Structural Restoration and 2-D Basin Modeling in Fold and Thrust Belts – A Case Study from Western Newfoundland*

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Search and Discovery Article #30570 (2018)**
Posted July 9, 2018

*Adapted from oral presentation given at 2018 AAPG Annual Convention & Exhibition, Salt Lake City, Utah, May 20-23, 2018

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Abstract

The Early Paleozoic fold and thrust belt on the west coast of Newfoundland hosts a frontier petroleum system that has minor production and several shallow wells with light oil shows. The basin sits at the structural front of the northeastern Canadian Appalachians, recording the complex tectonic history of Ordovician to Devonian shortening events. During the Taconian (Ordovician) and Acadian (Devonian) orogenies, westward thrusting imbricated continental slope and rise deposits, creating thrust sheets that repeat Lower Paleozoic strata. We present two-dimensional (2-D) basin models to assess the thermal evolution, transformation, migration, and accumulation of hydrocarbons.

Two viable source rocks for this petroleum system have been identified in the Cow Head Group hosted in distal continental slope and rise deposits, with TOC concentrations of up to 10.35 wt.% and a type I/II kerogen with high hydrogen index (HI) values of over 840 [mg HC/g TOC]. This initial investigation presents a 2D petroleum basin model approach including a structural restoration of the fold and thrust belt. The model is calibrated with petrophysical property logs collected from two well, Seamus #1 and Finnegan #1 drilled in 2010. Geochemical data from outcrop samples and oil seeps were used to characterize the source rock quality. Maturity data from pyrolysis analysis are used as additional calibration data.

Our 2-D model for the area shows that kerogen transformation starts prior to the Acadian reverse faulting. Maturity data from outcrop samples indicates that a substantial amount of overburden (approximately 2 km) was present after the Acadian orogeny.

This 2D model gives an in-depth understanding of the evolution of the petroleum system in western Newfoundland and contributes to a better understanding of hydrocarbon generation and migration in fold and thrust belts in general. Understanding these critical elements in a petroleum system context can in turn provide proper risk assessment for future exploration efforts in fold and thrust belts.

References Cited

Green, P.F., I.R. Duddy, and K.A. Hegarty, 2002, Quantifying exhumation from apatite fission-track analysis and vitrinite reflectance data: Precision, accuracy and latest results from the Atlantic margin of NW Europe: Geological Society London Special Publication, v. 196/1, p. 331-354.

Waldron, J.W.F., A.D. Henry, and J.C. Bradley, 2003, Development of a folded thrust stack: Humber Arm allochthon, Bay of Islands, Newfoundland Appalachians: Canadian Journal of Earth Sciences, v. 40, p. 237-253.

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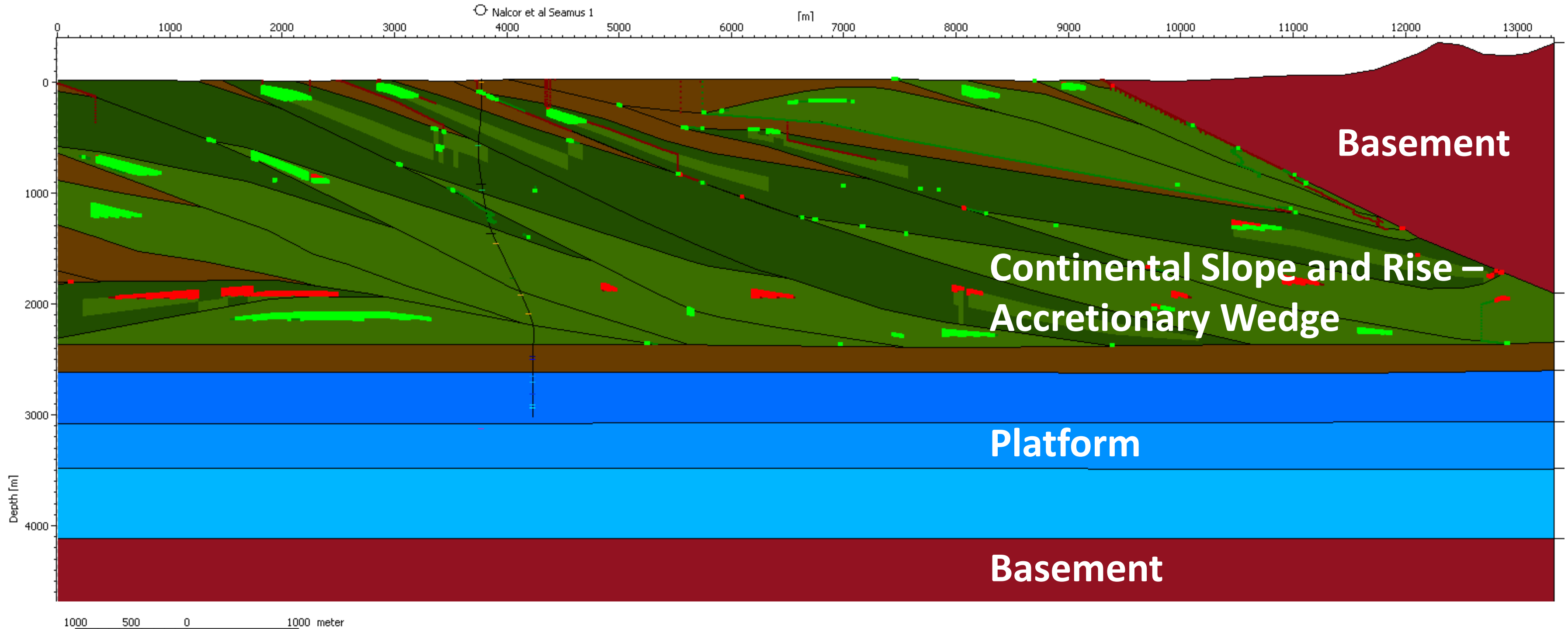


JEAN G. FUNKHOUSER MEMORIAL GRANT GRANTS-IN-AID

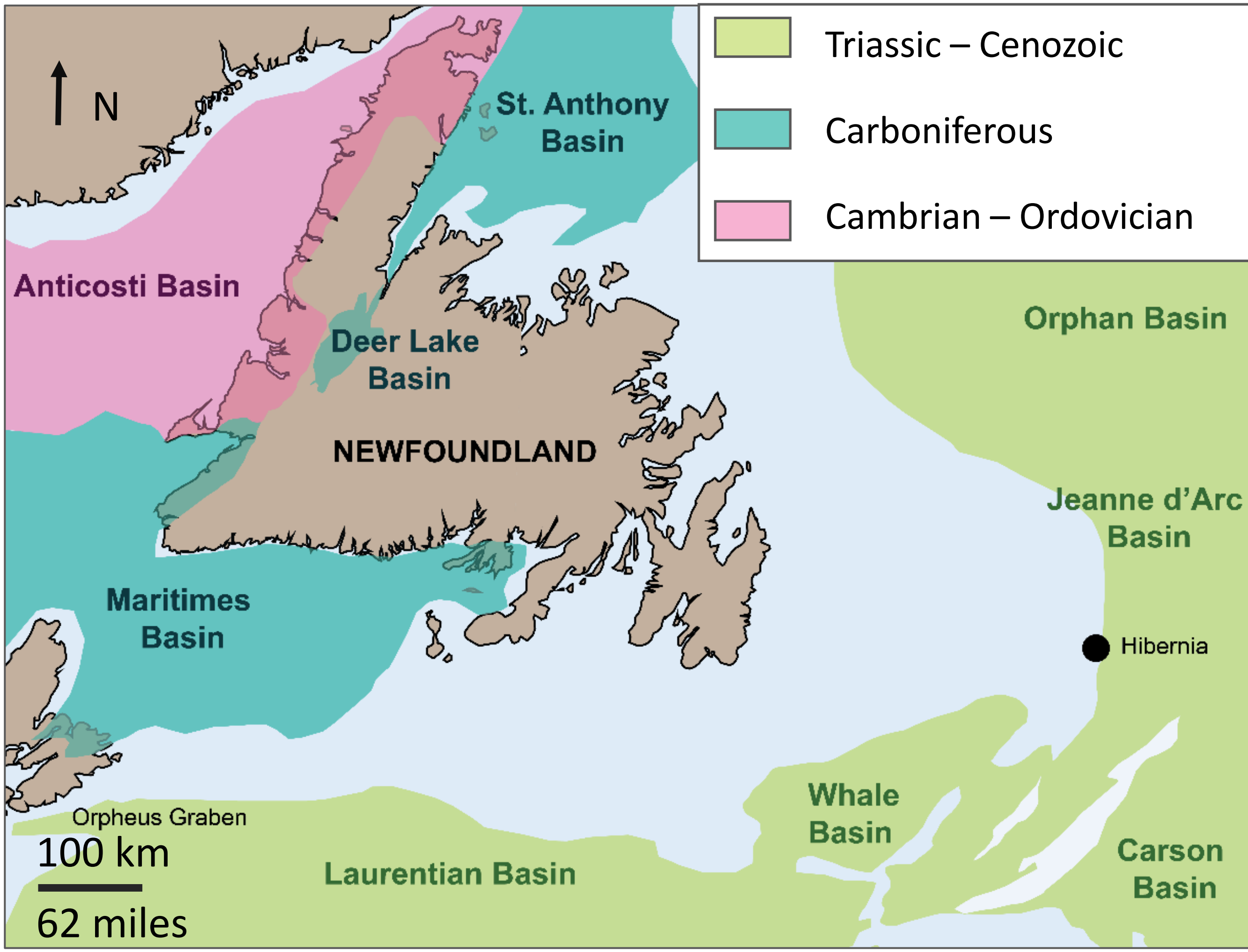
GEOTRACK

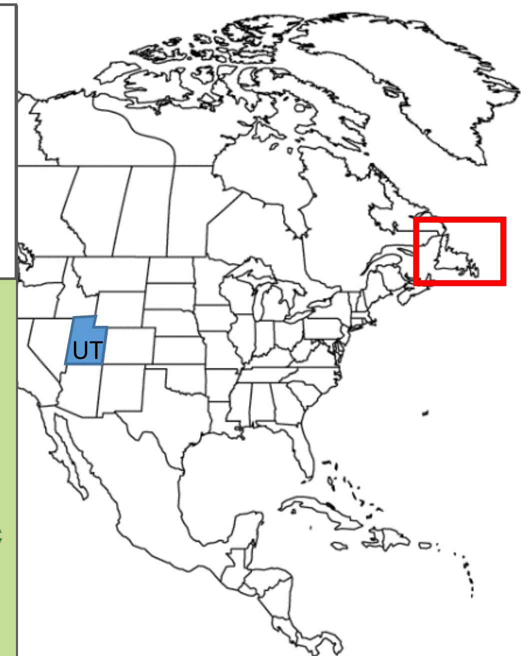
PRA Platte River Associates, Inc.

Petroleum Exploration Enhancement Program

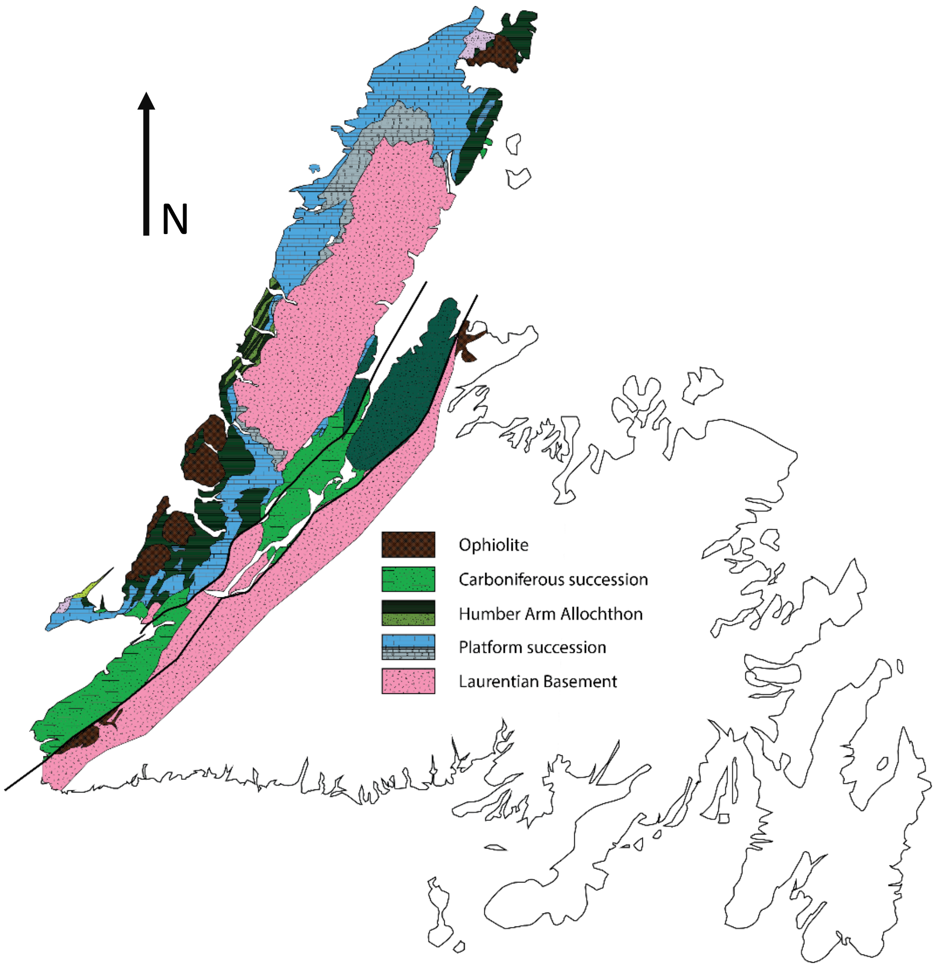
Newfoundland Labrador Natural Resources

REGIONAL GEOLOGY

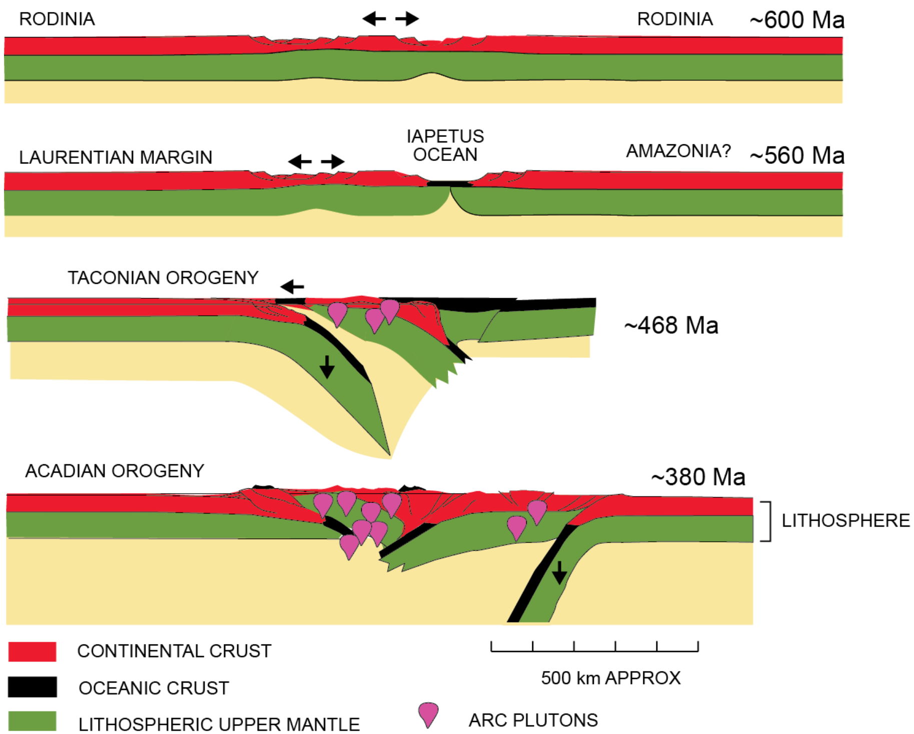




Regional Geology & Tectonic Evolution



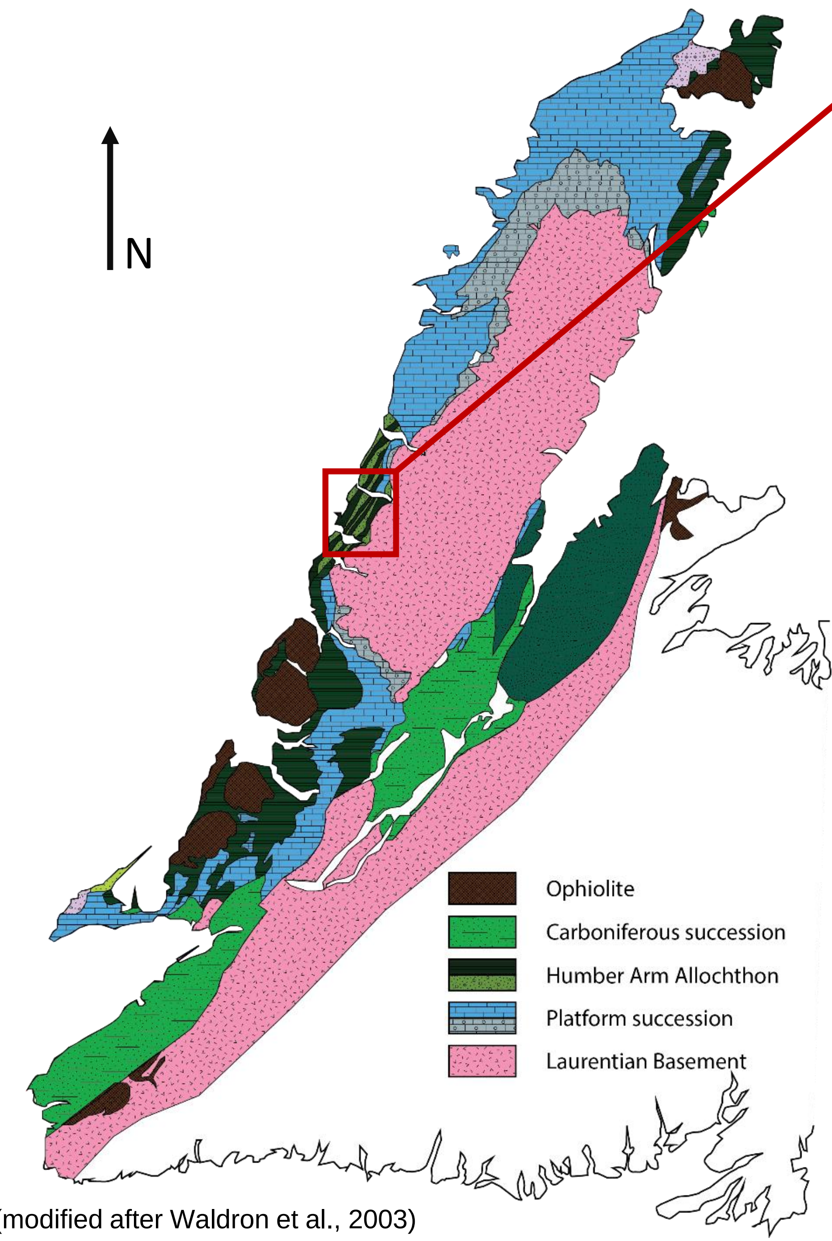
(modified after Waldron et al., 2003)



(modified after Waldron and van Staal, 2001)

No geologic information available after the Acadian (Devonian) Orogeny

Study Area – Western Newfoundland



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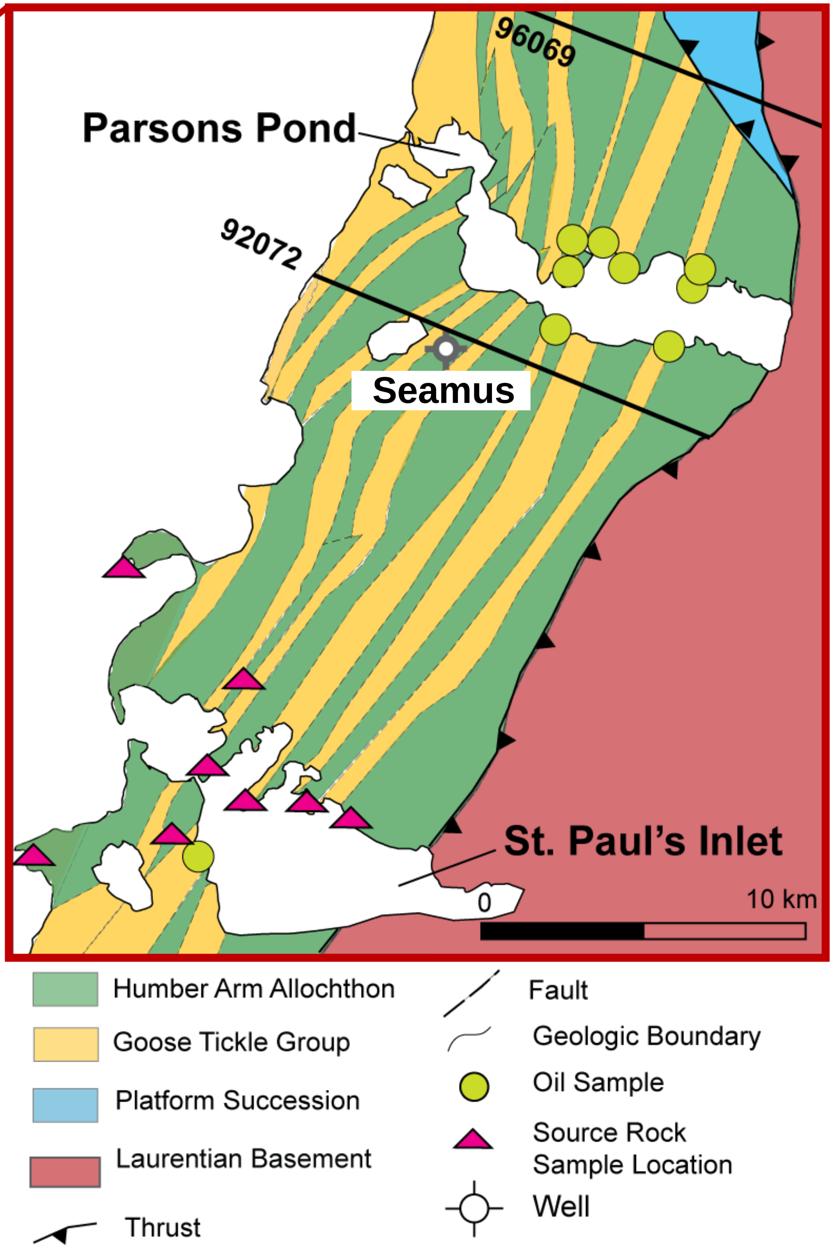
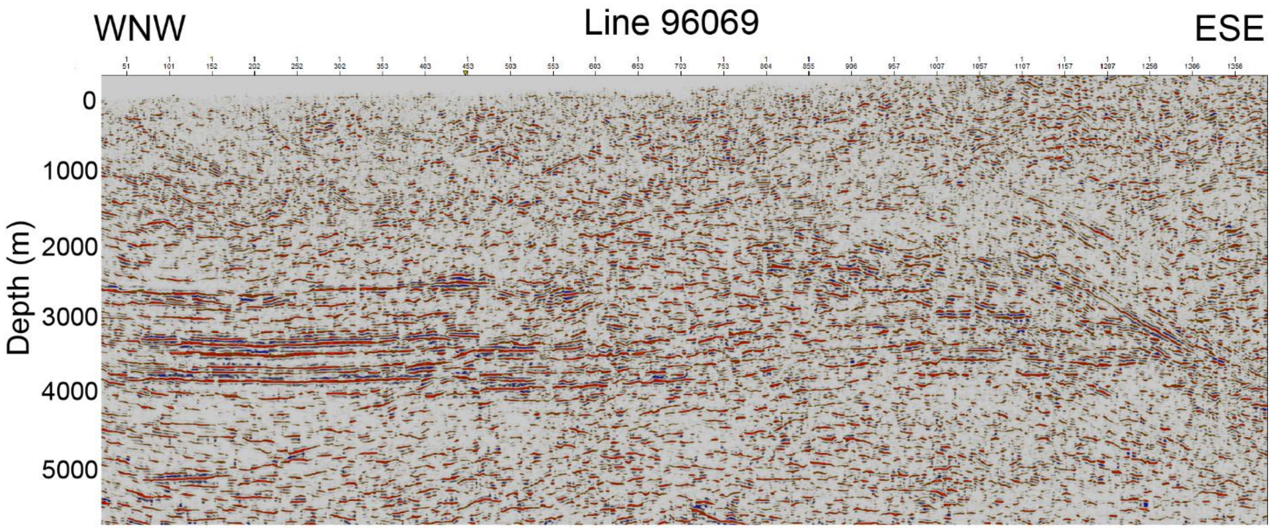
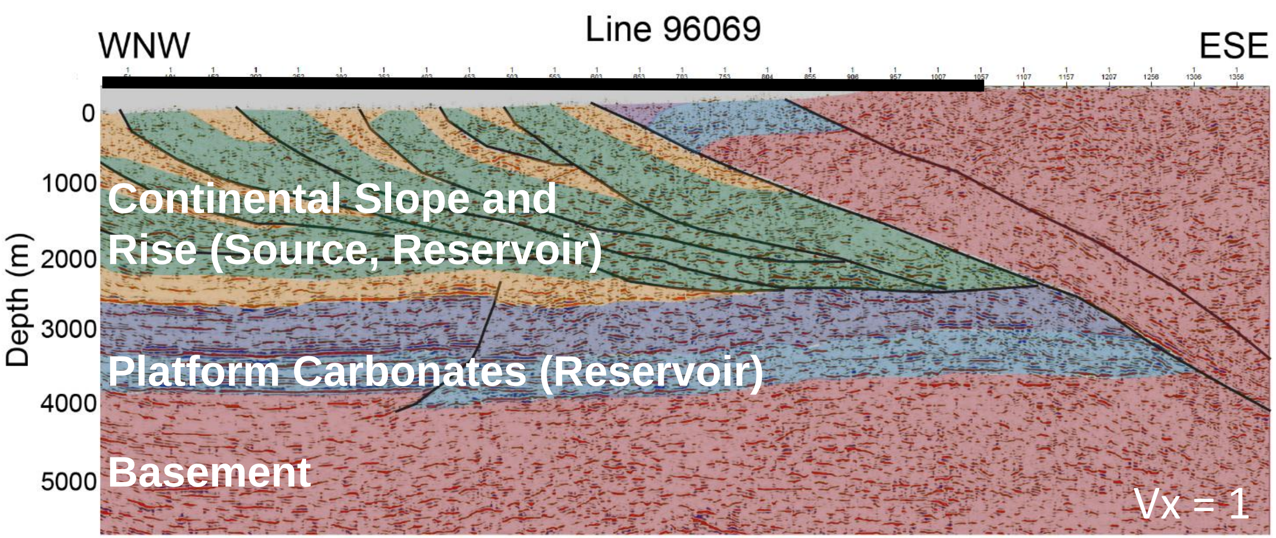
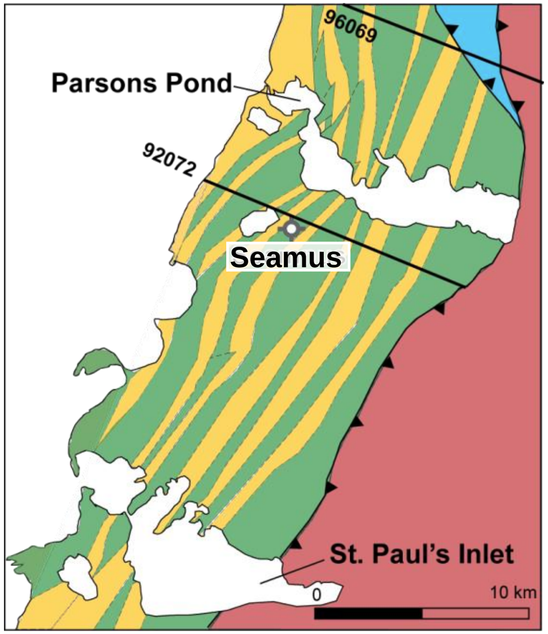


Modified, unpublished geologic map (Shawna White).

2D Seismic Profile – Parsons Pond



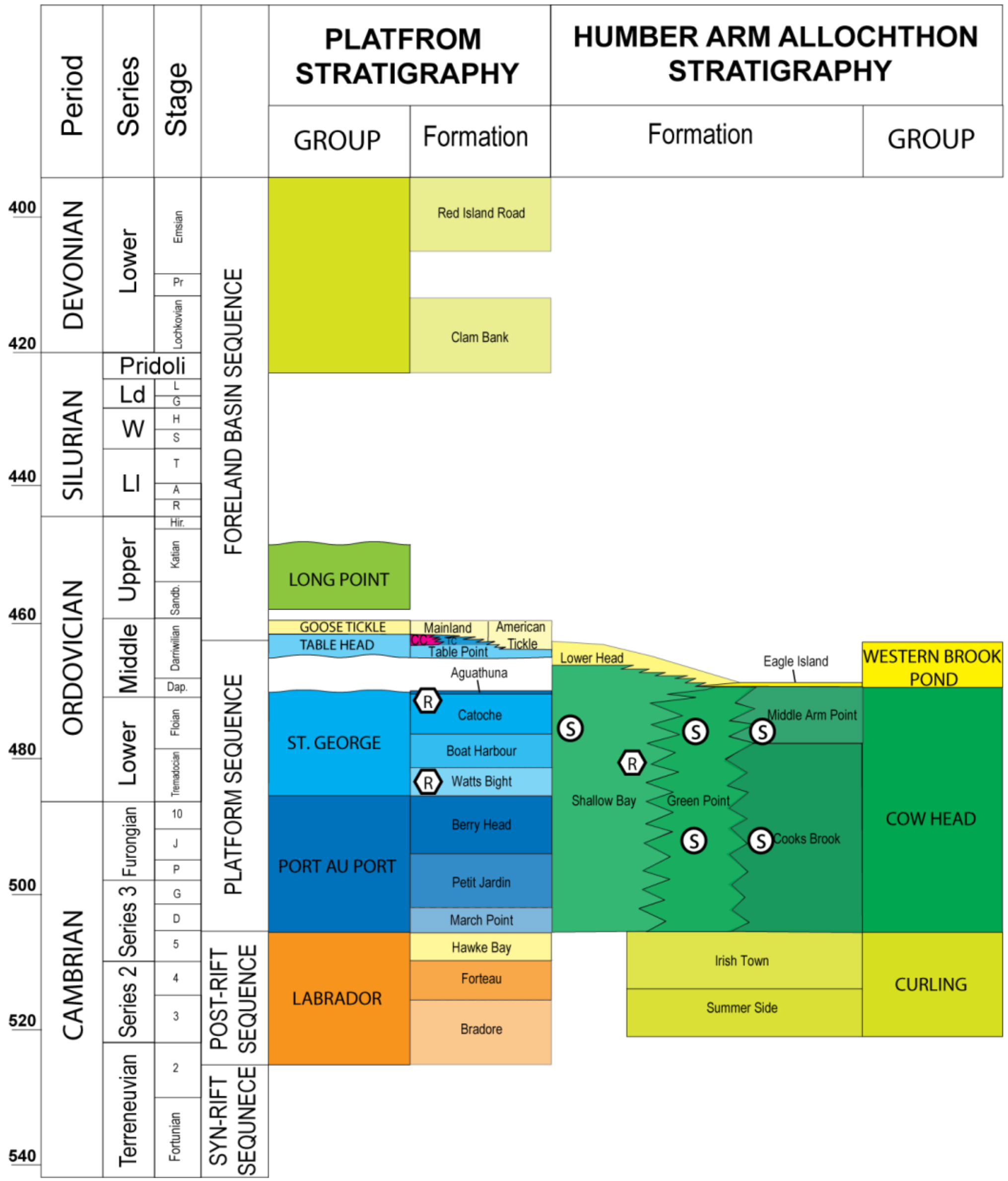




Parsons Pond Area

- Major reverse fault (evidence from seismic and mapping)
- Imbricated continental slope and rise above platform

Petroleum System



Source
- Late Cambrian Cooks Brook/Green Point Fm.
- Middle Ordovician Middle Arm Point/Shalllow Bay Fm

Reservoir
- St. George Group
- Interformational Cow Head Group

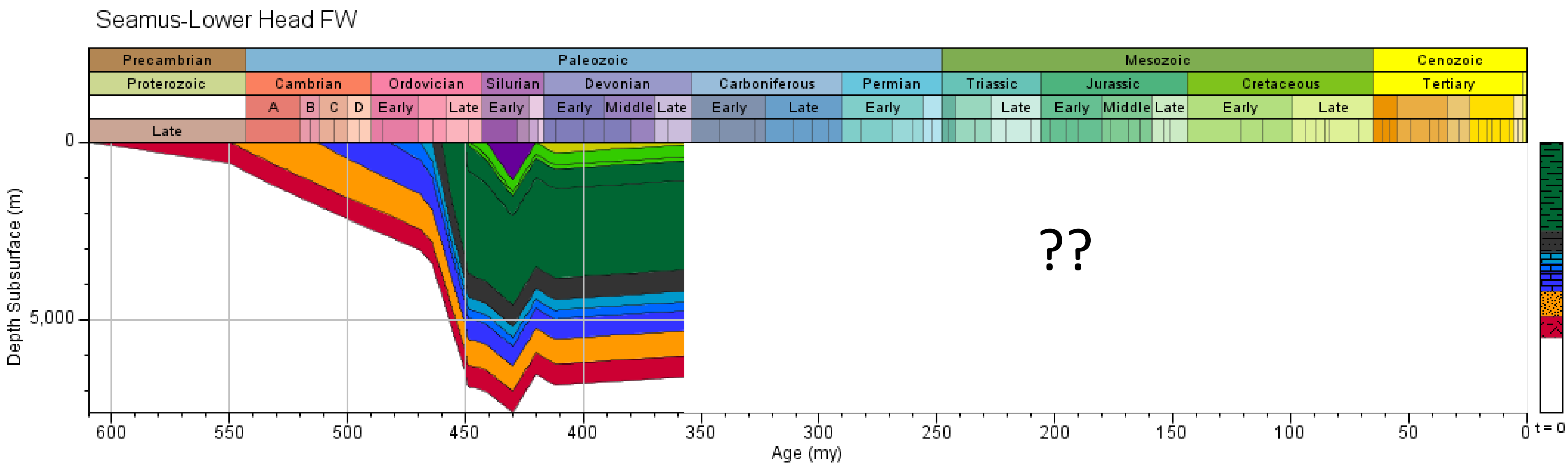
Seal
- Goose Tickle Group
- Western Brook Pond Group

Trap
- Structural traps
- Stratigraphic traps

Maturation
- ??

Migration/Accumulation
- ??

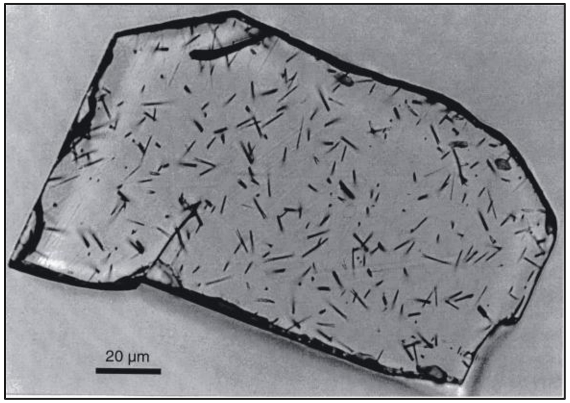
CHALLENGES IN FRONTIER BASINS



QUESTIONS WE WOULD LIKE TO ANSWER
- Maturity development within the basin
- Timing of oil generation and migration
- Impact of the fold and thrust-belt geometry on maturity development
- Geometry of migration pathways

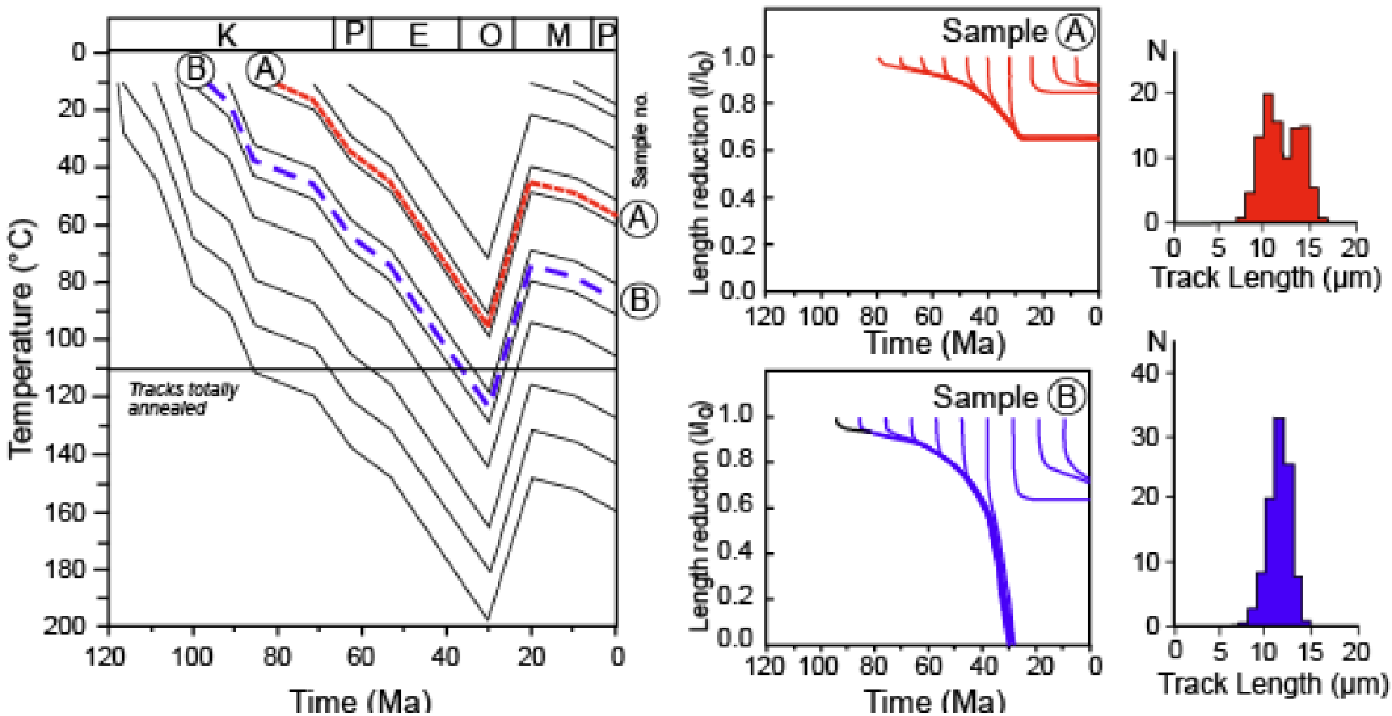
UNCERTAINTIES
- **Amount of erosion**
- Paleo Water Deoth (PWD)
- Sediment Water Interface Temperature(SWIT)

Apatite Fission Track Analysis



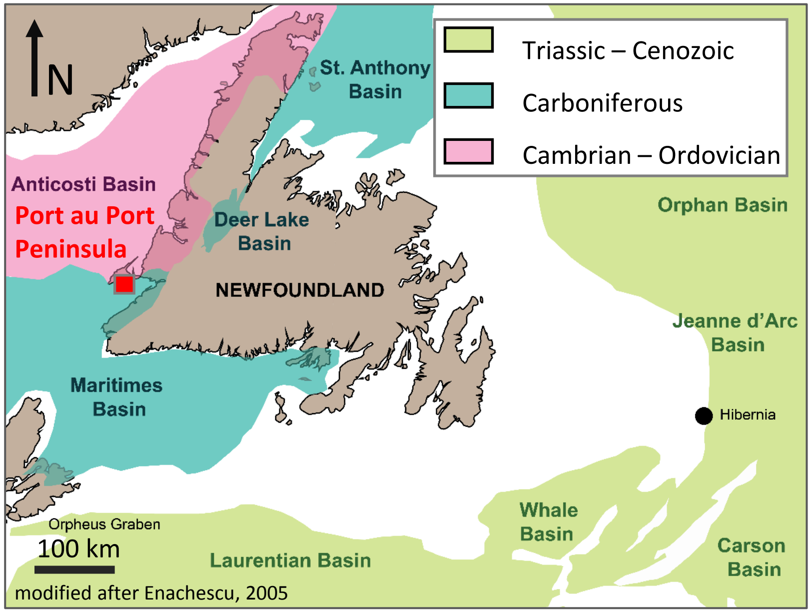
Gleadow et al. 2002

- Apatite fission tracks are a result of ^{238}U decay destroying the crystal lattice along their flight paths
- Initial track length is ~15µm
- Tracks heal with increasing temperature
- Tracks disappear when temperature increases over 110°C
- Annealing temperature and annealing rates dependent on Cl content in apatite

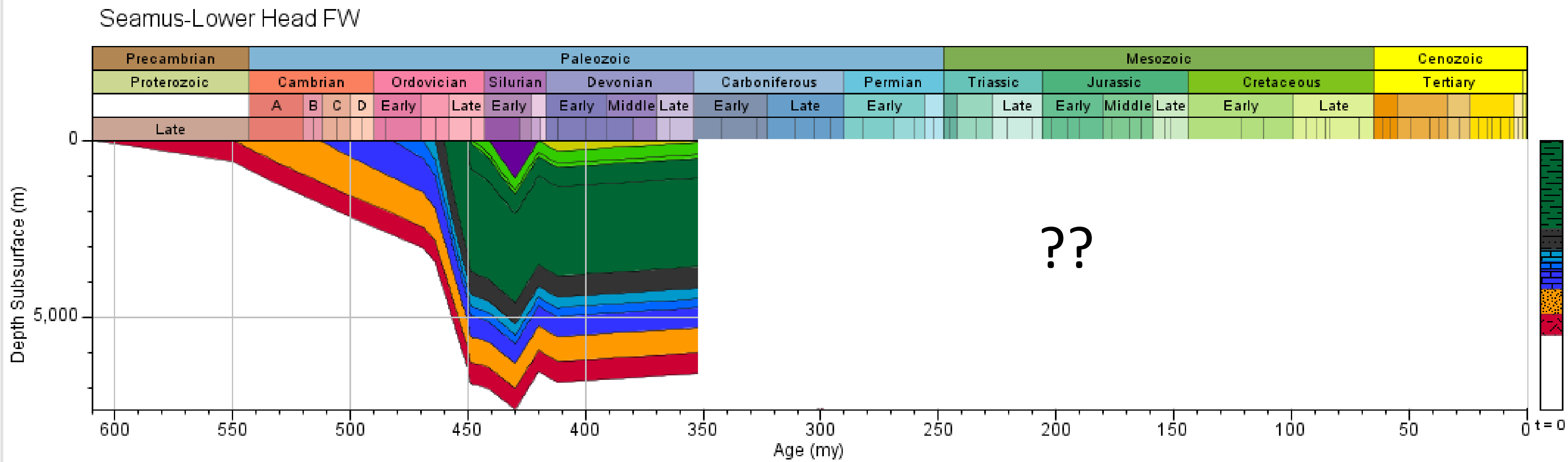


Green et al. 2002

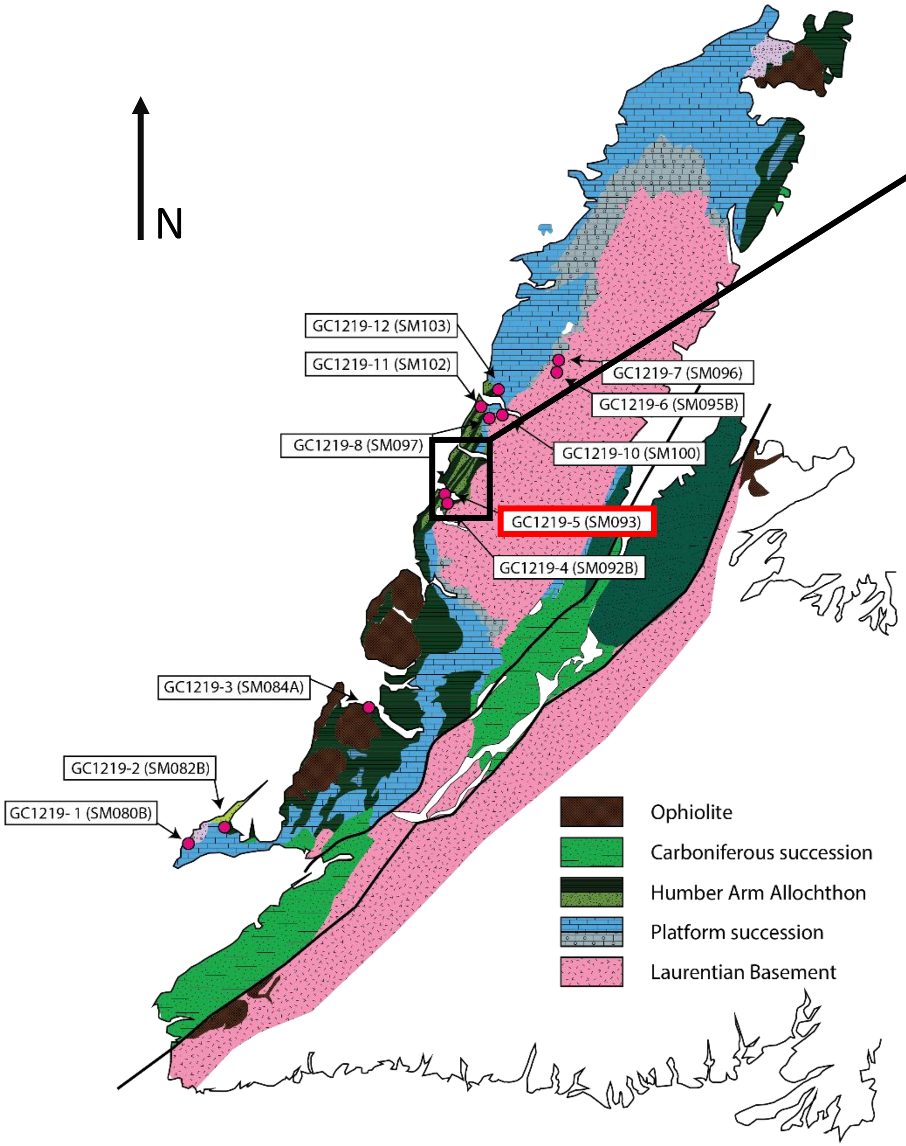
APATITE FISSION TRACK – APPLICATION



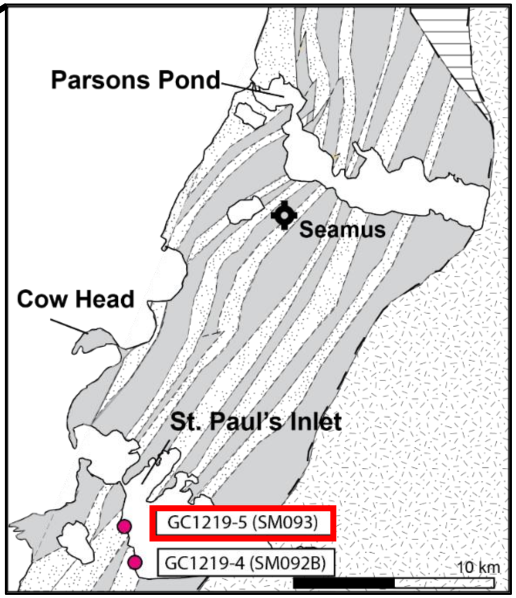
- Thermal history framework
- Timing and magnitude of paleo-thermal events
- Paleo-geothermal gradients
- Constraints on the thermal maximum and therefore the maturity of sediments in the basin
- Reconstruction of uplift and erosion history where there are gaps in the geologic record



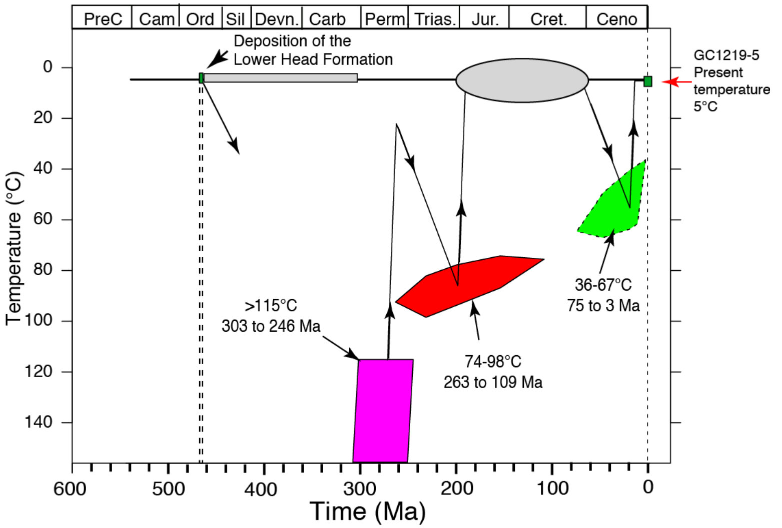
Apatite Fission Track Results – St. Paul's Inlet



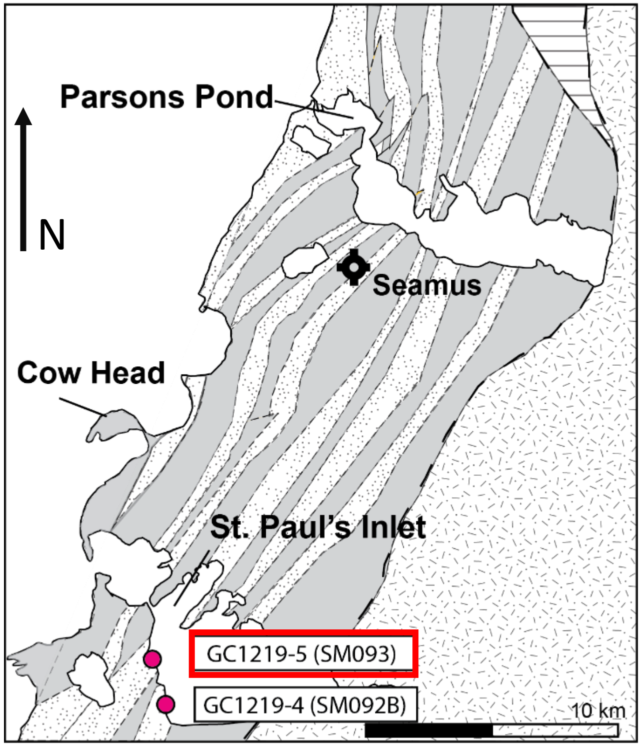
(modified after Waldron et al., 2003)

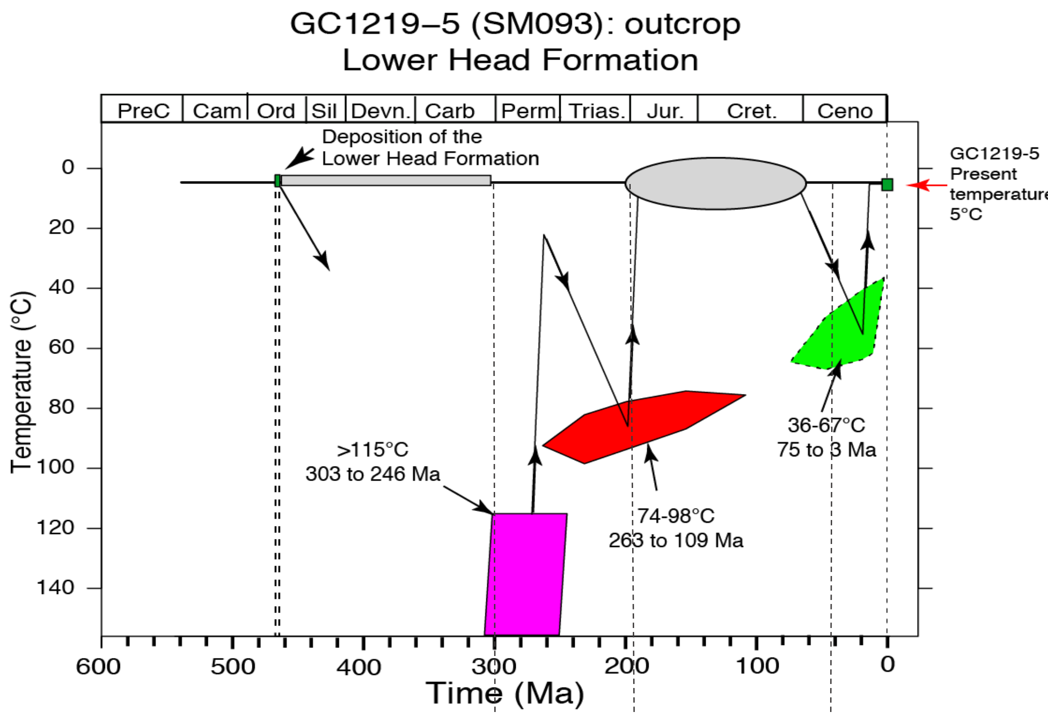


GC1219–5 (SM093): outcrop
Lower Head Formation

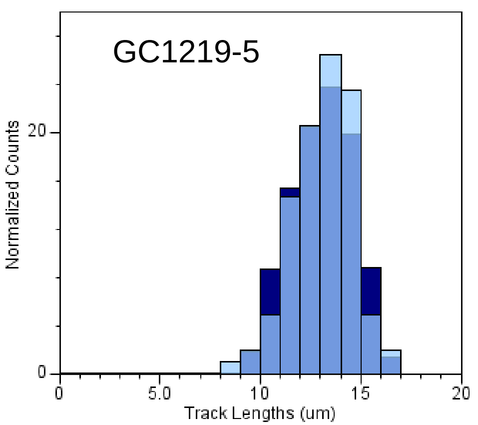


Burial History Calibration





Apatite Fission Tracks



Track Age: 235.7 ± 14 Ma

Calculated Track Length

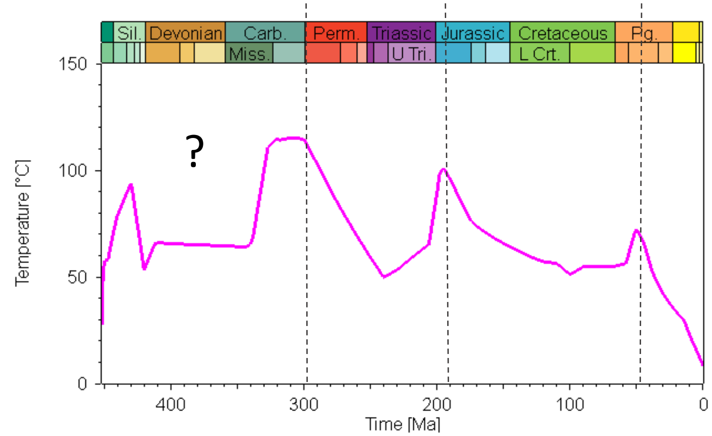
Calculated Mean = 13.1 (um)

Calculated Std. Dev. = 1.5 (um)

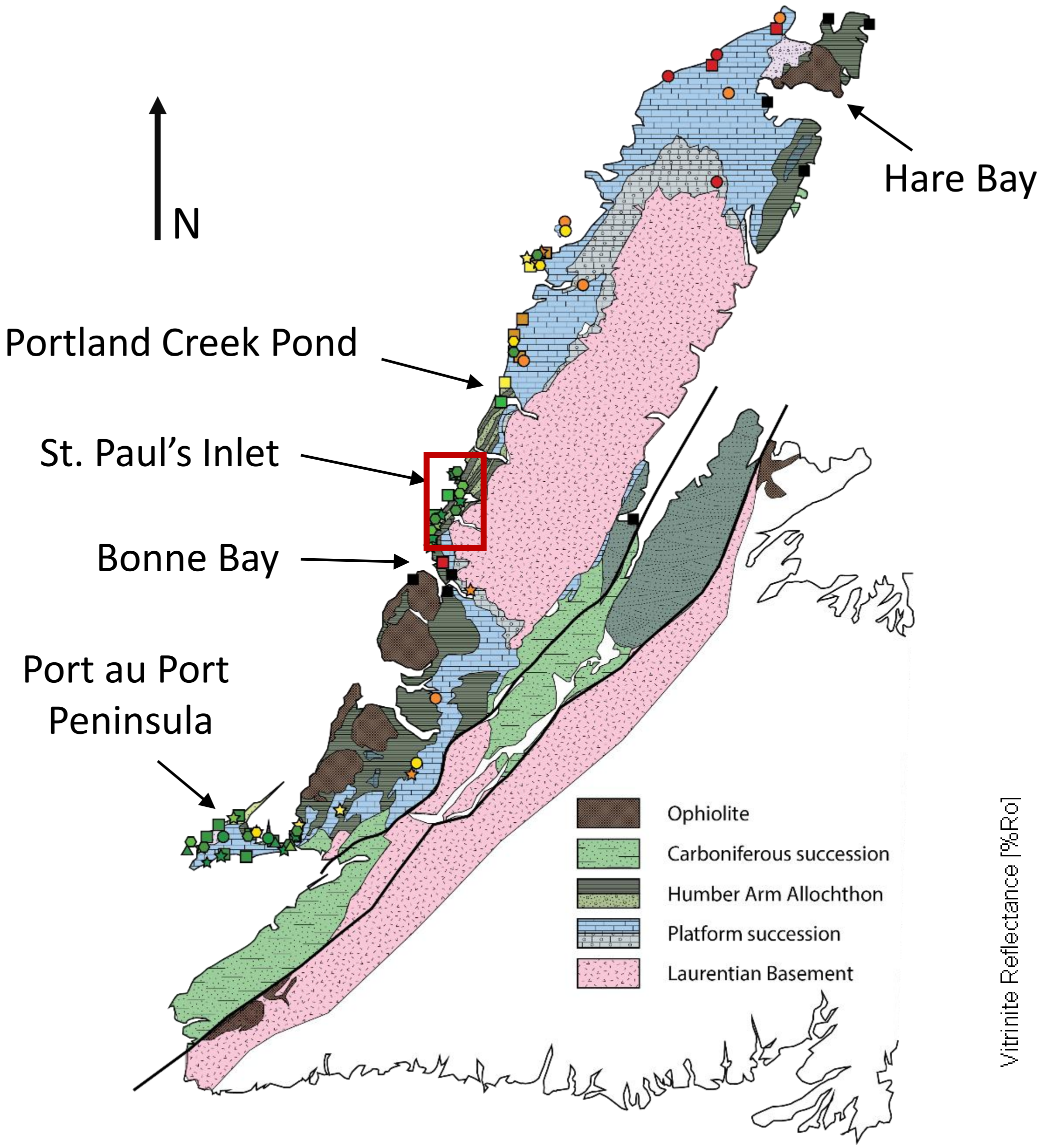
Measured Track Length

Measured Mean = 13.1 (um)

Measured Std. Dev. = 1.5 (um)



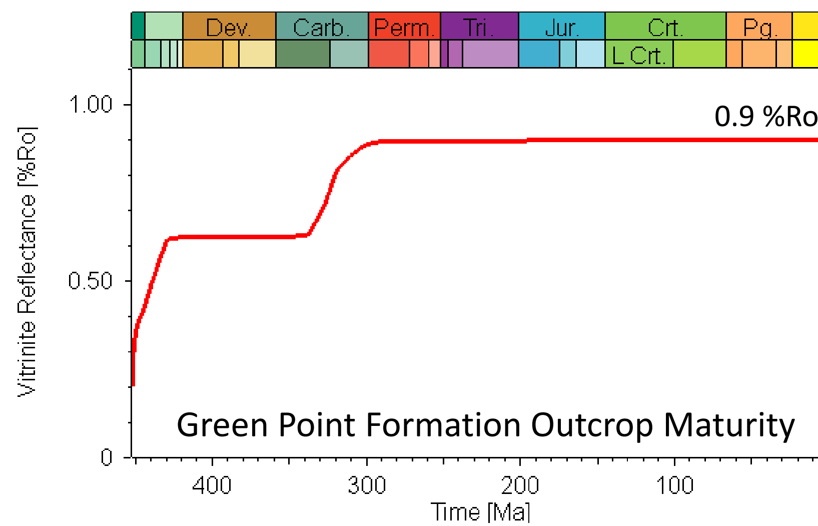
ADDITIONAL THERMAL CONSTRAINTS



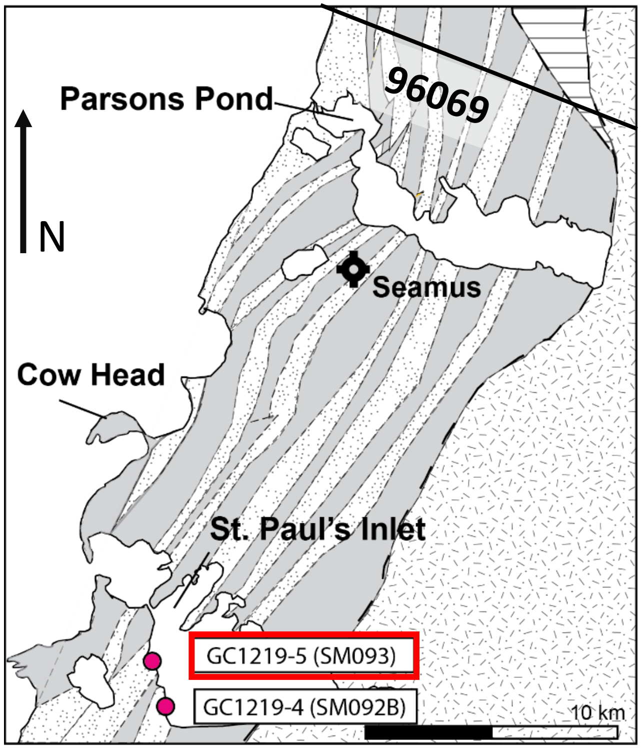
(modified after Waldron et al., 2003)

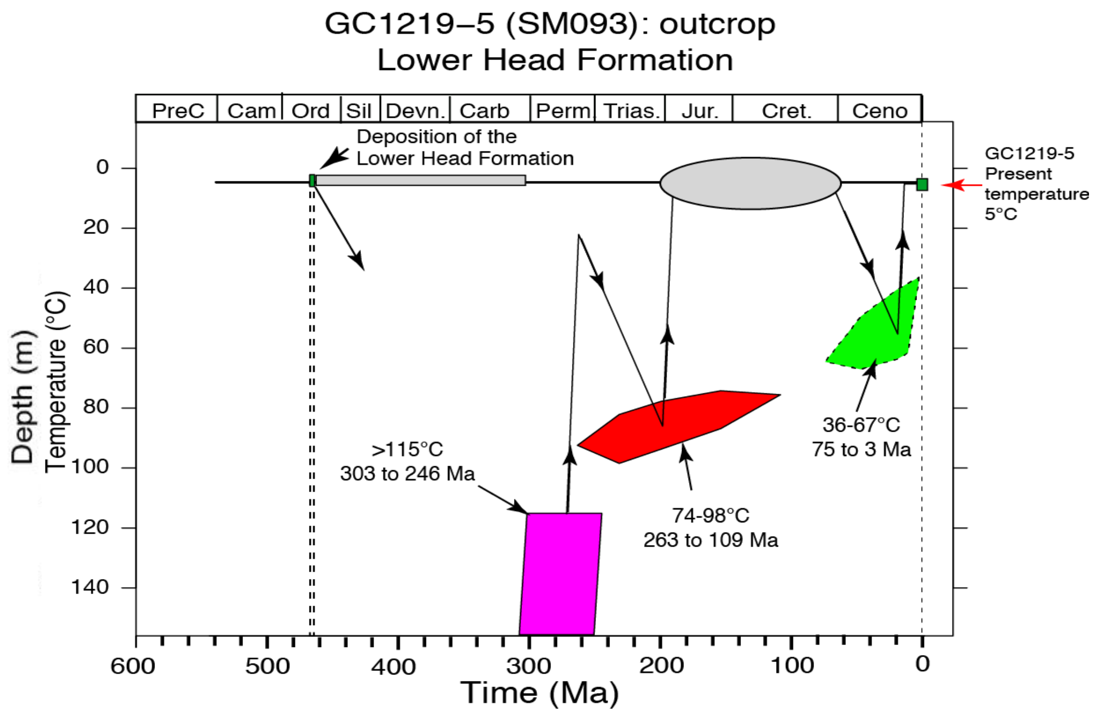
Temp.	VRo	GRo	CAI	TAI	AAI
0-50	0.5	0.5	1.0	2.0	1.0
50-90	1.0	1.0	1.5	2.5	2.0 2.5
90-120	1.5	2.0	2.0	3.0	3.0
120-150	2.0	3.0	3.0		4.0
150-200	3.0 4.0	4.0	4.0	4.0	
>200					

Compiled data from: Nowlan and Barnes 1987; Weaver 1988; Macauley 1987; Williams and Cawood 1989; Sinclair 1990; Saunders et al. 1992; Sangaster et al. 1994; Fowler et al. 1995; Williams et al 1998; Conliffe et al 2017.



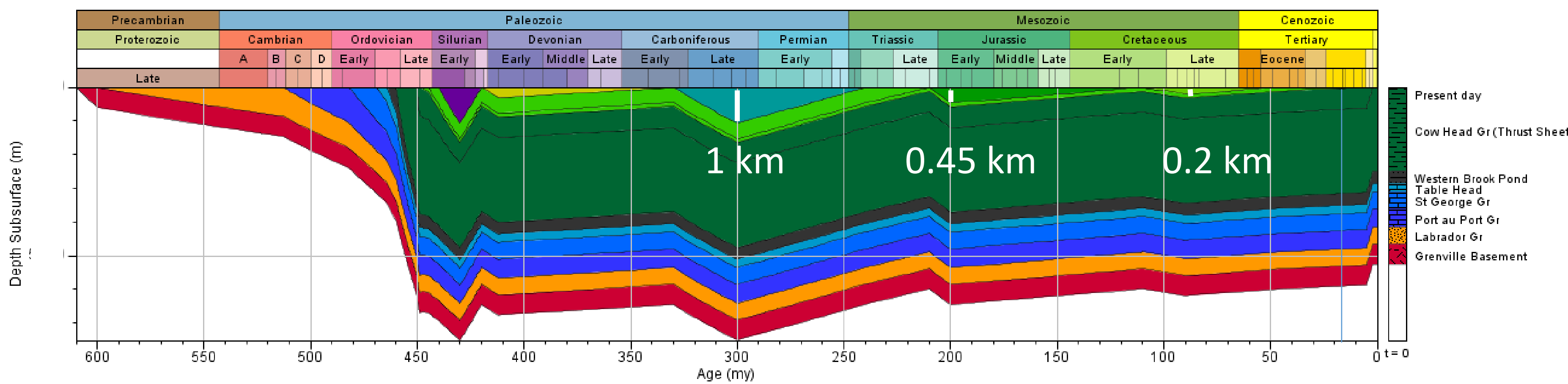
BURIAL HISTORY – ST. PAUL'S INLET



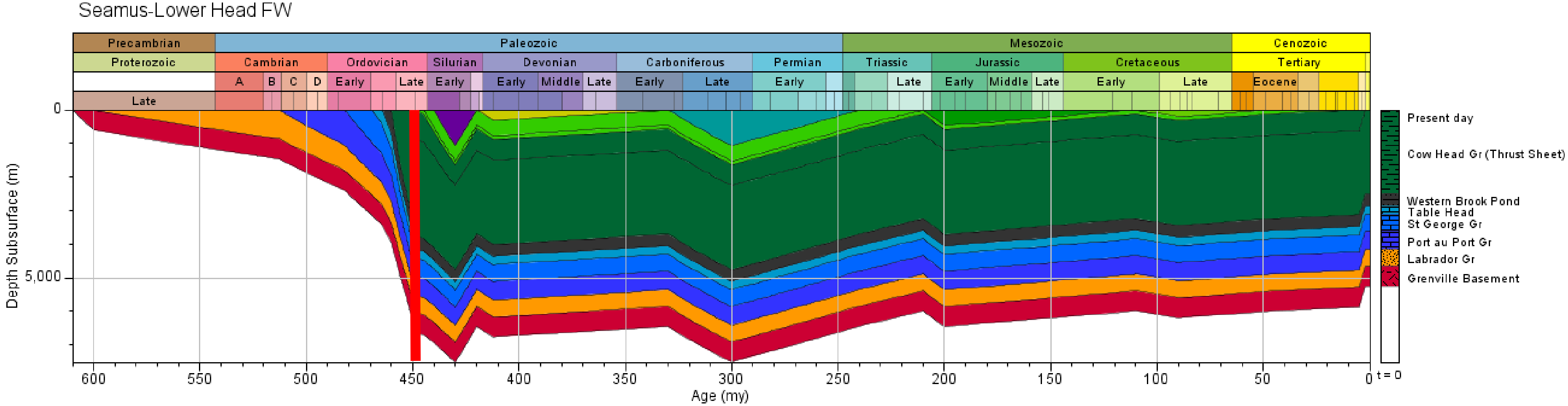


Seamus-Lower Head FW

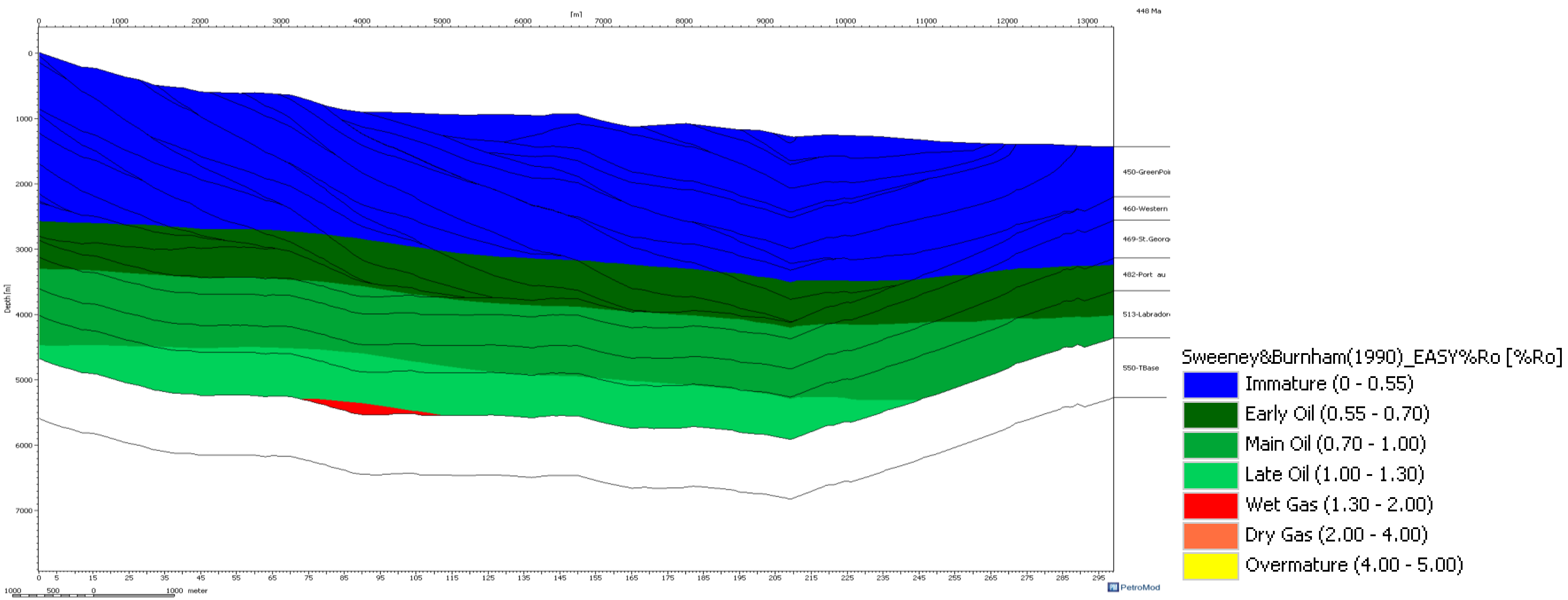
GC1919-5



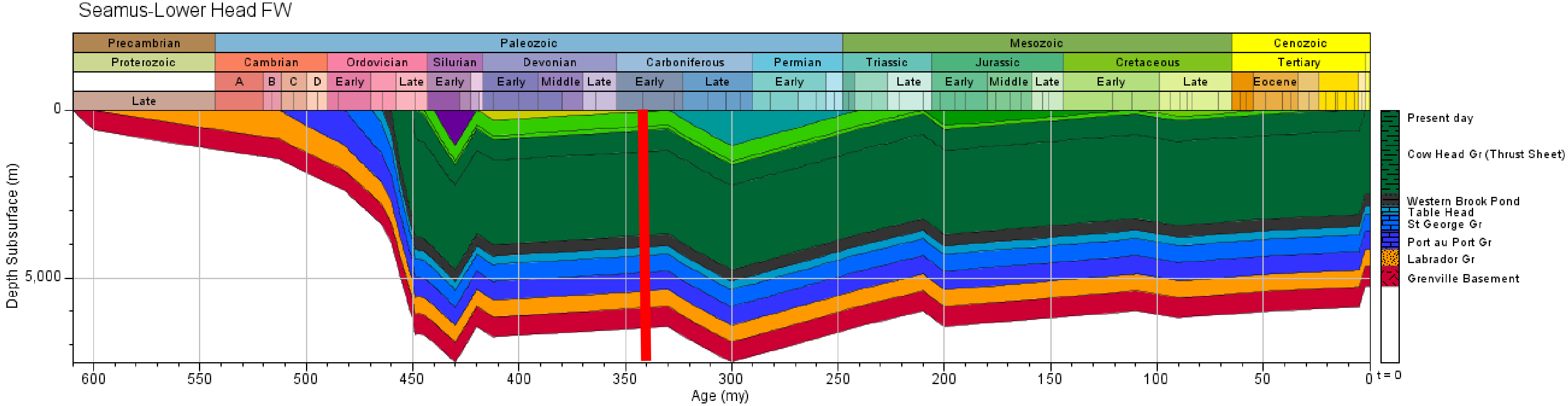
Thermal Maturity Through Time



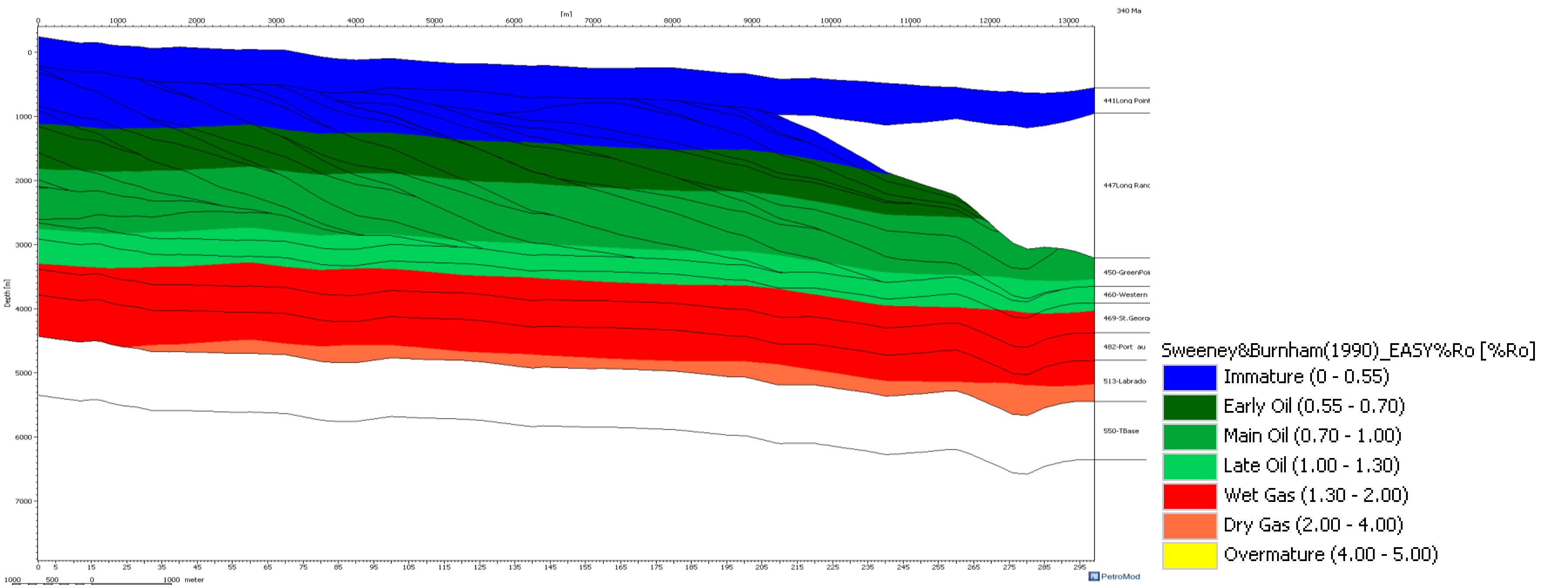
448 Ma



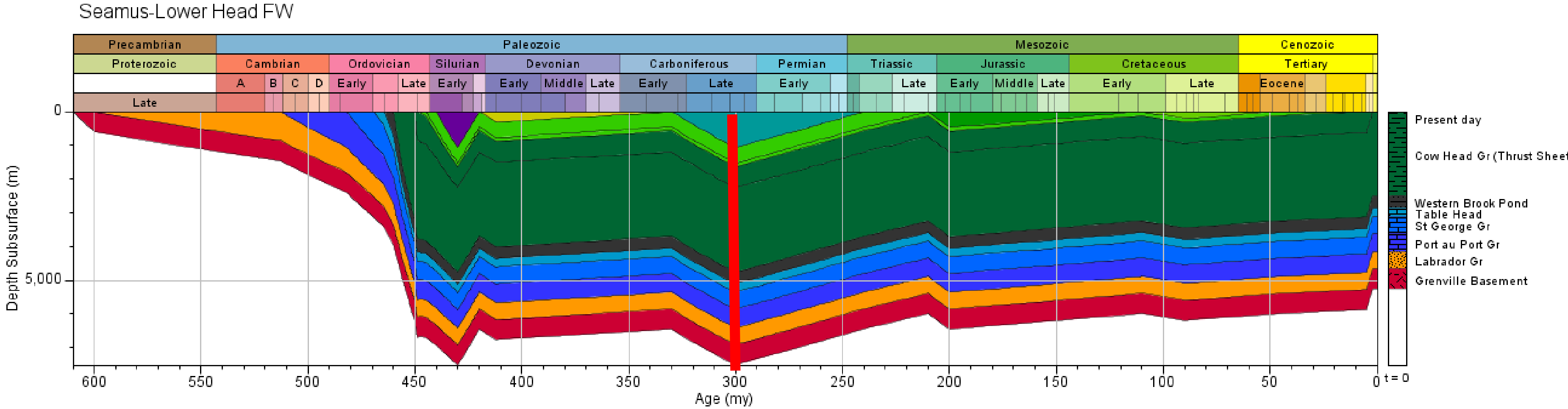
THERMAL MATURITY THROUGH TIME



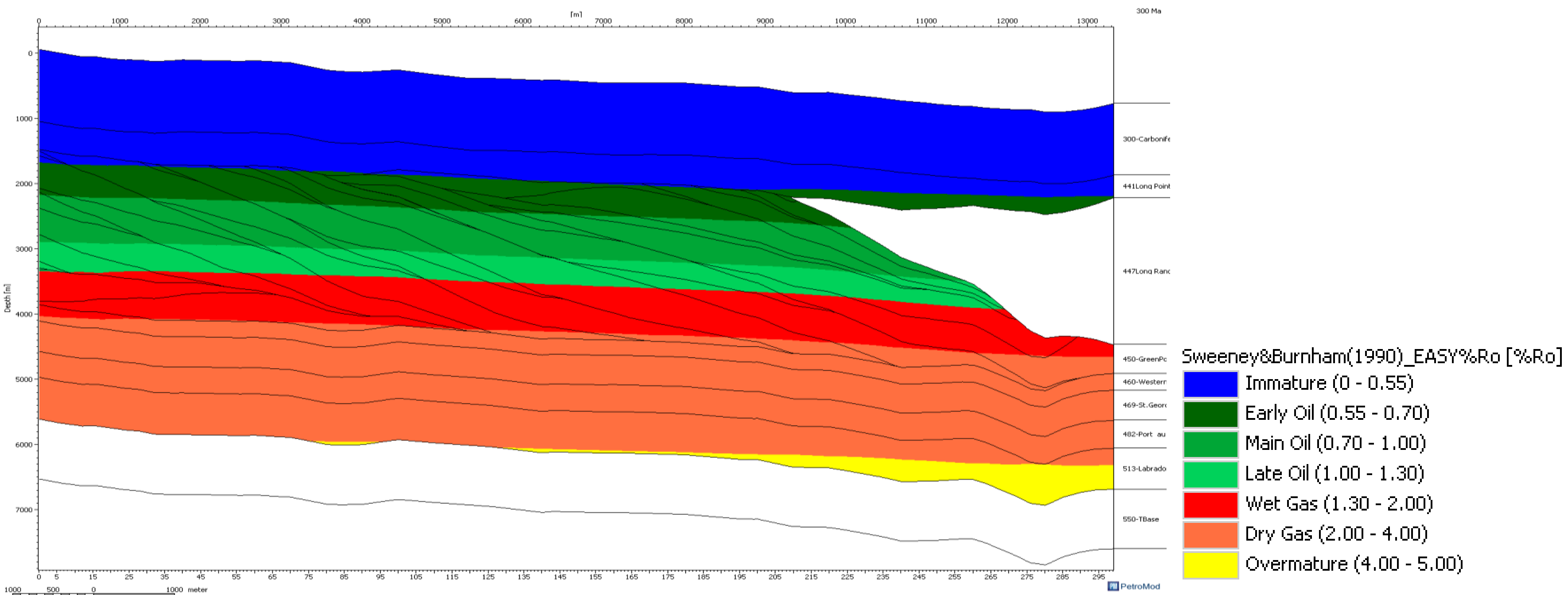
340 Ma



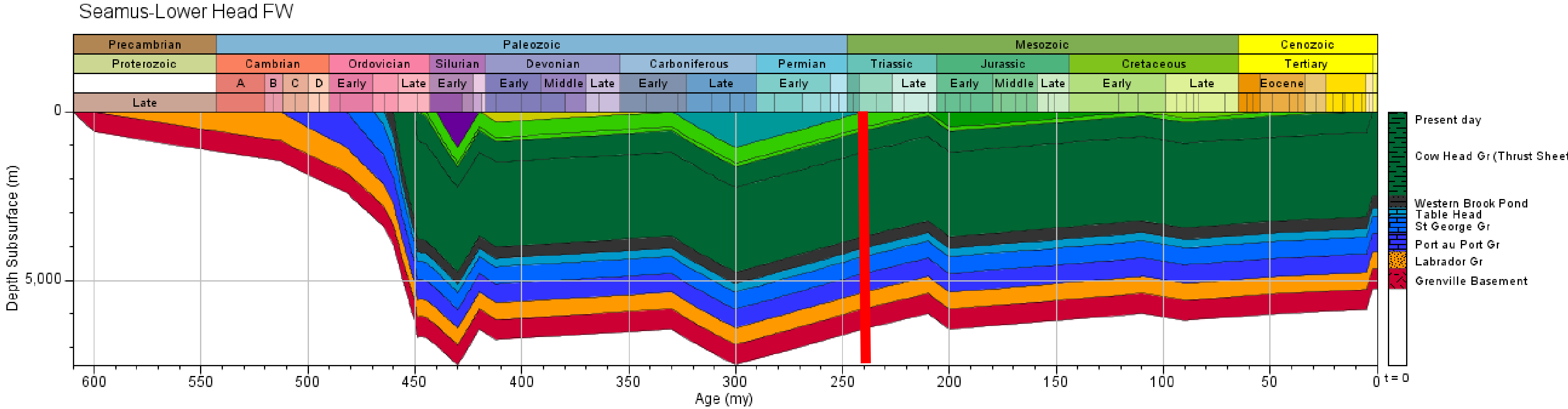
Thermal Maturity Through Time



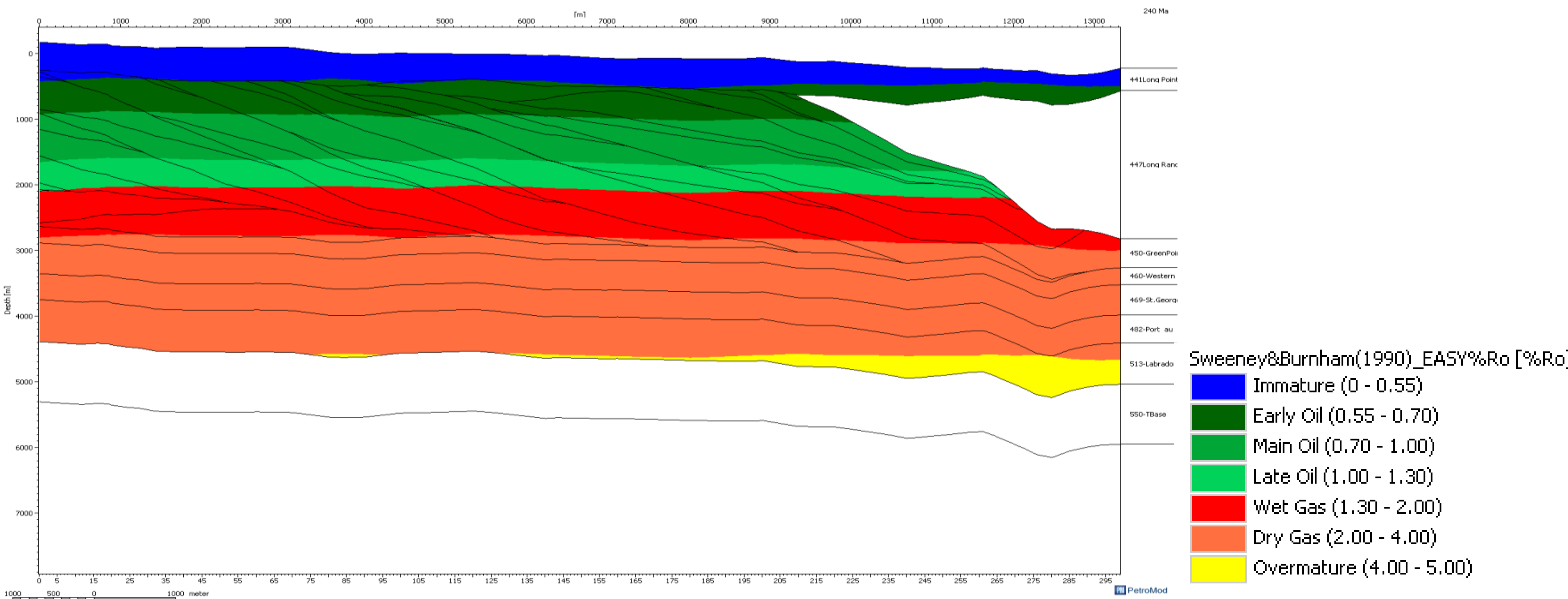
300 Ma



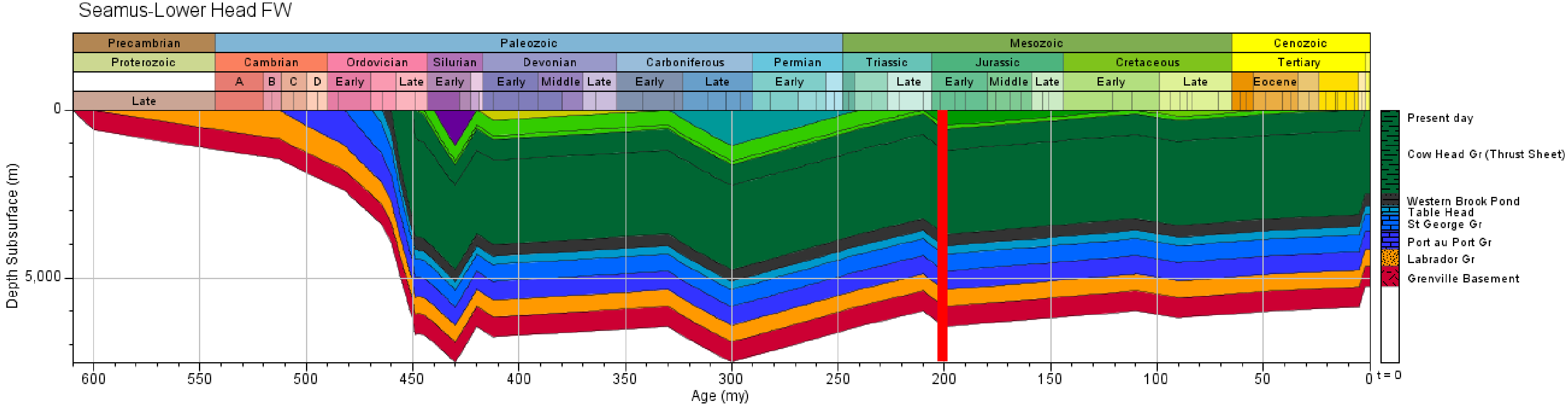
THERMAL MATURITY THROUGH TIME



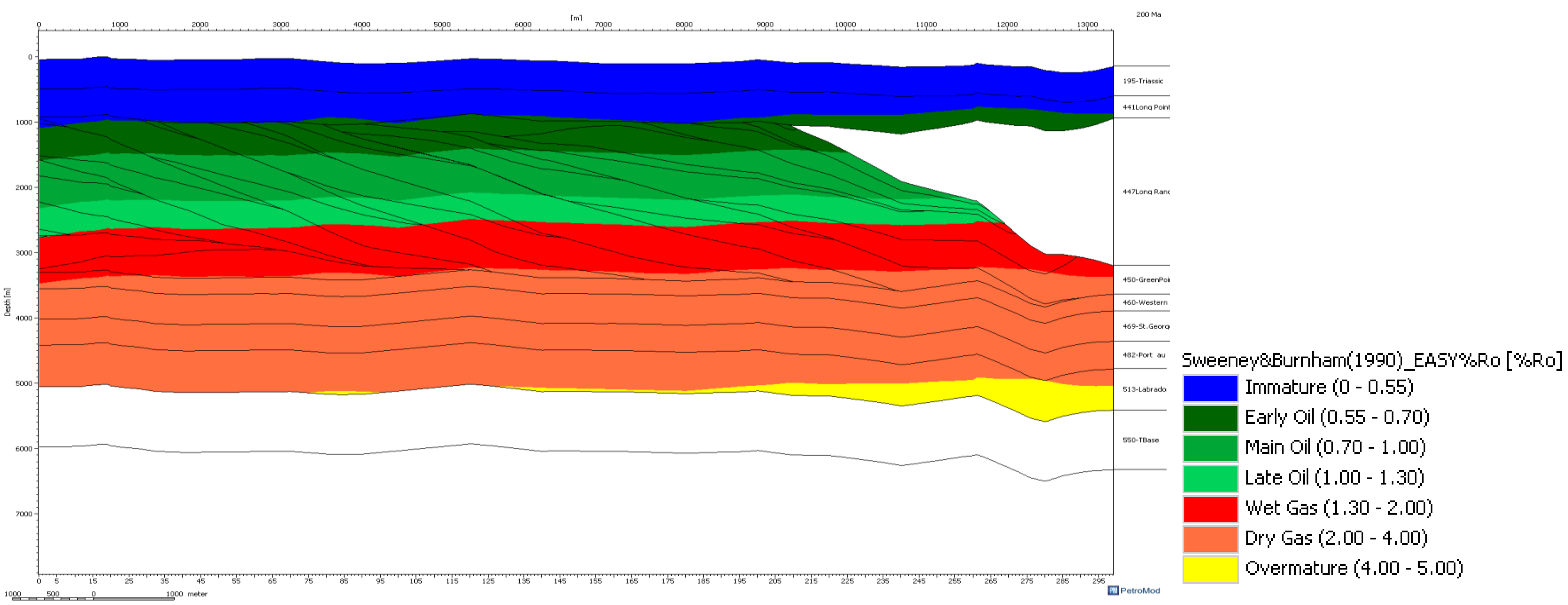
240 Ma



THERMAL MATURITY THROUGH TIME

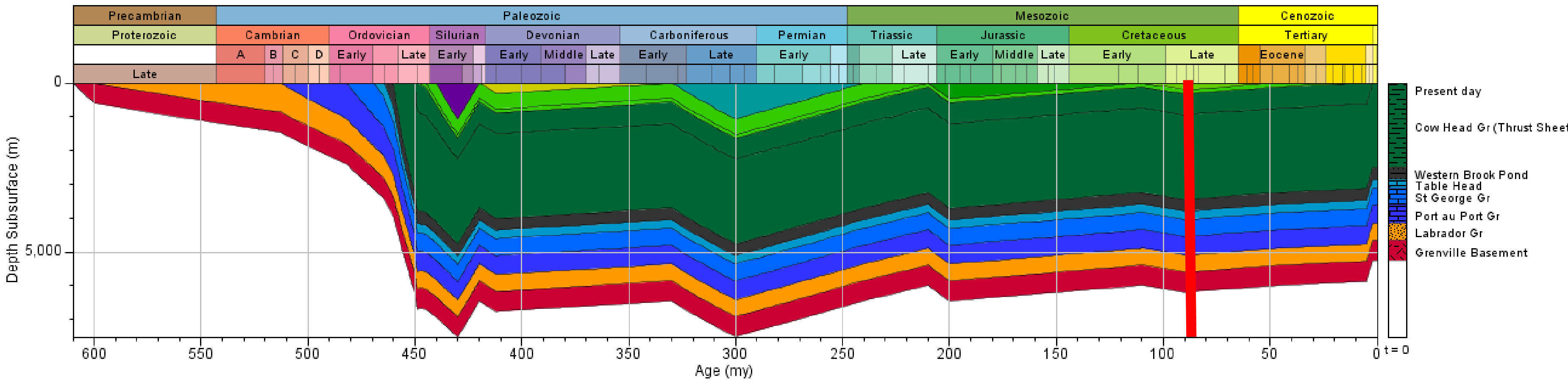


200 Ma

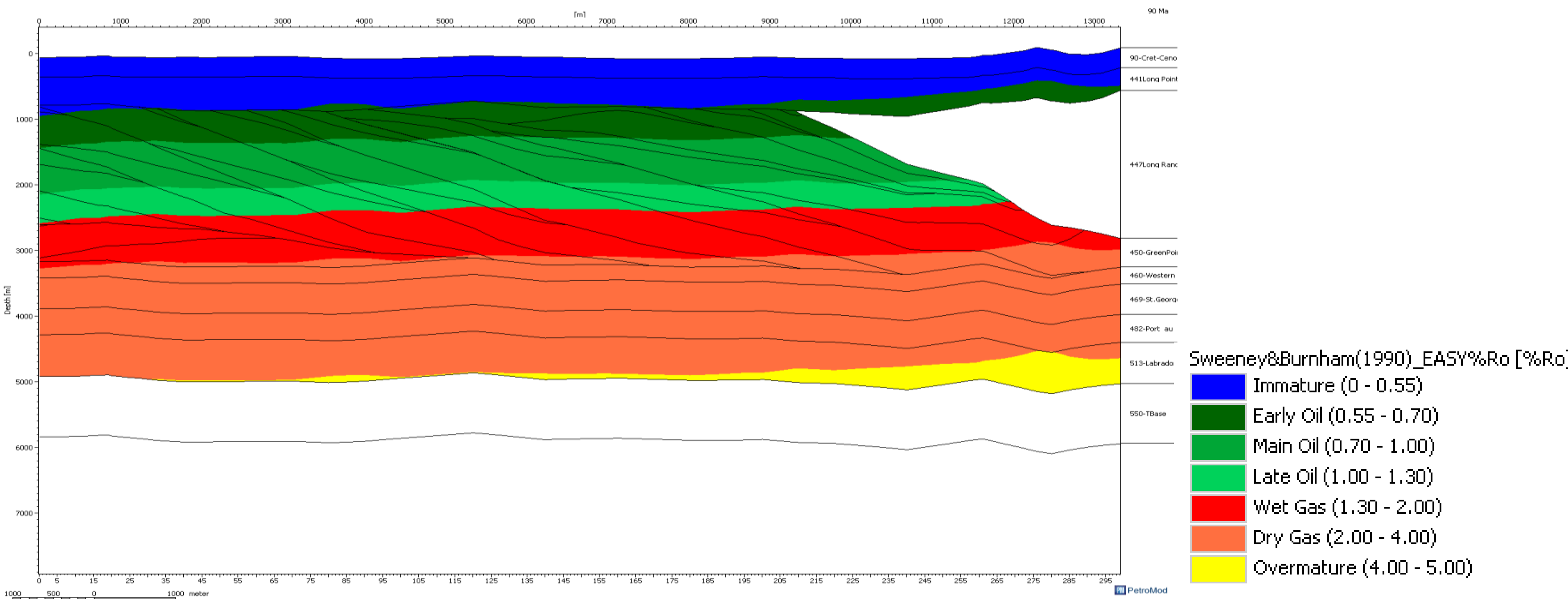


Thermal Maturity Through Time

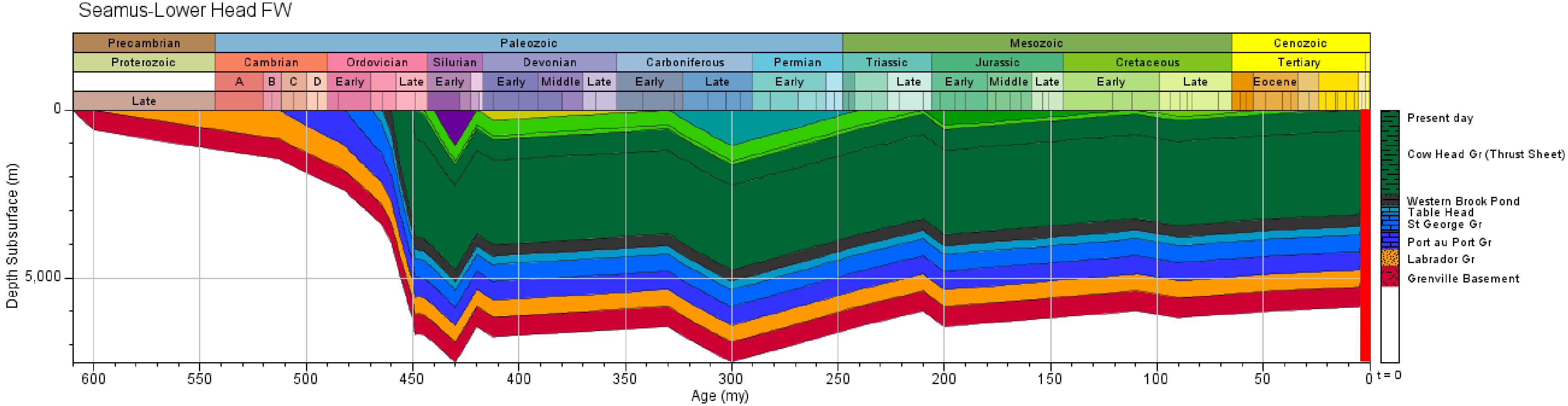
Seamus-Lower Head FW



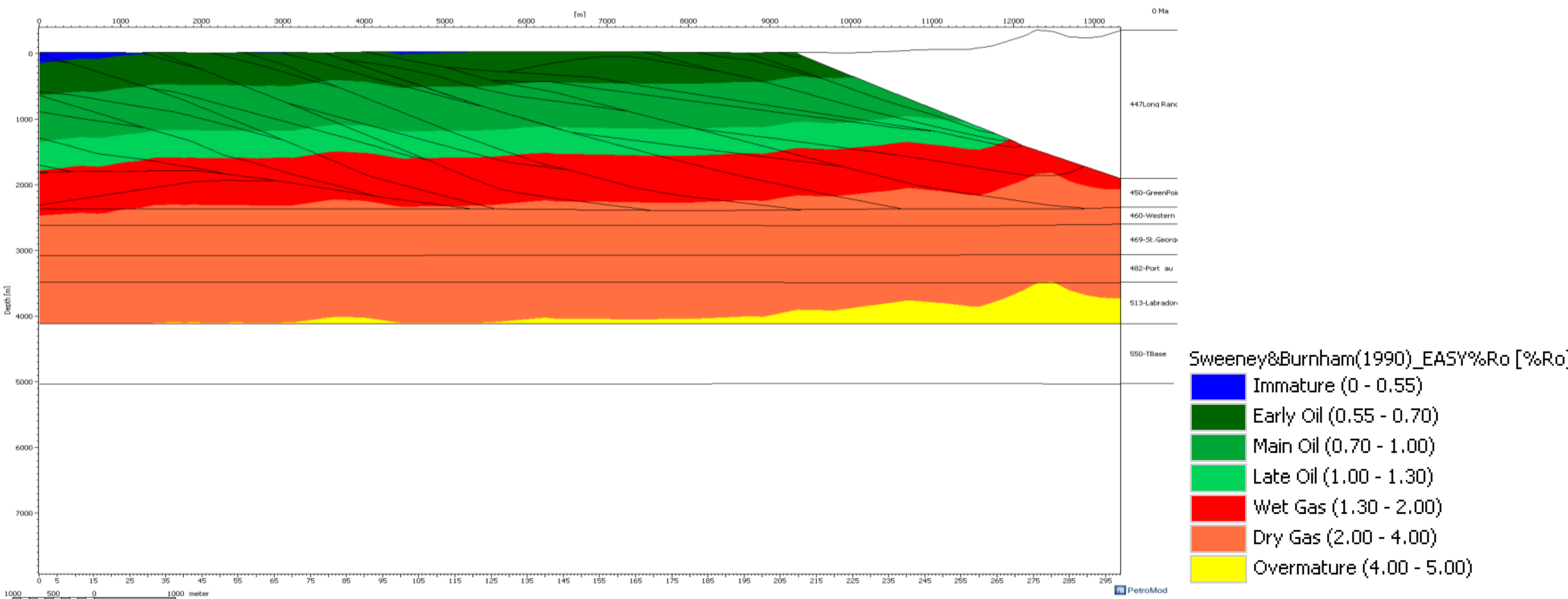
90 Ma



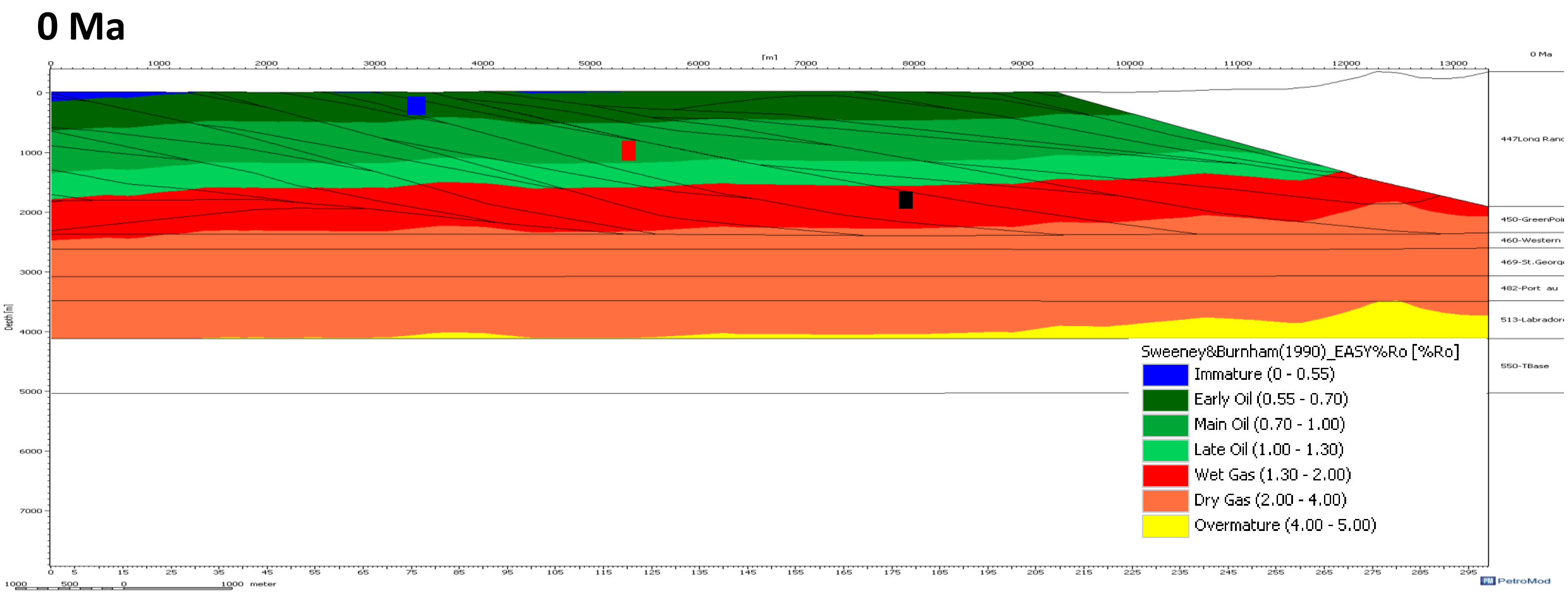
Thermal Maturity Through Time

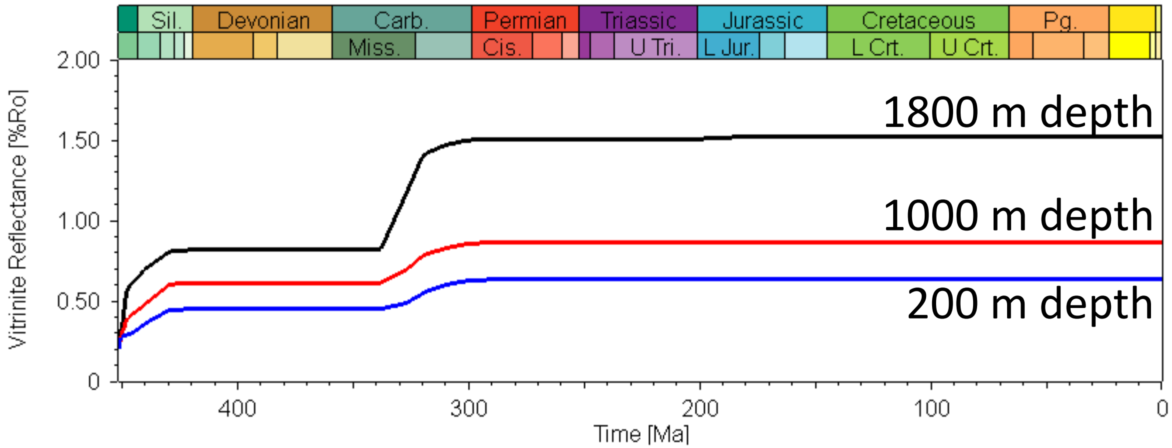


0 Ma



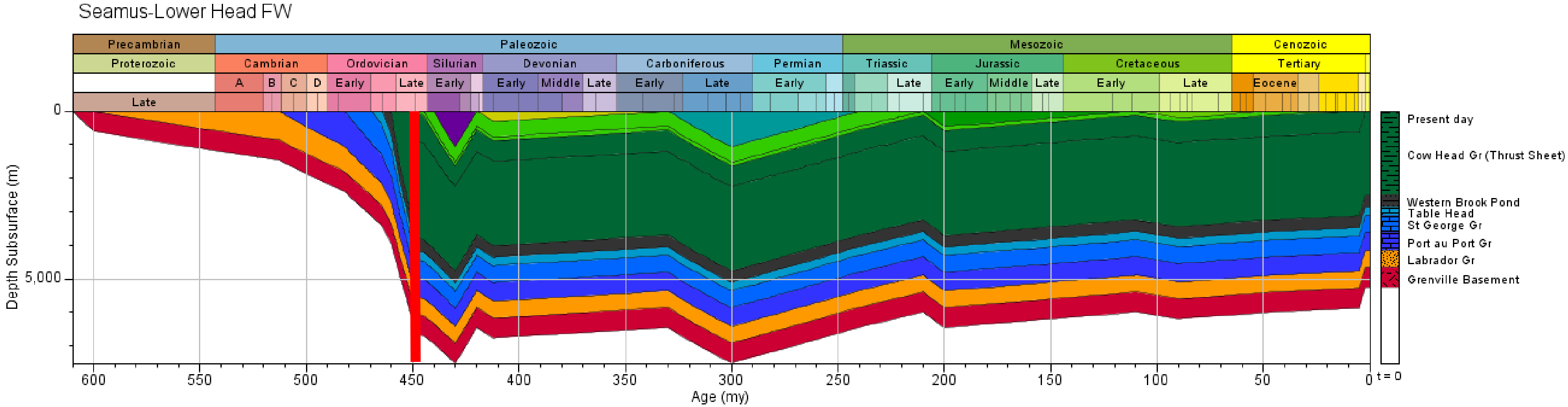
Thermal Maturity Through Time



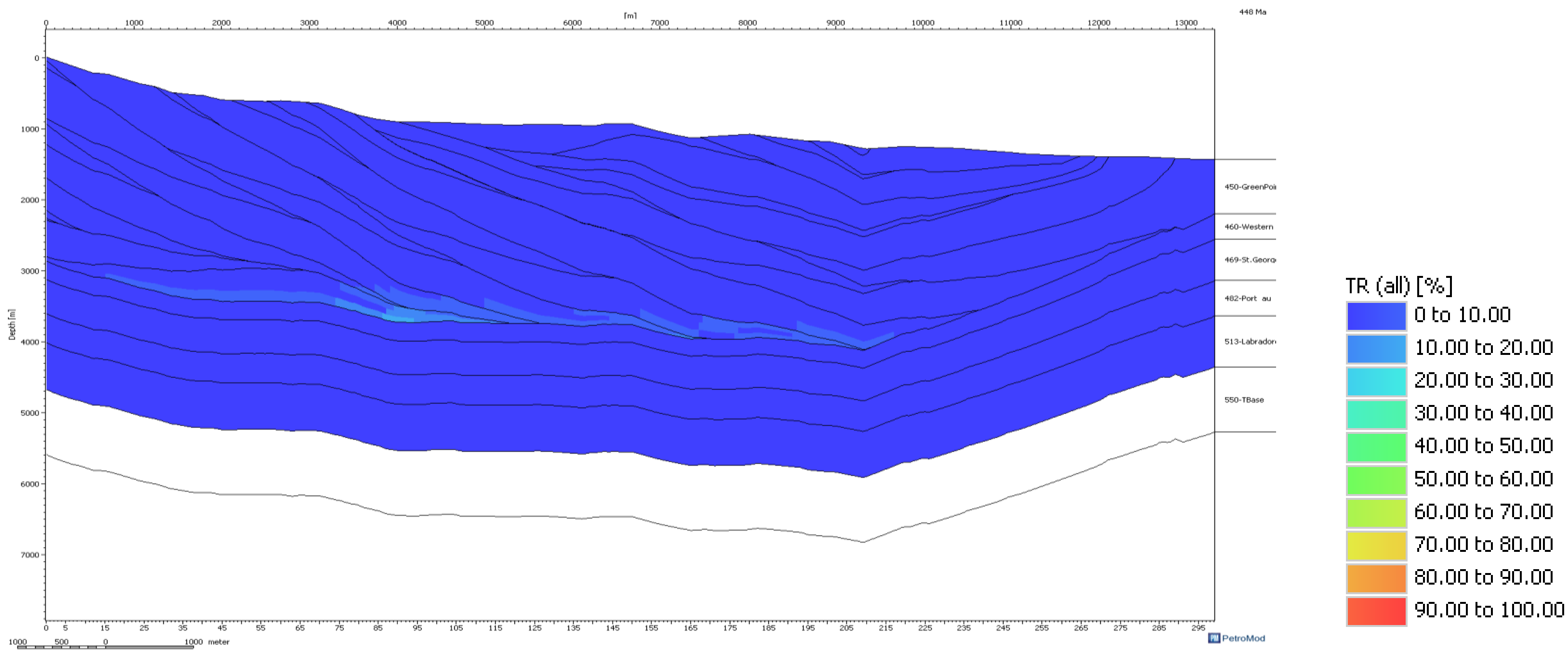


- Thermal maturity of the source rock is dependent on its structural position
- Thermal maturity increases during the Acadian Orogeny and Carboniferous sedimentation

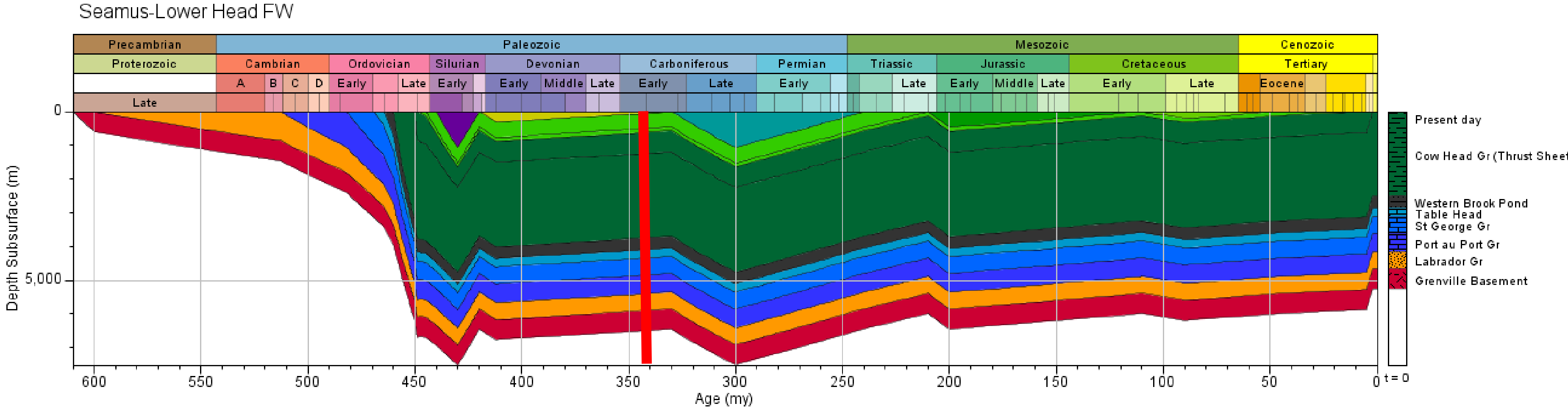
Transformation Ratio Through Time



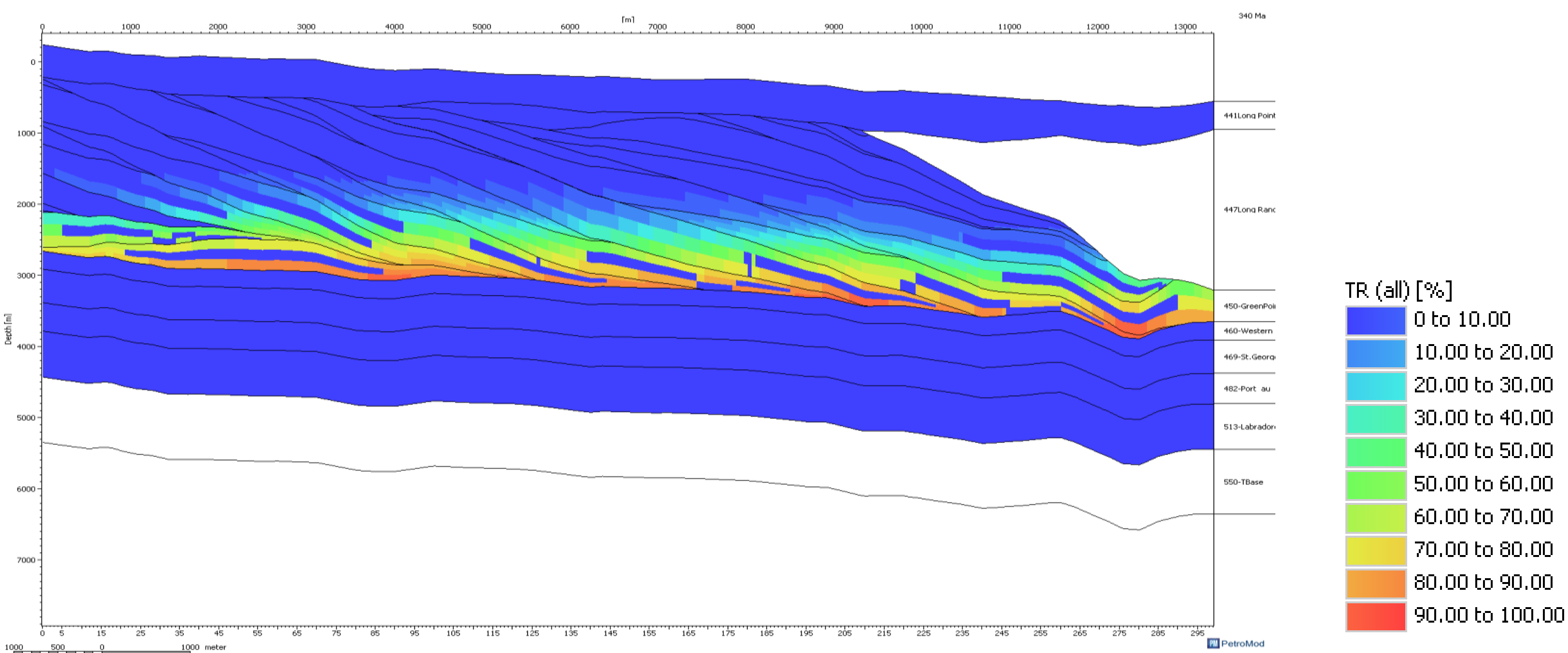
448 Ma



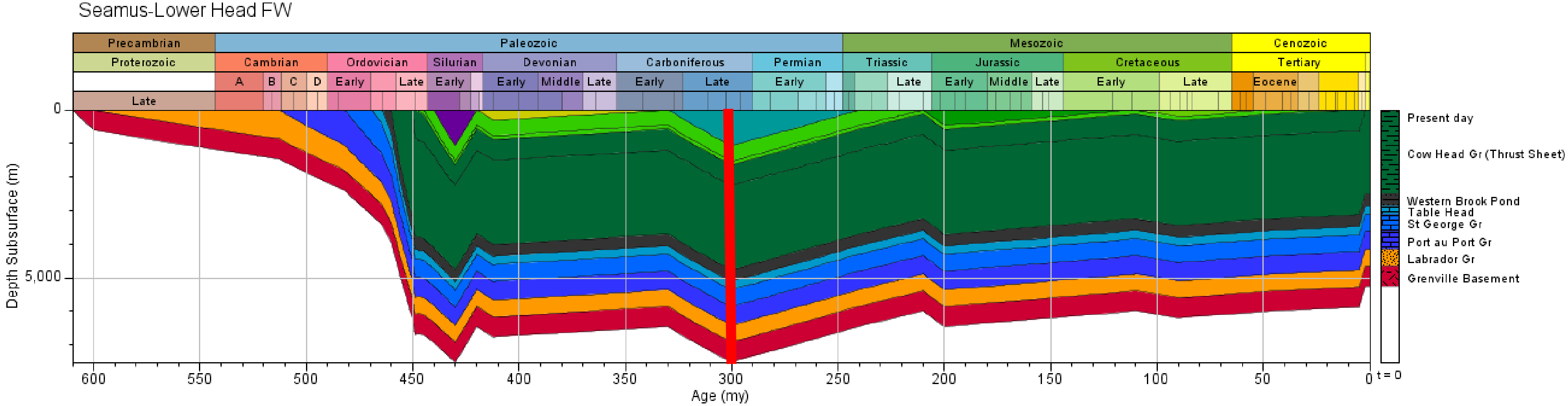
Transformation Ratio Through Time



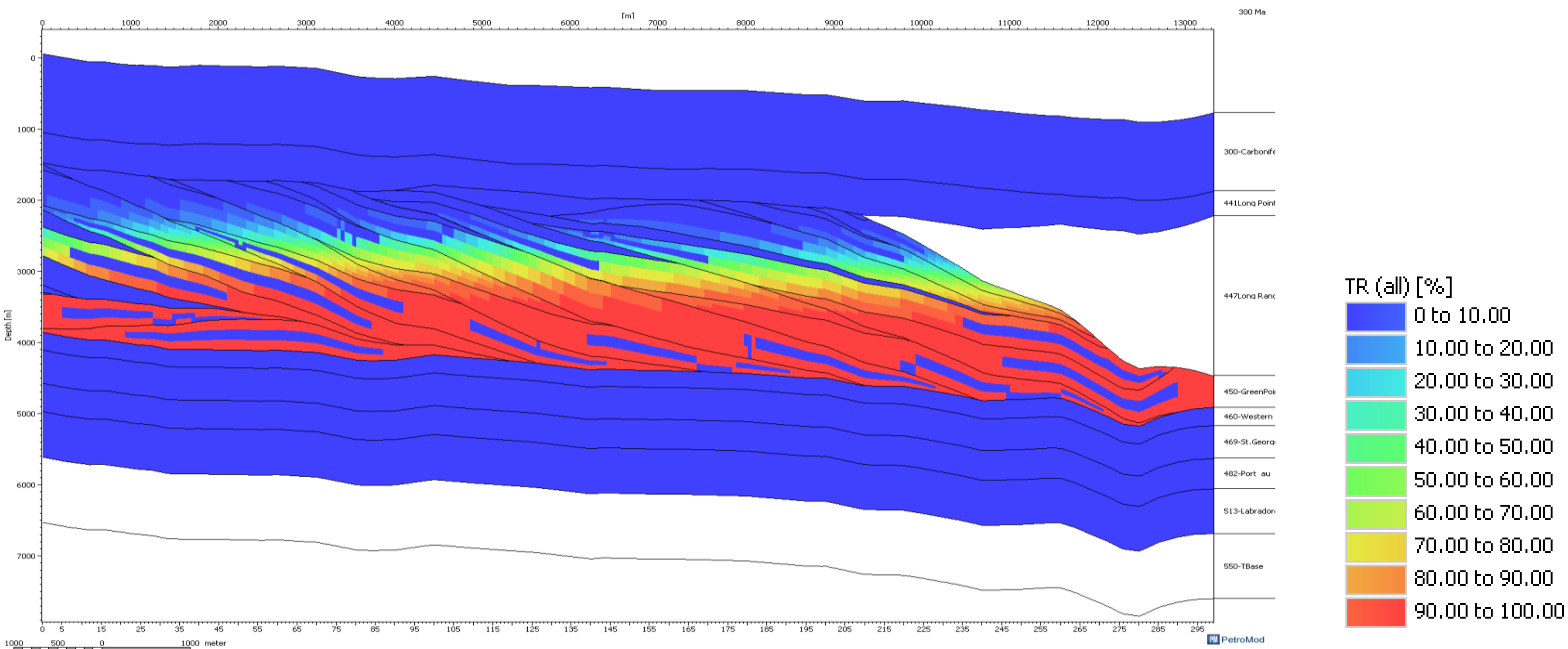
340 Ma



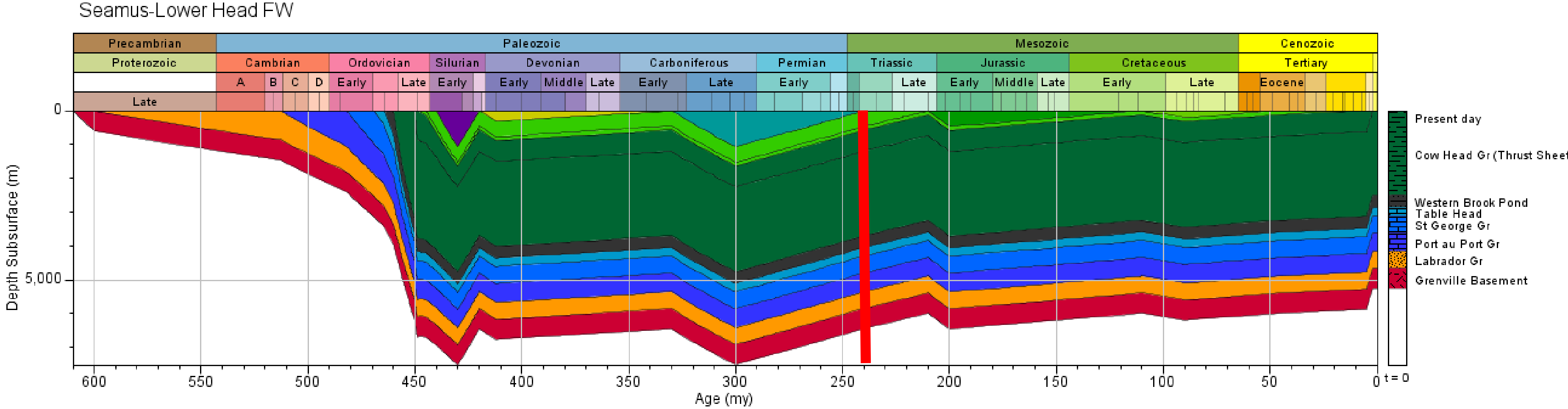
Transformation Ratio Through Time



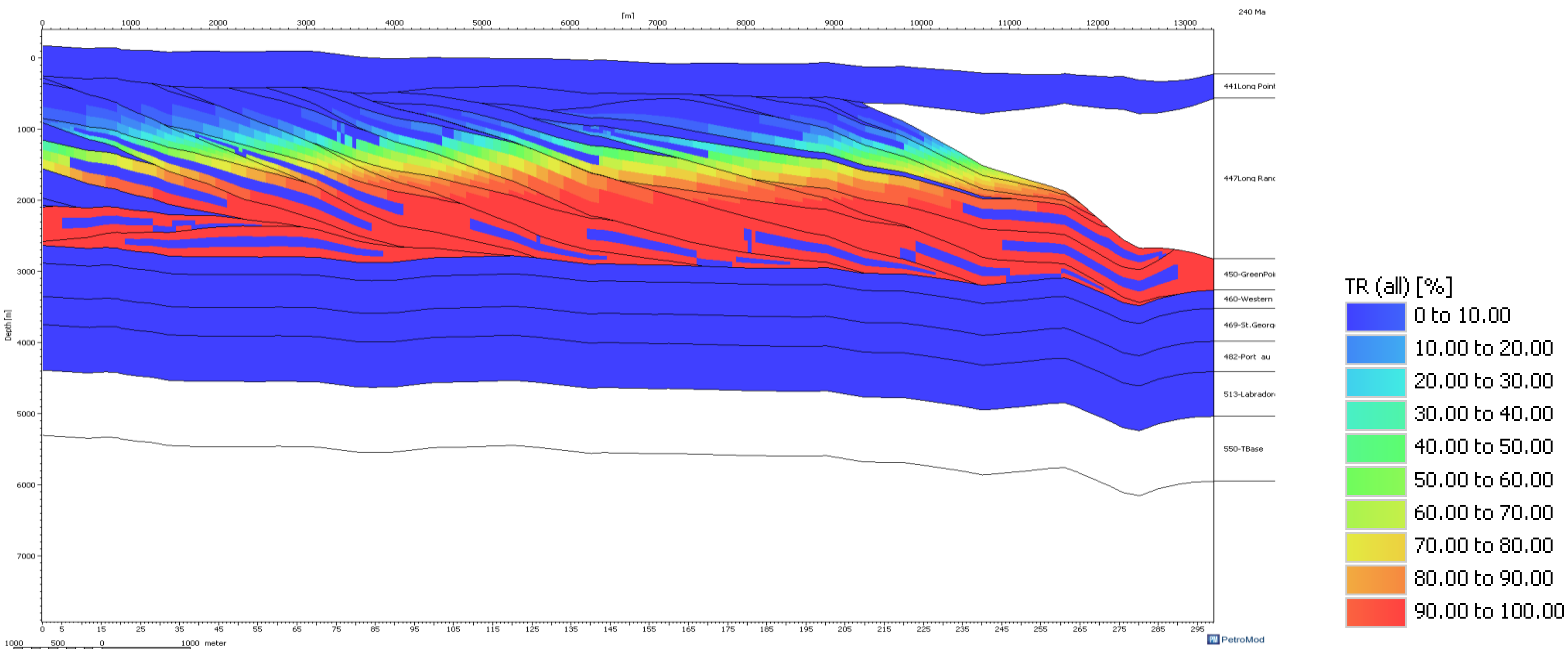
300 Ma



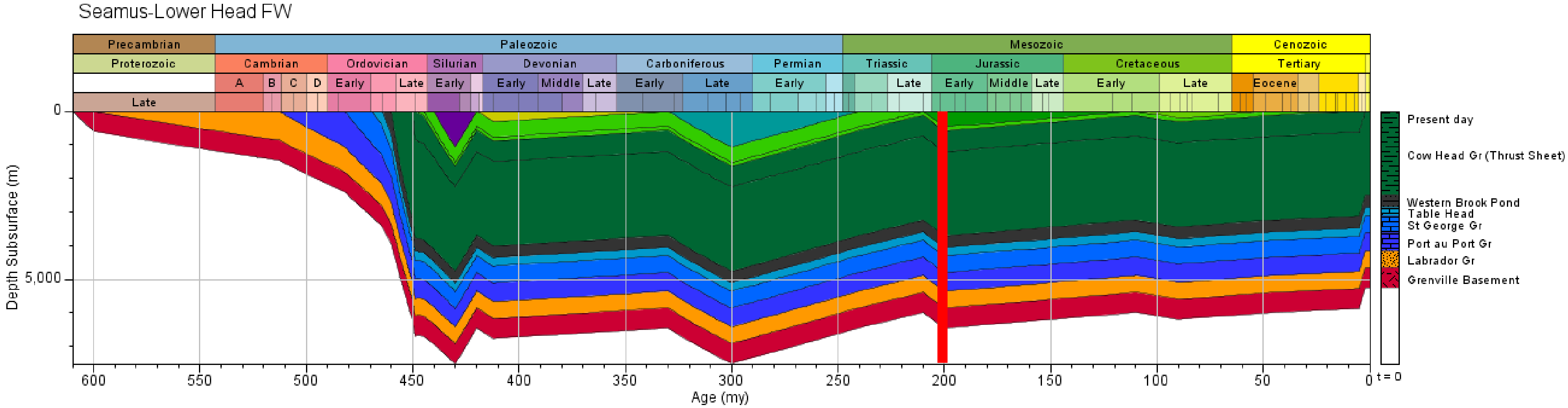
Transformation Ratio Through Time



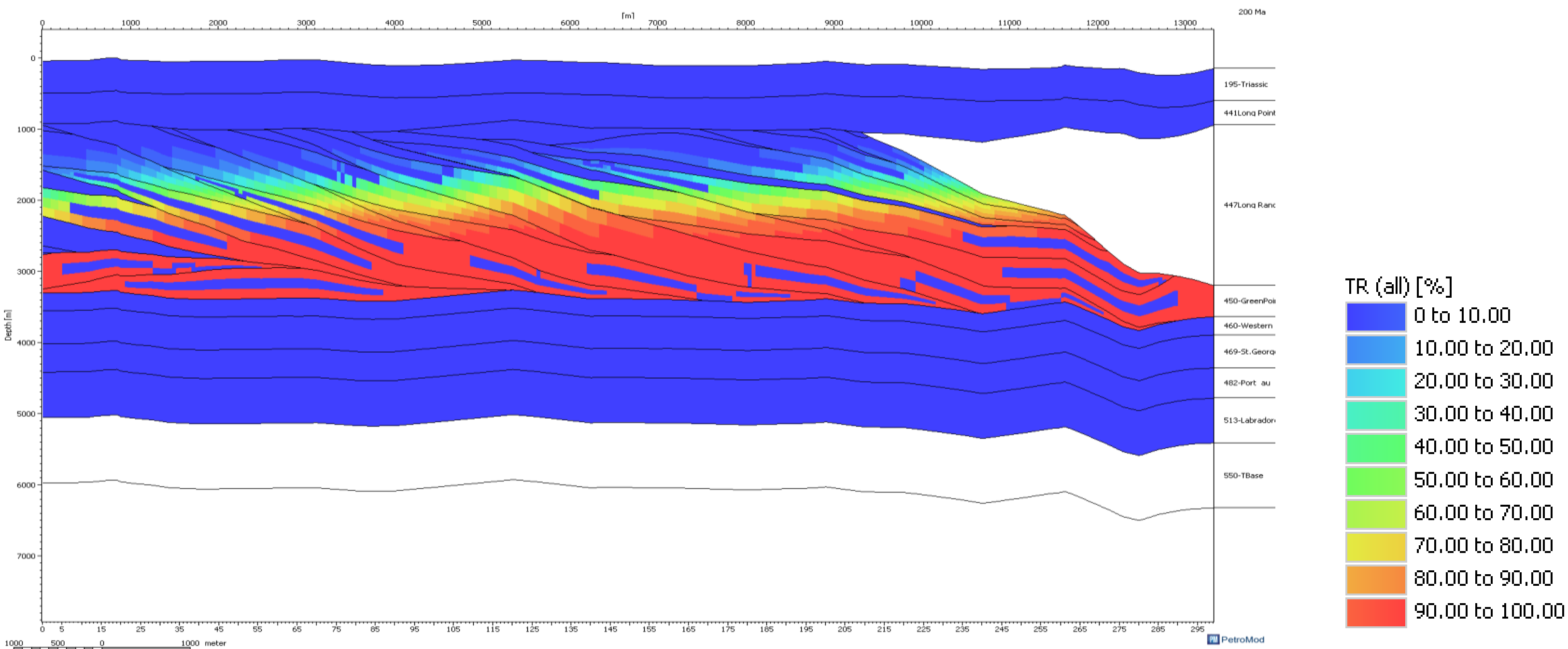
240 Ma



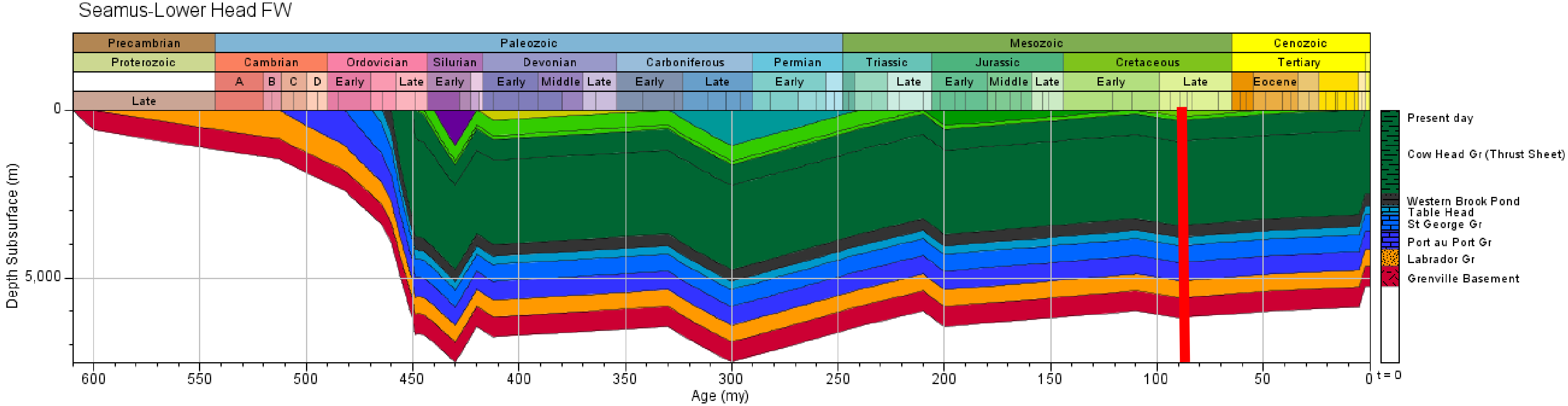
TRANSFORMATION RATIO THROUGH TIME



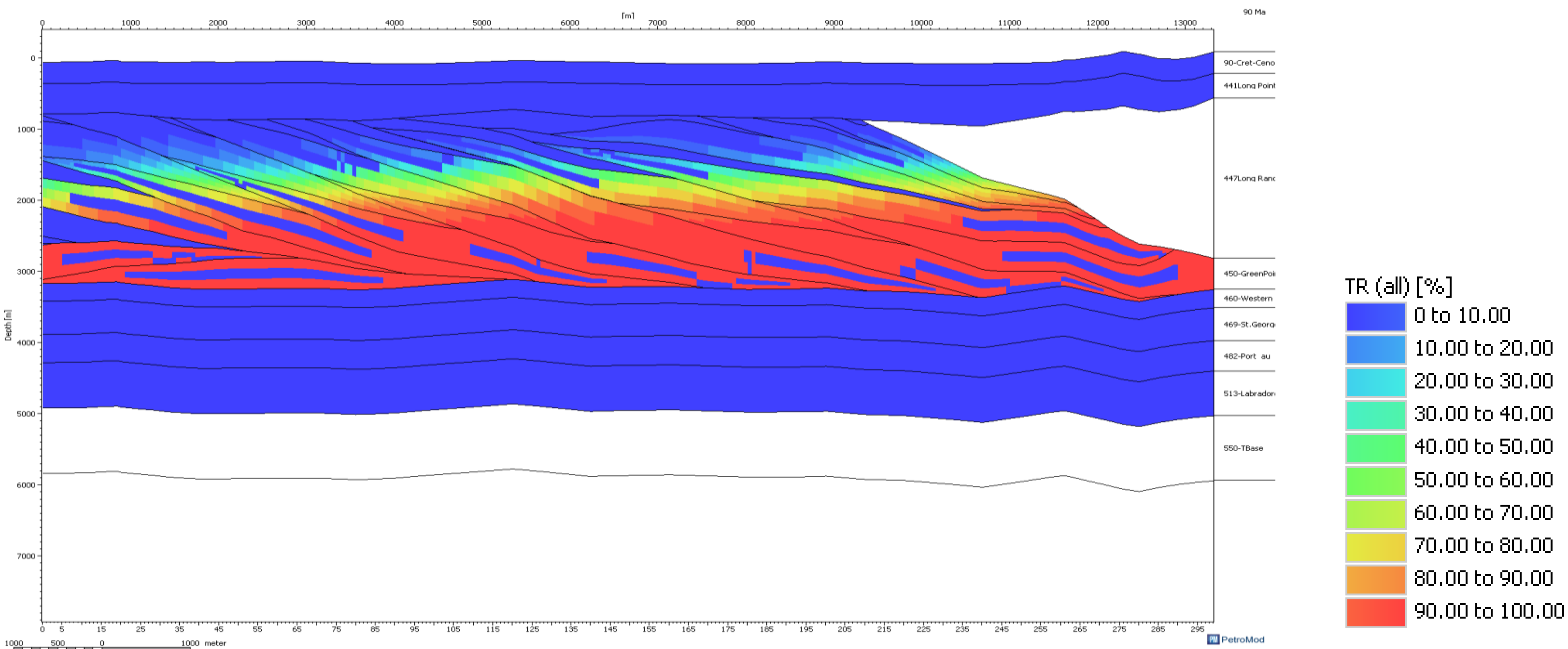
200 Ma



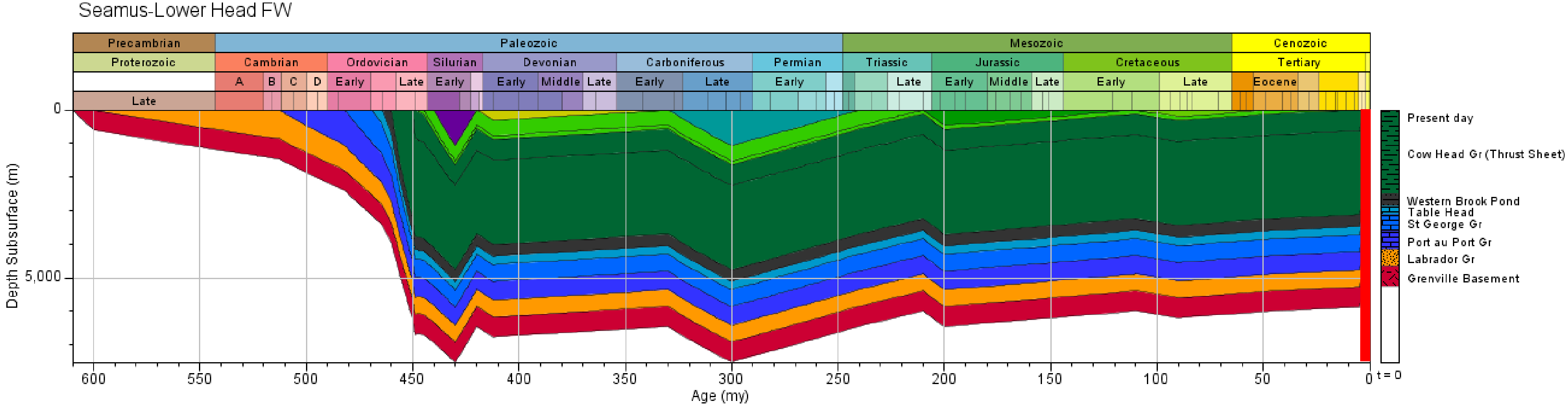
TRANSFORMATION RATIO THROUGH TIME



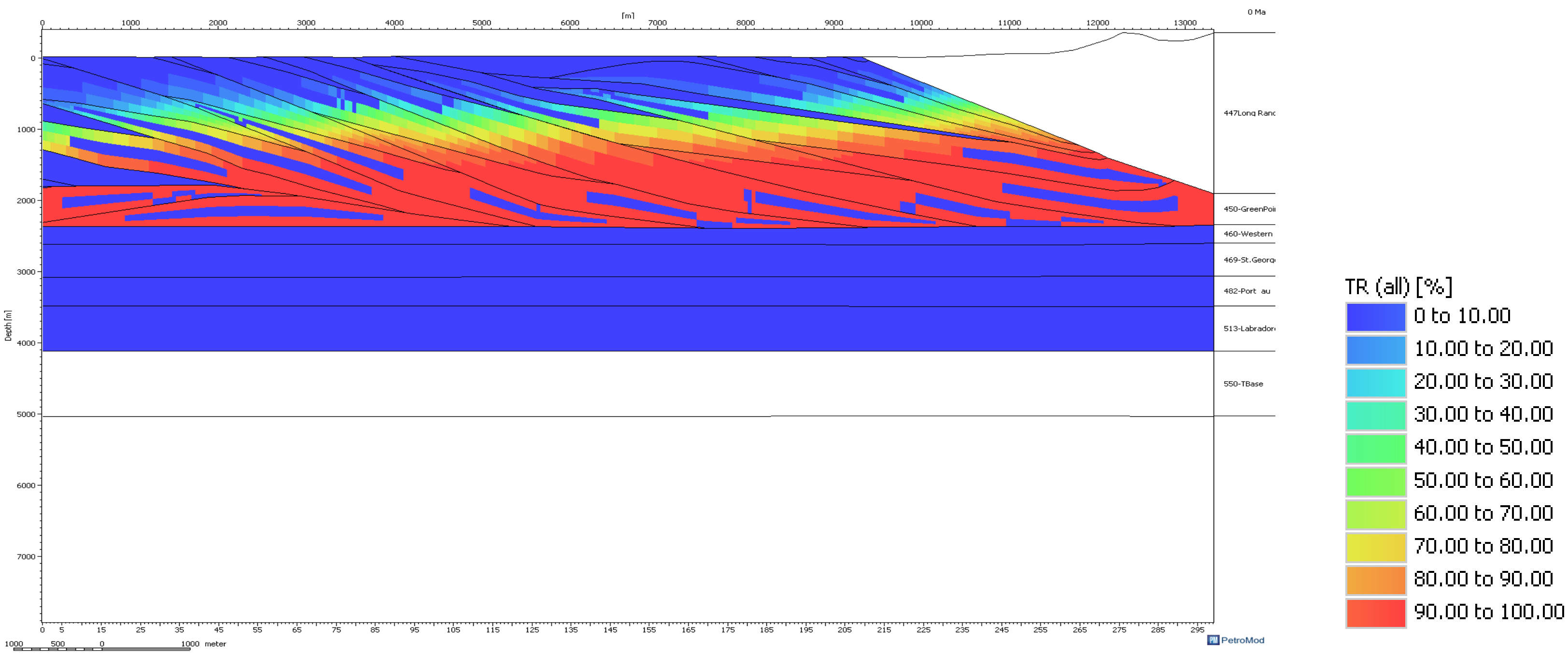
90 Ma



TRANSFORMATION RATIO THROUGH TIME

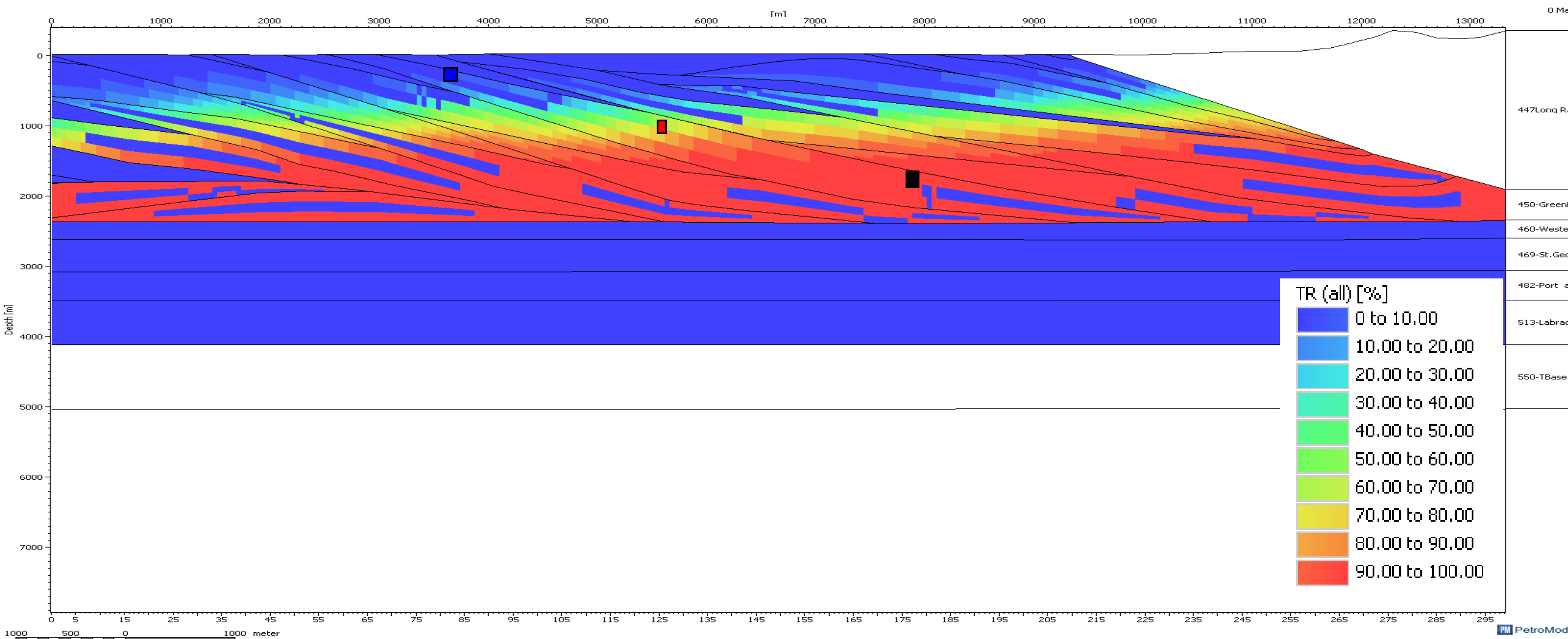


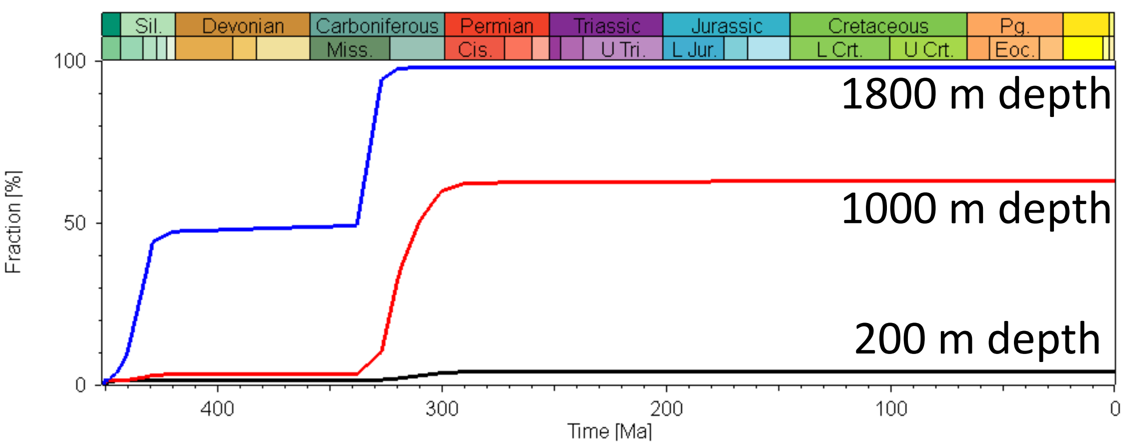
0 Ma



Transformation Ratio Through Time

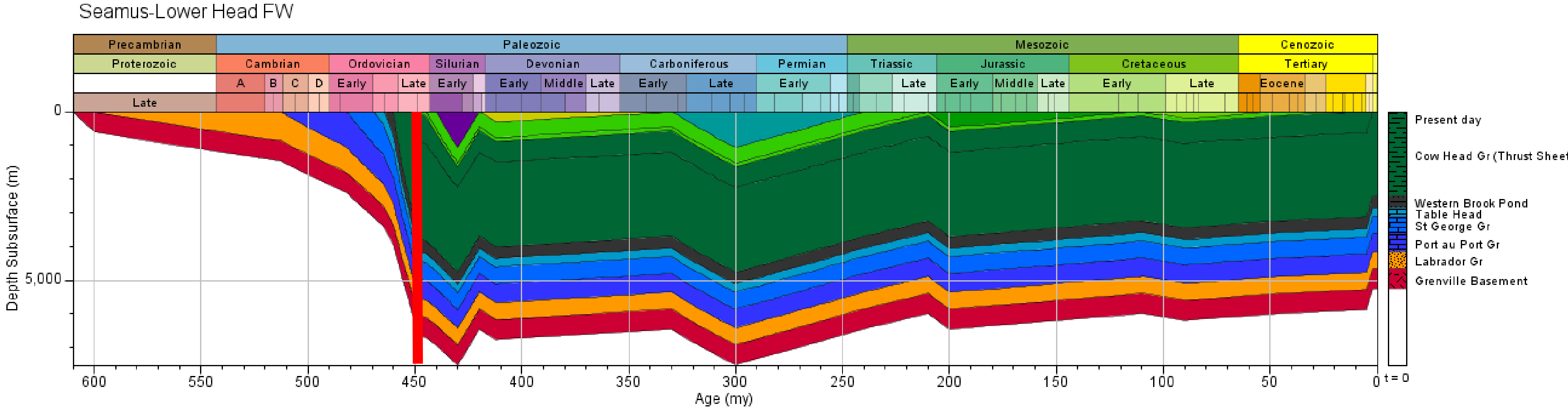
0 Ma



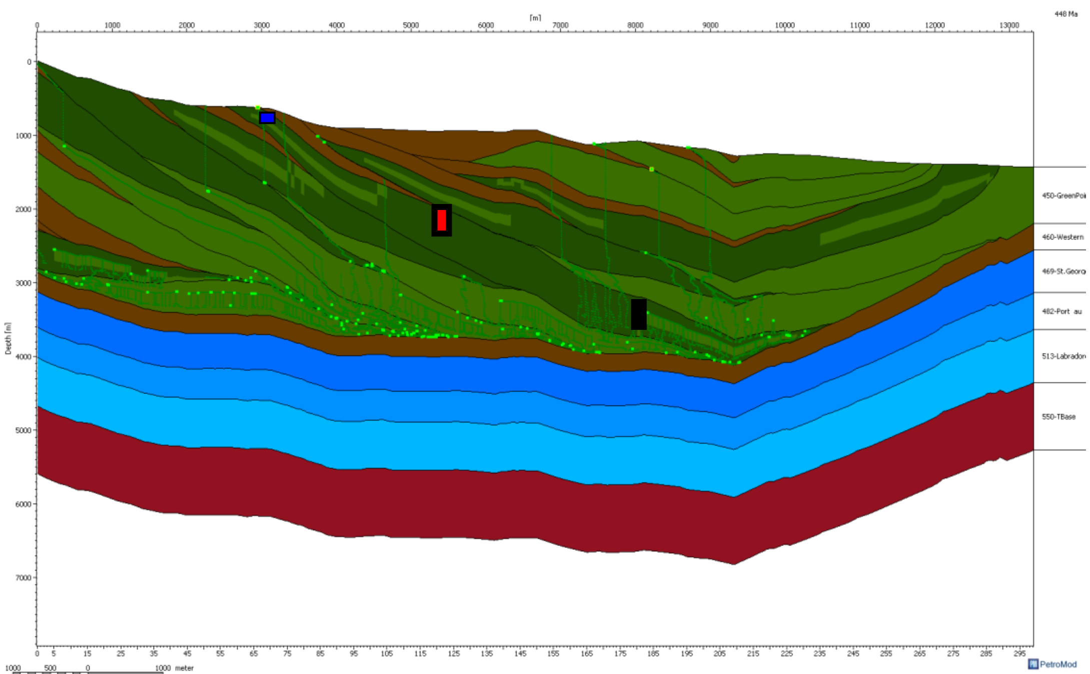


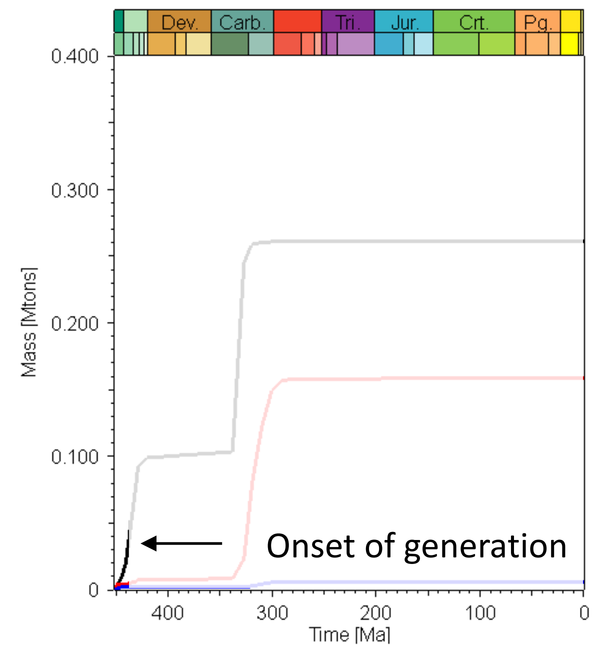
- Transformation ratio dependent on the structural position of the source rock
- Transformation ratio is linked to the major burial events

Generation & Migration Through Time

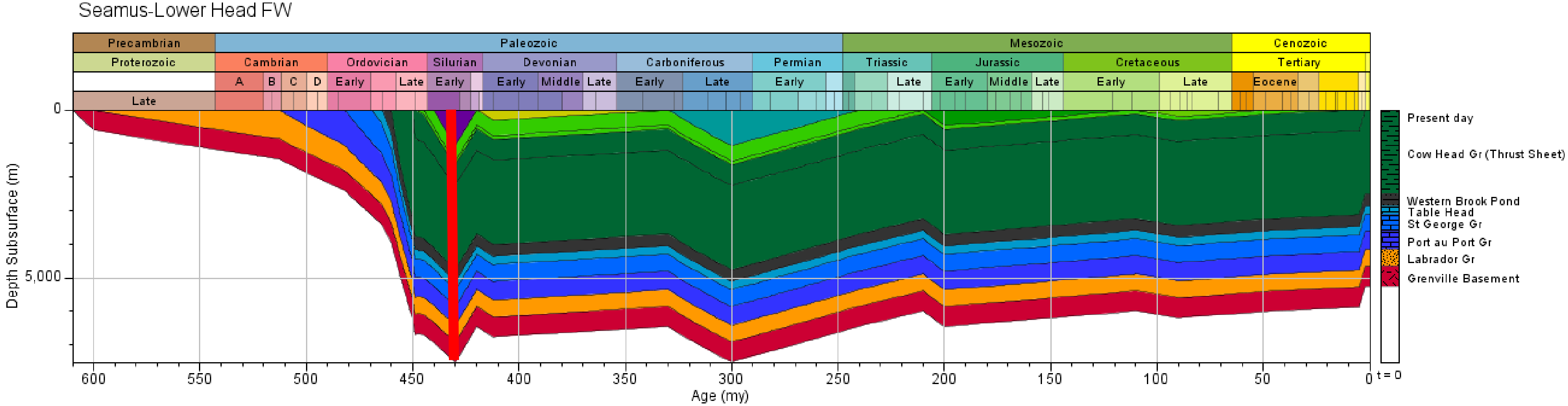


448 Ma

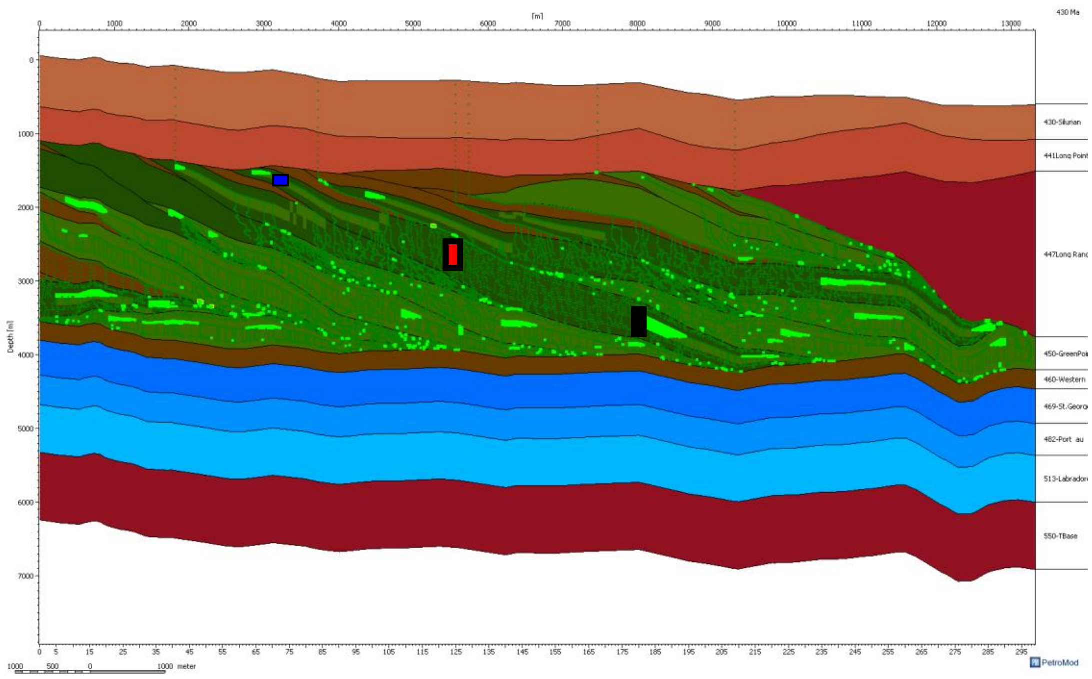


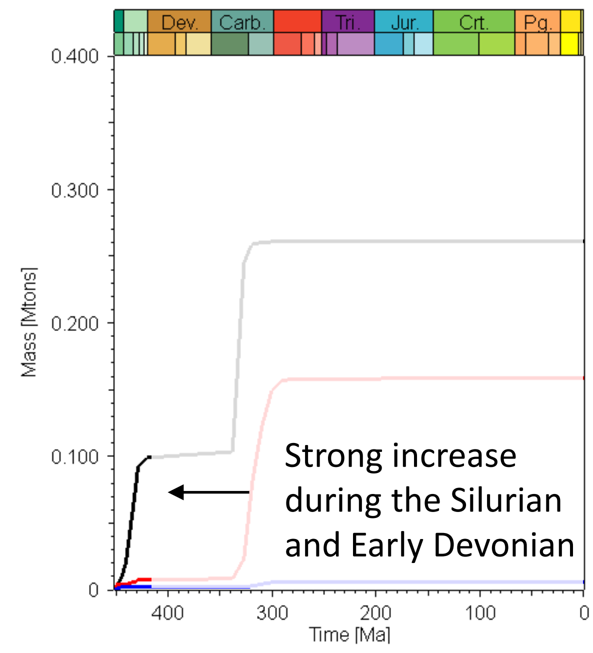


Generation & Migration Through Time

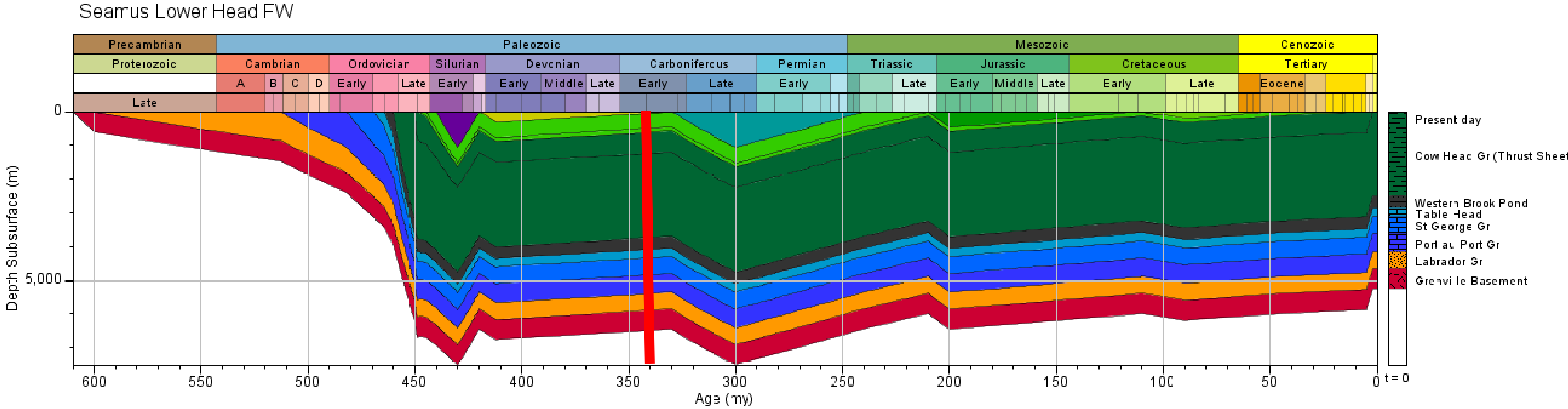


430 Ma

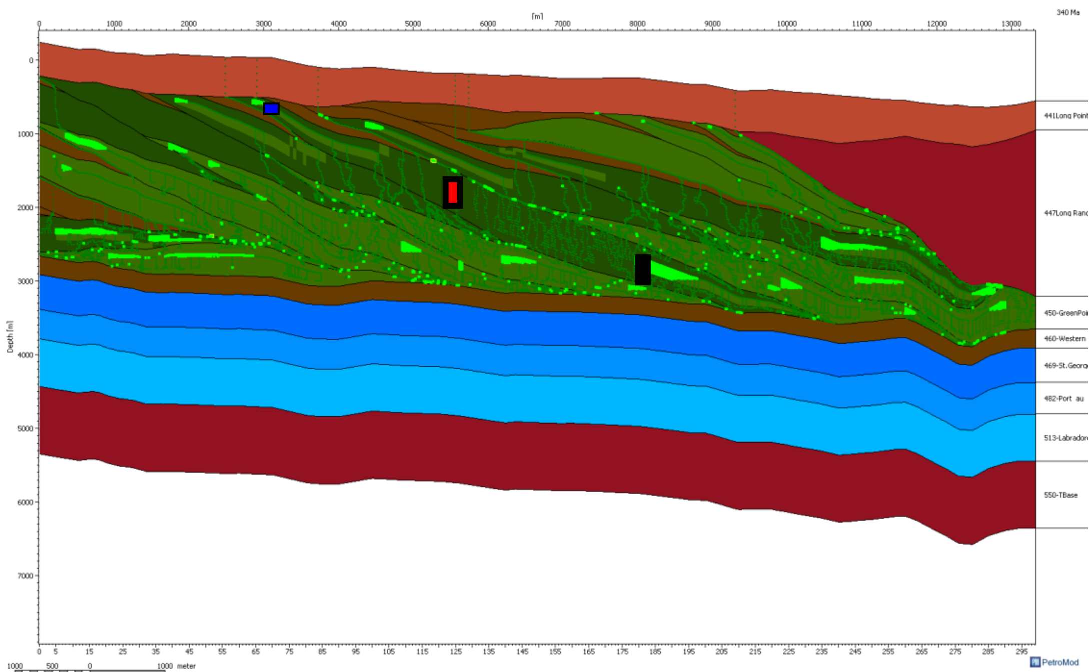


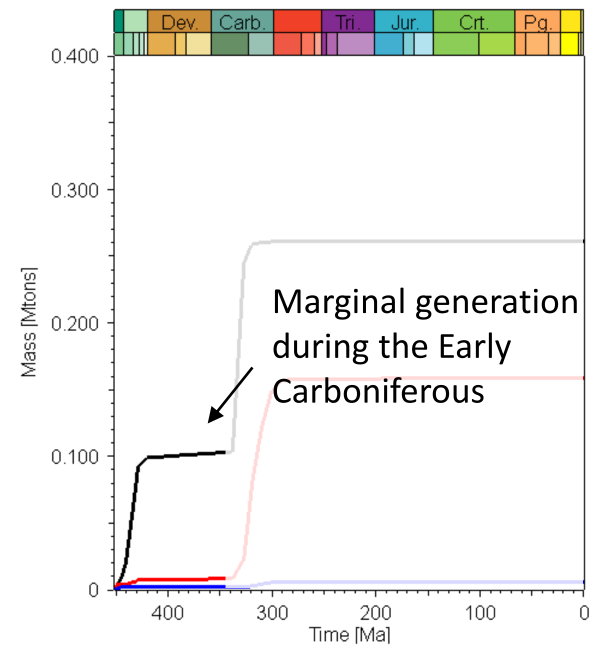


Generation & Migration Through Time

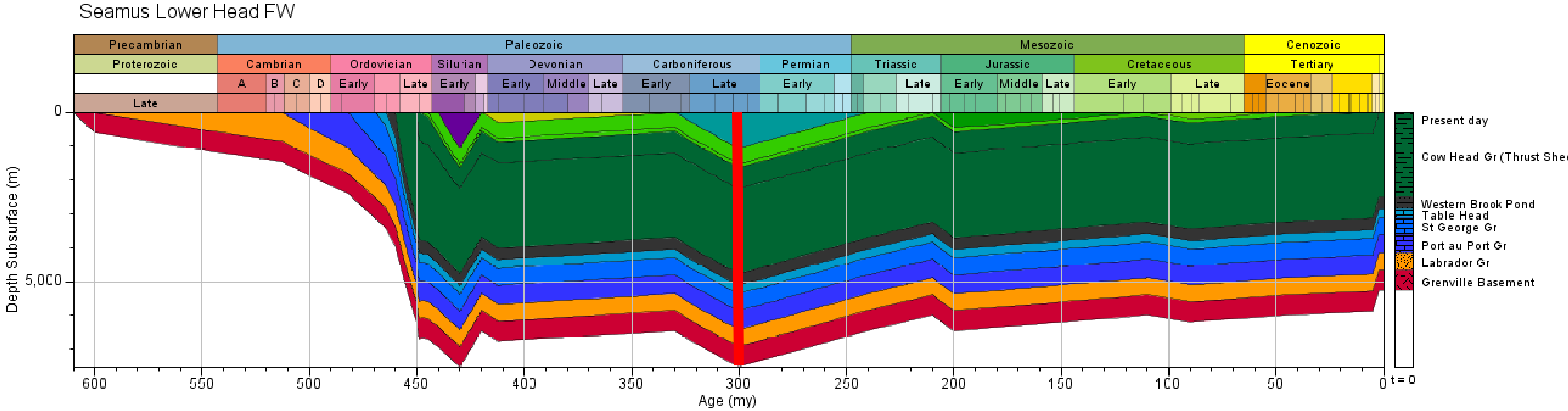


340 Ma

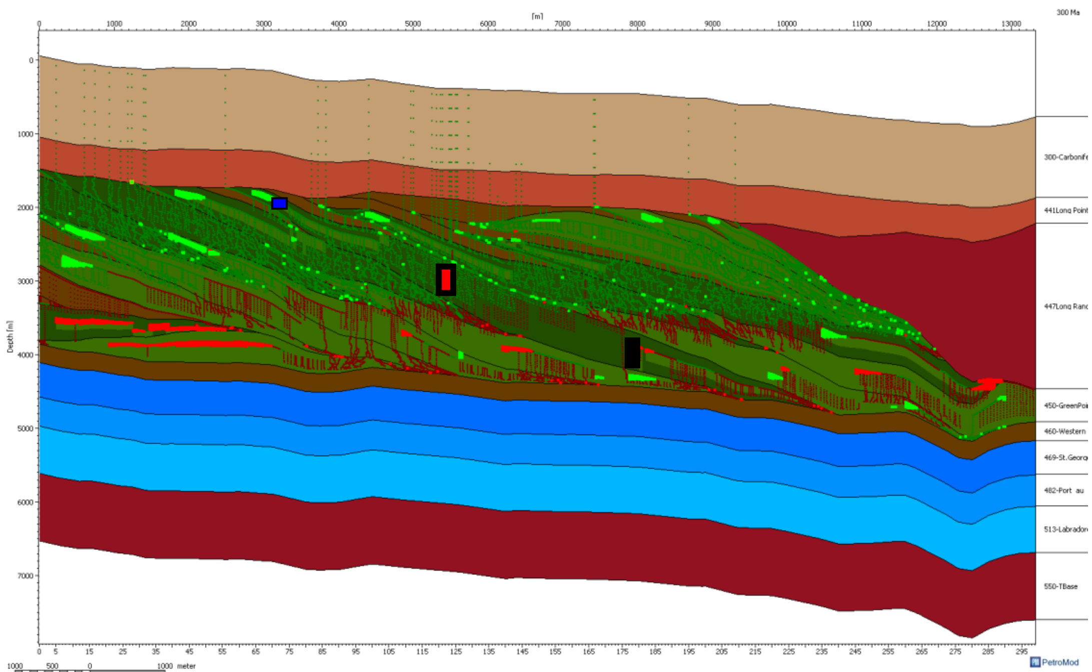


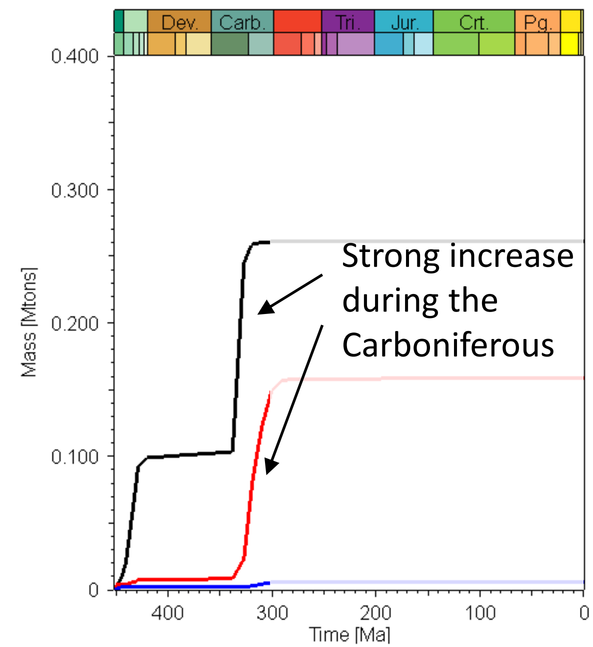


GENERATION & MIGRATION THROUGH TIME



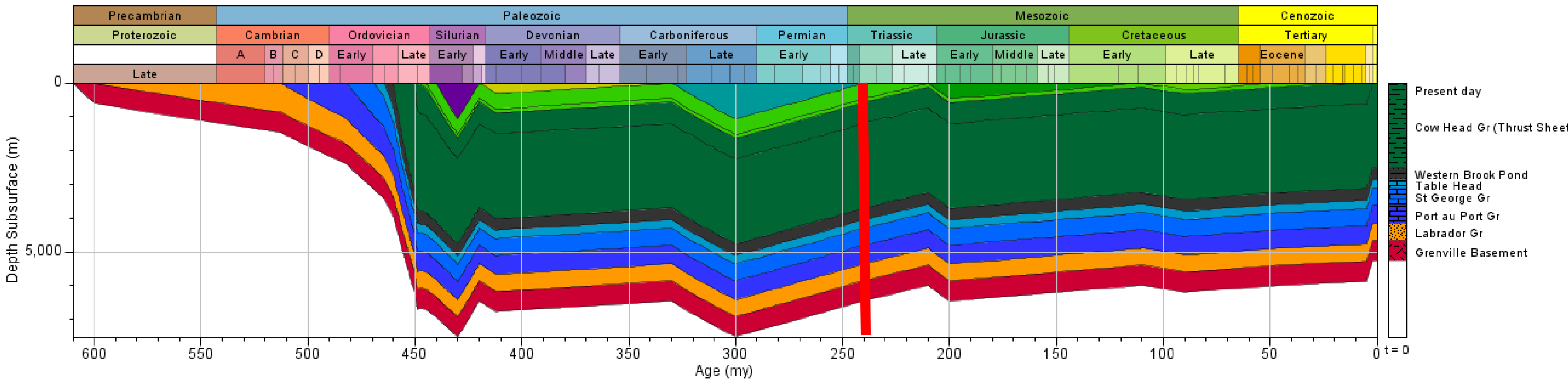
300 Ma



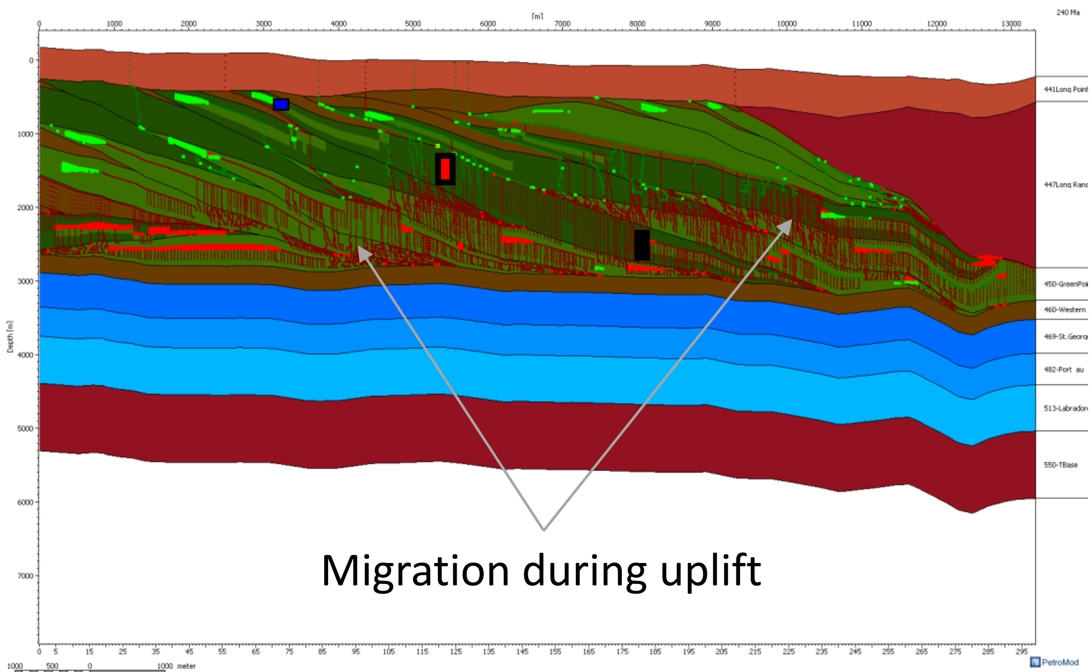


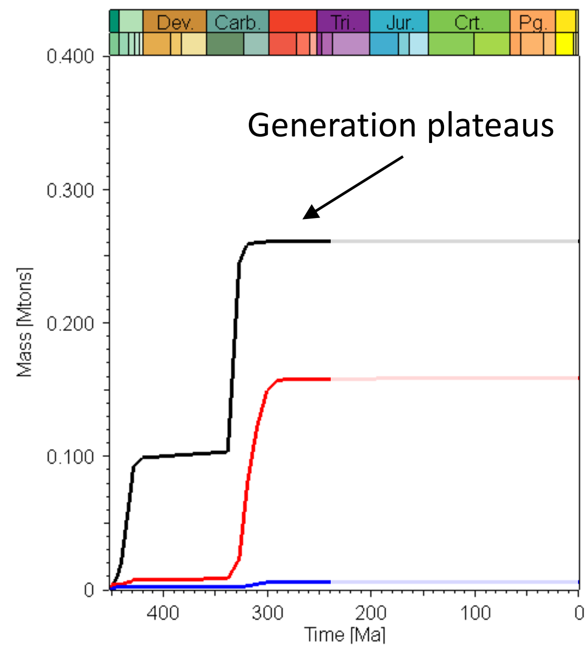
Generation & Migration Through Time

Seamus-Lower Head FW

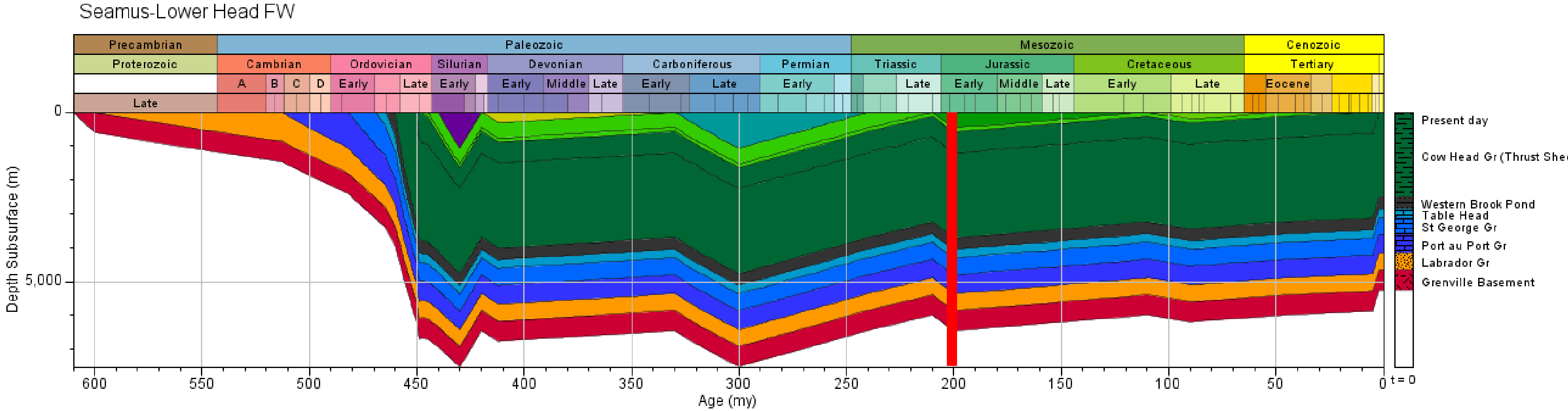


240 Ma

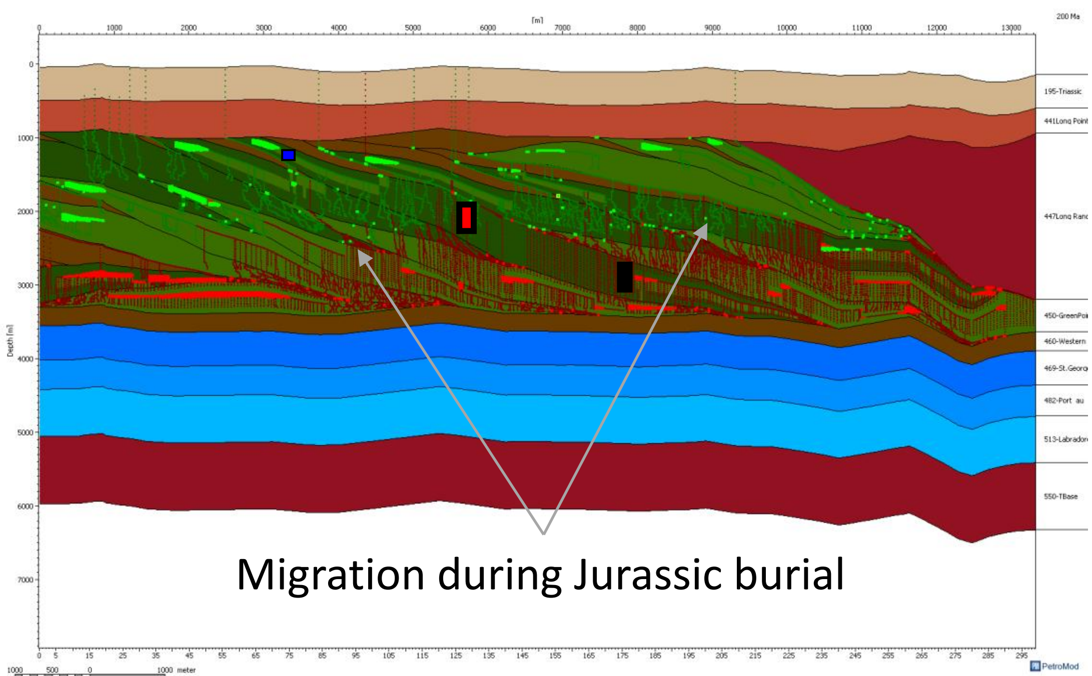


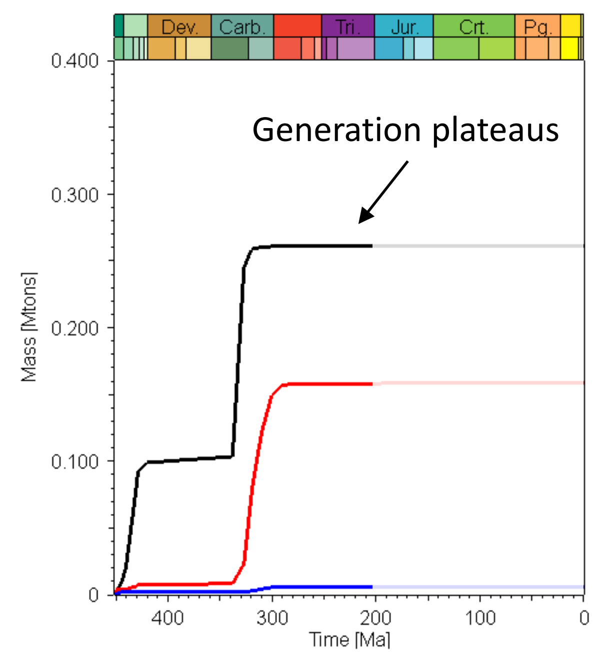


Generation & Migration Through Time

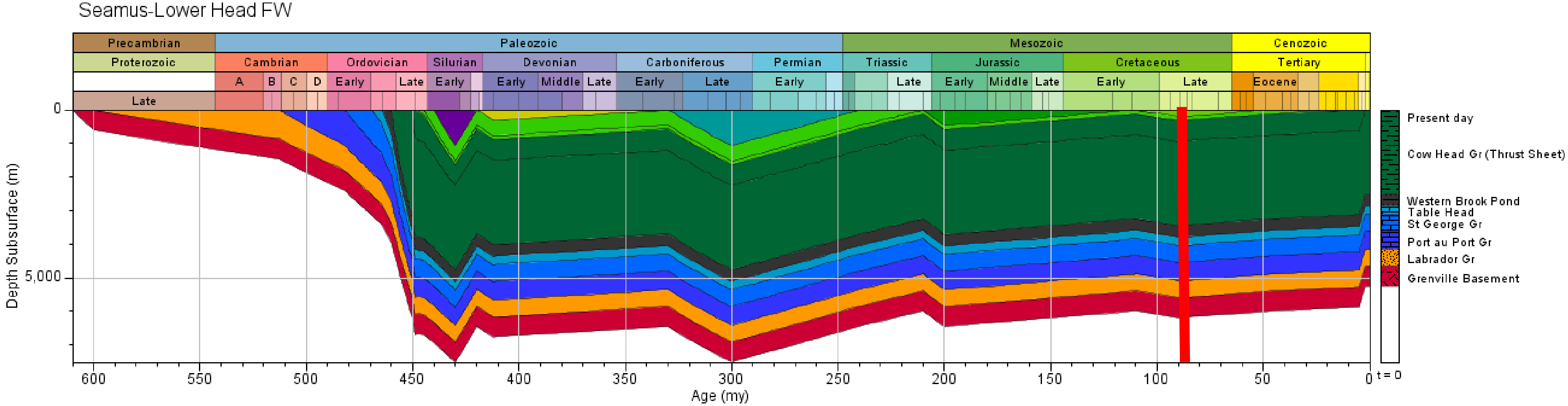


200 Ma

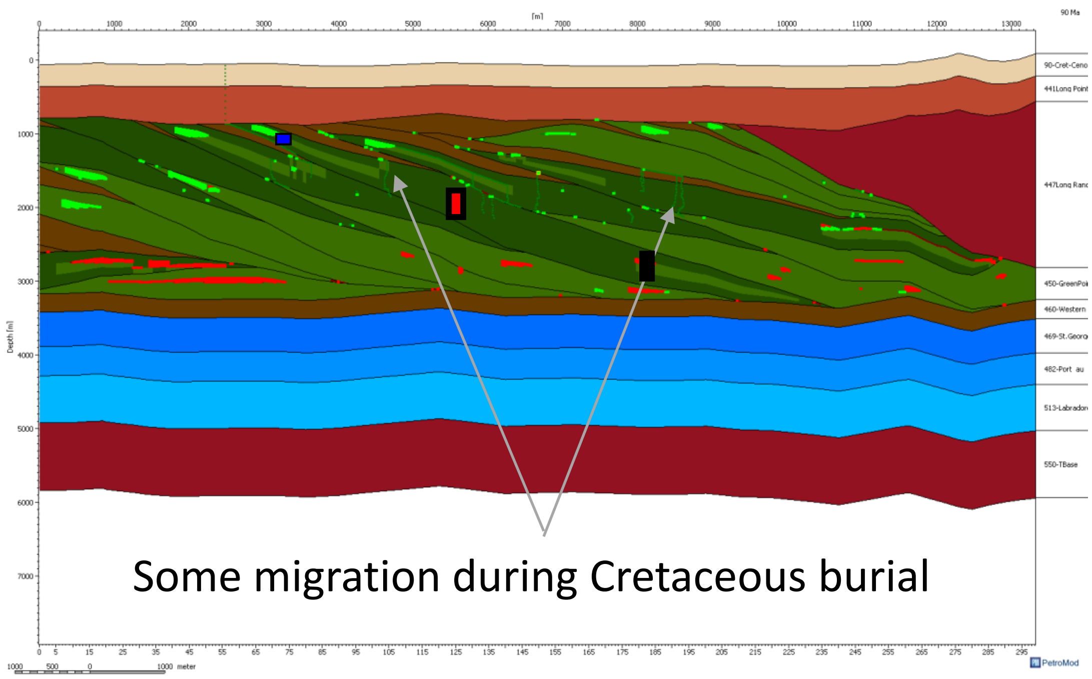


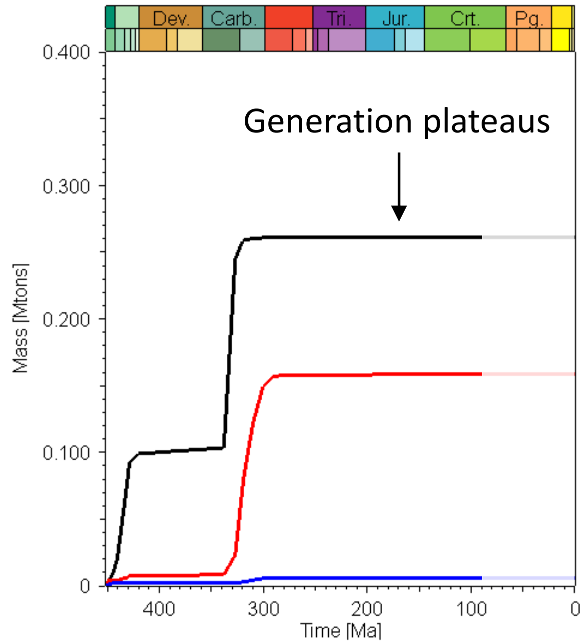


Generation & Migration Through Time

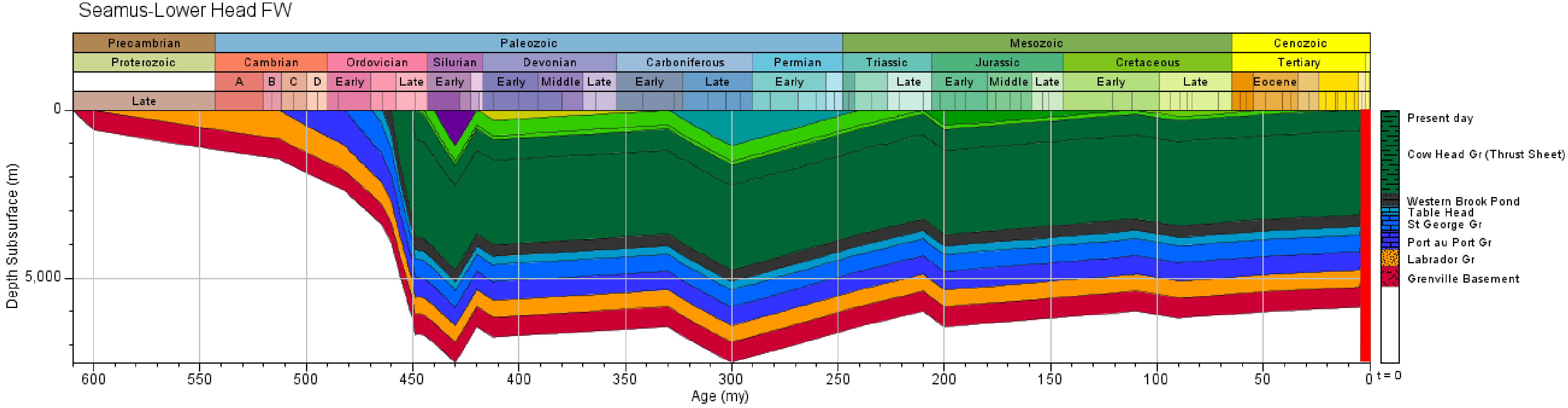


90 Ma

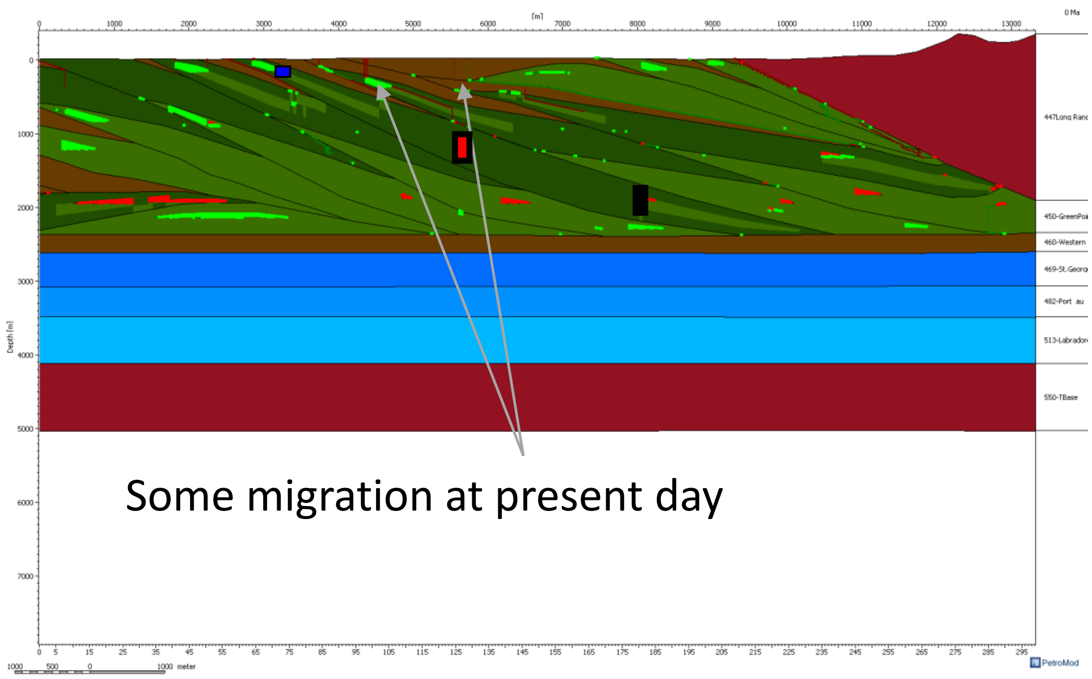


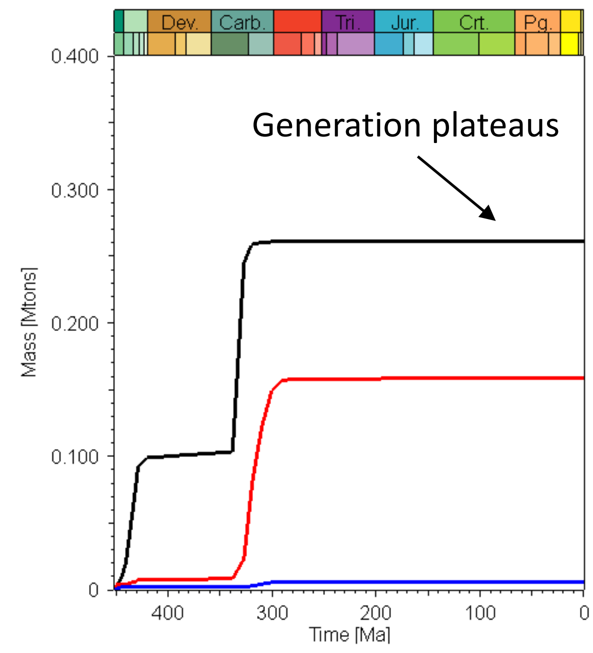


Generation & Migration Through Time

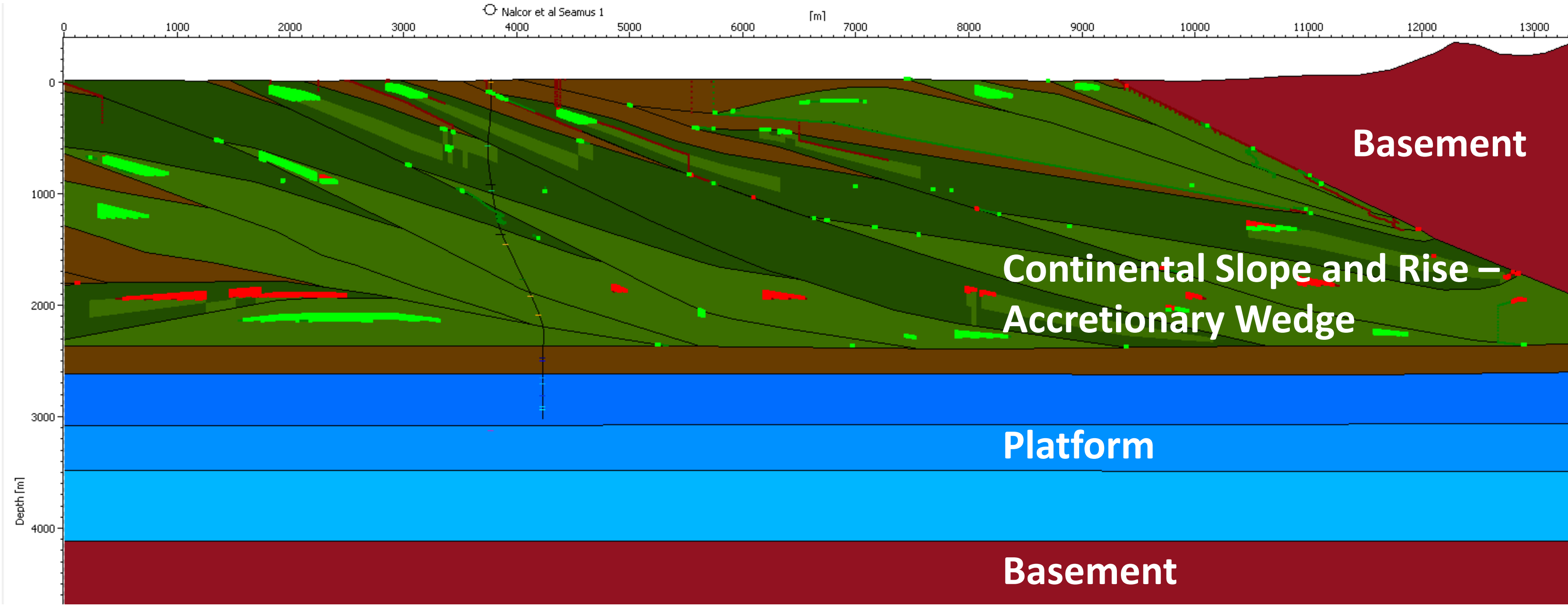


0 Ma





PRESENT DAY



- No oil generation at present day
- Accumulation mostly in isolated conglomerate lenses (1 to 20 m; 3 to 66 ft) within the accretionary wedge
- Present day oil shows could be explained by along bed and along fault migration

Basin History

- Three distinct tectonic events (detected by AFTA) have a significant impact on the oil generation and migration history of the basin
  - Alleghanian Orogeny
  - Opening of the Atlantic Ocean
  - Opening of the Labrador Sea
- Carboniferous basin extended over most of western Newfoundland with sediment thicknesses ranging from 2.5 km (South) to 1 km (North)
- Substantial cooling since mid-Cenozoic in western Newfoundland suggests denudation of up to 1 km overburden with deposition into adjacent sedimentary basins

Generation – Migration & Accumulation

- Oil generation started before the Acadian Orogeny around 445 Ma.
- The main oil generation occurred during the Acadian Orogeny and Carboniferous sedimentation.
- Later burial and uplift events possibly reactivated faults and provided migration conduits for oil.
- Present day thermal maturity of the source rocks is dependent on the structural position within the imbricated stack
- Accumulations can be found in isolated conglomerate lenses within the Cambrian and Ordovician continental slope and rise sediments.
- No oil generation at present day
- Present day oil shows could be explained by along bed and along fault migration

ACKNOWLEDGEMENT

- **Ian Duddy (Geotrack)**
- **Oliver Schenk (Schlumberger Aachen, Germany)**
- **University of Alberta SURGE (Studies in Unconventional Reservoir GEology)**
- **Platte River Associates, Inc.**
- **Province of Newfoundland and Labrador**
- **Petroleum Exploration Enhancement Program**
- **AAPG Grants-in-Aid**

JEAN G. FUNKHOUSER MEMORIAL GRANT GRANTS-IN-AID

GEOTRACK

PRA Platte River Associates, Inc.

PETROLEUM EXPLORATION ENHANCEMENT PROGRAM

Newfoundland Labrador Natural Resources