Nova Scotia Play Fairway Analysis: Gross Depositional Environments and Hydrocarbon Prospectivity*

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Abstract

The Play Fairway Analysis (PFA) programme initiated by OETR (Offshore Energy Technical Research Association of Nova Scotia) is fundamentally based on the creation of Gross Depositional Environment (GDE) maps for key intervals. These maps are created through a thorough integration of paleo-environment data from wells with seismic facies analysis.

The methodology is essentially based on a rigorous sequence stratigraphic approach. The major innovation in this PFA study was the creation of a systematic sequence stratigraphic framework offshore Nova Scotia. This analysis was based on twenty key wells of which six had new biostratigraphic analyses.

The information from these key wells was extrapolated using seismic stratigraphy. Accurate well to seismic ties were established through careful calibration of sonic and density data together with well established well/seismic correlations methods. In order to ensure the highest possible resolution for calibration to the wells, key seismic lines were reprocessed to improve bandwidth and imaging. These well data were extrapolated using a large seismic database (~70,000 km of 2D and ~30,000 km^2 of 3D).

The PFA workflow imposes a rigorous and disciplined integration process. This is designed to ensure that the various input elements of the study are internally consistent. The integration process is continual throughout the programme and is tested fully during the creation of the GDE maps. These maps necessarily have to honour all the data and interpretation that feeds into the process (from the most basic tectonic history, through biostratigraphy, depositional processes as evidenced by sedimentological studies, seismic stratigraphy and, in this instance, salt kinematics).

The PFA project included some fourteen horizons that were mapped seismically for structural and stratigraphic control. Of these, nine surfaces have significance for understanding the most prospective Cretaceous and Jurassic plays. The GDE maps for the most important intervals are interrogated for predictions of distribution of reservoirs, sources and seals.

This paper presents the overall methodology and illustrates the workflow with an example of source rock distribution.

Selected References

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Gradstein, F.M., J.G. Ogg, and A.G. Smith, 2004, A geologic time scale 2004: Cambridge University Press, 589 p.

MacRae, A., J. Weston, K. Cooper, D. Shaw, P. Ascoli, R. Fensome, G. Williams, [?], Resolving long-standing inconsistencies between Biostratigraphic methods on the Scotian Margin in delta foreset settings: a testable model for foreslope reworking: Offshore Energy Research, Web accessed 9 August 2011, http://www.offshoreenergyresearch.ca/Portals/0/2.00-2.45%20Academic%20Panel%20on%20Special%20Projects%20-%20Andrew%20MacRae.pdf

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OETR Offshore Energy Technical Research Association

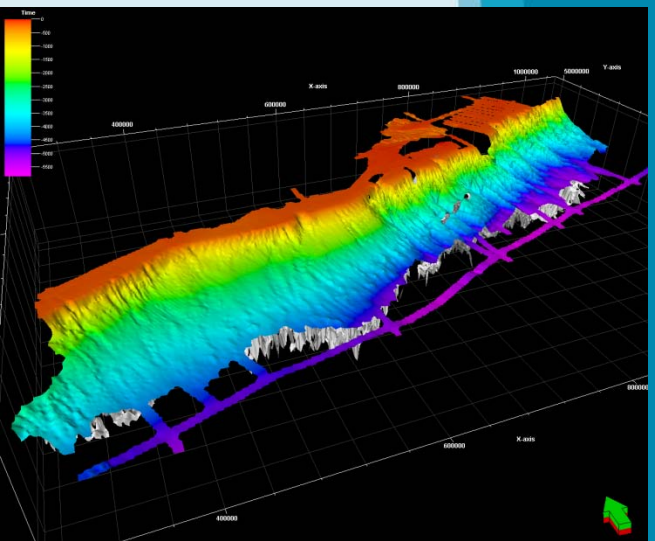
Play Fairway Analysis

A Study of Nova Scotia's Offshore Basin

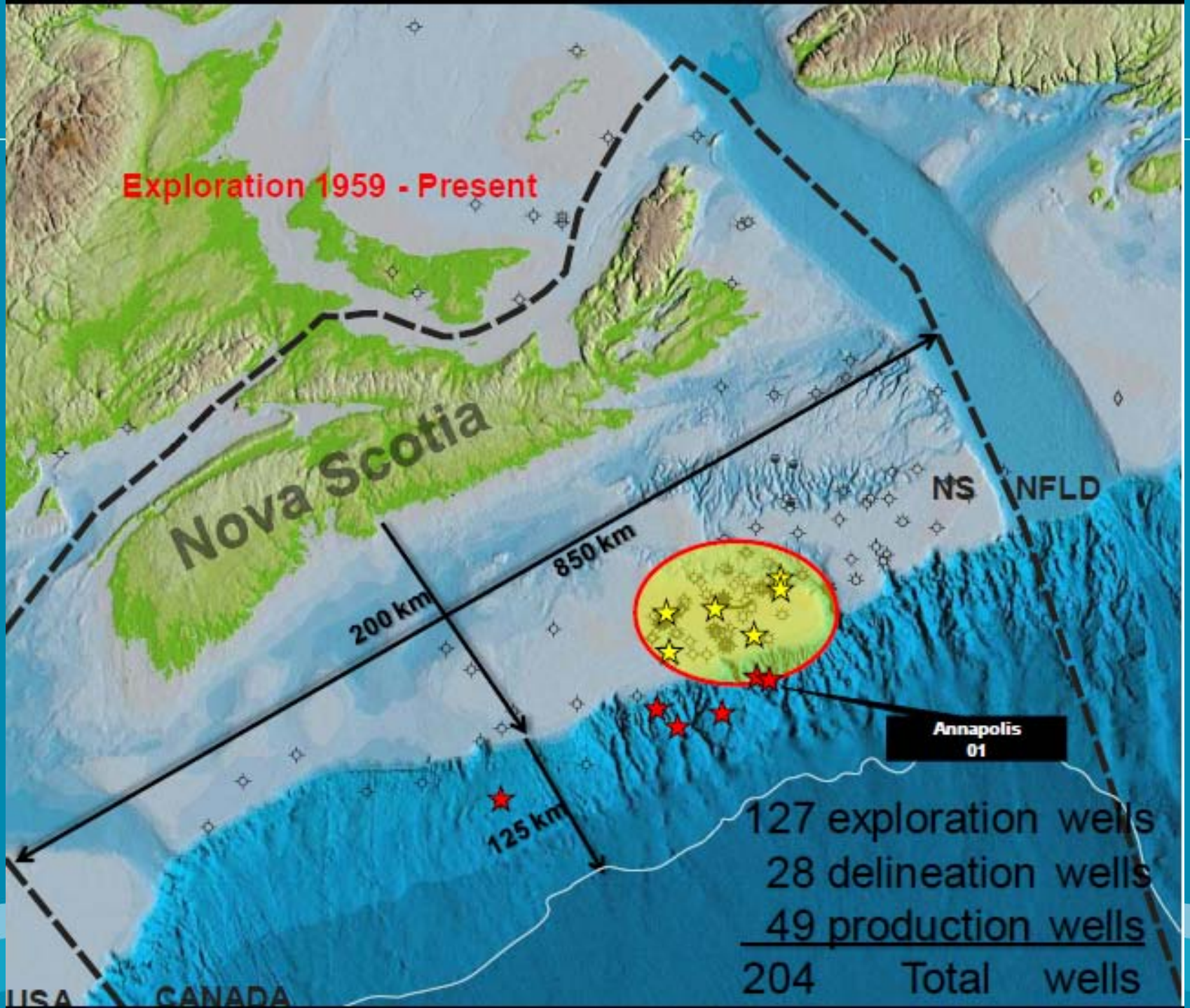
Nova Scotia Play Fairway Analysis

Gross Depositional Environments and Hydrocarbon Prospectivity

Hamish Wilson, Matt Luheshi, David Roberts, Bernard Colletta



RPS Energy


Exploration 1959 - Present
Nova Scotia
NS
NFLD
850 km
200 km
125 km
Annapolis
01
127 exploration wells
28 delineation wells
49 production wells
204 Total wells
USA
CANADA


NOVA SCOTIA
Department of Energy


OETR

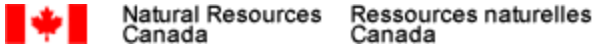

RPS Energy


CNSOPB
CANADA-NOVA SCOTIA
OFFSHORE PETROLEUM BOARD


DALHOUSIE
UNIVERSITY
Inspiring Minds


CANADA
1842
GEOLOGICAL SURVEY · COMMISSION GÉOLOGIQUE


SAINT MARY'S
UNIVERSITY
SINCE 1802
One University. One World. Yours.


Natural Resources Canada
Ressources naturelles Canada


BeicipFranlab


Ifremer


BioSTRATIGRAPHIC
Associates International


TGS


GeoPro


FUGRO

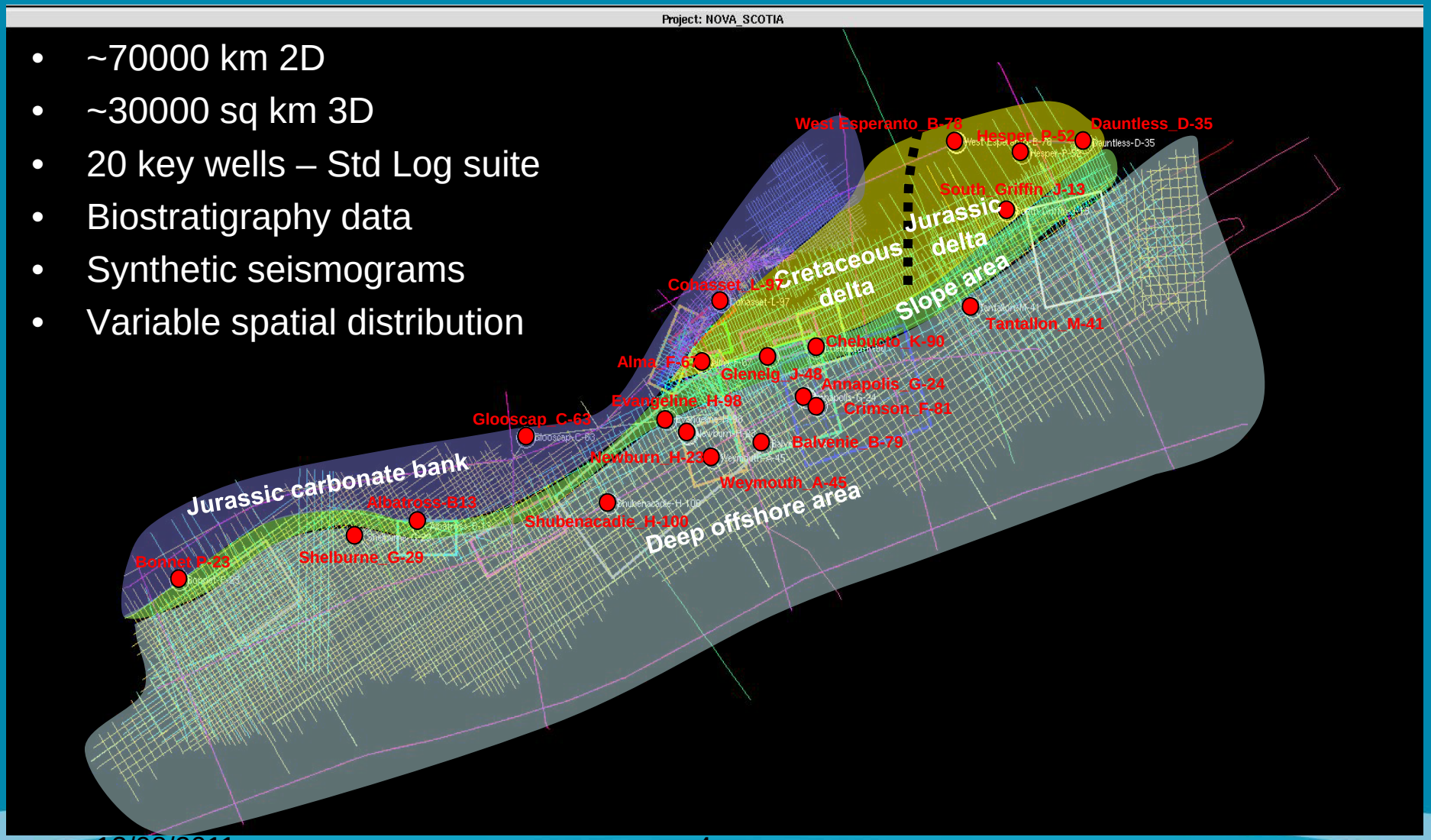

ion
GX TECHNOLOGY


IHS


G G
L

Database

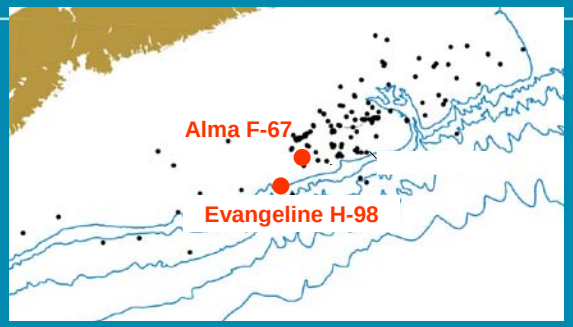
- ~70000 km 2D
- ~30000 sq km 3D
- 20 key wells – Std Log suite
- Biostratigraphy data
- Synthetic seismograms
- Variable spatial distribution



Outline

- Demonstrated that there are two source rock types on the margin, extending prospectivity outside the Sable Delta region
- Shown that there is a way to de-risk reservoir/seal both on the shelf but also in the deeper water.
- Developed a rigorous petroleum systems model to predict charge/migration
- Un-risked YTF resources of 121 TCF and 8bn bbls in three regions
  - **Deep water oil play in the South West and Gas to the North East**
  - **Remaining gas potential in the Sable delta itself in dip closed features**
  - **Gas and Oil in Sable rim and in the underexplored region to the North East of Sable**

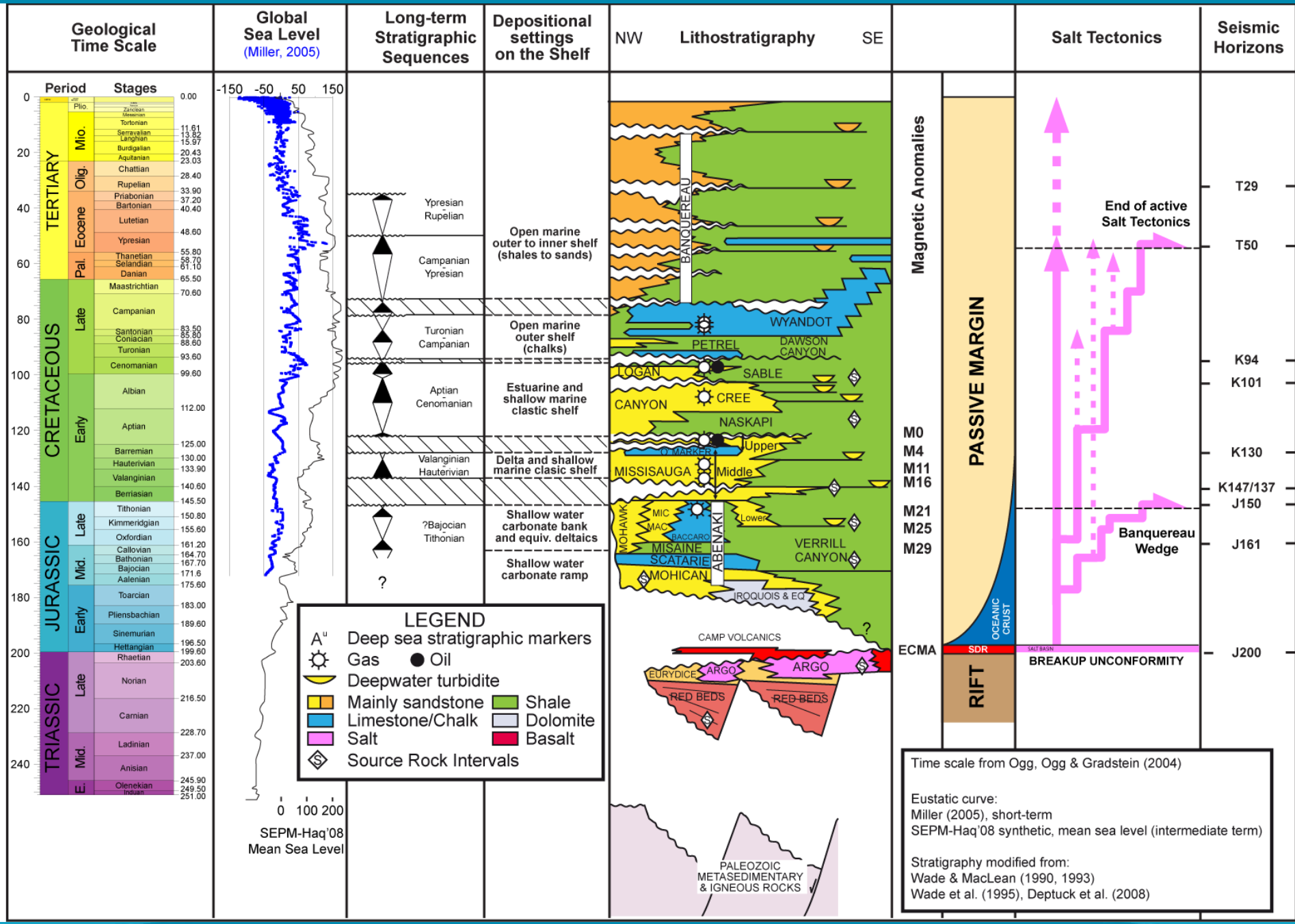
Stratigraphic Framework – Scotian Margin, offshore eastern Canada

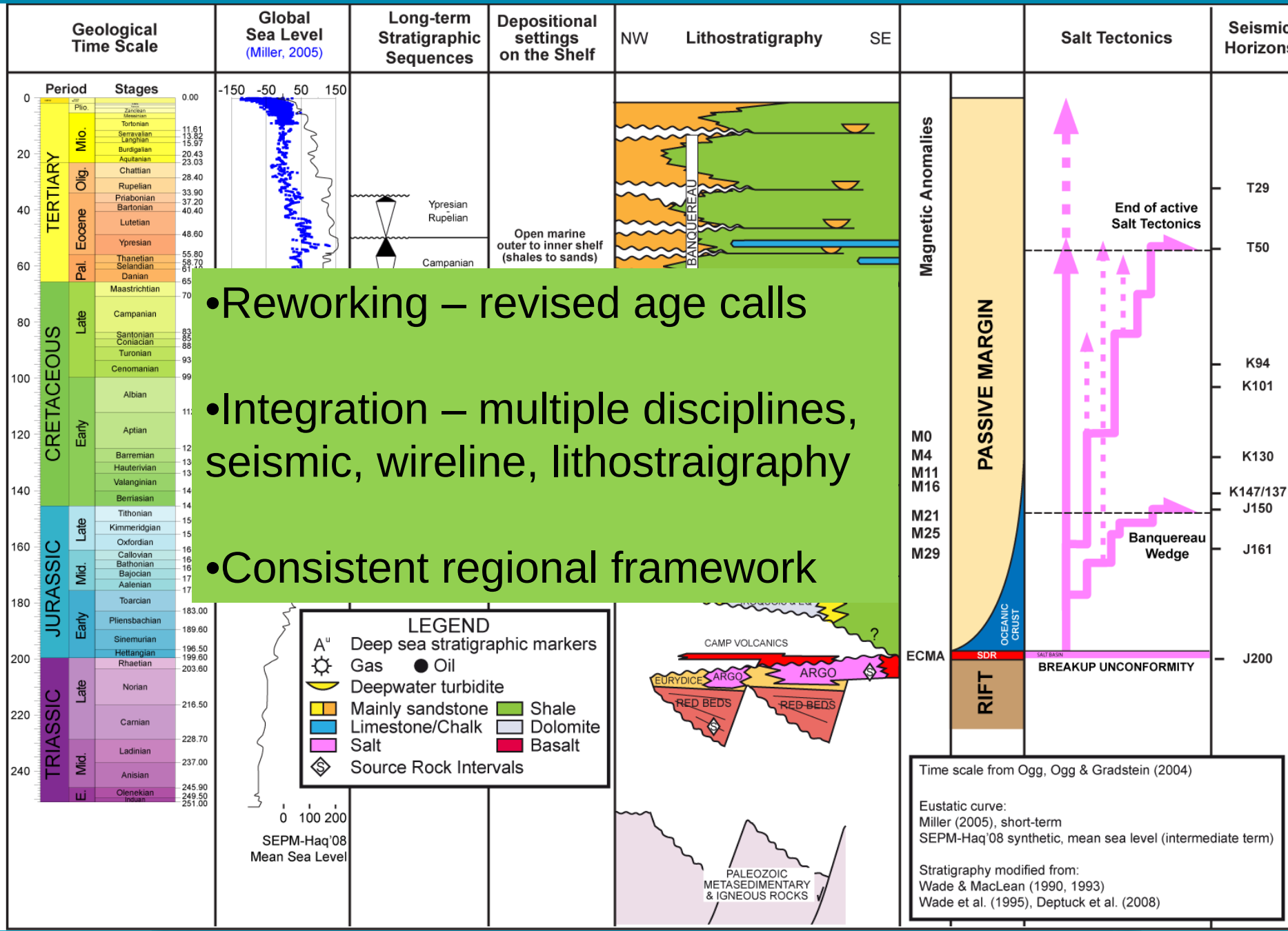


Is Naskapi Member in Alma F-67 Barremian or Aptian? (~350m difference in Barr/Aptian boundary)

Is the bottom 1500m (!) of Evangeline Aptian or Mid-Late Albian?

Andrew MacRae (SMU)


Geological Time Scale
Period
Stages
TERTIARY
CRETACEOUS
JURASSIC
TRIASSIC
Plio.
Mio.
Olig.
Eocene
Pal.
Late
Early
Mid.
E.
Zanclean
Messinian
Tortonian
Serravalian
Langhian
Burdigalian
Aquitanian
Chattian
Rupelian
Priabonian
Bartonian
Lutetian
Ypresian
Thanetian
Selandian
Danian
Maastrichtian
Campanian
Santonian
Coniacian
Turonian
Cenomanian
Albian
Aptian
Barremian
Hauterivian
Valanginian
Berriasian
Tithonian
Kimmeridgian
Oxfordian
Callovian
Bathonian
Bajocian
Aalenian
Toarcian
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Ladinian
Anisian
Olenekian
Induan
0.00
11.61
13.82
15.97
20.43
23.03
28.40
33.90
37.20
40.40
48.60
55.80
58.70
61.10
65.50
70.60
83.50
85.80
88.60
93.60
99.60
112.00
125.00
130.00
133.90
140.60
145.50
150.80
155.60
161.20
164.70
167.70
171.6
175.60
183.00
189.60
196.50
199.60
203.60
216.50
228.70
237.00
245.90
249.50
251.00
Global Sea Level
(Miller, 2005)
-150 -50 50 150
0 100 200
SEPM-Haq'08
Mean Sea Level
Long-term Stratigraphic Sequences
Ypresian
Rupelian
Campanian
Ypresian
Turonian
Campanian
Aptian
Cenomanian
Valanginian
Hauterivian
?Bajocian
Tithonian
?
Depositional settings on the Shelf
Open marine outer to inner shelf (shales to sands)
Open marine outer shelf (chalks)
Estuarine and shallow marine clastic shelf
Delta and shallow marine clasic shelf
Shallow water carbonate bank and equiv. deltaics
Shallow water carbonate ramp
NW
Lithostratigraphy
SE
BANQUEREAU
WYANDOT
PETREL
DAWSON CANYON
LOGAN
SABLE
CANYON
CREE
NASKAPI
Upper
O MARKER
MISSISAUGA
Middle
MOHAWK
MIC MAC
BACCARO
MISAINE
SCATARIE
ABENAKI
Lower
VERRILL CANYON
MOHICAN
IROQUOIS & EQ
?
CAMP VOLCANICS
EURYDICE
ARGO
ARGO
RED BEDS
RED BEDS
PALEOZOIC METASEDIMENTARY & IGNEOUS ROCKS
LEGEND
Deep sea stratigraphic markers
Gas
Oil
Deepwater turbidite
Mainly sandstone
Shale
Limestone/Chalk
Dolomite
Salt
Basalt
Source Rock Intervals
Magnetic Anomalies
M0
M4
M11
M16
M21
M25
M29
ECMA
PASSIVE MARGIN
OCEANIC CRUST
SDR
SALT BASIN
RIFT
Salt Tectonics
End of active Salt Tectonics
Banquereau Wedge
BREAKUP UNCONFORMITY
Seismic Horizons
T29
T50
K94
K101
K130
K147/137
J150
J161
J200
Time scale from Ogg, Ogg & Gradstein (2004)
Eustatic curve:
Miller (2005), short-term
SEPM-Haq'08 synthetic, mean sea level (intermediate term)
Stratigraphy modified from:
Wade & MacLean (1990, 1993)
Wade et al. (1995), Deptuck et al. (2008)

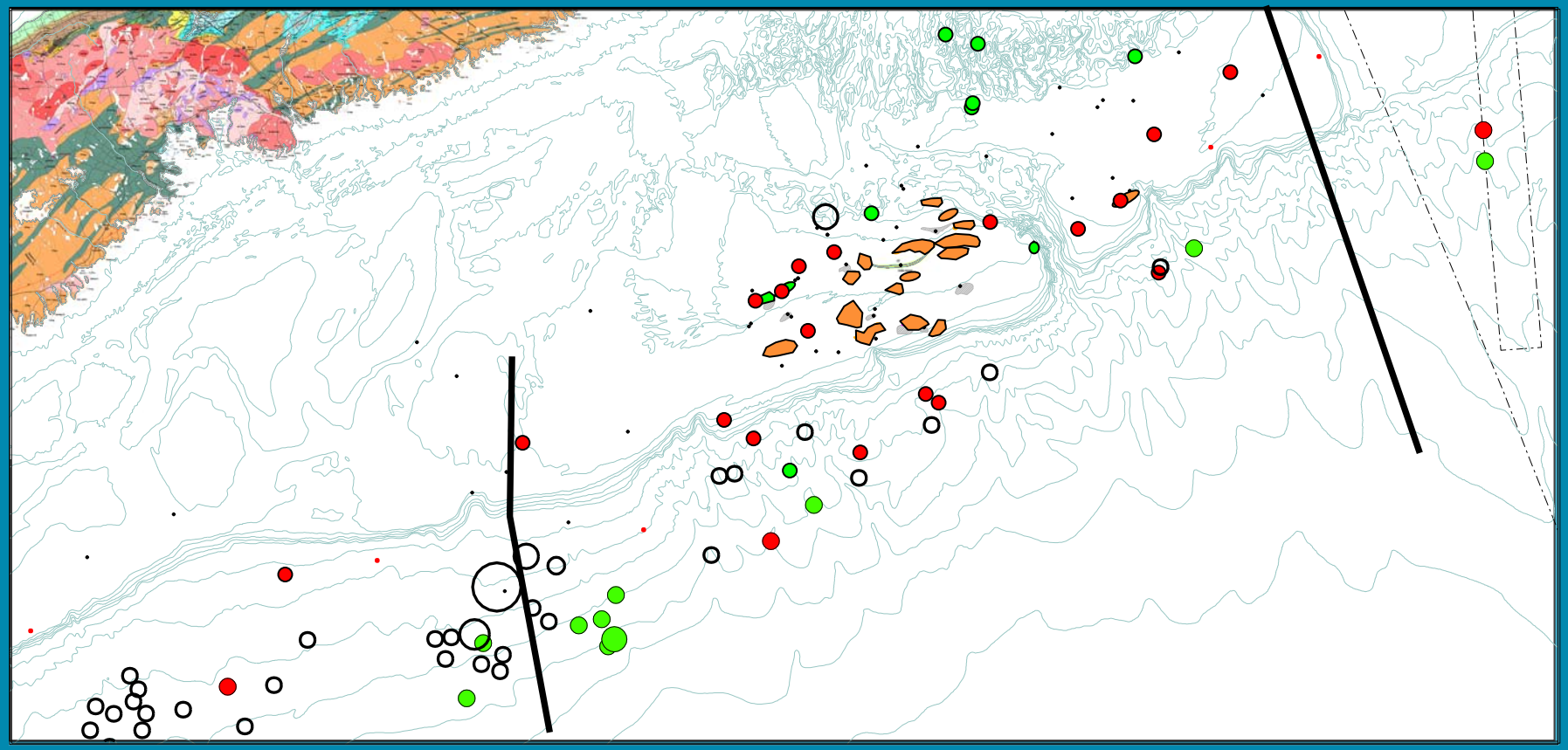


- Reworking – revised age calls
- Integration – multiple disciplines, seismic, wireline, lithostraigraphy
- Consistent regional framework

Hydrocarbon occurrences and molecular analysis

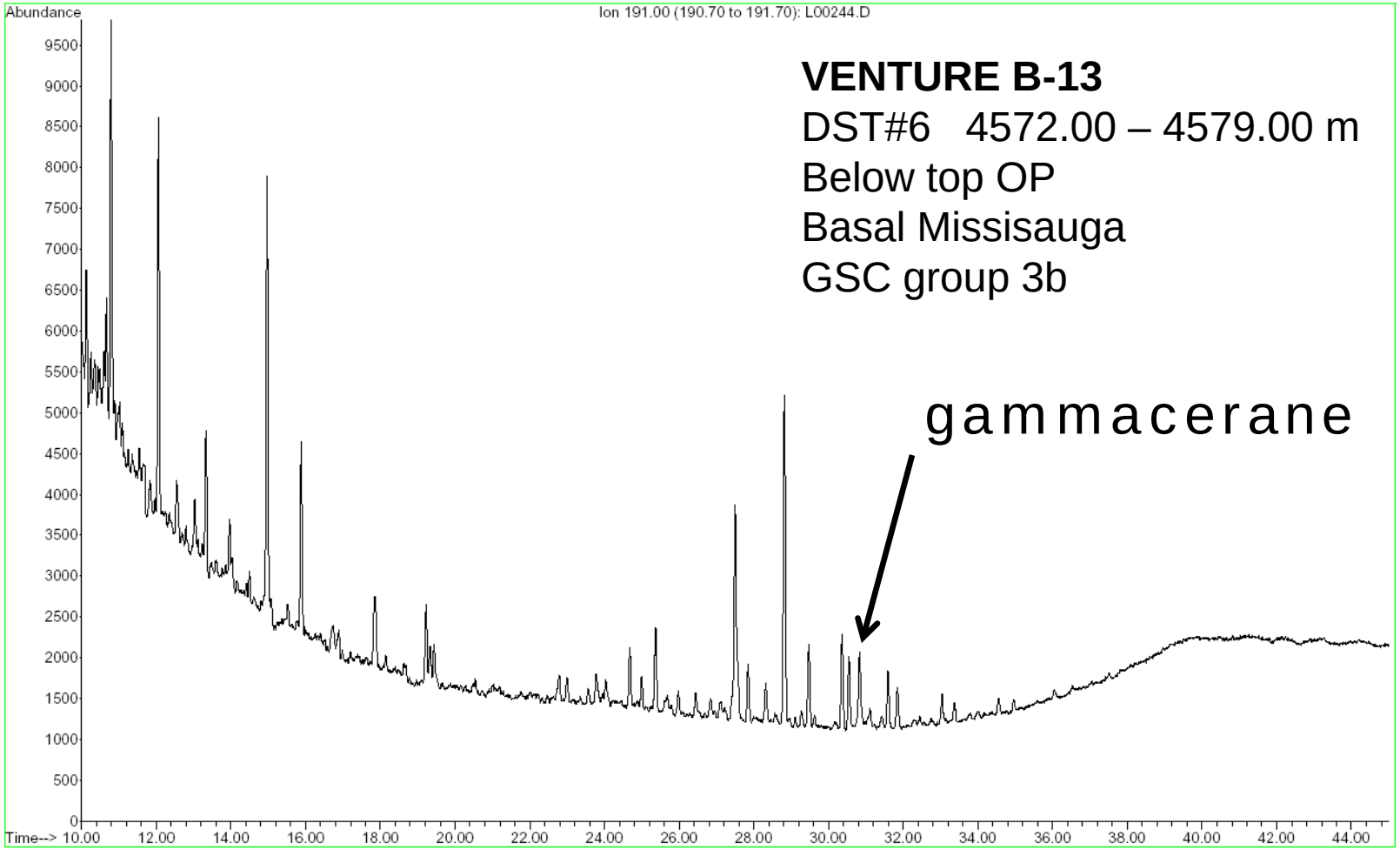
Hydrocarbon occurrences

FIELDS SHOWS PISTONS DHI

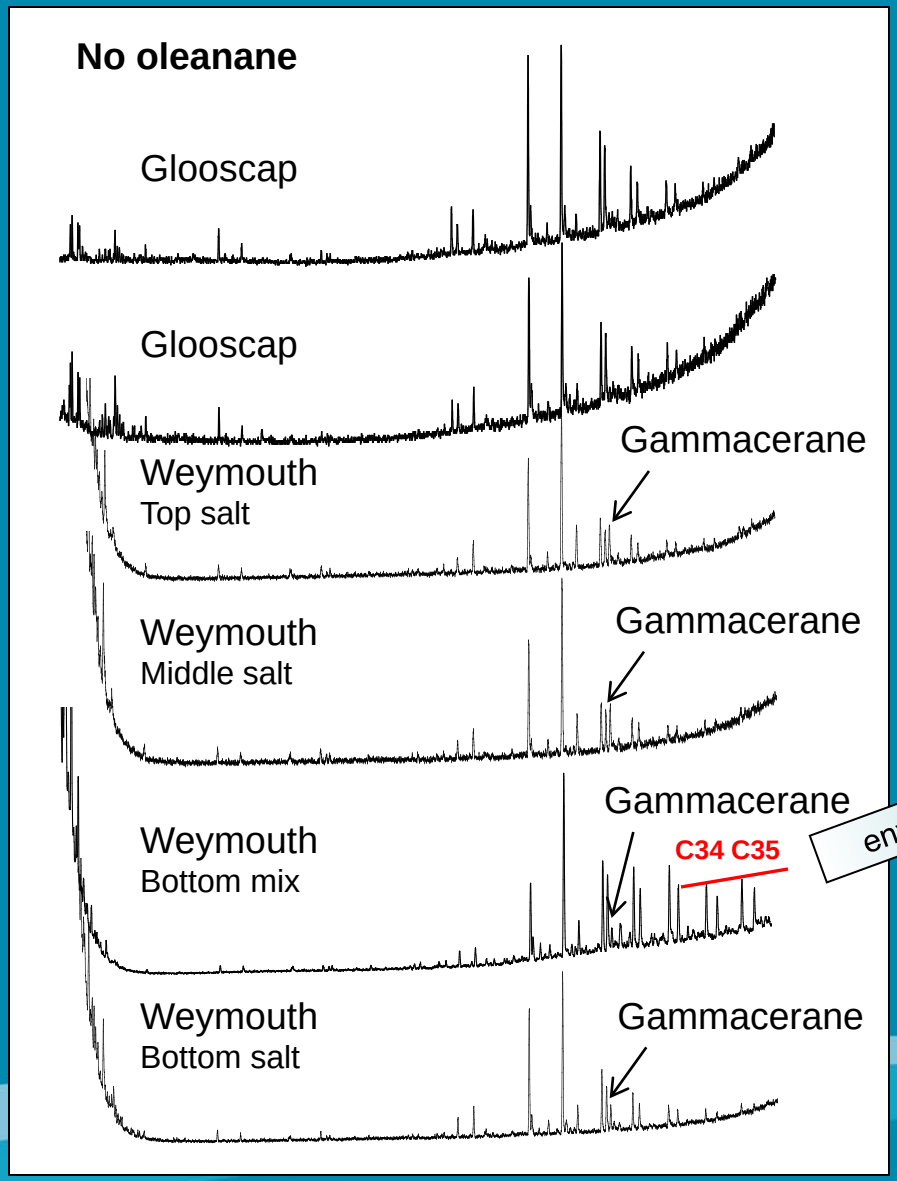


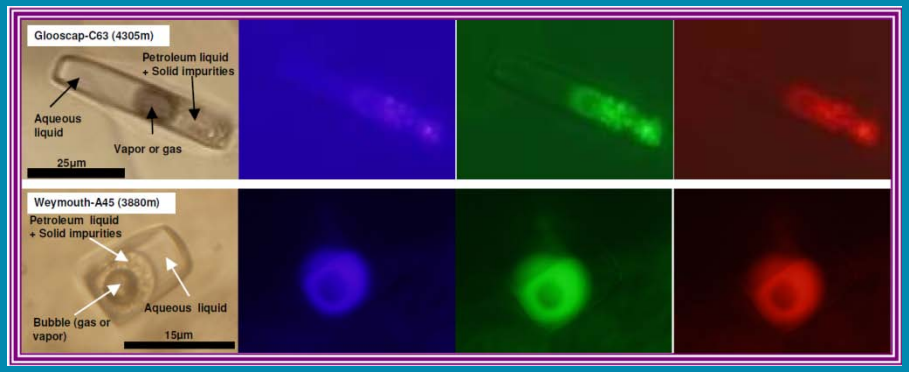
Venture B-13

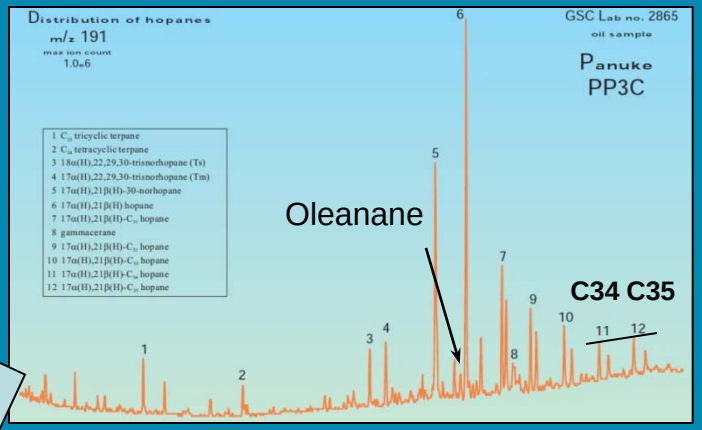
```
File       :\\S5-cal-tiger\msd_data\Oils\L00244.D
Operator   : sla
Acquired   : 16 Jun 2010  12:57     using AcqMethod BIOMARK1
Instrument :   5973
Sample Name: #244  Venture B-13  DST#6  4572-4579 m
Misc Info  : 74.8  mg sats
Vial Number: 1
```



Hydrocarbon Fluid Inclusions from Glooscap and Weymouth



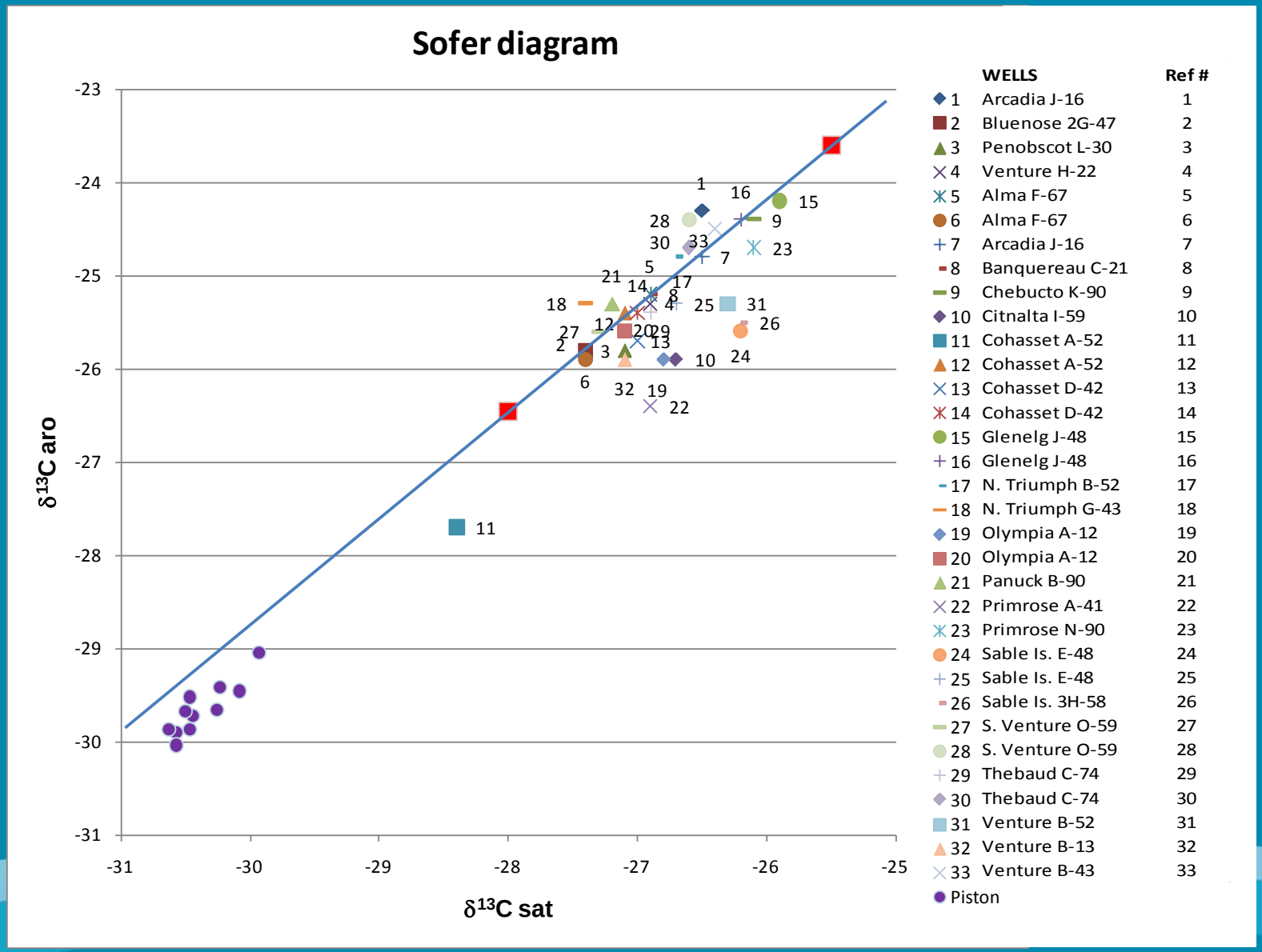




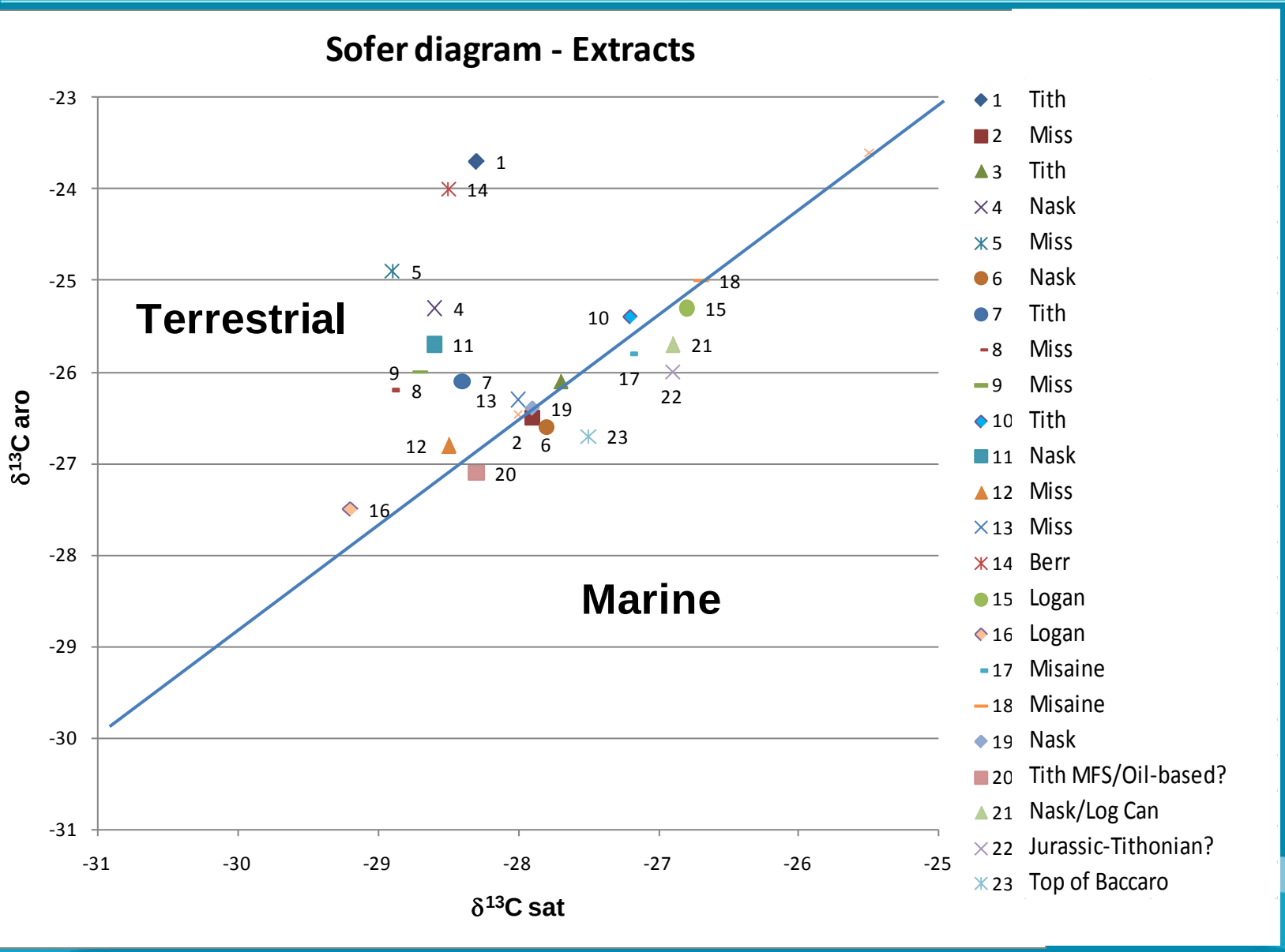
environment

- **Ratio C35 to C34 homohopanes ~ 1 is indicative of a source rock deposited in a carbonate environment**
- **Oleanane in deep Panucke suggests either contamination (oil-based mud) or leaching Upper Cretaceous along the migration path**

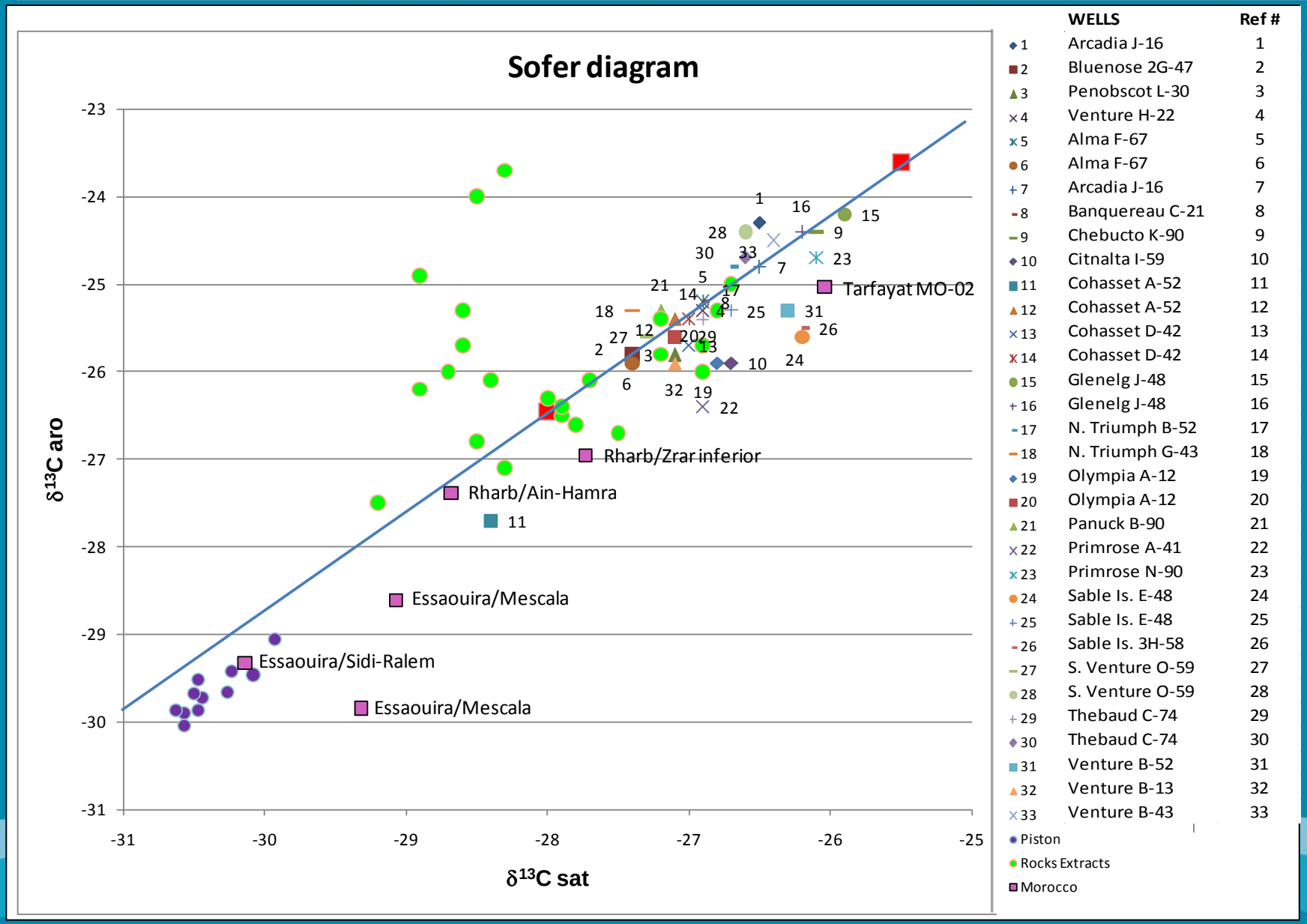
Isotope distribution



Isotope - Extracts



All isotopes including Morocco oils



Forensic Geochemistry

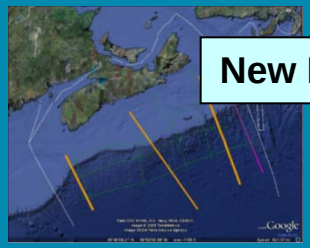
- Proof that there are two source rock groups
  - **One largely marine**
  - **The other mixed marine terrestrial**
- Evidence for a restricted hypersaline source rock
- Similar characteristics from oils on the conjugate margin in Morocco

Geochemistry

- 4 source rocks; 2 independent systems
- Deltaic
  - **Upper Jurassic/Tithonian**
  - **Lower Cretaceous/Hauterivian-Aptian**
  - **Albian**
- Regional Early Jurassic restricted marine to marine

Tectonics programme

New Refraction Line



SISMAR reprocessing

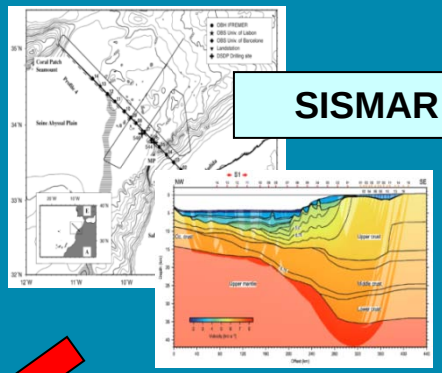
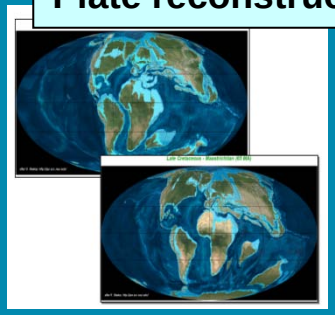
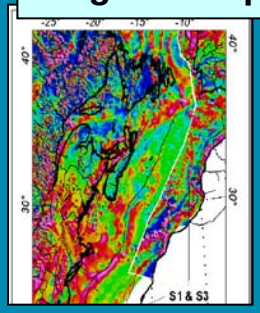


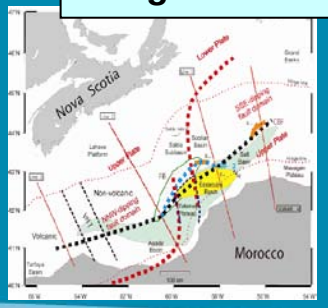
Plate reconstruction



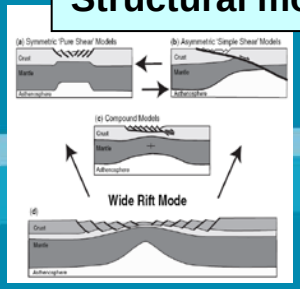
Magnetic reprocessing



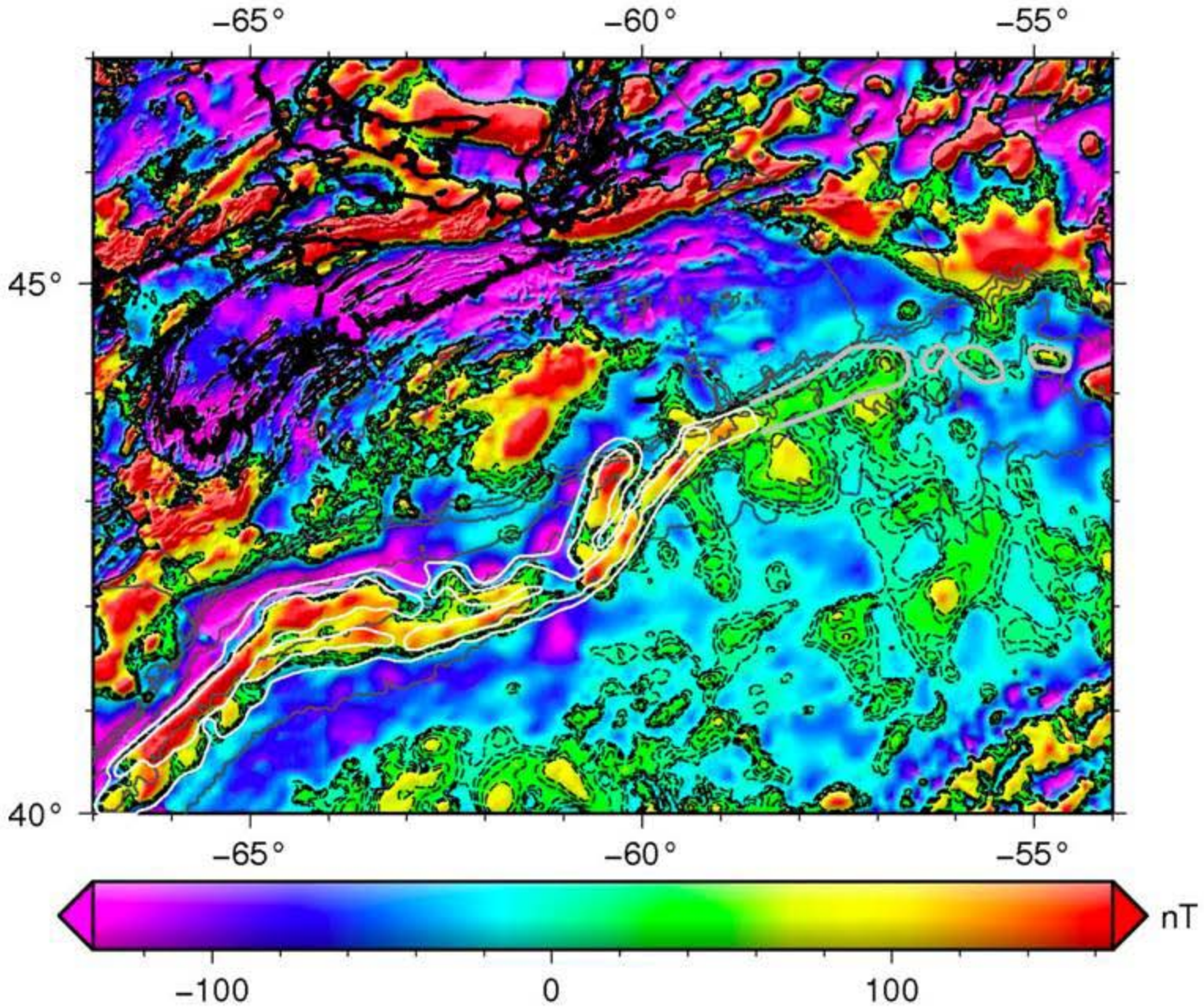
Integrated interpretation



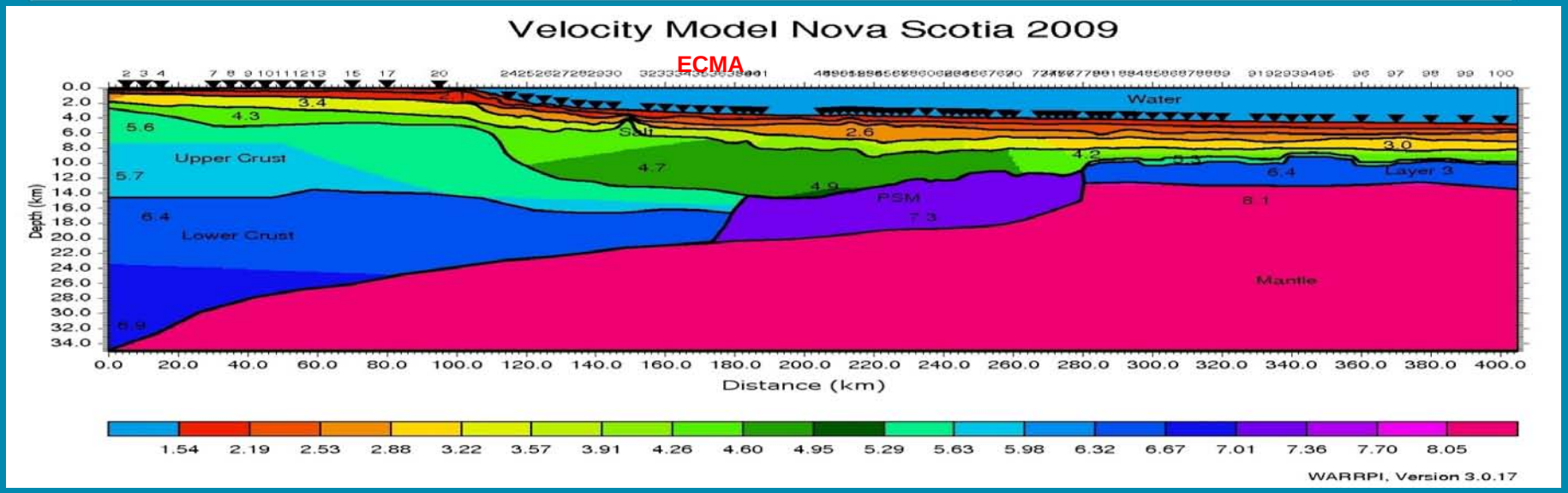
Structural modelling

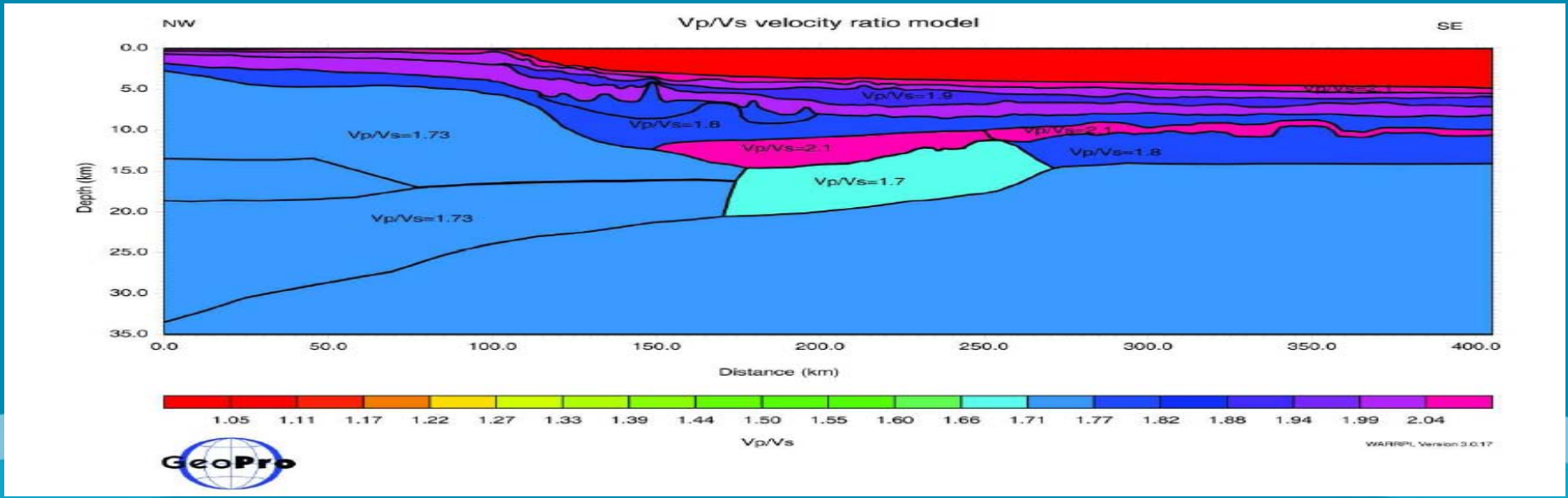


ECMA_FUGRO

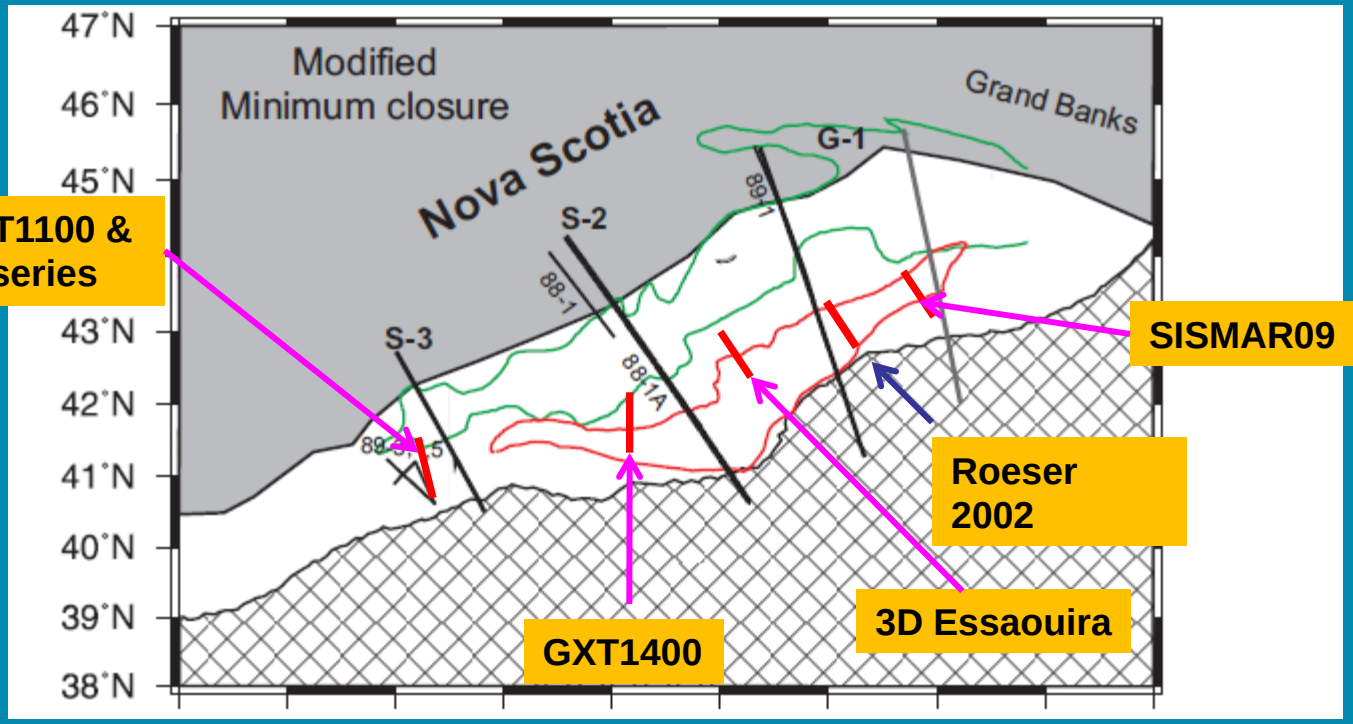


GEOPRO – Vp & Vp/Vs models





SDR observations (approx locations) – Nova Scotia & Morocco



Reconstruction after Fig. 3.6 (b) Louden et. al. 2010; SDR identification PFA project

KEY CONCLUSIONS

- Nova Scotia and Morocco are conjugate volcanic passive margins

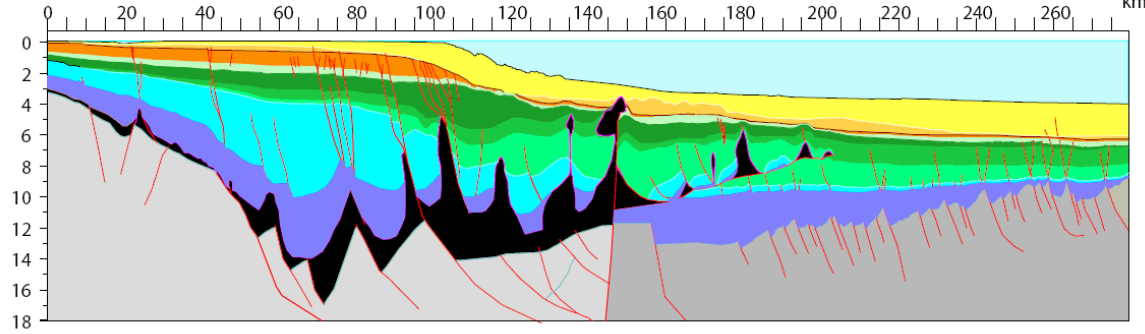
- Salt basins are wholly confined to continental crust stretched in the Late(?) Triassic

- Subaerial spreading initiated by CAMP event in the Earliest Jurassic

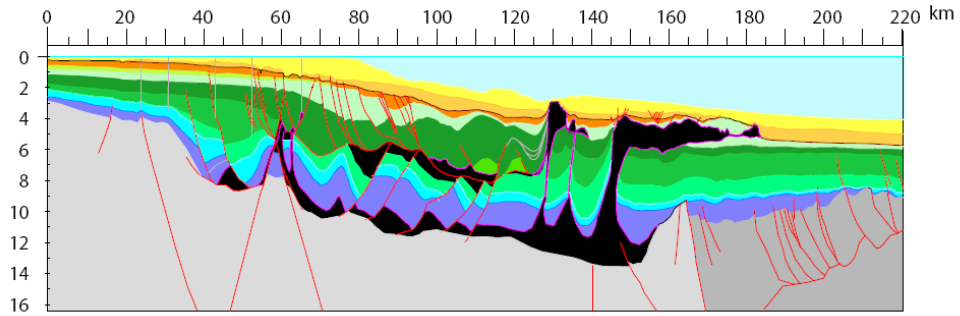
- Initial post rift water depths therefore probably less than 200m may have favoured anoxic conditions **- ? a new petroleum system**

- Avalon (Late J-EK) deltas record response to the Avalon uplift due to Newfoundland –Iberia rifting

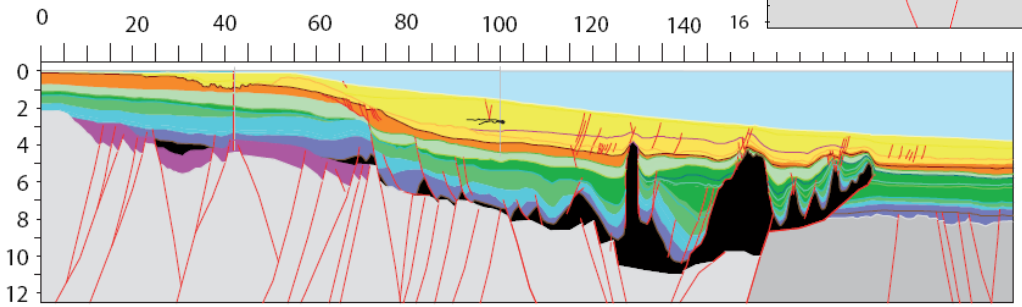
Basin Architecture



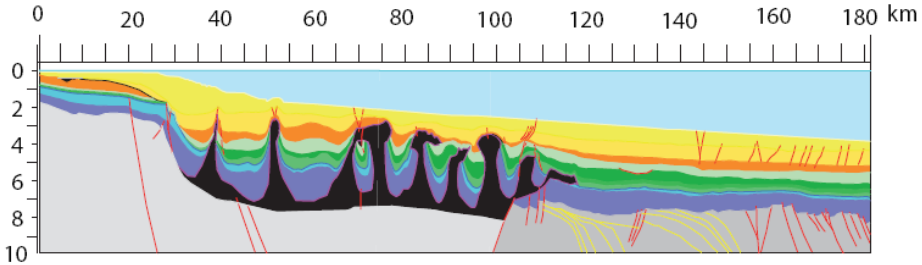
NovSPAN 1600



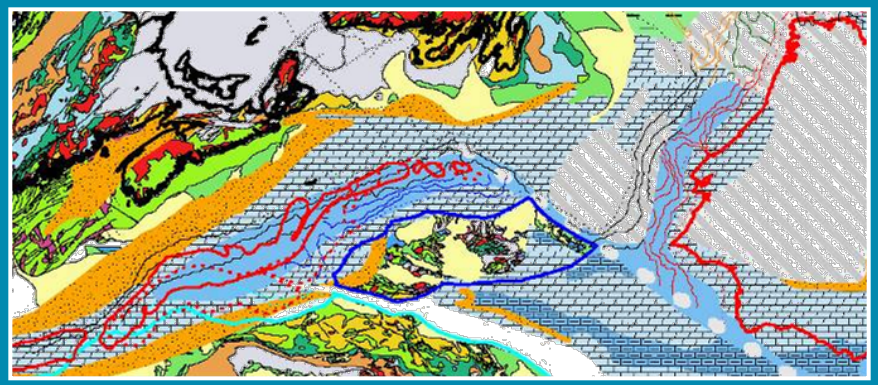
NovSPAN 1400



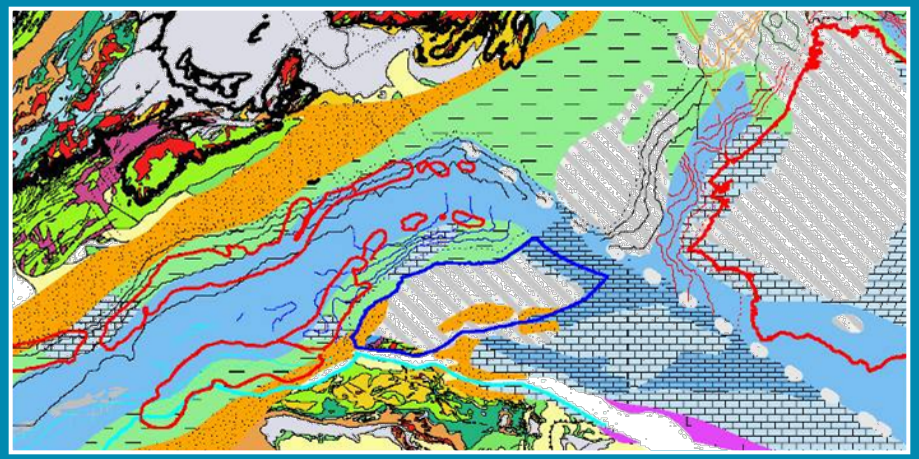
NovSPAN 1100



Sequence Stratigraphy



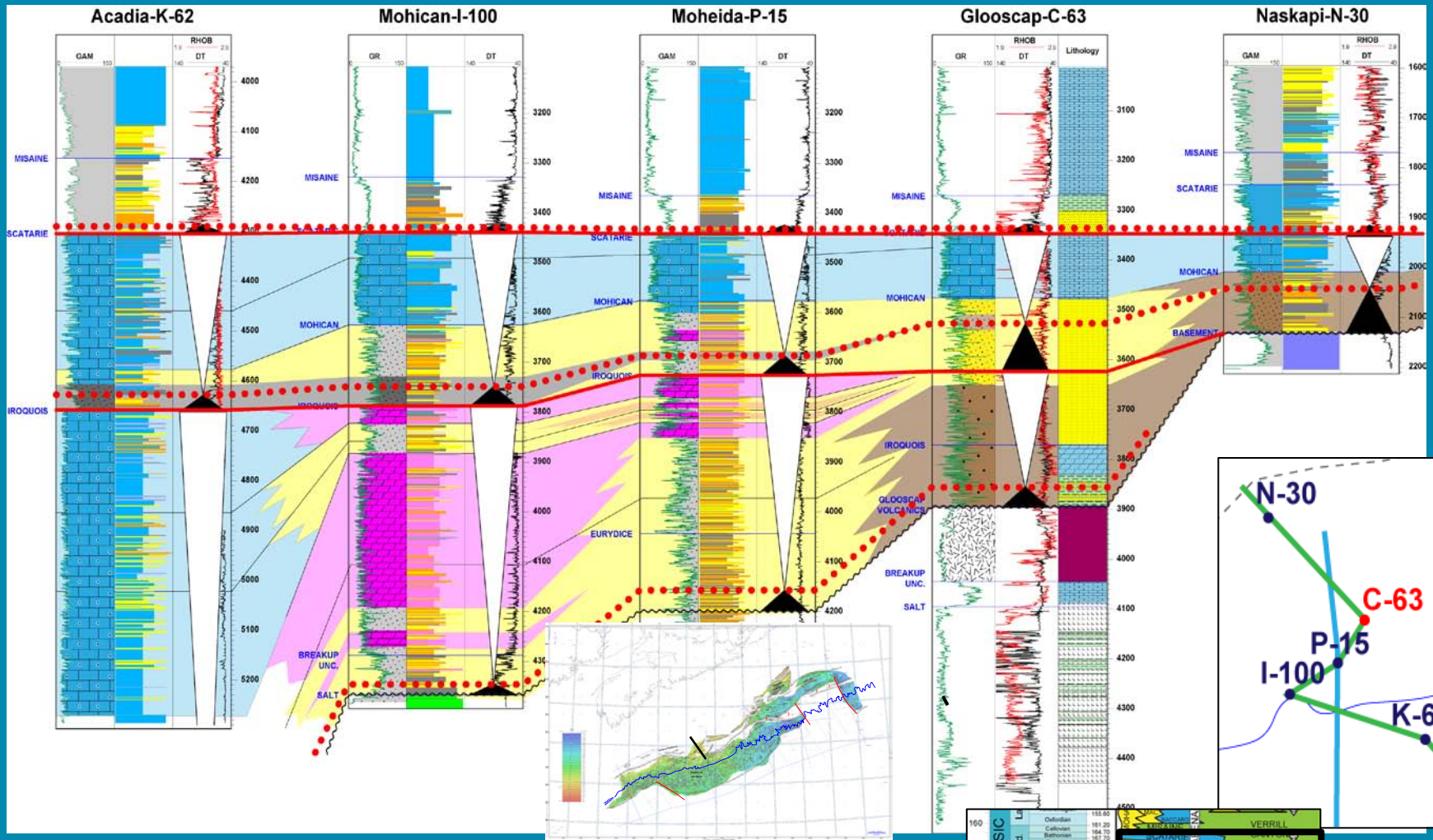
190 Ma



170 Ma

Stratigraphy of the Middle Jurassic

South — North

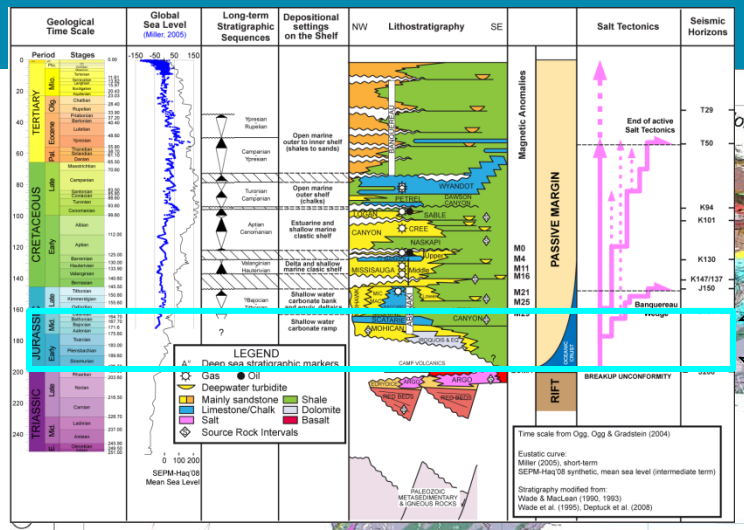


Depositional architecture for each sequence

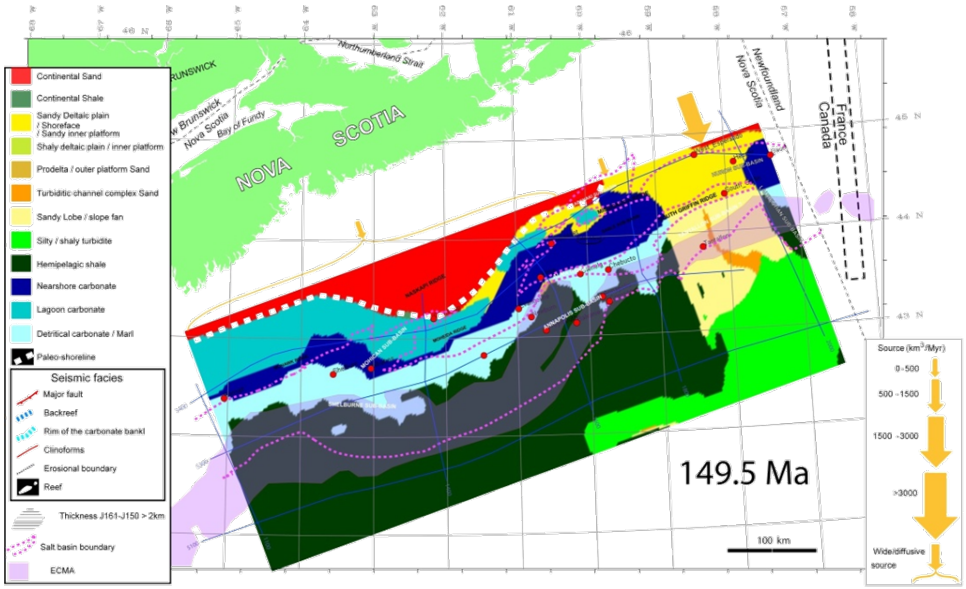
1. Prograding clastics, ending up with shallow marine carbonates
2. Expansion of shallow marine carbonate through time (1st order transgression)

T200 ▸ J163 isopach map

Eq. Iroquois / Mohican / Scatarie Fm

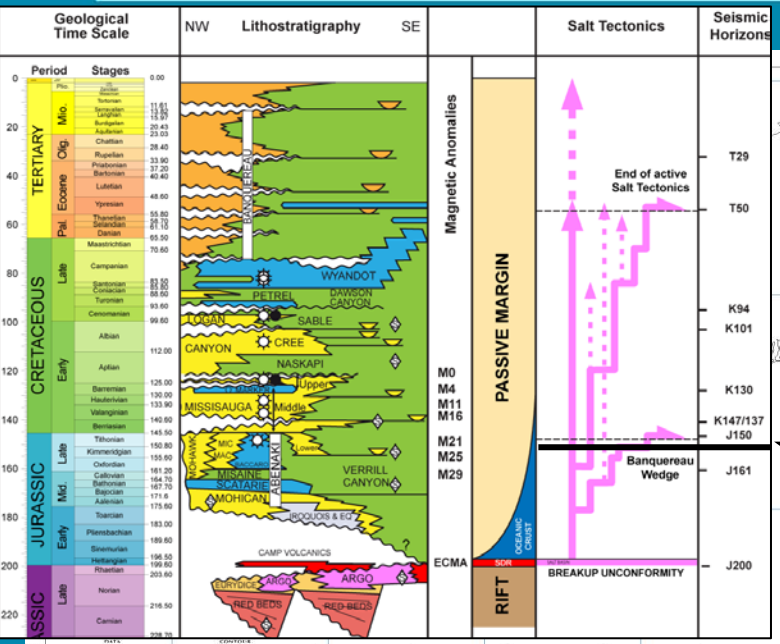


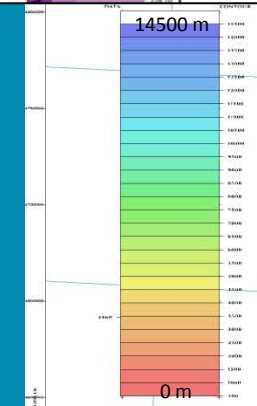
Jurassic modeling results : GDE maps dress-up for key stratigraphic intervals



LATE JURASSIC FORMATION
MICMAC - BACCARO - LOWER MISSISAUGA

Allochthonous salt movement related to Jurassic delta loading





Laurentian sub-basin

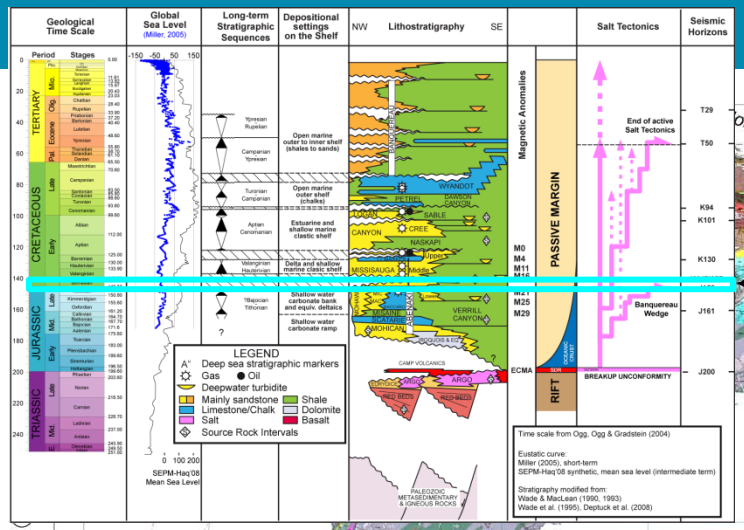
Banquereau detachment wedge

Autochthonous salt province

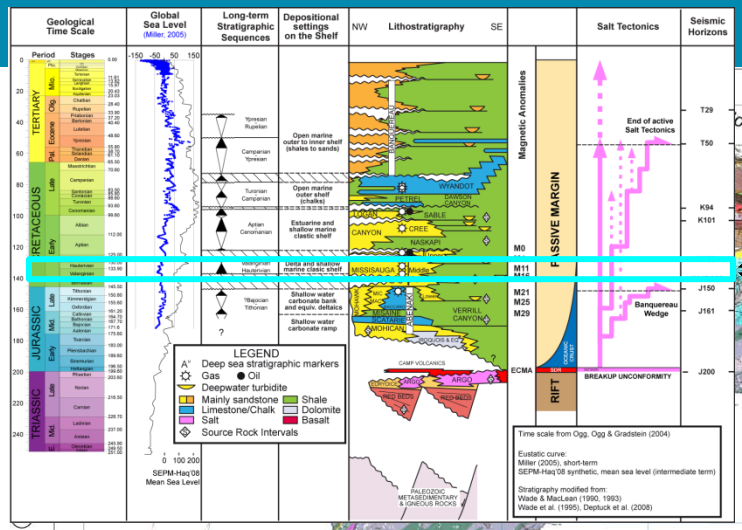
50 km

J150 ▸ K137 isopach map

Eq. Lower Missisauga Fm.

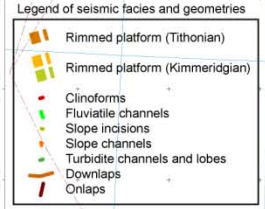


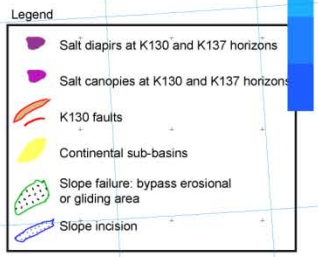
Middle Missisauga seismic facies and geometries

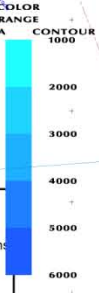


K137 ▸ K130 thickness map

J150 ▸ K137 isopach map







20 reference wells
2010 reprocessed GXT-NovaSPAN 2D seismic lines
2010 reprocessed TGS 2D seismic lines

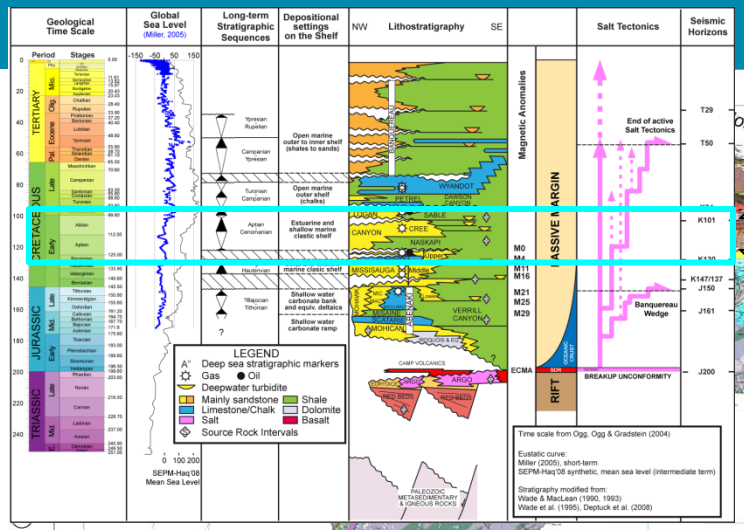
Projection system: Universal Transverse Mercator - Zone 20N
Datum: NAD 27
Ellipsoid: Clarke 1866

Datum plane = Mean Sea Level
Contour interval: 200 m

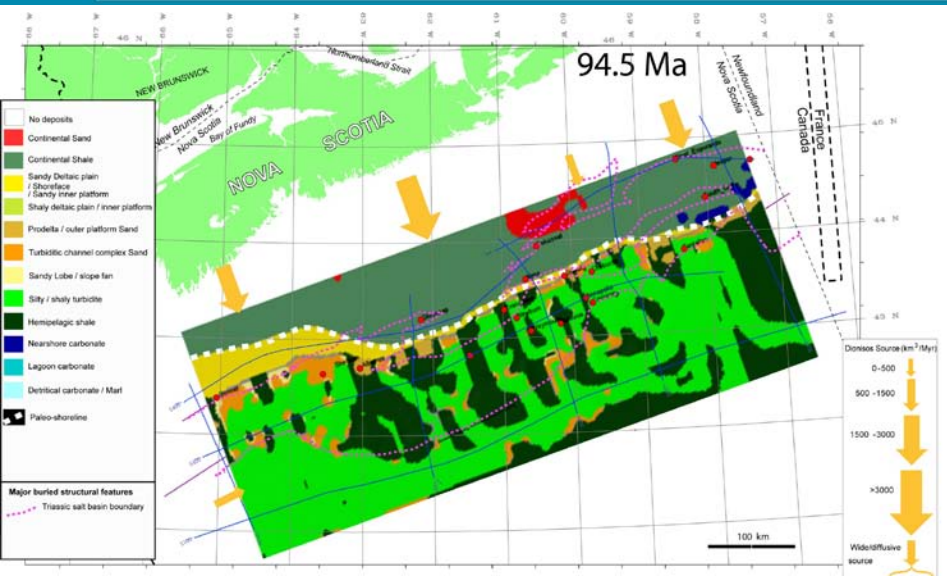
Geological Map of the Province of Nova Scotia
J.D. Keppie, 2000, Ref: Map ME 2000-1
See separate legend to Plate XXX

K130 ▸ K101 isopach map

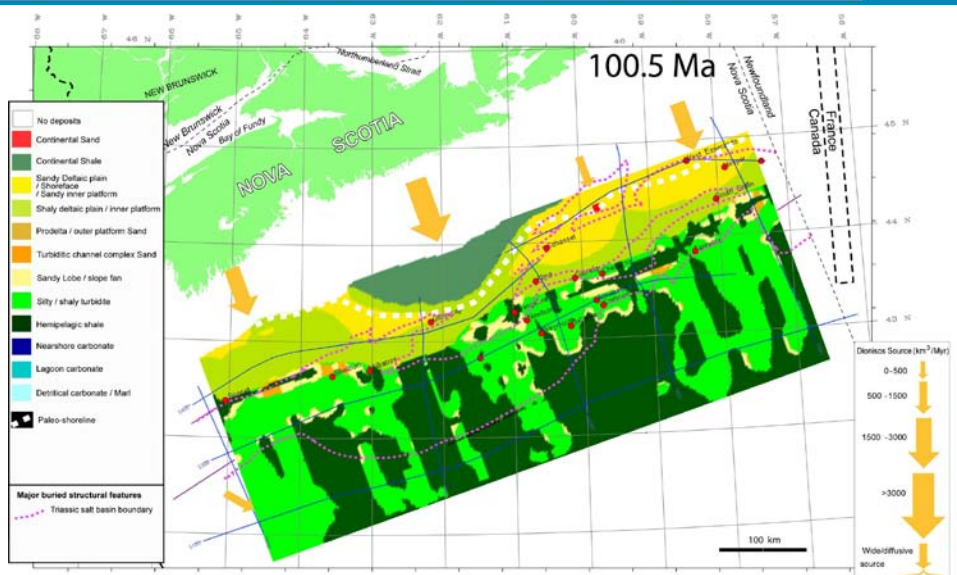
Eq. Upper Missisauga + Logan Canyon Fm.



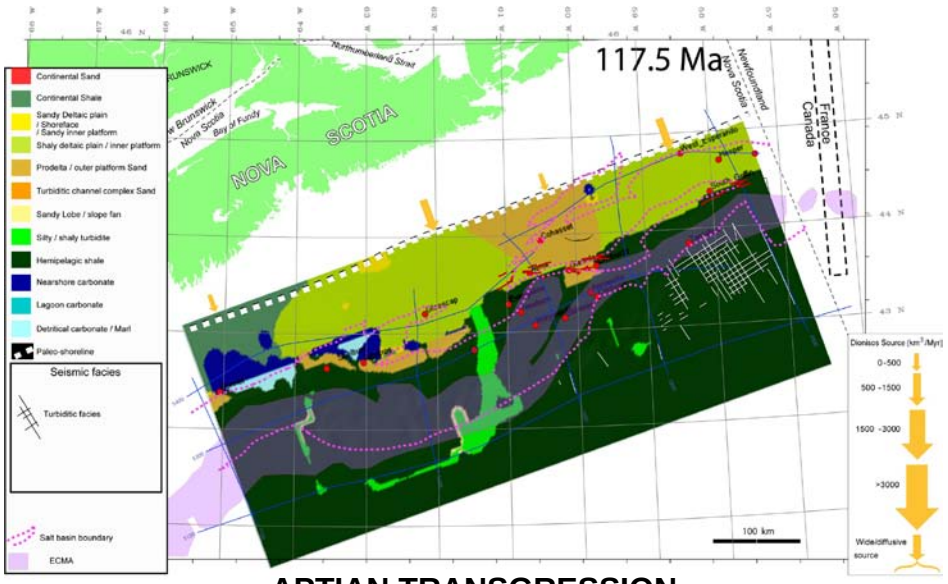
Cretaceous modeling results : GDE maps dress-up for key stratigraphic intervals



TOP CENOMANIAN



CENOMANIAN DEPOSITS

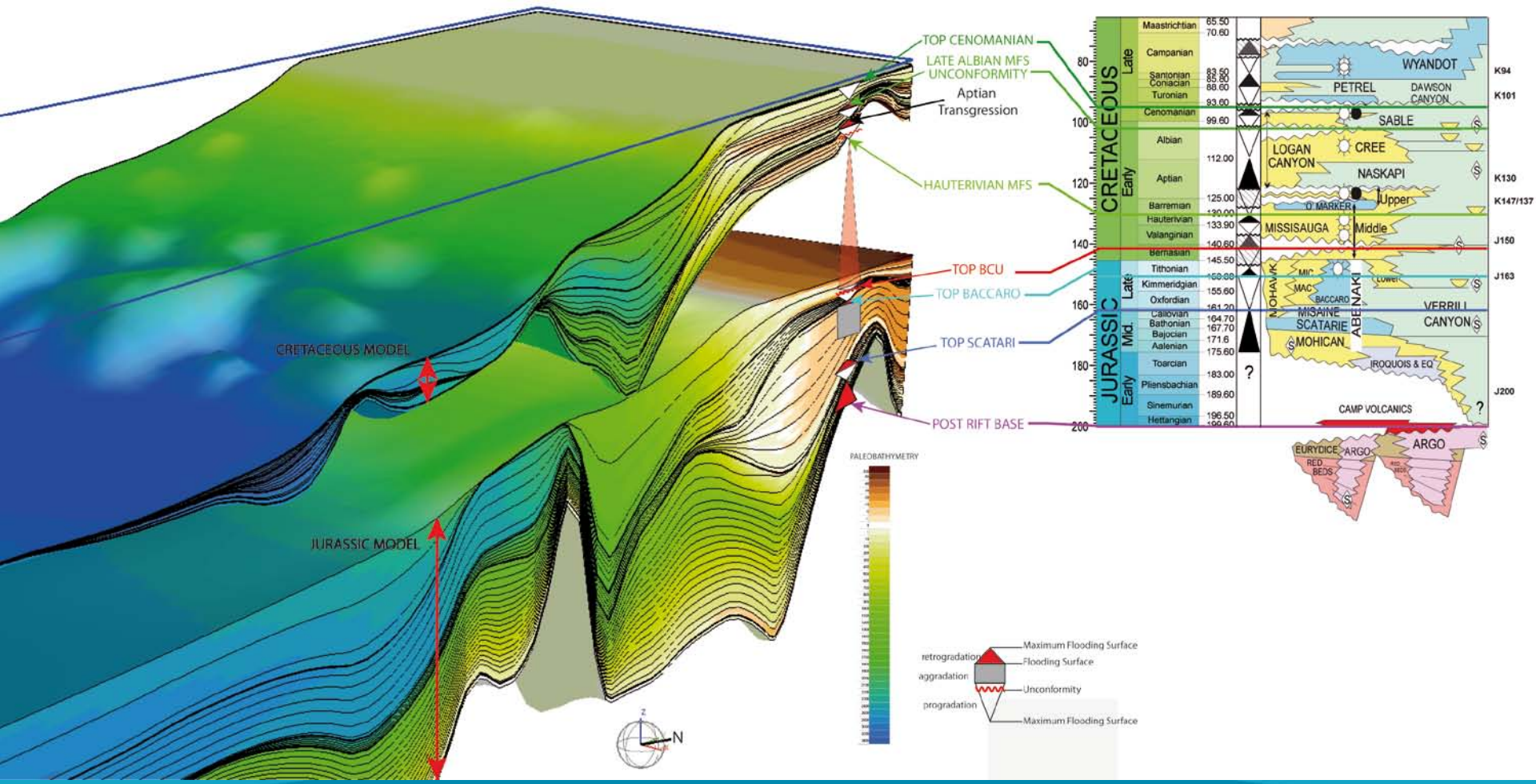


APTIAN TRANSGRESSION

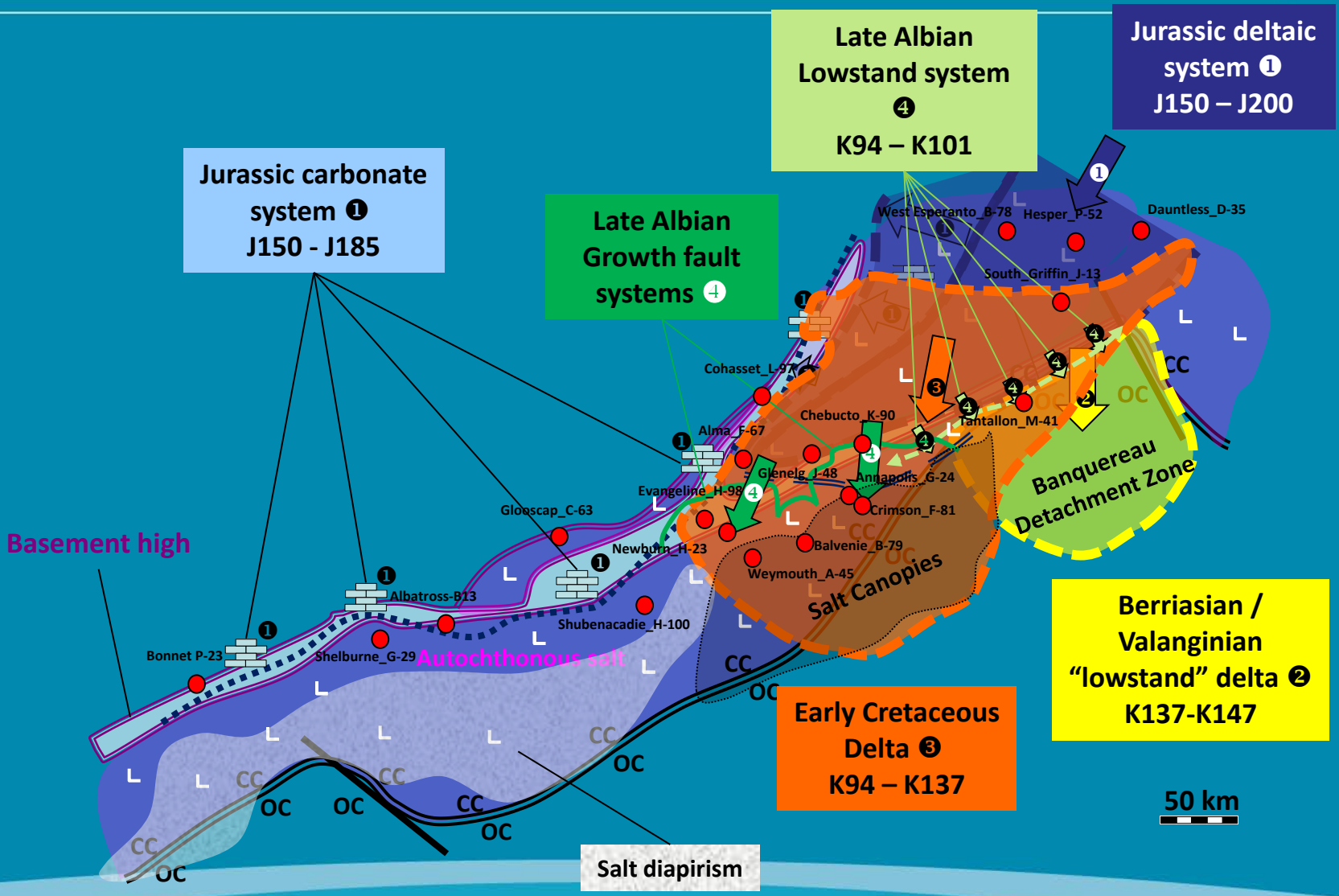
DIONISOS® Calibration: 2 models with « qualitative » and « quantitative » calibration

Depositional profile with key sequences ….

…that fit the stratigraphic conceptual model

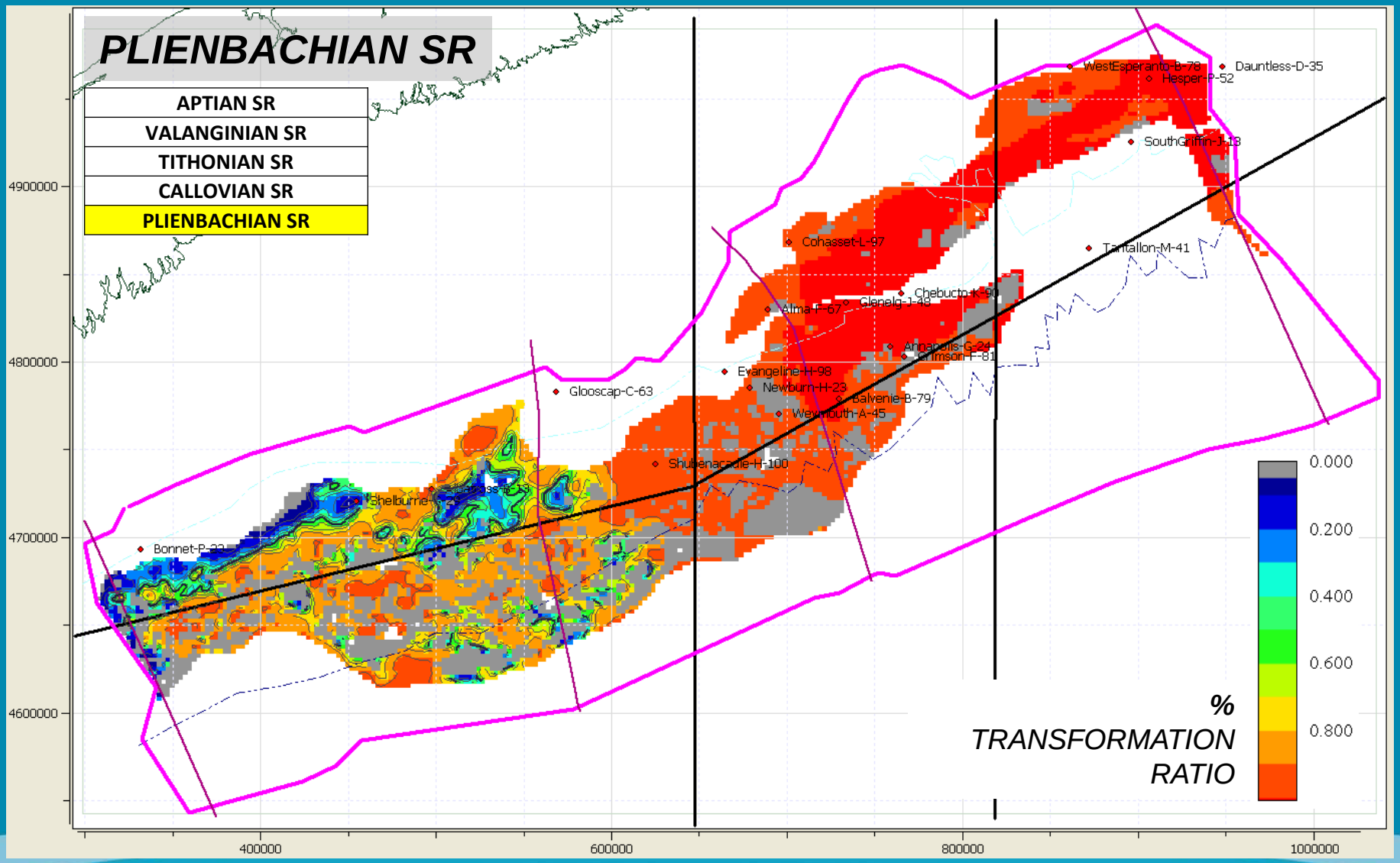


Jurassic and Cretaceous systems



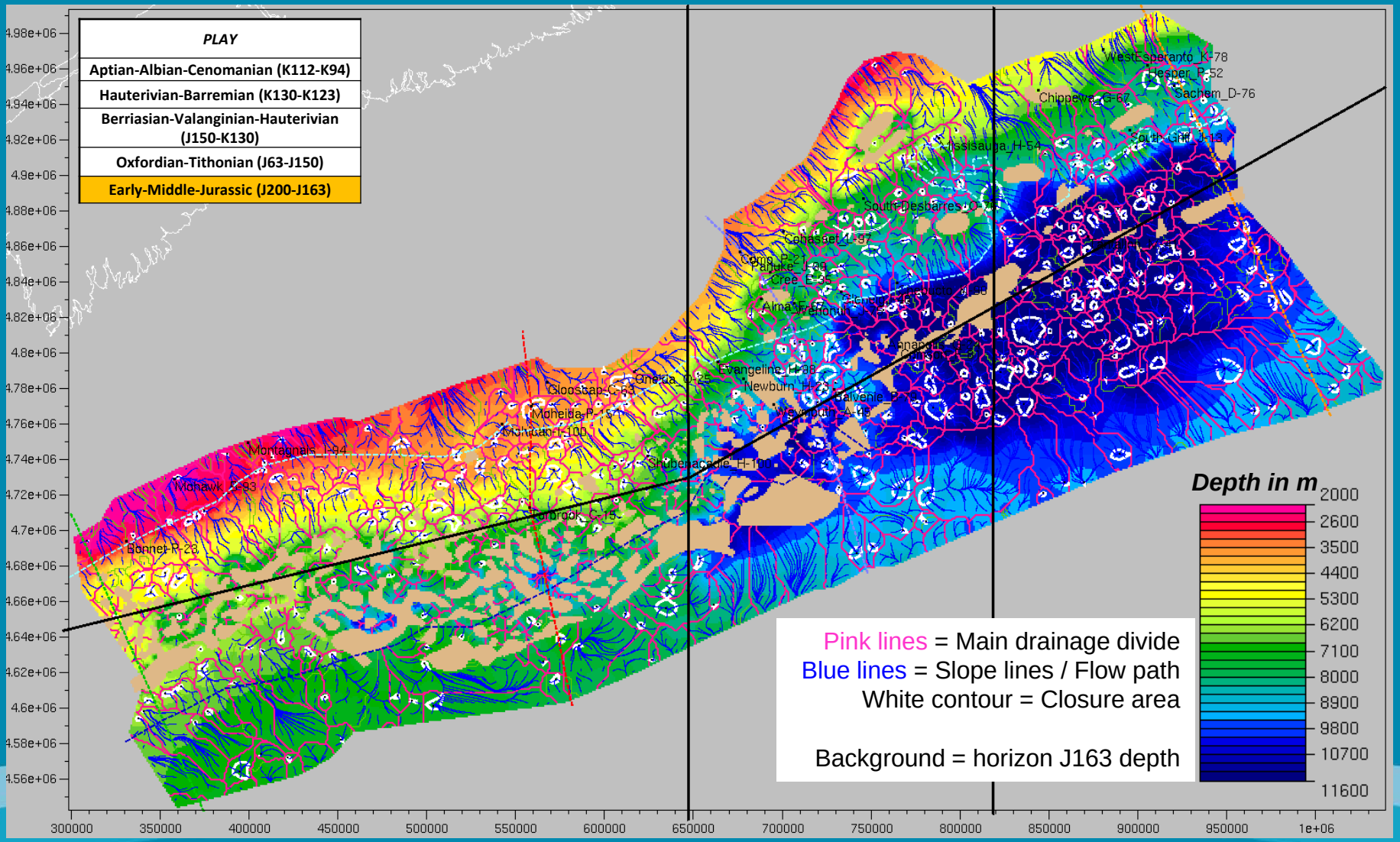
Petroleum Systems

Source Rocks Modeling – Transformation Ratio

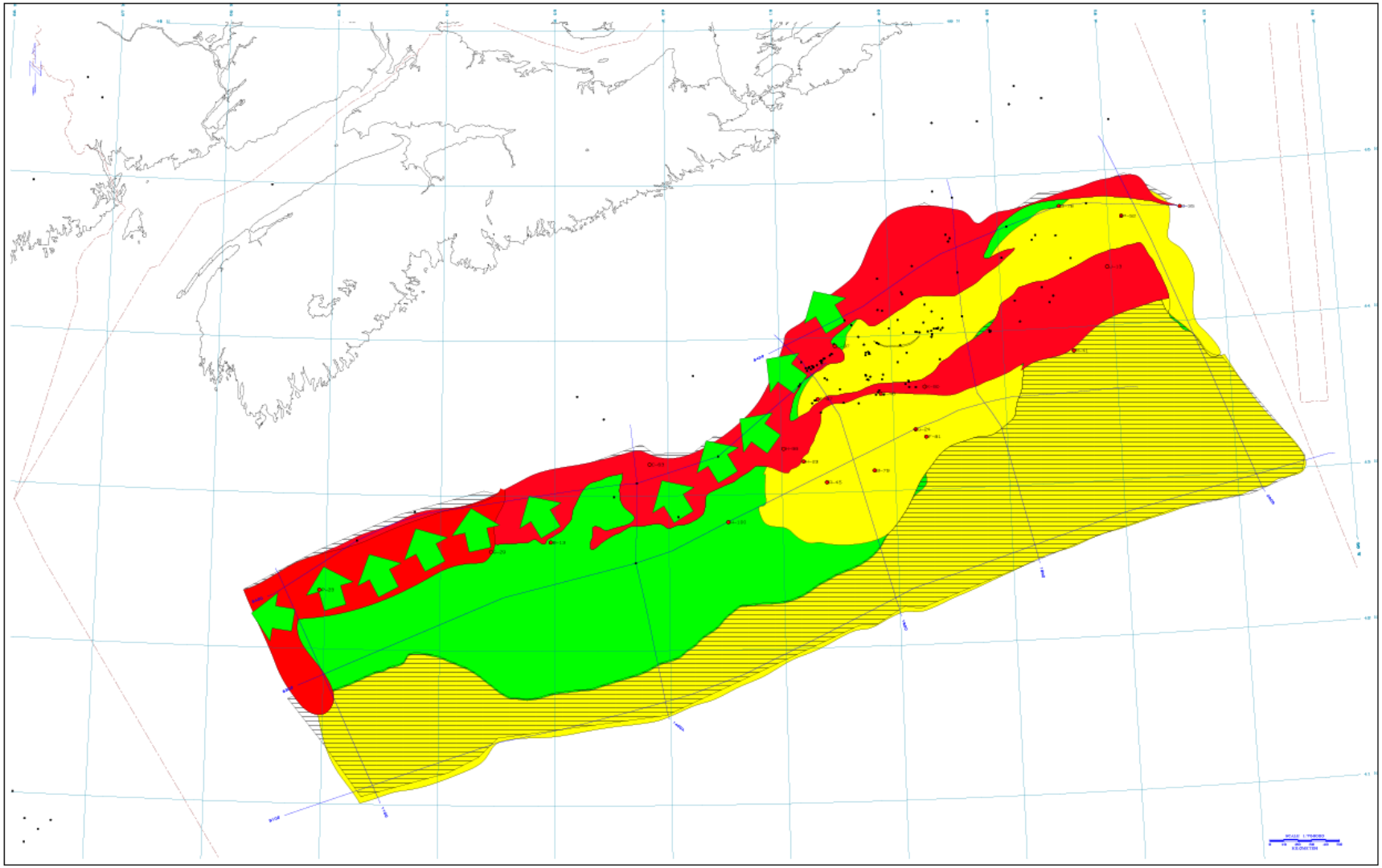


Migration and Accumulation Modeling – Drainage Areas Overview

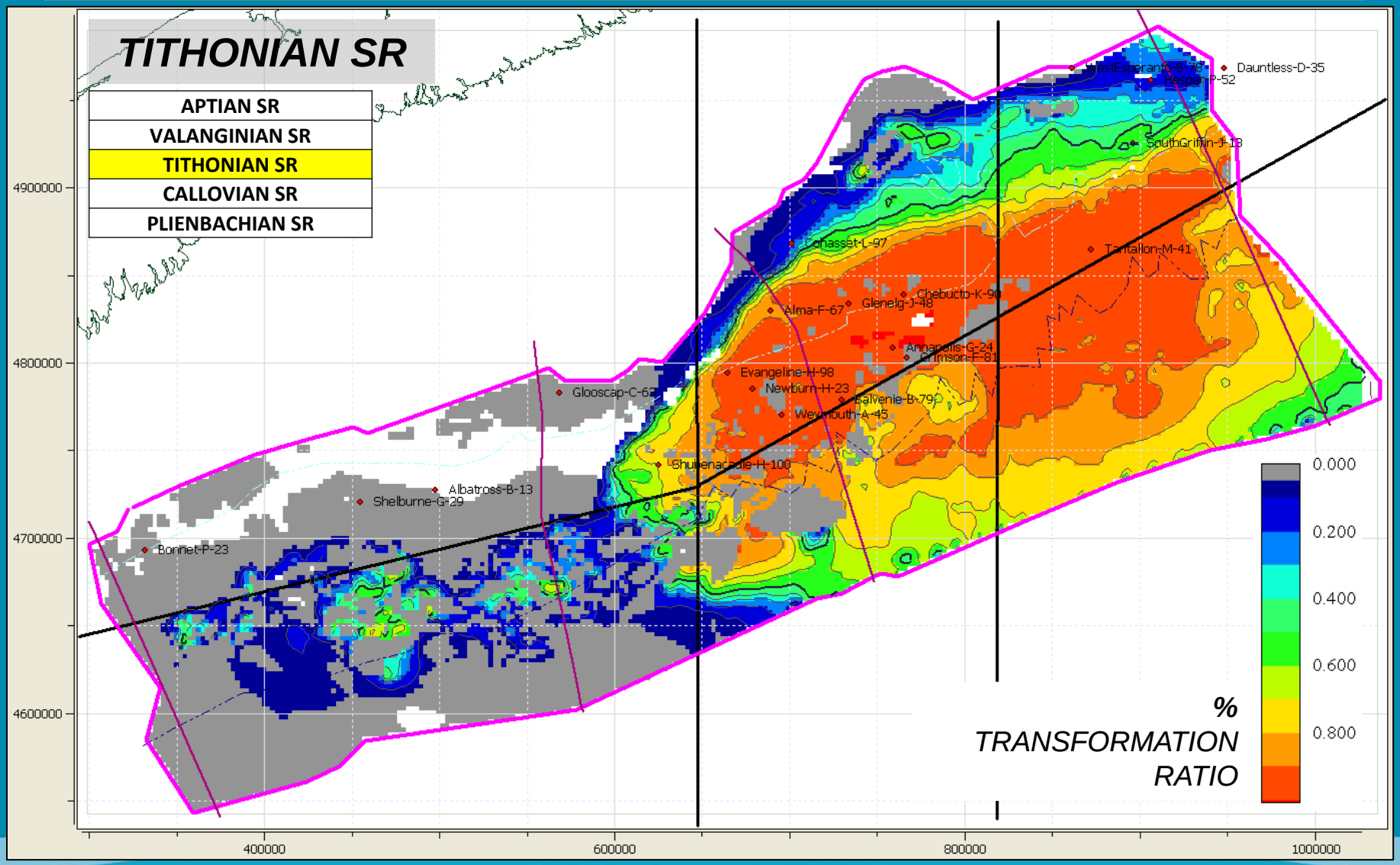
Early-Middle-Jurassic (J200-J163)



Pleinsbachian SR
Transformation ratio * Presence + Lateral migration potential

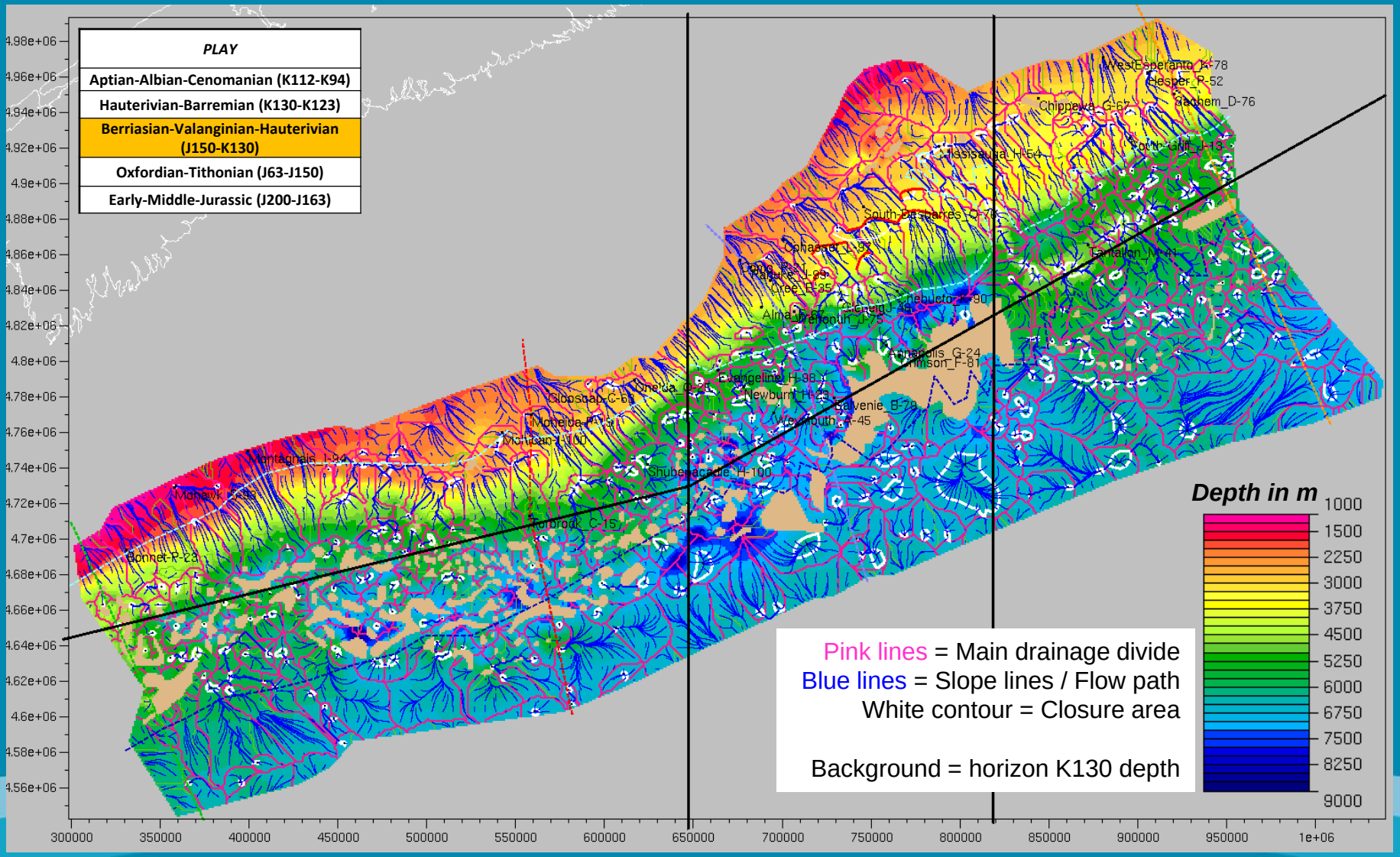


Source Rocks Modeling – Transformation Ratio

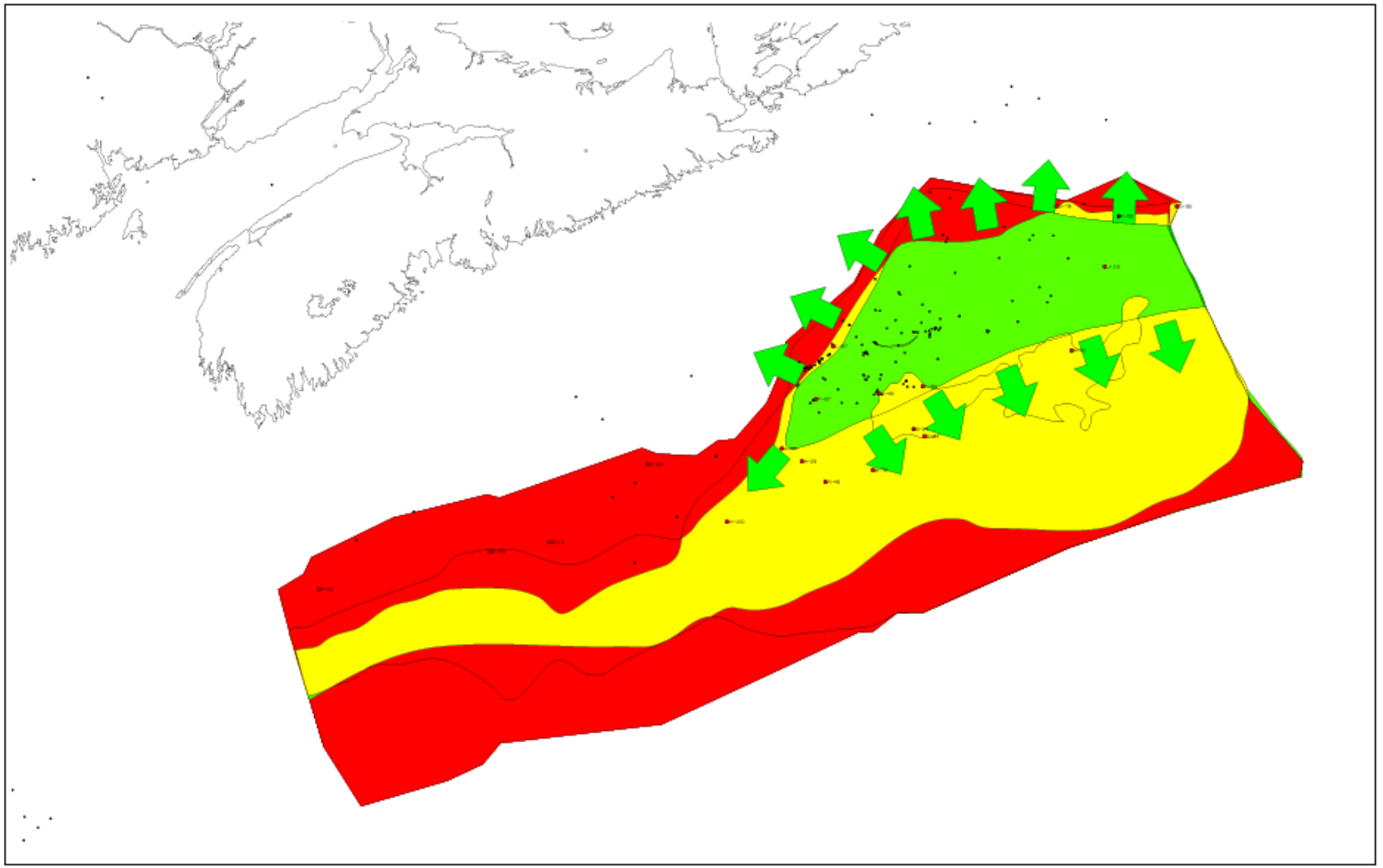


Migration and Accumulation Modeling – Drainage Areas Overview

Berriasian-Valanginian-Hauterivian (J150-K130)



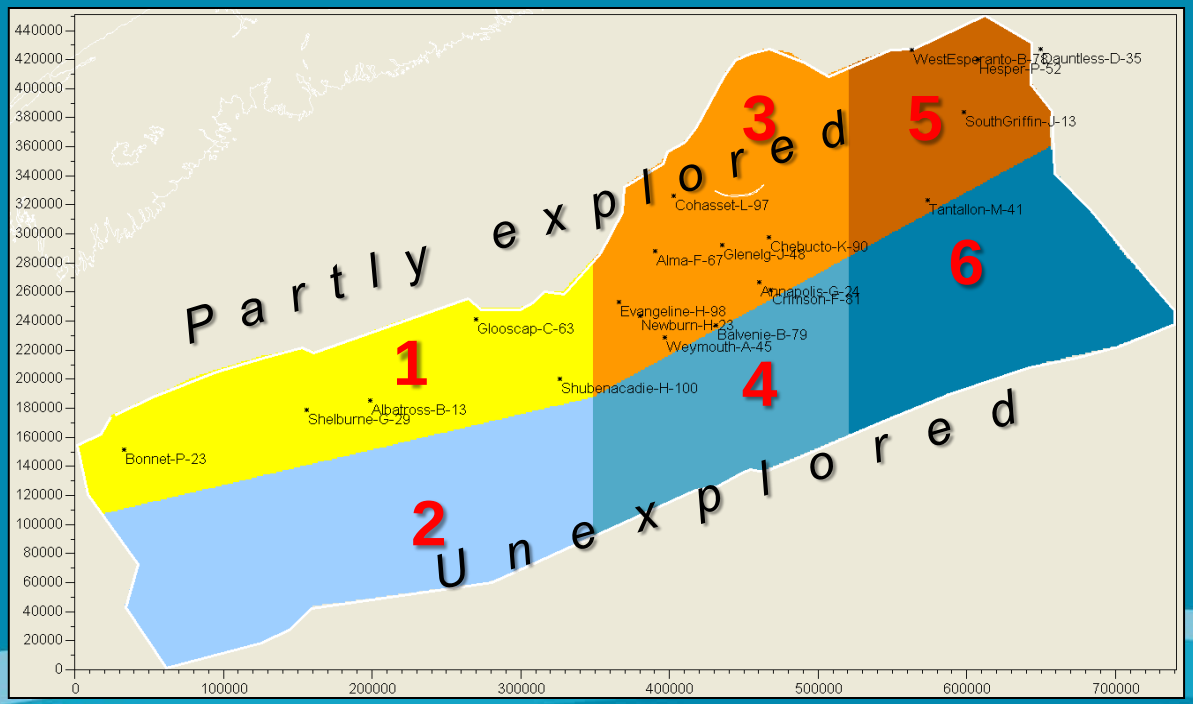
Tithonian SR
Transformation ratio * Presence + Lateral migration potential

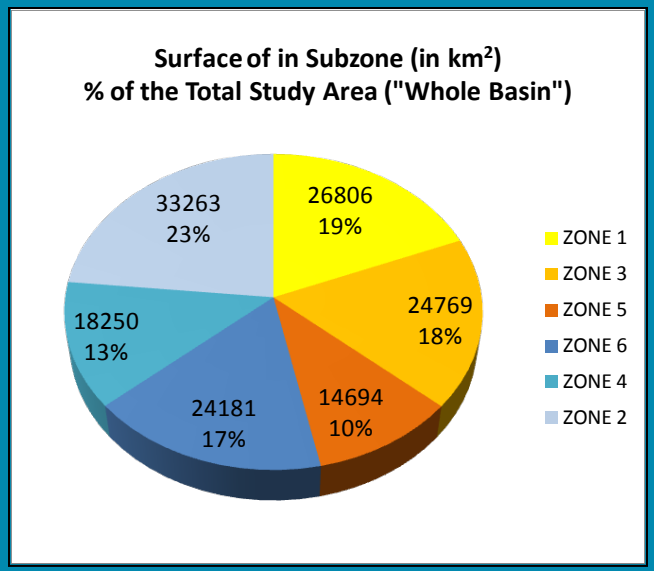


Introduction to 3D Basin Modeling – Study Area and Subzones Definition

By Zones	Number of cell in TEMIS 3D runs (each maps)	Surface (km2)
ZONE 1	4289	26806
ZONE 3	3963	24769
ZONE 5	2351	14694
ZONE 6	3869	24181
ZONE 4	2920	18250
ZONE 2	5322	33263
Whole Basin	**22714**	**141963**

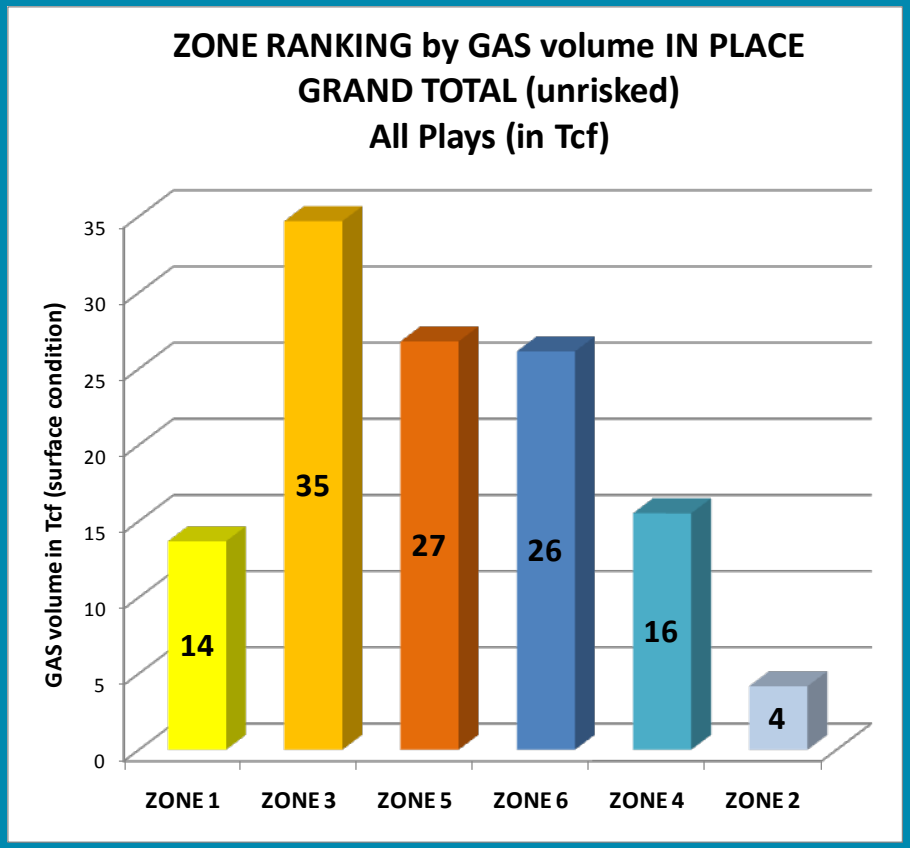
Subzones defined on the basis of geological concept, and on exploration concerns. There is no wells drilled in Basin Zones (in blue). The limit with Platform Zones (in yellow-brown) is close to the isobath 2000 m.

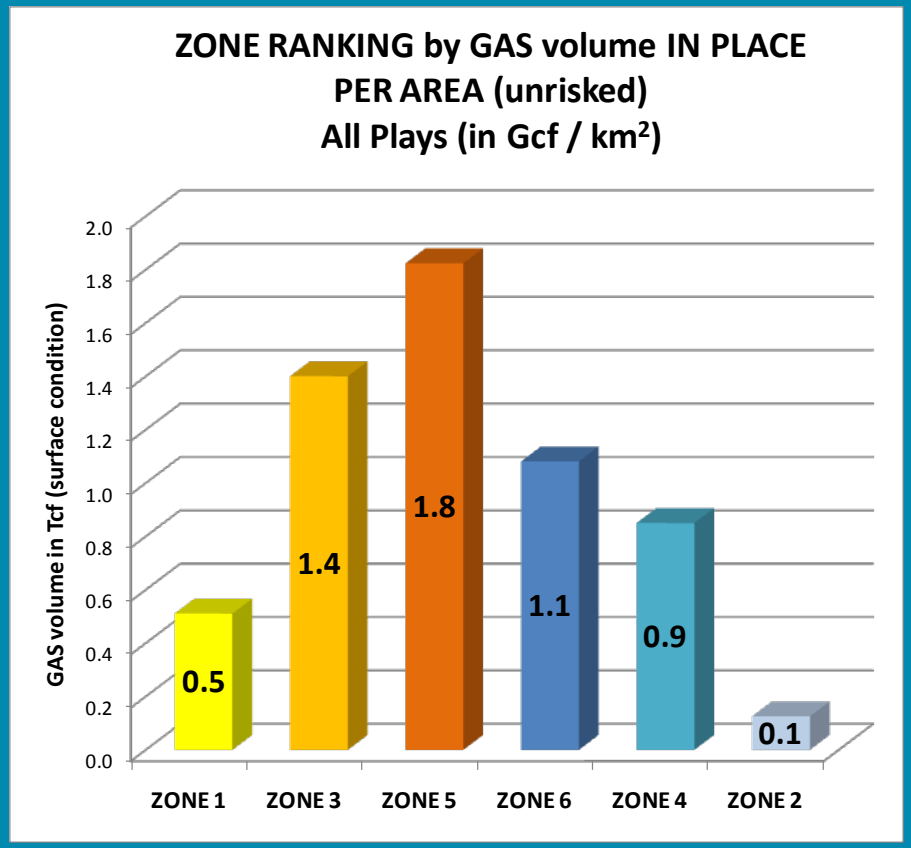




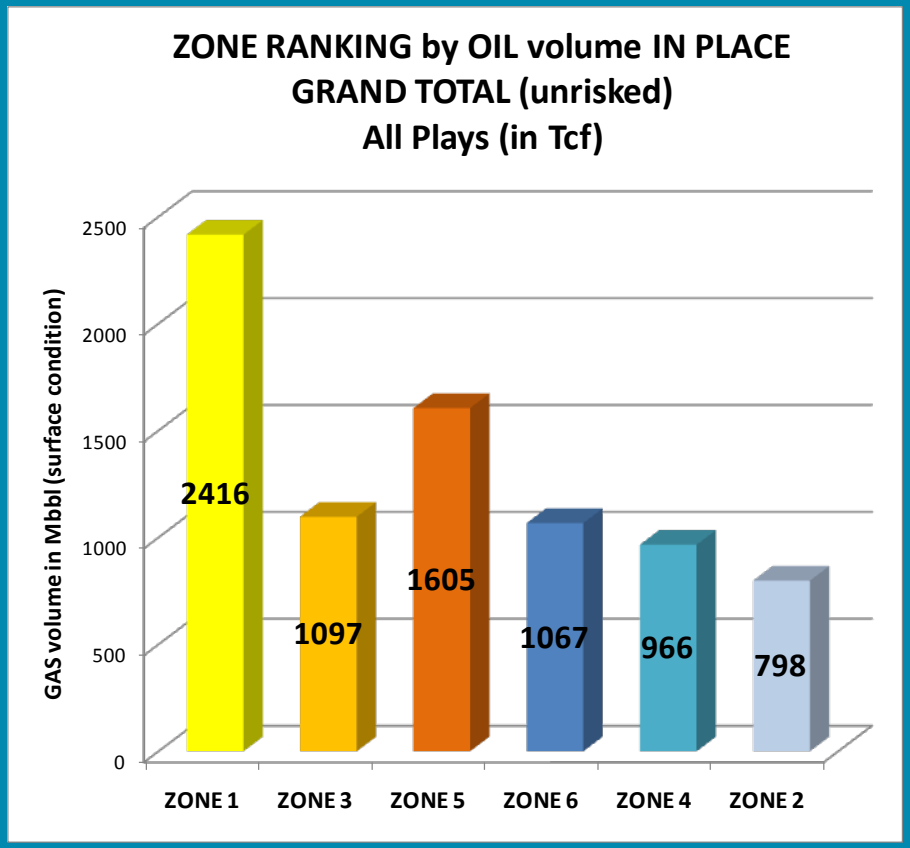
Most of the discoveries are in the Zone 3

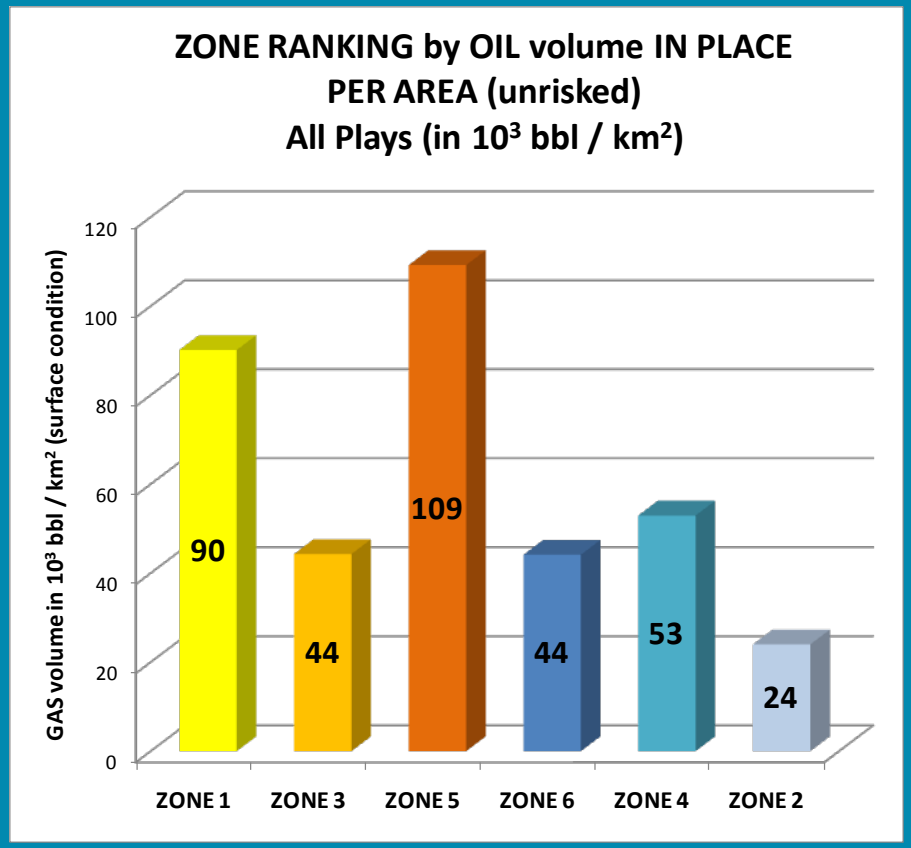
CONCLUSION – ZONE RANKING – GAS VOLUME IN PLACE





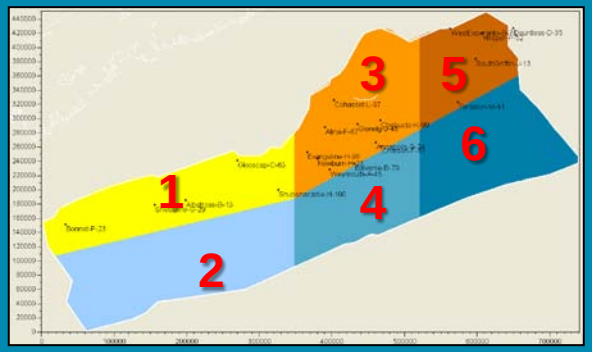
CONCLUSION – ZONE RANKING – OIL VOLUME IN PLACE





CONCLUSION – Total HC Volume in the Basin

By ZONE	*TOTAL GAS volume in surface (Tcf) IN PLACE UNRISKED*	*TOTAL OIL volume in surface (Mbbl) IN PLACE UNRISKED*	*TOTAL GAS volume in surface per AREA (Gcf / km²) IN PLACE UNRISKED*	*TOTAL OIL volume in surface (Kbbl / km²) IN PLACE UNRISKED*
ZONE 1	14	2416	**0.5**	**90**
ZONE 3	35	1097	**1.4**	**44**
ZONE 5	27	1605	**1.8**	**109**
ZONE 6	26	1067	**1.1**	**44**
ZONE 4	16	966	**0.9**	**53**
ZONE 2	4	798	**0.1**	**24**
Whole Basin	121	7950	**0.9**	**56.0**



→ All closed structure (4 ways traps) considered, even subtle ones (in term of closure height, closure area, reservoir thickness).

→ Model rather optimistic in term of source rocks and plays (5 SRs and 5 potential reservoirs layers).

→ "Real reservoir" can be scattered in the play interval, non economic and/or non significant (in production tests).

Conclusions

- YTF Unrisked of 120 TCF Gas, and 8bn bbls oil in world scale structures
- Two main source rocks
  - **Pleinsbachian**
  - **Tithonian**
- Three Play Systems
  - **Jurassic carbonates (reef and oolites)**
  - **Middle and Upper Jurassic Clastics**
  - **Lower Cretaceous delta and turbidites**
- Rigorous stratigraphic framework to develop prospects