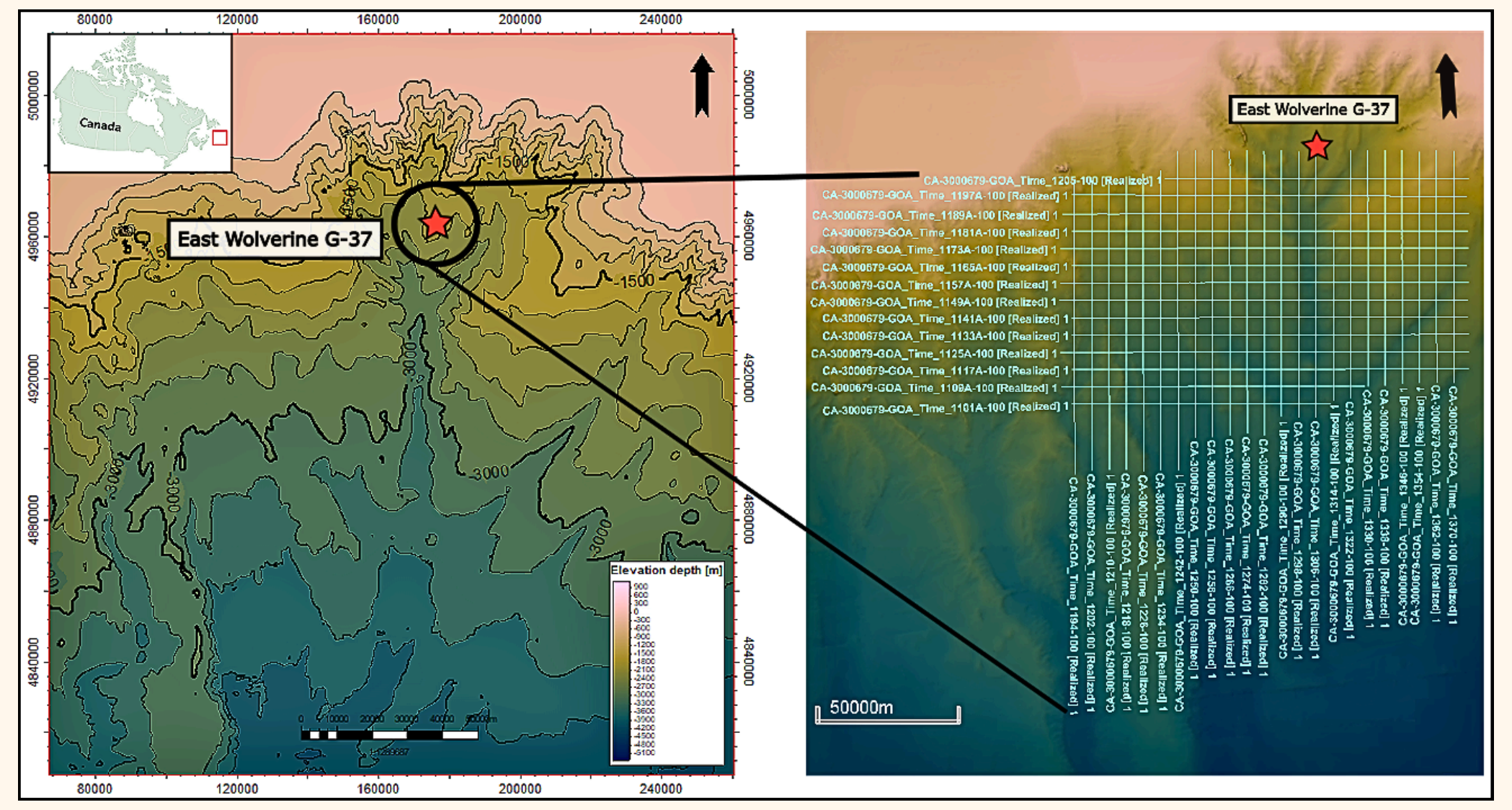

Canada
East Wolverine G-37
Elevation depth [m]
50000m

Figure 2. Bathymetry map of Grand Banks region. Red star marks the East Wolverine G-37 well location.

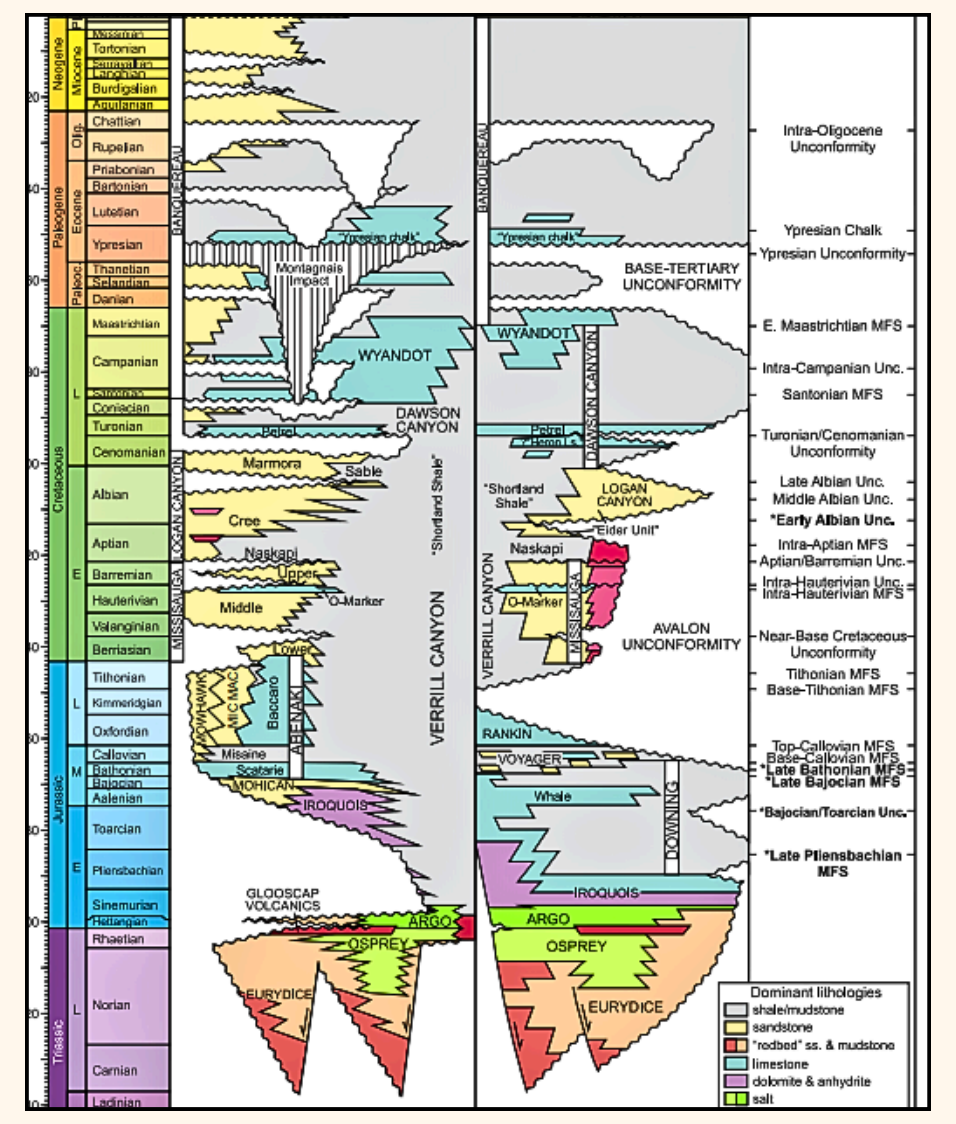
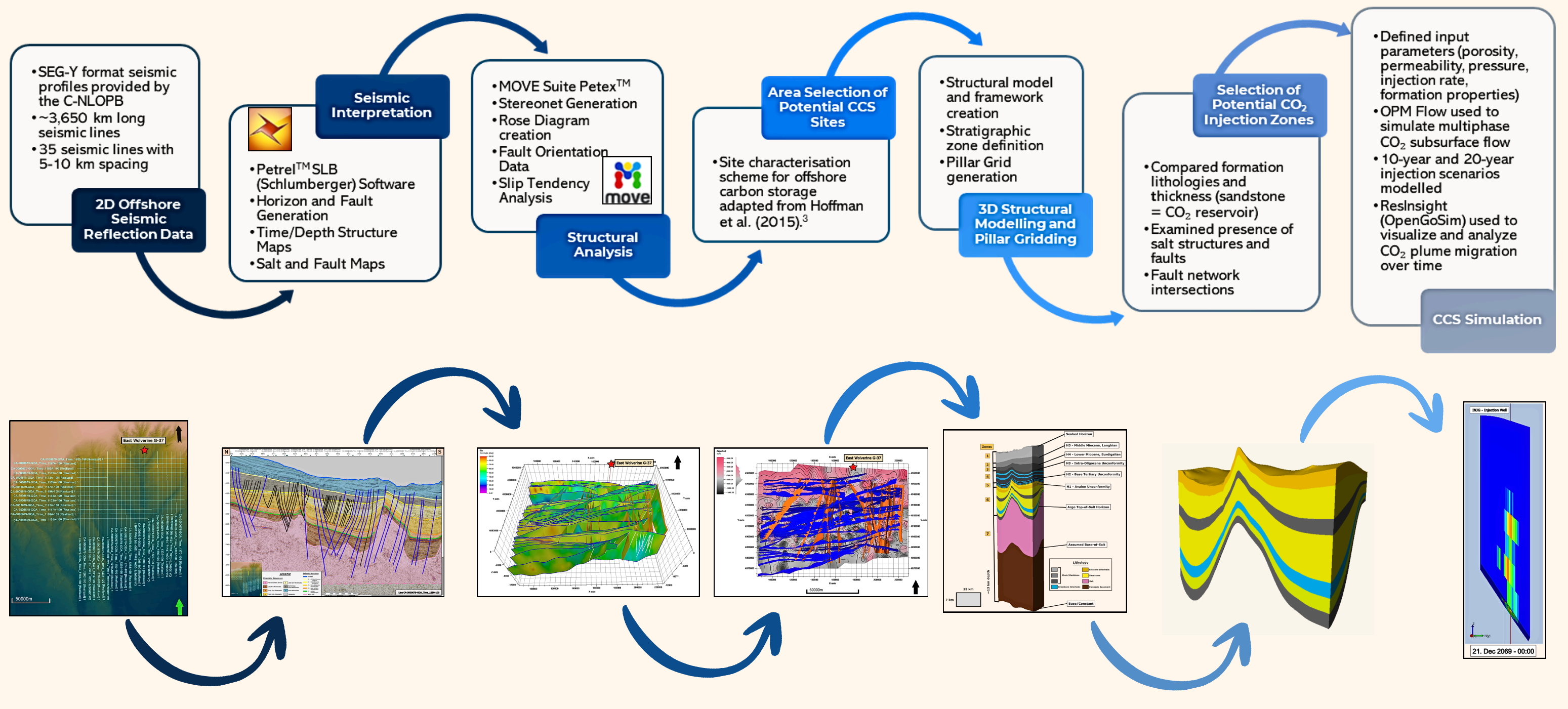

Intra-Oligocene Unconformity
Ypresian Chalk
Ypresian Unconformity
BASE-TERTIARY UNCONFORMITY
E. Maastrichtian MFS
Intra-Campanian Unc.
Santonian MFS
Turonian/Cenomanian Unconformity
Late Albian Unc.
Middle Albian Unc.
Early Albian Unc.
AVALON UNCONFORMITY
Tithonian MFS
Base-Tithonian MFS
Late Pliensbachian MFS
WYANDOT
DAWSON CANYON
LOGAN CANYON
VERRILL CANYON
IROQUOIS
ARGO
OSPREY
EURYDICE
GLOOSCAP VOLCANICS
Dominant lithologies
shale/mudstone
sandstone
limestone
dolomite & anhydrite
salt

Figure 3. Mesozoic lithostratigraphy of Laurentian Basin in southern Grand Banks adapted from Weston et al. (2023)[2].

3 Methodology



- SEG-Y format seismic profiles provided by the C-NLOPB
- ~3,650 km long seismic lines
- 35 seismic lines with 5-10 km spacing

2D Offshore Seismic Reflection Data

Seismic Interpretation

- Petrel™ SLB (Schlumberger) Software
- Horizon and Fault Generation
- Time/Depth Structure Maps
- Salt and Fault Maps

- MOVE Suite Petex™
- Stereonet Generation
- Rose Diagram creation
- Fault Orientation Data
- Slip Tendency Analysis

Structural Analysis

Area Selection of Potential CCS Sites

- Site characterisation scheme for offshore carbon storage adapted from Hoffman et al. (2015).[3]

- Structural model and framework creation
- Stratigraphic zone definition
- Pillar Grid generation

3D Structural Modelling and Pillar Gridding

Selection of Potential CO_2 Injection Zones

- Compared formation lithologies and thickness (sandstone = CO_2 reservoir)
- Examined presence of salt structures and faults
- Fault network intersections

- Defined input parameters (porosity, permeability, pressure, injection rate, formation properties)
- OPM Flow used to simulate multiphase CO_2 subsurface flow
- 10-year and 20-year injection scenarios modelled
- ResInsight (OpenGoSim) used to visualize and analyze CO_2 plume migration over time

CCS Simulation

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4 Results

A 2D Seismic Interpretation

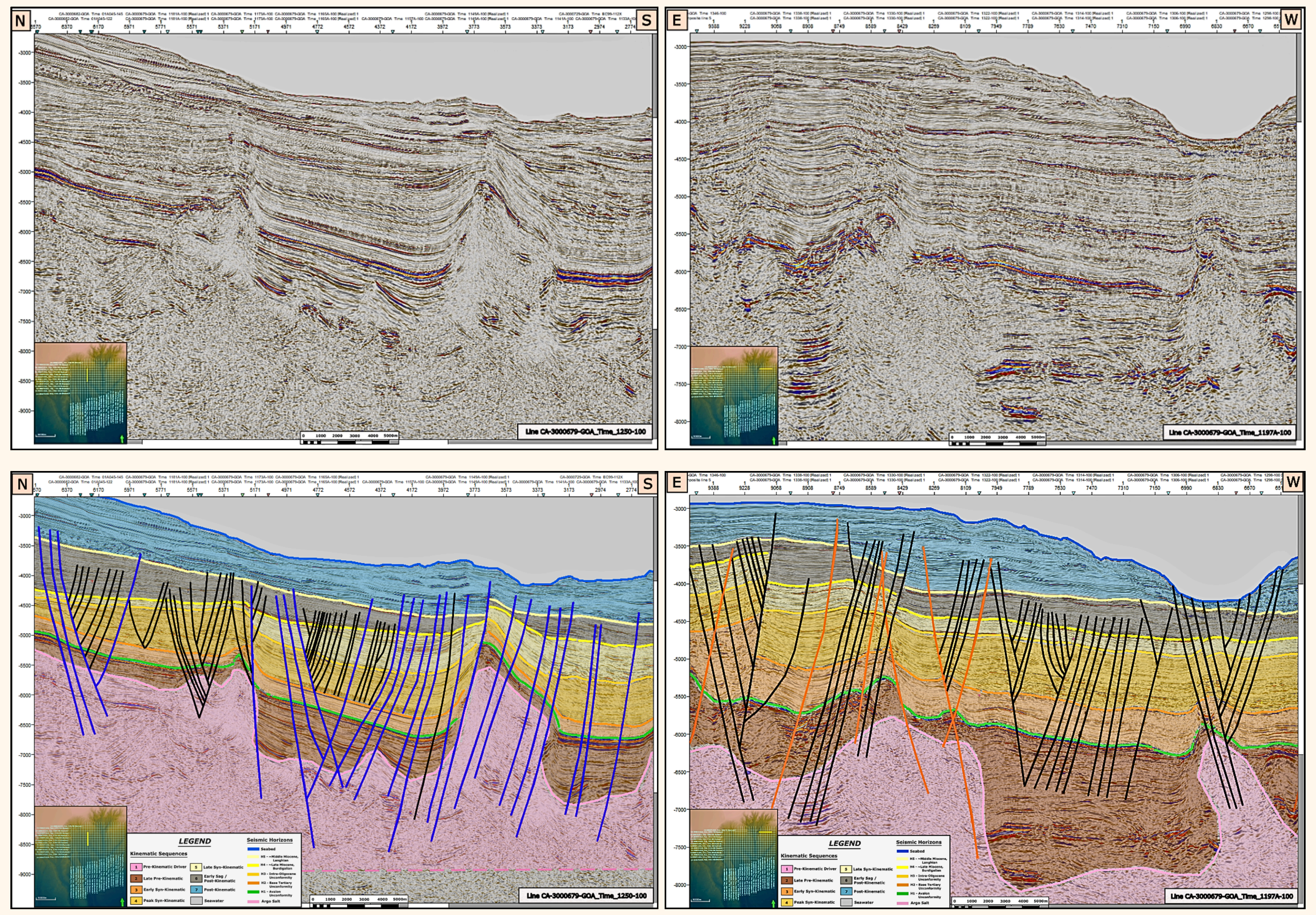
N
S
E
W
Line CA-3000679-GOA_Time_1250-100
Line CA-3000679-GOA_Time_1197A-100
LEGEND
Kinematic Sequences
Pre-Kinematic Driver
Late Pre-Kinematic
Early Syn-Kinematic
Peak Syn-Kinematic
Late Syn-Kinematic
Early Sag / Post-Kinematic
Post-Kinematic
Seawater
Seismic Horizons
Seabed
H5 - Middle Miocene, Langhian
H4 - Lower Miocene, Burdigalian
H3 - Intra-Oligocene Unconformity
H2 - Base Tertiary Unconformity
H1 - Avalon Unconformity
Argo Salt

Figure 4. Uninterpreted (top) and interpreted (bottom) N-S and E-W oriented seismic profiles. Coloured fault sticks (Blue and Orange) correspond to fault interpretations incorporated into fault maps presented in Figures 7 and 8.

B Salt Tectonics and Basin Architecture

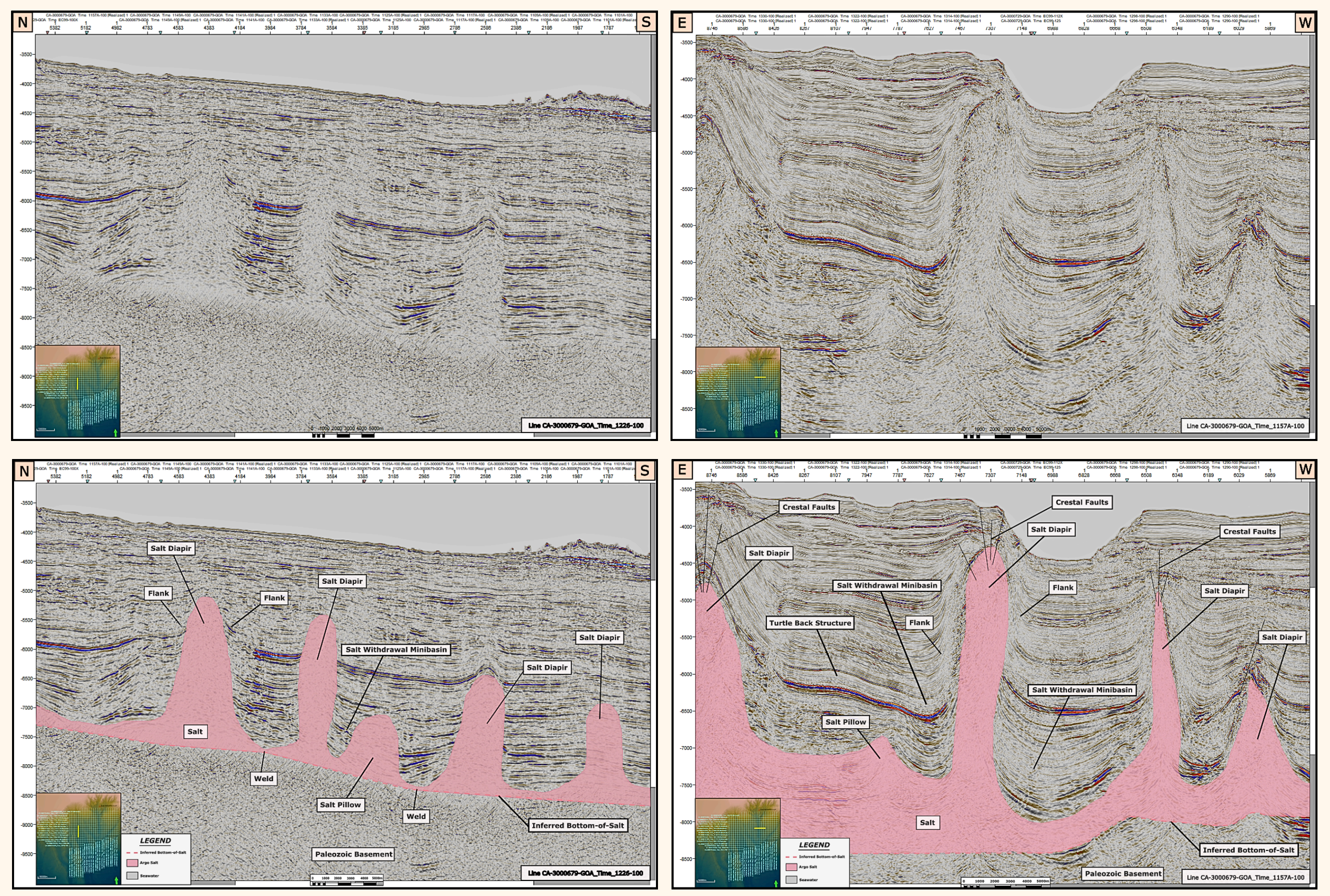
N
S
E
W
Salt Diapir
Flank
Salt Withdrawal Minibasin
Salt
Weld
Salt Pillow
Inferred Bottom-of-Salt
Crestal Faults
Turtle Back Structure
Paleozoic Basement
LEGEND
Inferred Bottom-of-Salt
Argo Salt
Seawater
Line CA-3000679-GOA_Time_1226-100
Line CA-3000679-GOA_Time_1157A-100

Figure 5. Uninterpreted (top) and interpreted (bottom) N-S and E-W oriented seismic profiles. Interpreted figures include annotations of salt structures (pink) present in the region.

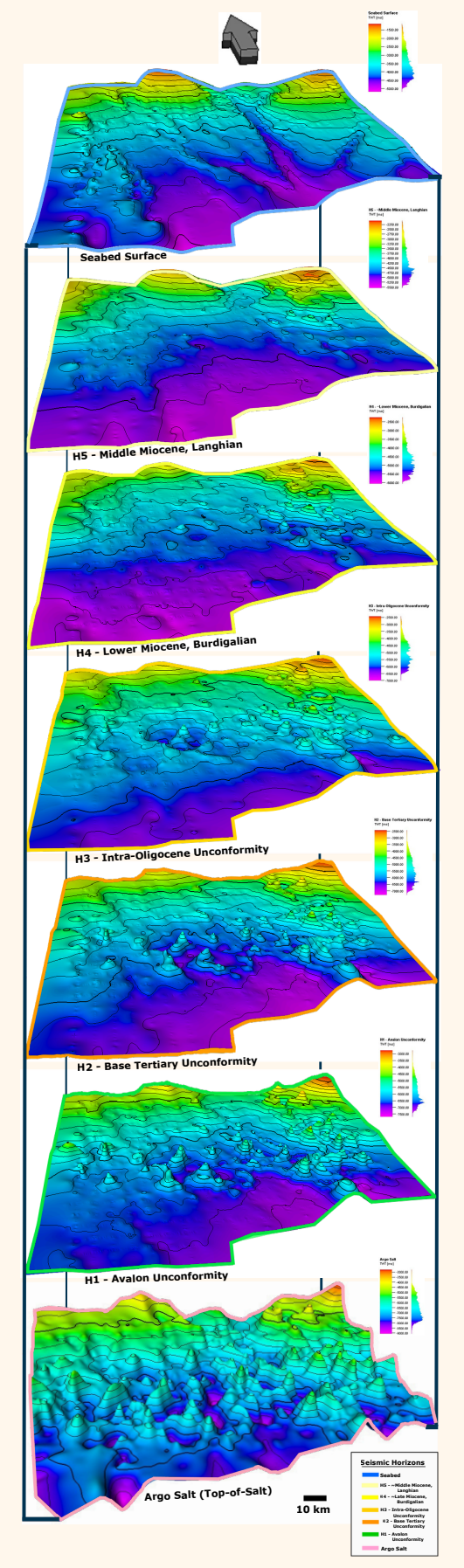
Seabed Surface
H5 - Middle Miocene, Langhian
H4 - Lower Miocene, Burdigalian
H3 - Intra-Oligocene Unconformity
H2 - Base Tertiary Unconformity
H1 - Avalon Unconformity
Argo Salt (Top-of-Salt)
10 km

Figure 6. Time structure maps of interpreted seismic horizons.

C Fault Geometry and Structural Framework Analysis

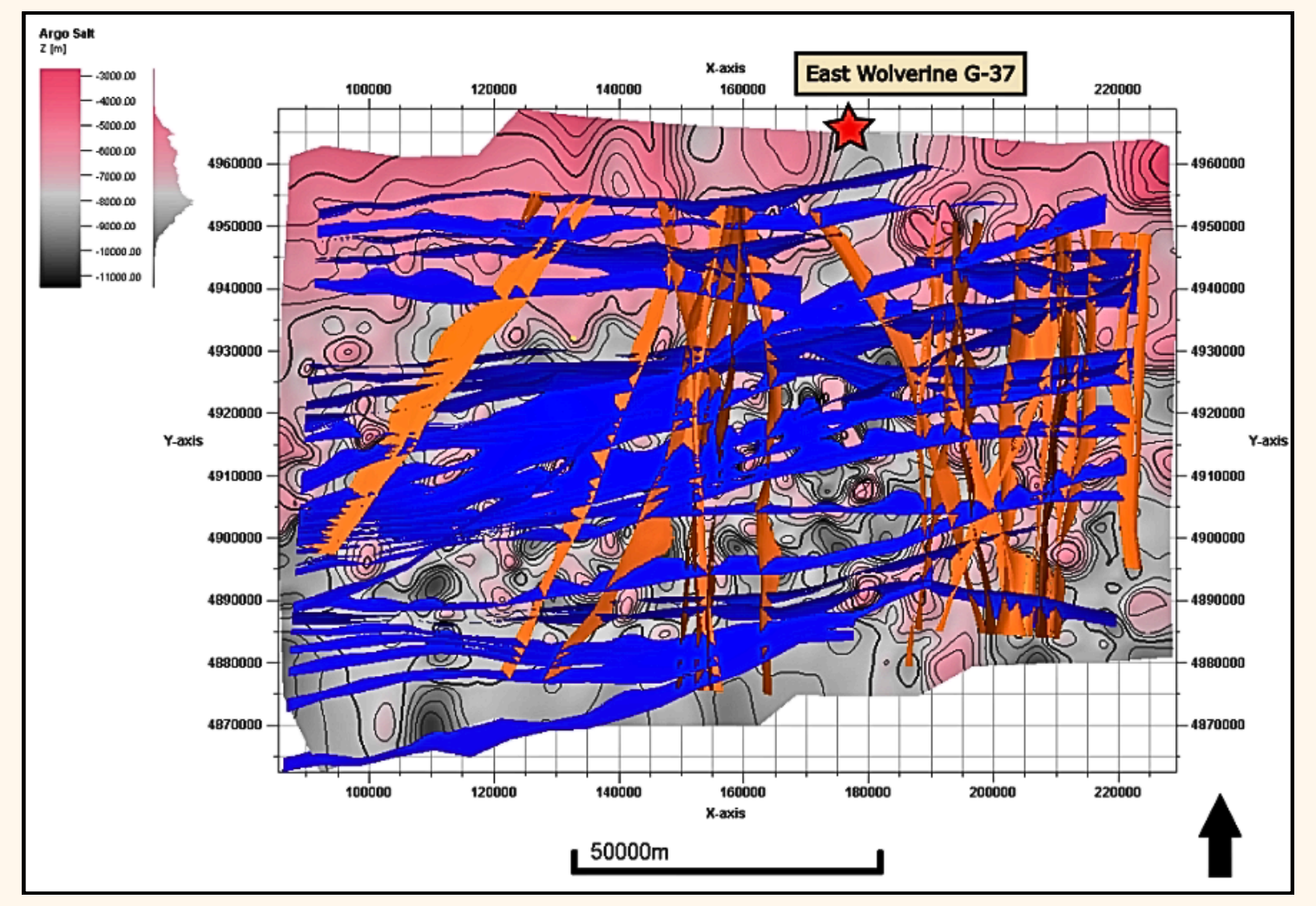
Argo Salt
Z [m]
East Wolverine G-37
X-axis
Y-axis
50000m

Figure 7. 2D fault map overlayed with Top-of-Salt depth structure map (Argo Formation). Two fault populations trending ~N-S (orange) and E-W (blue). The East Wolverine G-37 well is marked with red star.

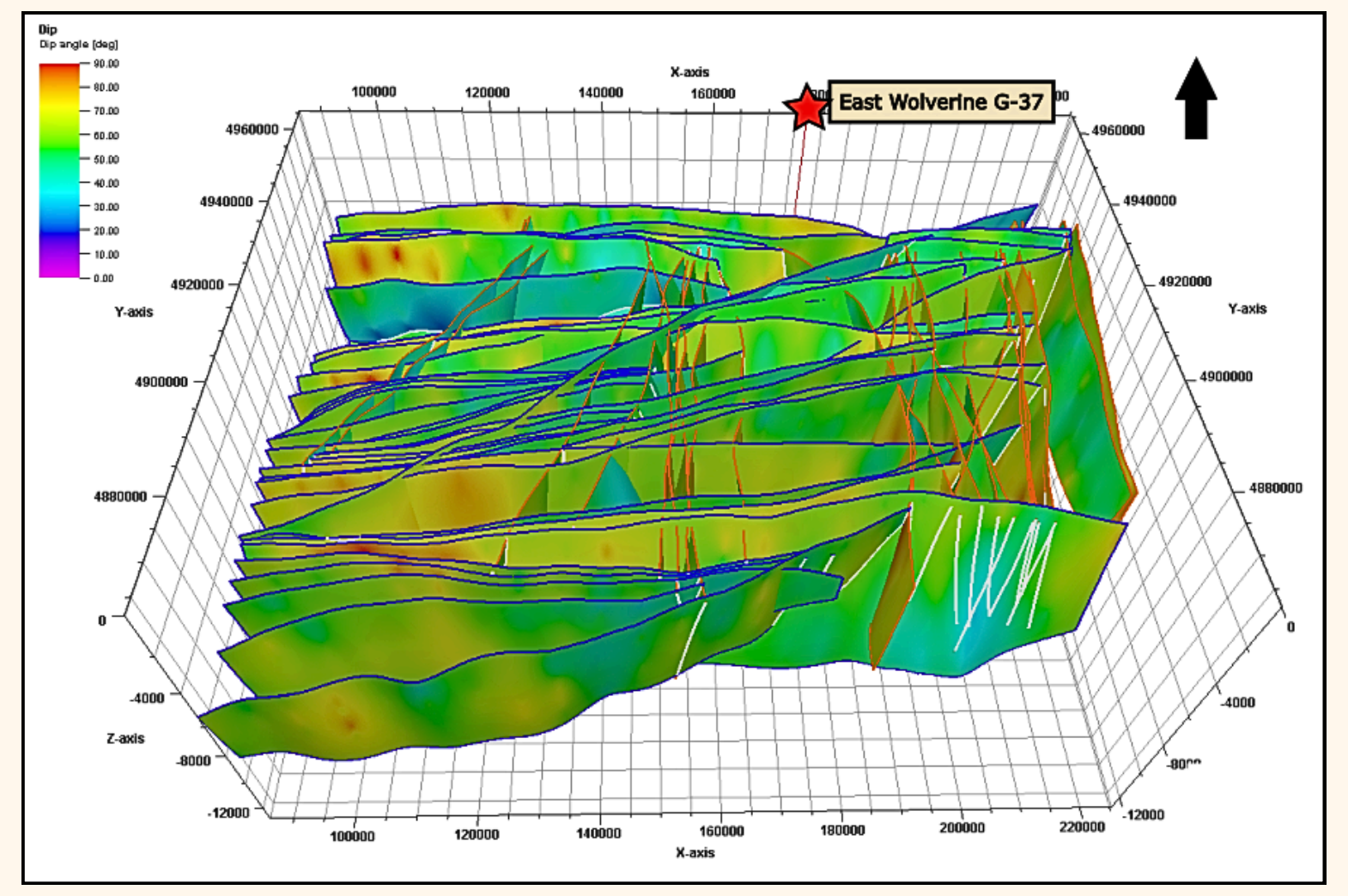
Dip
Dip angle [deg]
East Wolverine G-37
X-axis
Y-axis
Z-axis

Figure 8. 3D fault map with Dip Angle attribute (degrees). The East Wolverine G-37 well is marked with red star.

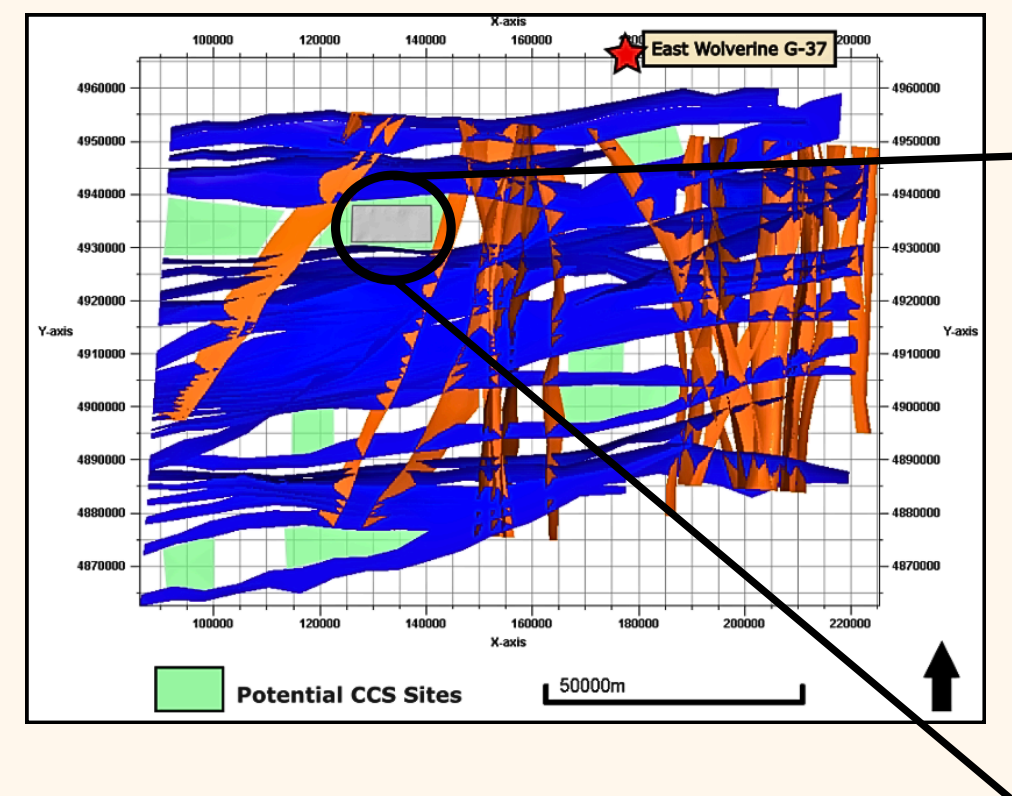
East Wolverine G-37
X-axis
Y-axis
Potential CCS Sites
50000m

Figure 9. 2D fault map depicting 2 fault populations (blue and orange) marked with potential sites for CCS integration. The East Wolverine G-37 well is marked with red star.

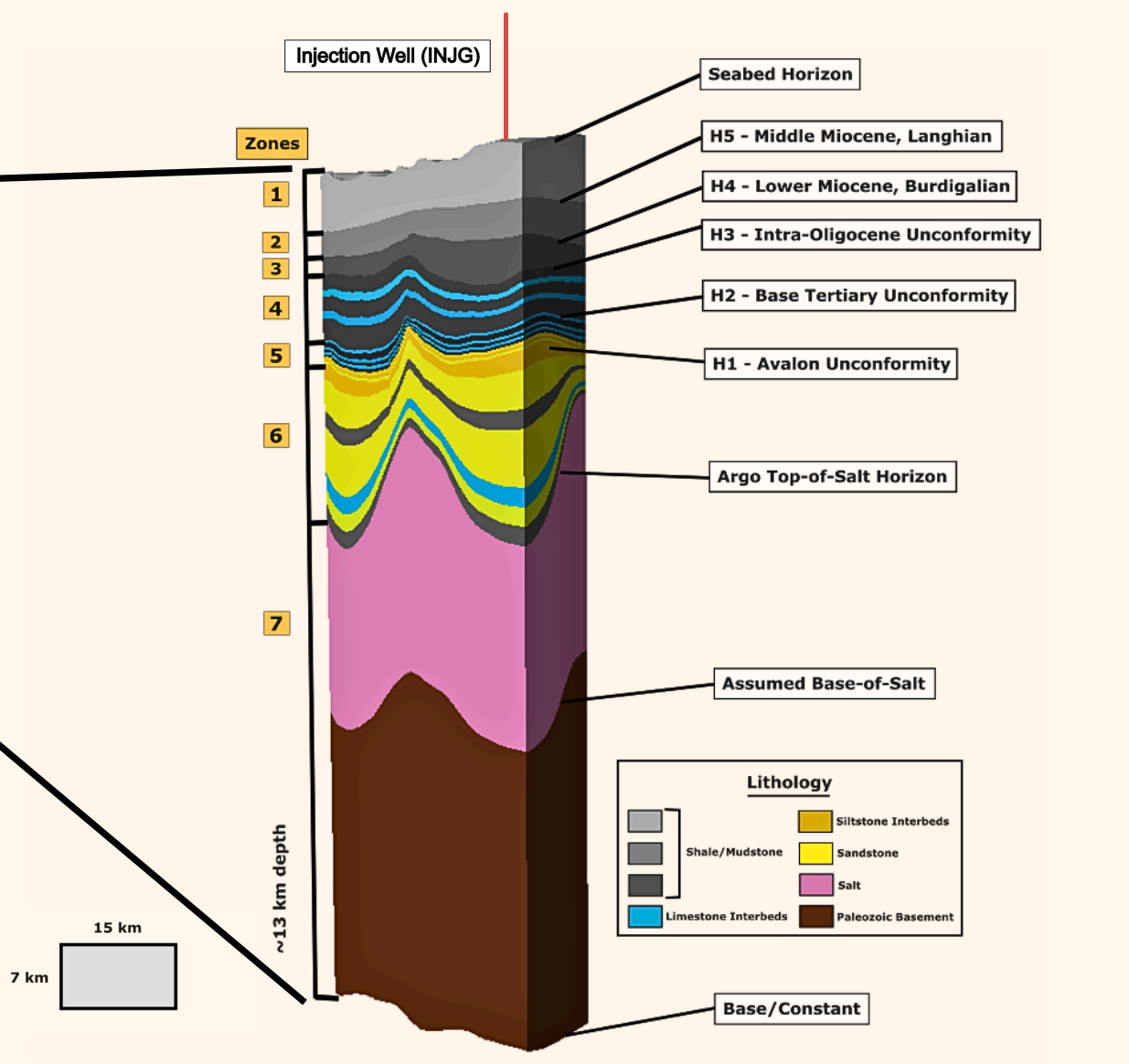
Injection Well (INJG)
Zones
1
2
3
4
5
6
7
Seabed Horizon
H5 - Middle Miocene, Langhian
H4 - Lower Miocene, Burdigalian
H3 - Intra-Oligocene Unconformity
H2 - Base Tertiary Unconformity
H1 - Avalon Unconformity
Argo Top-of-Salt Horizon
Assumed Base-of-Salt
Lithology
Shale/Mudstone
Limestone Interbeds
Siltstone Interbeds
Sandstone
Salt
Paleozoic Basement
Base/Constant
15 km
7 km
~13 km depth

Figure 10. 3D pillar grid of a 15 km x 7 km region that was identified as a potential CCS site.

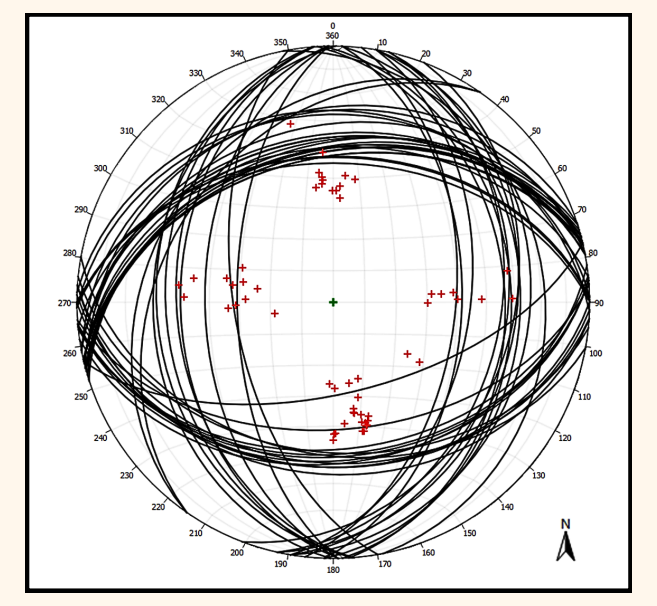

Figure 11. Stereonet plot depicting two fault populations based on fault strike orientations.

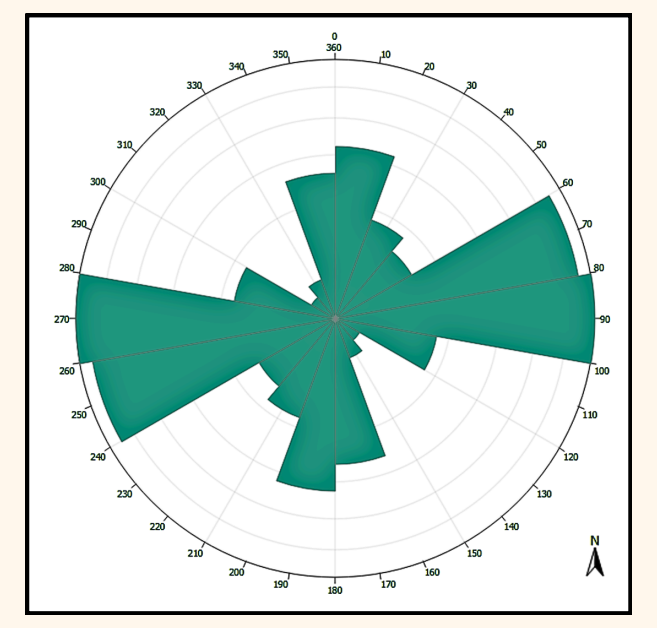

Figure 12. Bidirectional rose diagram of fault strike orientations showing two fault populations trending ~ N-S and E-W.

- Fault maps reveal two distinct N-S and E-W normal fault sets associated with widespread salt structures, graben, and half-graben structures, indicating Mesozoic extension and coupled fault-salt evolution.
- This presents a complex yet strategically favourable setting where faults may act as barriers or conduits for fluid flow, while salt influences trapping efficiency.

D Slip Tendency Stress Orientation Scenarios

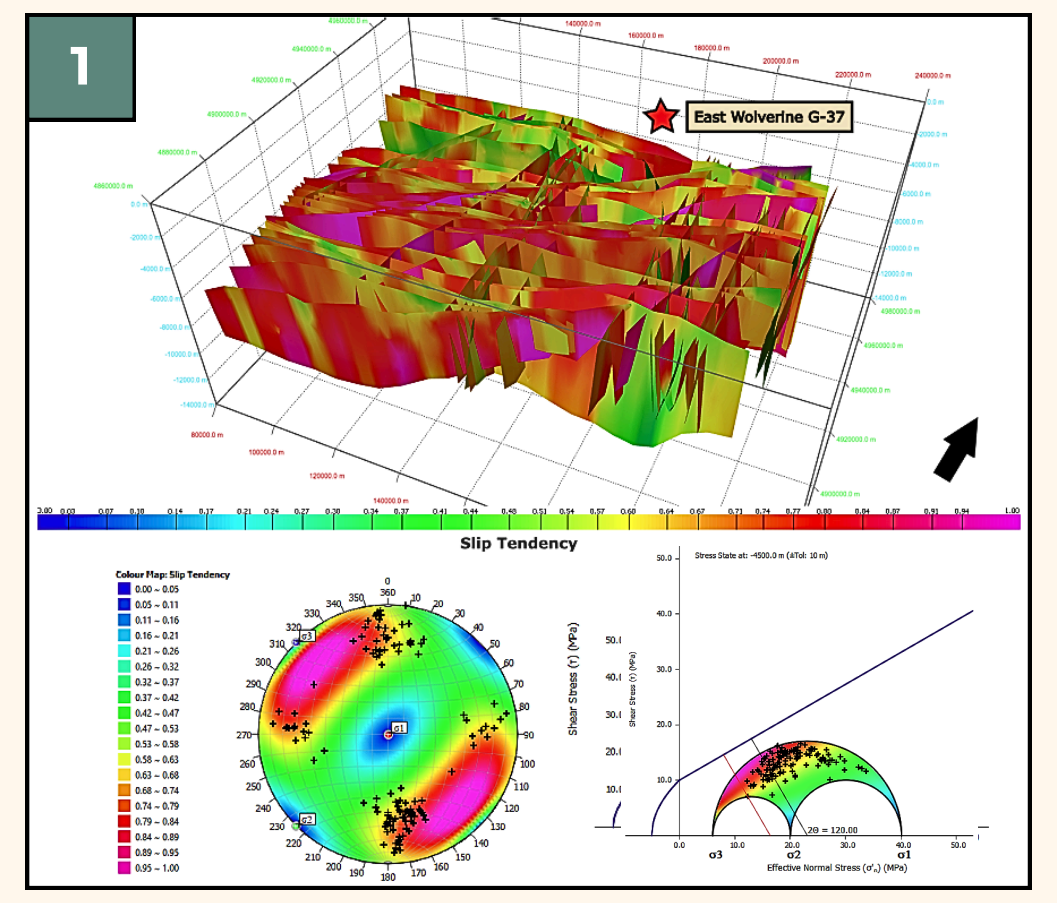
1
East Wolverine G-37
Slip Tendency
Colour Map: Slip Tendency

Figure 13. Slip tendency fault map Scenario 1: Present-day stress orientation estimate constrained from World Stress Map by Heidbach et al. (2025)[4].

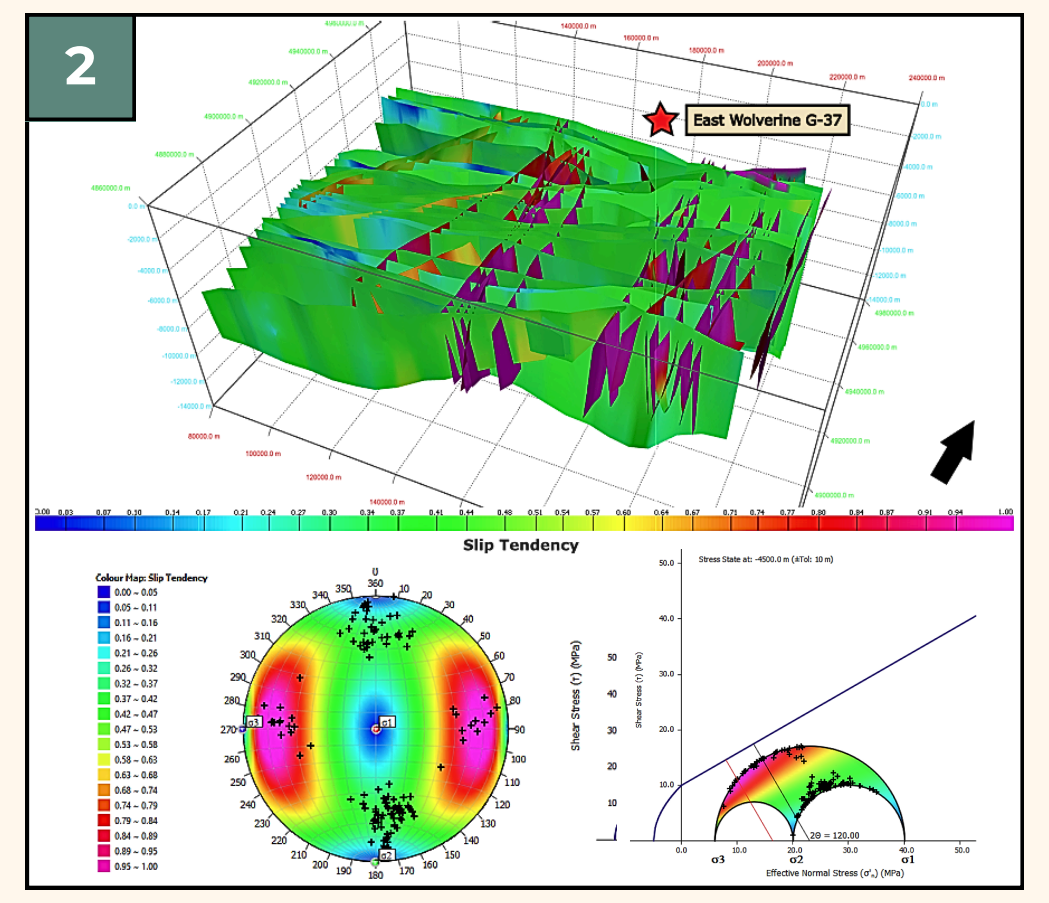
2
East Wolverine G-37
Slip Tendency

Figure 14. Slip tendency fault map Scenario 2: Strike-parallel extension, minimum reactivation end-member.

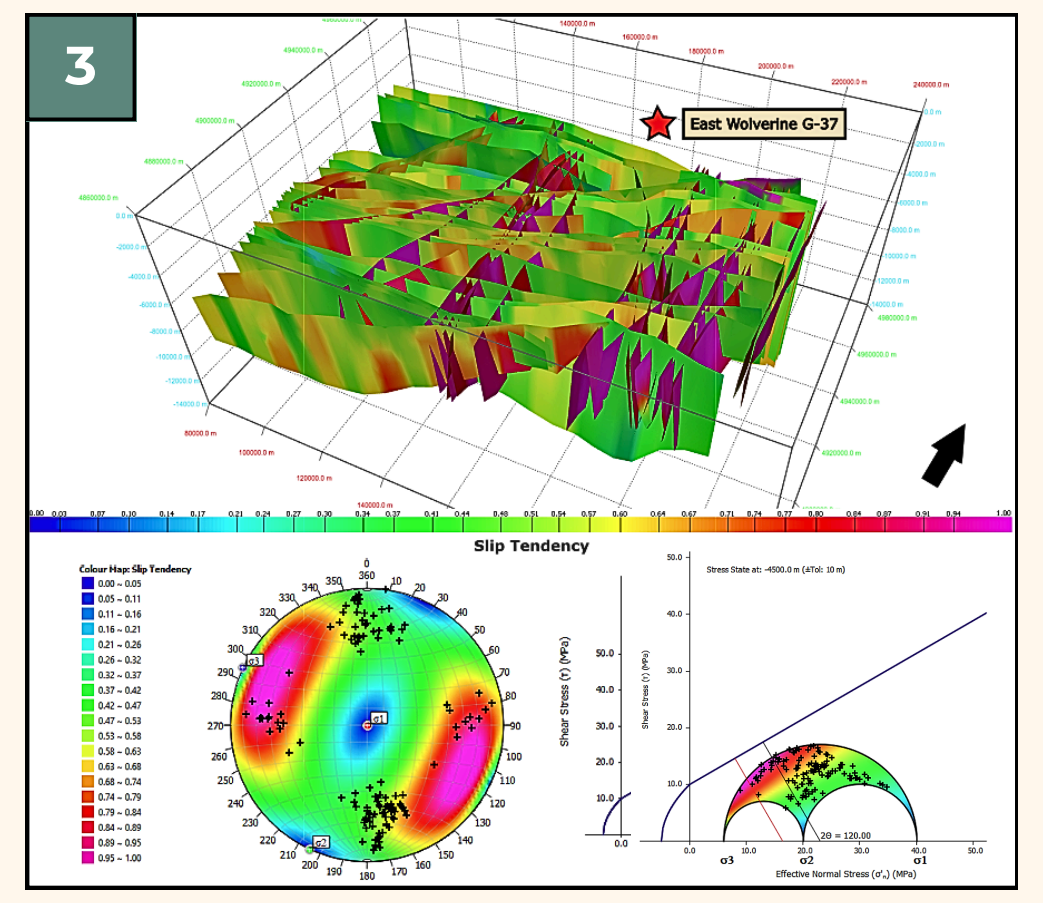
3
East Wolverine G-37
Slip Tendency

Figure 15. Slip tendency fault map Scenario 3: Optimally-oriented failure, maximum reactivation end-member.

σ_1 is vertical (plunge = 90°) at 4,500 m for all scenarios. Only horizontal stress azimuths vary between scenarios.

Slip Tendency Stress Orientations (Plunge/Azimuth)	σ1	σ2	σ3	Fracture Stability
Scenario 1	90/135	0/045	0/135	5.0 MPa
Scenario 2	90/135	0/000	0/090	5.2 MPa
Scenario 3	90/045	0/025	0/115	3.2 MPa

- N-S faults maintain high slip tendency (Ts > 0.75) across all scenarios, indicating reactivation potential independent of stress field orientation uncertainty.
- E-W faults are stress-sensitive, with low Ts when σ3 is fault-parallel (Scenario 2) and moderate-high Ts as σ3 rotates to 115°-135° (Scenarios 1 and 3).
- Contrasting Ts behaviour of fault populations suggests a structurally complex margin origin involving both orthogonal extension and strike-slip deformation, consistent with a transform component in the margin's structural inheritance.
- Local stress regime remains poorly constrained due to limited WSM 2025[4] coverage in region (stress indicators provided for Scotian Margin, coverage does not extend into hinge zone between Cobequid-Chedabucto Fault System and Newfoundland Fracture Zone).

E CO_2 Injection Simulations

1 10-Year Injection Simulation

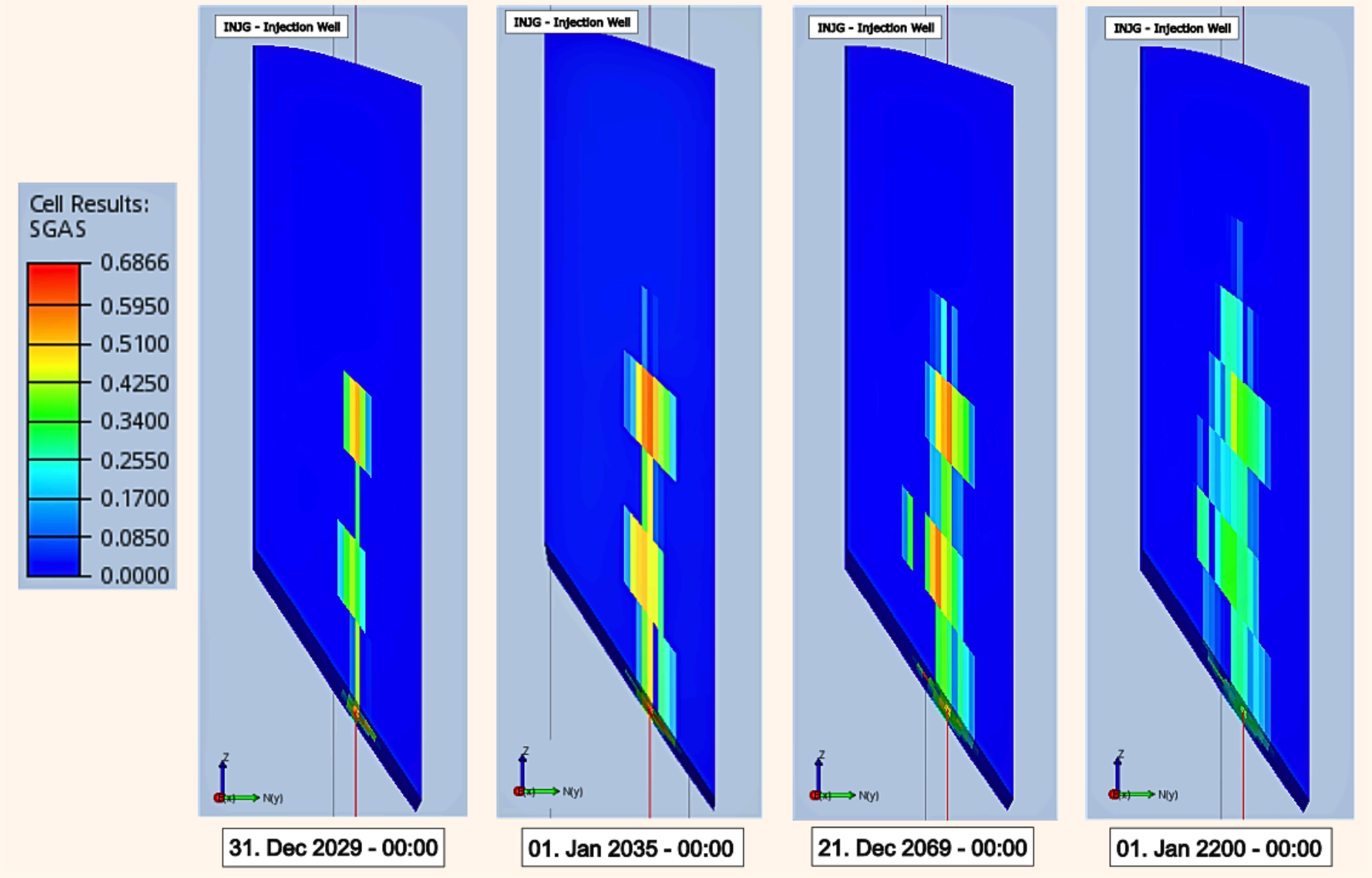
Cell Results: SGAS
0.6866
0.5950
0.5100
0.4250
0.3400
0.2550
0.1700
0.0850
0.0000
INJG - Injection Well
31. Dec 2029 - 00:00
01. Jan 2035 - 00:00
21. Dec 2069 - 00:00
01. Jan 2200 - 00:00

Figure 16. 10-year CO_2 injection simulation in target Zone 6 (Figure 15) at a depth of 4578 m below seabed. 1 Mt/year was injected over 10 years (10 Mt total), with plume migration monitored over a 175-year simulation period (Jan 2025 - Jan 2200).

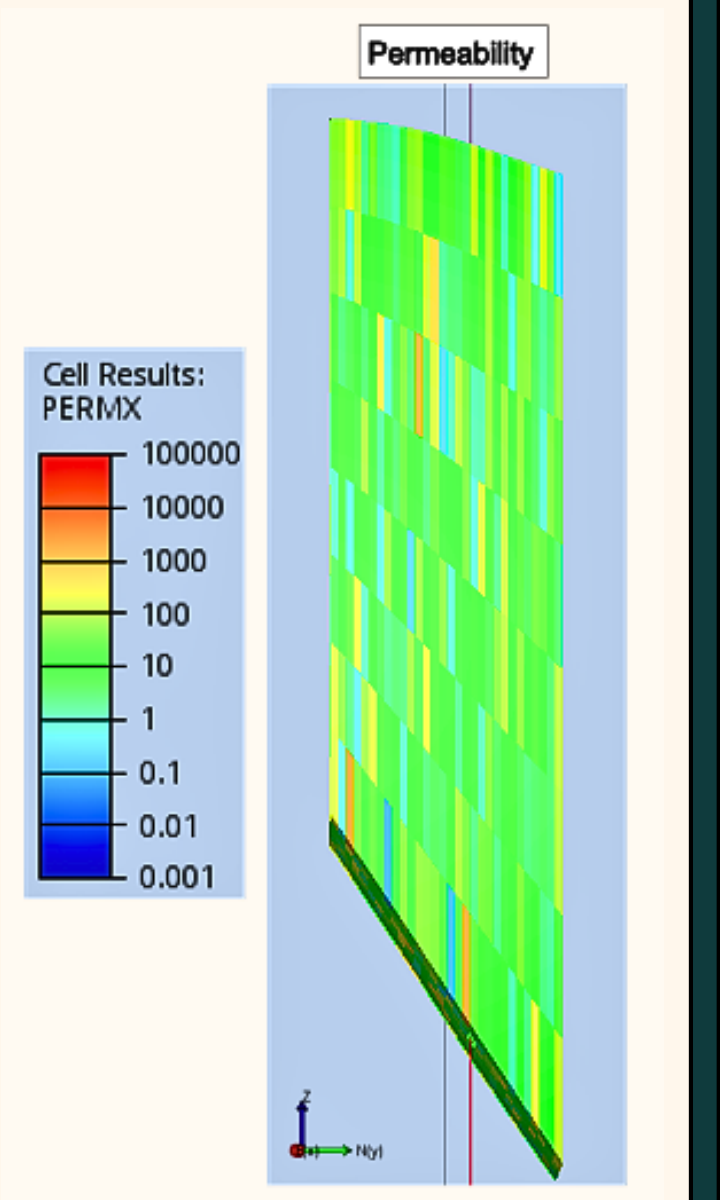
Permeability
Cell Results: PERMX
100000
10000
1000
100
10
1
0.1
0.01
0.001

Figure 17. 3D permeability model (PERMX) of target Zone 6 in Simulation 1.

2 20-Year Injection Simulation

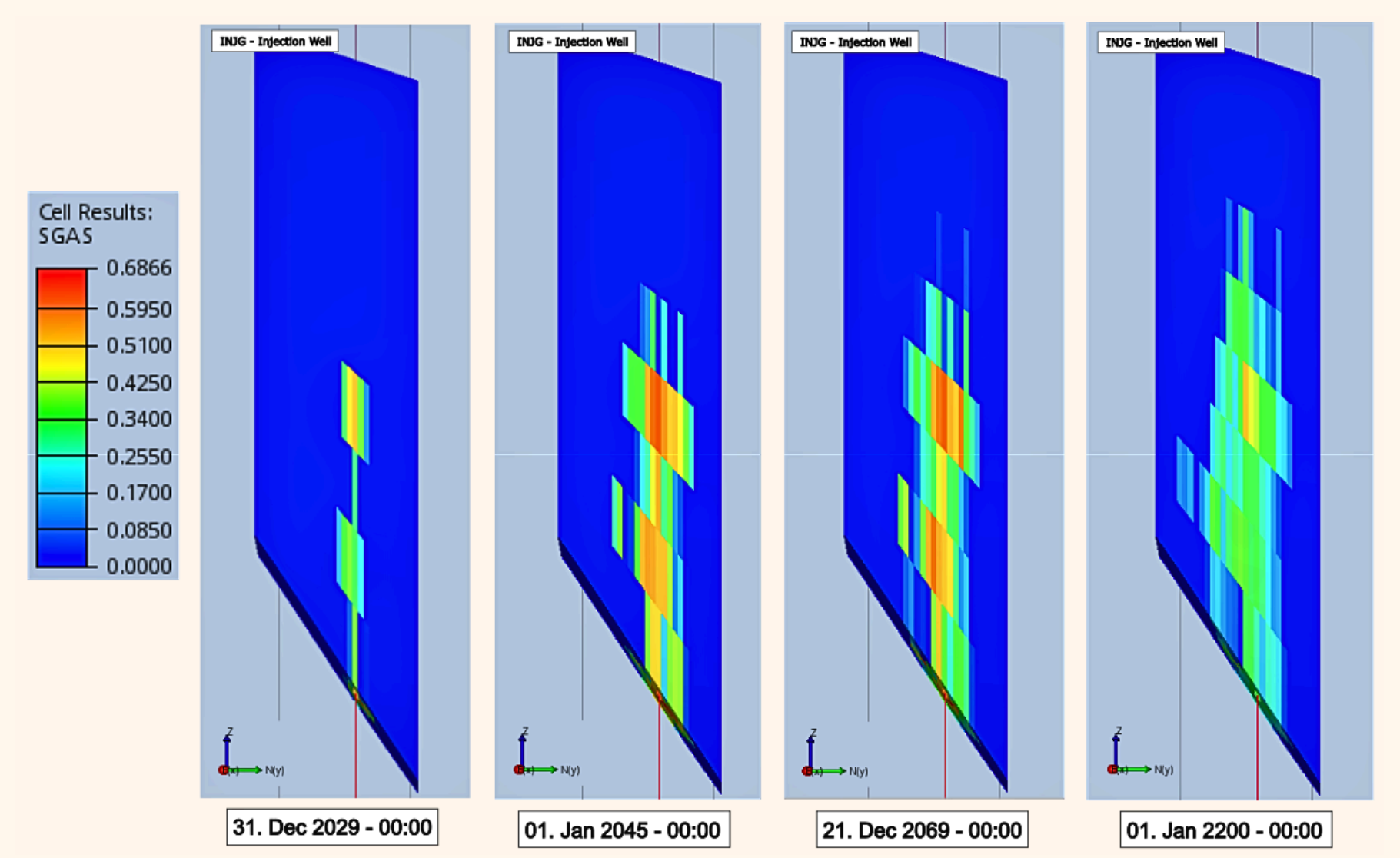
Cell Results: SGAS
0.6866
0.5950
0.5100
0.4250
0.3400
0.2550
0.1700
0.0850
0.0000
INJG - Injection Well
31. Dec 2029 - 00:00
01. Jan 2045 - 00:00
21. Dec 2069 - 00:00
01. Jan 2200 - 00:00

Figure 18. 20-year CO_2 injection simulation in target Zone 6 (Figure 15) at a depth of 4578 m below seabed. 1 Mt/year was injected over 20 years (20 Mt total), with plume migration monitored over a 175-year simulation period (Jan 2025 - Jan 2200).

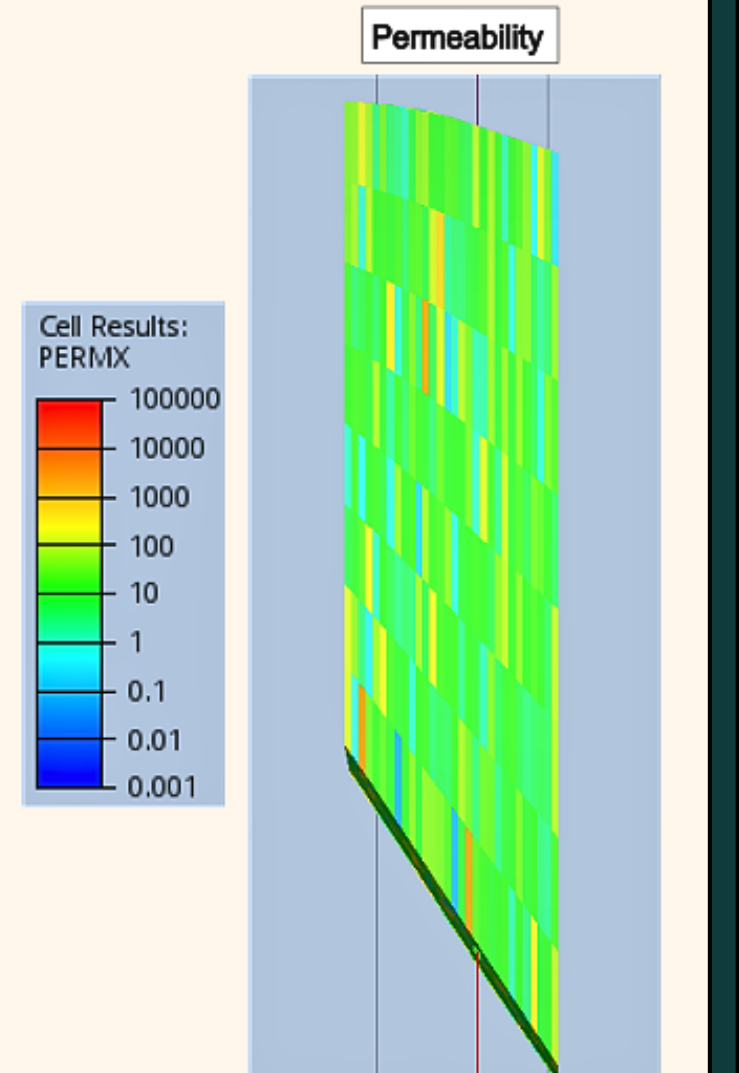
Permeability
Cell Results: PERMX
100000
10000
1000
100
10
1
0.1
0.01
0.001

Figure 19. 3D permeability model (PERMX) of target Zone 6 in Simulation 2.

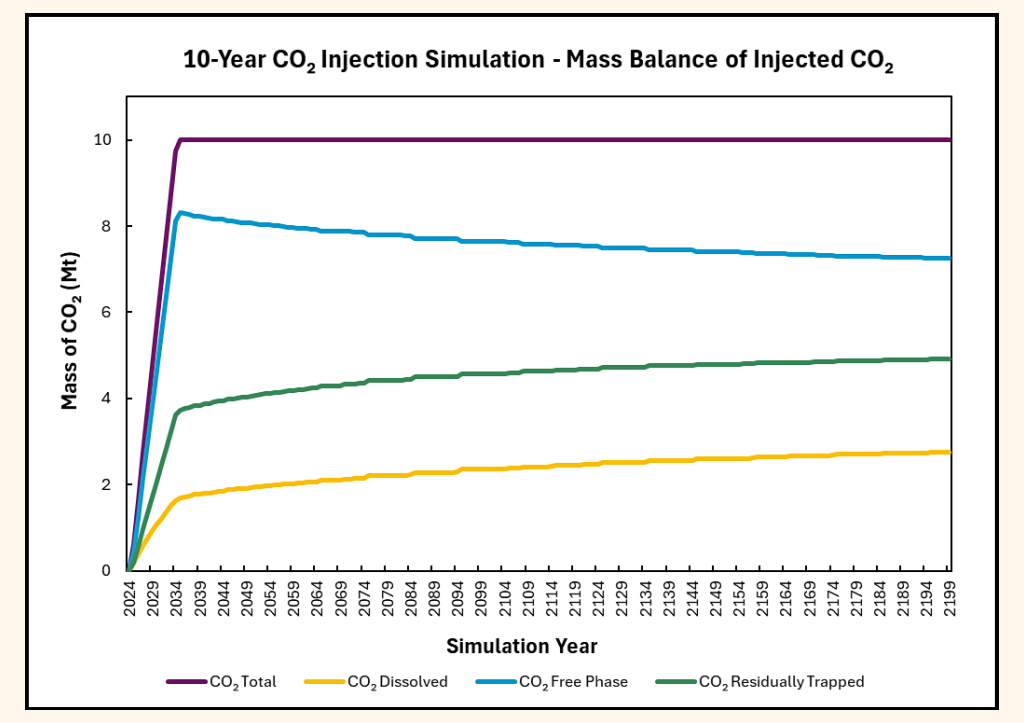

Figure 20. Mass balance of injected CO_2 for the 10-year injection simulation (10 Mt total). Free phase CO_2 decreases after injection ceases in 2035, while residual and dissolution trapping increase over 175 years.

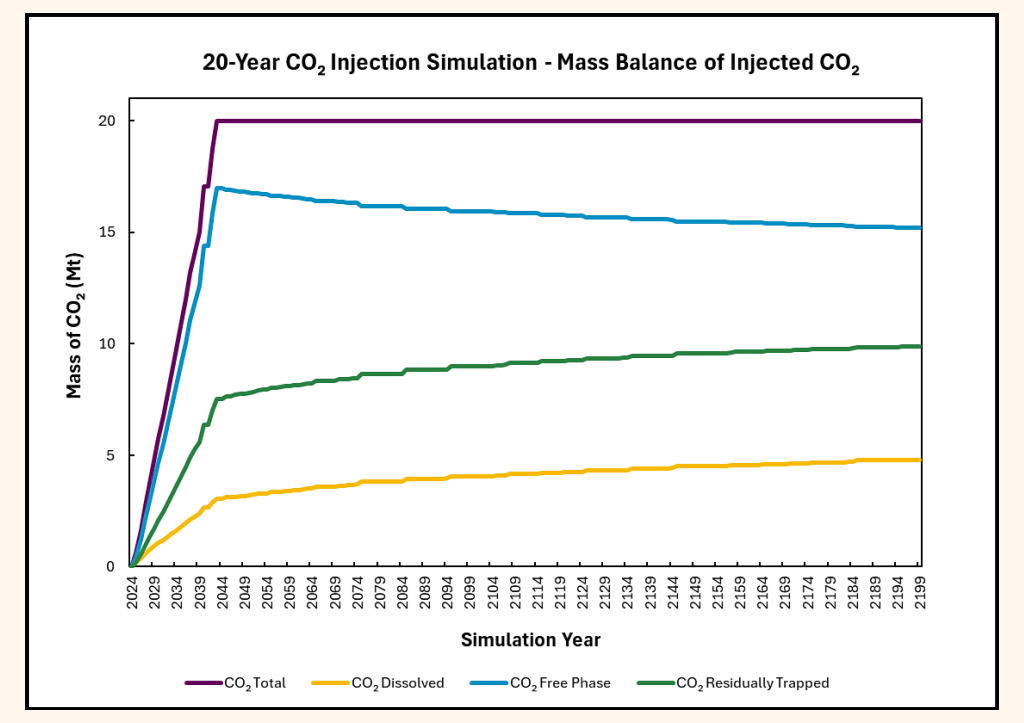

Figure 21. Mass balance of injected CO_2 for the 20-year injection simulation (20 Mt total). Despite double the injected volume, residual and dissolution trapping continue to increase throughout post-injection monitoring period.

5 Key Takeaways

1. N-S and E-W fault trends and salt-fault interactions reveal a heterogeneous margin shaped by multiple phases of rifting, strike-slip deformation, and structural inheritance which is inconsistent with a simple passive margin model.
2. The hinge zone between the Cobequid-Chedabucto Fault System and the Newfoundland Fracture Zone may record a transform-rift transition where earlier strike-slip deformation was overprinted by later extension; however, this requires further investigation.
3. Both simulations show CO_2 migration toward salt diapir flank with the 20-year scenario producing a larger plume (20 Mt vs 10 Mt). Both demonstrate effective containment and trapping within Zone 6. Future work incorporating faults and salt geometry is needed to fully assess storage security.

6 Acknowledgements and References

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References