Seismic Inversion and Source Rock Evaluation on Jurassic Organic Rich Intervals in the Scotian Basin, Nova Scotia

Natasha Morrison
Dalhousie University – Halifax, NS

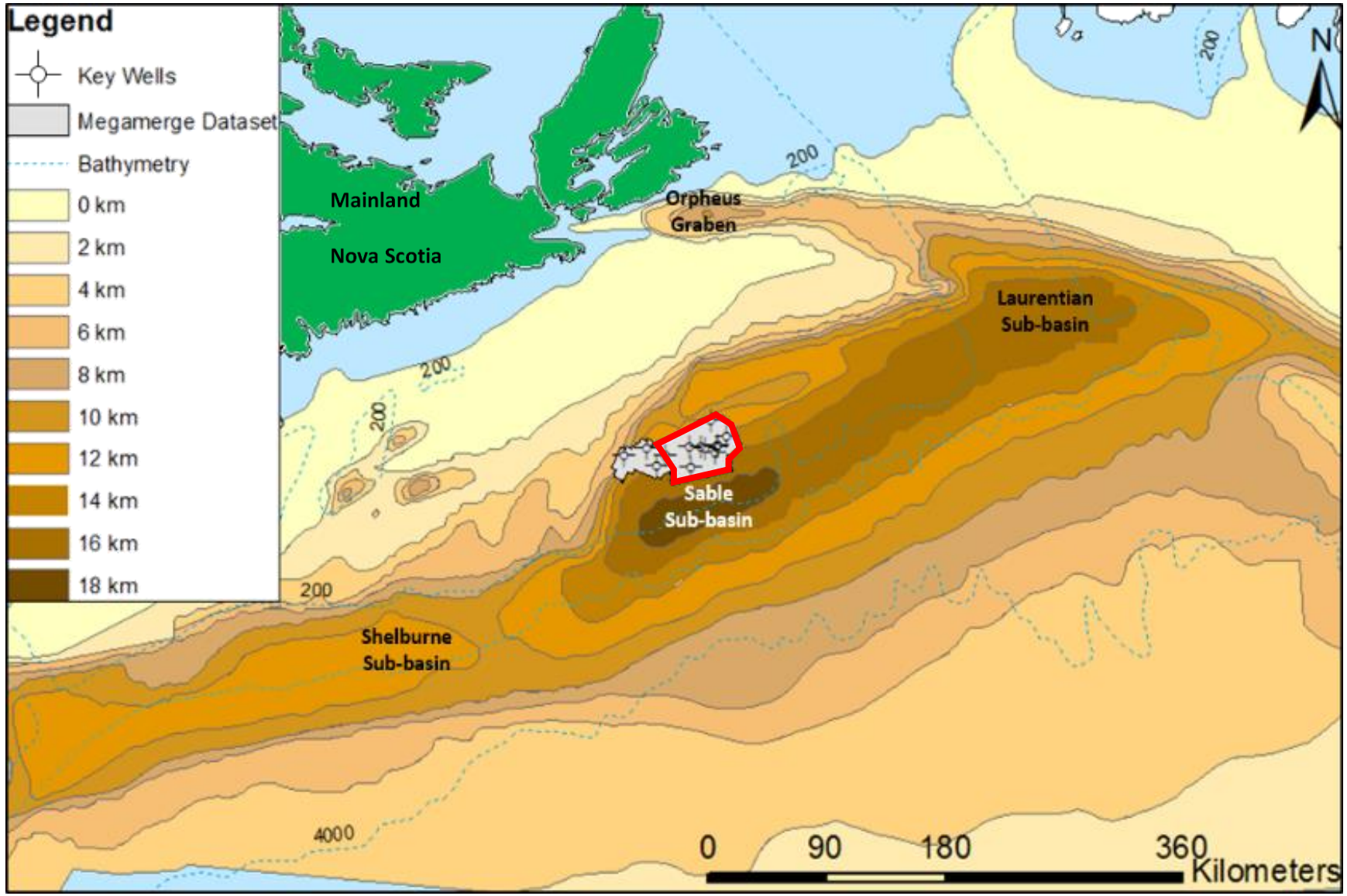
OBJECTIVES

Key objectives in this study were to:

1. Apply wireline TOC Determinations to eleven key wells
2. Apply a seismic inversion to the Eastern portion of the Sable Mega-Merge
3. Attempt the "Source Rock from Seismic" method to help identify the known or possible organic rich intervals of the Middle and Late Jurassic and map their extent
4. Investigate the controls of deposition and preservation of organic matter within the Sable Sub-basin;

These objectives were met by:

1. Defining a stratigraphic framework within the Jurassic strata, calibrated to the available wells
2. Delineating faults present within the stratigraphic framework
3. Completing an analysis of geochemical data available for wells with in the study area
4. Running a 3D seismic inversion on the Eastern portion of the Sable MegaMerge survey



SOURCE ROCK

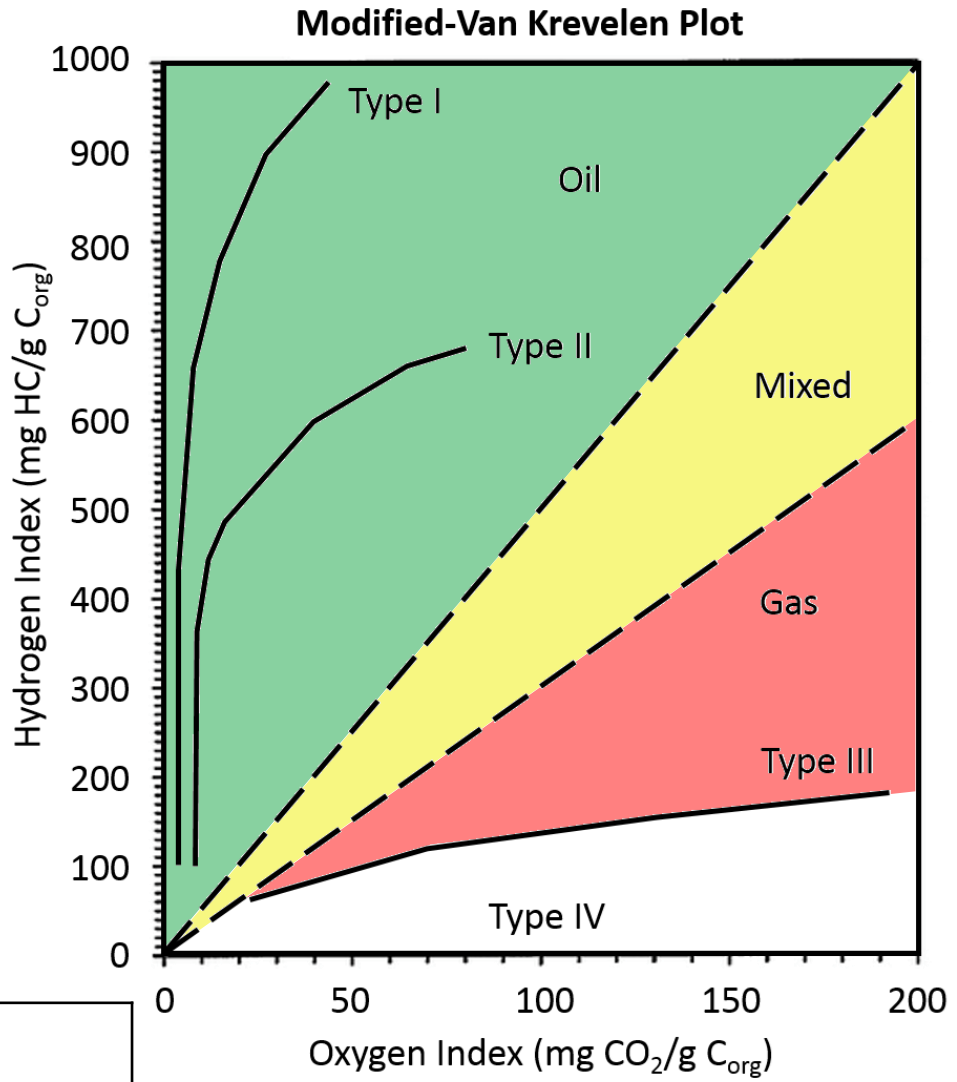
Source rocks: rock units containing sufficient organic matter of suitable chemical composition to generate and expel hydrocarbons via biogenic or thermal processes

Measured by Total Organic Carbon (TOC):

- Measured by RockEval Pyrolysis
- 0.5% absolute minimum

Classified by Kerogen Type:

- Type I - Lacustrine
- Type II - Marine
- Type III - Terrestrial
- Type IV - Recycled or Oxidized OM



Modified from AAPG 2015

Potential	TOC (wt %)	Rock-Eval (mg/g rock) S1	Rock-Eval (mg/g rock) S2	Bitumen (ppm)	HCs (ppm)
Poor	<0.5	<0.5	<2.5	<500	<300
Fair	0.5-1	0.5-1	2.5-5	500-1000	300-600
Good	1-2	1-2	5-10	1000-2000	600-1200
Very Good	2-4	2-4	10-20	2000-4000	1200-2400
Excellent	>4	>4	>20	>4000	>2400

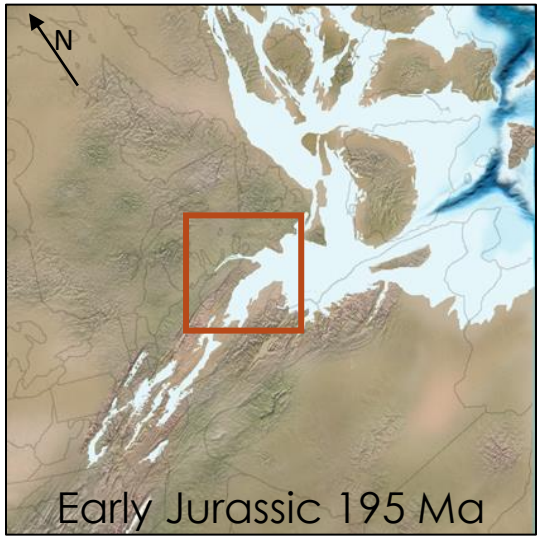
Peters et al. 2005

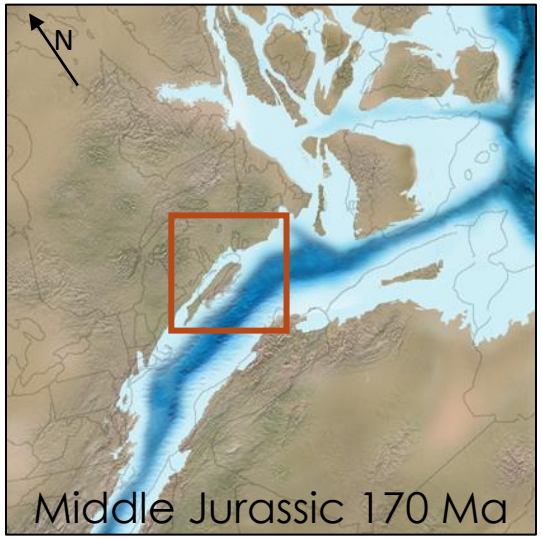
SCOTIAN MARGIN GEOLOGY

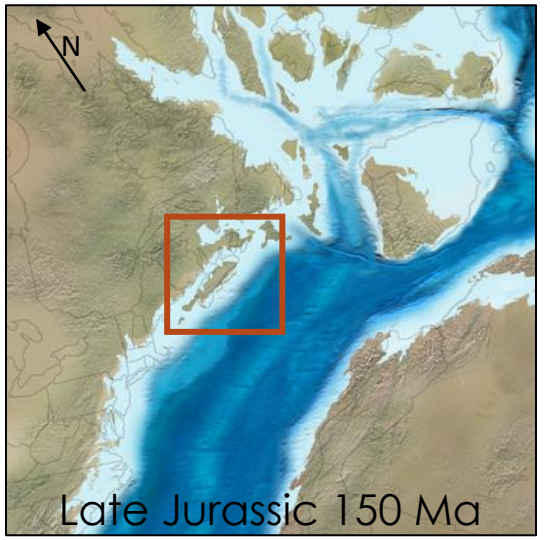
300,000 km^2

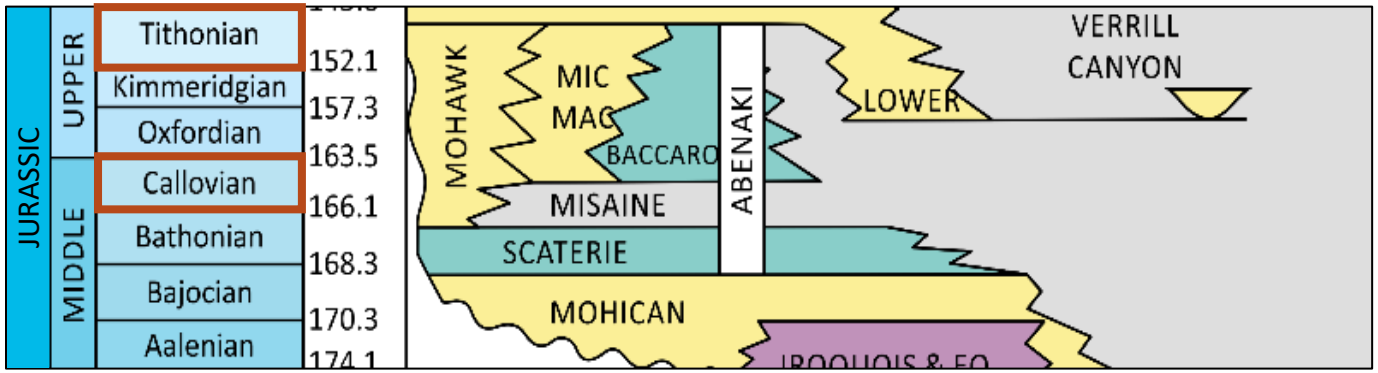
Deposition: began in Early Triassic
250 Ma Continuous Sedimentation

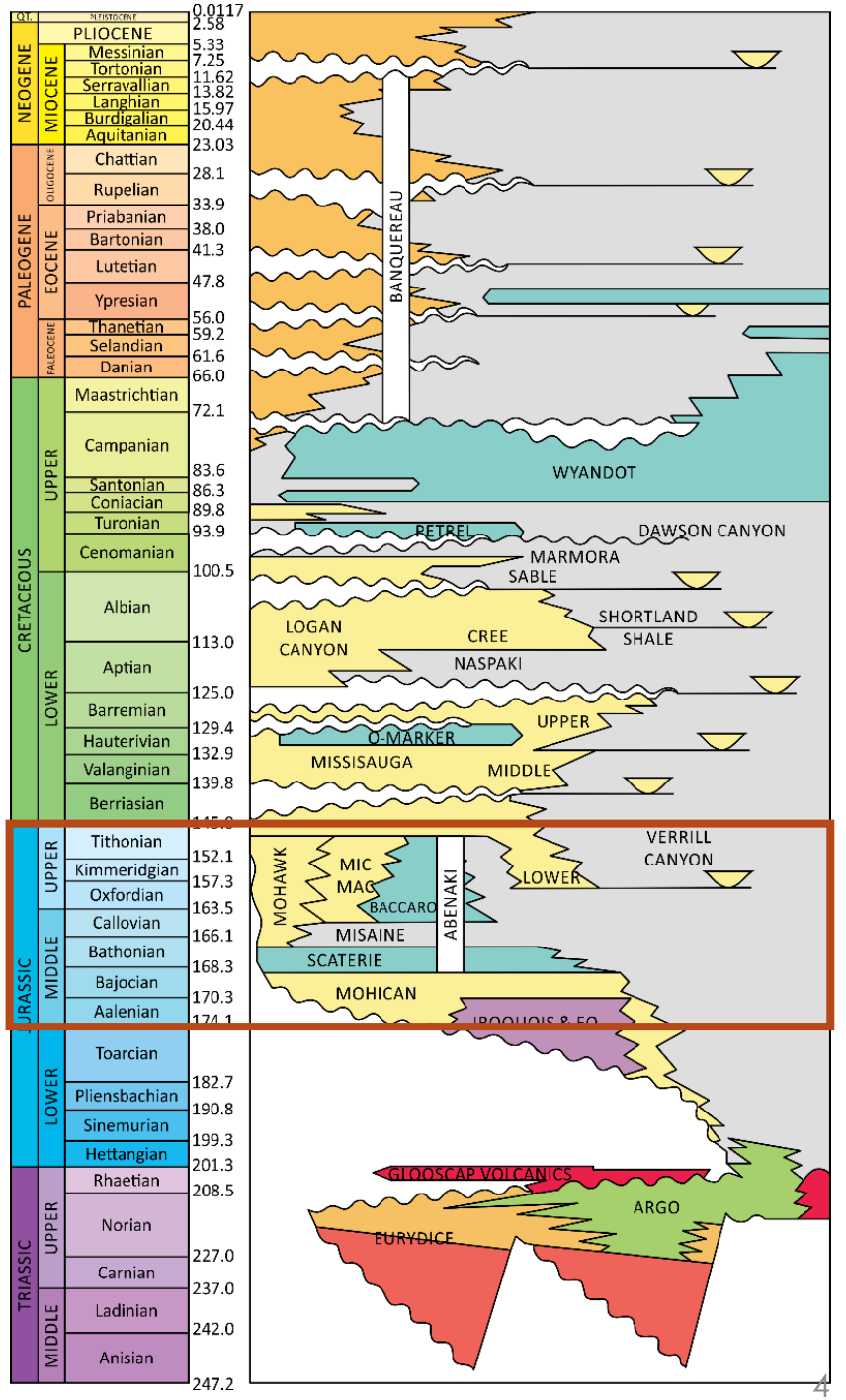
Environments: Deltaic
Carbonate
Deepwater











JURASSIC SOURCE ROCKS

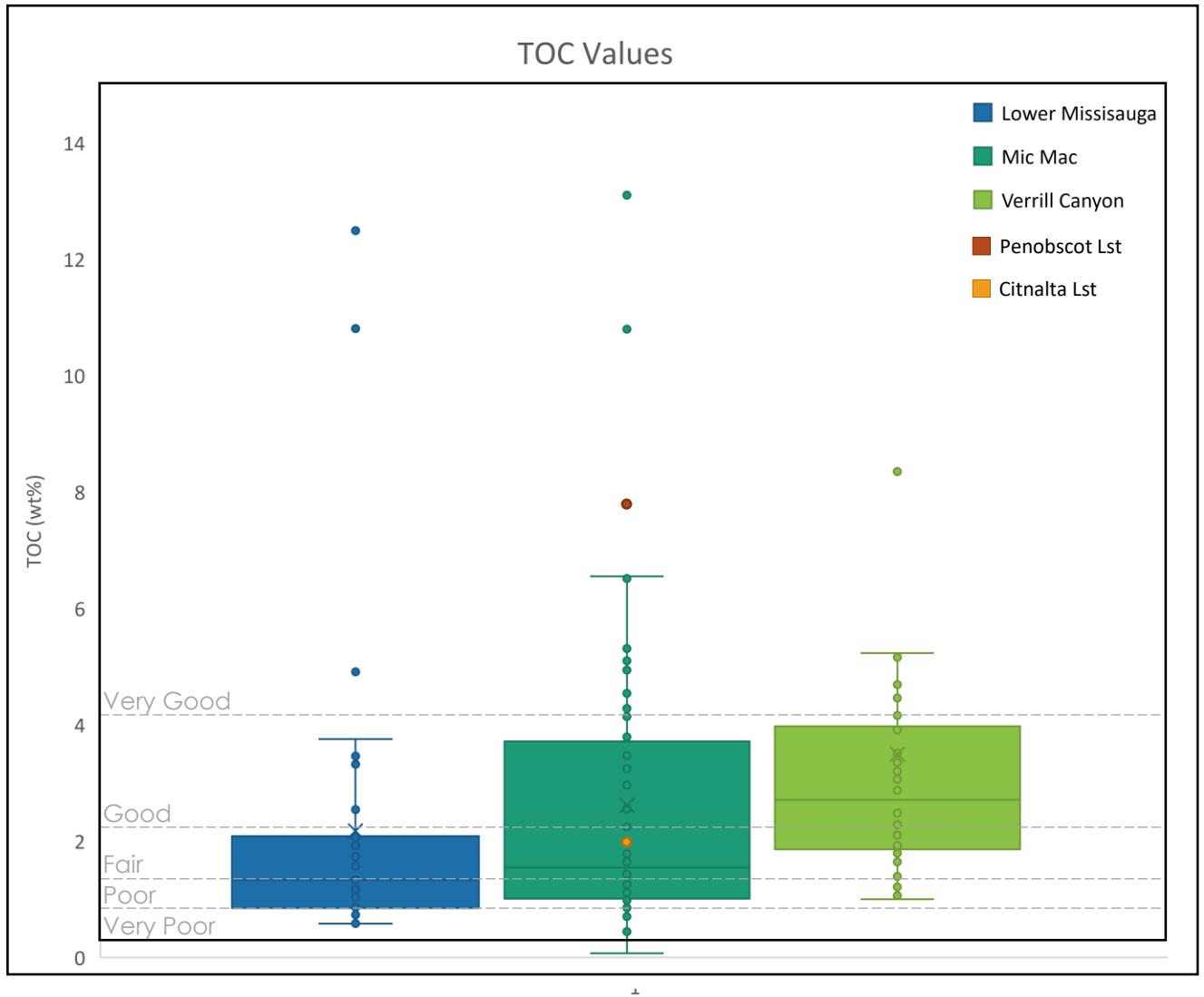
Formations of Interest:

- Lower Mississauga Mb.
  - Shales & marls
  - Predom. Type III
  - Minor Type IIB
  - Gas & some condensate prone

  → Poor → Fair
- Mic Mac Fm.
  - Shales, marls & limestones
  - Type II & III
  - Oil, condensate & gas prone

  → Fair → Good
- Verrill Canyon Fm.
  - Shales
  - Predom. Type II
  - Some Type III
  - Condensate & gas prone

  → Good



WELL & SEISMIC DATASET

Well Dataset

47 wells within MM constraints

- 11 Development
- 22 Exploration
- 14 Delineation

Drilled between 1967-2000

Cretaceous – Jurassic Fms

MegaMerge 3D Cube

Approx. 2890 km^2

8 potential 3D volumes merged

Post-processed dataset

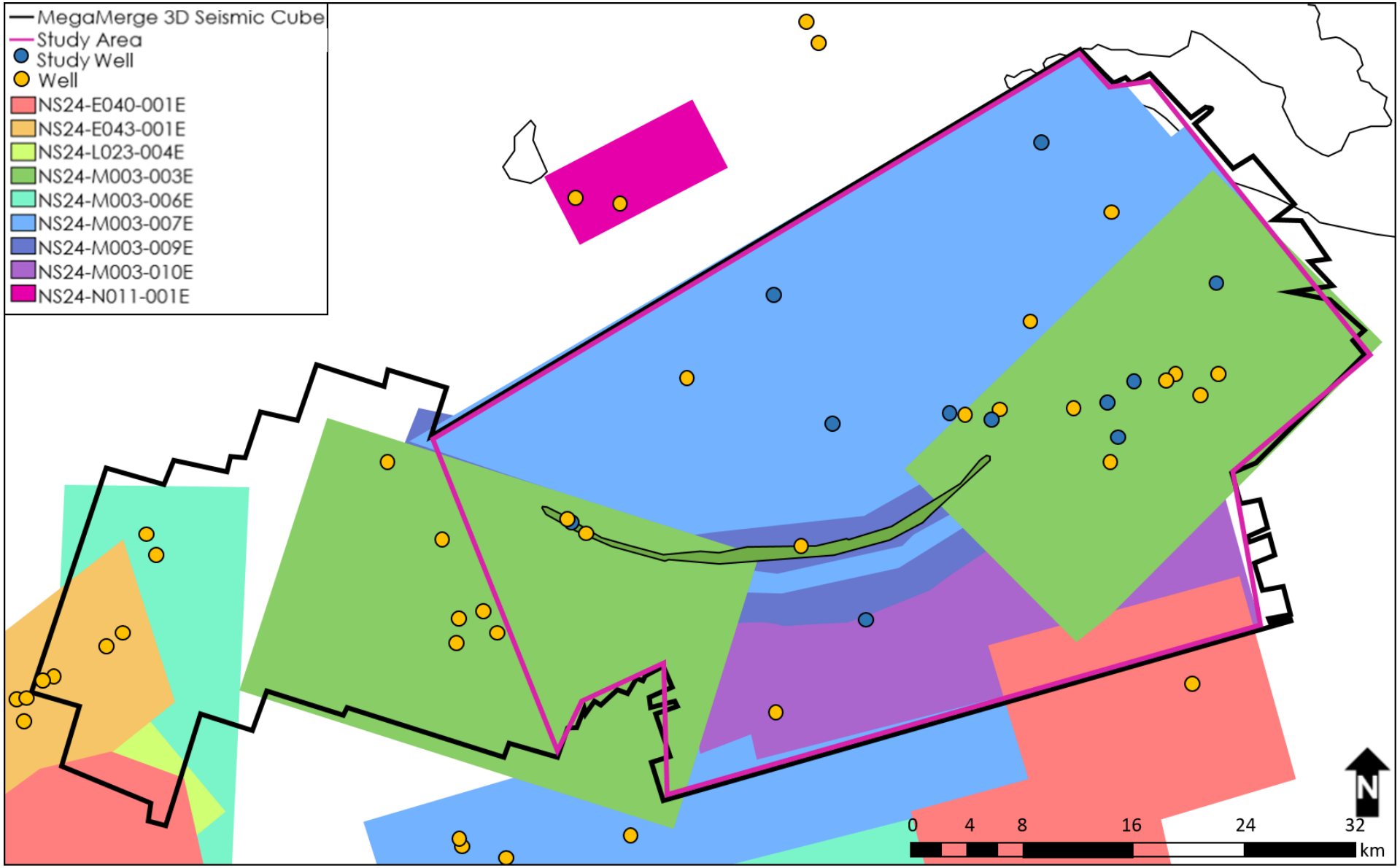
Study Area

Approx. 2120 km^2

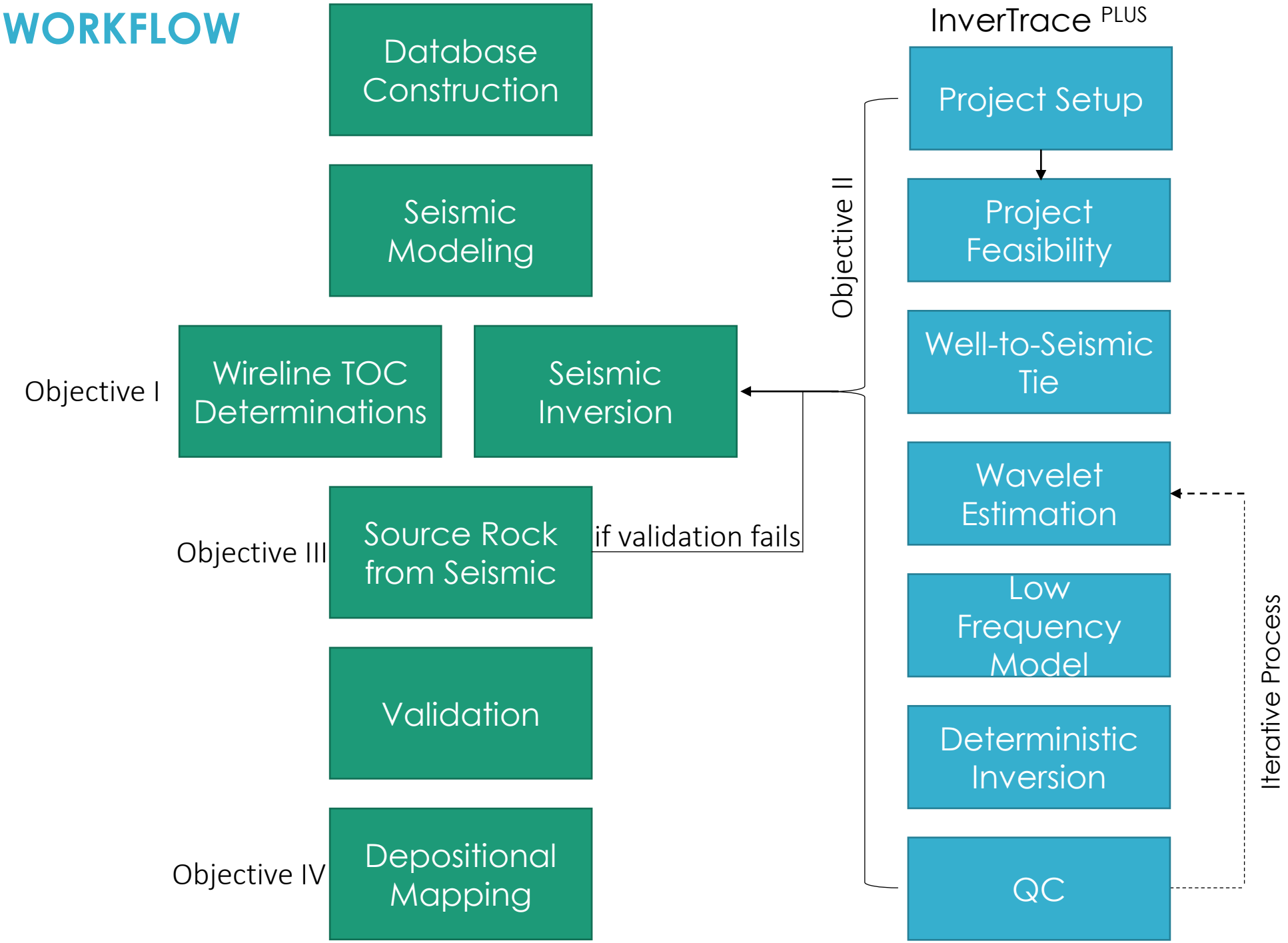
26 wells within constrains

11 with geochemical data

15 wells used in inversion



PROJECT WORKFLOW



TOC RESTORATION

Methods

Jarvie (2005)

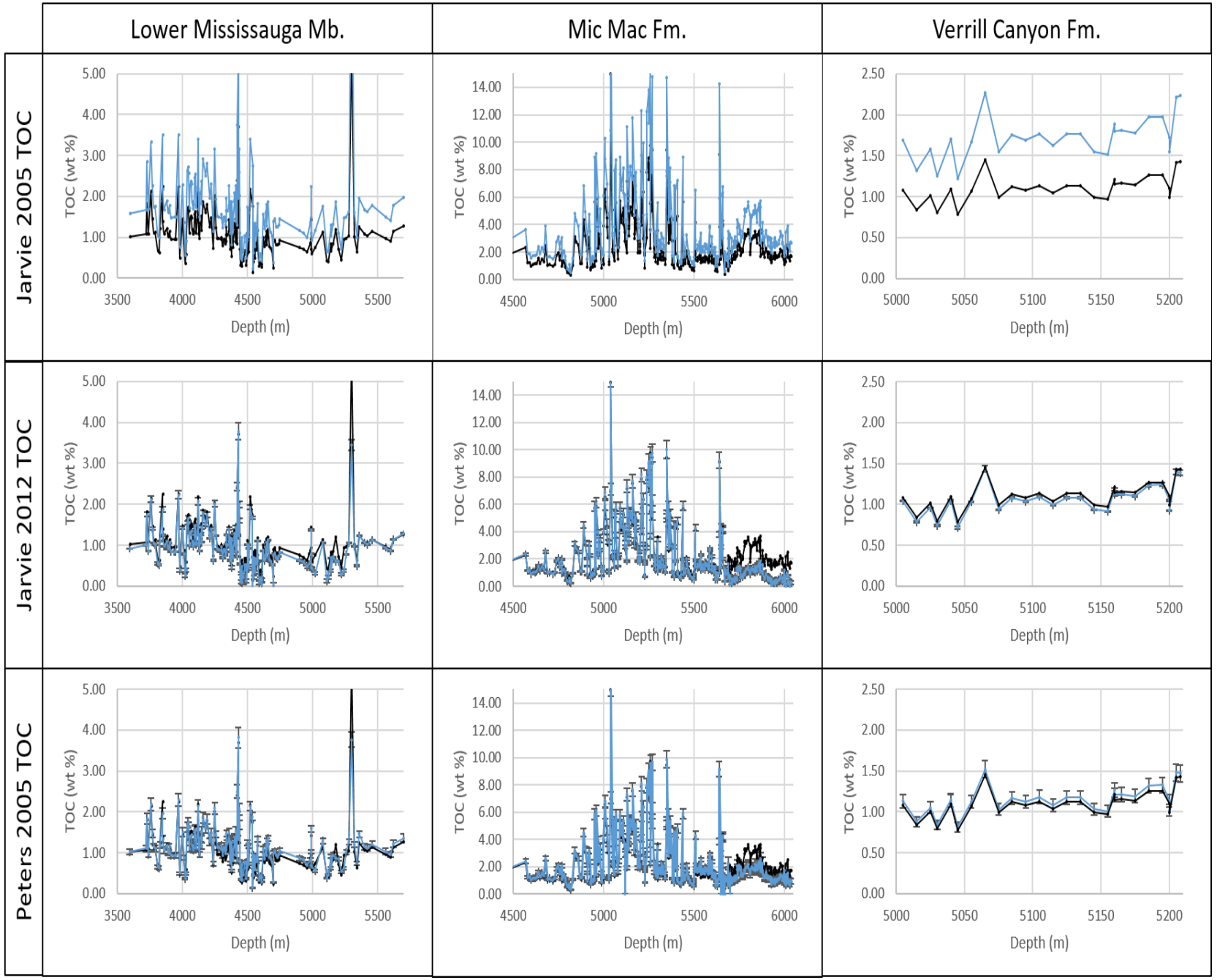
$$TOC^0 = \frac{TOC^x}{0.64}$$

Jarvie (2012)

$$TOC^0 = \frac{TOC_{pbdkfree}}{1 - \frac{\%\ GOC}{100}}$$

Peters (2005)

$$TOC^0 = \frac{83.33 * HI^x * TOC^x}{\left(HI^0 * (1 - F) * \left((83.33 - TOC^x)\right) + (HI^x * TOC^x)\right)}$$



Measured TOC

Restored TOC

TOC RESTORATION

Methods

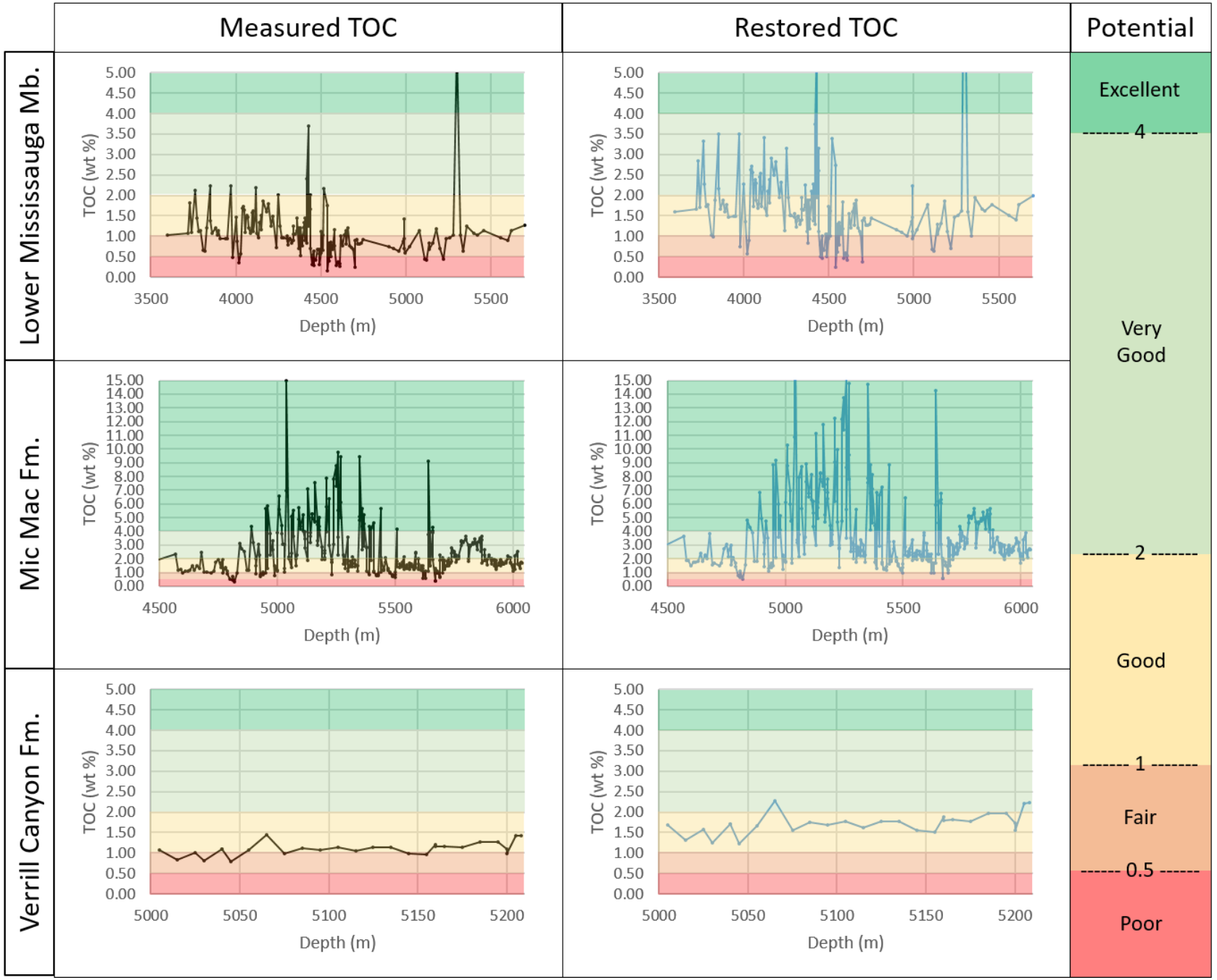
Jarvie (2005)

$$TOC^0 = \frac{TOC^x}{0.64}$$

Increases TOC consistently by 36%

Formations of Interest:

- Lower Mississauga Mb.
  - Fair – Good
    - Good – Very Good
- Mic Mac Fm.
  - Fair – Excellent
    - Very Good - Excellent
- Verrill Canyon Fm.
  - Fair – Good
    - Good



TOC DETERMINATIONS

Passey Method

Scales sonic and resistivity logs

Requires maturity estimation LOM

$$\Delta LogR = \frac{\log(RESD/RESD_{base}) + 0.02 * (\Delta t - \Delta t_{base})}{3.281}$$

$$TOC\% = \Delta LogR * 10^{(0.297 - (0.1688 * LOM))}$$

Issler Method

Cross-plots sonic or density vs resistivity logs

No subjective user input

$$TOC\% = 0.0714*(\Delta T + 195 * \log(RESD_{fm})) - 31.86$$

$$TOC\% = -0.1429 * (DEN_b - 1014)/(\log(RESD_{fm}) + 4.122) - 45.14$$

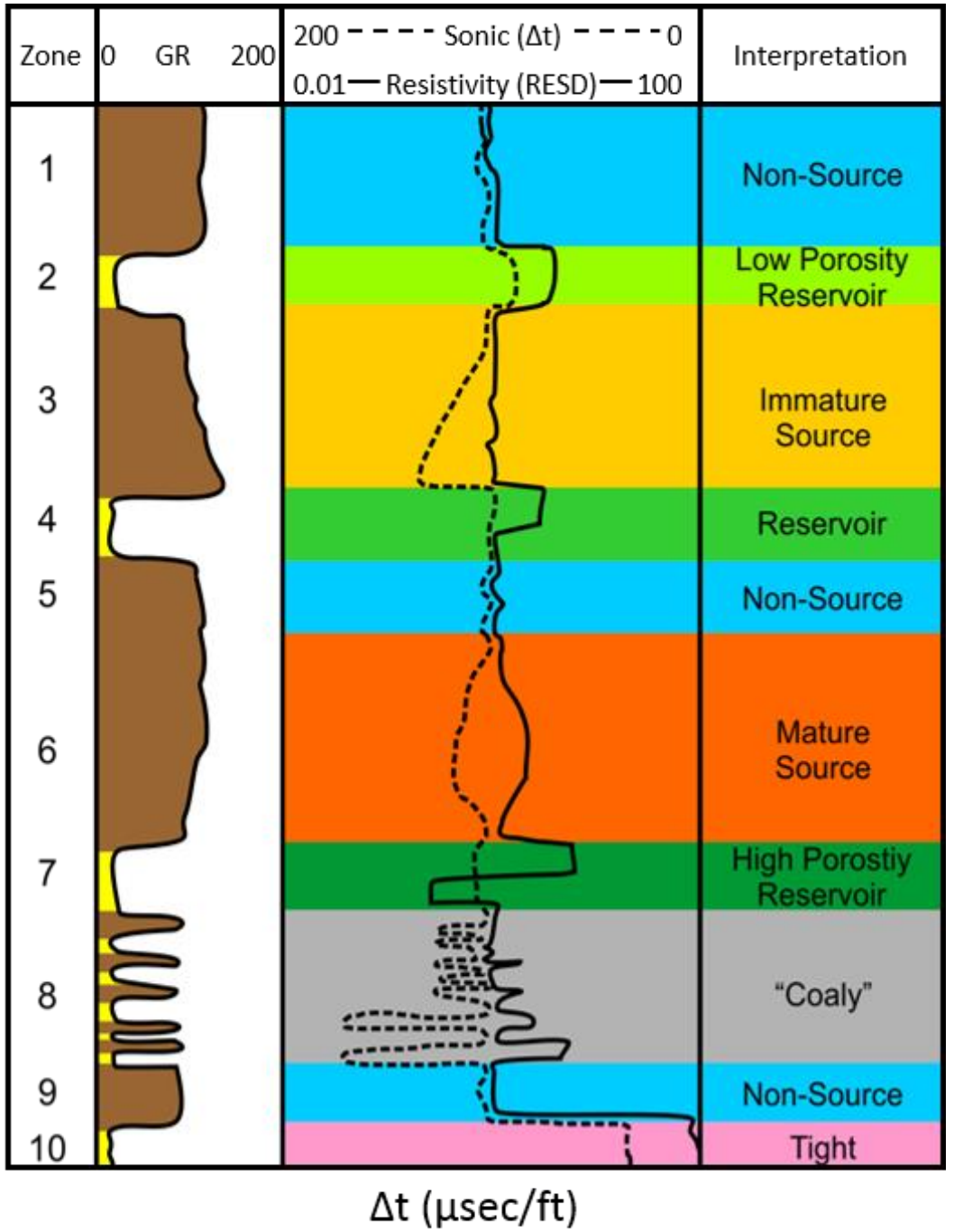
Sonic/Resistivity Cross Plots

Cross-plots sonic with resistivity logs

Deviation from regression indicates TOC enrichment

Does not estimate TOC values

$$D = - 6.906 + (3.186 * \log(\Delta t)) + (0.487 * \log(RESD75°))$$



TOC DETERMINATIONS

Passey Method

Scales sonic and resistivity logs

Requires maturity estimation LOM

$$\Delta LogR = \frac{\log(RESD/RESD_{base}) + 0.02 * (\Delta t - \Delta t_{base})}{3.281}$$

$$TOC\% = \Delta LogR * 10^{(0.297 - (0.1688 * LOM))}$$

Issler Method

Cross-plots sonic or density vs resistivity logs

No subjective user input

$$TOC\% = 0.0714*(\Delta T + 195 * \log(RESD_{fm})) - 31.86$$

$$TOC\% = -0.1429 * (DEN_b - 1014)/(\log(RESD_{fm}) + 4.122) - 45.14$$

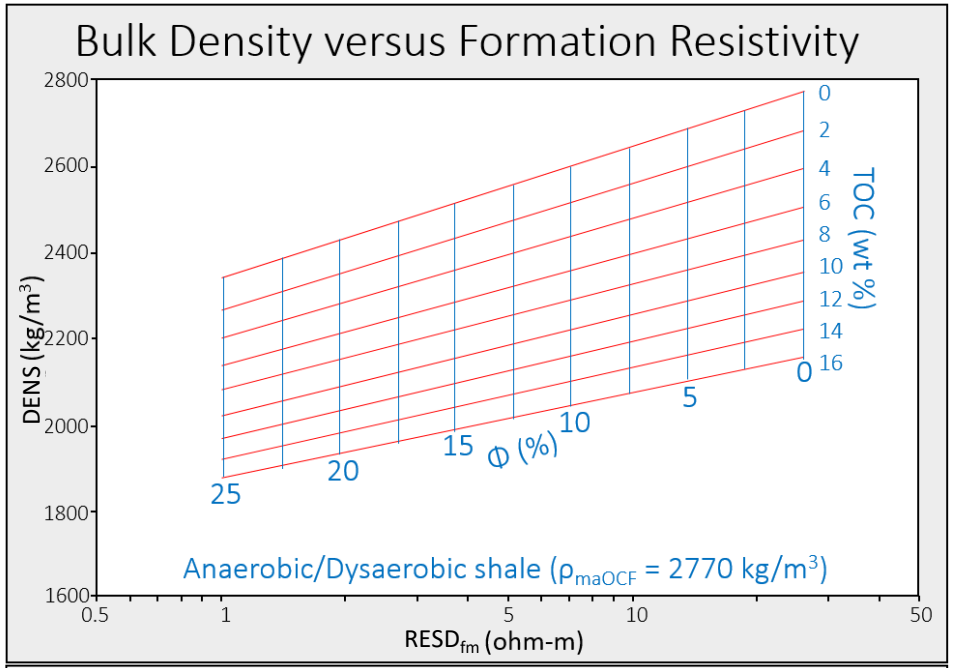
Sonic/Resistivity Cross Plots

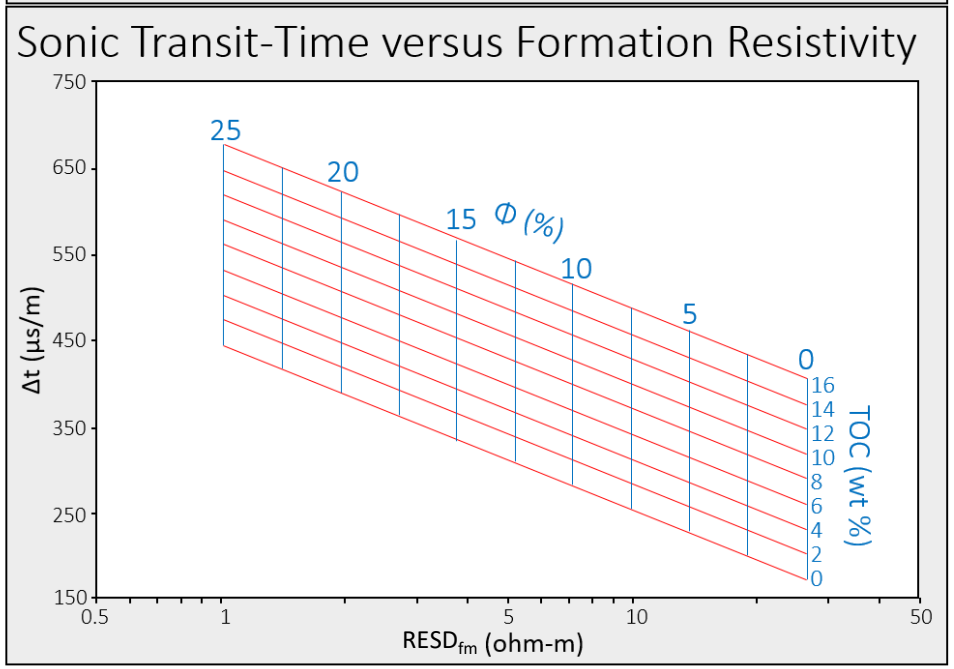
Cross-plots sonic with resistivity logs

Deviation from regression indicates TOC enrichment

Does not estimate TOC values

$$D = - 6.906 + (3.186 * \log(\Delta t)) + (0.487 * \log(RESD75°))$$





TOC DETERMINATIONS

Passey Method

Scales sonic and resistivity logs

Requires maturity estimation LOM

$$\Delta LogR = \frac{\log(RESD/RESD_{base}) + 0.02 * (\Delta t - \Delta t_{base})}{3.281}$$

$$TOC\% = \Delta LogR * 10^{(0.297 - (0.1688 * LOM))}$$

Issler Method

Cross-plots sonic or density vs resistivity logs

No subjective user input

$$TOC\% = 0.0714*(\Delta T + 195 * \log(RESD_{fm})) - 31.86$$

$$TOC\% = -0.1429 * (DEN_b - 1014)/(\log(RESD_{fm}) + 4$$

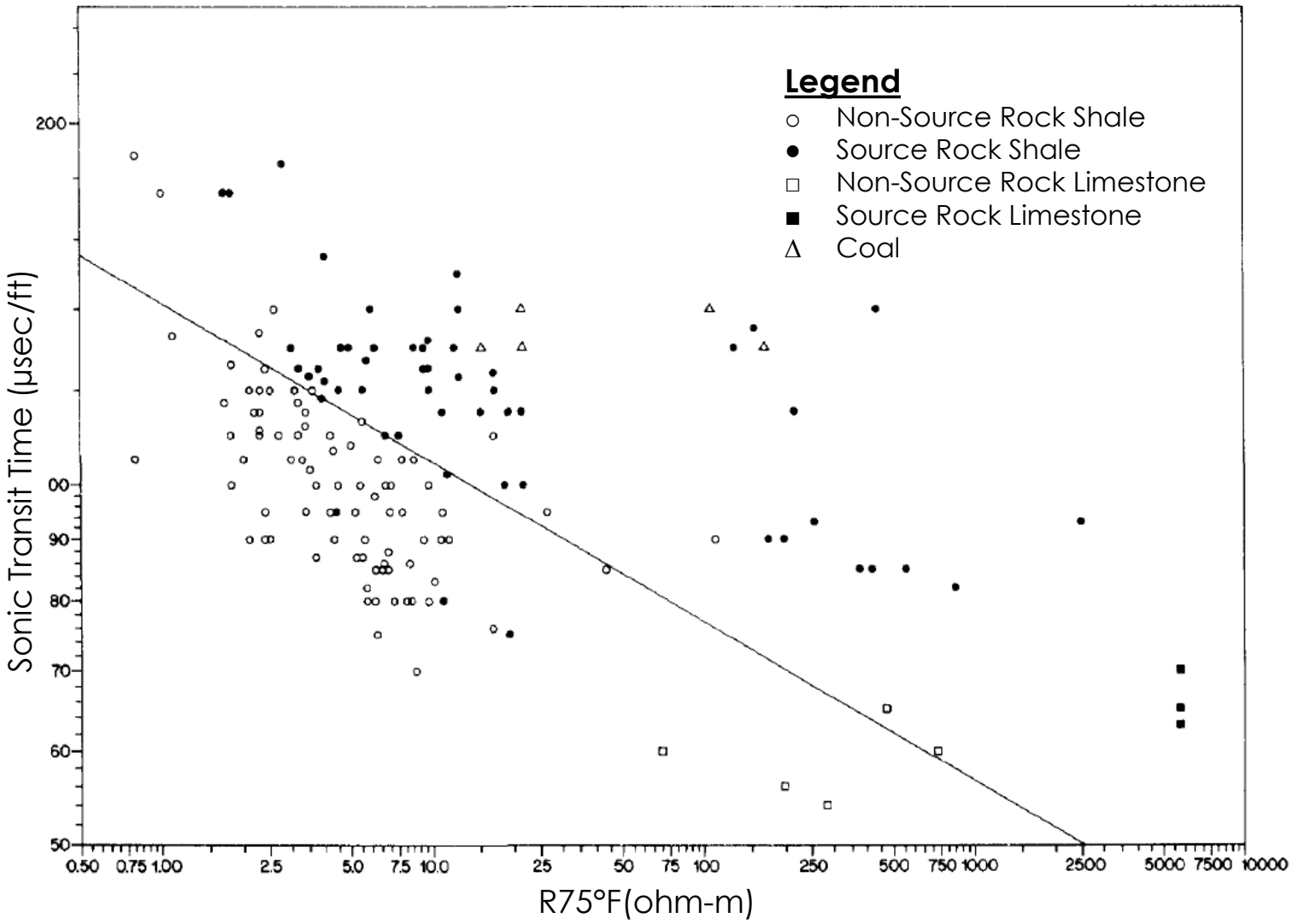
Sonic/Resistivity Cross Plots

Cross-plots sonic with resistivity logs

Deviation from regression indicates TOC enrichment

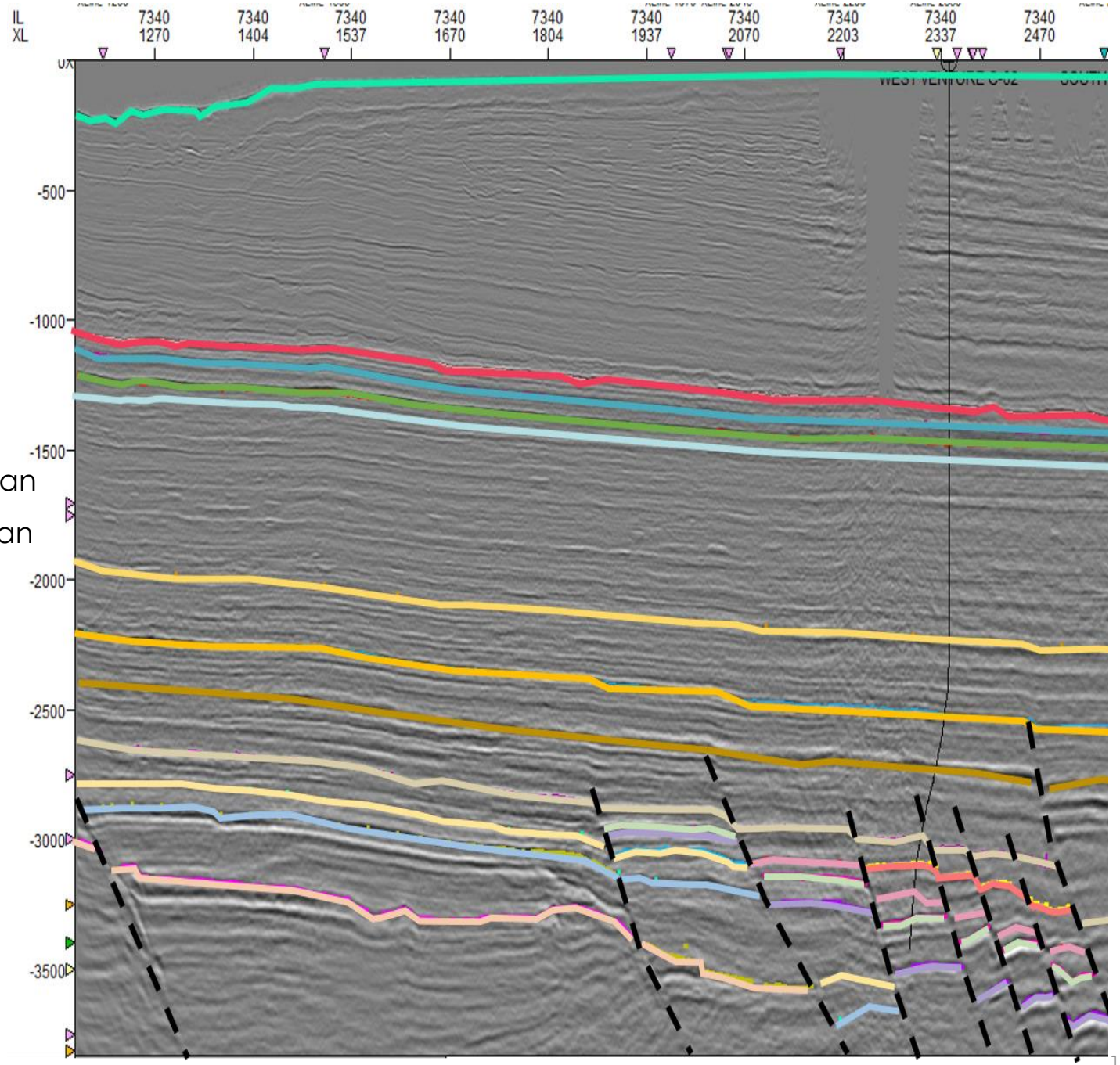
Does not estimate TOC values

$$D = - 6.906 + (3.186 * \log(\Delta t)) + (0.487 * \log(RESD$$

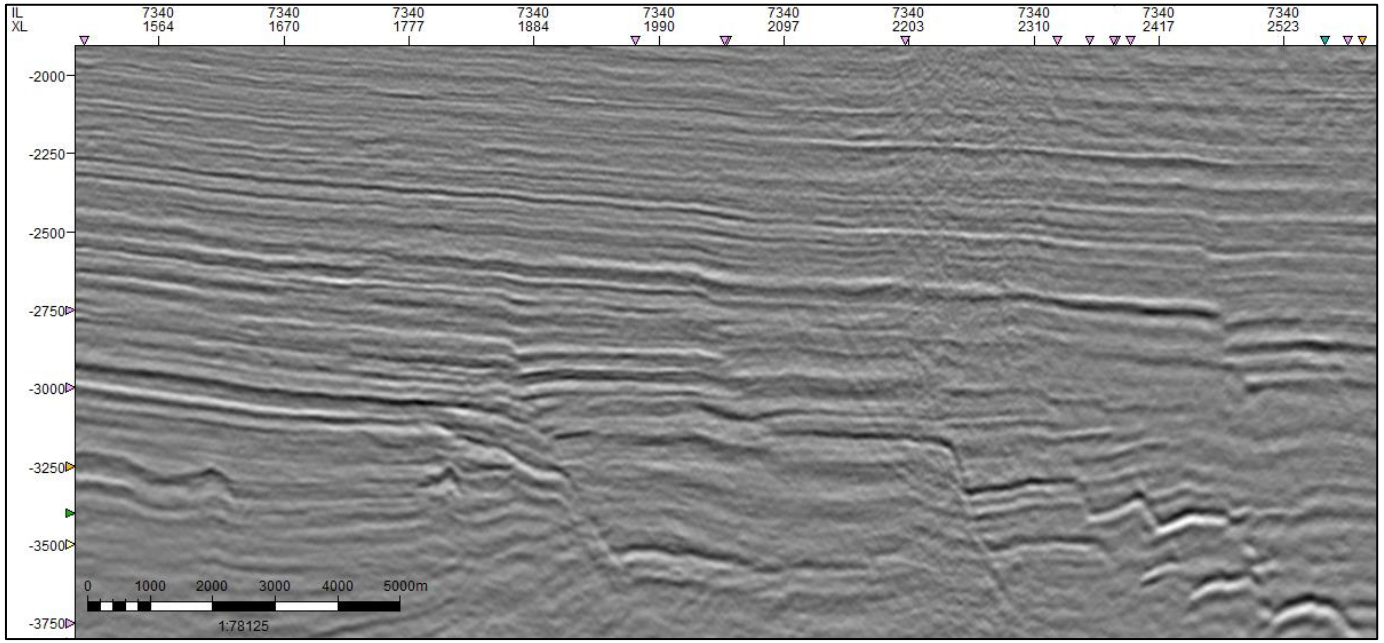


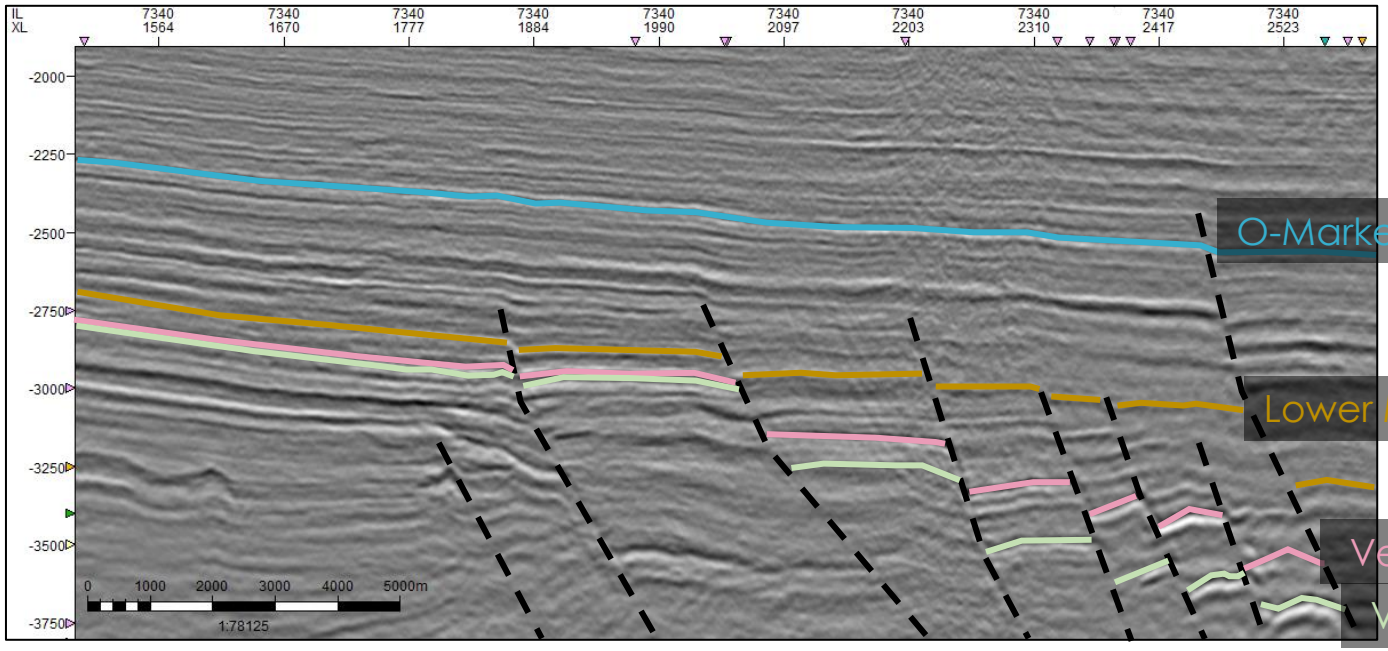
HORIZON INTERPRETATION

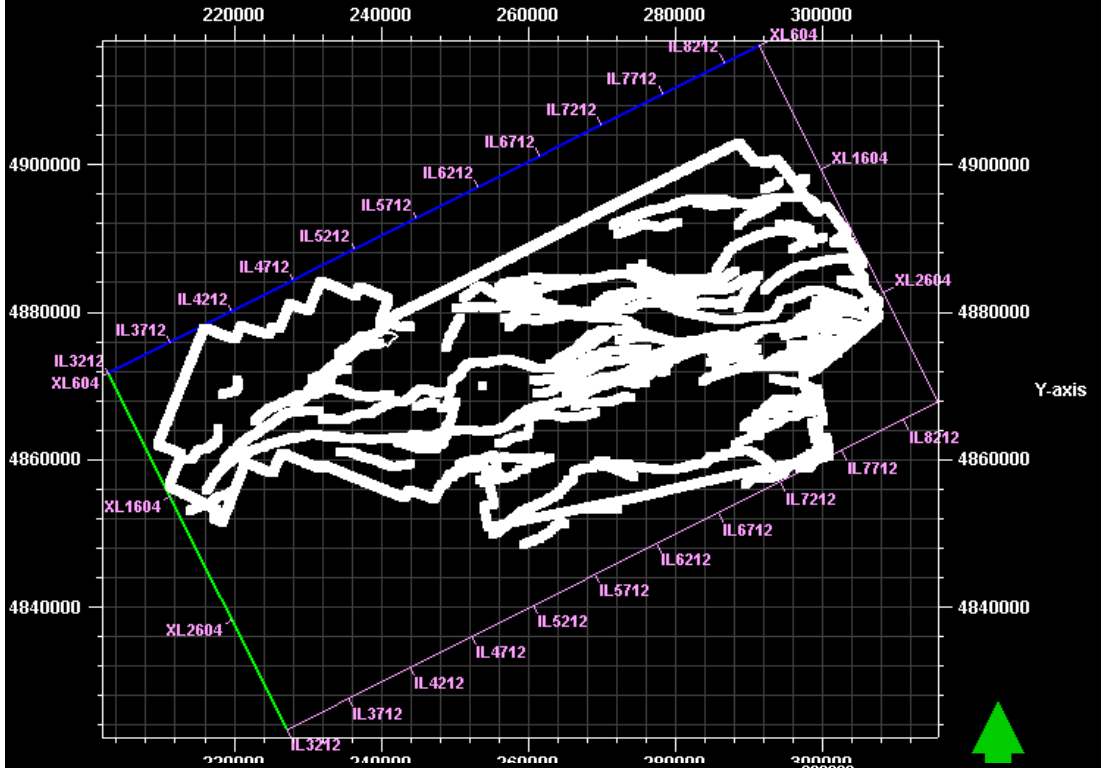
Horizons Interpreted:	Approx. Age:
Sea Floor	Current
Wyandot Fm.	Maastrichtian - Coniacian
Dawson Canyon Fm.	Coniacian - Turonian
Petrel Mb.	Turonian
Logan Canyon Fm.	Albian - Aptian
Missisauga Fm.	
Upper Mb.	Aptian - Barremian
Middle Mb.	Hauterivian - Valanginian
Lower Mb.	Berriasian - Kimmeridgian
Venture Limestones	
3 Lime	Tithonian - Bathonian
6 Lime	Tithonian - Bathonian
9 Lime	Tithonian - Bathonian
Y Lime	Tithonian - Bathonian
Z Lime	Tithonian - Bathonian
Z2 Lime	Tithonian - Bathonian
Citnalta Lime	Tithonian - Bathonian
Penobscot Lime	Tithonian - Bathonian
Top Salt	Norian - Hettangian

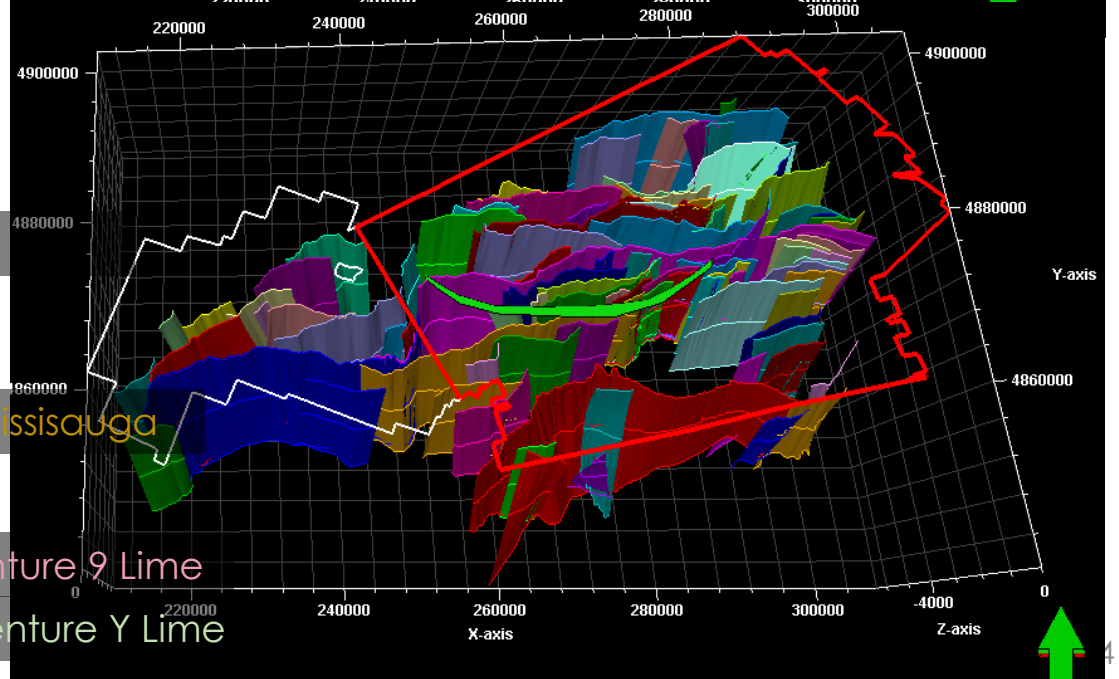


FAULT INTERPRETATION









SEISMIC INVERSION

InverTrace^{PLUS}

CGG Jason

Deterministic

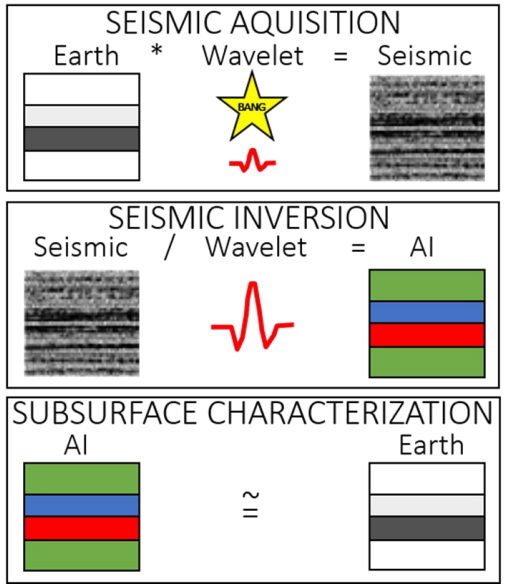
Constrained Sparse Spike Inversion

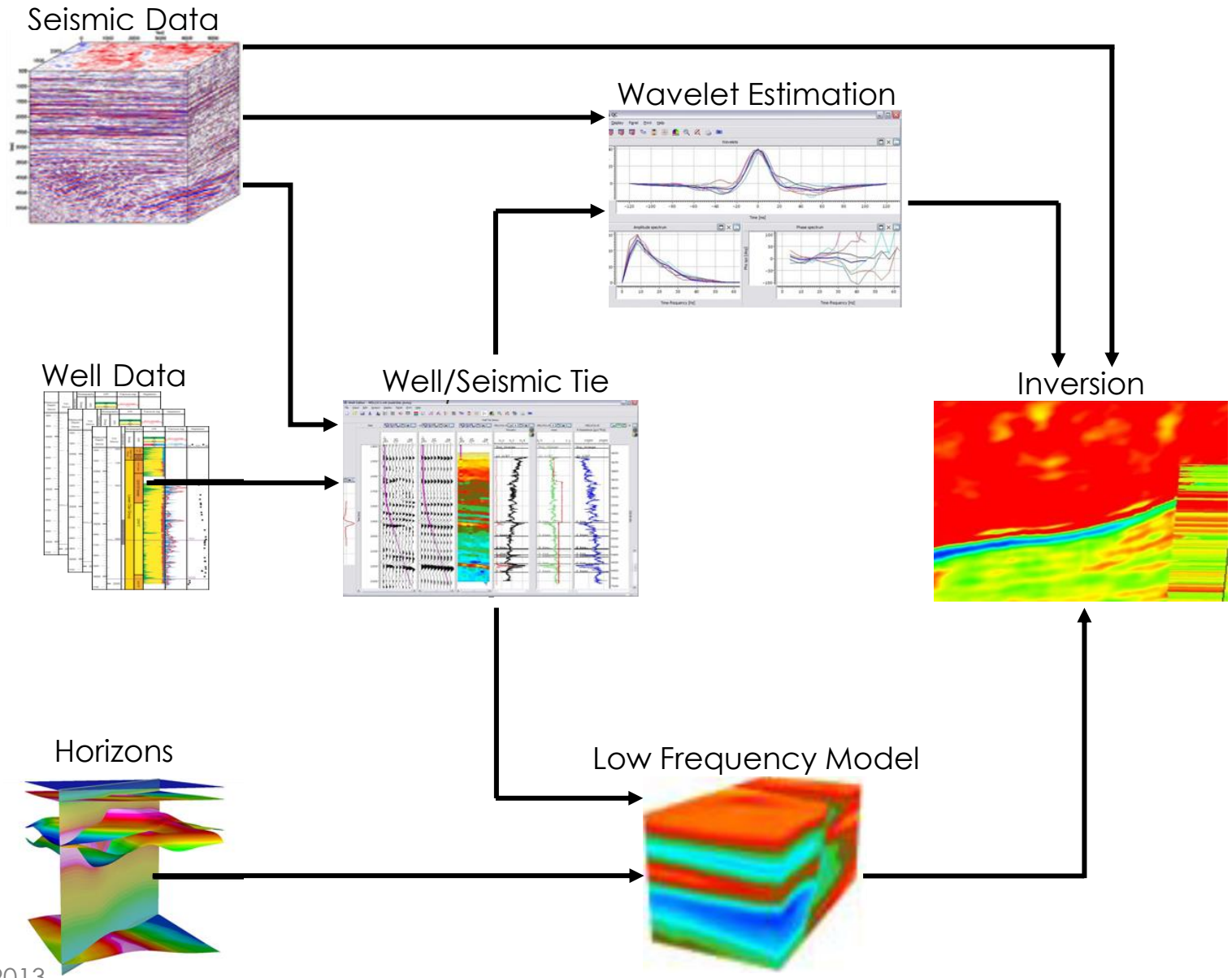
Creates acoustic impedance cube

Workflow

Input requirements:

- 3D seismic cube
- Seismic horizons
- Well logs (sonic & density)
- Wavelet





Modified from Jason, 2013

SOURCE ROCK FROM SEISMIC

Løseth et al. 2011

AI decreases non-linearly with increasing TOC

- AI decrease = Top source rock
- AI increase = Base source rock

Can create a TOC profile

- AI Range = TOC %

Workflow

Input requirements:

- 3D seismic cube
- Seismic horizons
- Well logs (sonic & density)
- Wavelet

Parameters

TOC > 3-4% and <25%

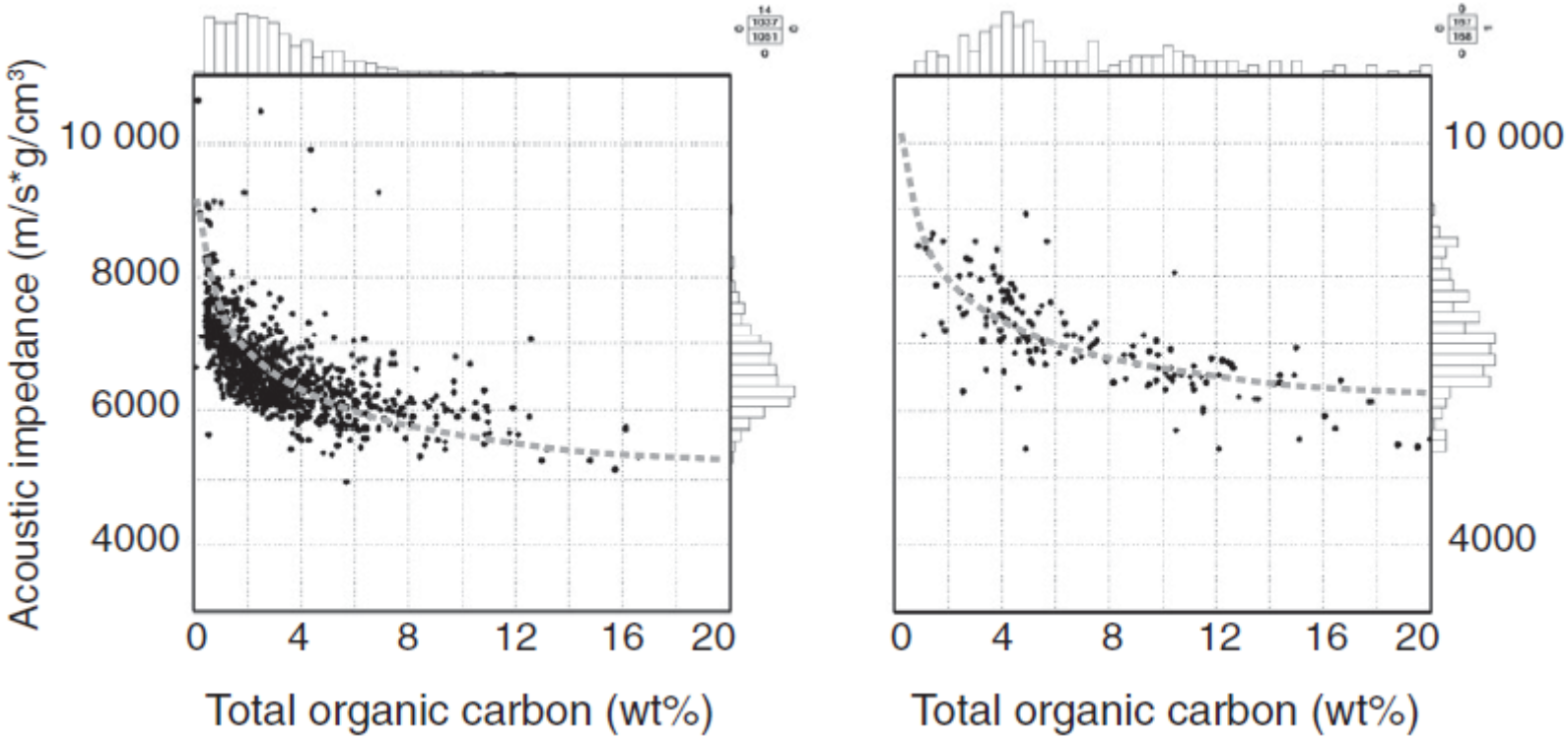
Above 4500 m depth

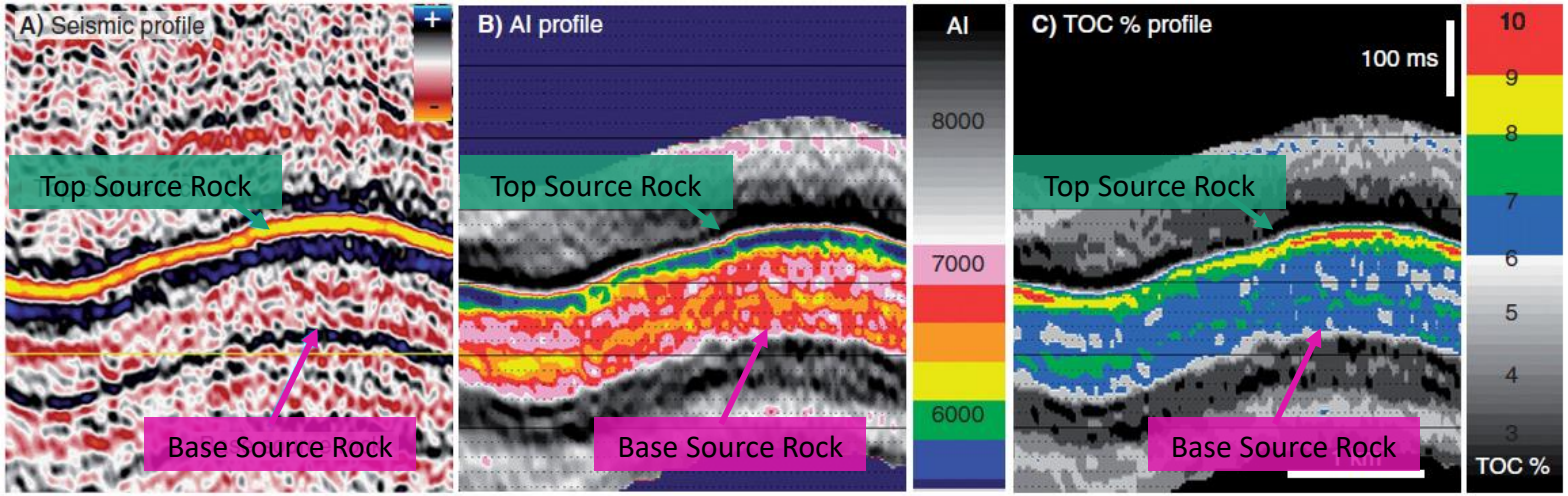
- Relationship only stable to mature oil window

> 20 m shale thickness

Kimmeridge Clay, southern England

Hekkingen Formation, Barents Sea





RESULTS - PASSEY METHOD

Completed on both sonic and density logs

- Baseline taken at each formation/member or drastic lithology change
- Baseline taken from closest well if unable to establish

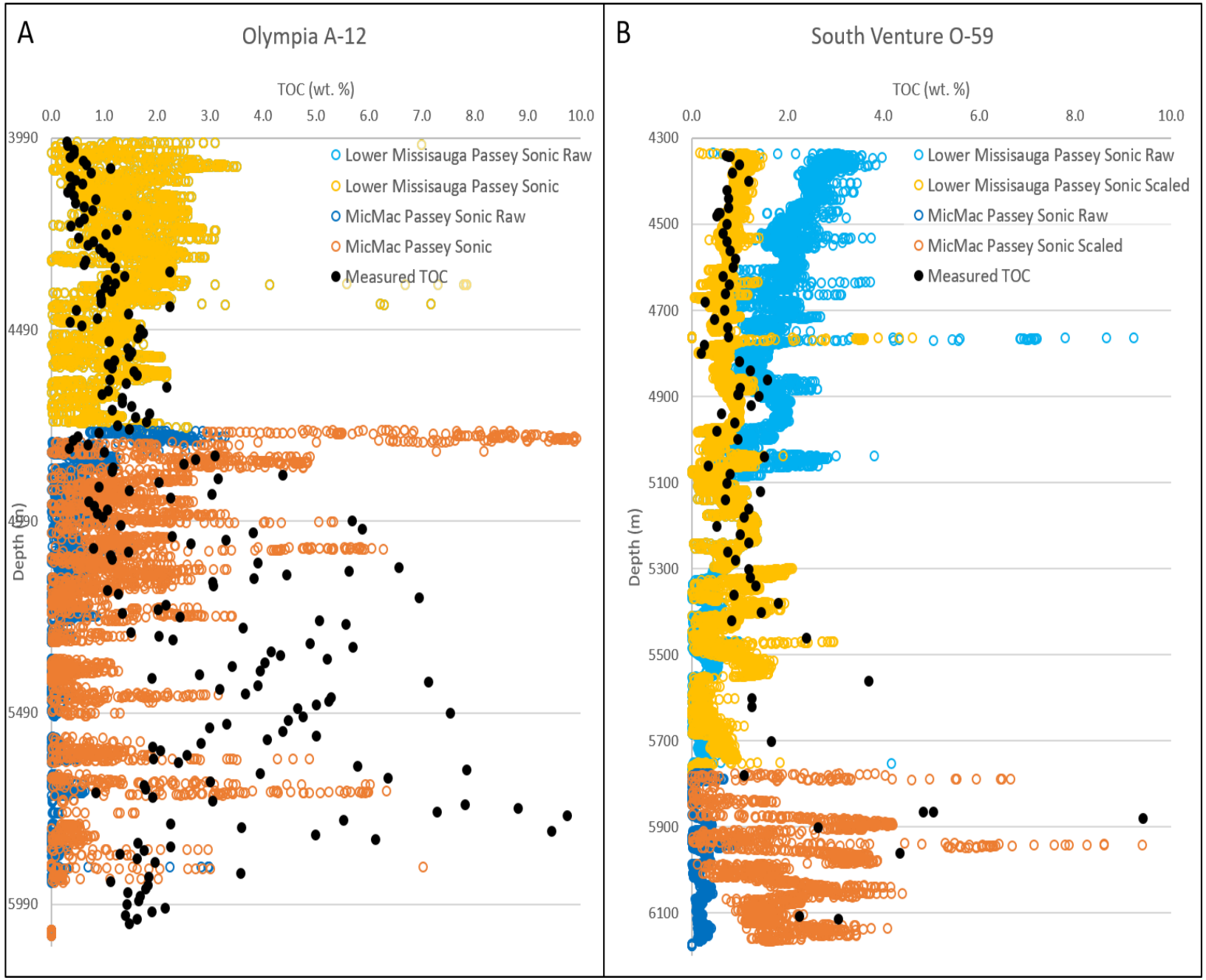
RockEval data used to calibrate calculations

Olympia A-12

Lower Missisauga	Corrections		Baselines	
	Sonic Scale Factor	Sonic Offset Factor	Sonic AC µs/m	Resistivity ILD OHMM
3995 – 4300 m 4300 – 4751.8 m	0.5 0.5	2 2	225	3.5
Mic Mac	Corrections		Baselines	
	Sonic Scale Factor	Sonic Offset Factor	Sonic AC µs/m	Resistivity ILD OHMM
4751.8 – 5300 m 5300 – 6071.2 m	2 2	2 5	270	2.1

South Venture O-59

Lower Missisauga	Corrections		Baselines	
	Sonic Scale Factor	Sonic Offset Factor	Sonic AC µs/m	Resistivity ILD OHMM
4335 – 4750 m 4750 – 5100 m 5100 – 5300 m 5300 – 5776.2 m	0.5 0.5 1 1	0.75 1 1 3	250	2.5
Mic Mac	Corrections		Baselines	
	Sonic Scale Factor	Sonic Offset Factor	Sonic AC µs/m	Resistivity ILD OHMM
	1	10	250	1.9

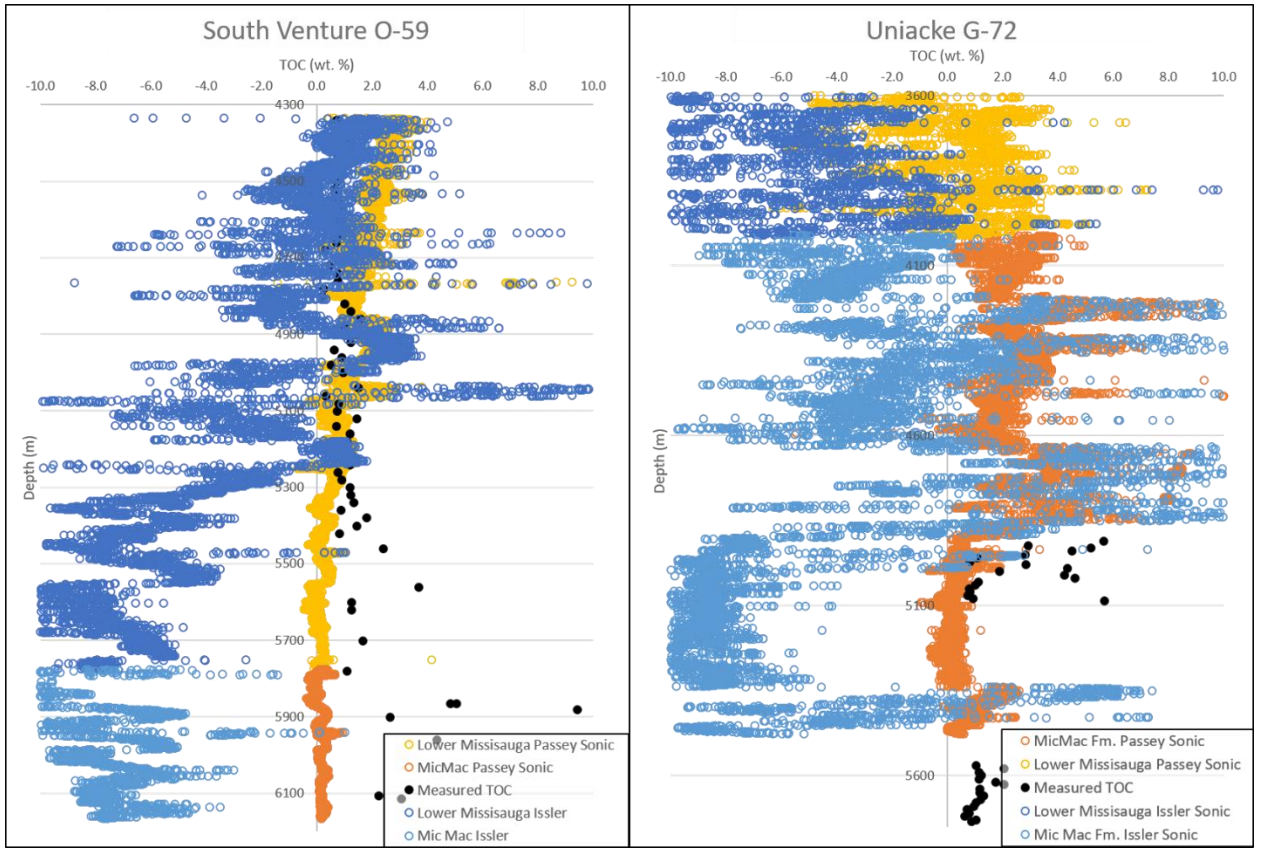


RESULTS – ISSLER METHOD

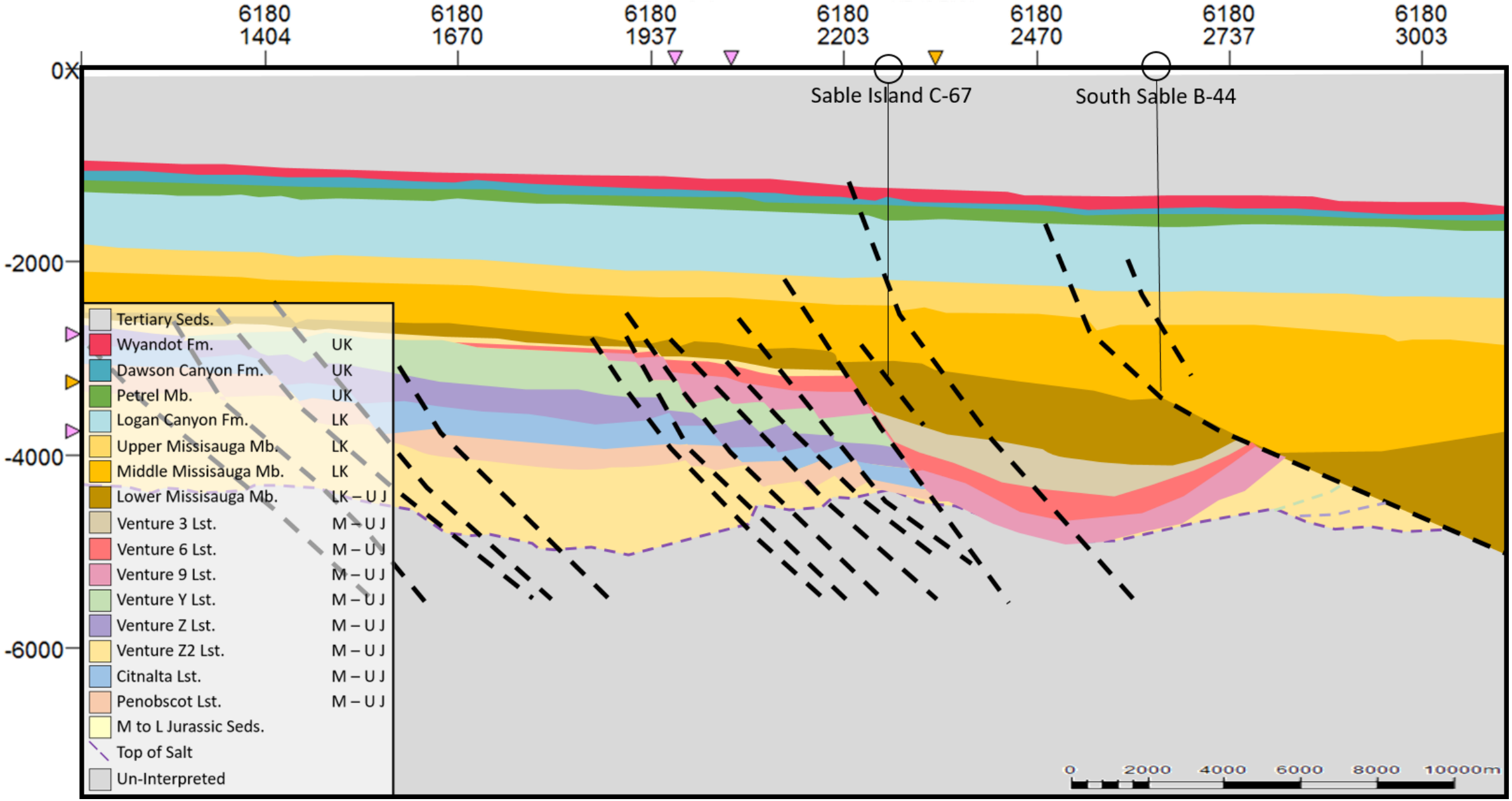
Completed on both sonic and density logs

- Baseline taken at each formation/member or drastic lithology change
- Baseline taken from closest well if unable to establish

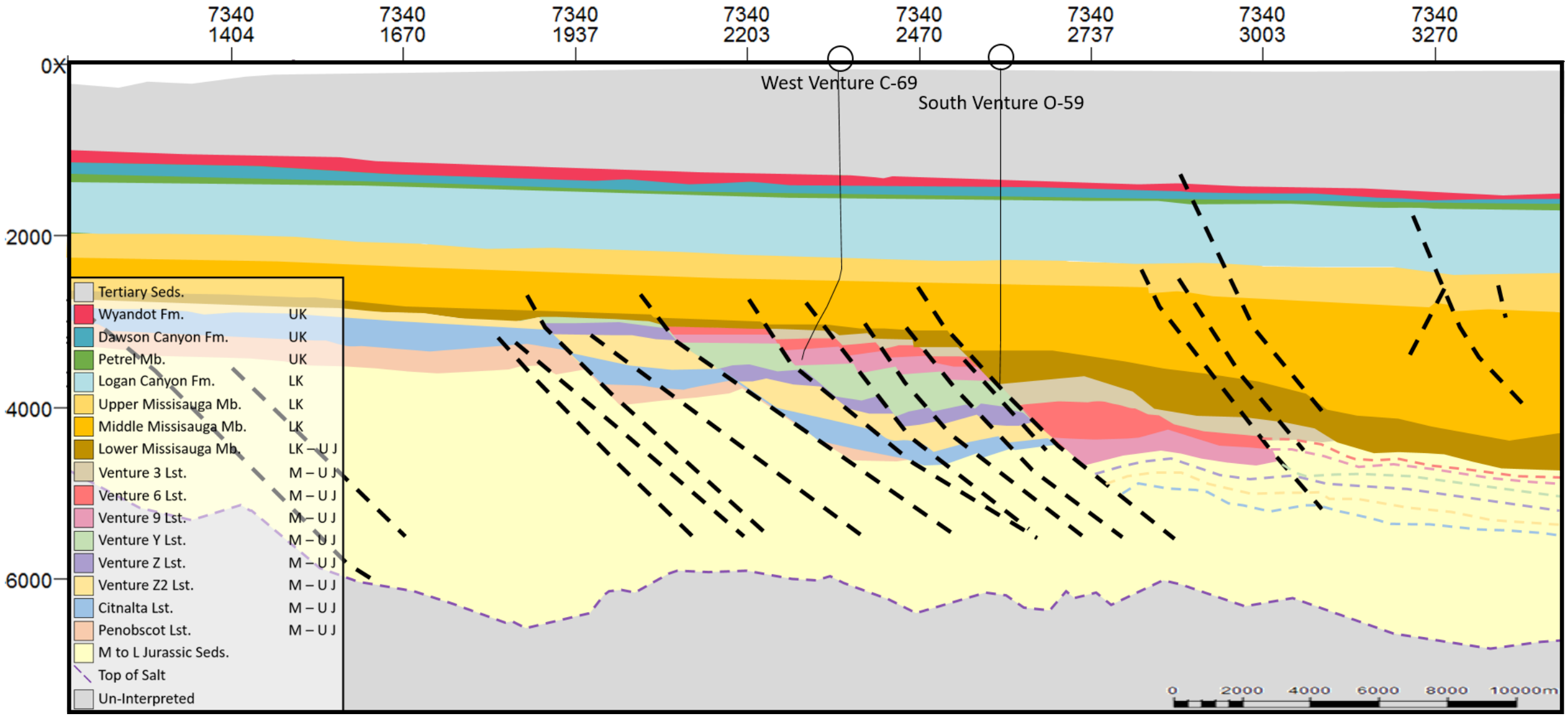
RockEval data used to calibrate calculations



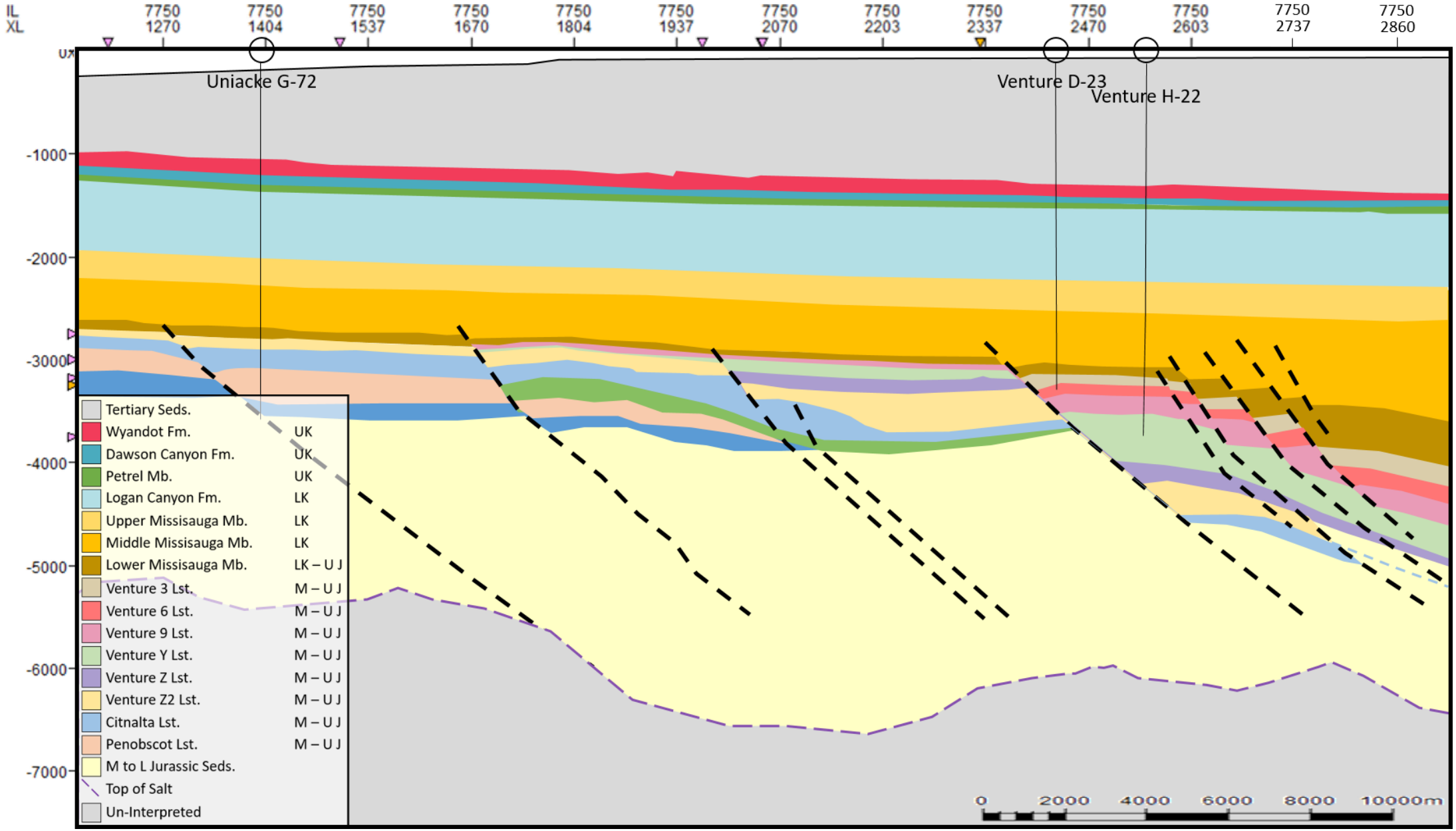
LITHOSTRATIGRAPHIC CROSS SECTIONS



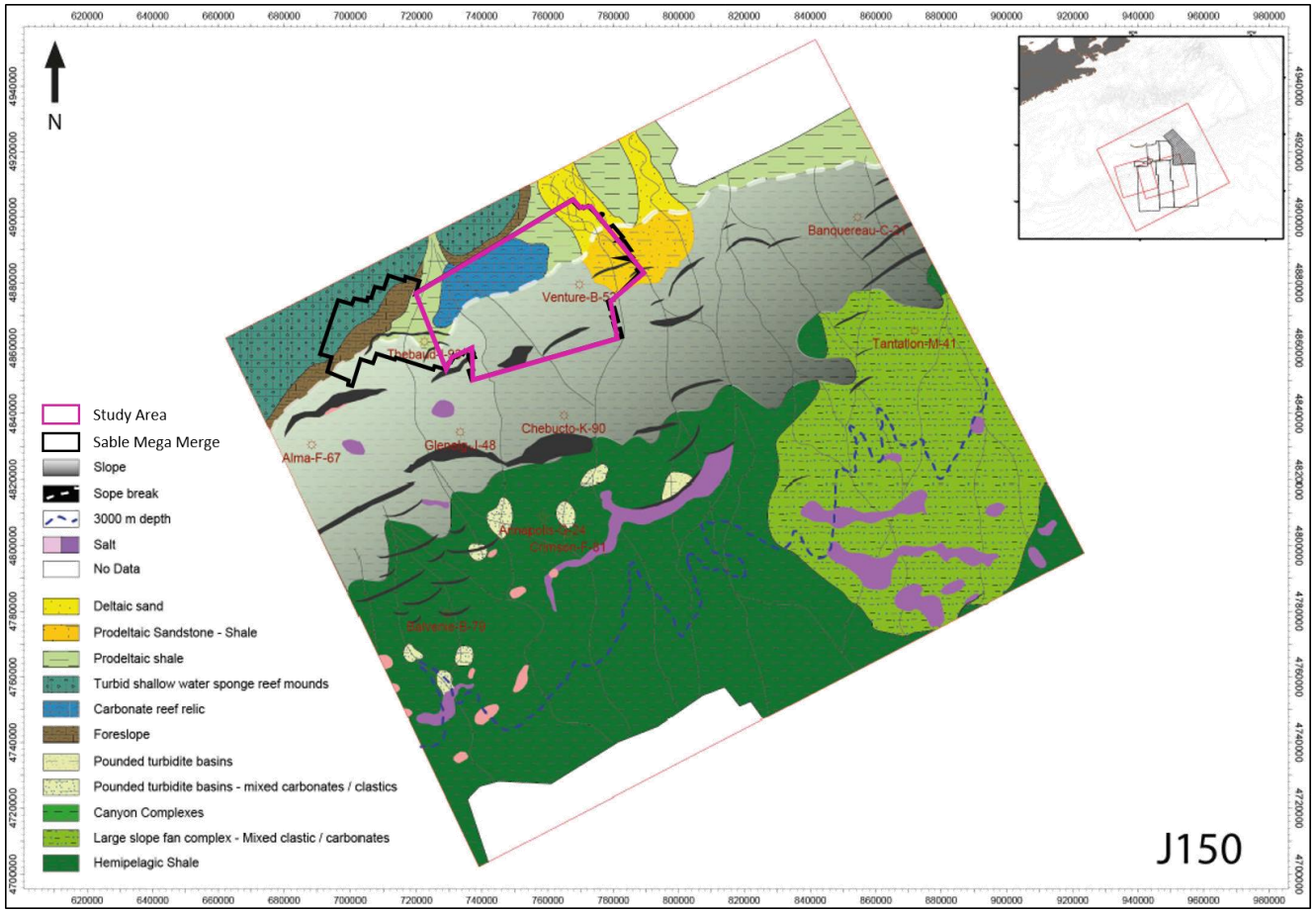
LITHOSTRATIGRAPHIC CROSS SECTIONS



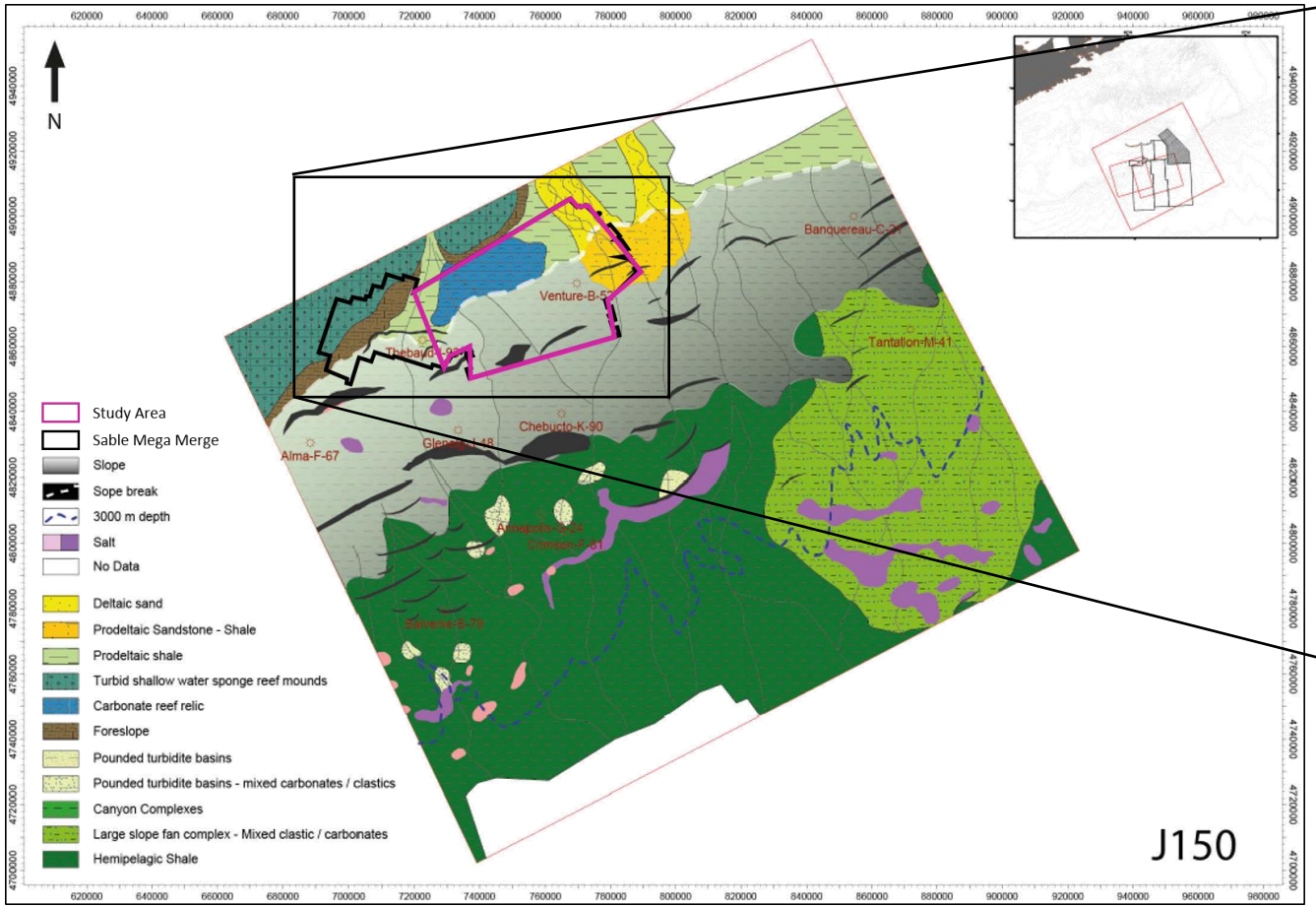
LITHOSTRATIGRAPHIC CROSS SECTIONS

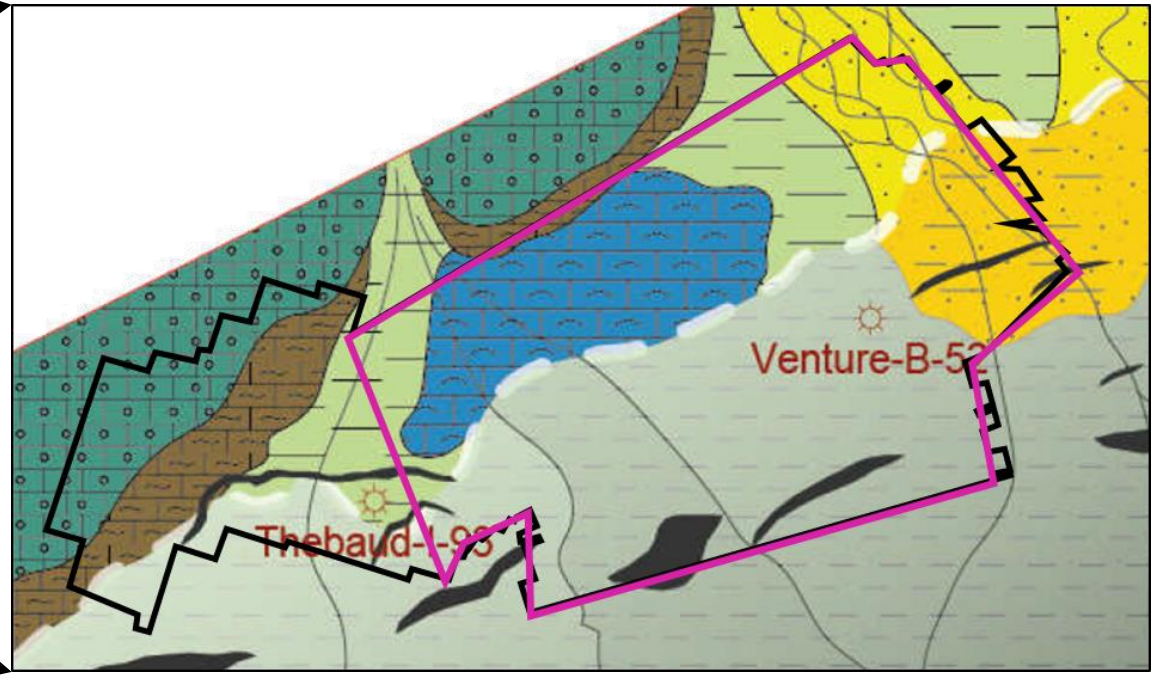


GROSS DEPOSITIONAL MODELING



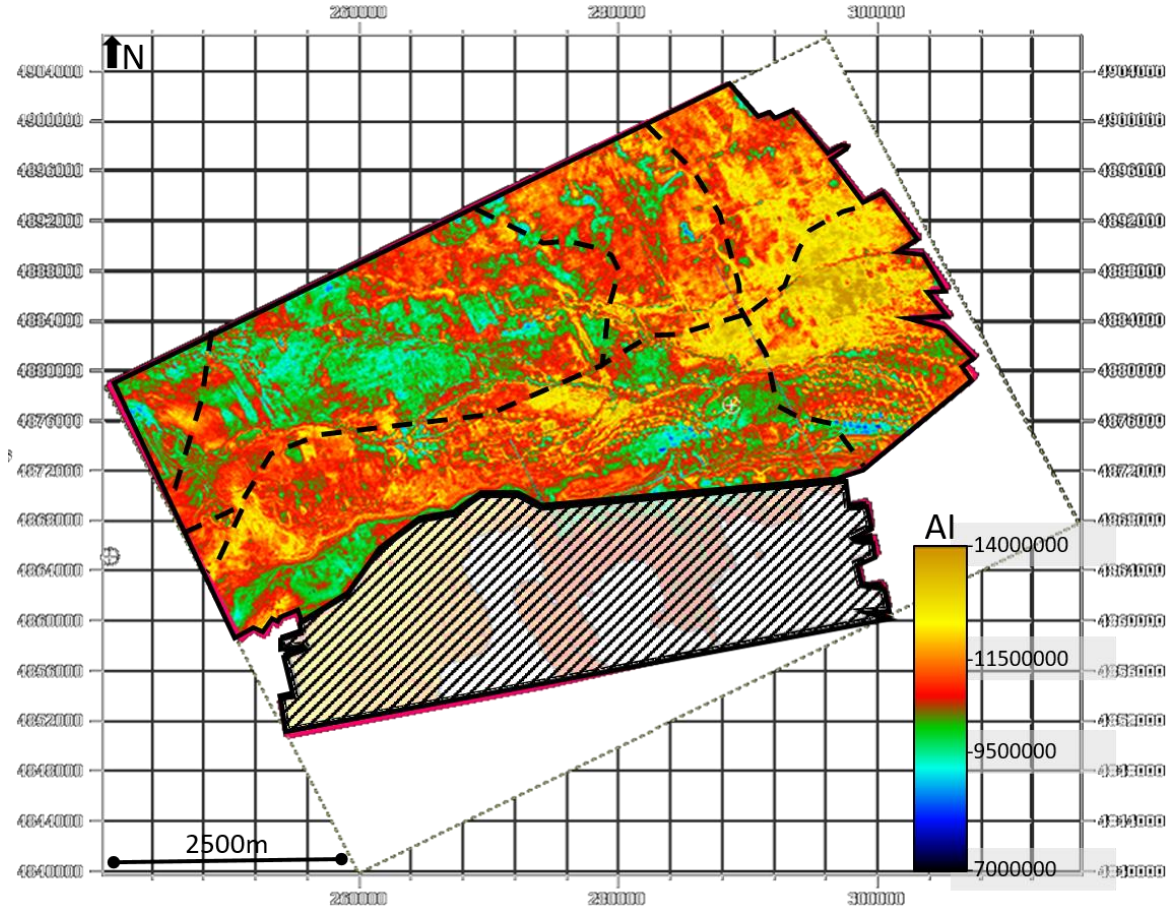
GROSS DEPOSITIONAL MODELING

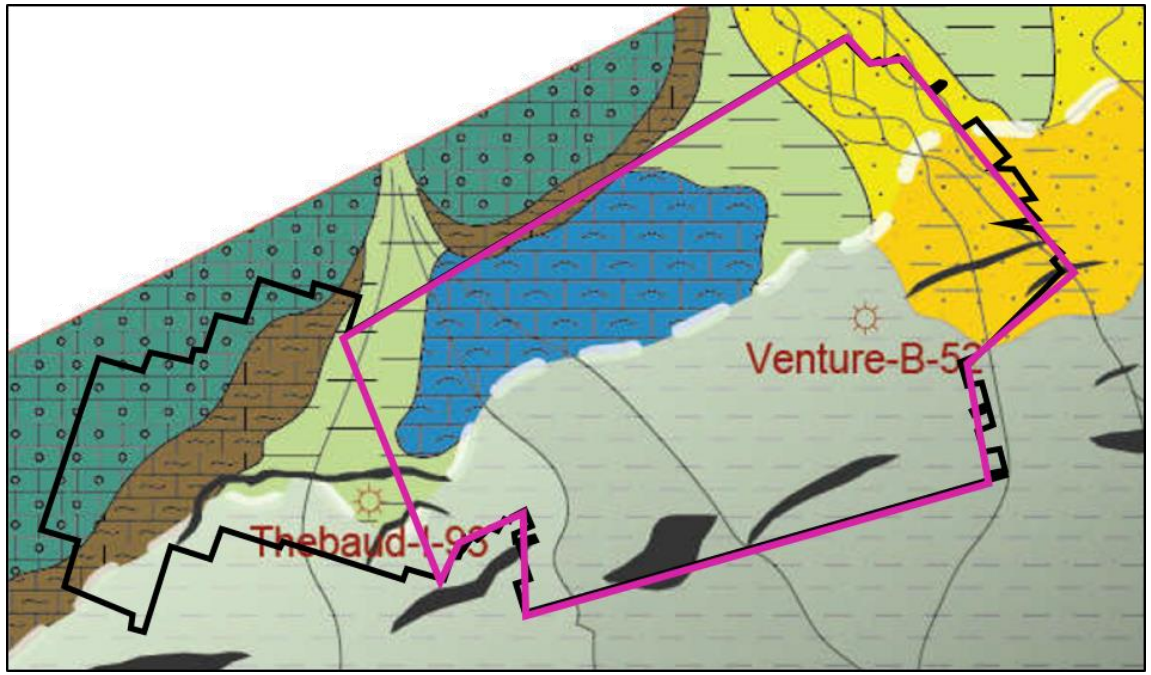




Prodeltaic Shale
Carbonate Reef Relic
Pounded Turbidite Basin
Deltaic Sand
Prodeltaic Sandstone-Shale
Study Area

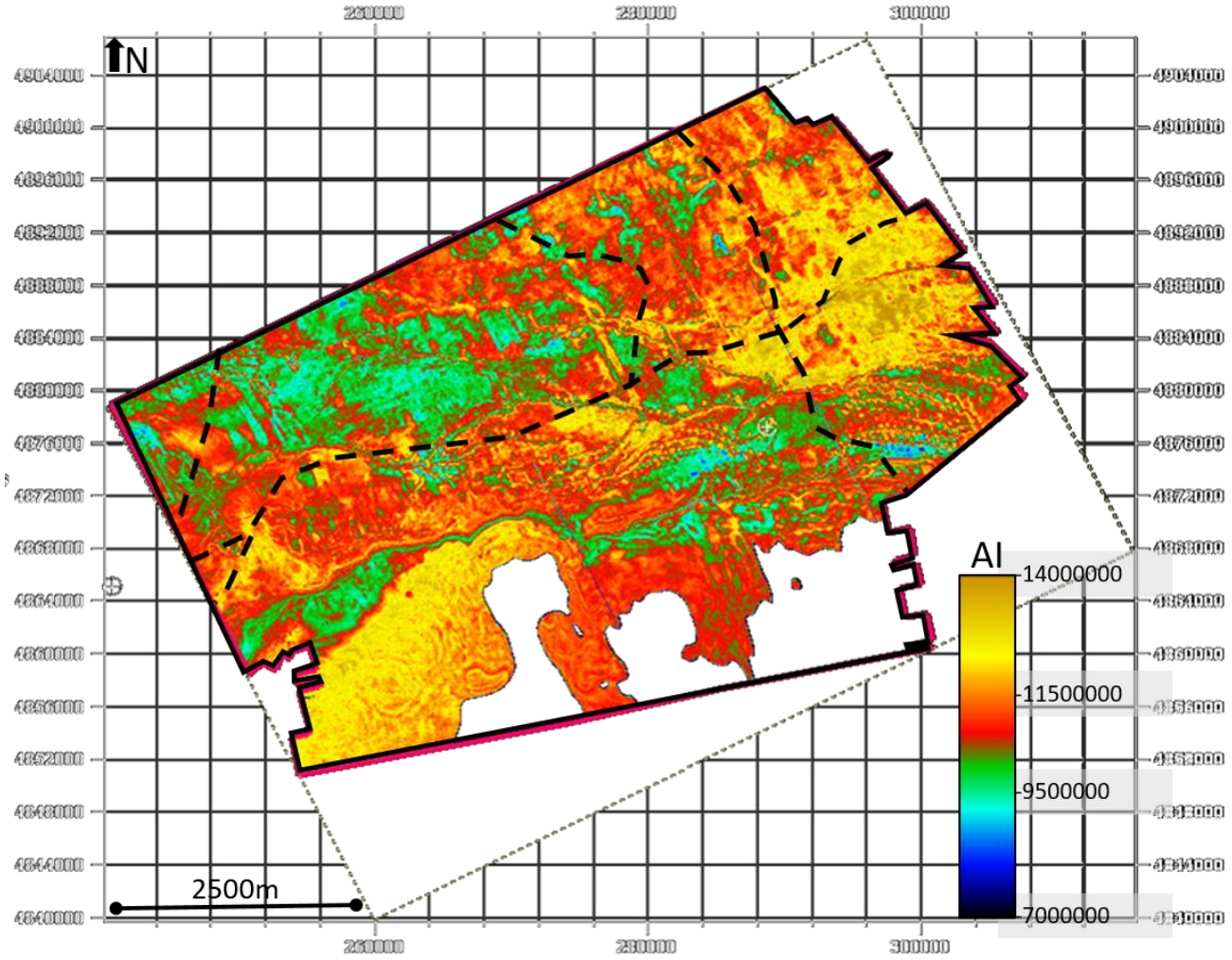
GROSS DEPOSITIONAL MODELING

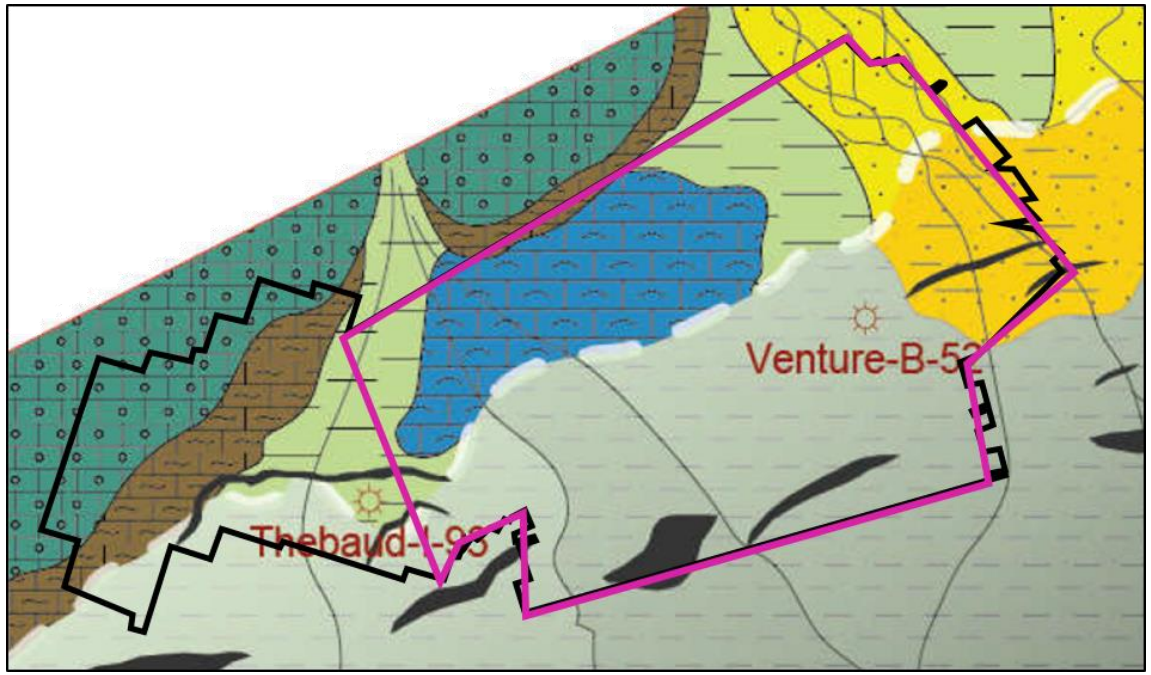




- Prodeltaic Shale
- Carbonate Reef Relic
- Pounded Turbidite Basin
- Deltaic Sand
- Prodeltaic Sandstone-Shale
- Below Seismic Resolution

GROSS DEPOSITIONAL MODELING





- Prodeltaic Shale
- Carbonate Reef Relic
- Pounded Turbidite Basin
- Deltaic Sand
- Prodeltaic Sandstone-Shale

TOC DETERMINATIONS

Passey Method

Scales sonic and resistivity logs

Requires maturity estimation LOM

$$\Delta LogR = \frac{\log(RESD/RESD_{base}) + 0.02 * (\Delta t - \Delta t_{base})}{3.281}$$

$$TOC\% = \Delta LogR * 10^{(0.297 - (0.1688 * LOM))}$$

Issler Method

Cross-plots sonic or density vs resistivity logs

No subjective user input

$$TOC\% = 0.0714*(\Delta T + 195 * \log(RESD_{fm})) - 31.86$$

$$TOC\% = -0.1429 * (DEN_b - 1014)/(\log(RESD_{fm}) + 4.122) - 45.14$$

Sonic/Resistivity Cross Plots

Cross-plots sonic with resistivity logs

Deviation from regression indicates TOC enrichment

Does not estimate TOC values

$$D = - 6.906 + (3.186 * \log(\Delta t)) + (0.487 * \log(RESD75°)$$