Lacustrine source rock potential in the Middle Triassic – Early Jurassic Chignecto Subbasin, offshore Eastern Canada

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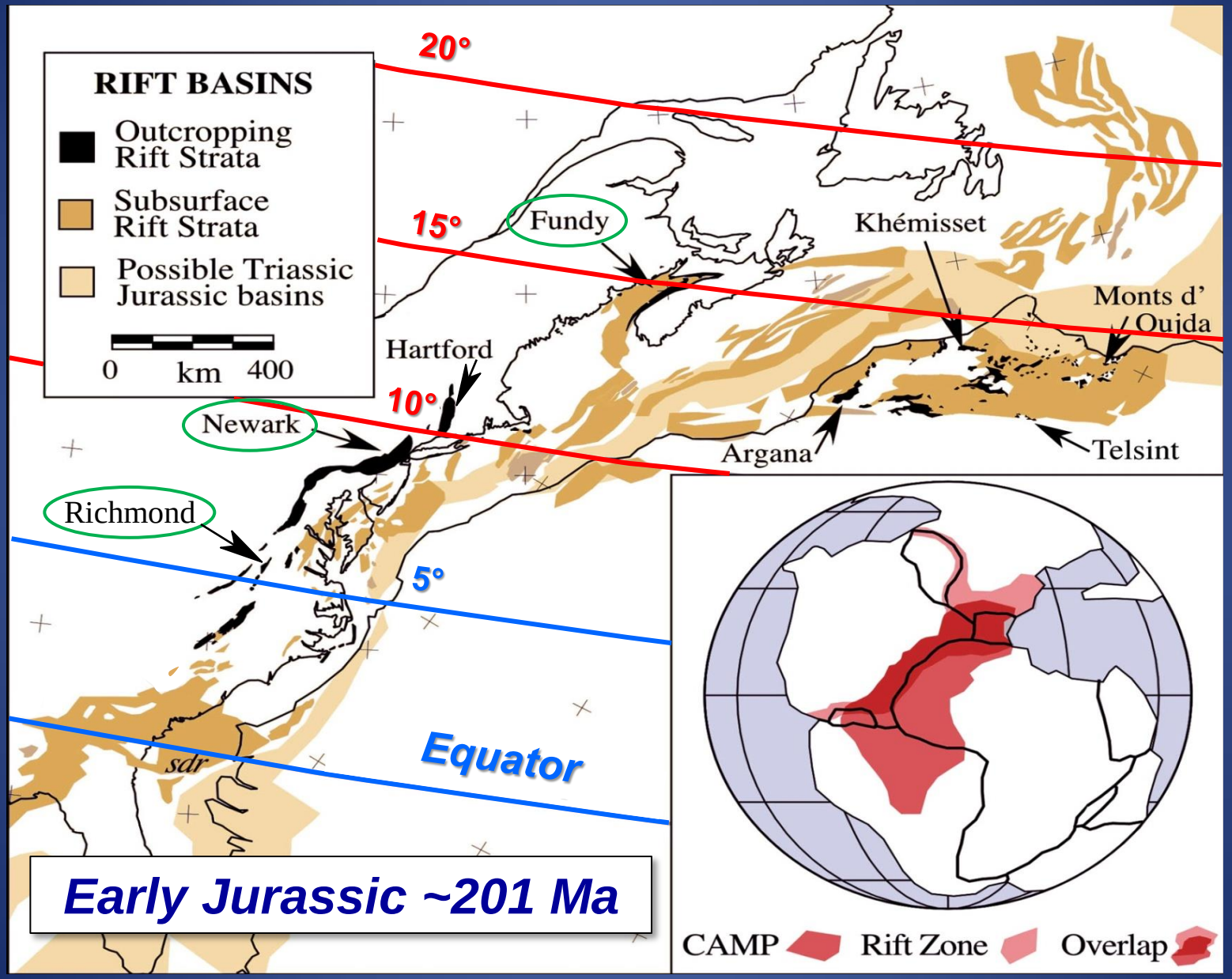
CNSOPB
CANADA-NOVA SCOTIA
OFFSHORE PETROLEUM BOARD

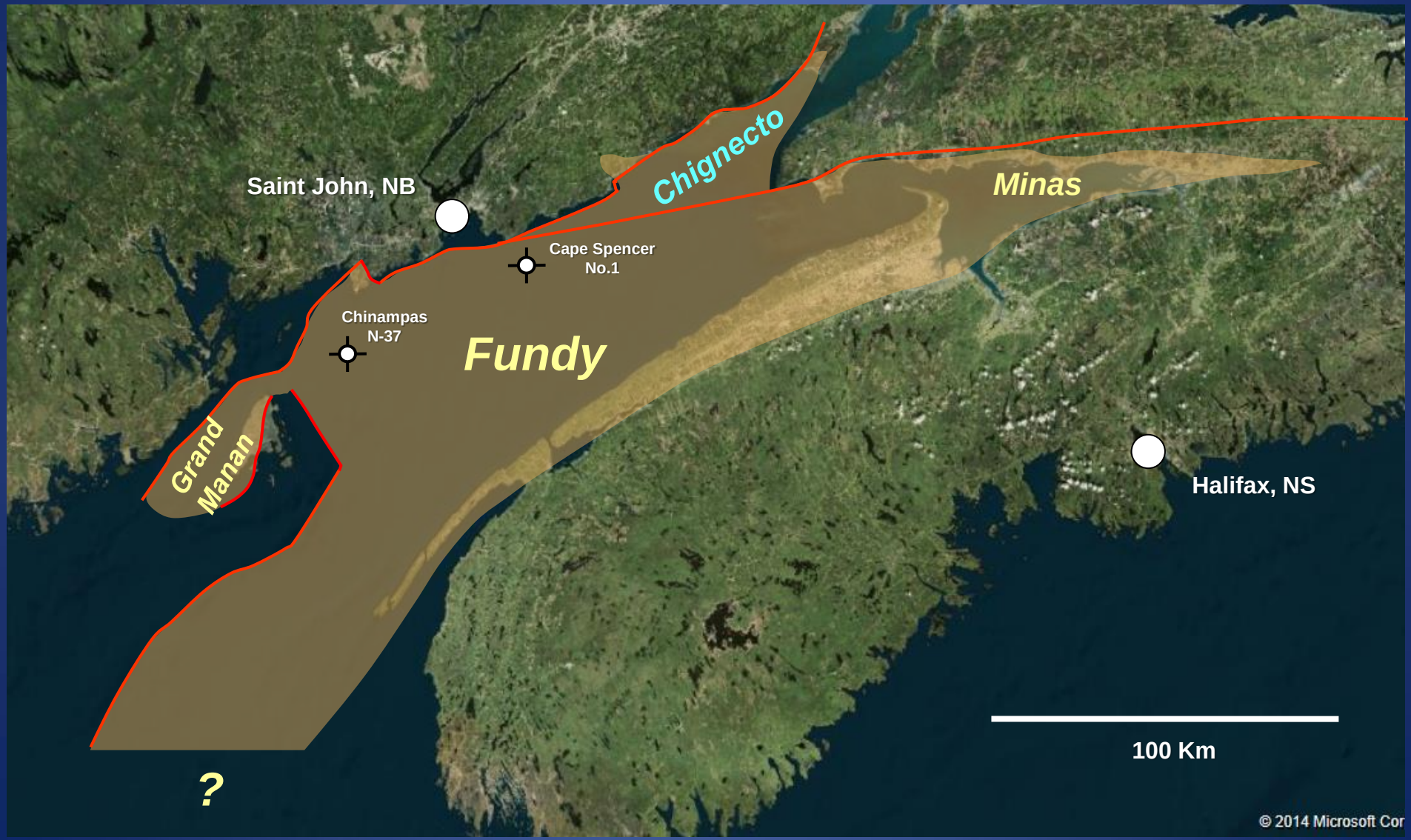
August 15, 2014

Newark Supergroup Basins

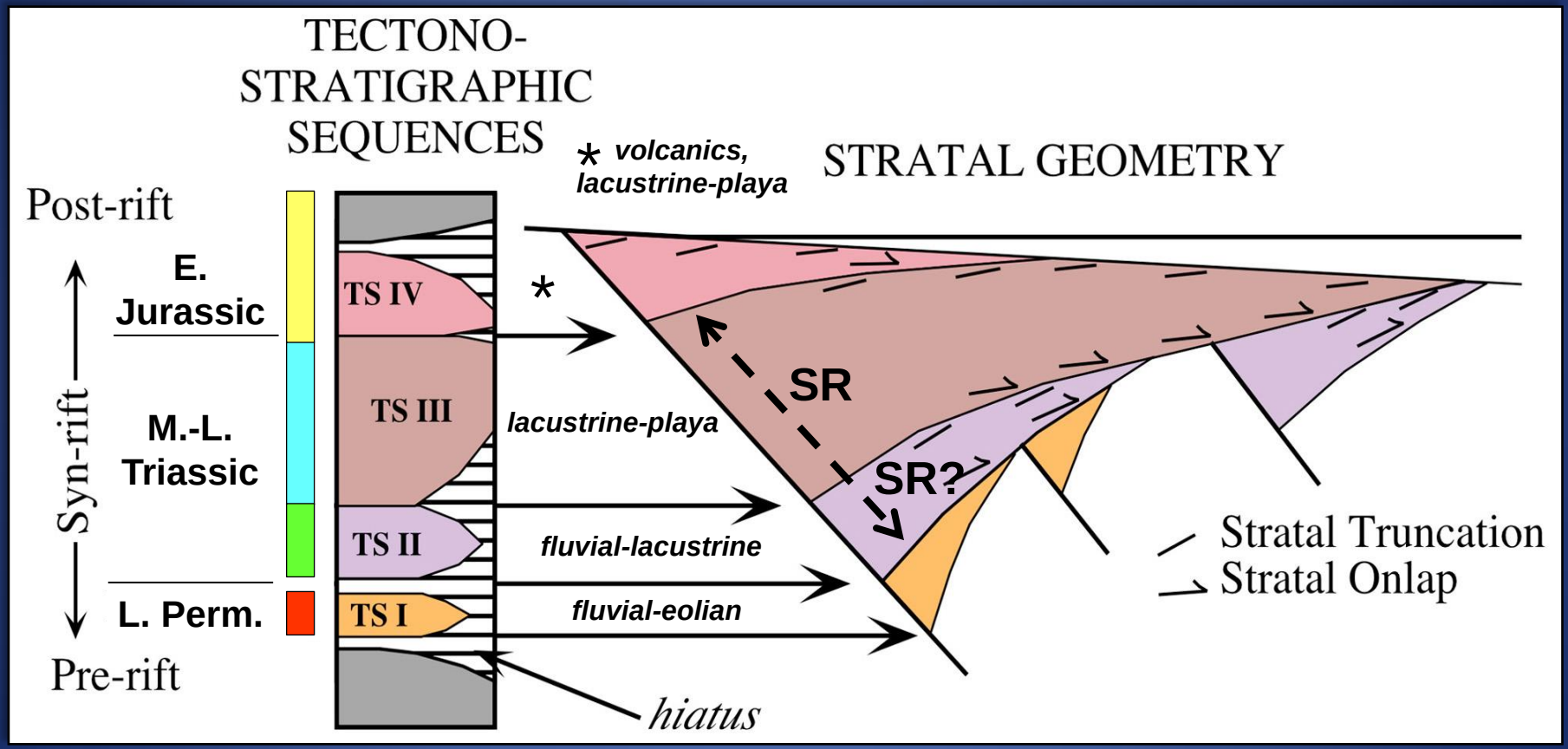


Modified after Olsen & Et-Touhami, 2008

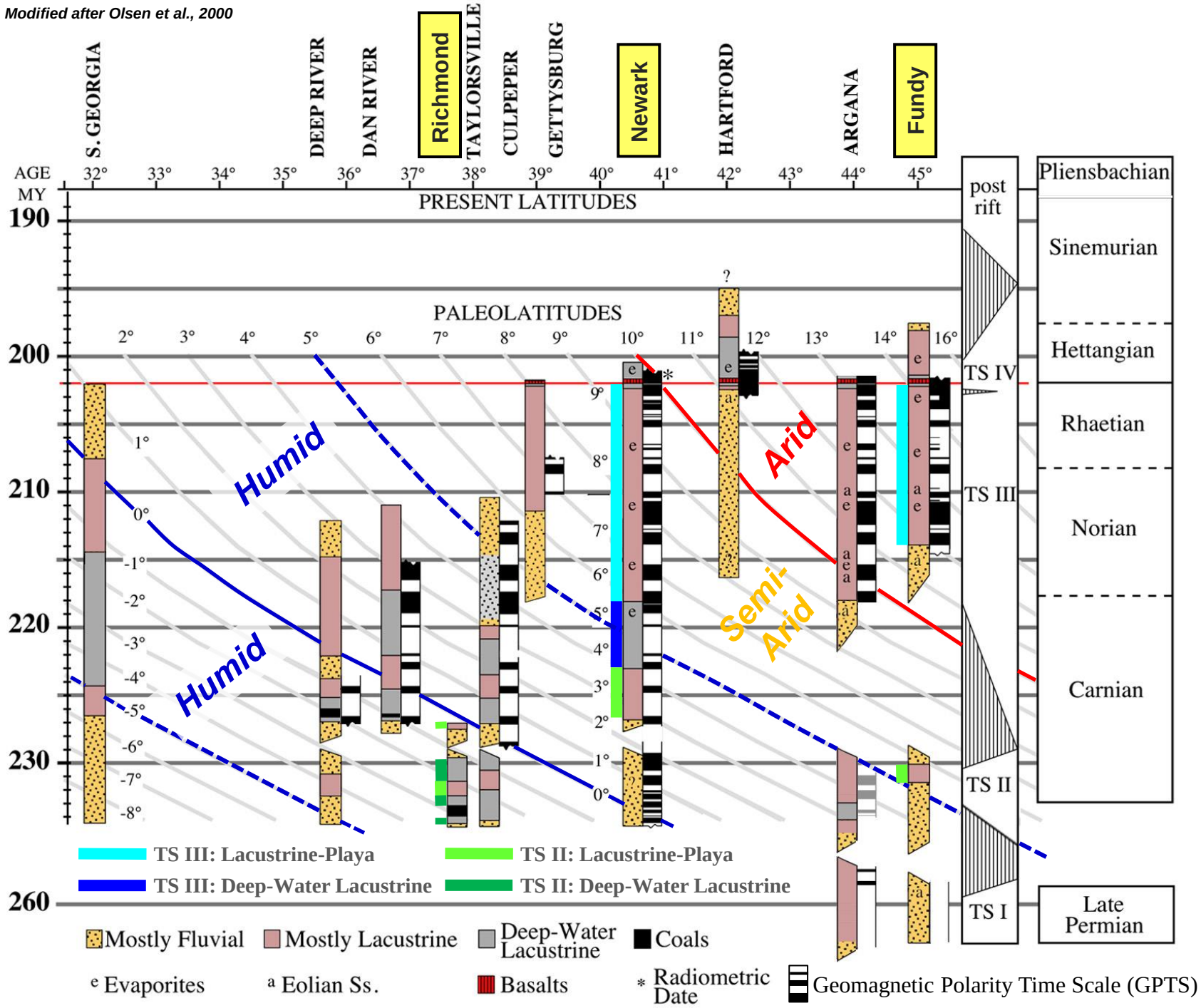
Fundy Basins



Tectonostratigraphic (TS) Model – Newark Supergroup Basins



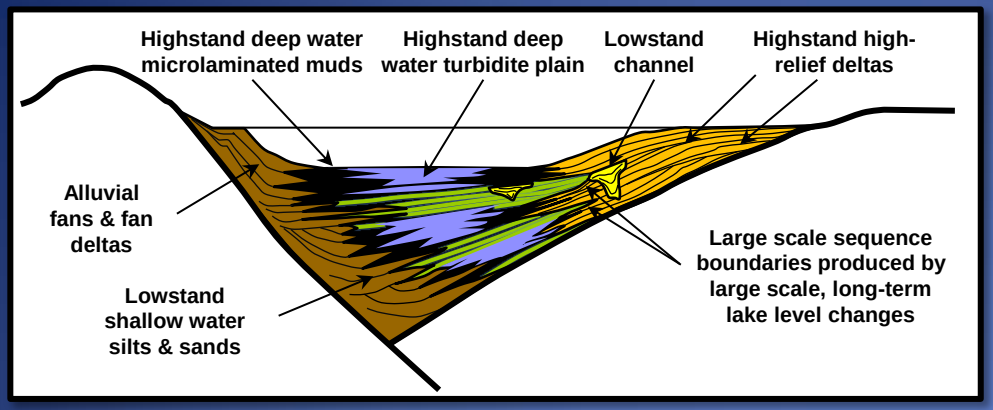
Modified after Olsen (1997); Olsen & Et-Touhami (2008)


Modified after Olsen et al., 2000
S. GEORGIA
DEEP RIVER
DAN RIVER
Richmond
TAYLORSVILLE
CULPEPER
GETTYSBURG
Newark
HARTFORD
ARGANA
Fundy
AGE
MY
PRESENT LATITUDES
PALEOLATITUDES
190
200
210
220
230
260
Humid
Humid
Arid
Semi-
Arid
post
rift
TS IV
TS III
TS II
TS I
Pliensbachian
Sinemurian
Hettangian
Rhaetian
Norian
Carnian
Late
Permian
TS III: Lacustrine-Playa
TS II: Lacustrine-Playa
TS III: Deep-Water Lacustrine
TS II: Deep-Water Lacustrine
Mostly Fluvial
Mostly Lacustrine
Deep-Water Lacustrine
Coals
e Evaporites
a Eolian Ss.
Basalts
* Radiometric Date
Geomagnetic Polarity Time Scale (GPTS)

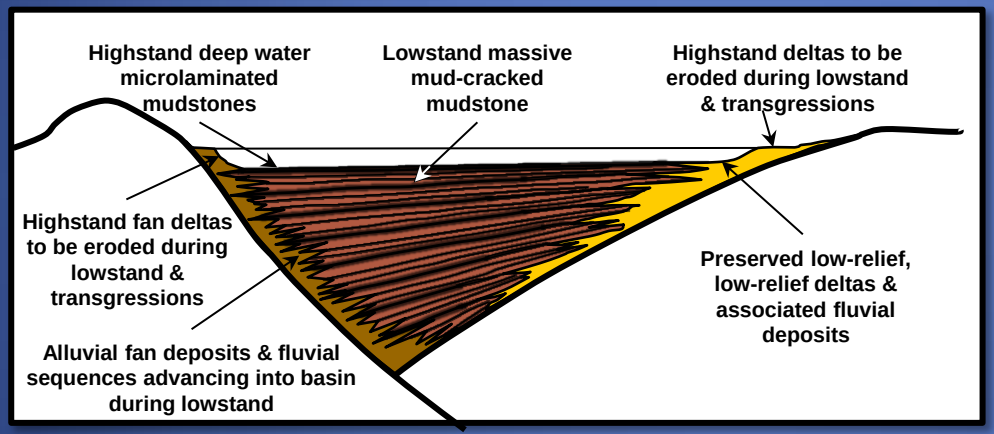
Lacustrine Basin Depositional Models

	OLSEN (1990)	BOHACS (2002)
Geography	Regional (E. N. America, Morocco)	Global
Age	Late Triassic	Devonian - Holocene
Data	Outcrops, boreholes, wells, rare seismic	Outcrops, wells, seismic
Sequences	Lacustrine facies	All associated facies
Controls	Paleolatitude, climate & tectonics	Tectonics & climate (accommodation & sediments + water)
Emphasis	Paleoclimate, paleomagnetics, geochronology	Petroleum systems

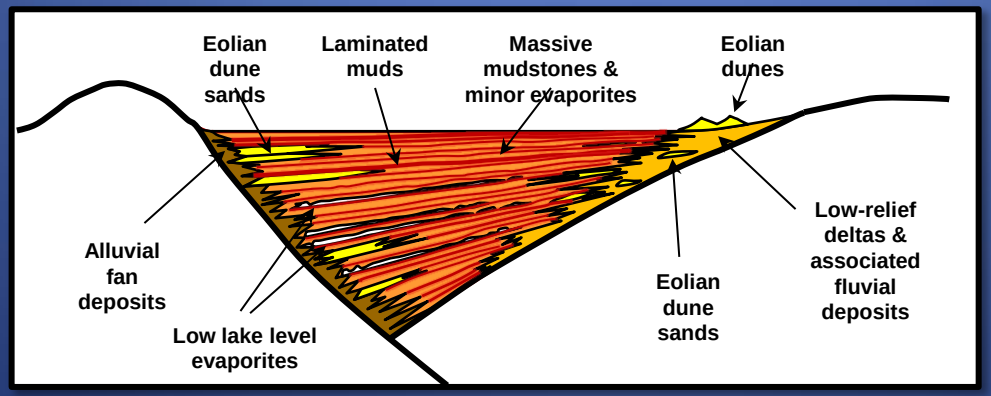
Olsen Model



Richmond Type
TS II



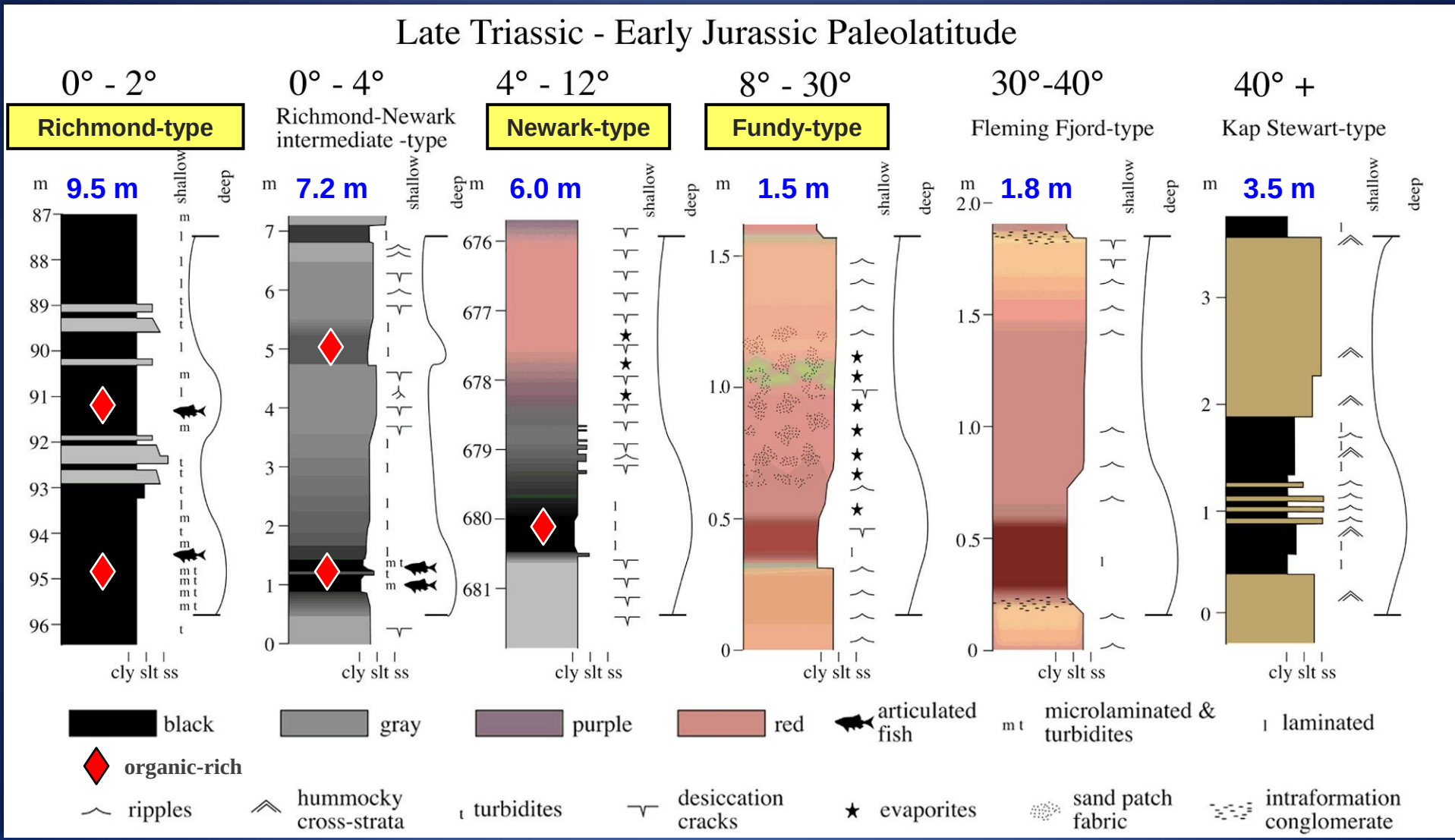
Newark Type
TS III



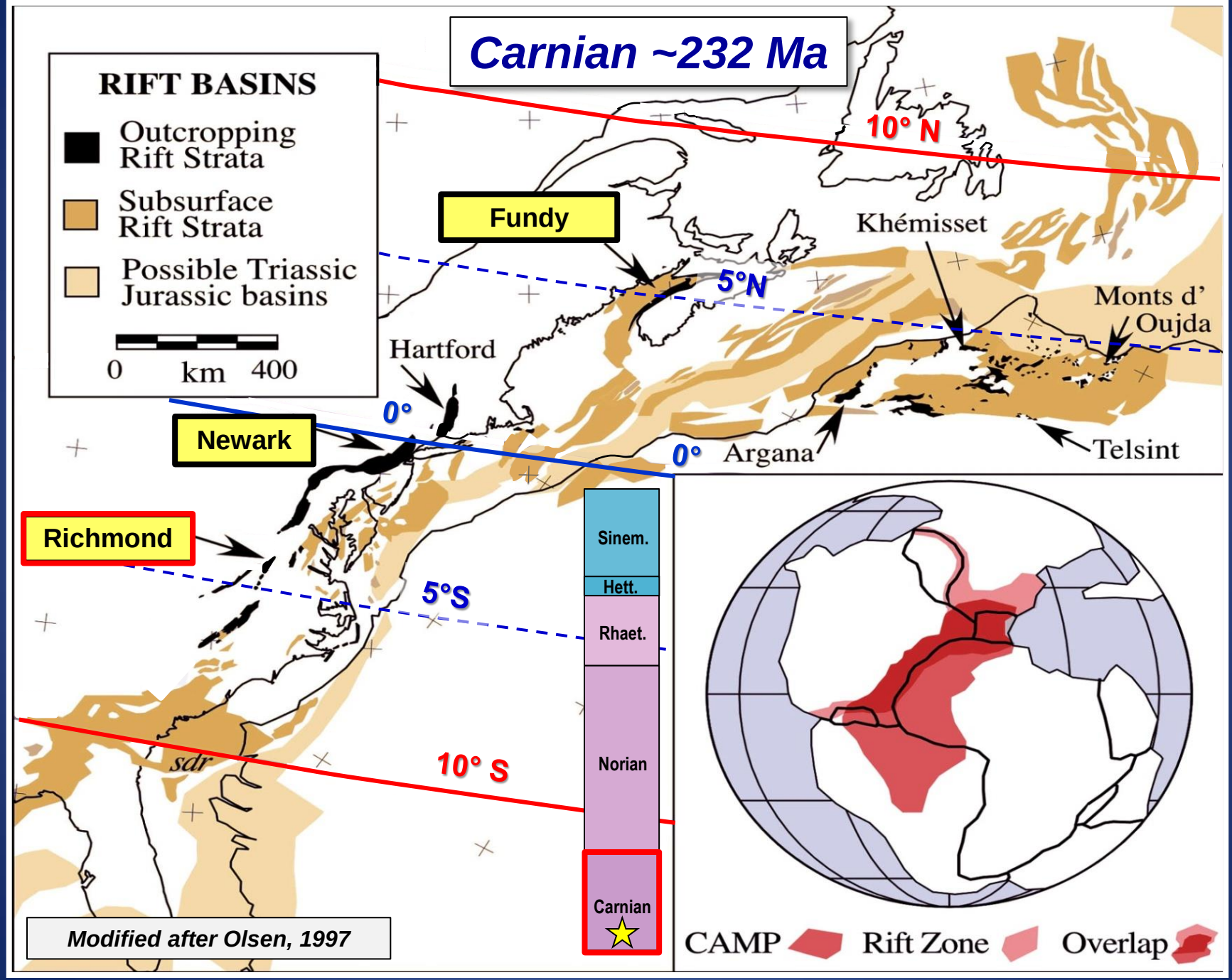
Fundy Type
TS III

Modified after Olsen (1997); Olsen & Et-Touhami (2008)

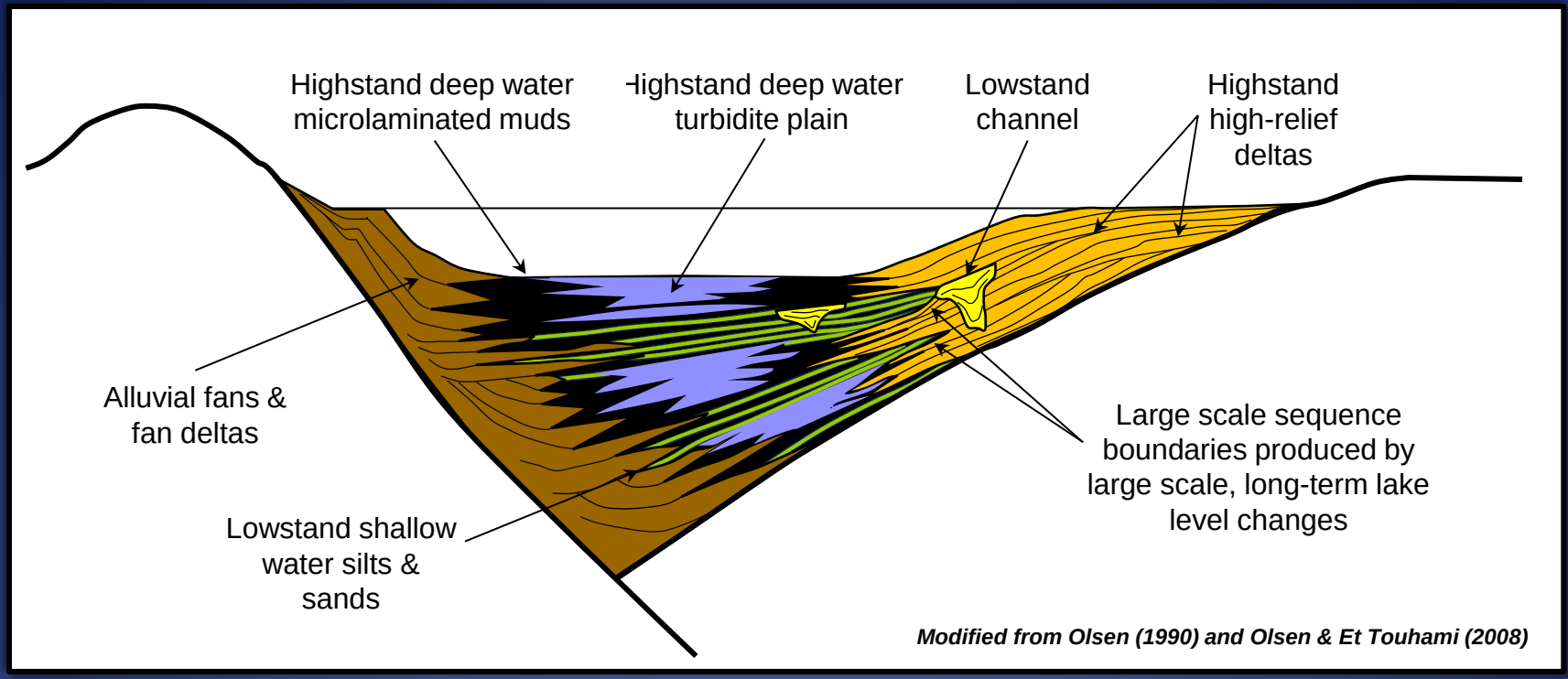
Lacustrine Cycles & Latitude



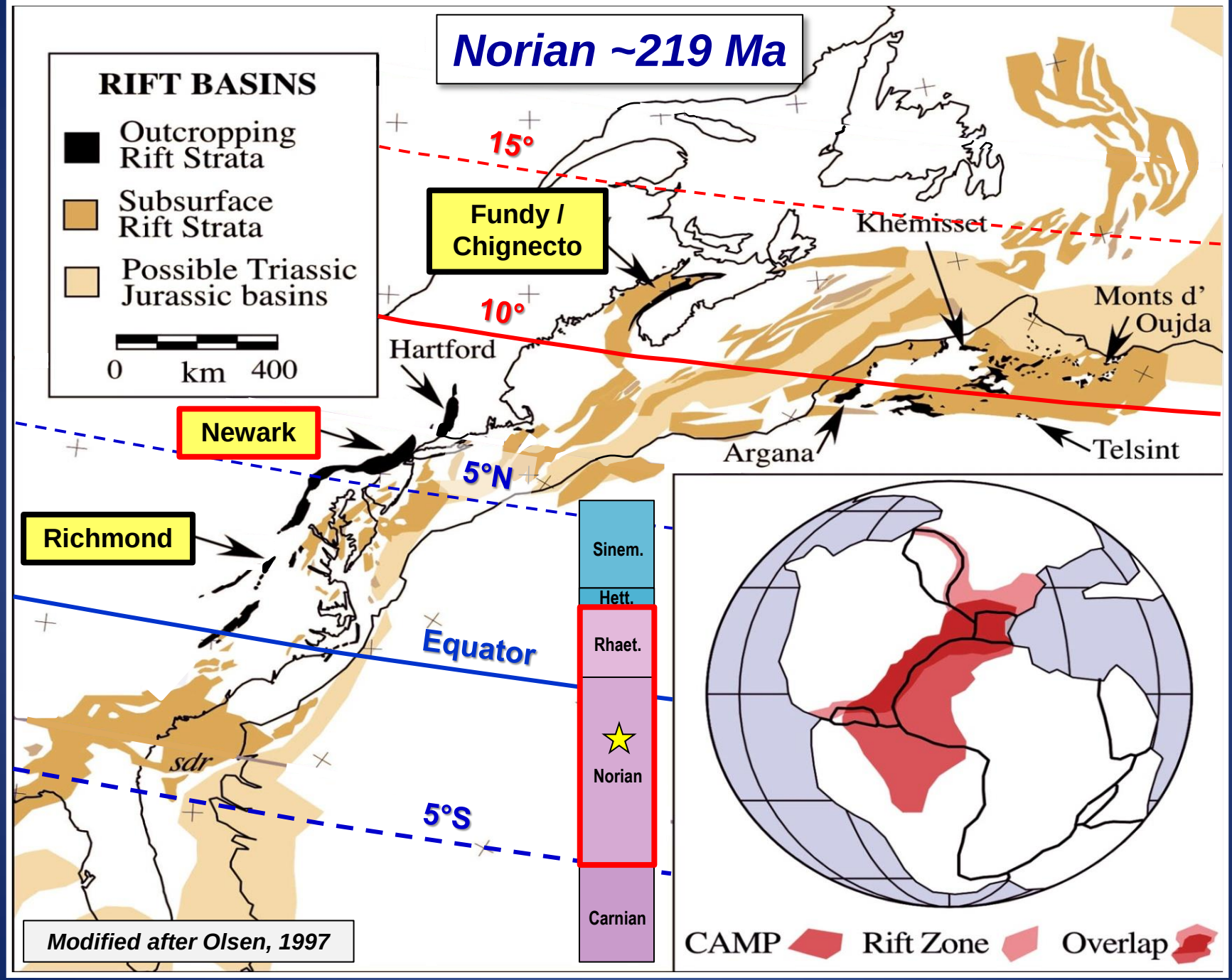
Modified after Olsen & Et-Touhami (2008)


Carnian ~232 Ma
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
10° N
Fundy
5°N
Khémisset
Monts d' Oujda
Hartford
0°
Newark
0°
Argana
Telsint
Richmond
5°S
10° S
sdr
Sinem.
Hett.
Rhaet.
Norian
Carnian
Modified after Olsen, 1997
CAMP
Rift Zone
Overlap

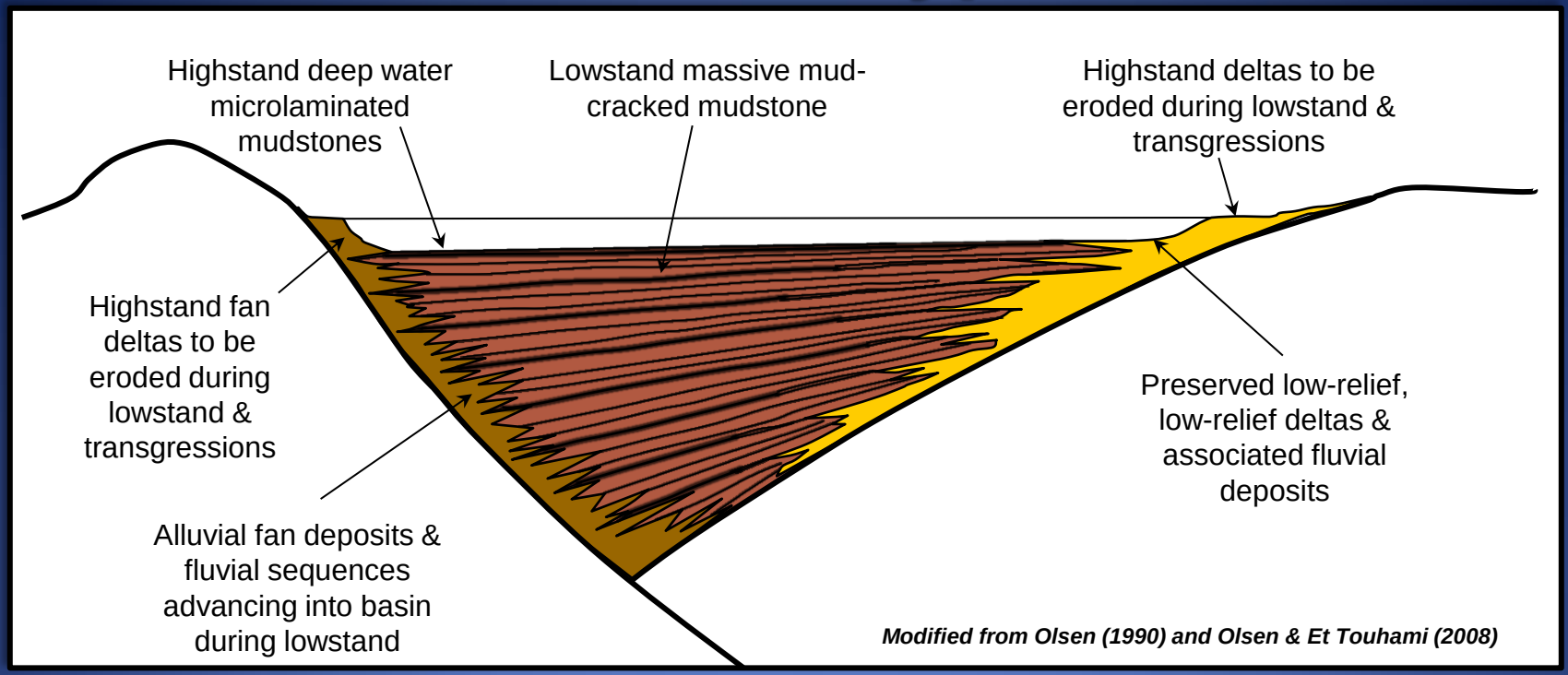
Richmond Type



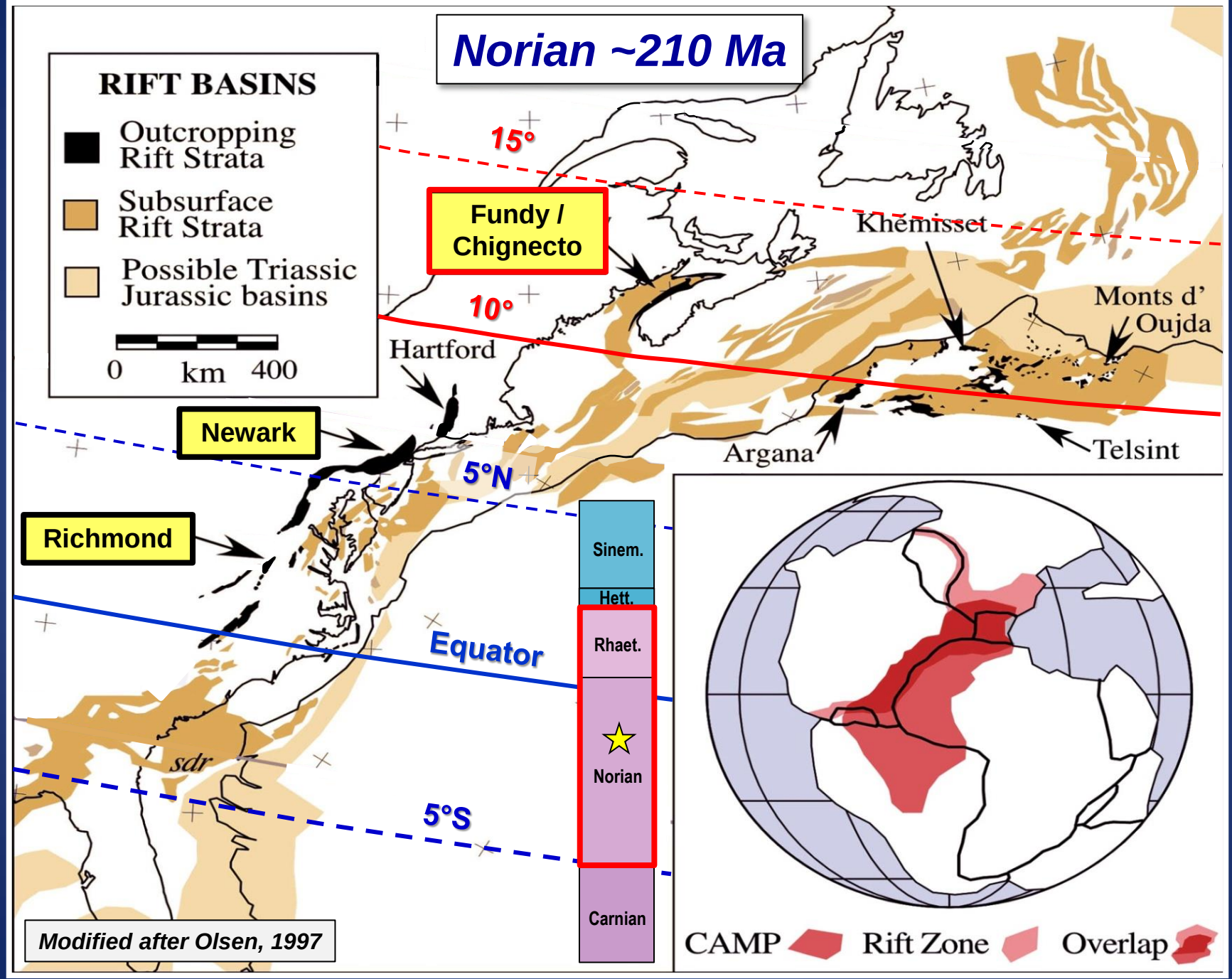
- **TS II – Vinita Mb.**
- ***0° - 2° paleolatitude***
- ***Humid, equatorial climate***
- ***Lacustrine-fluvial-alluvial facies***
- ***Long term submergence***
- ***Muted climatic cyclicity***


Norian ~219 Ma
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
15°
10°
5°N
Equator
5°S
Fundy / Chignecto
Newark
Richmond
Hartford
Khemisset
Monts d' Oujda
Argana
Telsint
sdr
Sinem.
Hett.
Rhaet.
Norian
Carnian
CAMP
Rift Zone
Overlap
Modified after Olsen, 1997

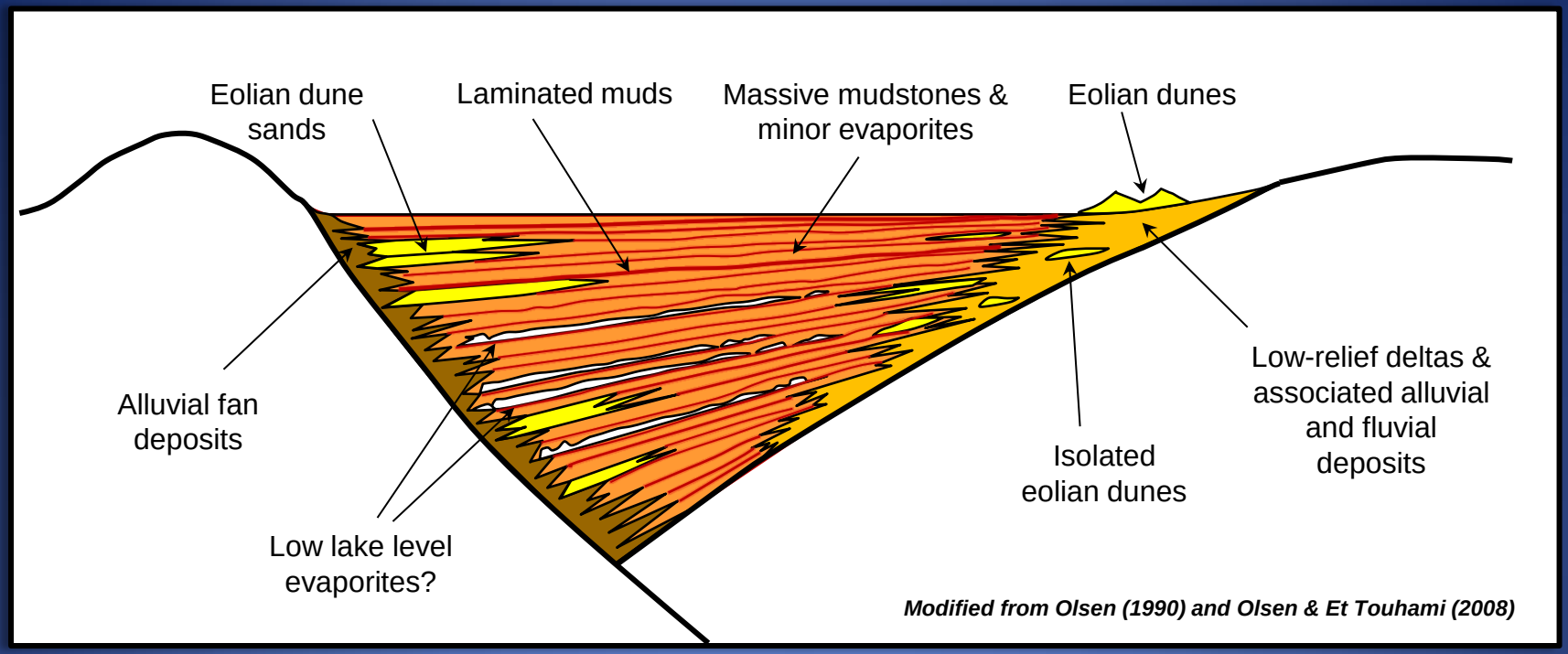
Newark Type



- **TS III – Lockatong Fm.**
- ***2° - 22° paleolatitude***
- ***Humid to semi-arid climate***
- ***Lacustrine-fluvial facies***
- ***Alternating submergence / exposure***
- ***Pronounced climatic cyclicity***

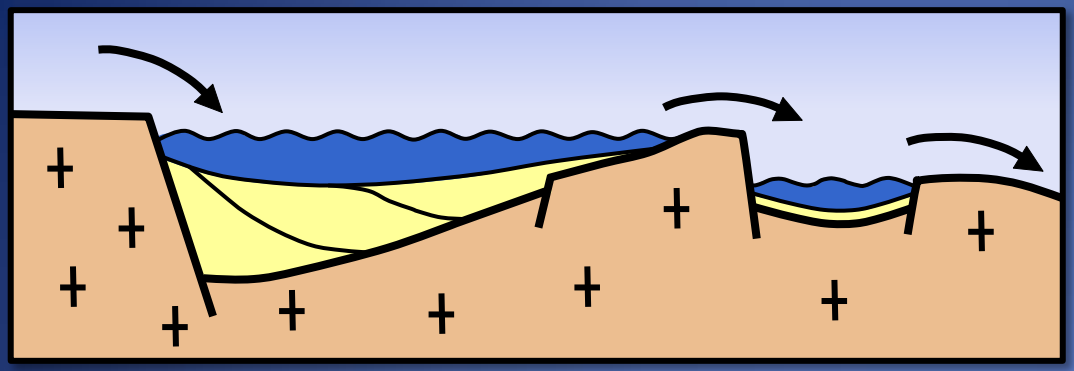

Norian ~210 Ma
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
15°
10°
5°N
Equator
5°S
Fundy / Chignecto
Newark
Richmond
Hartford
Khemisset
Monts d' Oujda
Argana
Telsint
sdr
Sinem.
Hett.
Rhaet.
Norian
Carnian
CAMP
Rift Zone
Overlap
Modified after Olsen, 1997

Fundy Type

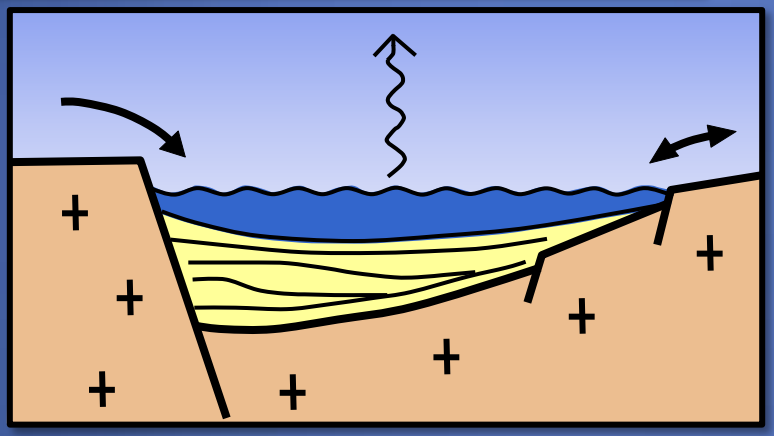


- **TS III – Blomidon Fm.**
- ***15° - 30° paleolatitude***
- ***Semi-arid to arid climate***
- ***Playa-lacustrine-fluvial-eolian facies***
- ***Exposure greater than submergence***
- ***Pronounced climatic cyclicity***

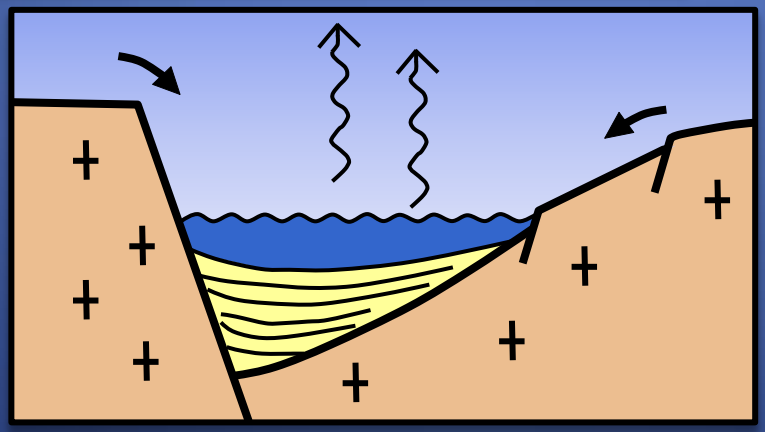
Bohacs Model



OVERFILLED
Fluvial-lacustrine

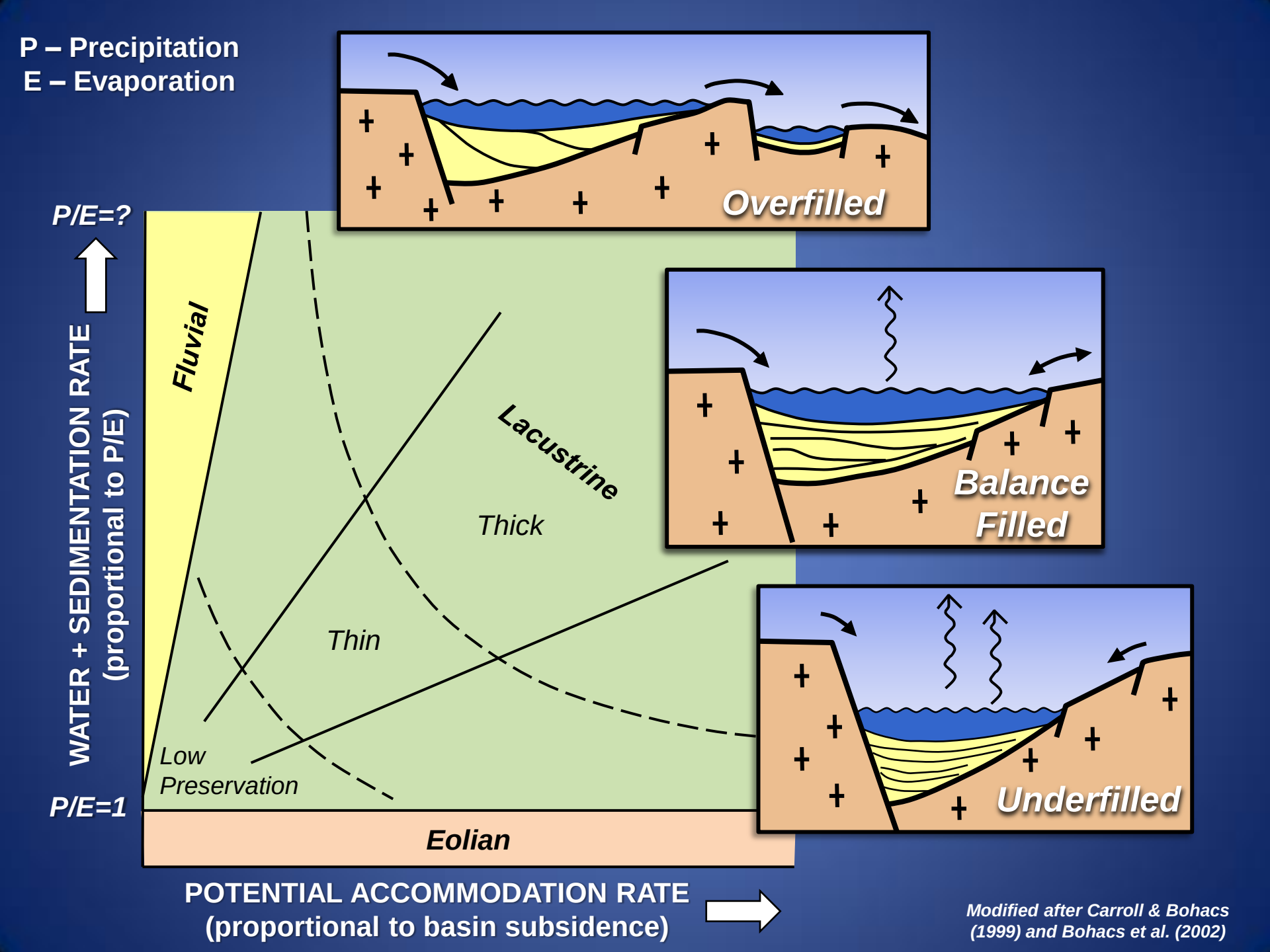


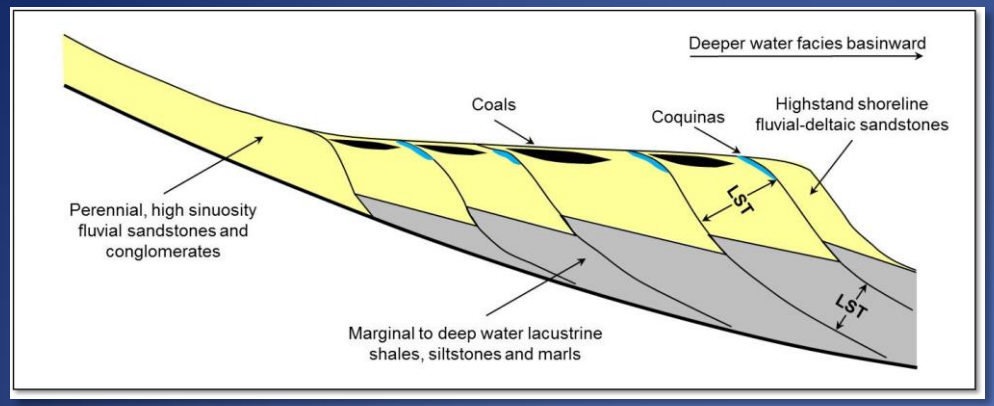
BALANCED FILLED
Fluctuating profundal



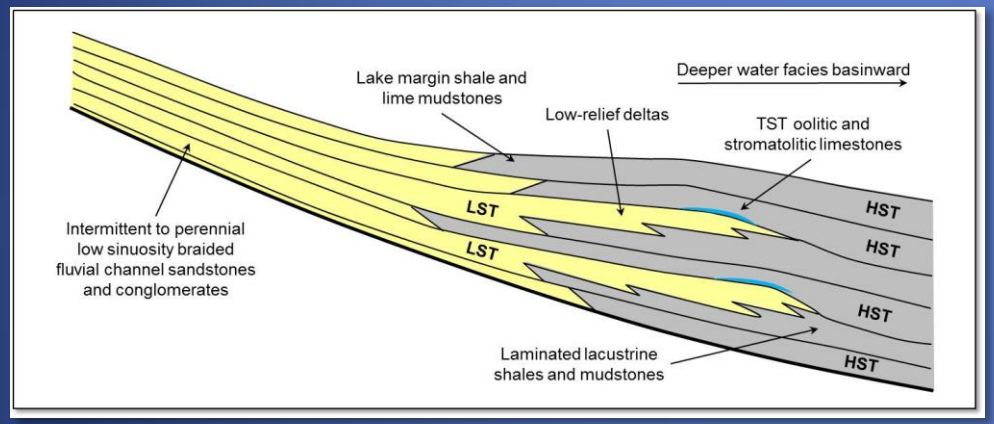
UNDERFILLED
Evaporative

Modified after Carroll & Bohacs (1999)

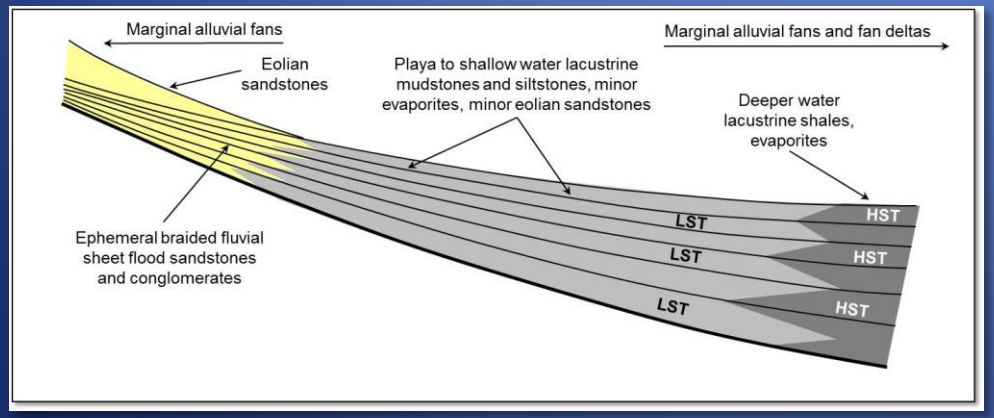

P – Precipitation
E – Evaporation
Overfilled
P/E=?
WATER + SEDIMENTATION RATE
(proportional to P/E)
Fluvial
Lacustrine
Thick
Balance
Filled
Thin
Low
Preservation
Underfilled
P/E=1
Eolian
POTENTIAL ACCOMMODATION RATE
(proportional to basin subsidence)
Modified after Carroll & Bohacs
(1999) and Bohacs et al. (2002)



OVERFILLED
Fluvial-Lacustrine



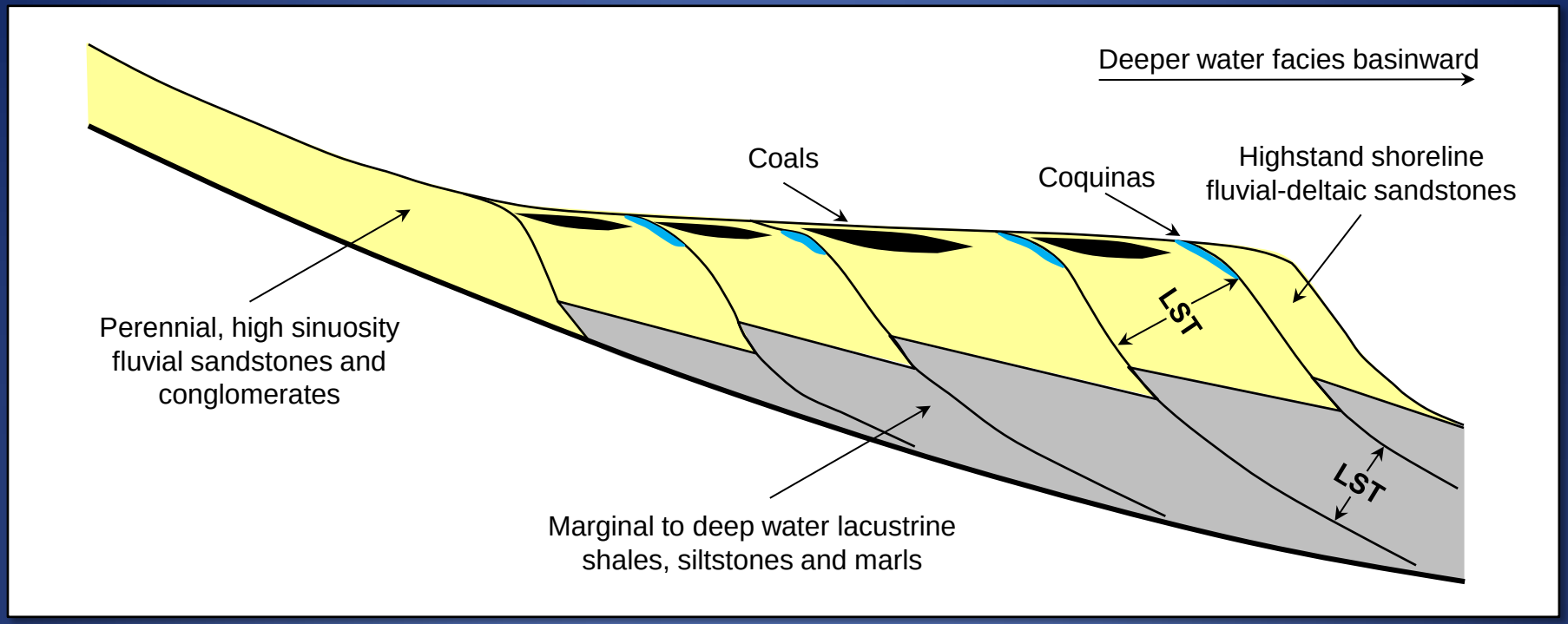
BALANCED-FILLED
Fluctuating Profundal



UNDERFILLED
Evaporative

Modified after Bohacs (2012)

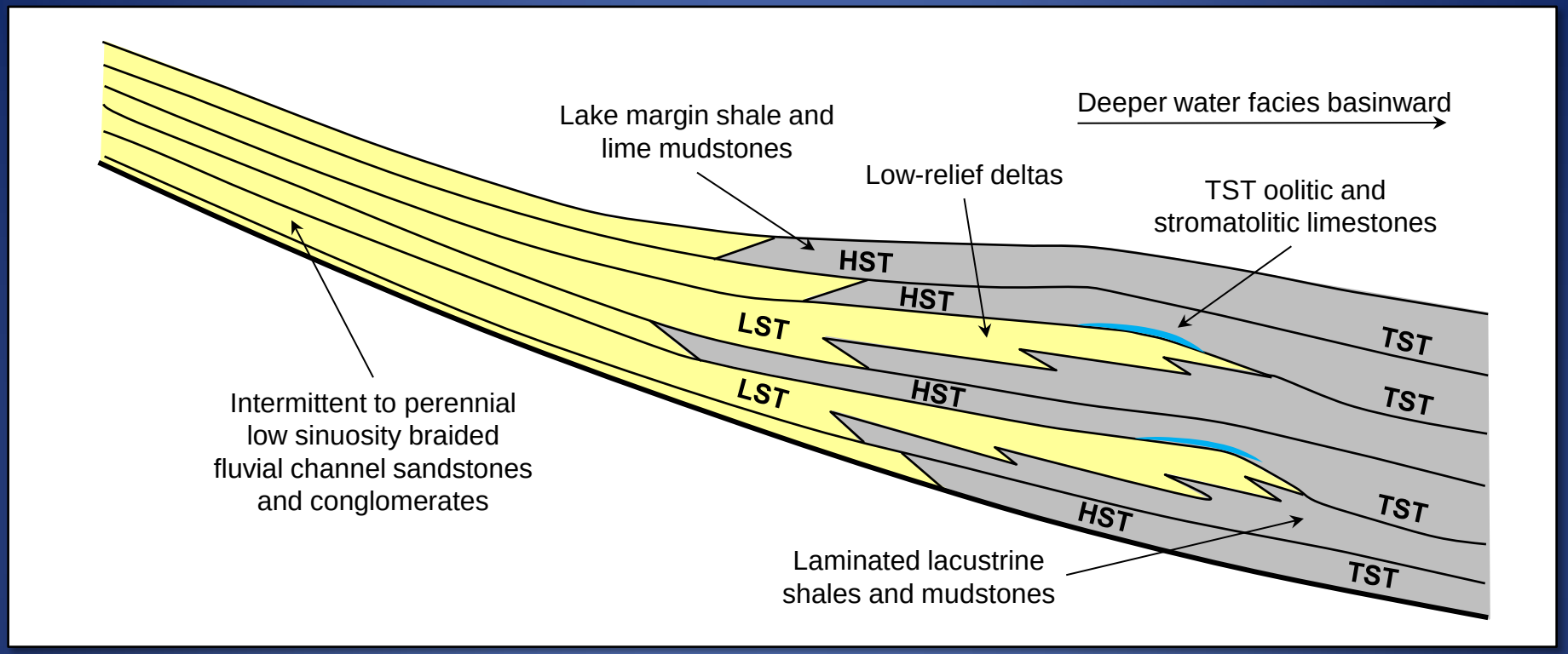
Overfilled Basin



Modified after Bohacs (2012)

- ***Deposition > subsidence***
- ***Open hydrology; fresh water***
- ***Fluvial-lacustrine facies association***
- ***Mostly progradational parasequences***
- ***Lowstand systems tract (LST) stacking patterns***
- ***Low to moderate TOC, Types I-III kerogens***

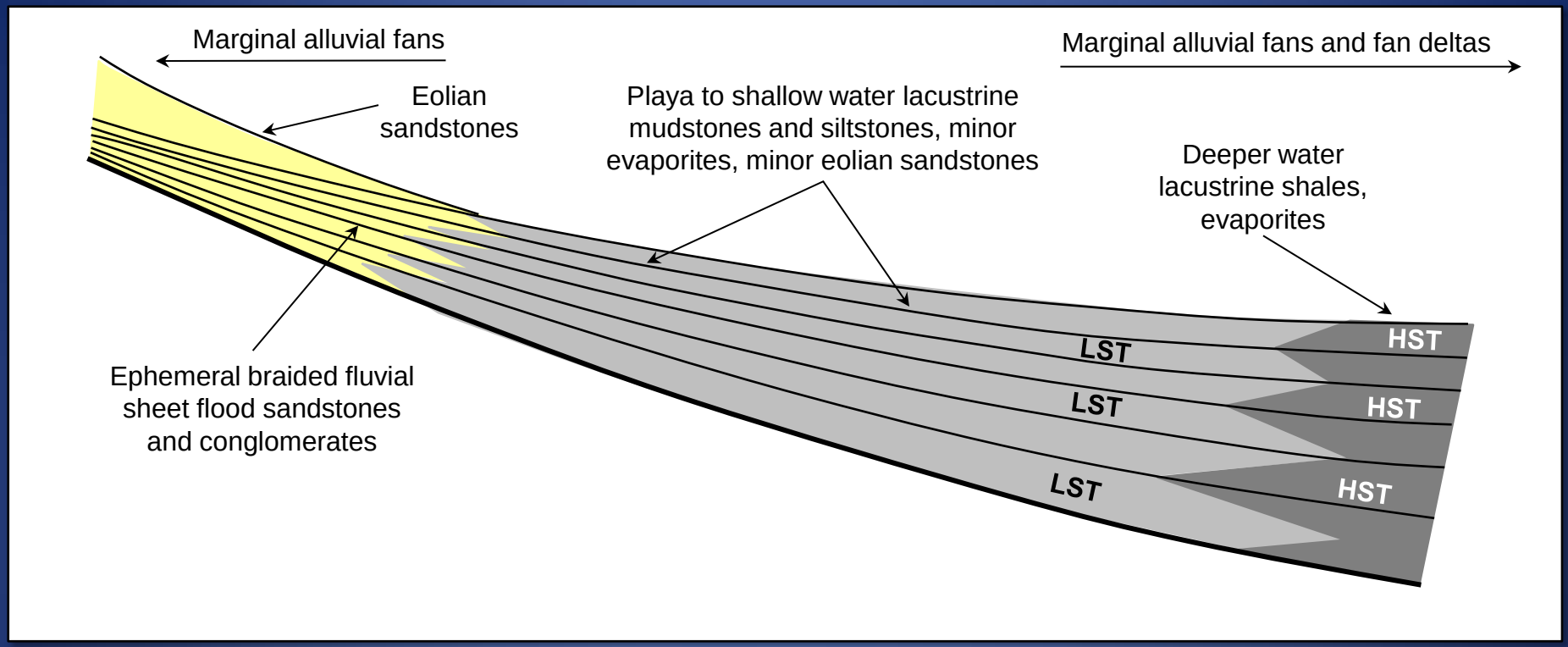
Balanced-fill Basin



Modified after Bohacs (2012)

- ***Deposition = subsidence***
- ***Open and closed hydrology; fresh-alkaline-saline***
- ***Fluctuating profundal (lacustrine) facies association***
- ***Mixed pro- and aggradational parasequences***
- ***Transgressive Systems Tract (TST) stacking patterns***
- ***Moderate-high TOC, Type I kerogens***

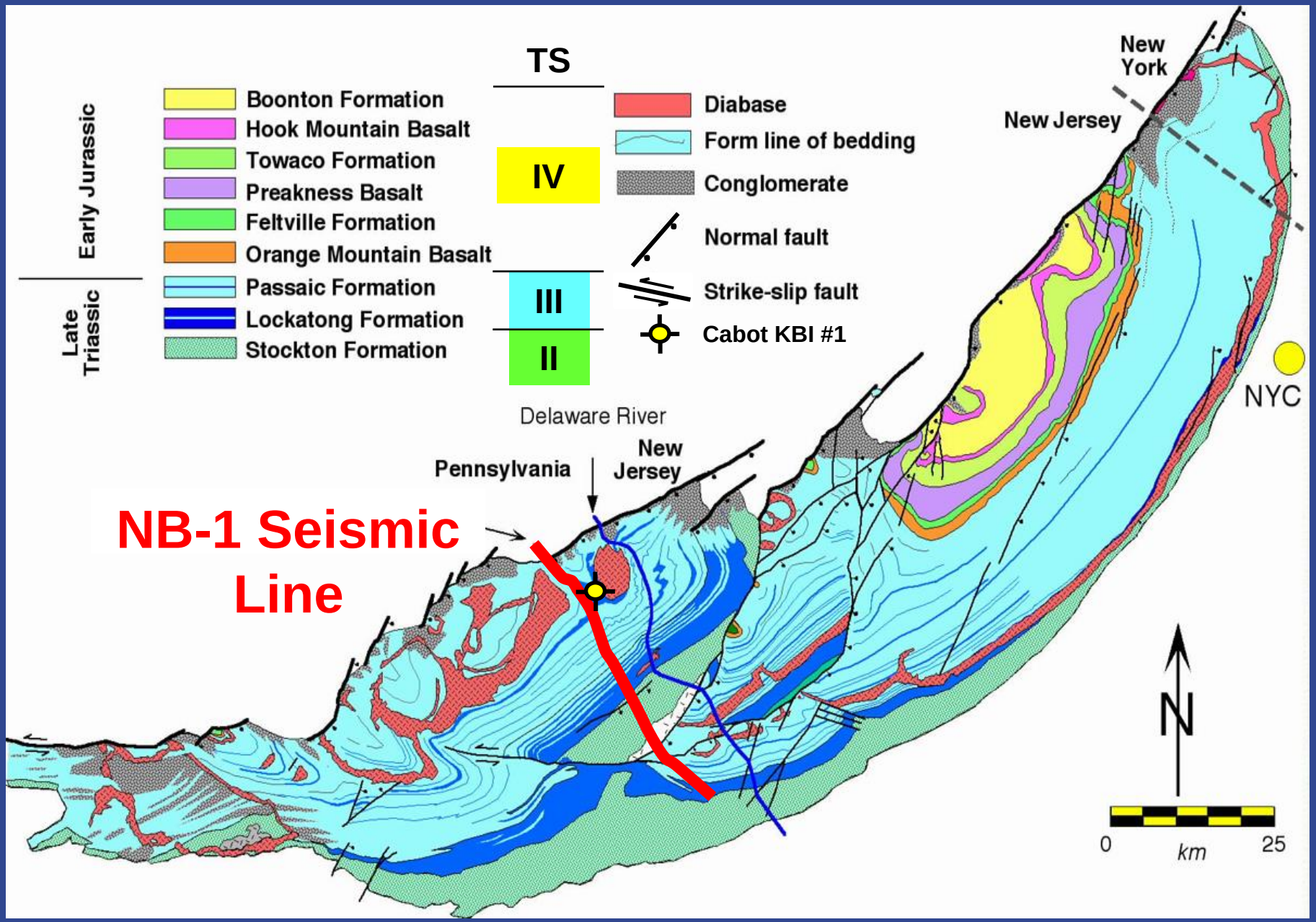
Underfilled Basin



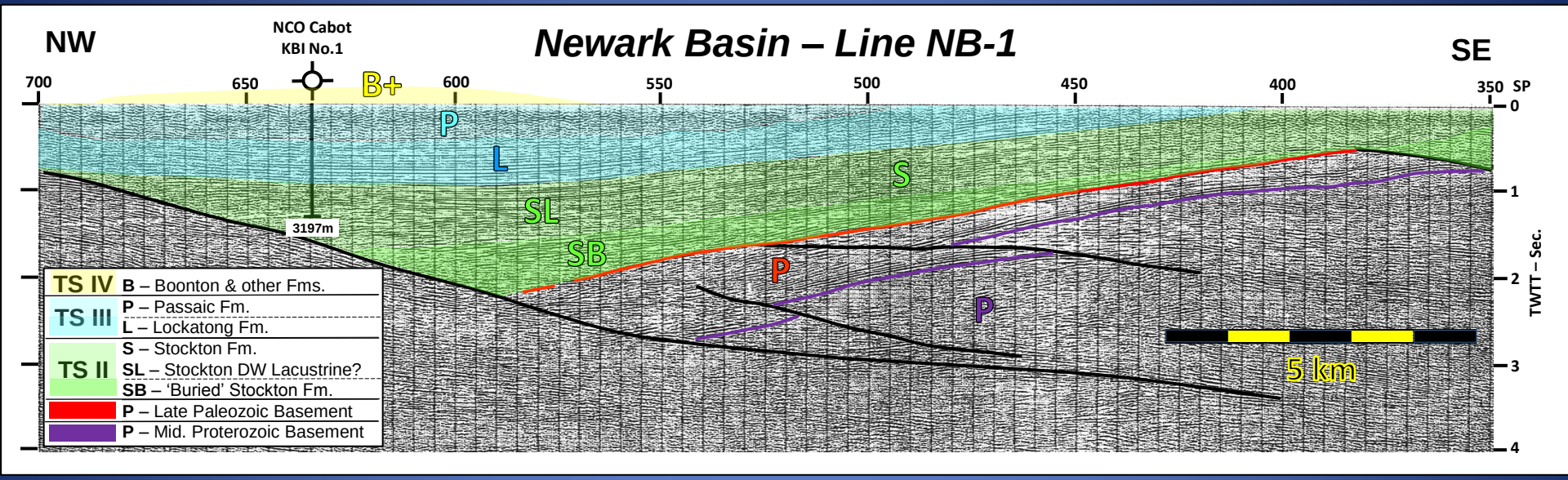
Modified after Bohacs (2012)

- ***Deposition < subsidence***
- ***Closed hydrology; saline-hypersaline***
- ***Evaporative playa-lacustrine facies association***
- ***Aggradational parasequences***
- ***Highstand Systems Tract (HST) stacking patterns***
- ***Low-high TOC, Type I kerogens***

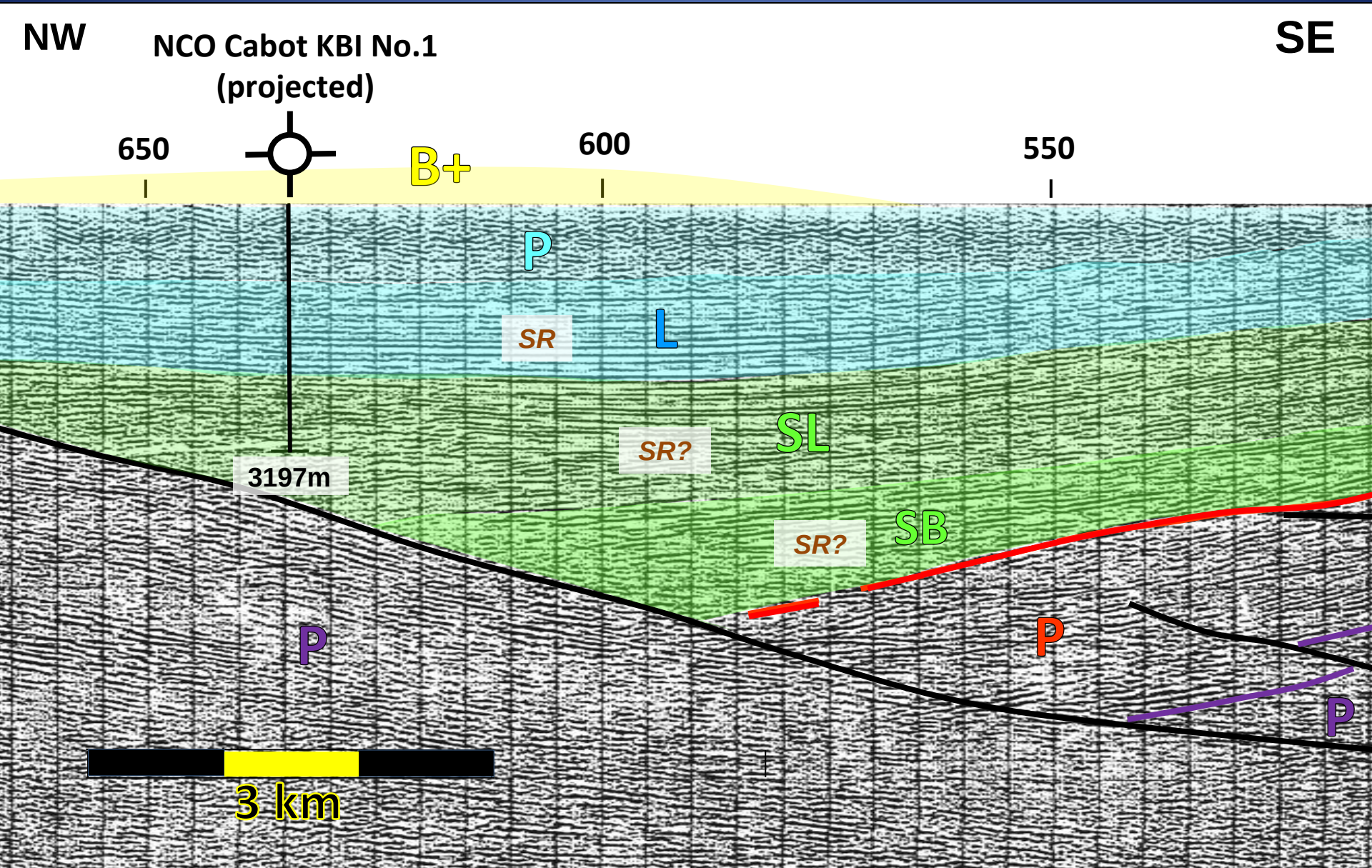
Newark Basin



Newark – Line NB-1

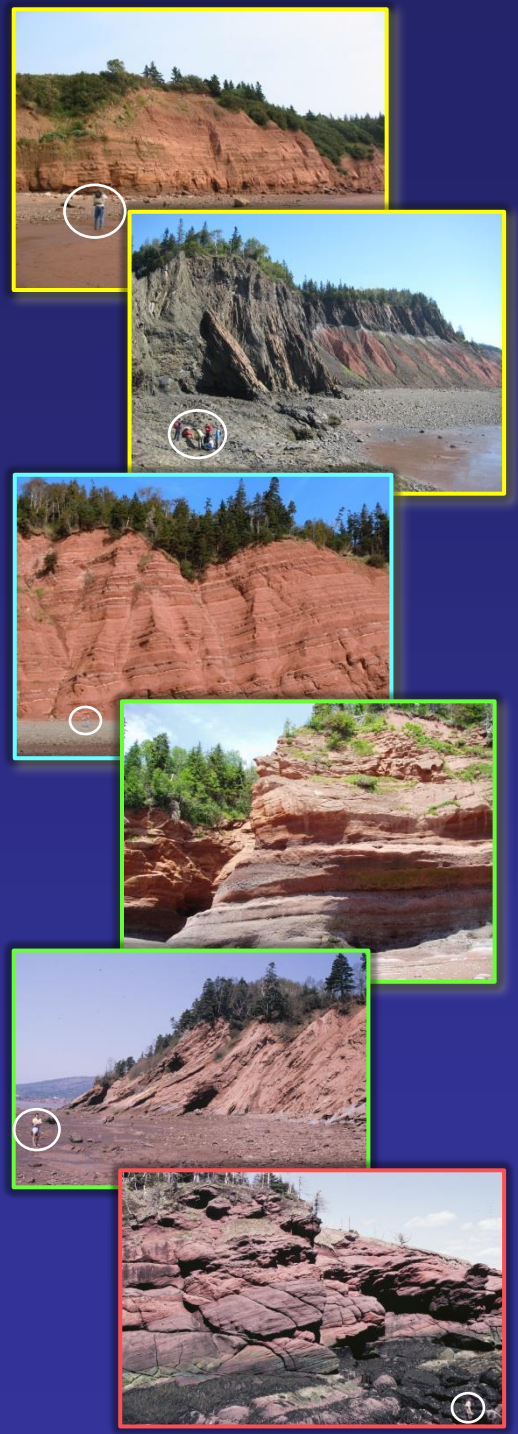


Newark – Line NB-1

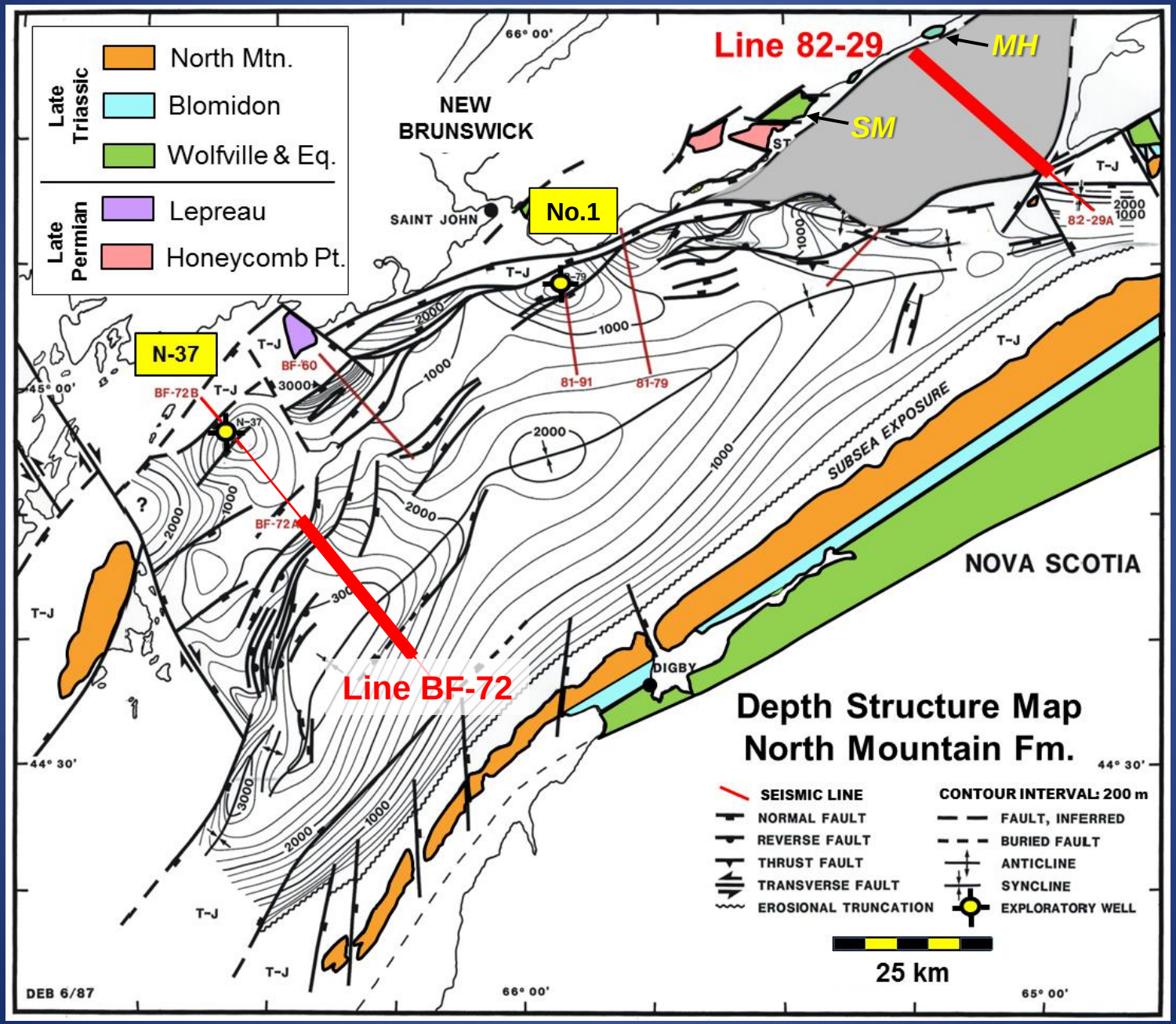


Fundy Basin Stratigraphy

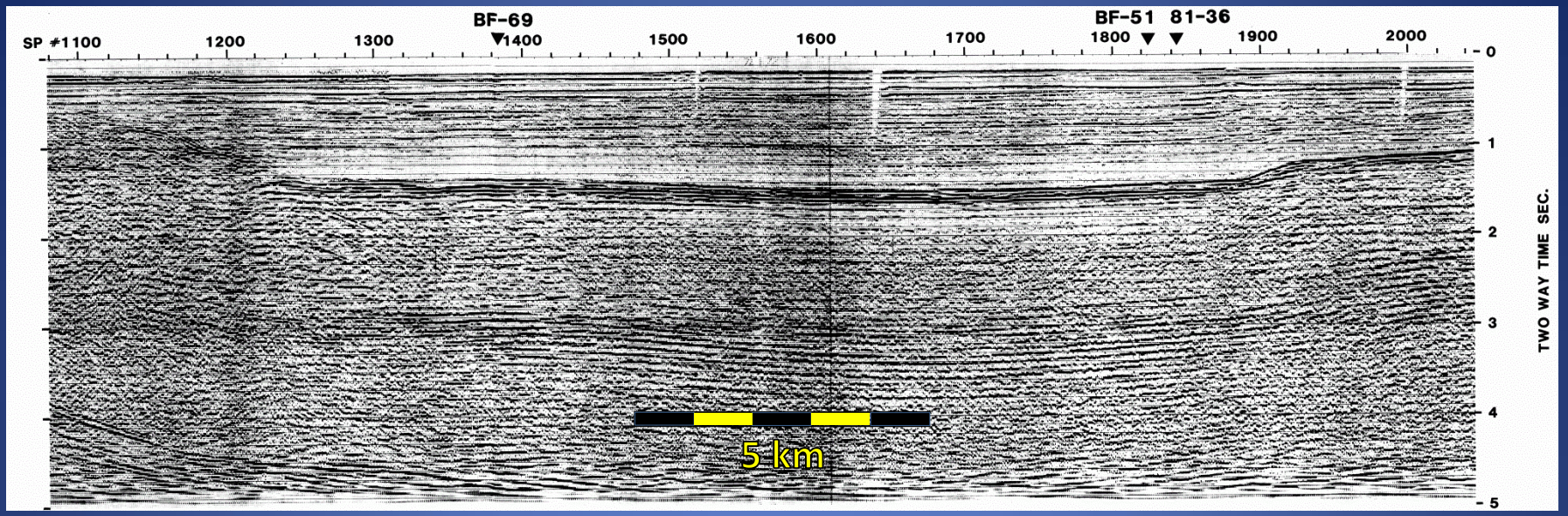
MYA	AGE	TS	LITH.	FORMATION	THICKNESS (m)	
					Onshore	Offshore
	HETTANGIAN	IV		McCoy Brook	140	3000+
201.3						
	RHAETIAN	IV		North Mountain	275	~1000
201.7						
~208.5	NORIAN	III		Blomidon	475	~3000
~227	CARNIAN	II		Wolfville	450	~3000
~242	ANISIAN	II		Carrs Brook	65	?
~255	LATE PERMIAN	I		Honeycomb Point	450	?

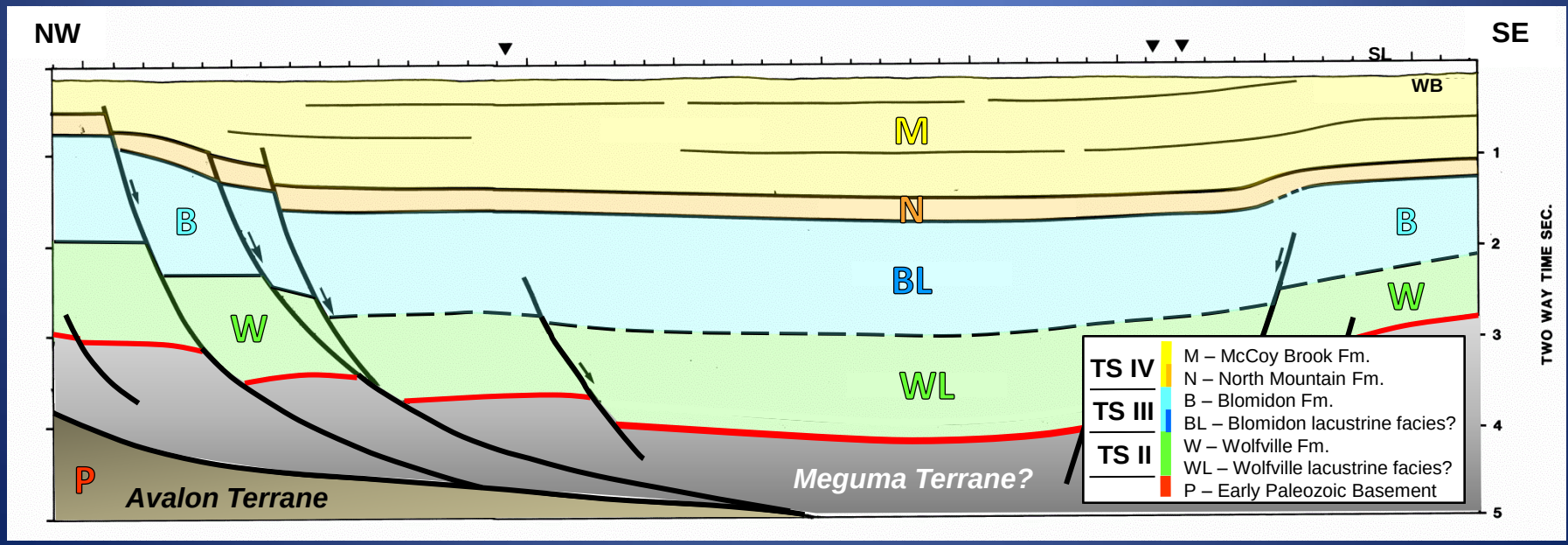


Fundy Basin

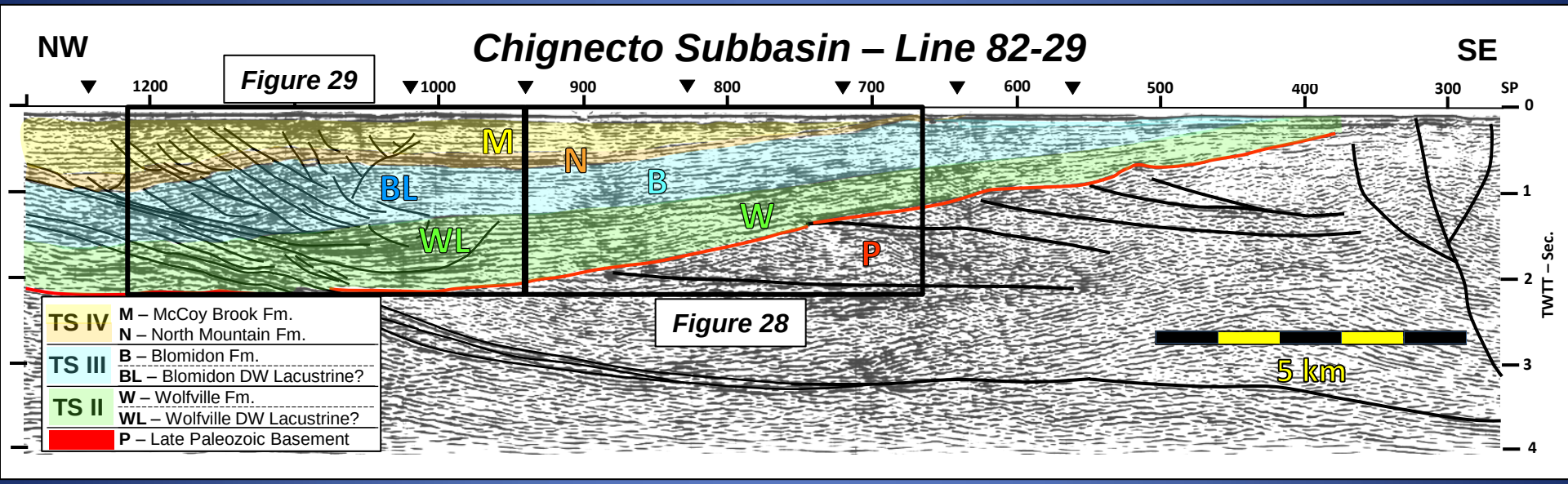

Late Triassic
North Mtn.
Blomidon
Wolfville & Eq.
Late Permian
Lepreau
Honeycomb Pt.
Line 82-29
MH
SM
NEW BRUNSWICK
SAINT JOHN
No.1
N-37
BF-60
BF-72B
BF-72A
81-91
81-79
82-29A
SUBSEA EXPOSURE
NOVA SCOTIA
DIGBY
Line BF-72
Depth Structure Map
North Mountain Fm.
SEISMIC LINE
NORMAL FAULT
REVERSE FAULT
THRUST FAULT
TRANSVERSE FAULT
EROSIONAL TRUNCATION
CONTOUR INTERVAL: 200 m
FAULT, INFERRED
BURIED FAULT
ANTICLINE
SYNCLINE
EXPLORATORY WELL
25 km
DEB 6/87
66° 00'
65° 00'
45° 00'
44° 30'

Fundy – Line BF-72

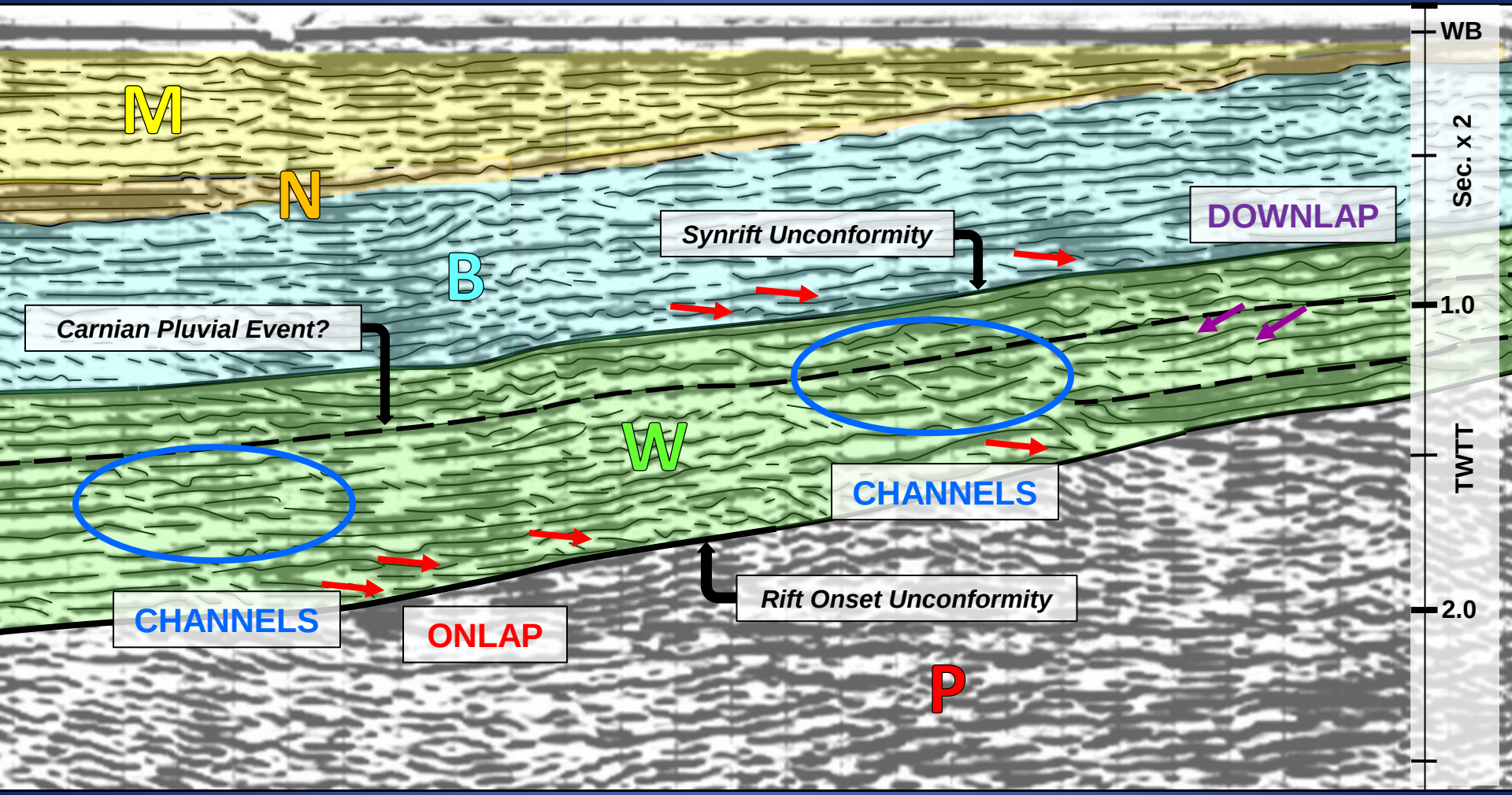




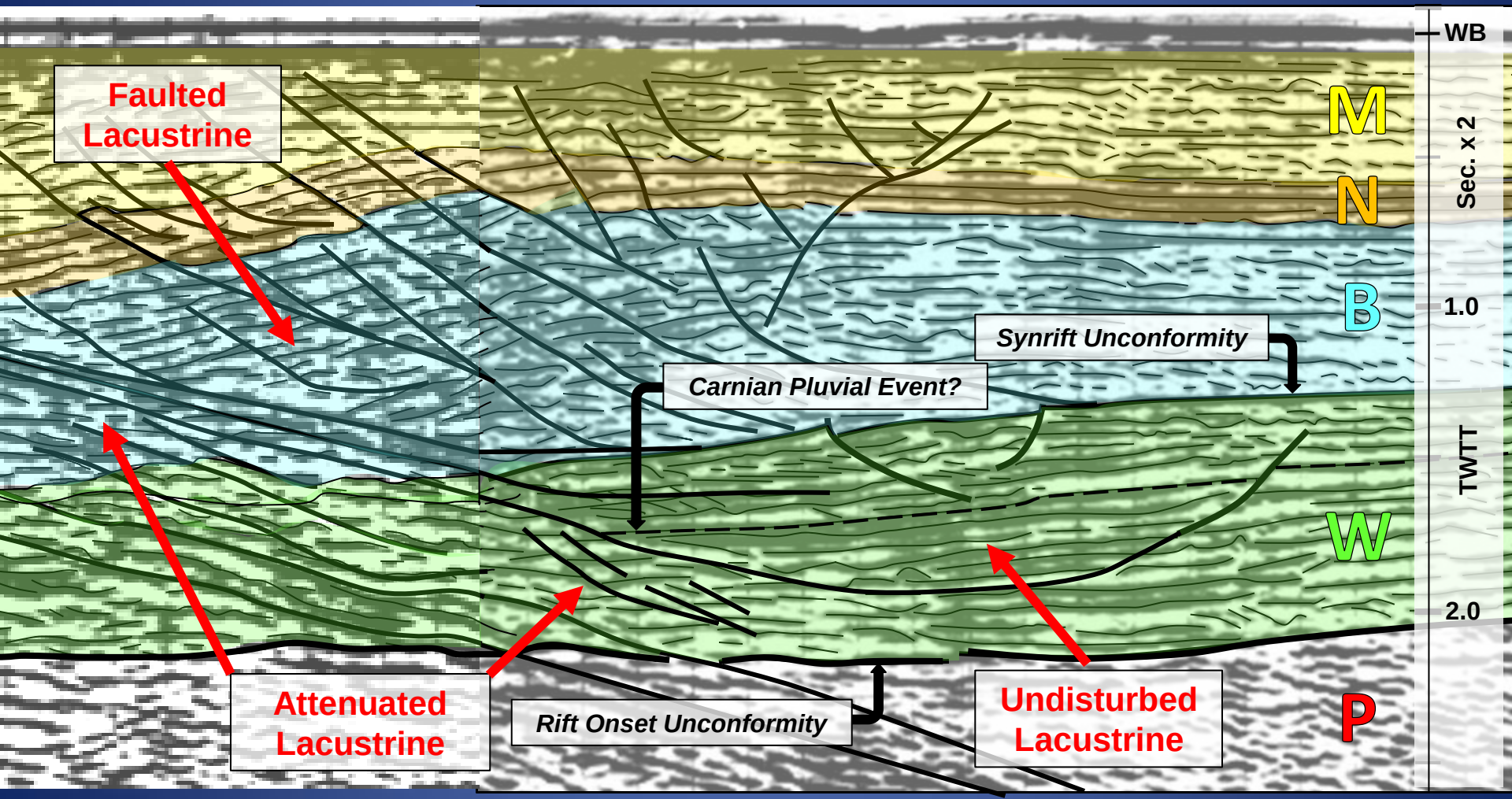
Chignecto – Line 82-29



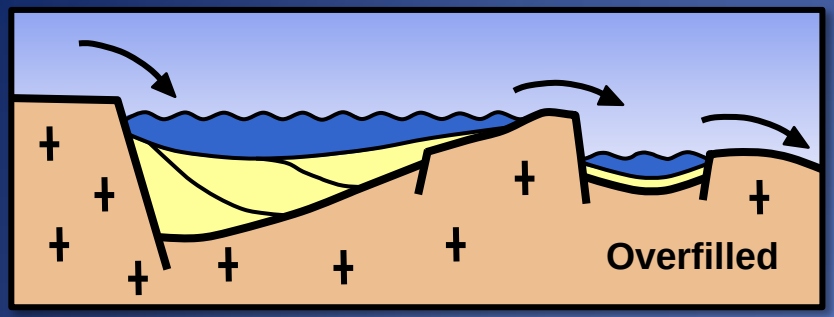
Chignecto – Line 82-29 (C)

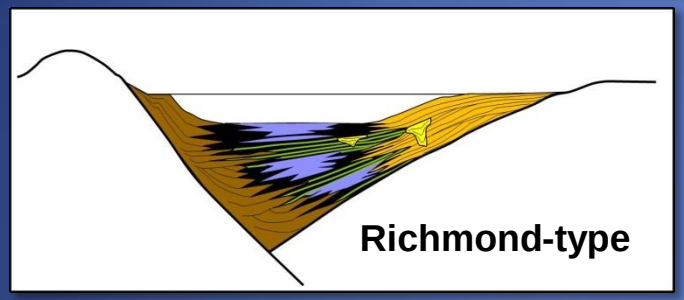


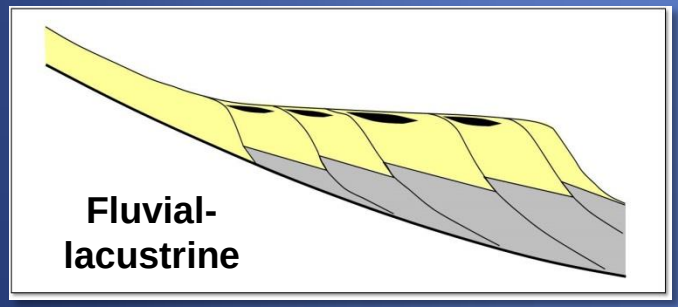
Chignecto – Line 82-29 (W)



LOWER Wolfville

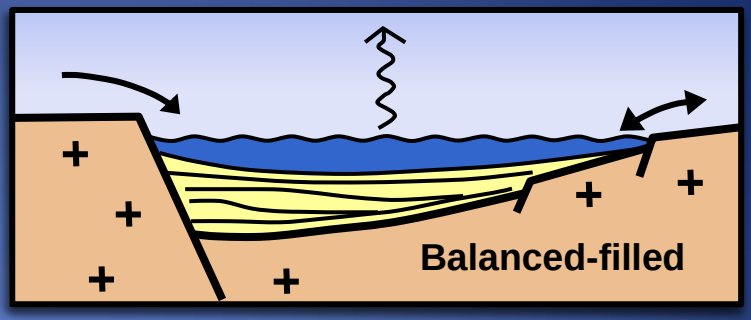


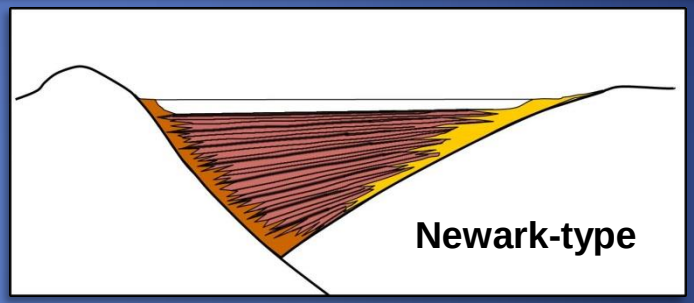


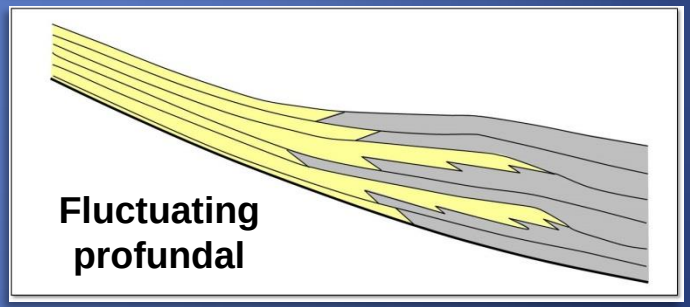


- *Overfilled / Richmond-type basin*
- *Deposition > subsidence*
- *Progradational strata*
- *Fluvial-lacustrine facies*
- *Low-moderate % TOCs*
- *Types I-III kerogens*

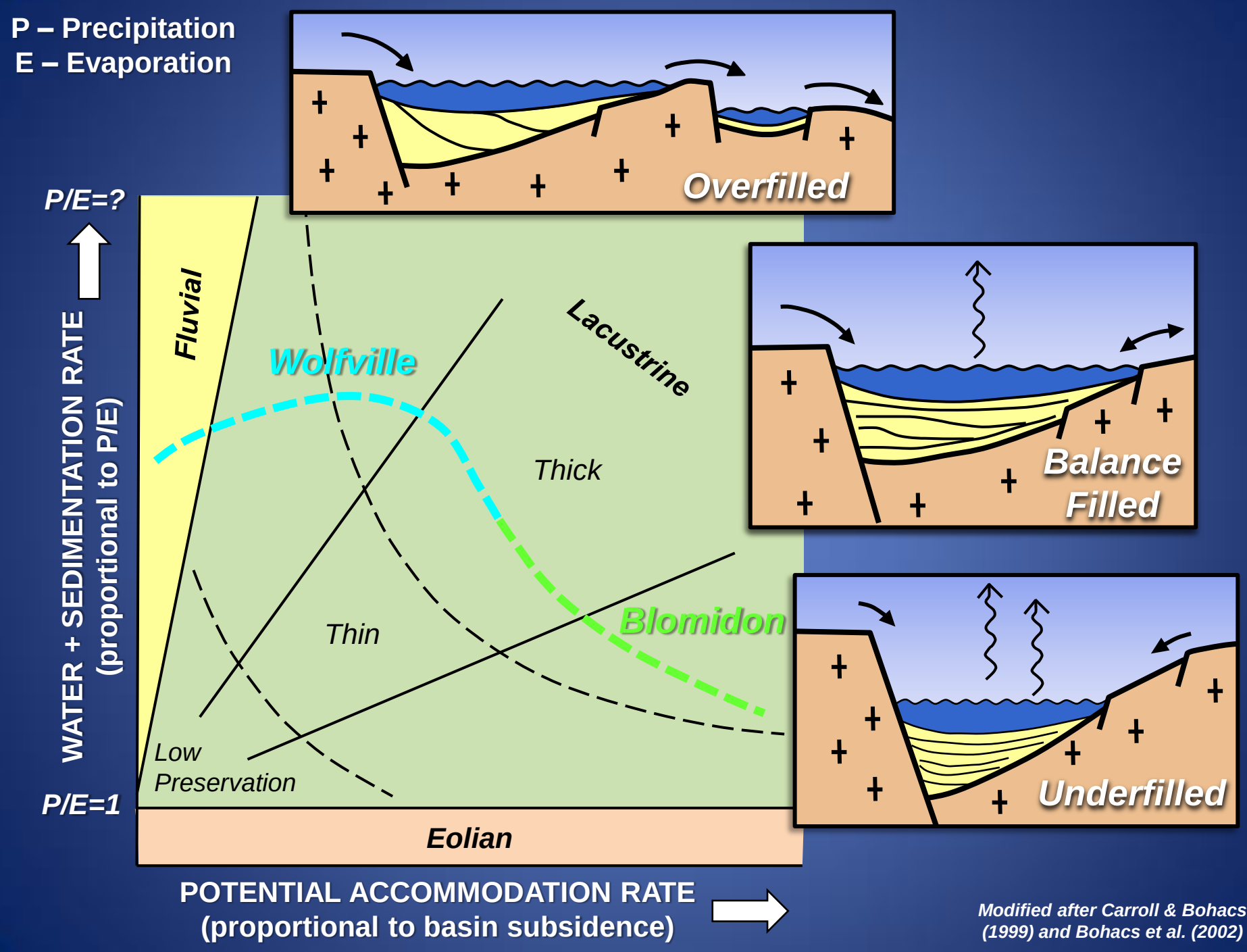
UPPER Wolfville

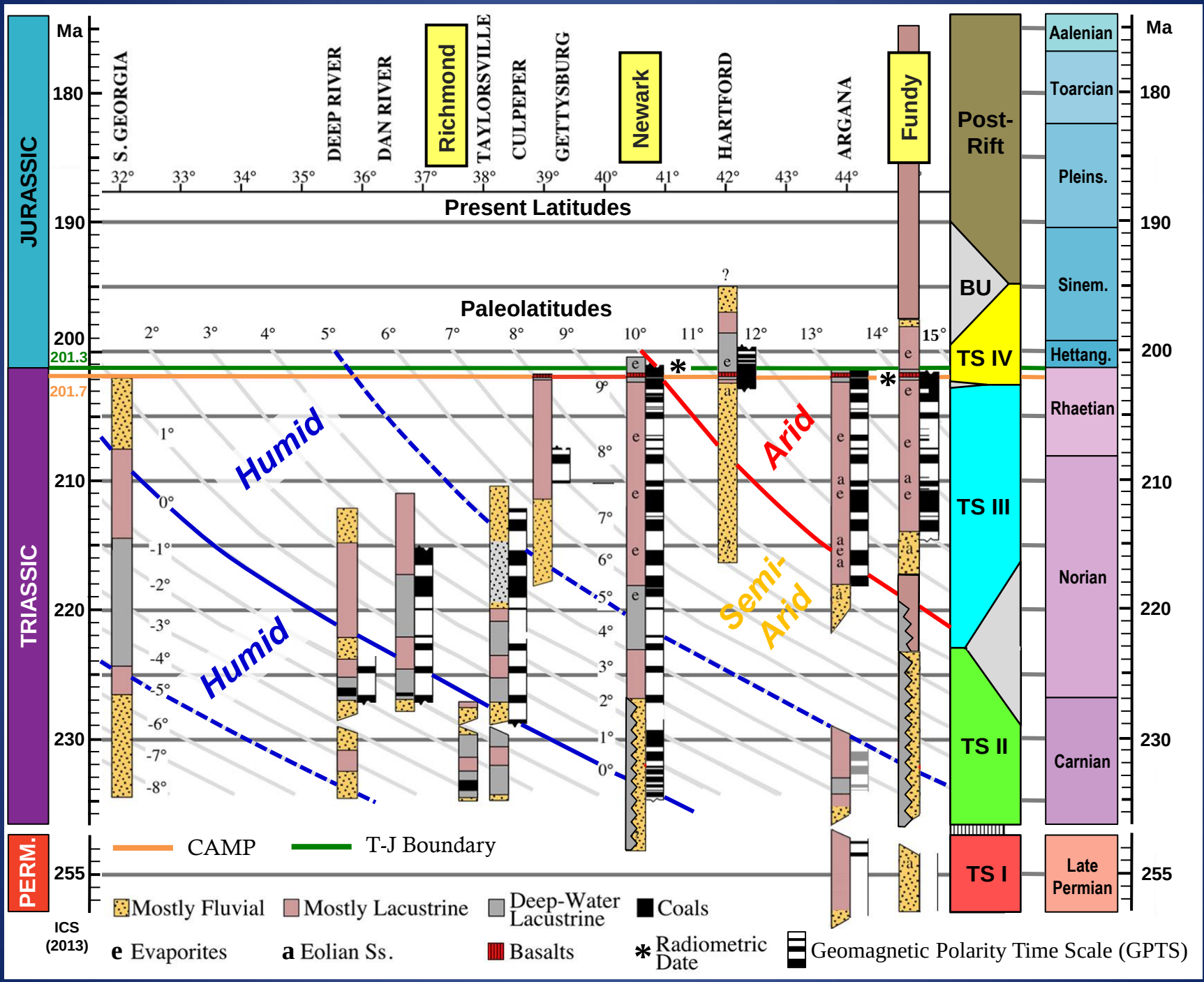


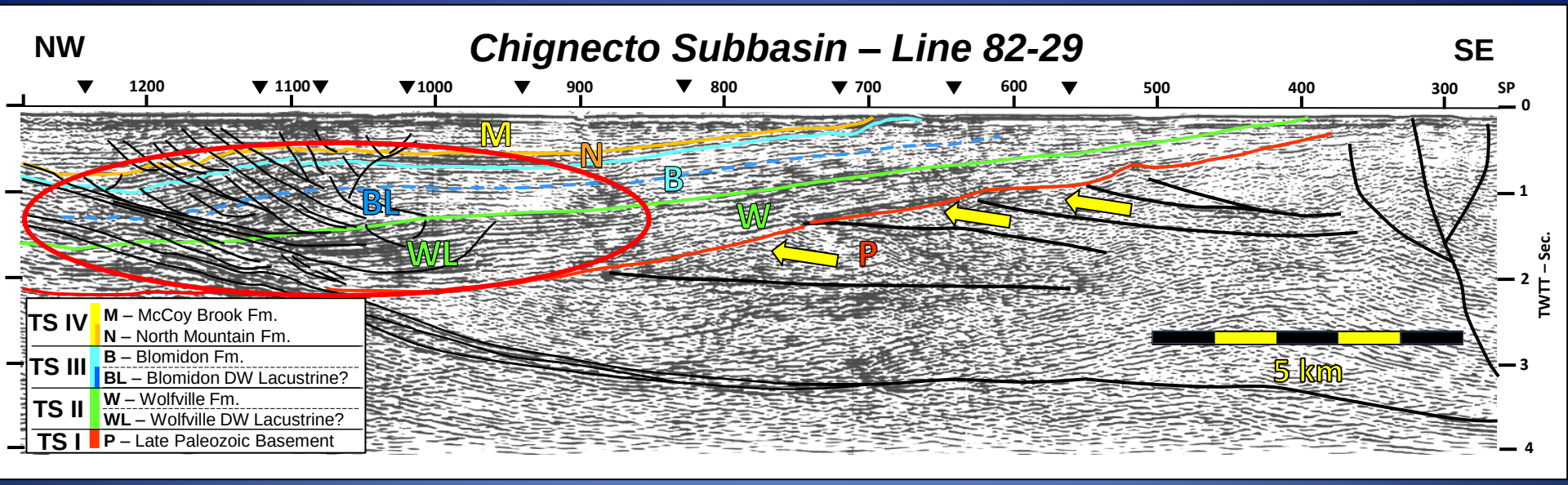


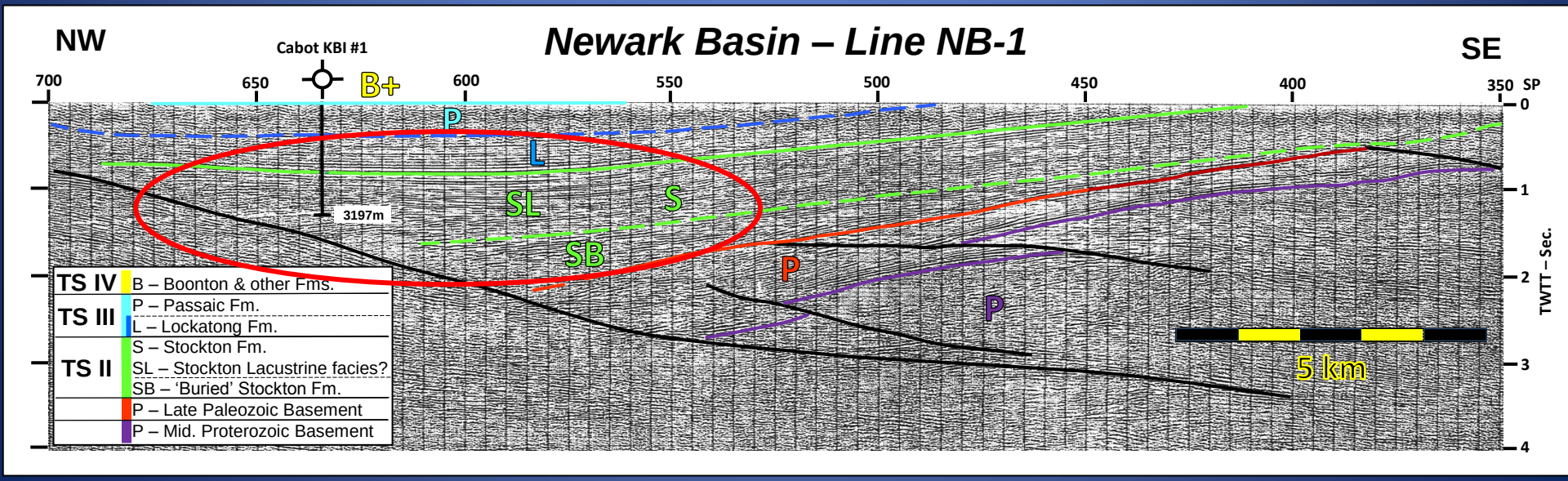


- *Balanced filled / Newark-type basin*
- *Deposition ≈ subsidence*
- *Aggradational strata*
- *Fluctuating profundal facies*
- *Moderate to high % TOCs*
- *Type I kerogens*


P – Precipitation
E – Evaporation
Overfilled
P/E=?
WATER + SEDIMENTATION RATE
(proportional to P/E)
Fluvial
Wolfville
Lacustrine
Thick
Balance
Filled
Blomidon
Thin
Low
Preservation
Underfilled
P/E=1
Eolian
POTENTIAL ACCOMMODATION RATE
(proportional to basin subsidence)
Modified after Carroll & Bohacs
(1999) and Bohacs et al. (2002)


JURASSIC
TRIASSIC
PERM.
Ma
180
190
200
210
220
230
255
201.3
201.7
S. GEORGIA
DEEP RIVER
DAN RIVER
Richmond
TAYLORSVILLE
CULPEPER
GETTYSBURG
Newark
HARTFORD
ARGANA
Fundy
32° 33° 34° 35° 36° 37° 38° 39° 40° 41° 42° 43° 44°
Present Latitudes
Paleolatitudes
2° 3° 4° 5° 6° 7° 8° 9° 10° 11° 12° 13° 14° 15°
1° 0° -1° -2° -3° -4° -5° -6° -7° -8°
9° 8° 7° 6° 5° 4° 3° 2° 1° 0°
Humid
Humid
Arid
Semi-Arid
Post-Rift
BU
TS IV
TS III
TS II
TS I
Aalenian
Toarcian
Pleins.
Sinem.
Hettang.
Rhaetian
Norian
Carnian
Late Permian
CAMP
T-J Boundary
Mostly Fluvial
Mostly Lacustrine
Deep-Water Lacustrine
Coals
e Evaporites
a Eolian Ss.
Basalts
Radiometric Date
Geomagnetic Polarity Time Scale (GPTS)
ICS (2013)

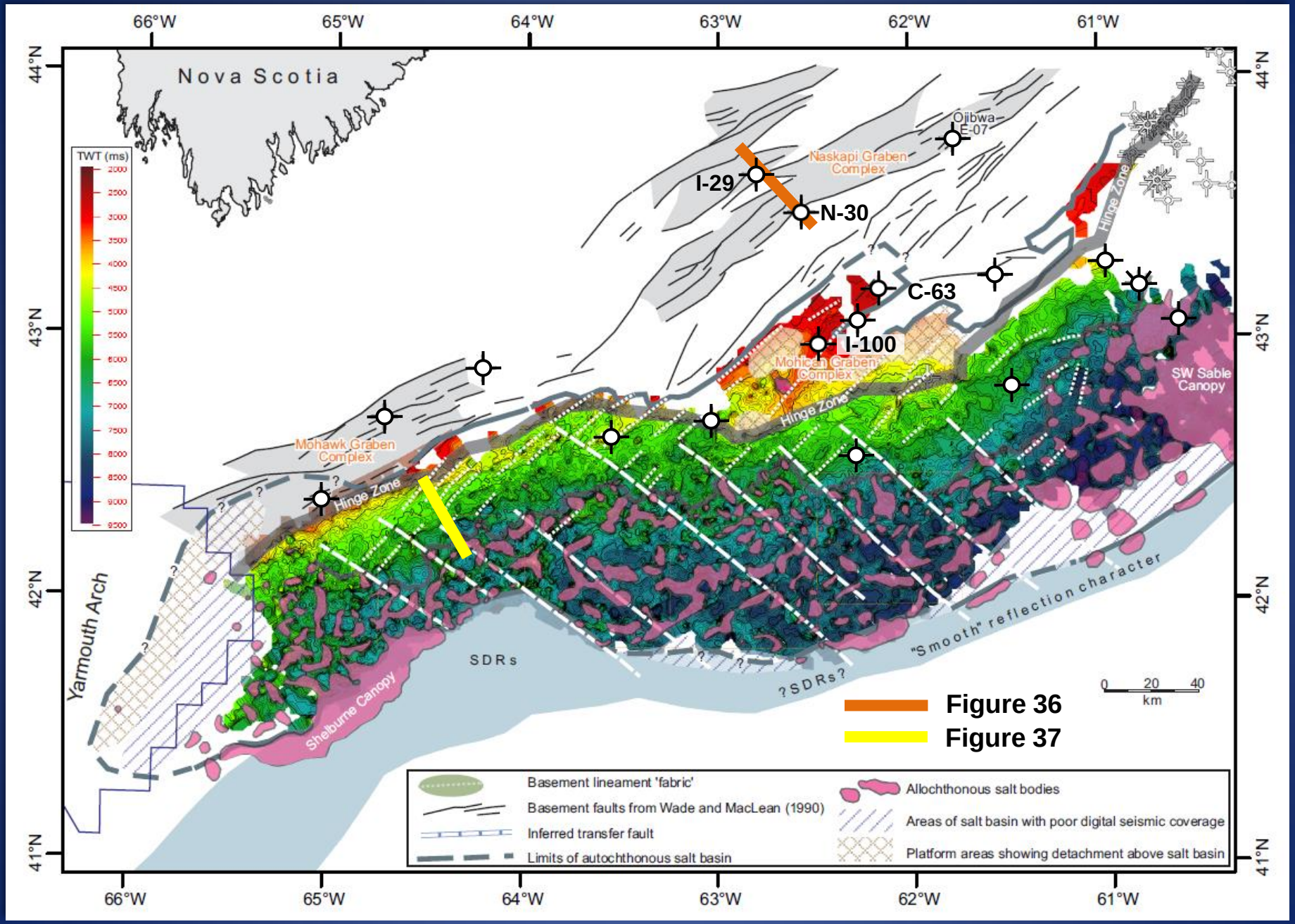

NW
Chignecto Subbasin – Line 82-29
SE
1200
1100
1000
900
800
700
600
500
400
300
SP
0
1
2
3
4
TWTT – Sec.
M
N
B
BL
W
WL
P
5 km
TS IV
M – McCoy Brook Fm.
N – North Mountain Fm.
TS III
B – Blomidon Fm.
BL – Blomidon DW Lacustrine?
TS II
W – Wolfville Fm.
WL – Wolfville DW Lacustrine?
TS I
P – Late Paleozoic Basement


NW
Cabot KBI #1
Newark Basin – Line NB-1
SE
700
650
600
550
500
450
400
350
SP
0
1
2
3
4
TWTT – Sec.
B+
P
L
SL
S
SB
3197m
P
P
5 km
TS IV
B – Boonton & other Fms.
TS III
P – Passaic Fm.
L – Lockatong Fm.
TS II
S – Stockton Fm.
SL – Stockton Lacustrine facies?
SB – 'Buried' Stockton Fm.
P – Late Paleozoic Basement
P – Mid. Proterozoic Basement

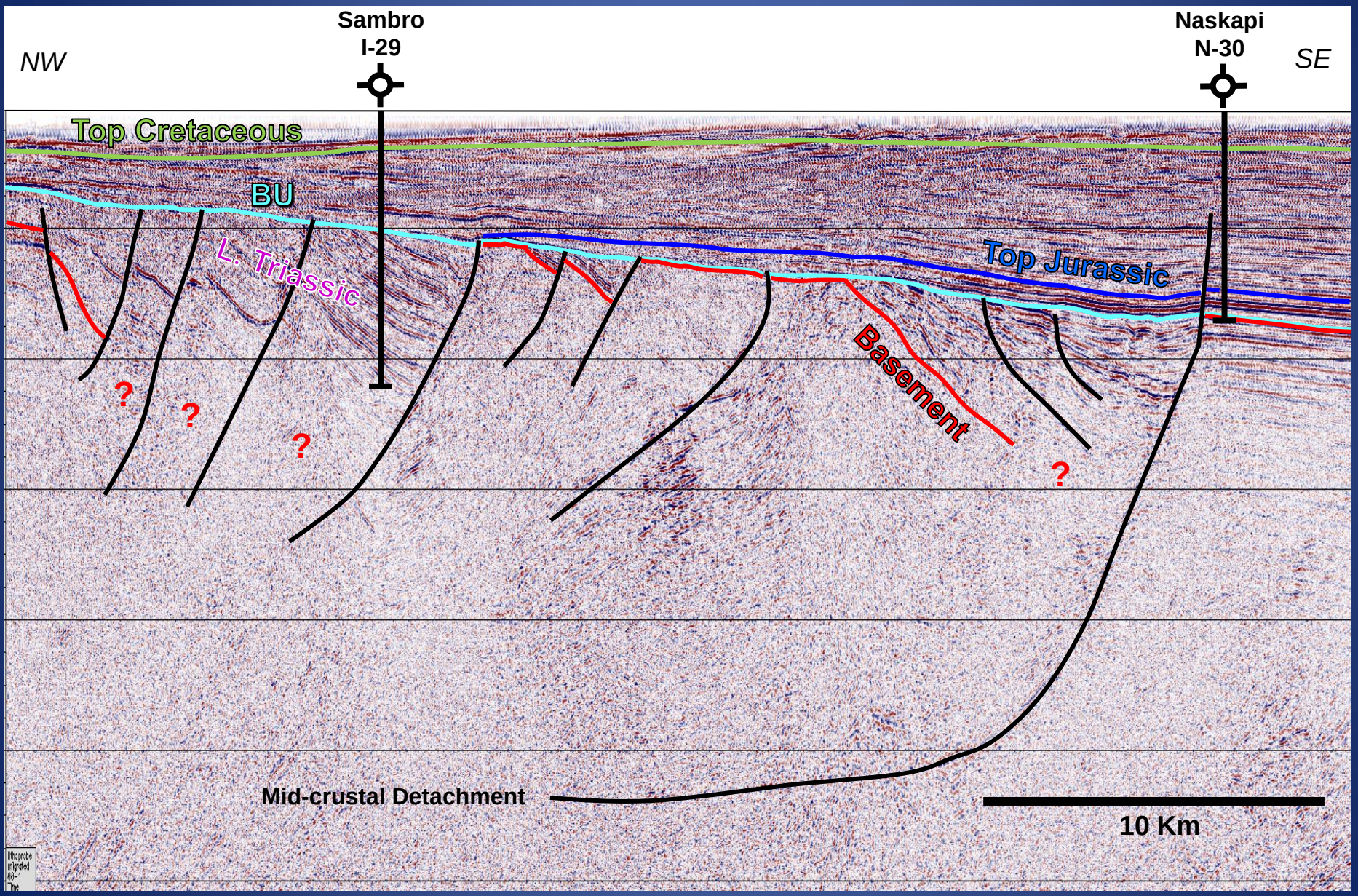
Newark SG Basins Source Rocks

BASIN	FORMATION	AGE [1]	PALEO-LATITUDE [2]	TS UNIT [3]	TOC (wt.%)		KEROGEN TYPE	REFERENCE
					Range	Average		
Hartford	Portland	E. Hettangian	~11°N	IV	--	3.2	II	Pratt *et al.* (1985)
	East Berlin	E. Hettangian	~11°N	IV	1.2-3.8	--	II [4]	Pratt *et al.* (1986)
Newark	Towaco	E. Hettangian	~9°N	IV	0.44-2.21	1.07	II	Katz *et al.* (1988)
					0.82-3.65	2.18	II [4]	Pratt *et al.* (1986)
	Feltville	E. Hettangian	~9°N	IV	0.33-11.24	2.38	I, II	Katz *et al.* (1988)
	Passaic	Carnian – Rhaetian	~6-9°N	III (Up.)	0.14-3.57	1.23	--	Katz *et al.* (1988)
					0.39-2.31	1.51	II [4]	Pratt *et al.* (1986)
	Lockatong	L. Carnian	~4-6°N	III (Lr.)	0.03-1.56	0.27	II [4]	PA-DCNR (2014)
					0.08-9.13	1.22	--	Katz *et al.* (1988)
					0.17-3.22	1.68	II [4]	Pratt *et al.* (1986)
Culpeper	Waterfall	E. Hettangian	~8°N	IV	--	~2	I, II	Smith & Robison (1988)
	Buckland	E. Hettangian	~8°N	IV	--	~1	I-II	Smith & Robison (1988)
					~0.5-7.0	~2.6	II	Pratt *et al.* (1985)
	Bull Run	L. Norian	~6-8°N	II	--	~0.8	III	Smith & Robison (1988)
Richmond-Taylorsville	Tuckahoe (Vinita Mb.)	M. Carnian	~1-3°S	II	~10	--	I	Olsen (1985)
Dan River	Cow Branch	E. Norian	~2-3°N	III	0.81-8.31	3.42	II, III	Reid & Milici (2008)
Deep River (Sanford)	Cumnock	E. Norian	~2°S	II	0.20-33.62	5.17	I, (II)	Reid & Milici (2008)
					0.10-6.242	1.33	Not stated	Reid *et al.* (2014)

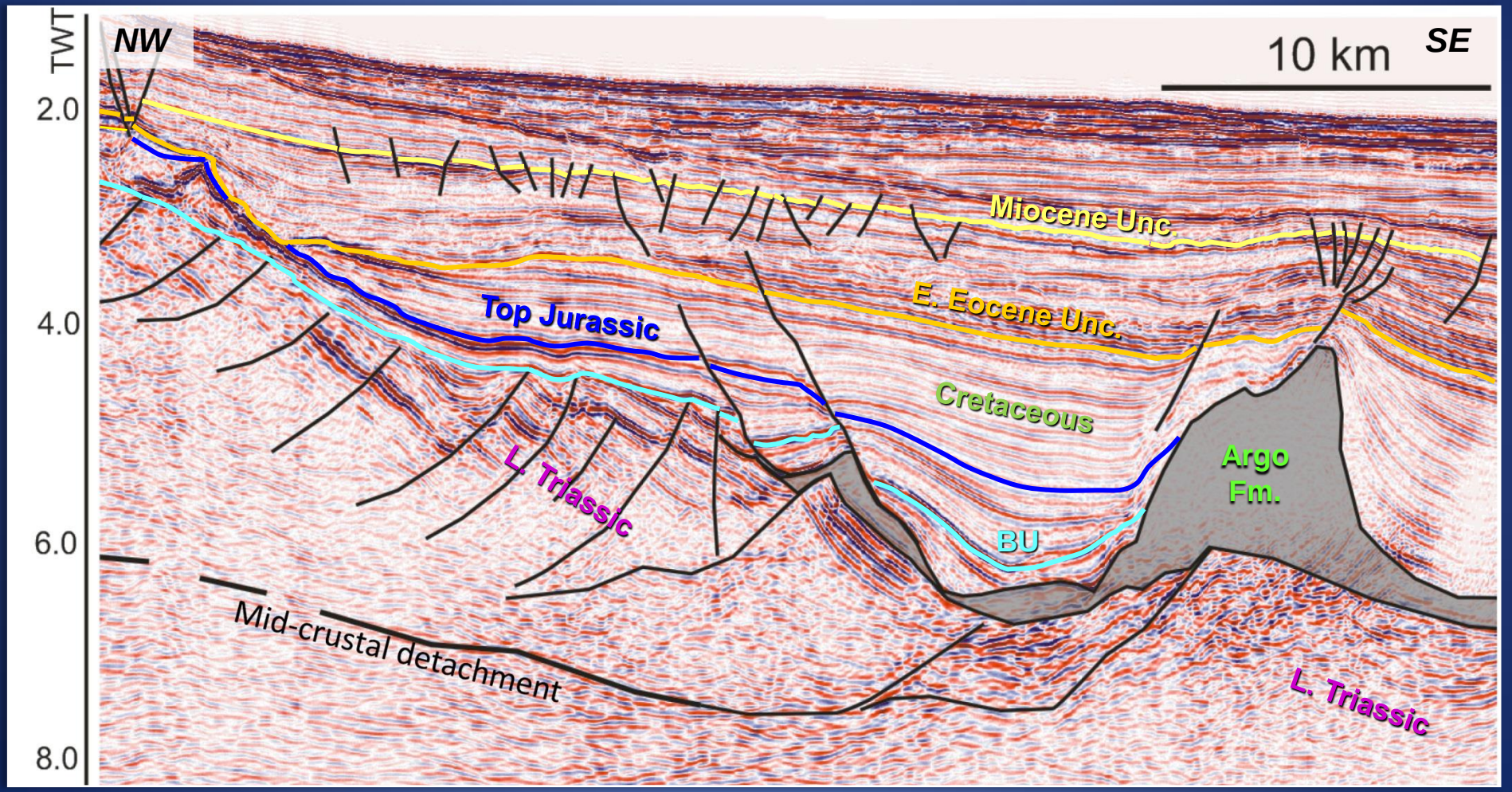
[1] Time scale from ICS (2014) and included in the revised nomogram (Figure 31) of Olsen *et al.* (2010).
[2] Approximate paleo-latitudes determined from the revised nomogram (Figure 31) of Olsen *et al.* (2010).
[3] Tectonostratigraphic units (TS) from Olsen (1997).
[4] Pratt *et al.* (1985).


66°W
65°W
64°W
63°W
62°W
61°W
44°N
43°N
42°N
41°N
Nova Scotia
TWT (ms)
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
I-29
N-30
Ojibwa E-07
Naskapi Graben Complex
Hinge Zone
C-63
I-100
Mohican Graben Complex
Hinge Zone
SW Sable Canopy
Mohawk Graben Complex
Hinge Zone
Yarmouth Arch
SDRs
?SDRs?
"Smooth" reflection character
Shelburne Canopy
0 20 40
km
Figure 36
Figure 37
Basement lineament 'fabric'
Basement faults from Wade and MacLean (1990)
Inferred transfer fault
Limits of autochthonous salt basin
Allochthonous salt bodies
Areas of salt basin with poor digital seismic coverage
Platform areas showing detachment above salt basin

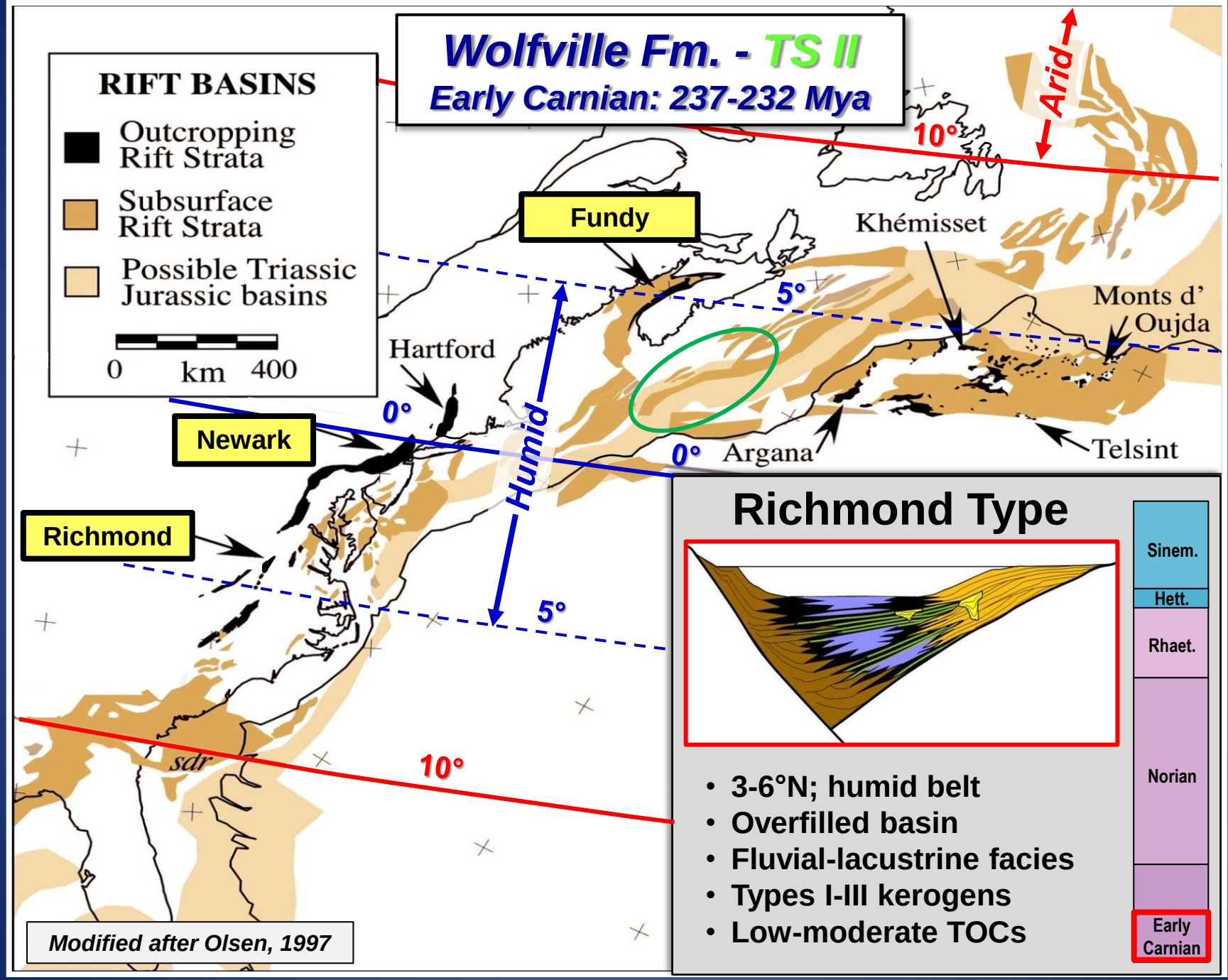
LaHave Platform – Line AGC 88-1

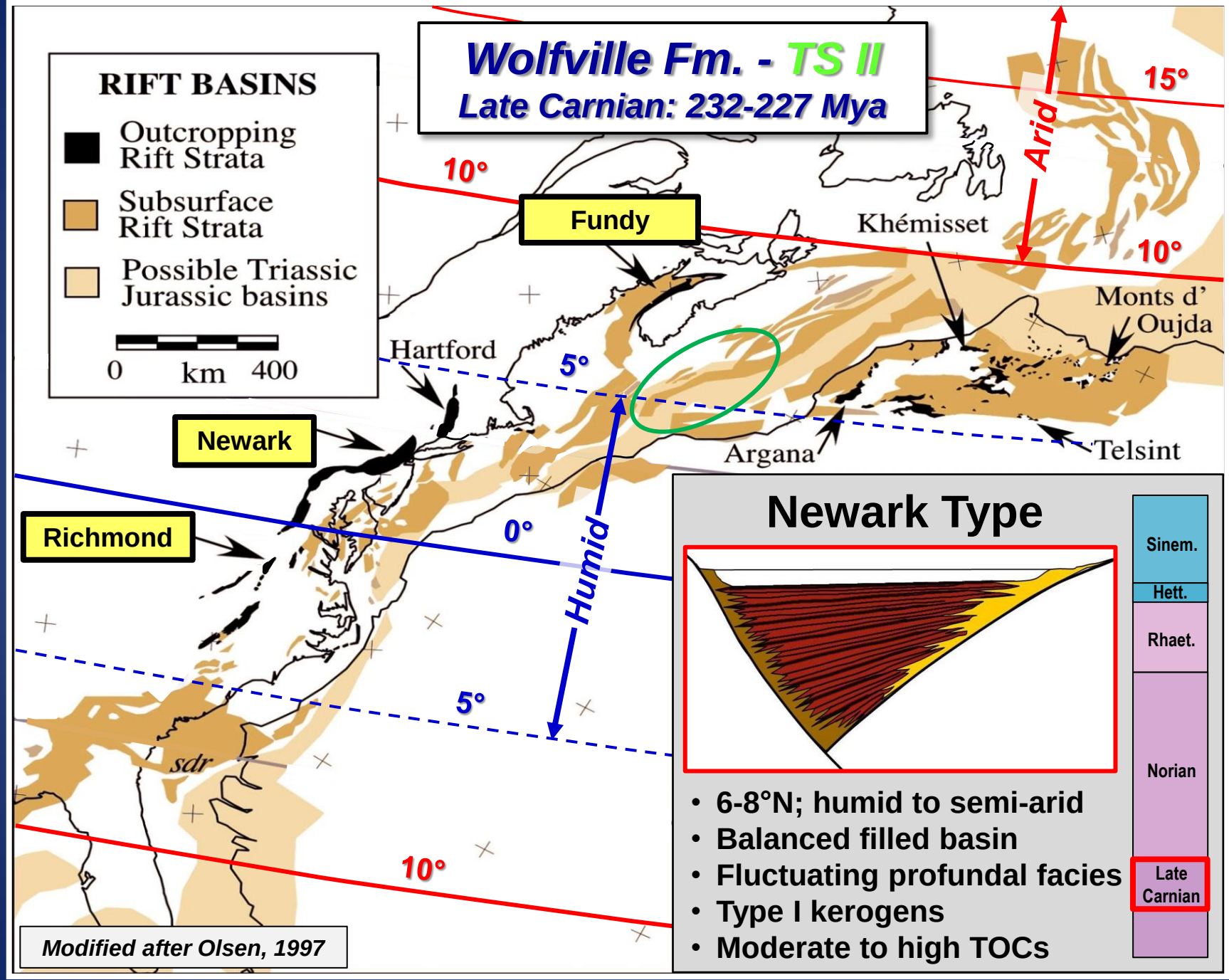


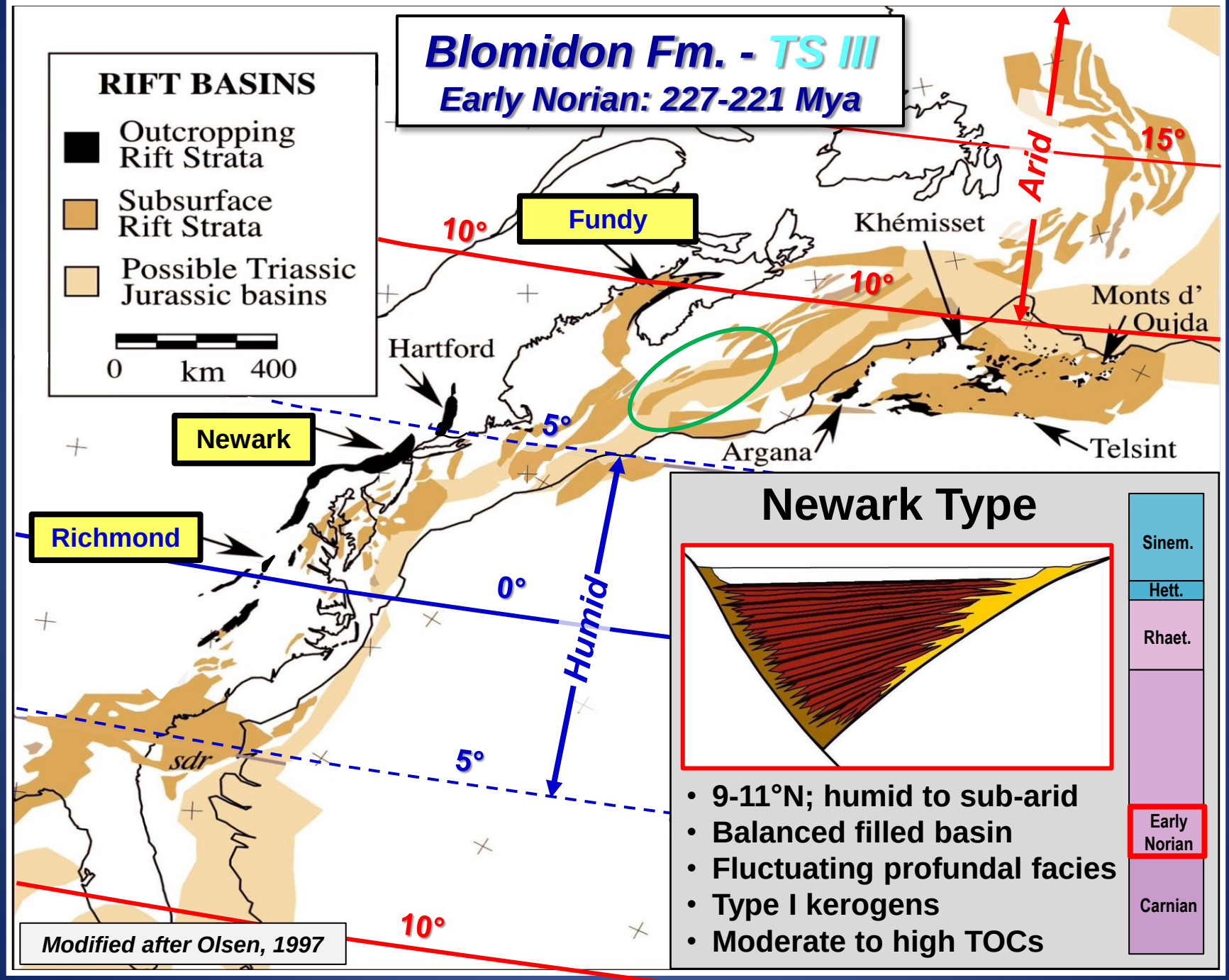
SW Scotian Slope



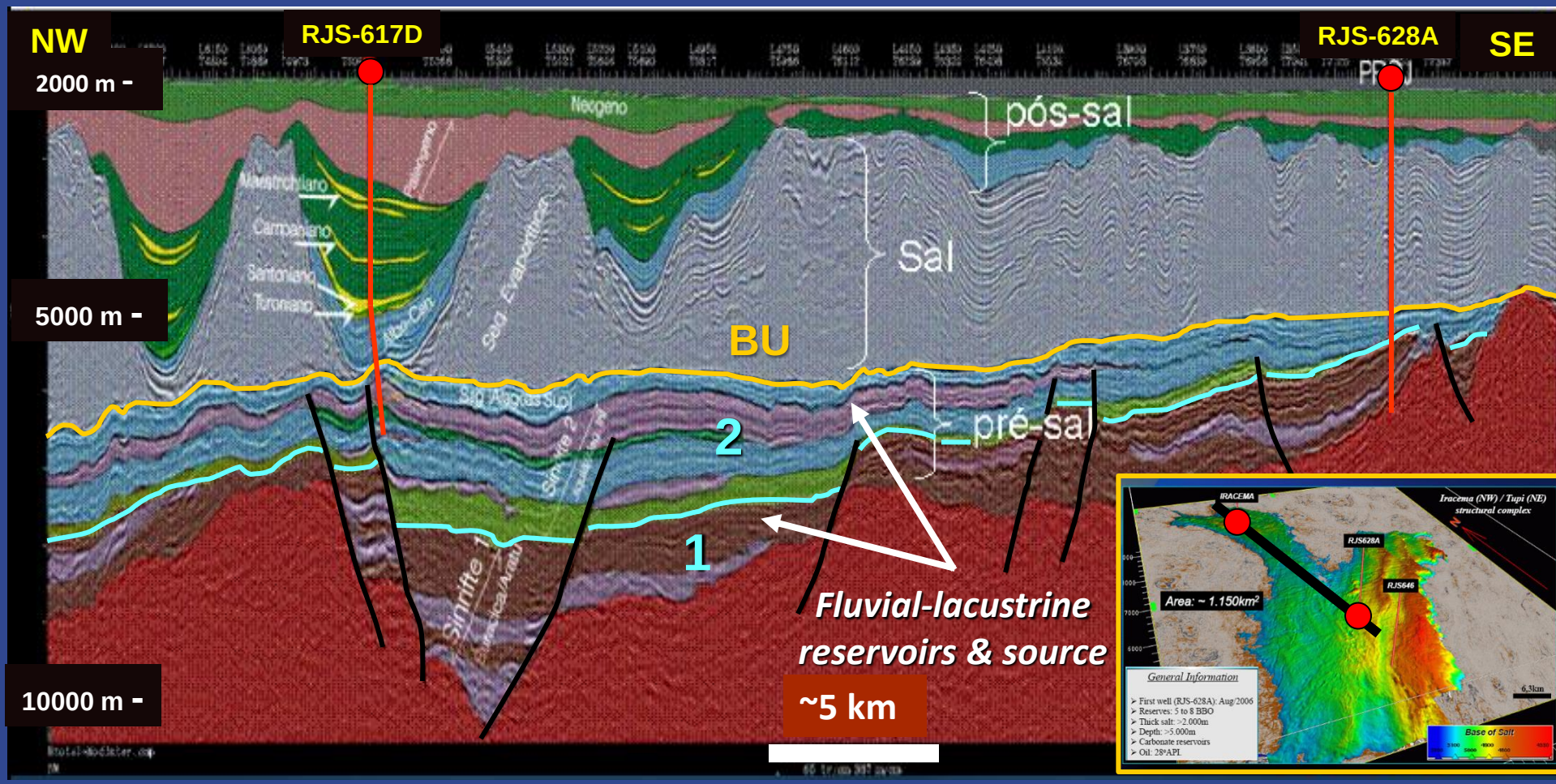
Deptuck (2011)


Wolfville Fm. - TS II
Early Carnian: 237-232 Mya
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
Arid
10°
Fundy
Khémisset
5°
Monts d' Oujda
Hartford
0°
Newark
Humid
0°
Argana
Telsint
Richmond
5°
sdr
10°
Modified after Olsen, 1997
Richmond Type
Sinem.
Hett.
Rhaet.
Norian
Early Carnian
• 3-6°N; humid belt
• Overfilled basin
• Fluvial-lacustrine facies
• Types I-III kerogens
• Low-moderate TOCs


Wolfville Fm. - TS II
Late Carnian: 232-227 Mya
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
Fundy
Newark
Richmond
Hartford
Khémisset
Monts d' Oujda
Argana
Telsint
sdr
15°
10°
5°
0°
5°
10°
Arid
Humid
Modified after Olsen, 1997
Newark Type
Sinem.
Hett.
Rhaet.
Norian
Late Carnian
• 6-8°N; humid to semi-arid
• Balanced filled basin
• Fluctuating profundal facies
• Type I kerogens
• Moderate to high TOCs


Blomidon Fm. - TS III
Early Norian: 227-221 Mya
RIFT BASINS
Outcropping Rift Strata
Subsurface Rift Strata
Possible Triassic Jurassic basins
0 km 400
Fundy
Hartford
Newark
Richmond
Khémisset
Monts d' Oujda
Argana
Telsint
sdr
Arid
Humid
15°
10°
10°
5°
0°
5°
10°
Newark Type
Sinem.
Hett.
Rhaet.
Early Norian
Carnian
• 9-11°N; humid to sub-arid
• Balanced filled basin
• Fluctuating profundal facies
• Type I kerogens
• Moderate to high TOCs
Modified after Olsen, 1997

Santos Basin – Pre-Salt



Modified after Formigli (Petrobras), 2007

Conclusions & Insights

- ***TS II / III: interpreted lacustrine facies deposited in overfilled to balanced filled lake basins.***
- ***Lake basin type, facies and proximity to equator considered to favour organic productivity.***
- ***Key Chignecto play elements identified with tectonic-induced fracturing within the Carnian-Norian prospective interval.***
- ***Potential exists for Late Triassic source rocks for offshore Nova Scotia pre-salt plays.***

END