Potential shelf sources for deepwater reservoirs along the southwestern Scotian Margin

….and the impact of a hybrid ‘bypass-ponded’ slope on reservoir distribution

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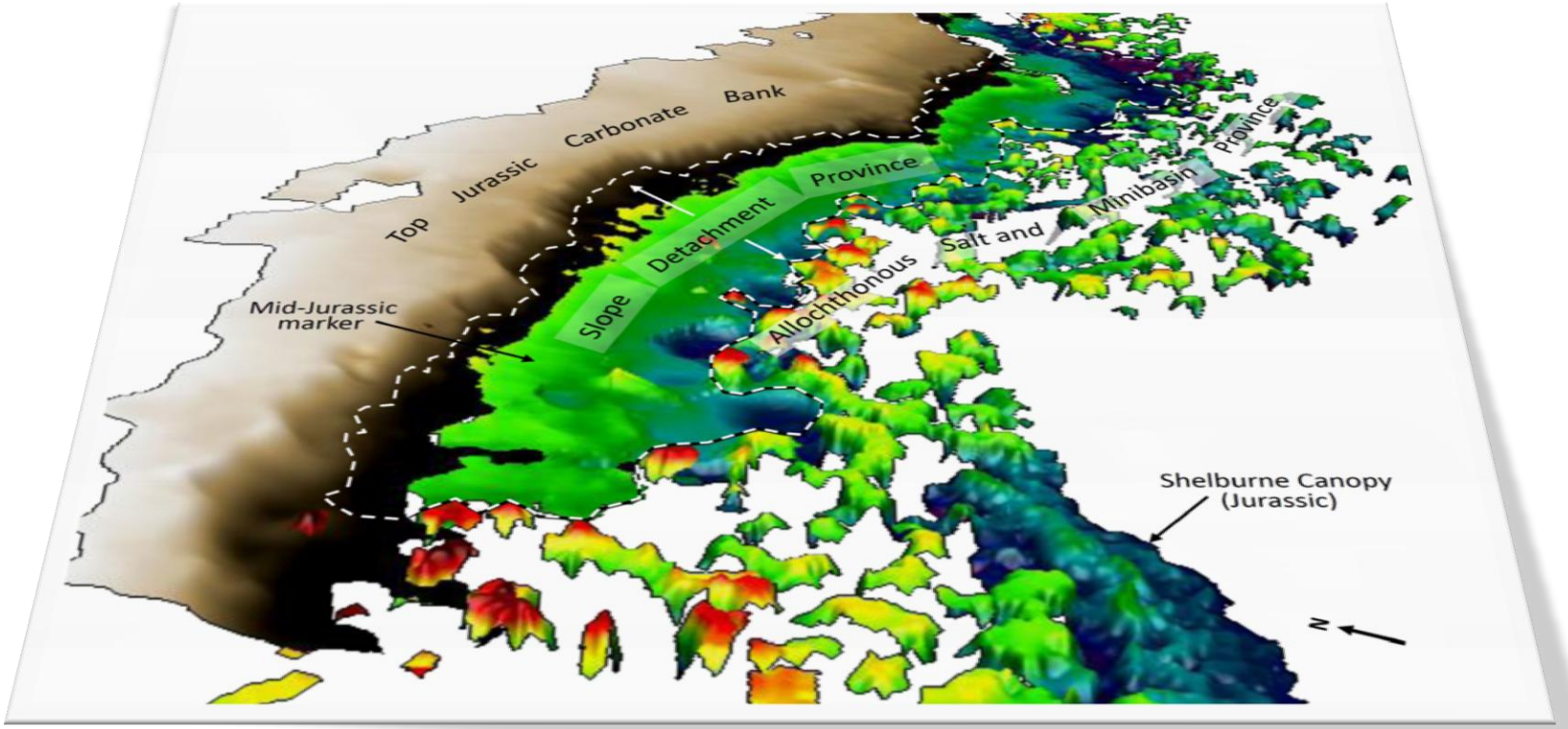


...for more details, see CNSOPB Geoscience Open File Report 2011-001MF

Key points of this talk

• The Mohican and Mohawk formations are the most likely sources for Jurassic deepwater reservoirs (the latter may have periodically breached the carbonate bank and supplied clastics directly onto the steep, heavily canyoned slope during periods of forced regression)

• foreslope to basinal resedimented carbonates (as in Tamabra) are worth further investigation

• The Sable Island Delta is the most likely source for Cretaceous deepwater reservoirs in the eastern parcels (NS11-1)

• Widespread erosion associated with the Montagnais bolide impact makes it hard to evaluate Cretaceous shelf sources further west, but multiple periods of canyoning indicate that sediment transport into deepwater did take place, and expanded Logan Canyon equivalent strata within minibasins warrants further study – Need 3D seismic data over these minibasins to properly evaluate!

• Southwestern margin is a hybrid bypass to ponded slope…. If Cretaceous reservoirs are present, they are likely to be thickest down-slope from slope detachment province (region of slope bypass), in an area where we simply don't have any well calibration yet

Objectives of this talk (and essentially the outline):

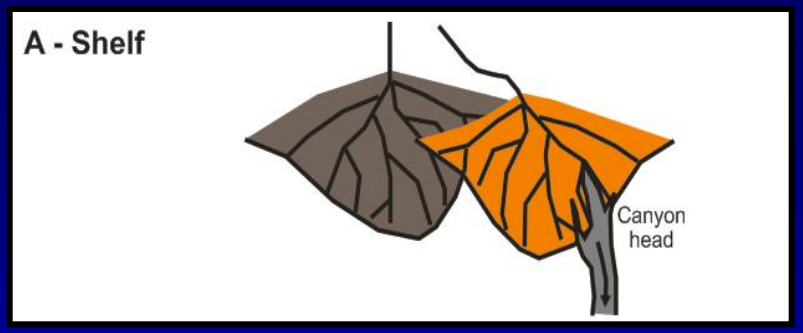
- To introduce you to the CNSOPB ongoing efforts to reduce uncertainty about the presence and distribution of deepwater reservoirs off Nova Scotia

- To highlight key learnings about why existing deepwater wells on the Scotian slope failed to find large quantities of reservoir

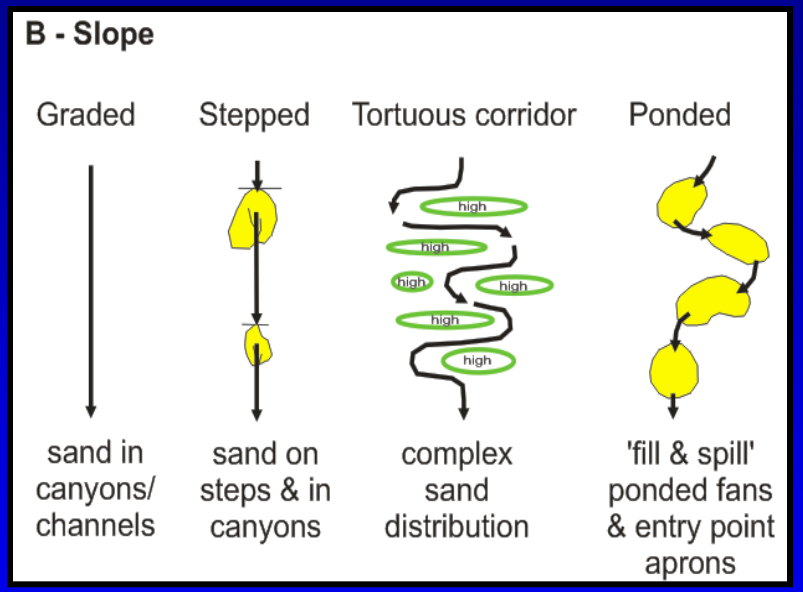
- To describe the morphology of the southwestern slope and highlight possible shelf sources that could have supplied reservoirs into deep water ***...ideas that warrant <u>further study</u>***

  -Jurassic
  -Cretaceous
  -Cenozoic

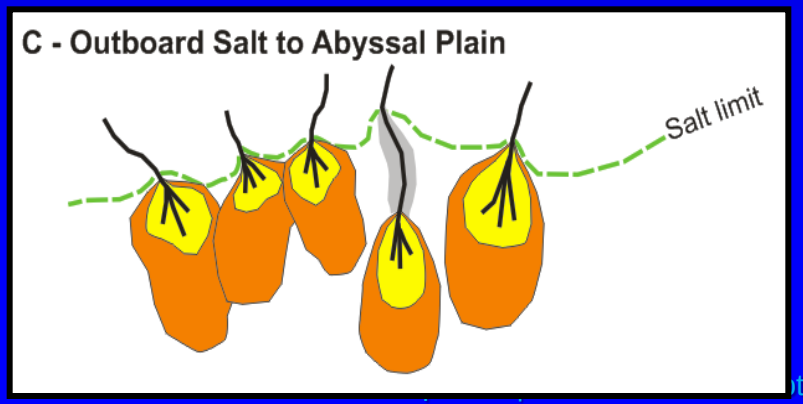
Piecing together the depositional systems from three directions:



Location of deltas and canyon heads through time – impacts down slope reservoir presence



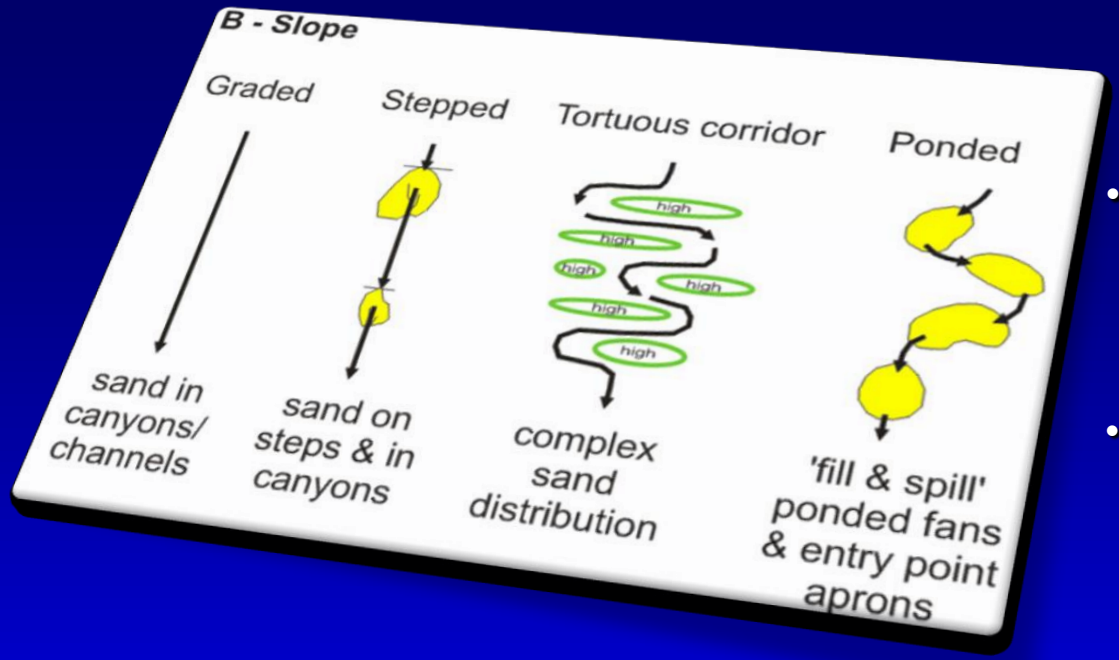
Temporal and spatial changes in slope morphology – impacts reservoir distribution (storage on slope vs basin floor)

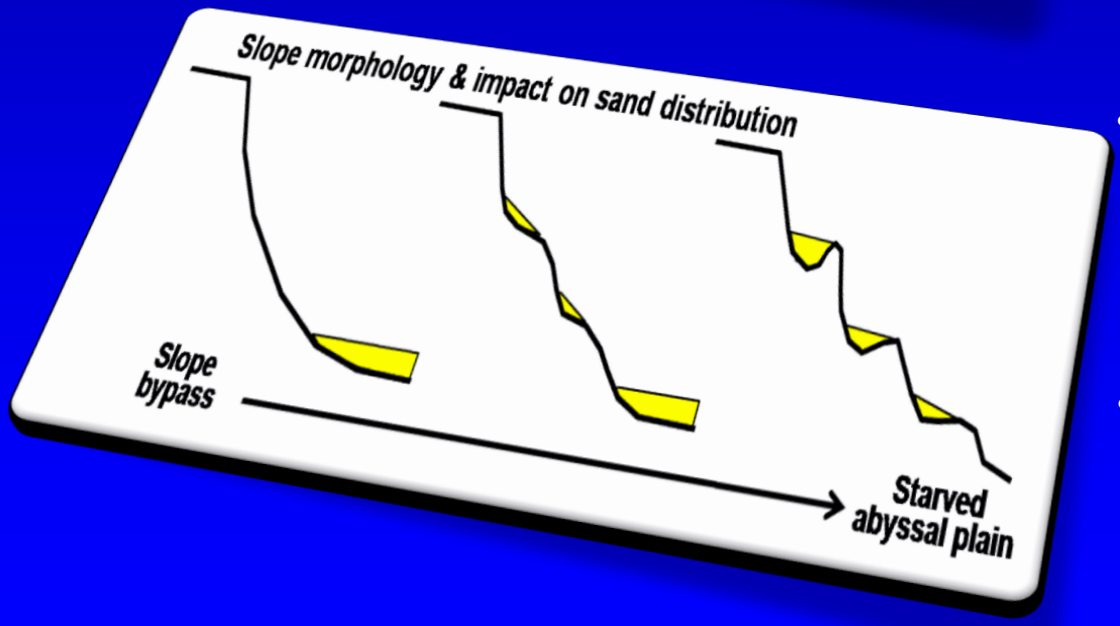


Fan systems that extend beyond the salt, onto the abyssal plain – provides a distal constraint for sediment transport corridors

Partitioning of clastics on the continental slope versus rise

- role of slope morphology -

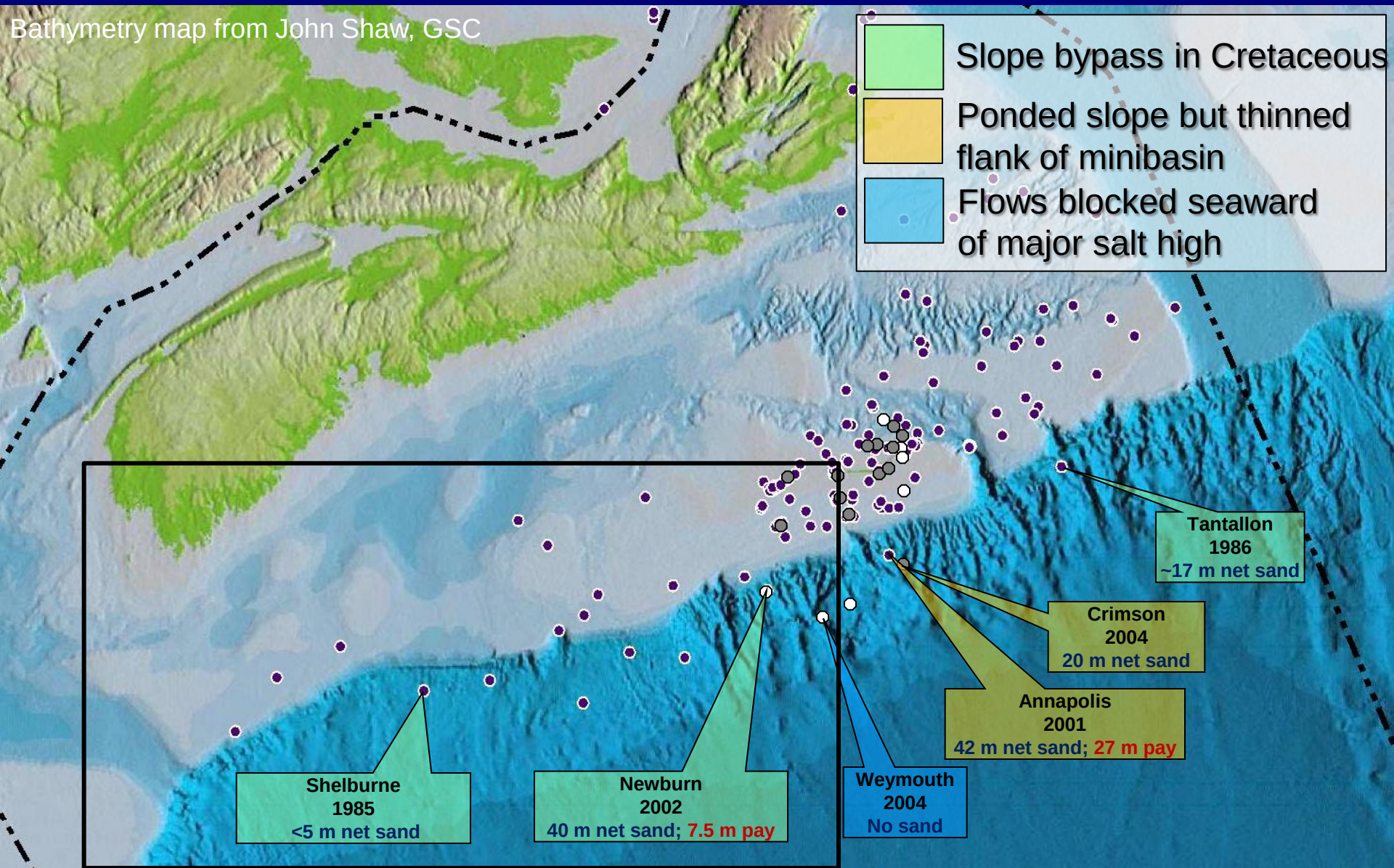




- Slopes with mobile substrates show a wide range of morphologies from graded, to simple steps, to complex corridors and ponded basins
- Degree of slope 'bumpiness' along a turbidite corridor probably depends on the rate of substrate mobility relative to the supply of sediment gravity flows capable of eroding highs and smoothing out lows
- Degree and shape of slope 'bumpiness' along a turbidite corridor controls the extent to which sands are stored on the slope or if they make it to the abyssal plain
- Preferential accumulation of sediment on the slope reflects the deceleration of sediment gravity flows upon encountered lower-gradient steps

What do we really know about turbidite potential?

Only 6 meaningful wells penetrated Lower Cretaceous deepwater strata (area >80 000 km^2)



Development of a bypass slope

- abrupt increase in postrift subsidence seaward of prominent hinge zone
- seaward tilting generated a steep bypass slope
- widespread detachment of Jurassic cover strata above variably thick autochthonous salt layer (raft tectonics)
- distinct absence of allochthonous salt bodies

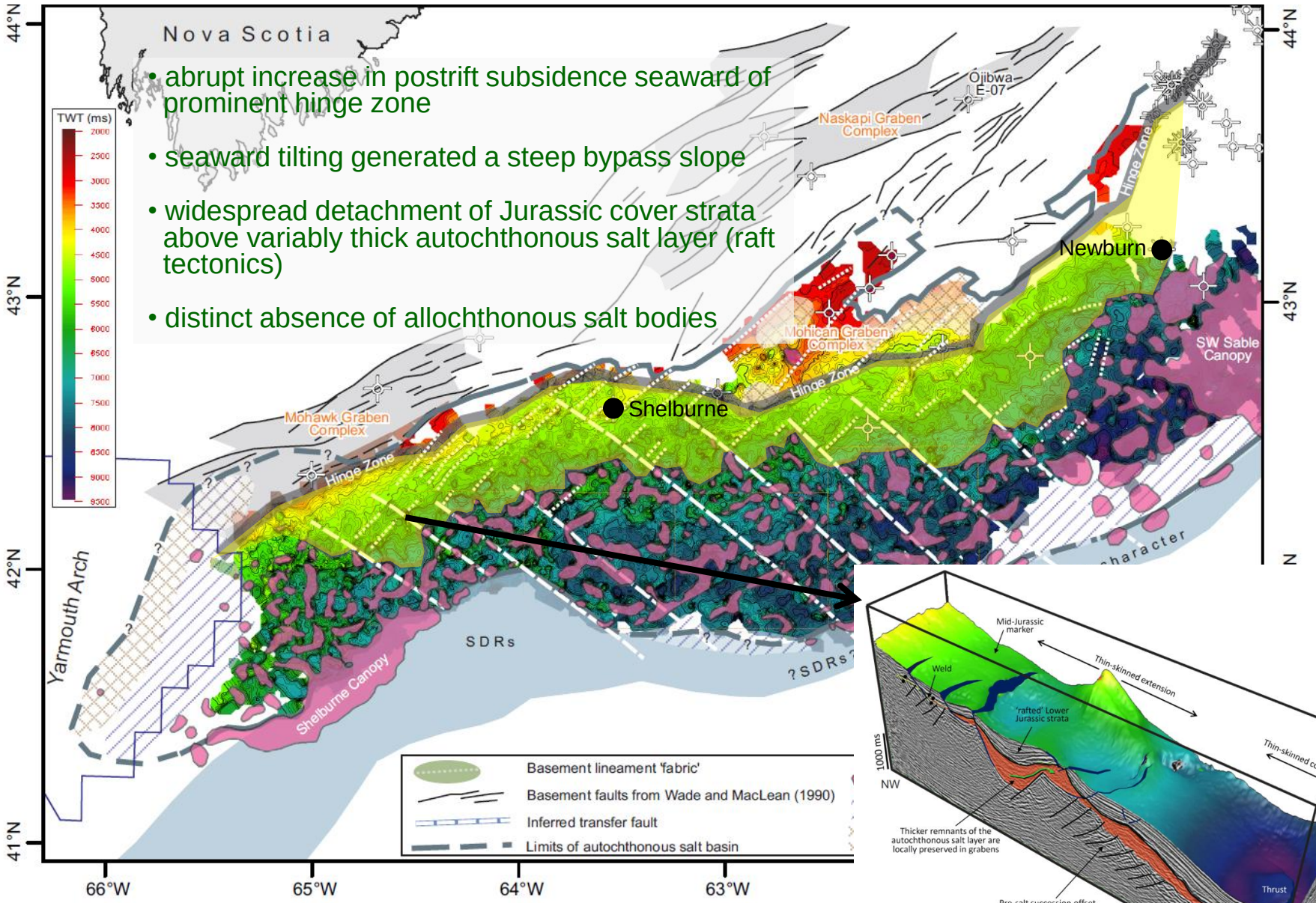
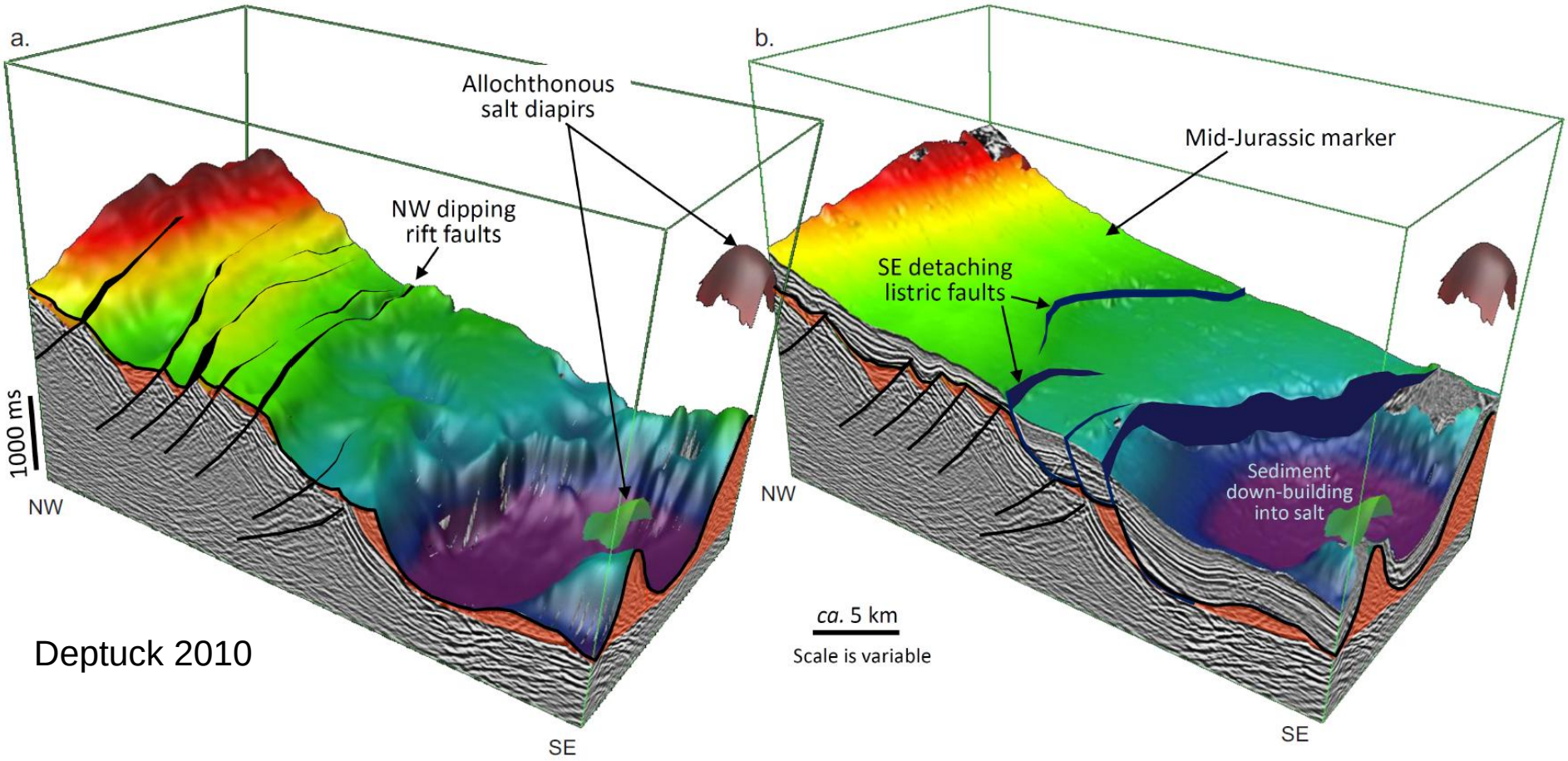
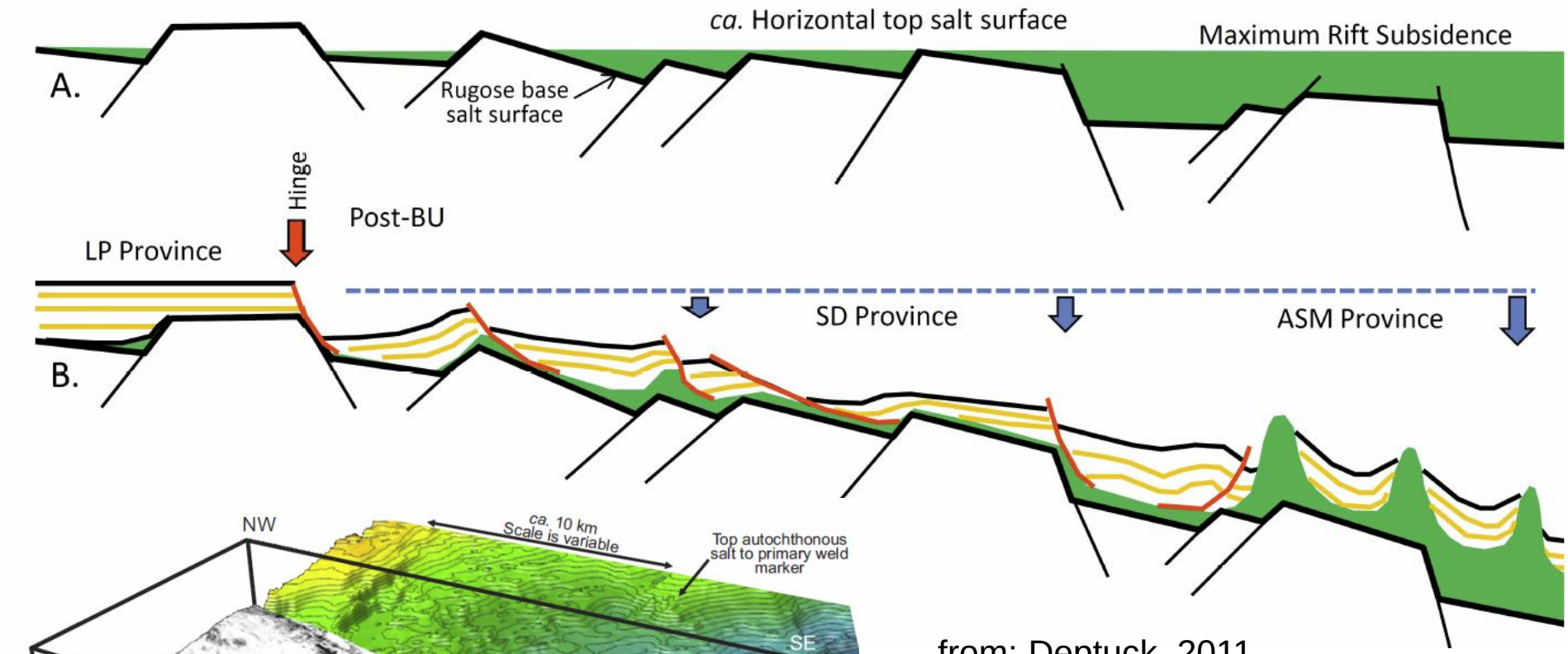


Figure 13c – Annotated map of the top autochthonous salt gridded surface, showing location and orientation transfer faults that appear to offset the landward margin of the ASM province.

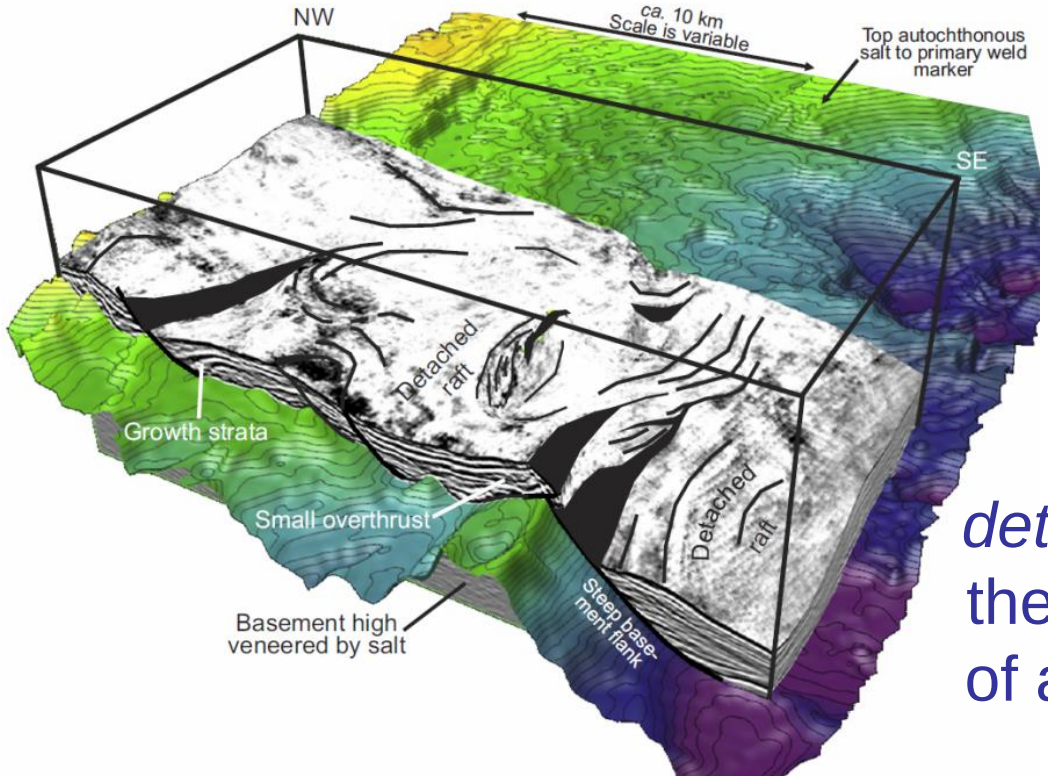
Basement faults (synrift; left) versus cover faults (postrift; right)



Deptuck 2010

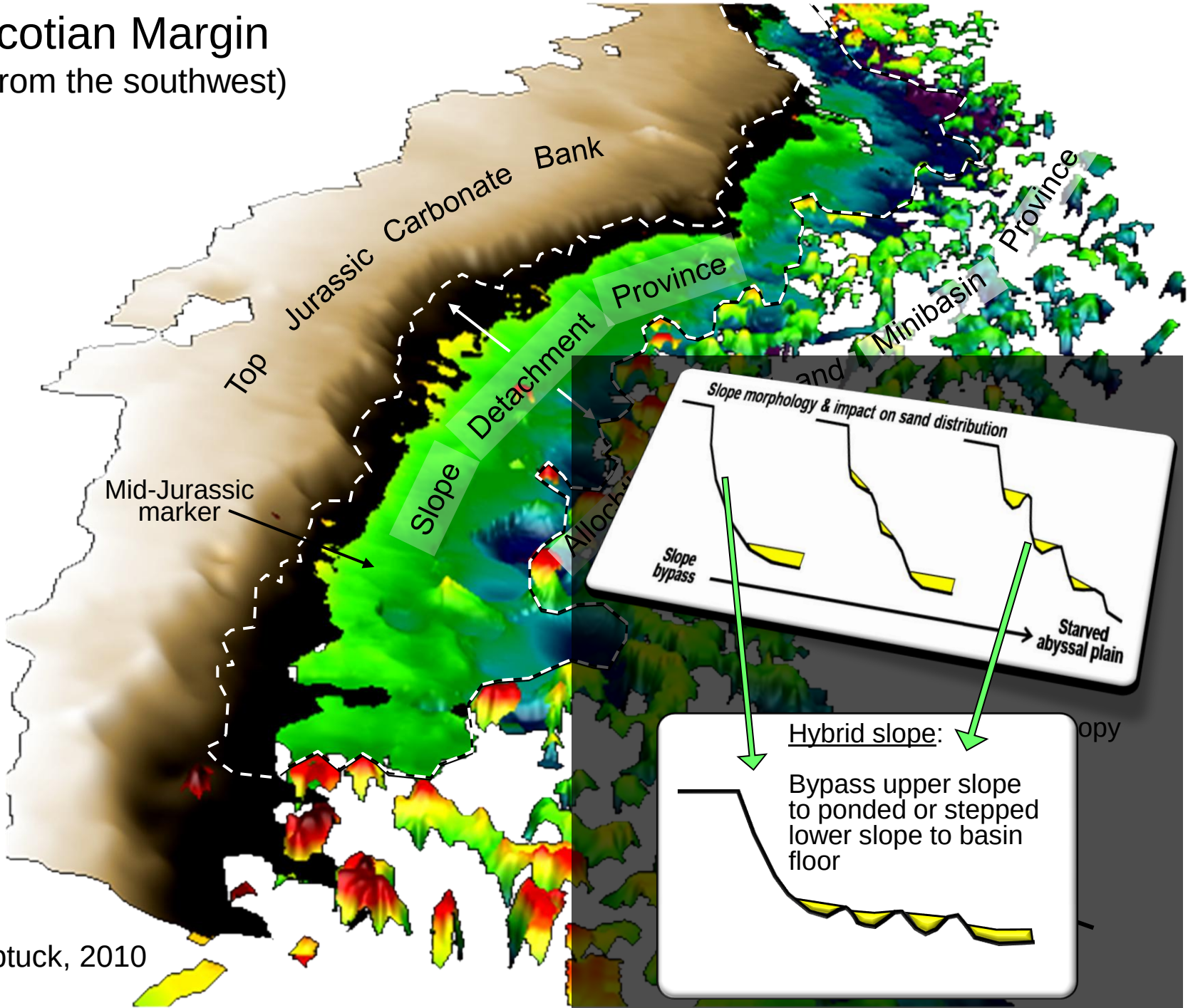


from: Deptuck, 2011



Steepening of the '*slope detachment province*' seaward of the hinge zone and development of a bypass (proximal) to ponded (distal) slope

SW Scotian Margin
(viewed from the southwest)



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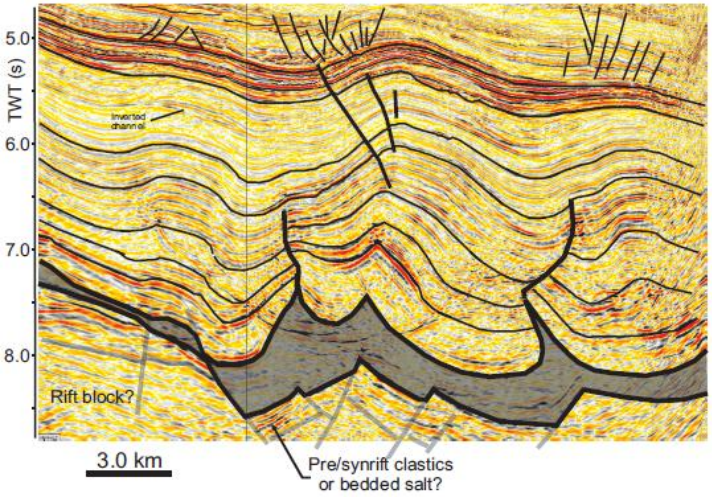
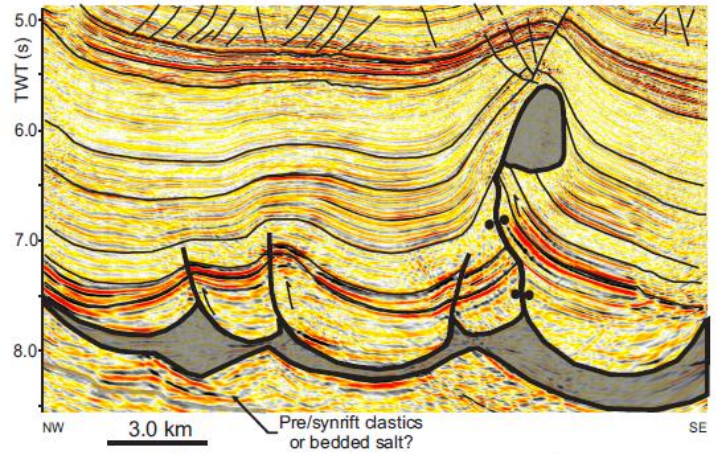
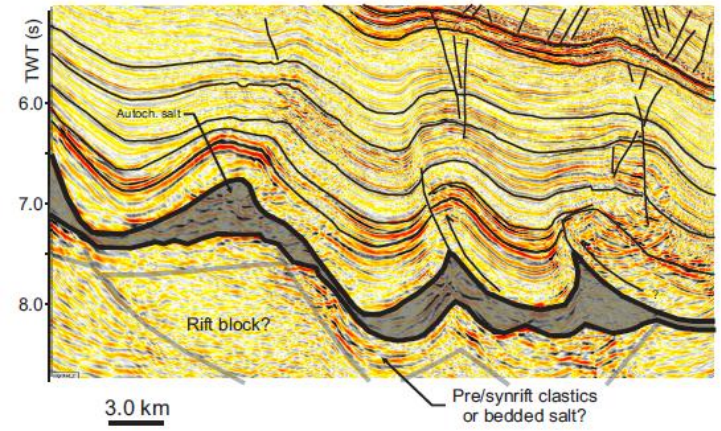






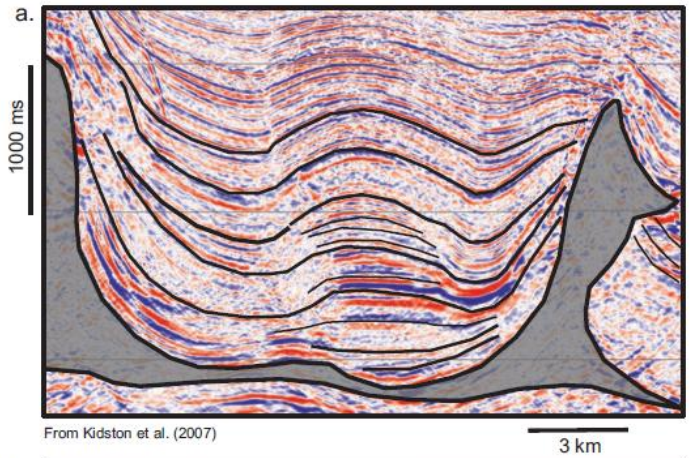
Increased occurrence of contractional structures along landward parts of the 'Allochthonous Salt and Minibasin Province'

(accommodating up-slope extension in the 'Slope Detachment Province')

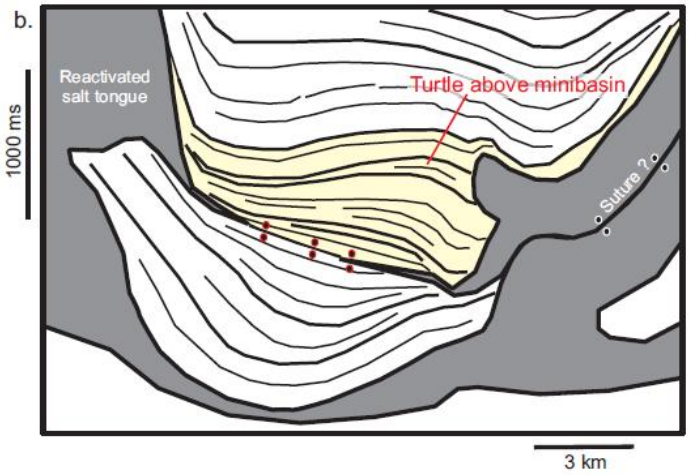
There is no calibration to help constrain what type or grade of sediment is incorporated into these structures, BUT we do know that sediment was transported from up-slope regions through canyons across much of the western slope (as will be shown later)...

So gravity flow deposits of some kind are assured down-slope of the region of canyoning and slope bypass!

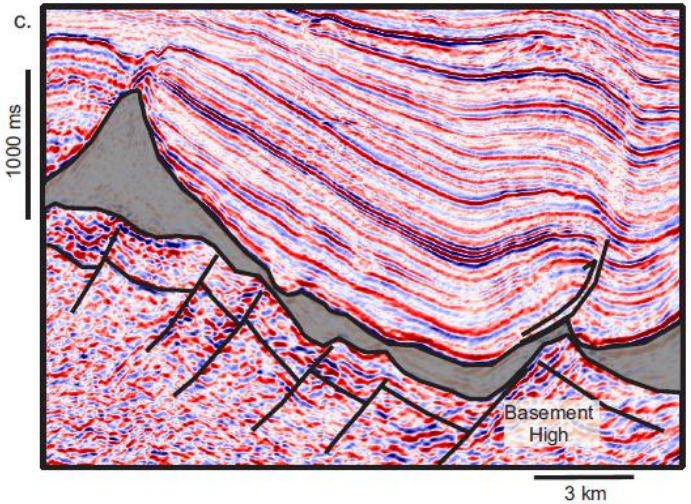
from: Deptuck, 2011



Parcel 3



Parcel 4



Parcel 1

Structures associated with both passive loading of salt (e.g. turtles – top two images) and contraction (e.g. folds – bottom image)

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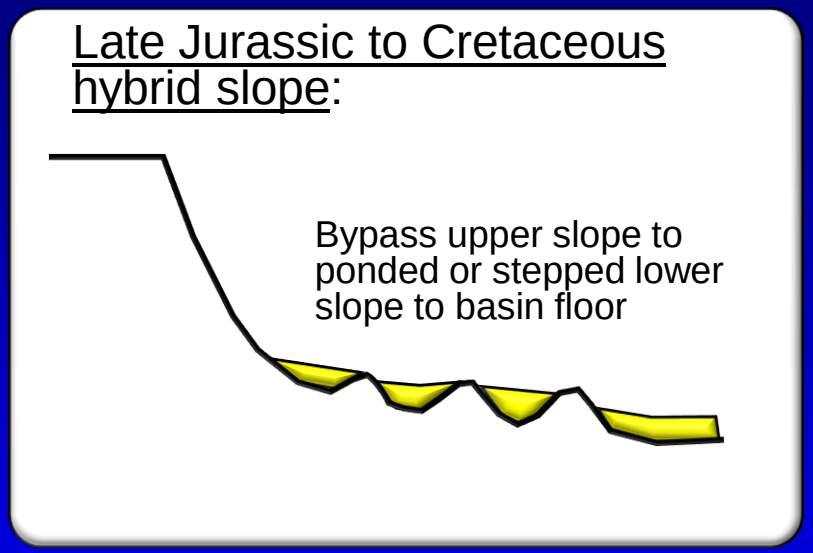
So gravity flow deposits of some kind are assured down-slope of the region of canyoning and slope bypass!

from: Deptuck, 2011 NS11-1 Call for bids package

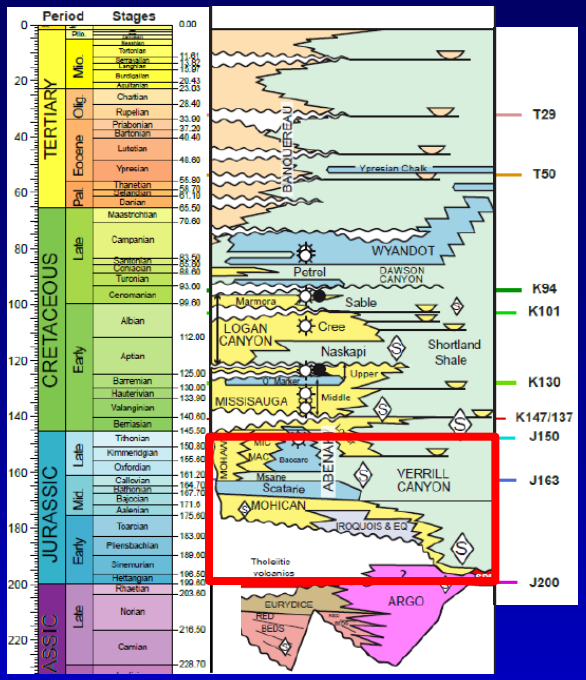
Now that we have an improved “first-order” understanding of paleo-slope morphology (i.e. a *bypass-ponded slope*)....

What are the potential shelf sources for deep-water reservoirs along the southwestern slope?

-Jurassic
-Cretaceous
-Cenozoic



Jurassic



Mohican Formation

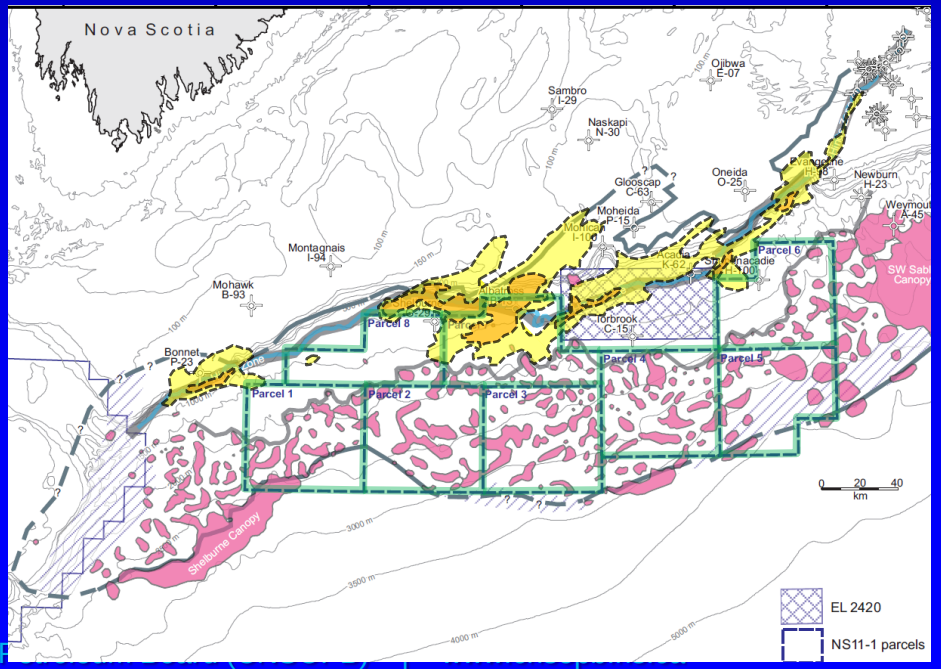
- Middle Jurassic quite thick and progradational in the Mohican Graben Complex and locally further west (proto shelf margin deposits during early hinge zone development)

Mohawk Fm

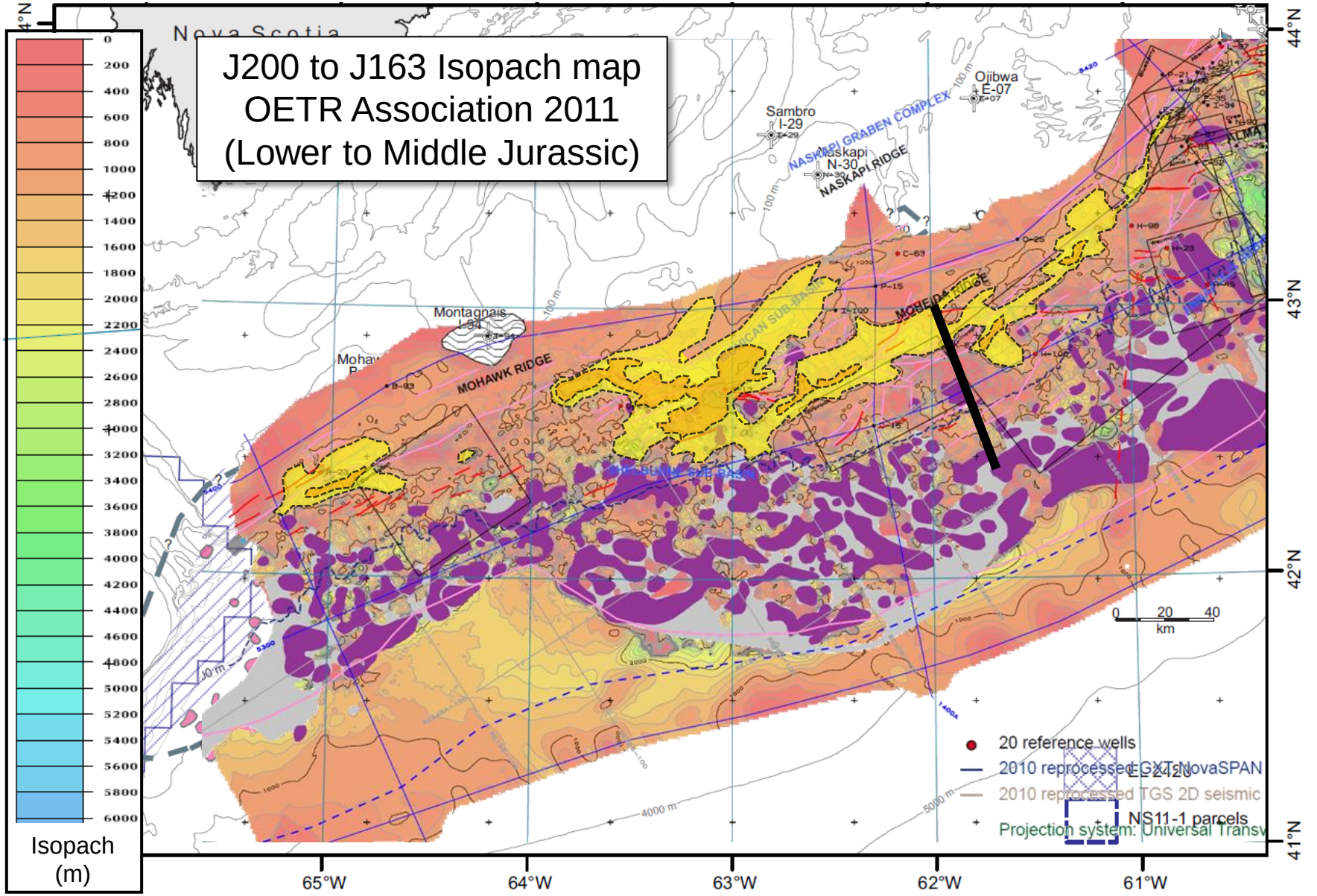
- some evidence that ‘inboard’ Middle to Upper Jurassic Abenaki-equivalent clastics periodically breached the carbonate bank and supplied clastics directly onto the steep, heavily canyoned slope (e.g. 500 m clastic section in Mohawk well)

Other Jurassic possibilities?

- foreslope to basinal debris flows and calci-turbidites resedimented from bank edge?



Local 1.2 to 4 km thick Lower to Middle Jurassic depocentres along margin hinge zone



Mohican Graben – progradational clinoforms (Mohican Formation)

"the Mohican Fm is a rapidly thickening, prograding, predominantly clastic sequence more than 2 km thick" (Wade and MacLean, 1990)

- formation is generally texturally immature (feldspathic)
- but grade and sorting may improve as sediment is partitioned during transport in to deepwater

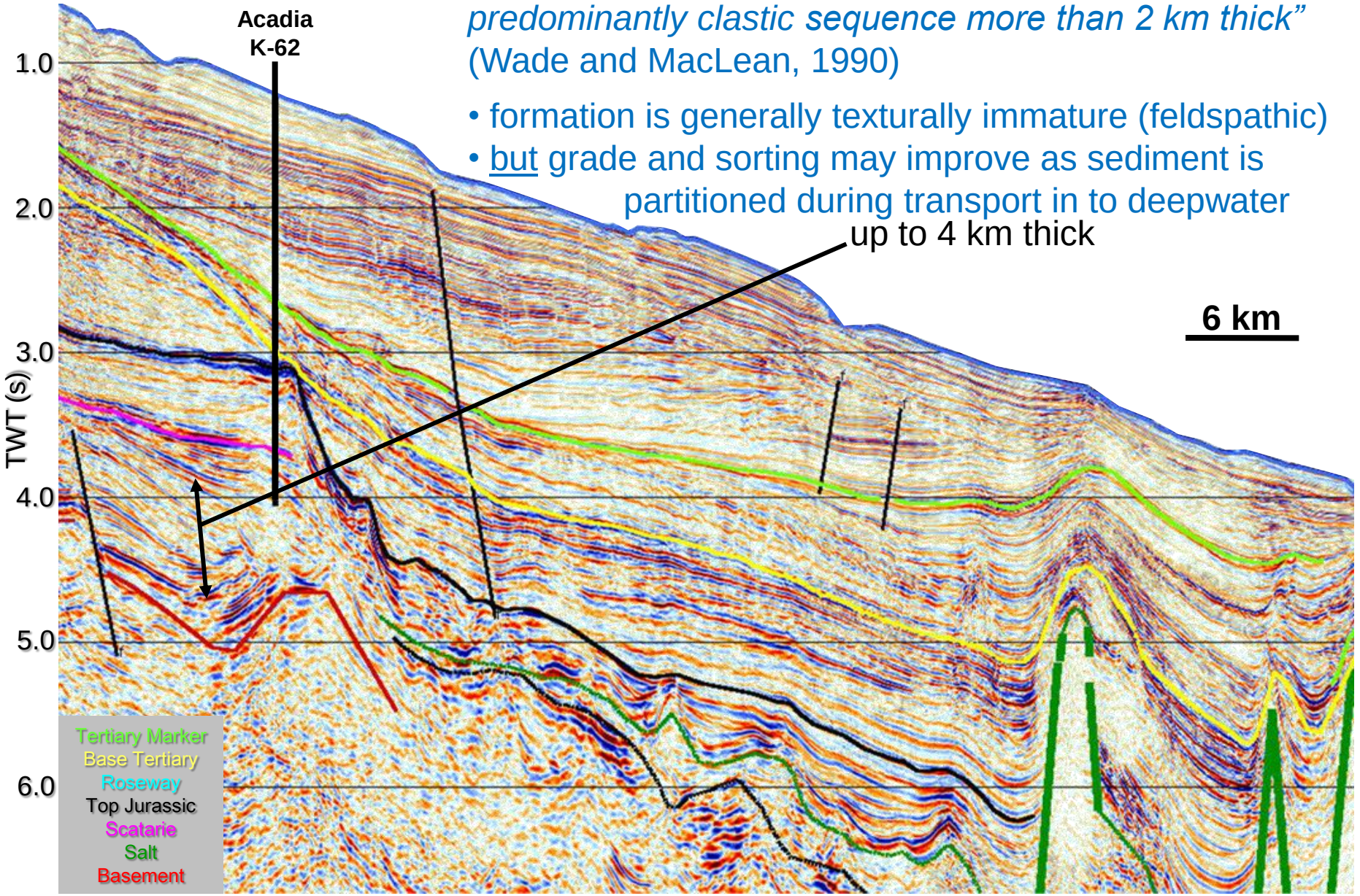
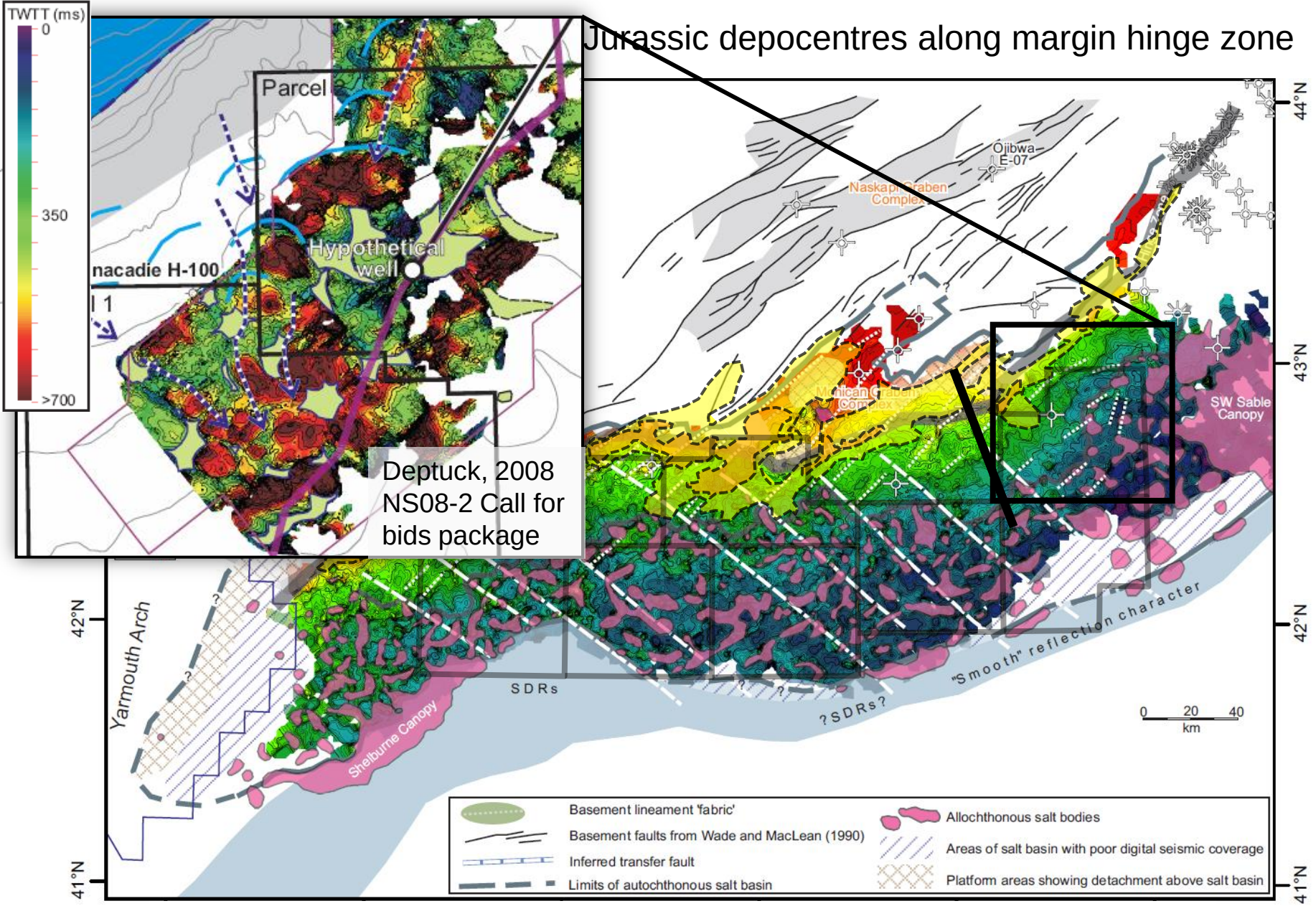


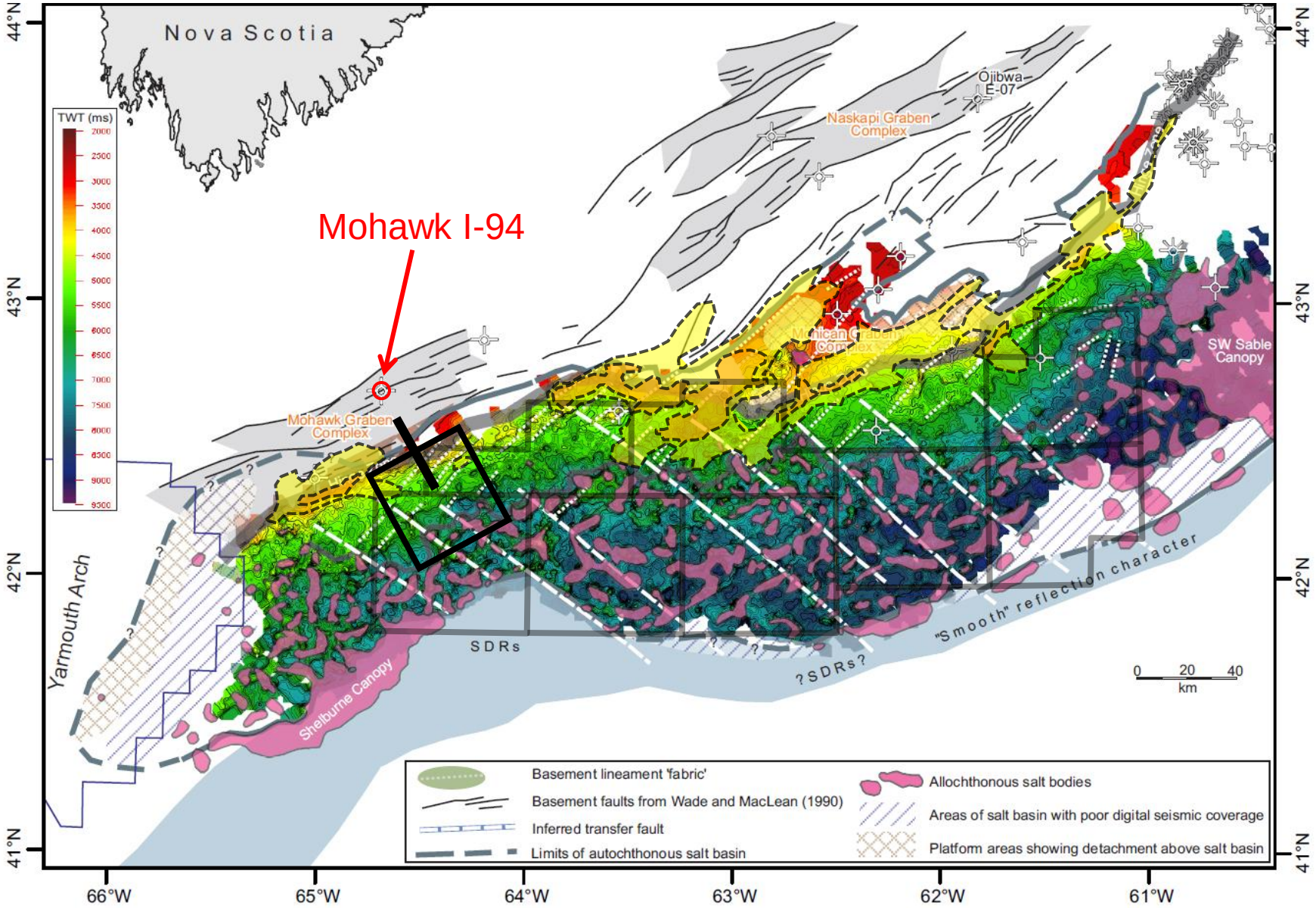
figure from Kidston et al. 2005

Jurassic depocentres along margin hinge zone

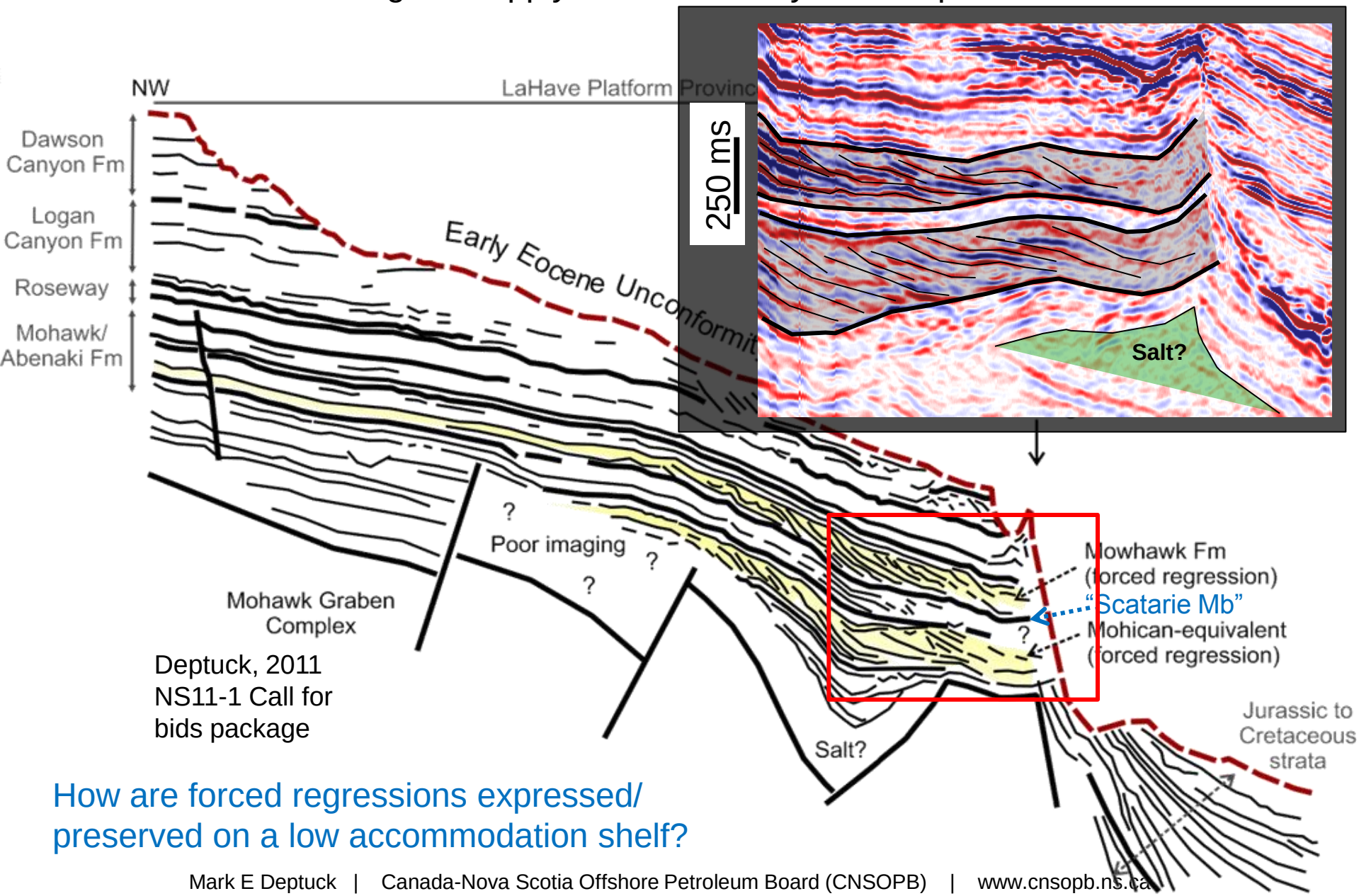


Lower to Middle Jurassic minibasins seaward of proto hinge zone

1.2 to 4 km thick Lower to Middle Jurassic depocentres along margin hinge zone



Did the inboard Mohawk/Mic Mac clastics periodically breach the carbonate bank edge to supply clastics directly into deep water?



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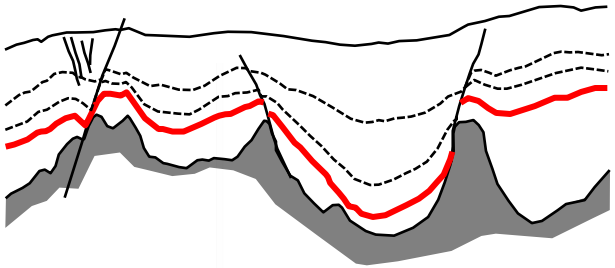
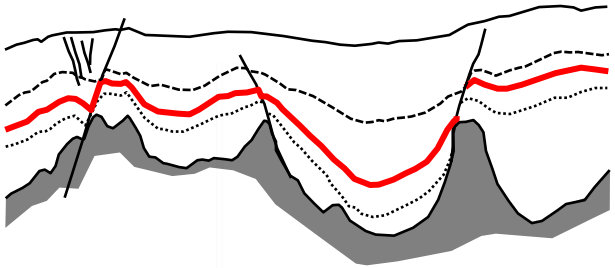
How are forced regressions expressed/ preserved on a low accommodation shelf?

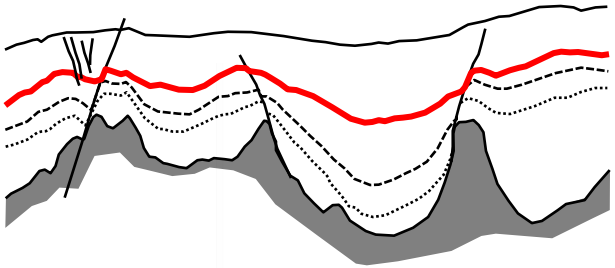
Unconformity below J163 – lower Middle Jurassic



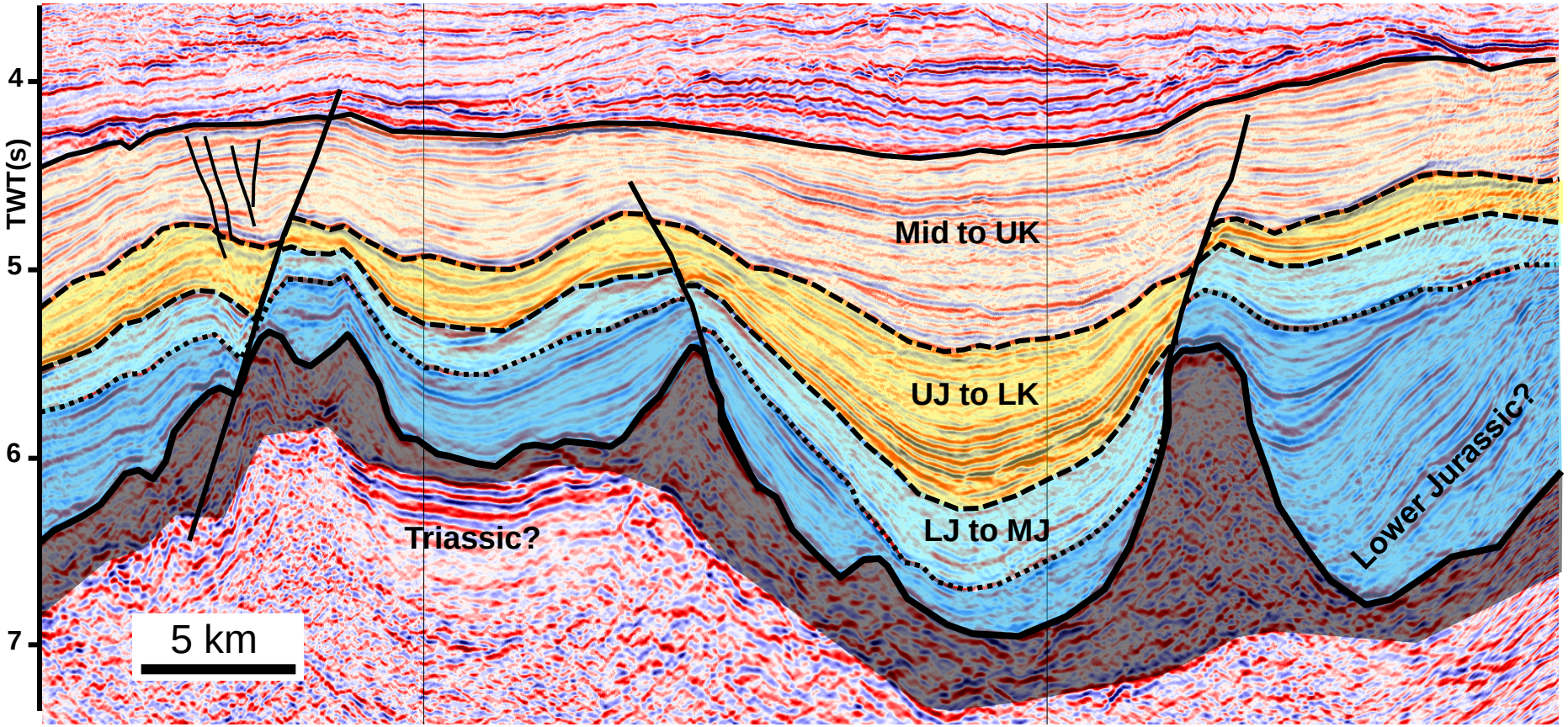
J163 – upper Middle Jurassic



K137/K130? Early Cretaceous

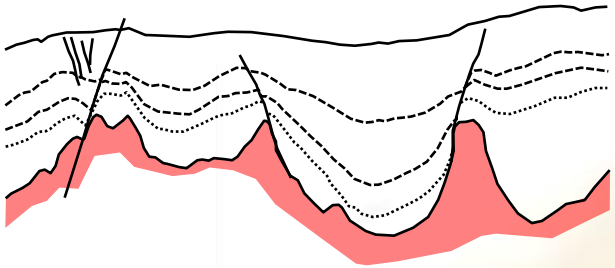


Representative profile near transition from bypass to deposition

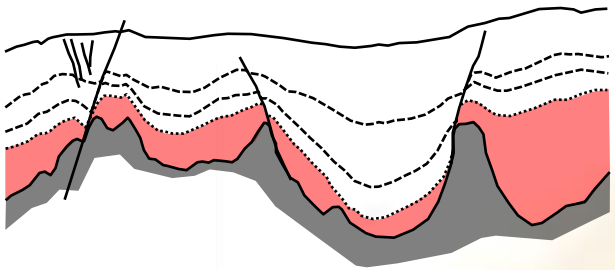


*Water column depth converted (shallows section by ~0.5 s twt)

Salt thickness map

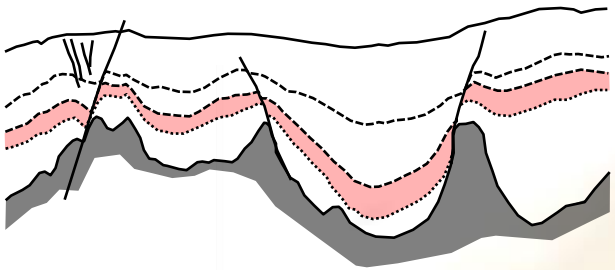


Time-thickness - Lower to Middle Jurassic



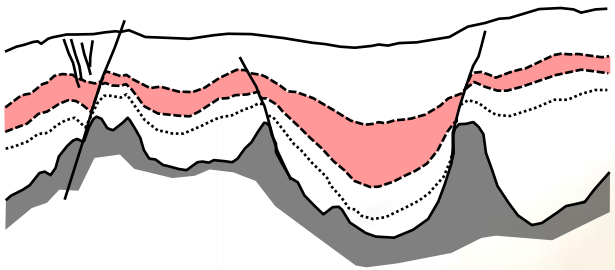
Red=thick

Time-thickness - Middle Jurassic



Red=thick

Upper Jurassic to Lower Cretaceous



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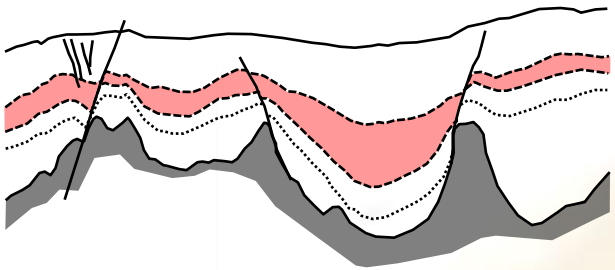
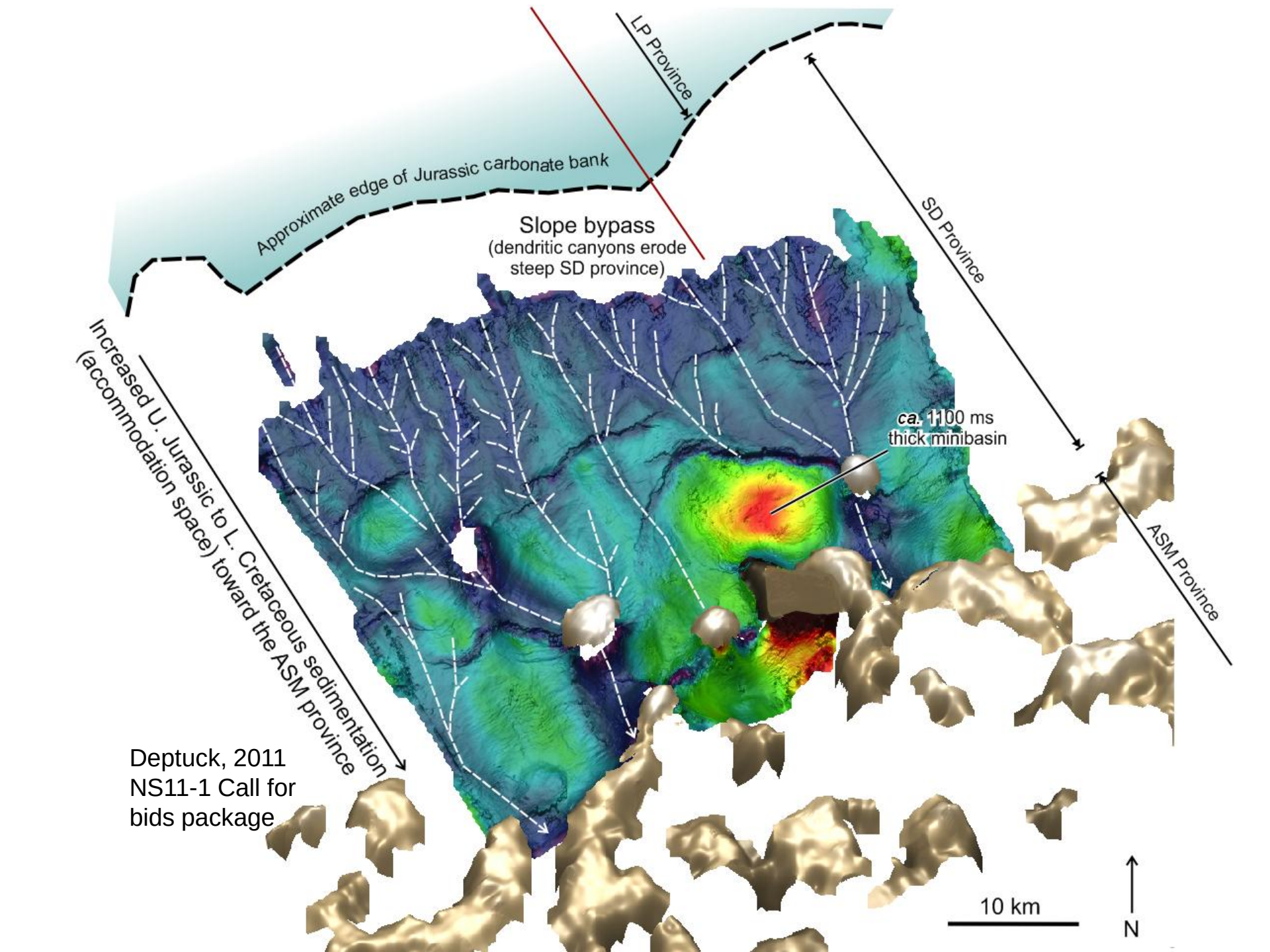
Upper Jurassic to Lower Cretaceous



Red=thick

Change from <u>sediment bypass to sediment accumulation</u>! Key question: What type of sediment was transported during multiple periods of canyoning?


LP Province
Approximate edge of Jurassic carbonate bank
Slope bypass
(dendritic canyons erode
steep SD province)
SD Province
ca. 1100 ms
thick minibasin
ASM Province
Increased U. Jurassic to L. Cretaceous sedimentation
(accommodation space) toward the ASM province
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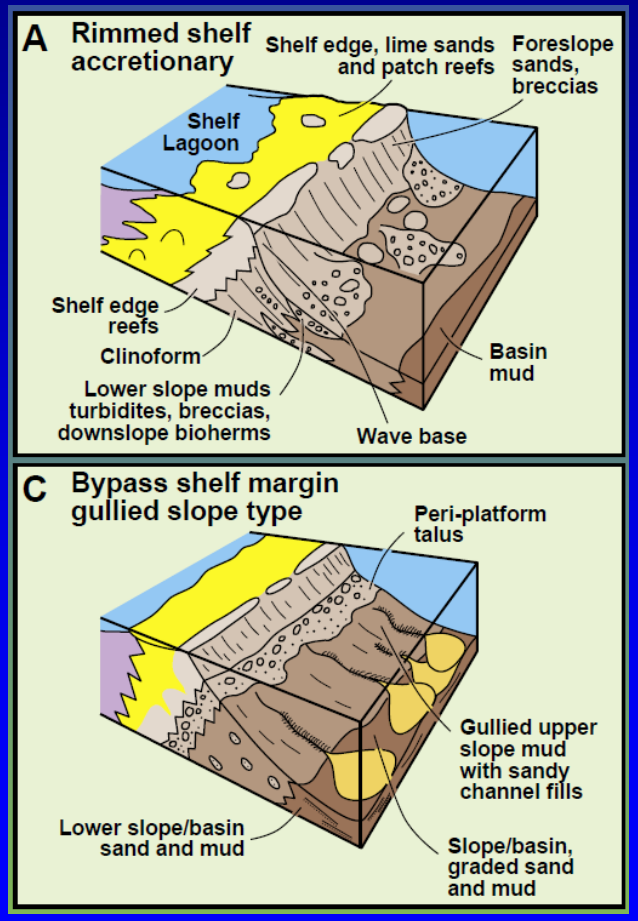
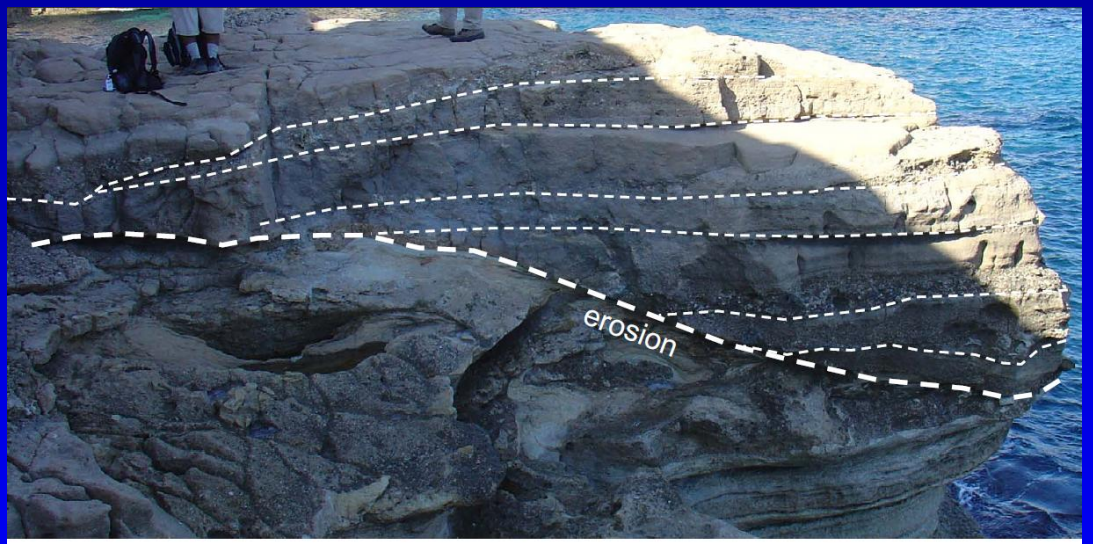
bids package
10 km
N

Could resedimented carbonates be viable Jurassic to earliest Cretaceous reservoirs on the SW carbonate foreslope to basin plain?

...shed from the Abenaki to Roseway carbonate margins?



Moore 2001

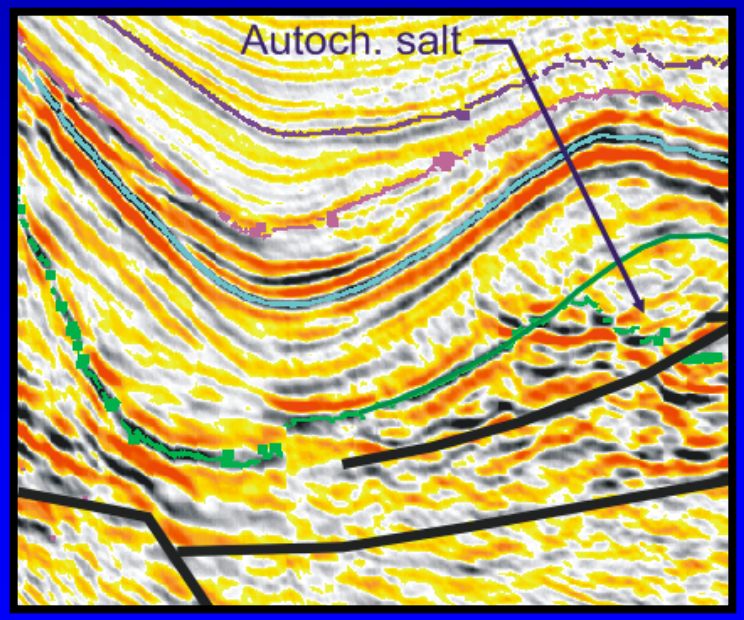


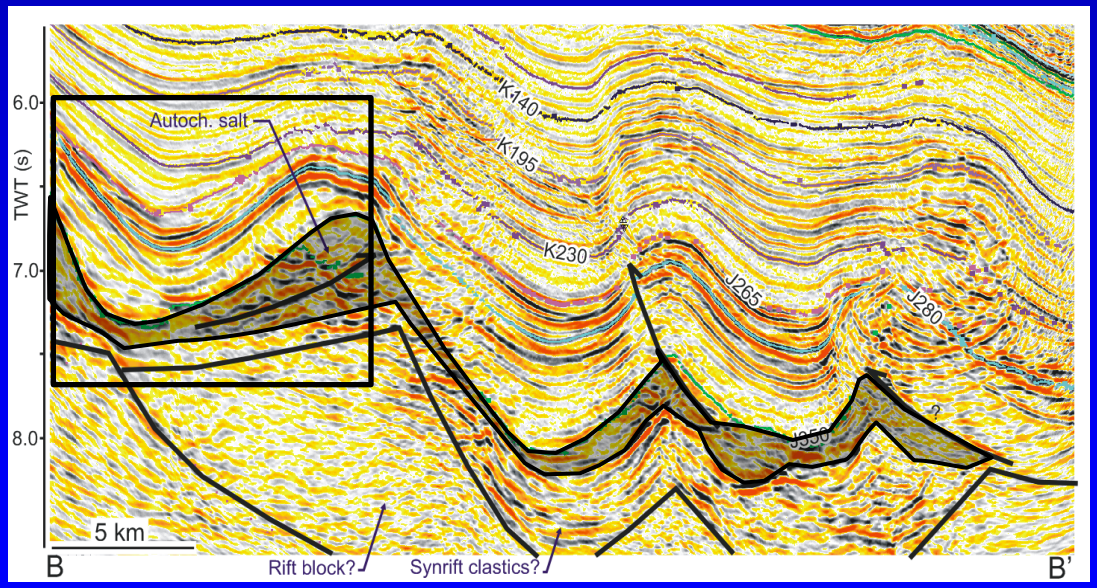
Submarine channel – incised into and filled with clastic carbonates (graded beds and lenses of bioclastic debrites)

Deptuck 2005, unpublished

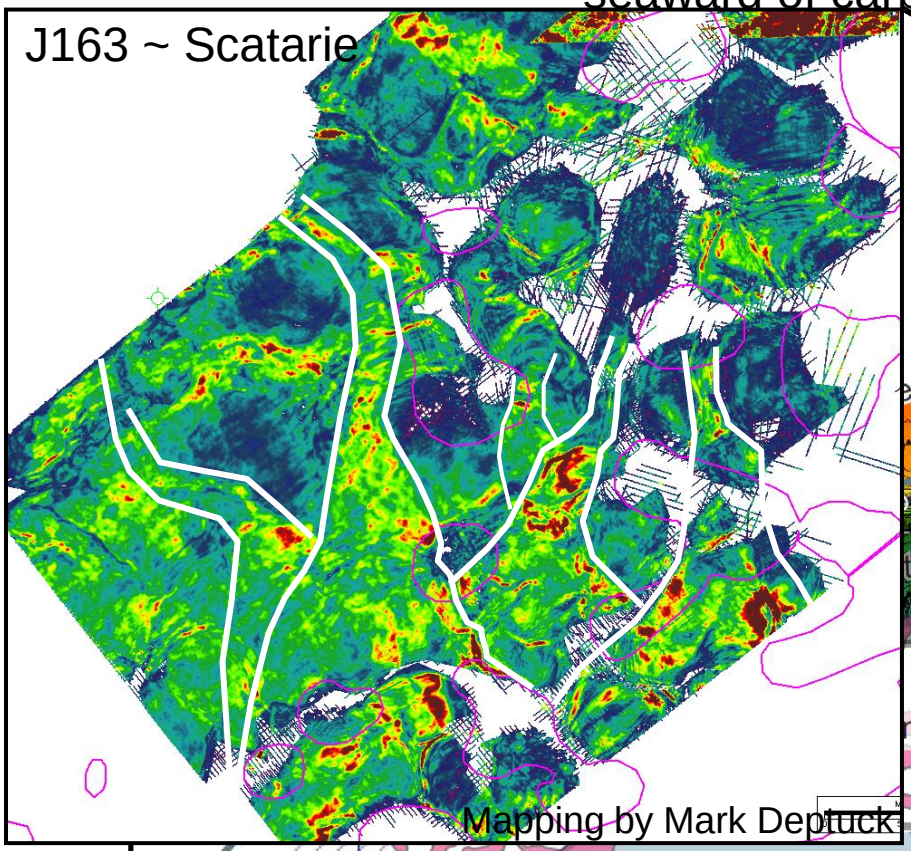
Why not foreslope calciclastic reservoirs?!

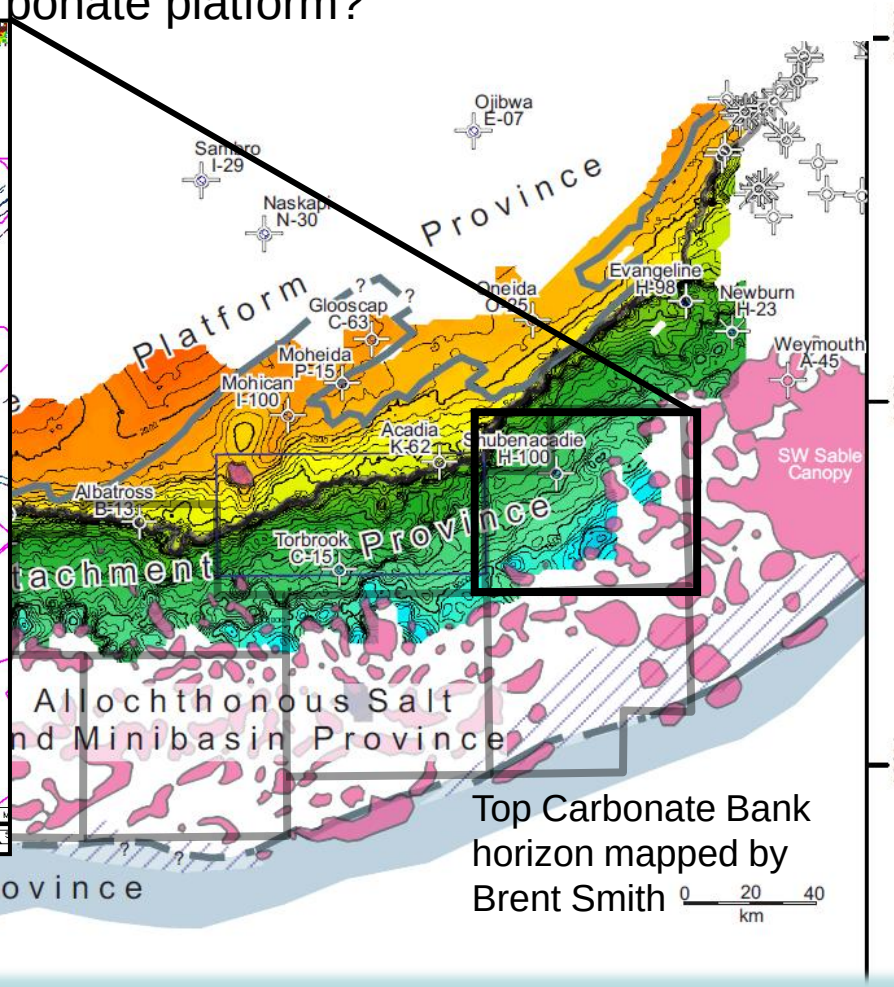
-Abenaki to Roseway foreslope is heavily gullied/canyoned at multiple levels
-Abenaki equivalent distal deposits have a high amplitude character with shingled seismic reflections that could represent offset stacked fans
-Amplitude extractions from the Thrumcap 3D survey support this interpretation
-Shelburne G-29 encountered skeletal and oolitic wackestone to packstones on the forelsope





Potential for Jurassic or even early Cretaceous calci-clastic submarine fans seaward of carbonate platform?

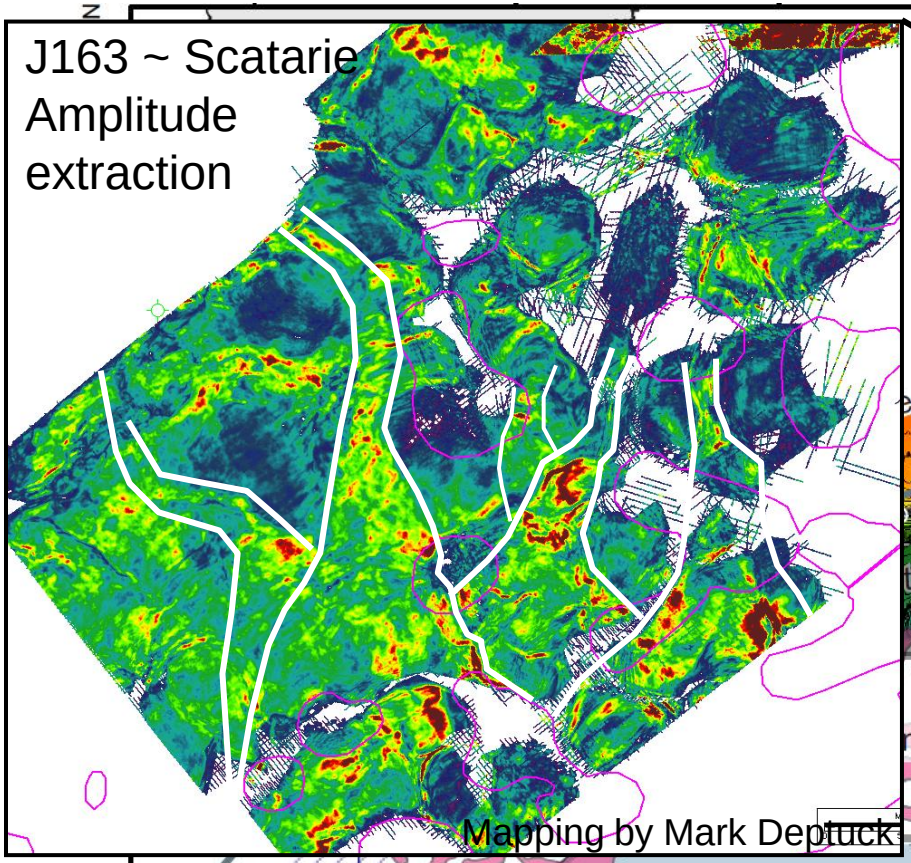


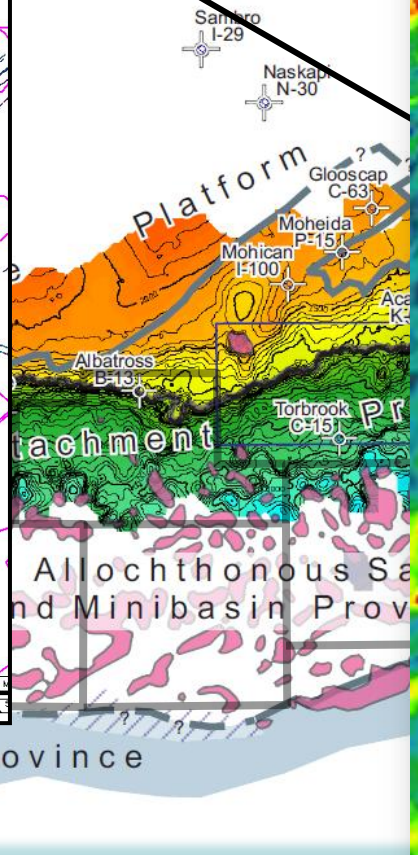


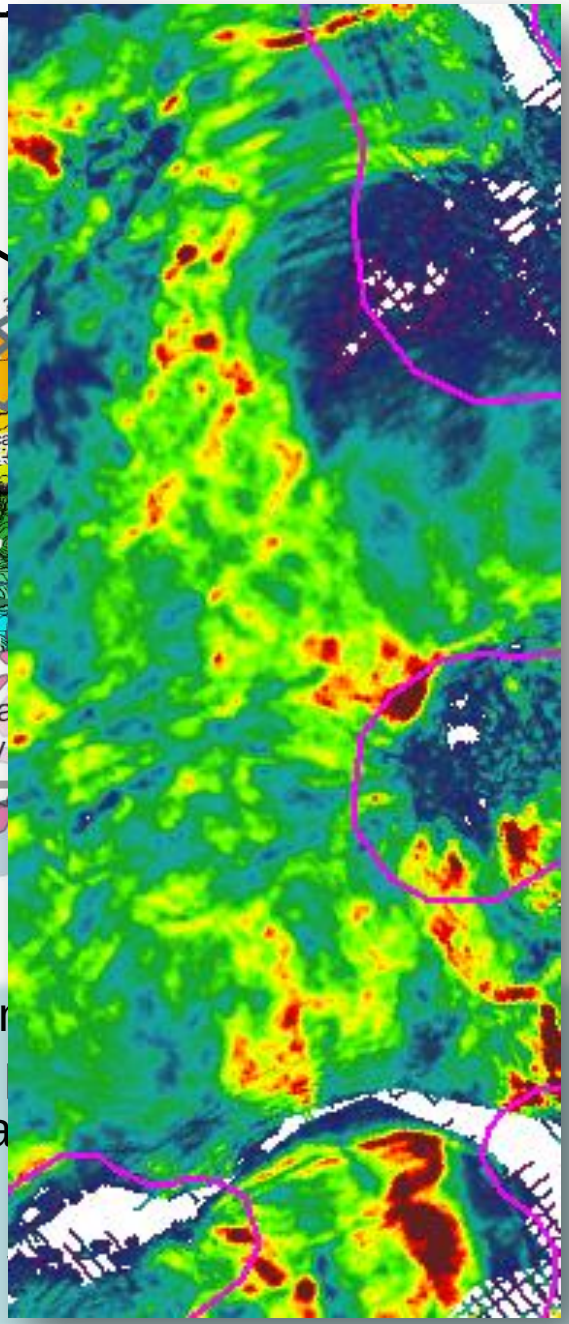
-Cretaceous Tamabra limestone facies (allochthonous carbonate breccias, carbonate debris flows and calci-turbidites) derived from the carbonate platform are very important reservoirs in the southern GoM with both primary and secondary porosity (Magoon et al. 2001)

-Outcrop studies of Early Permian carbonates in west Texas show that skeletal-ooid basin floor fans have good reservoir properties

Potential for Jurassic or even early Cretaceous calci-clastic submarine fans?







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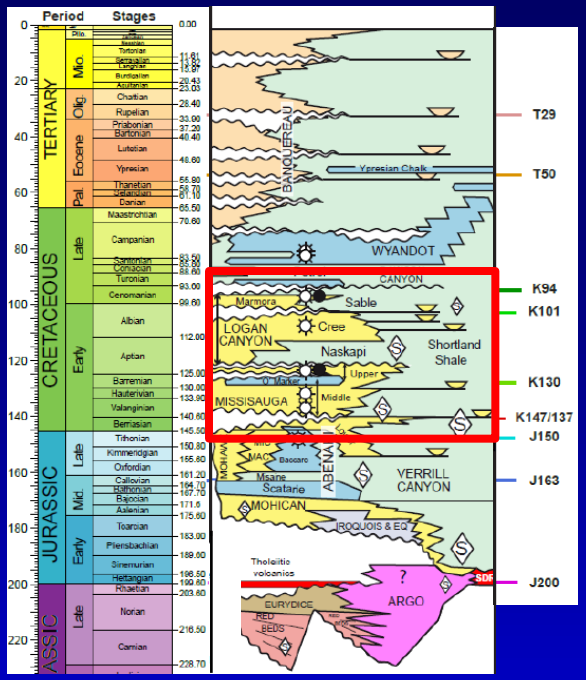
(Magoon et al. 2001)
-Outcrop studies of Early Permian carbonates in west Texas
basin floor fans have good reservoir properties

Cretaceous



Lower Cretaceous

-Sable Island Delta in east

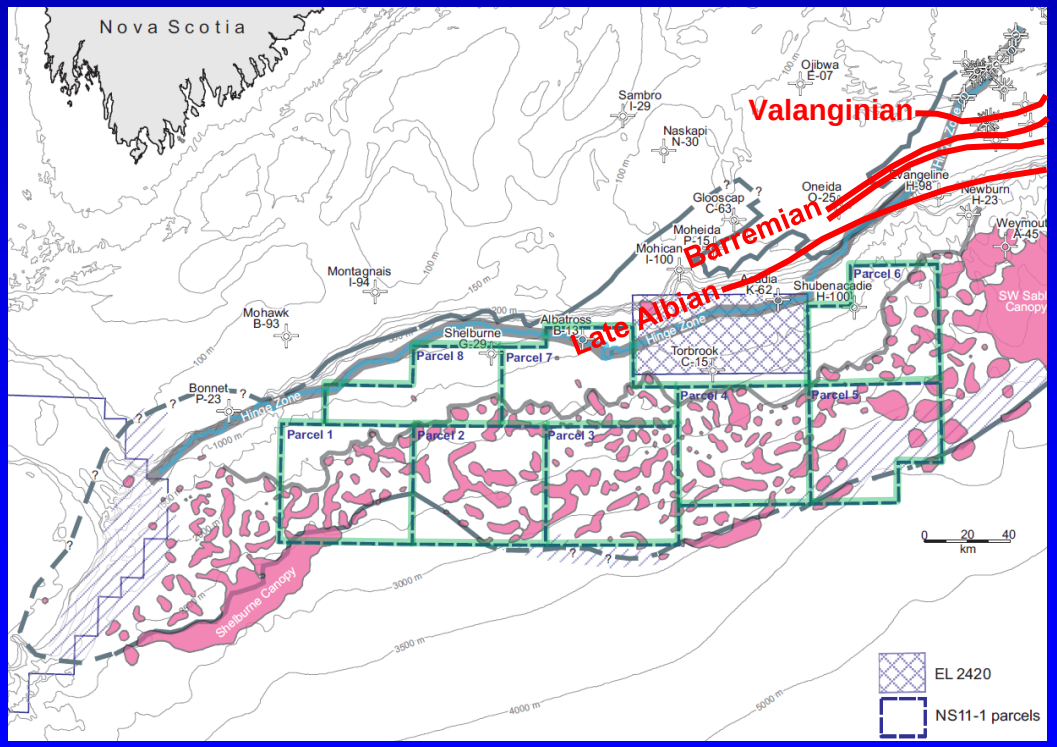
-largely condensed to the west (Roseway Fm - continuation of the carbonate bank)

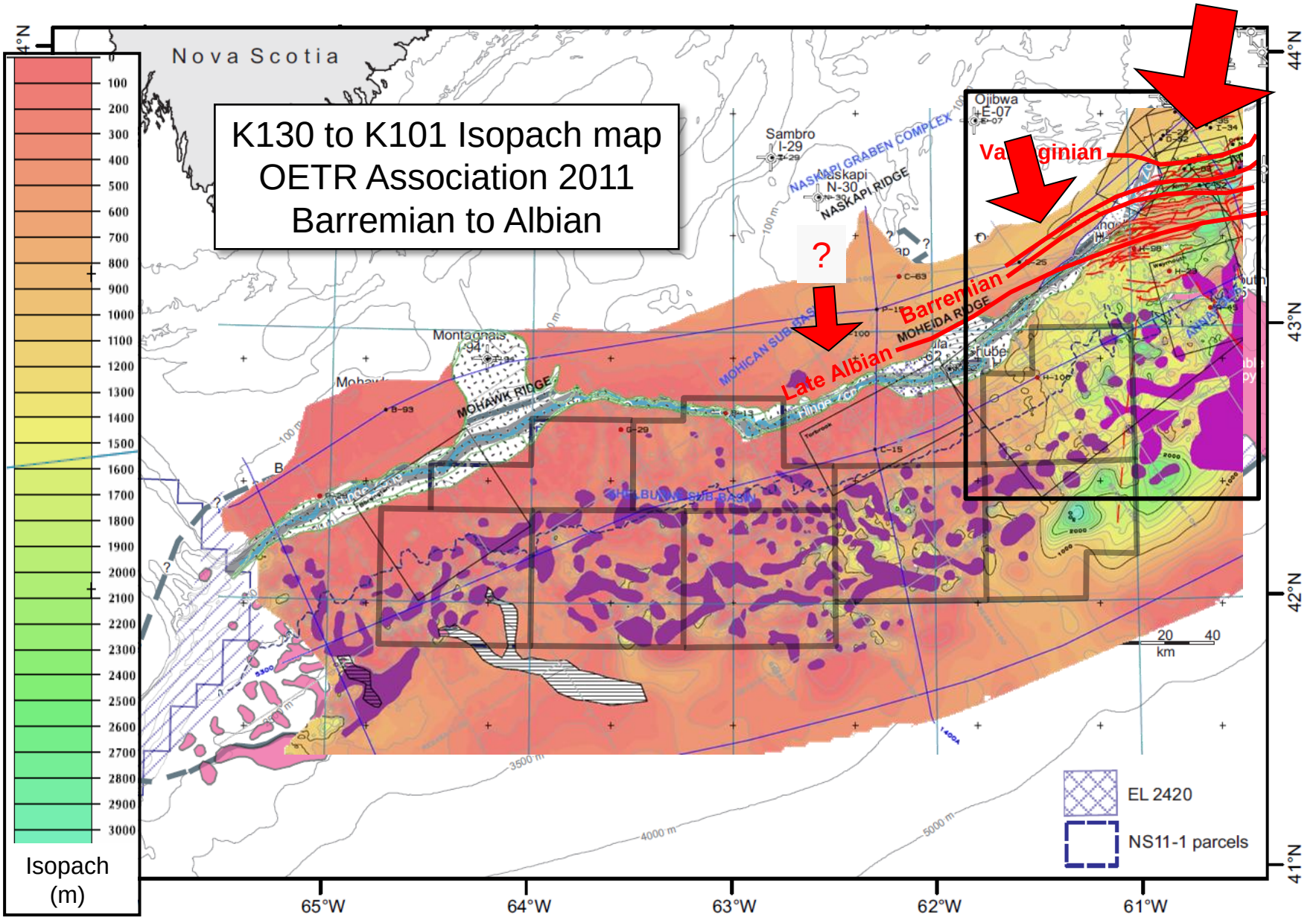
Mid Cretaceous

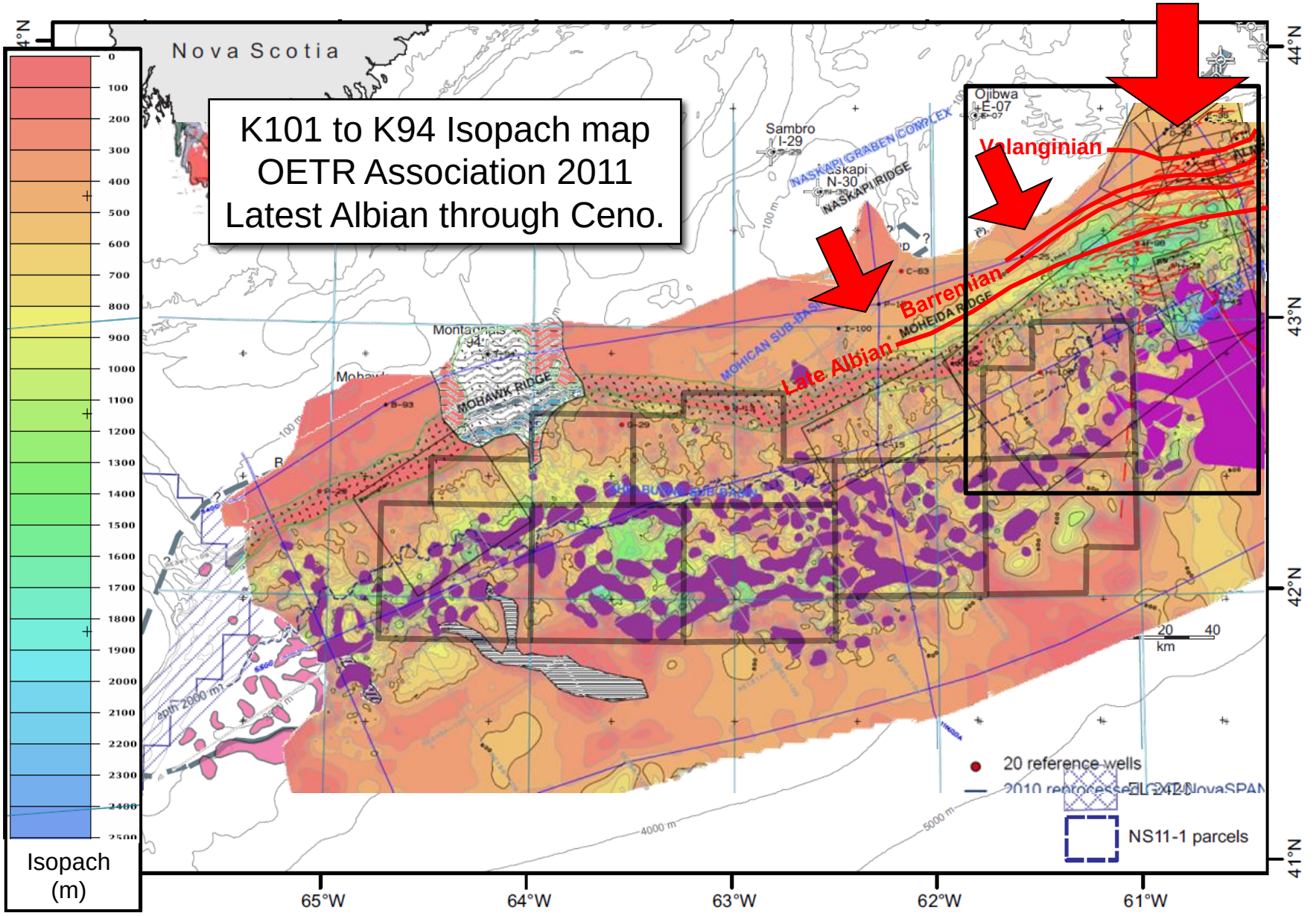
-Logan Canyon progrades to bank edge (eastern half of study area)

-Shelf-equivalent succession to the west is heavily eroded by Montagnais failure, but equivalent deepwater succession is quite thick

-some indications of Upper Cretaceous progradation just east of Montagnais

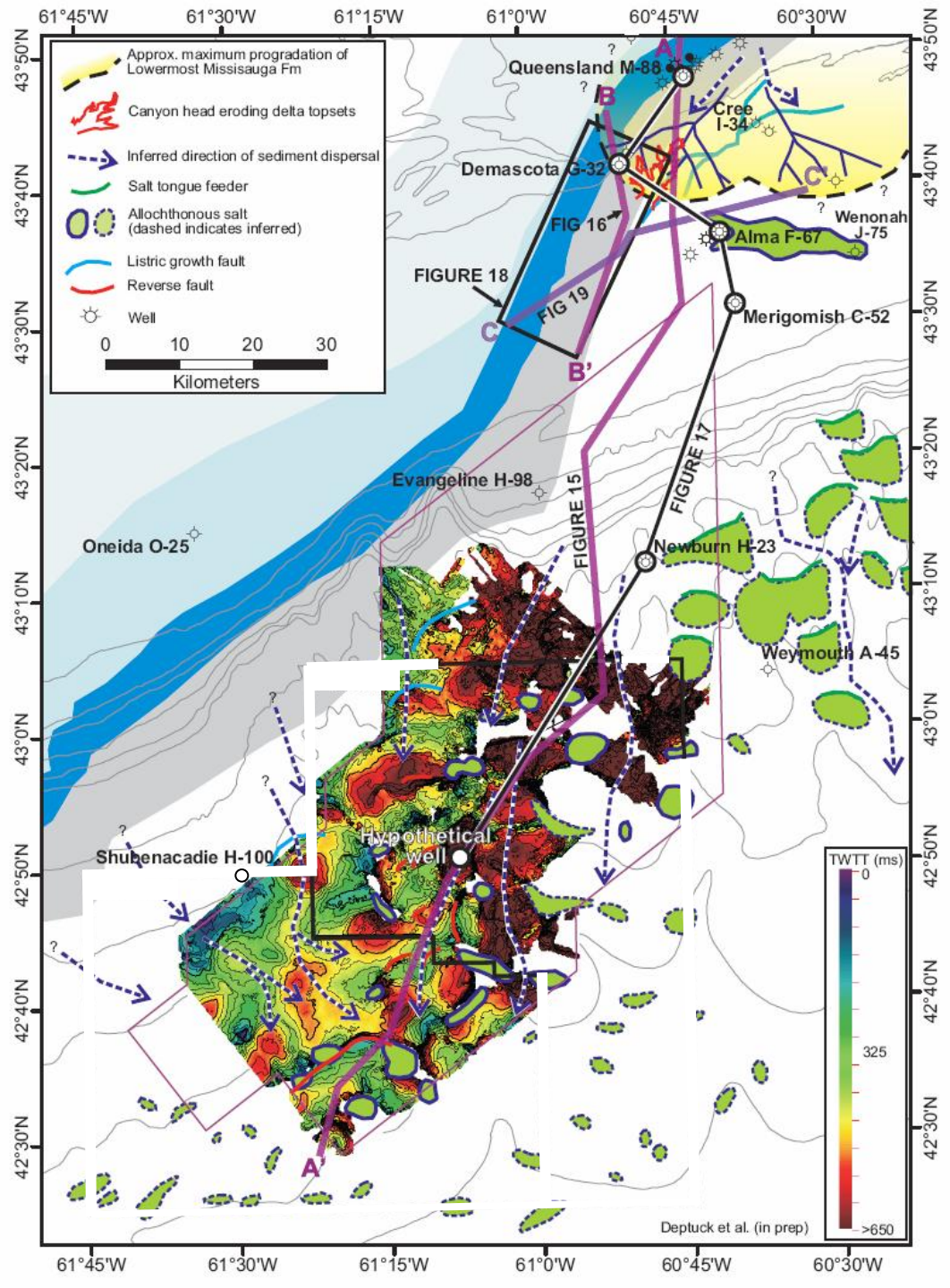



K130 to K101 Isopach map
OETR Association 2011
Barremian to Albian
Nova Scotia
Sambro
I-29
Uniskapi
N-30
NASKAPI RIDGE
NASKAPI GRABEN COMPLEX
Ojibwa
E-07
Valanginian
Barremian
MOHEIDA RIDGE
Late Albian
?
Montagnais
J-94
Mohawk
MOHAWK RIDGE
MOHICAN SUB-BASIN
Hibernia
Hibernia Ridge Complex
Torbrook
Isopach
(m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
20
40
km
EL 2420
NS11-1 parcels
65°W
64°W
63°W
62°W
61°W
44°N
43°N
42°N
41°N


K101 to K94 Isopach map
OETR Association 2011
Latest Albian through Ceno.
Nova Scotia
Sambro
I-29
Ojibwa
E-07
Uskapi
N-30
NASKAPI GRABEN COMPLEX
NASKAPI RIDGE
Valanginian
Barremian
Late Albian
MOHEIDA RIDGE
MOHICAN SUB-BASIN
Montagnais
94
MOHAWK RIDGE
Mohawk
B-93
C-63
I-100
C-29
C-15
100 m
4000 m
5000 m
depth 2000 m
20
40
km
20 reference wells
2010 reprocessed 3D NovaSPAN
EL 2427
NS11-1 parcels
Isopach
(m)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
44°N
43°N
42°N
41°N
65°W
64°W
63°W
62°W
61°W

Lowermost Missisauga Formation and equivalent succession

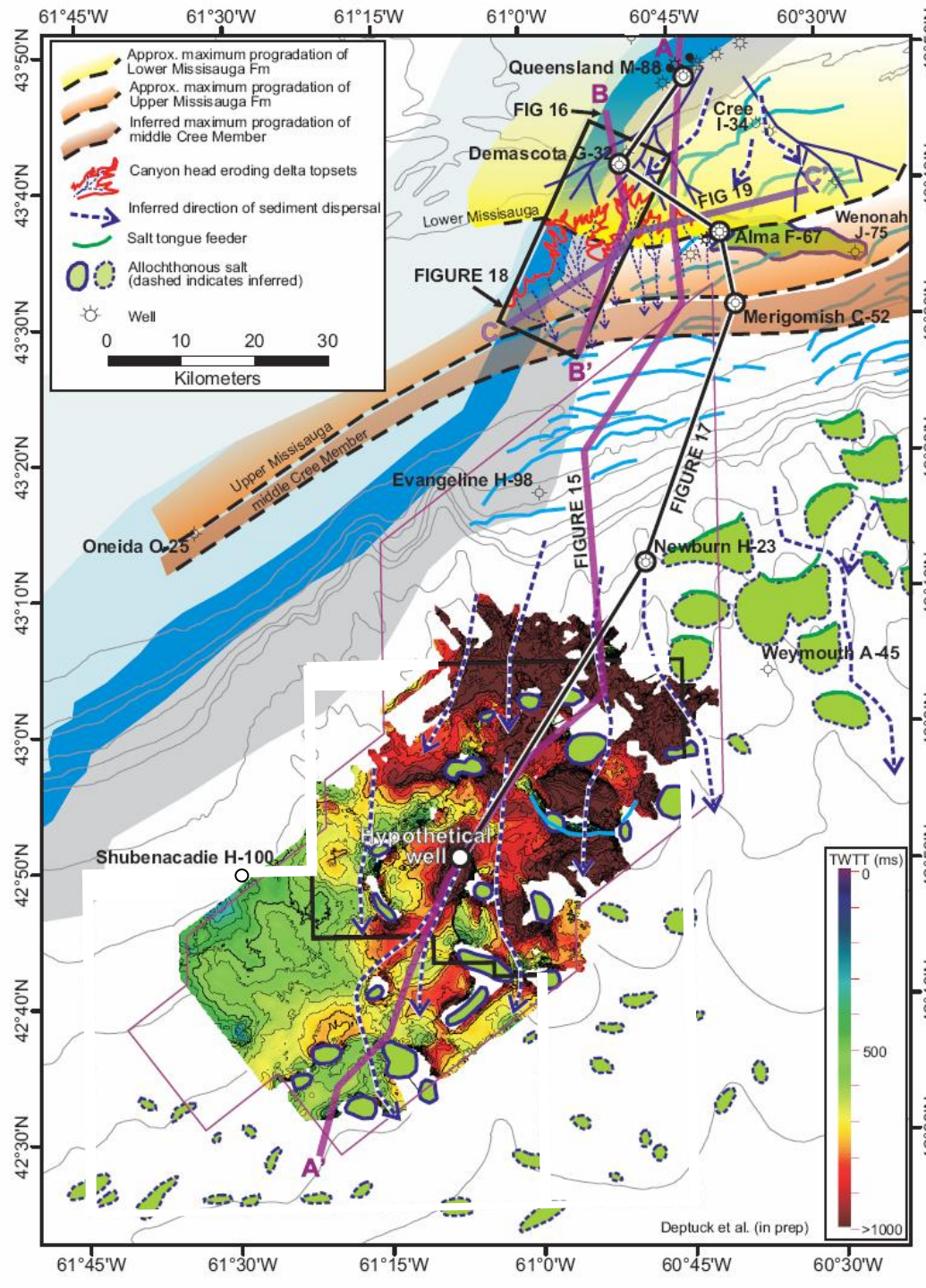
Southward progradation of Sable Island Delta



Deptuck 2008 NS08-2 CFBs package

Missisauga to lower Logan Canyon Formations and equivalent succession

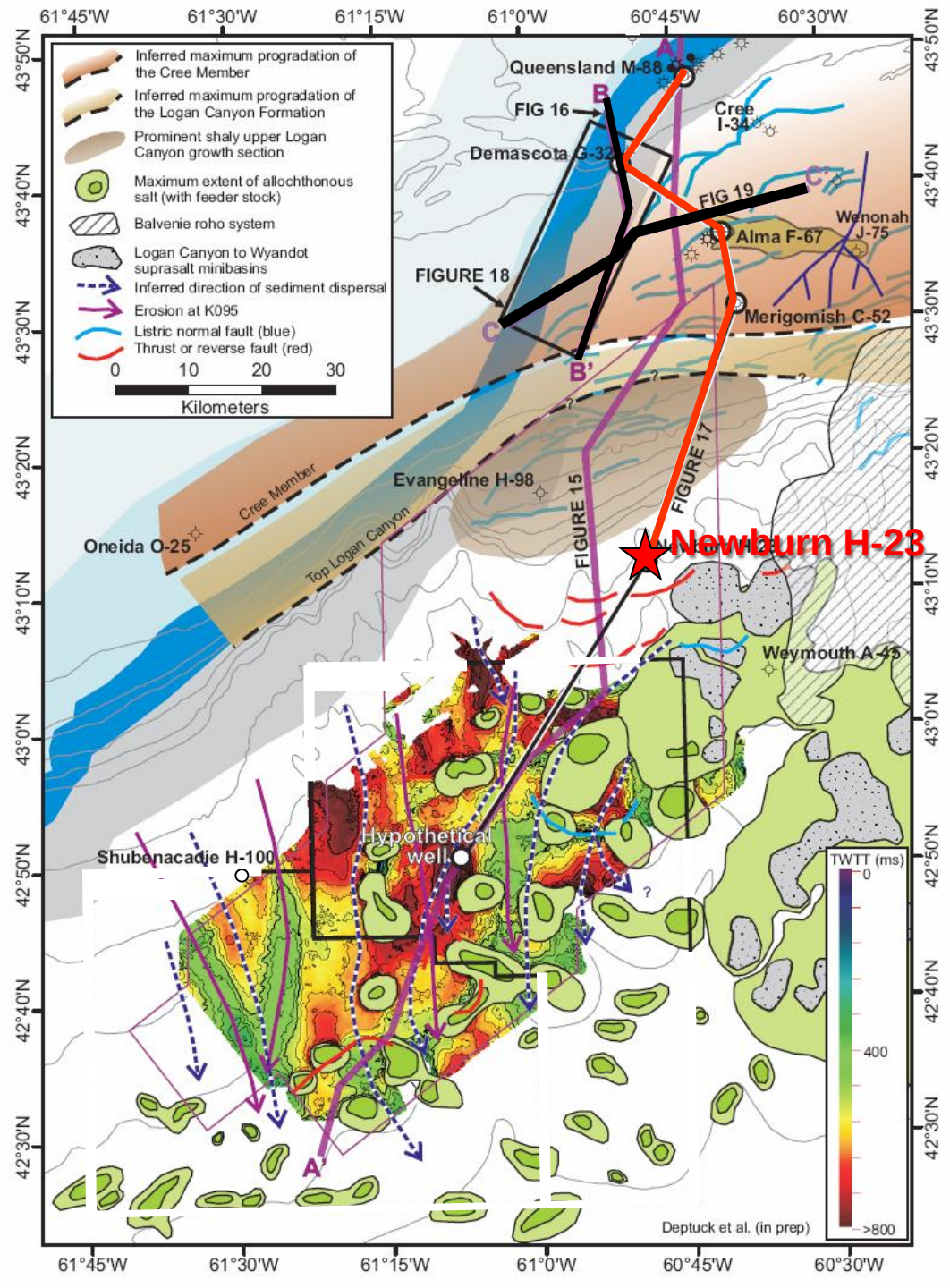
Southward progradation of Sable Island Delta

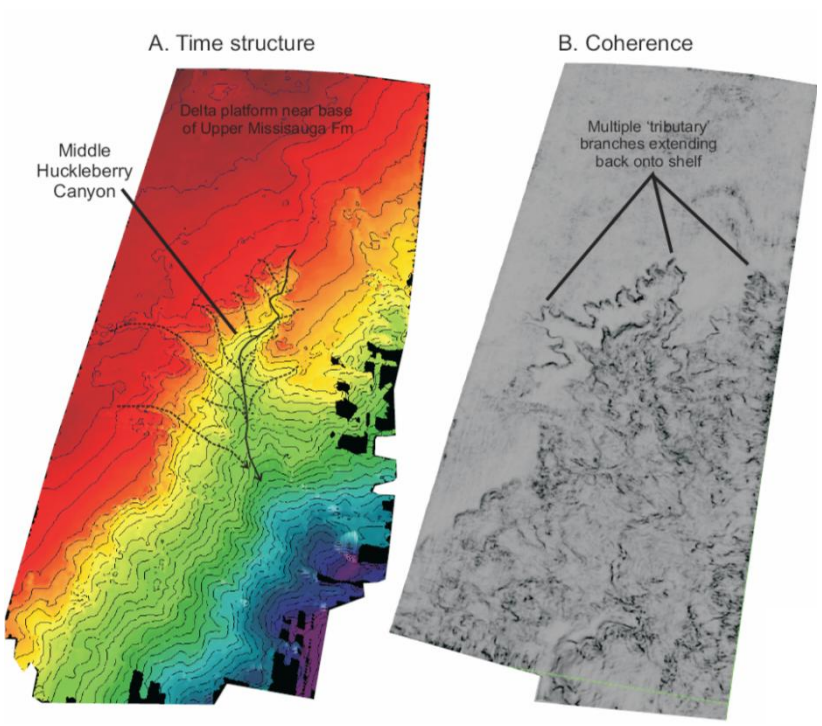


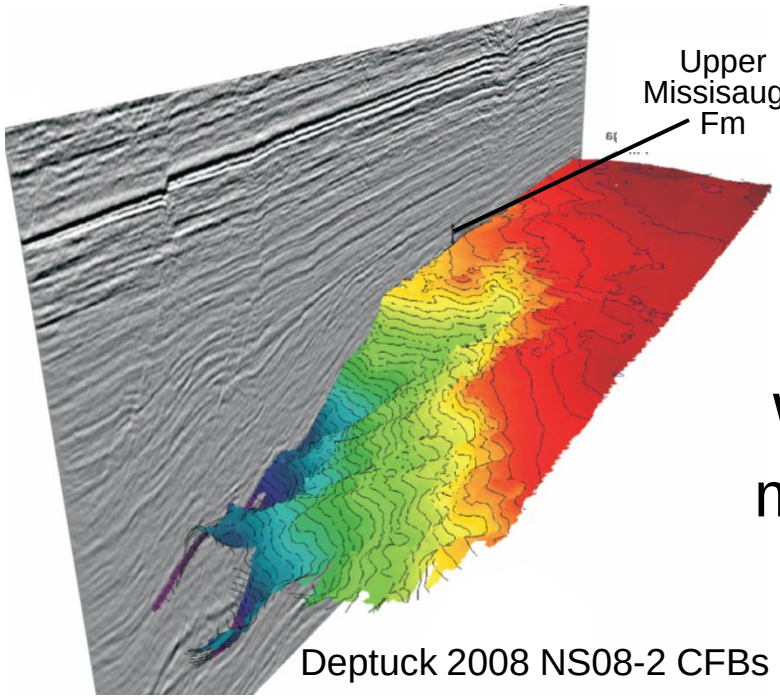
Deptuck 2008 NS08-2 CFBs package

Logan Canyon Formation and equivalent succession

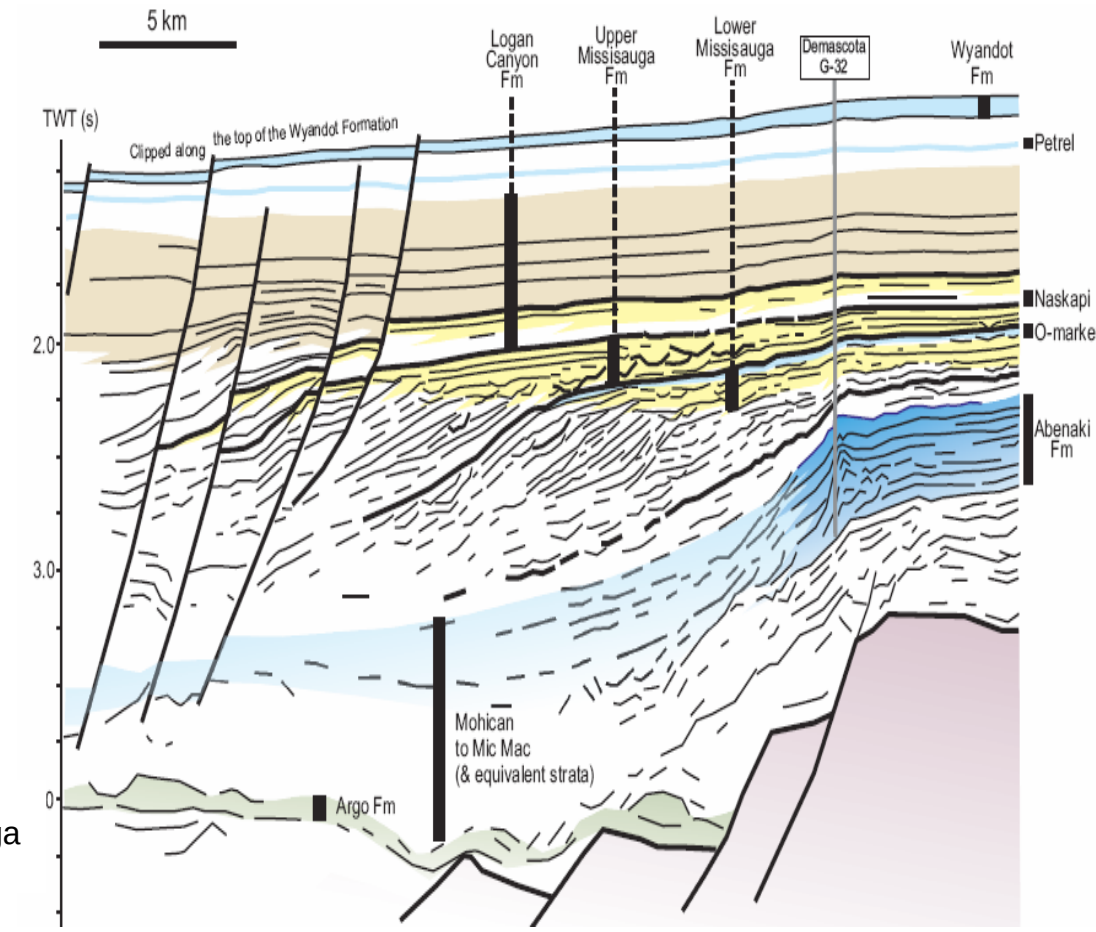
Southward progradation of Sable Island Delta







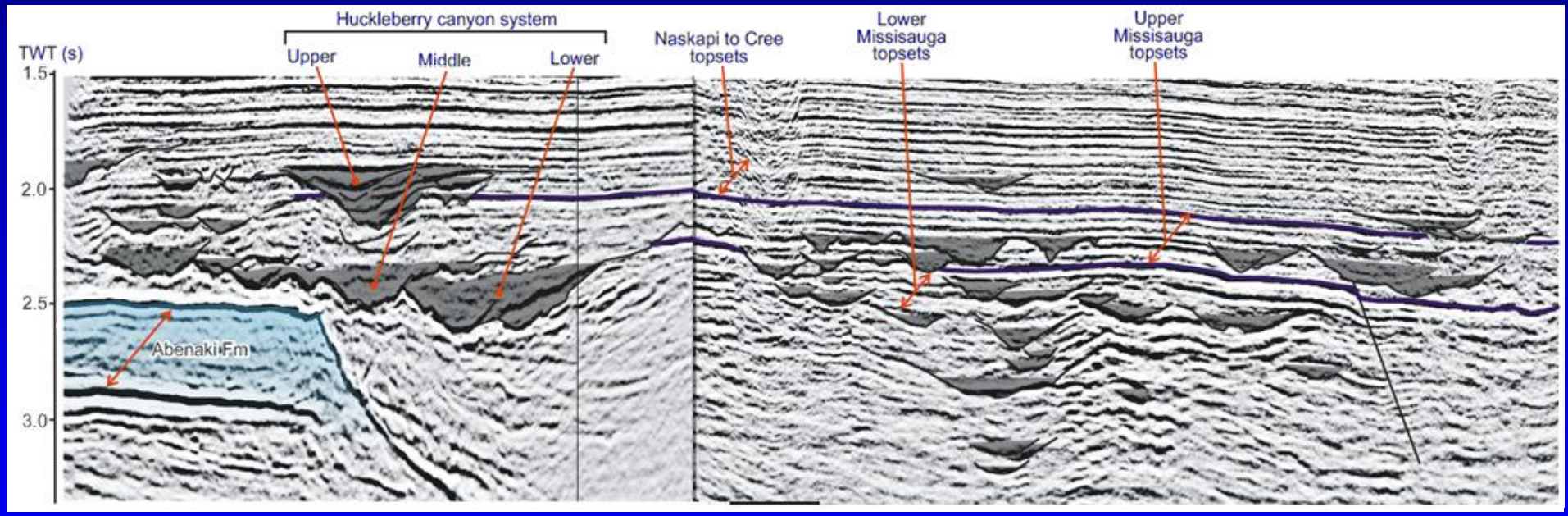
Deptuck 2008 NS08-2 CFBs package



Southward progradation of 'Sable Island Delta'

Western part of 'Sable Island Delta' most likely source for turbidite sands in Parcels 5 and 6 (and maybe 4)

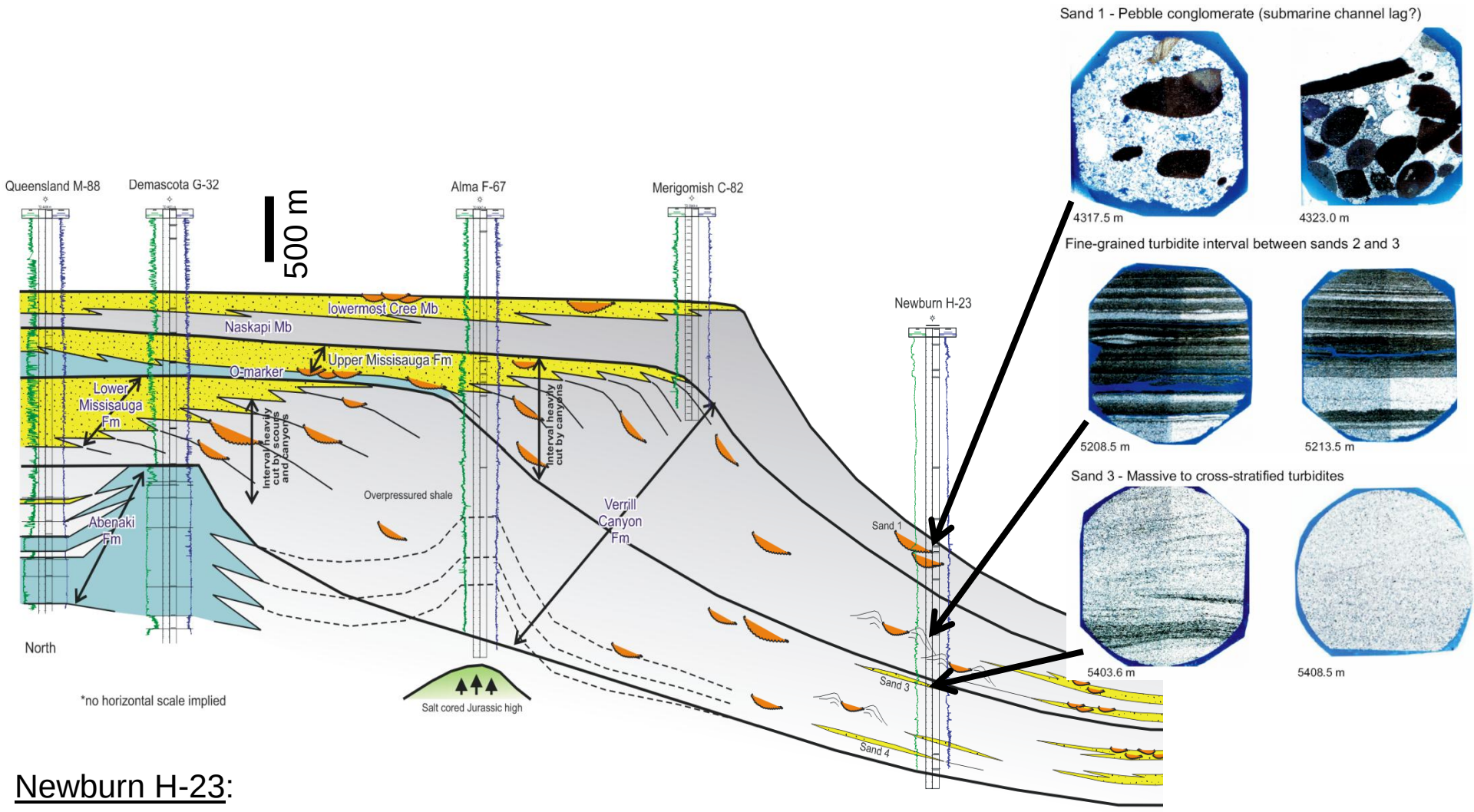
Multiple canyons on the Lower Cretaceous outer shelf to upper slope



W E

Deptuck 2008 NS08-2 CFBs package

Lithostratigraphic correlation of shelf strata to Newburne H-23

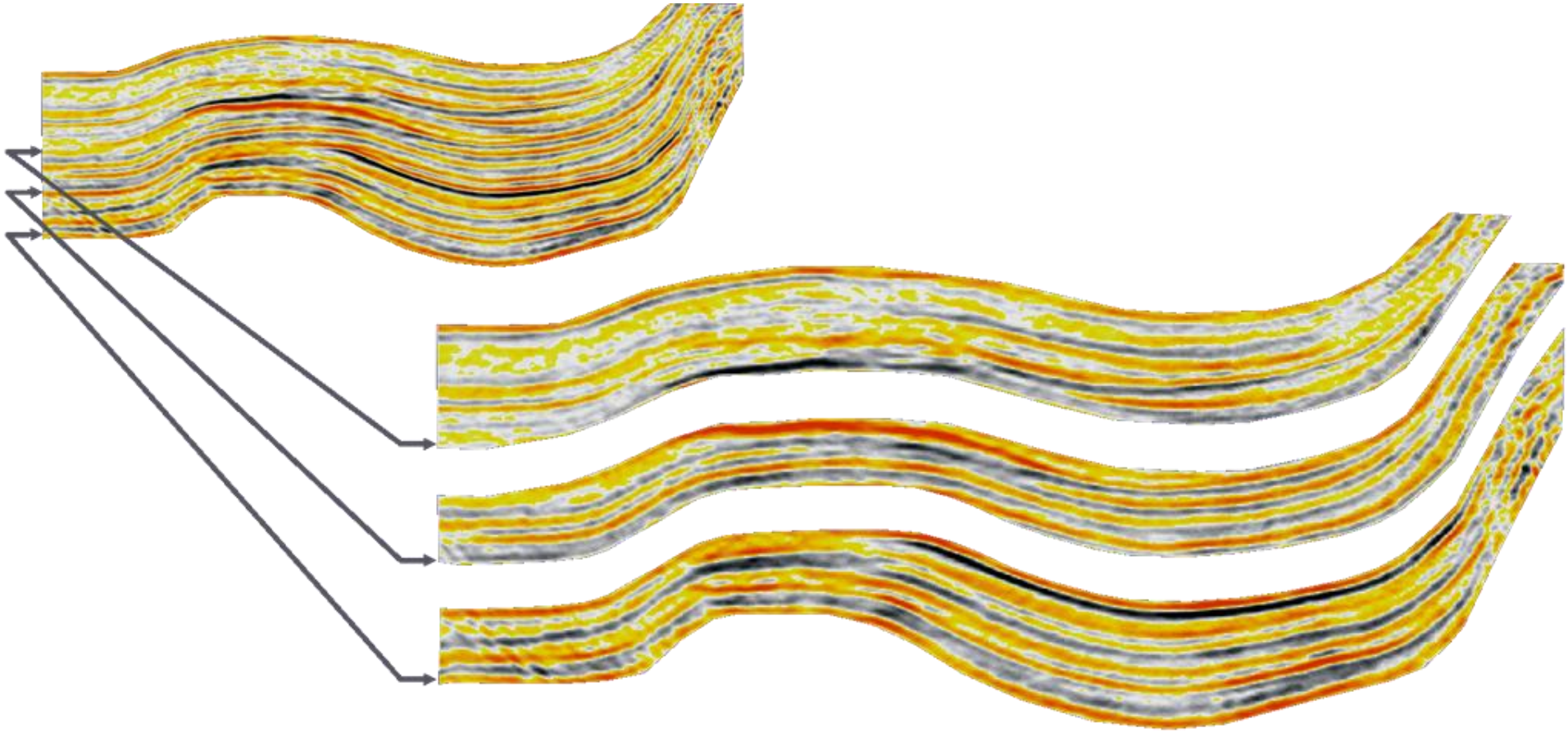


Newburn H-23:

- 4 gas-bearing turbidite sands (6-9 m thick, 8 m total pay, 14-19% porosity)
- pebble conglomerates in sand 1 – bypass channel lag
- 12 of 14 swc between sand 2 and 3 encountered fine-grained turbidites interpreted as overbank (levee) deposits adjacent to submarine channels

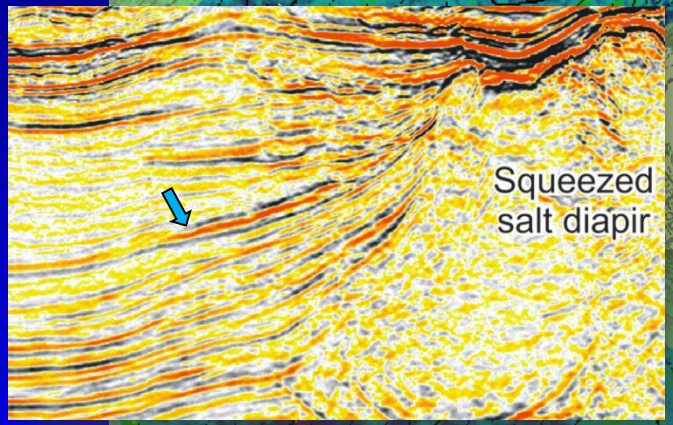
Deptuck 2008
NS08-2 Call for bids package

Seismic facies:
Subtle onlap-baselap of interpreted turbidite lobes within a succession of generally marly background deposits



Deptuck 2008 NS08-2 CFBs package

Albian submarine channel feeding slope-break fan (apron)



Salt

Salt

Salt

Salt

Salt

2.5 km

Amplitude extraction
from Early Albian marker

Early Eocene Unconformity - Time-structure Map

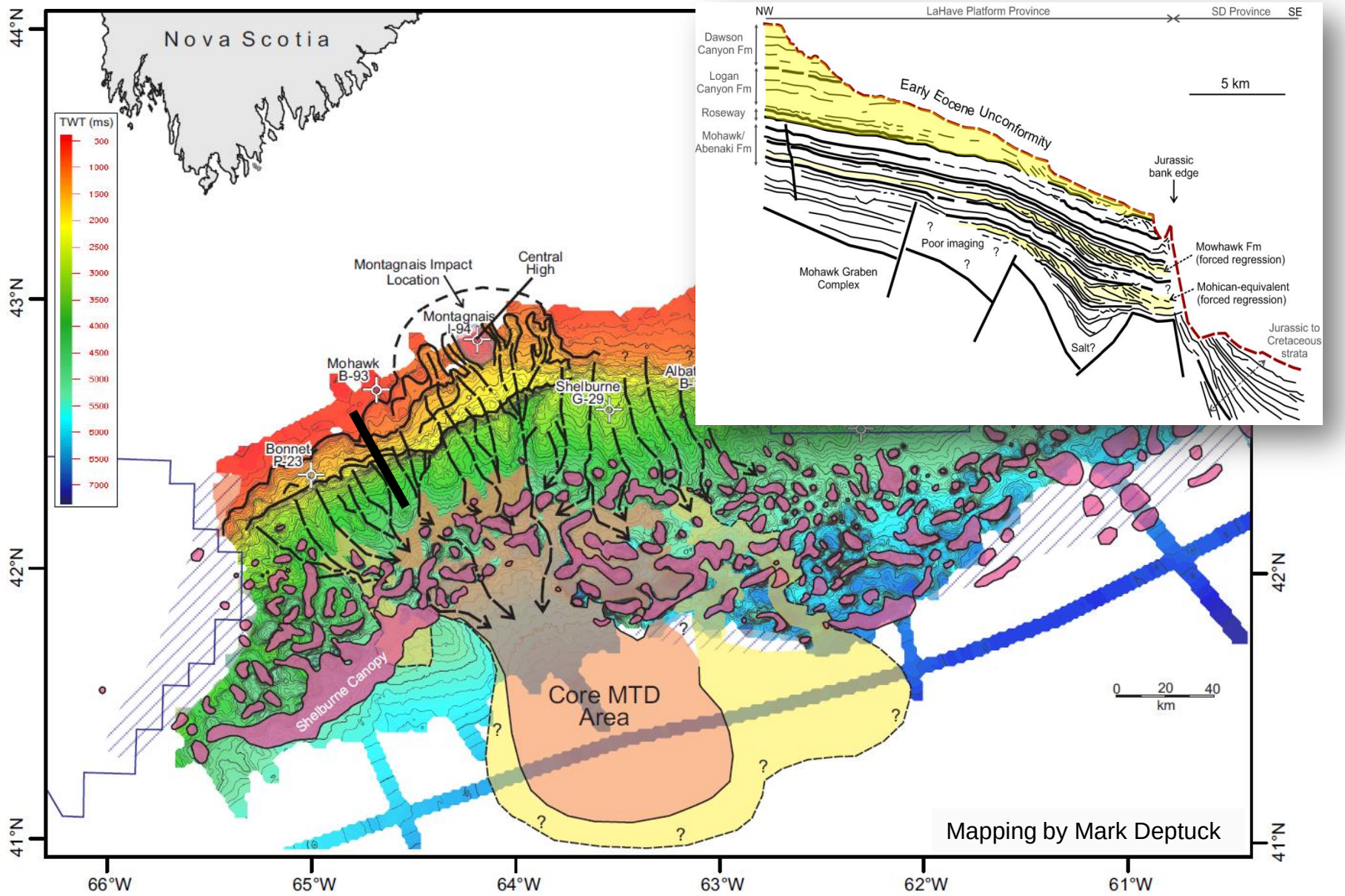
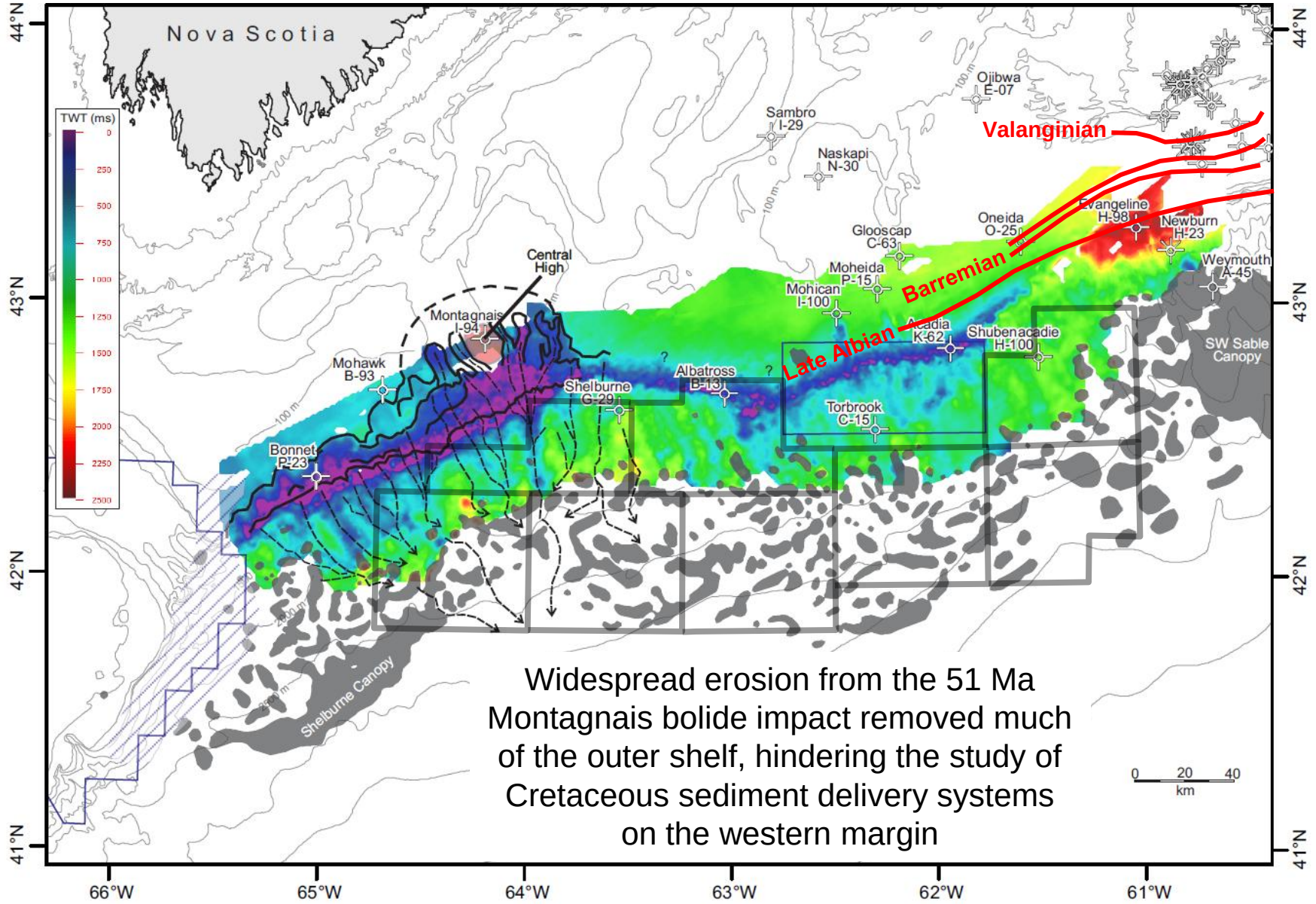


Figure 5b – Gridded time-structure map of the Early Eocene unconformity, annotated to show canyons that transported failed material directly down-slope from the impact site, where a widespread mass transport deposit is recognized. Orange indicates the primary core of the mass transport deposit, while yellow indicates peripheral mass wasted material. There is a high degree of uncertainty about its distribution in deepwater.

J150 to T50 - Cretaceous to Paleocene Time-thickness Map



Widespread erosion from the 51 Ma Montagnais bolide impact removed much of the outer shelf, hindering the study of Cretaceous sediment delivery systems on the western margin

Figure 6 – Time-thickness map between the top Jurassic carbonate bank marker and the Early Eocene unconformity, showing the widespread erosion of the Cretaceous to Paleocene stratigraphic succession caused, at least in part, by the bolide impact.

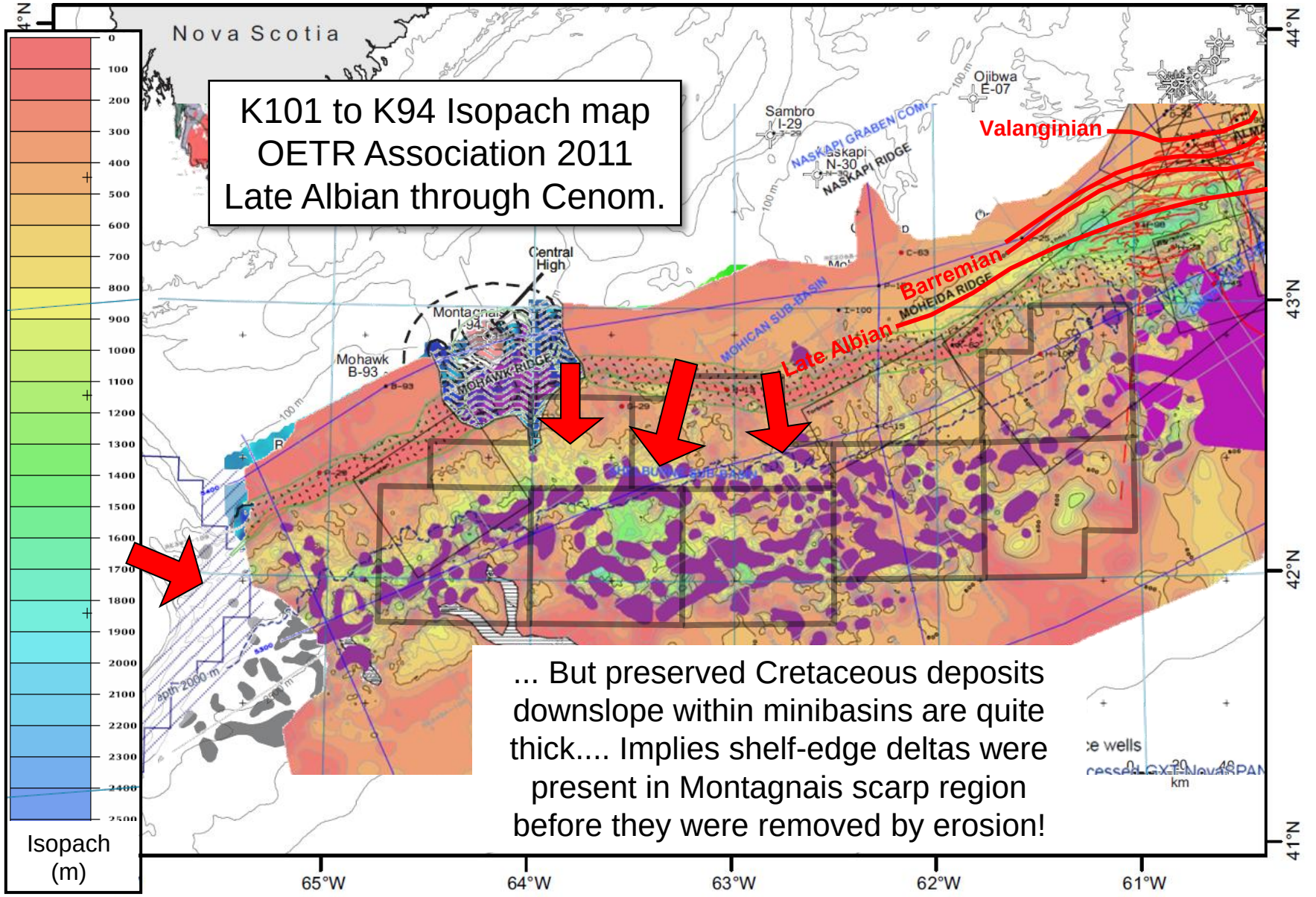
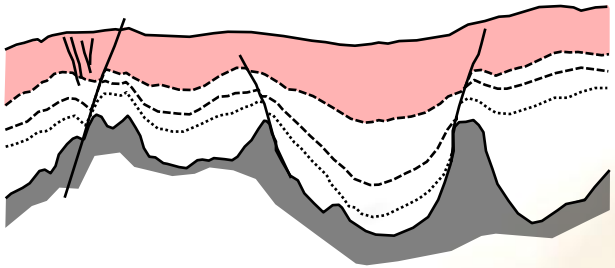
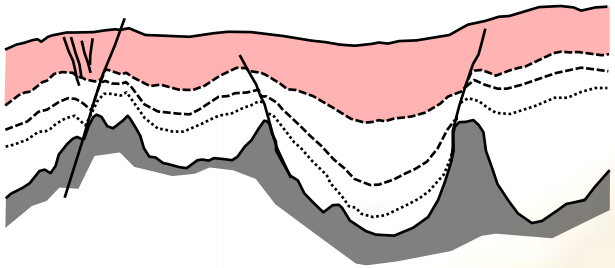


Figure 6 – Time-thickness map between the top Jurassic carbonate bank marker and the Early Eocene unconformity, showing the widespread erosion of the Cretaceous to Paleocene stratigraphic succession caused, at least in part, by the bolide impact.

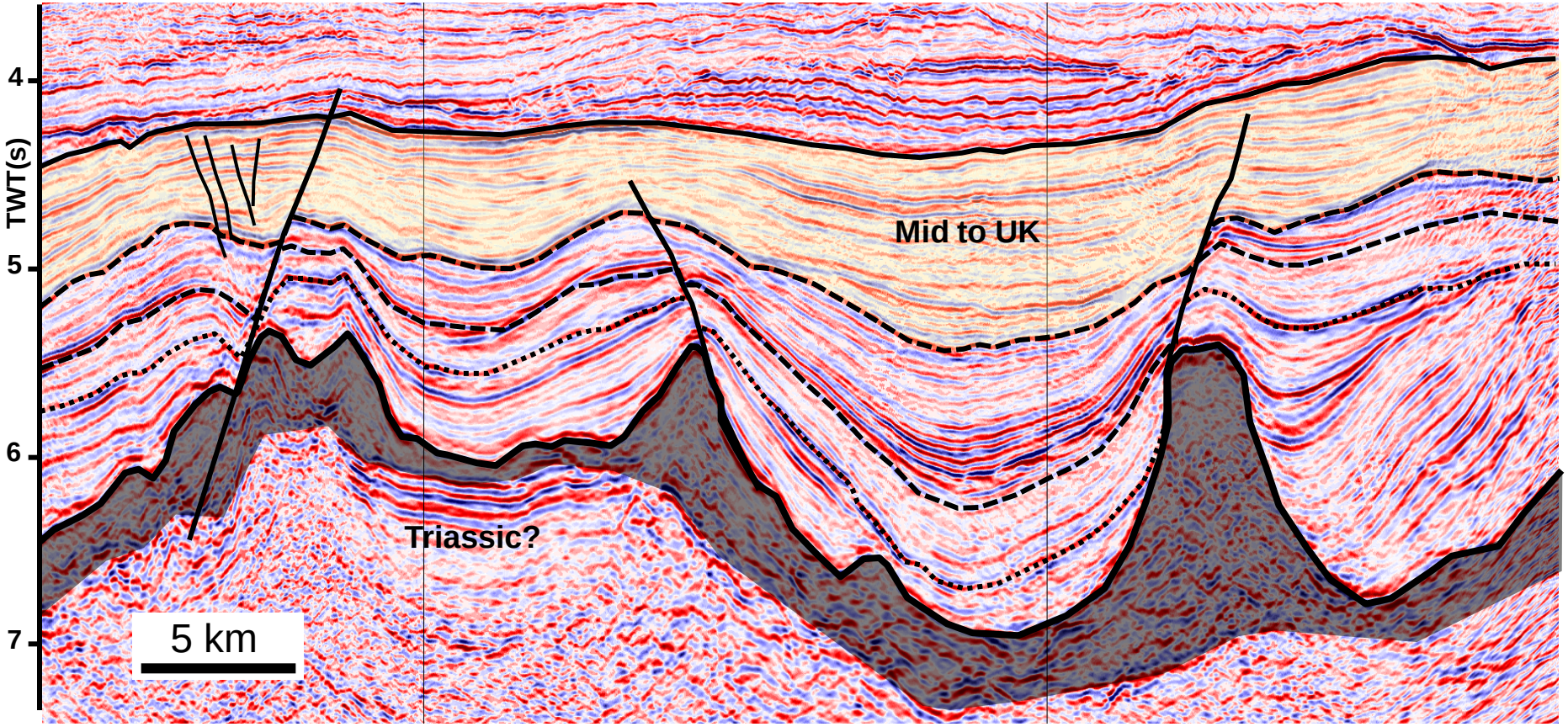
Albian to Cenomanian



Albian to Cenomanian



Representative profile near transition from bypass to deposition



*Water column depth converted (shallows section by ~0.5 s twt)

-smaller-scale channels
-some ponded sediments

Key Points

Southwestern margin is a hybrid bypass to ponded slope…. If Cretaceous reservoirs are present, they are likely to be thickest down-slope from slope detachment province (region of slope bypass), in an area where we simply don't have any calibration yet

Potential Reservoirs - Jurassic

• Mohican Fm locally quite thick and progradational in the Mohican Graben Complex and locally further west

• some evidence that Mohawk/Mic Mac clastics periodically breached the carbonate bank and supplied clastics directly onto the steep, heavily canyoned slope

• foreslope to basinal resedimented carbonates (as in Tamabra) are worth further investigation

Potential Reservoirs - Cretaceous:

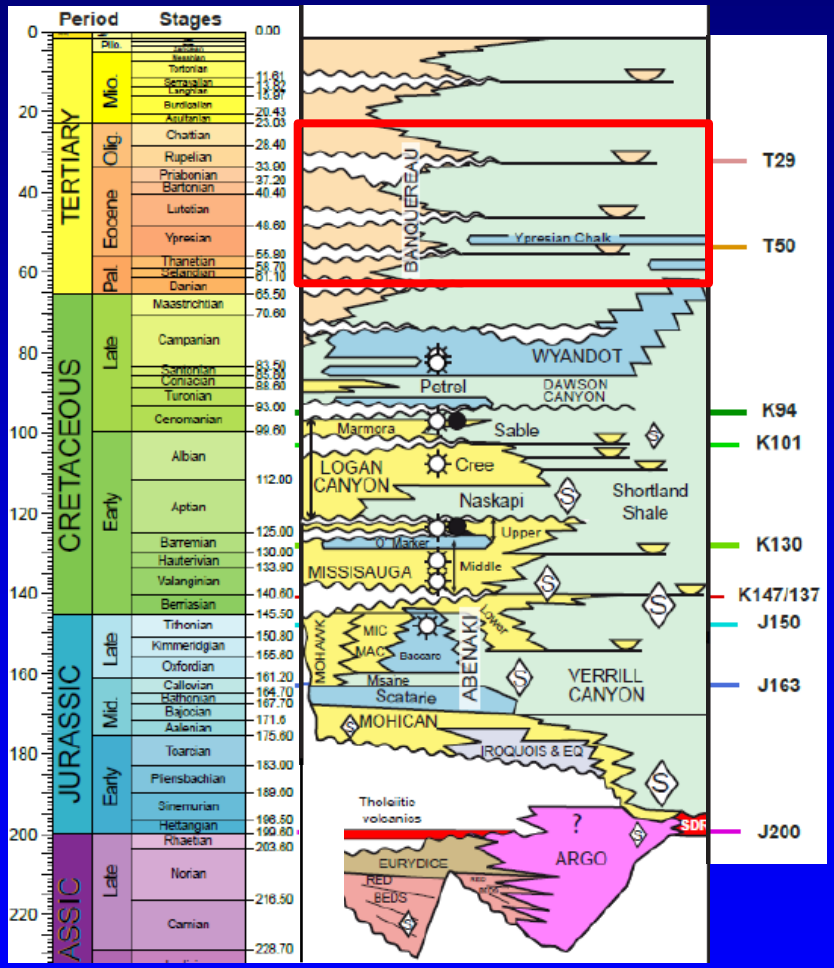
• turbidites sourced from Sable Island Delta (east)

• hard to evaluate further west due to heavy erosion associated with Montagnais bolide impact

• multiple periods of canyoning indicate that sediment transport into deepwater did take place, but grade is not known

• expanded Logan Canyon equivalent strata in down slope minibasins warrants further study – need 3D seismic to properly evaluate!

Cenozoic



- Poorly understood
- Numerous canyons, some with sinuous channels at base
- Complex interaction with well developed contourite systems (see Campbell PhD – defends on November 4th)
- Campbell and Deptuck (2011) paper on alternating down-slope and cross-slope deposits on the western Scotian margin

Early Eocene to Seafloor Time-thickness Map

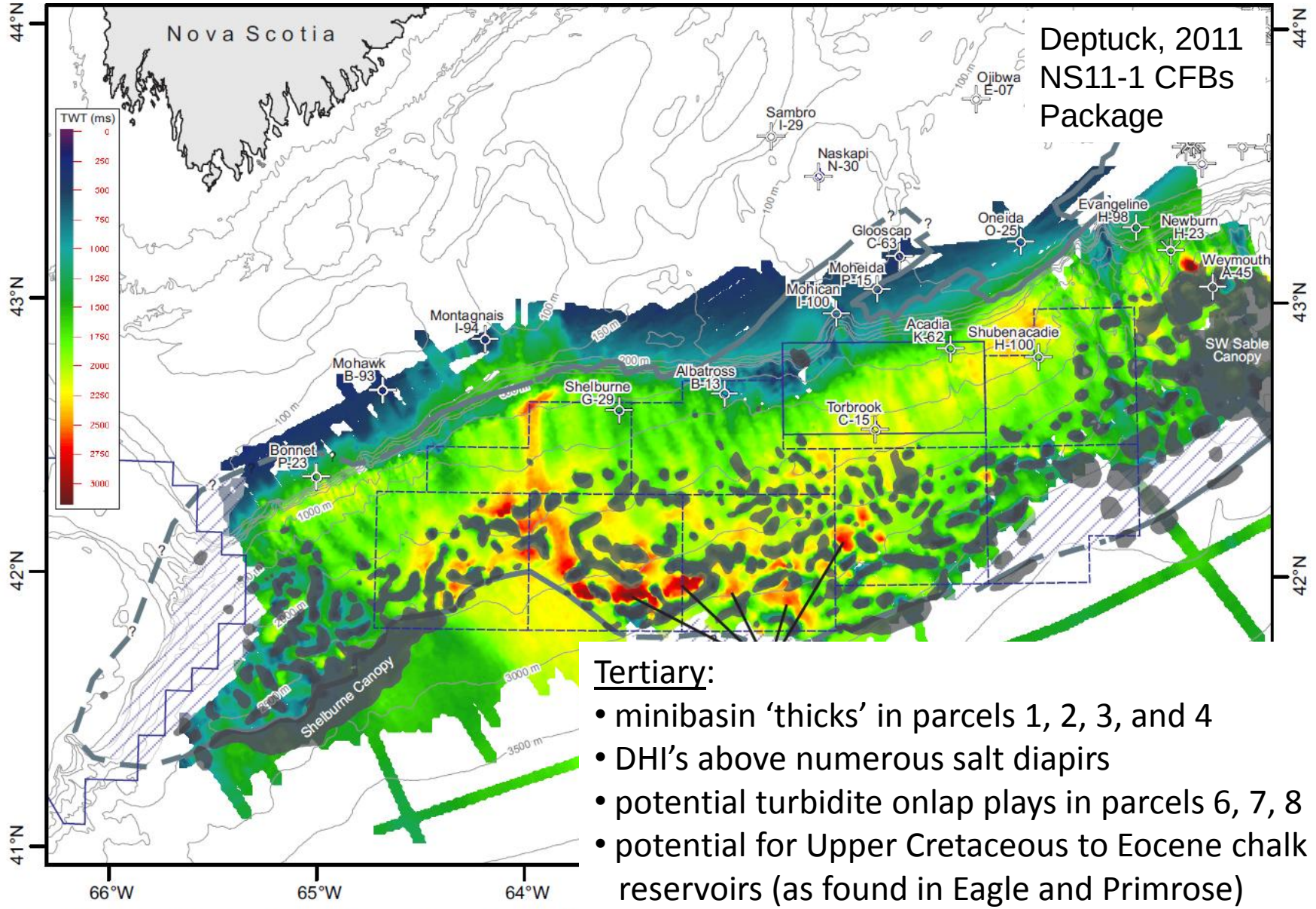
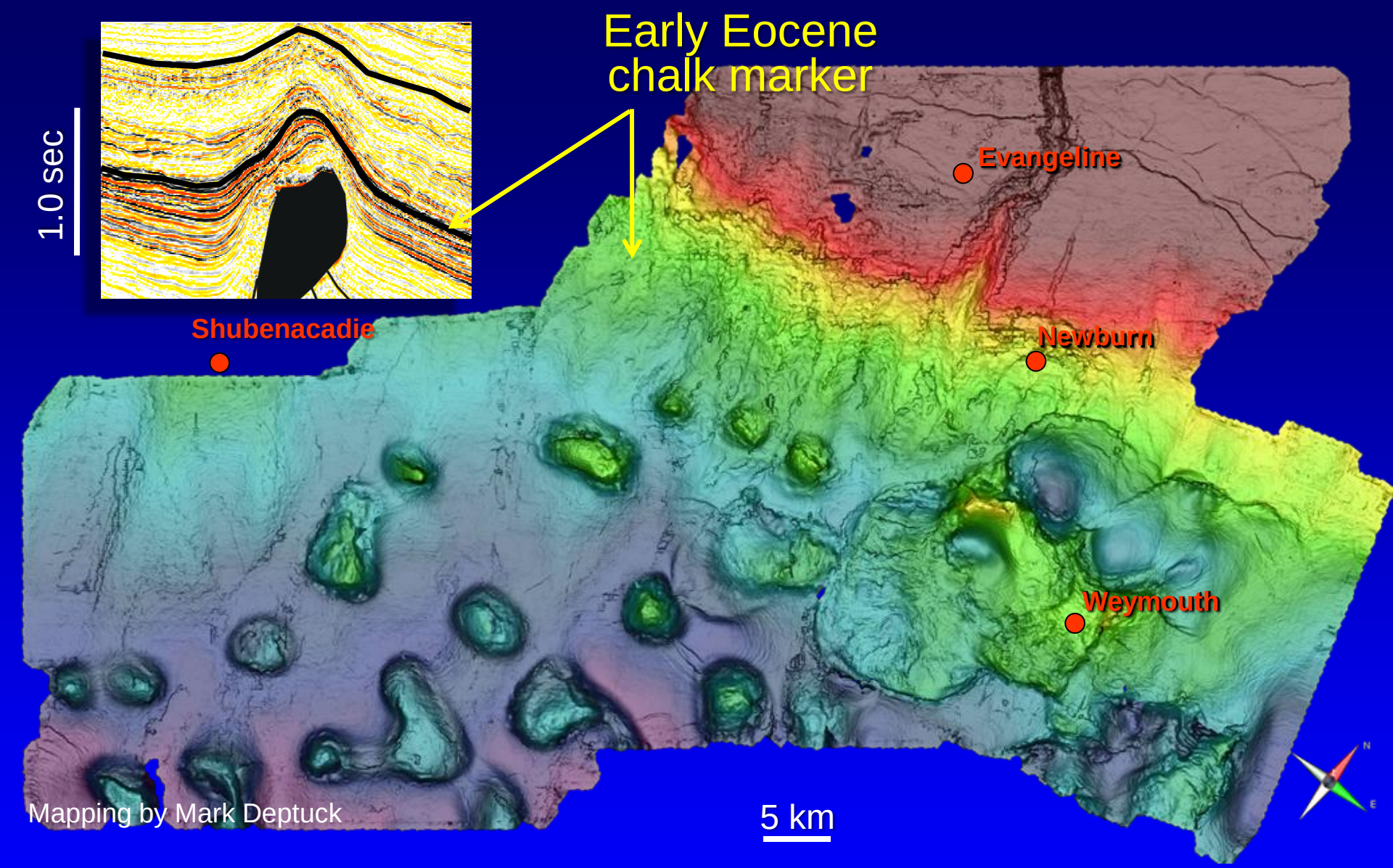


Figure 16 – Time-thickness map between the Early Eocene unconformity
a clear area of Cenozoic minibasins near the centre of the map.

<u>Tertiary</u>:

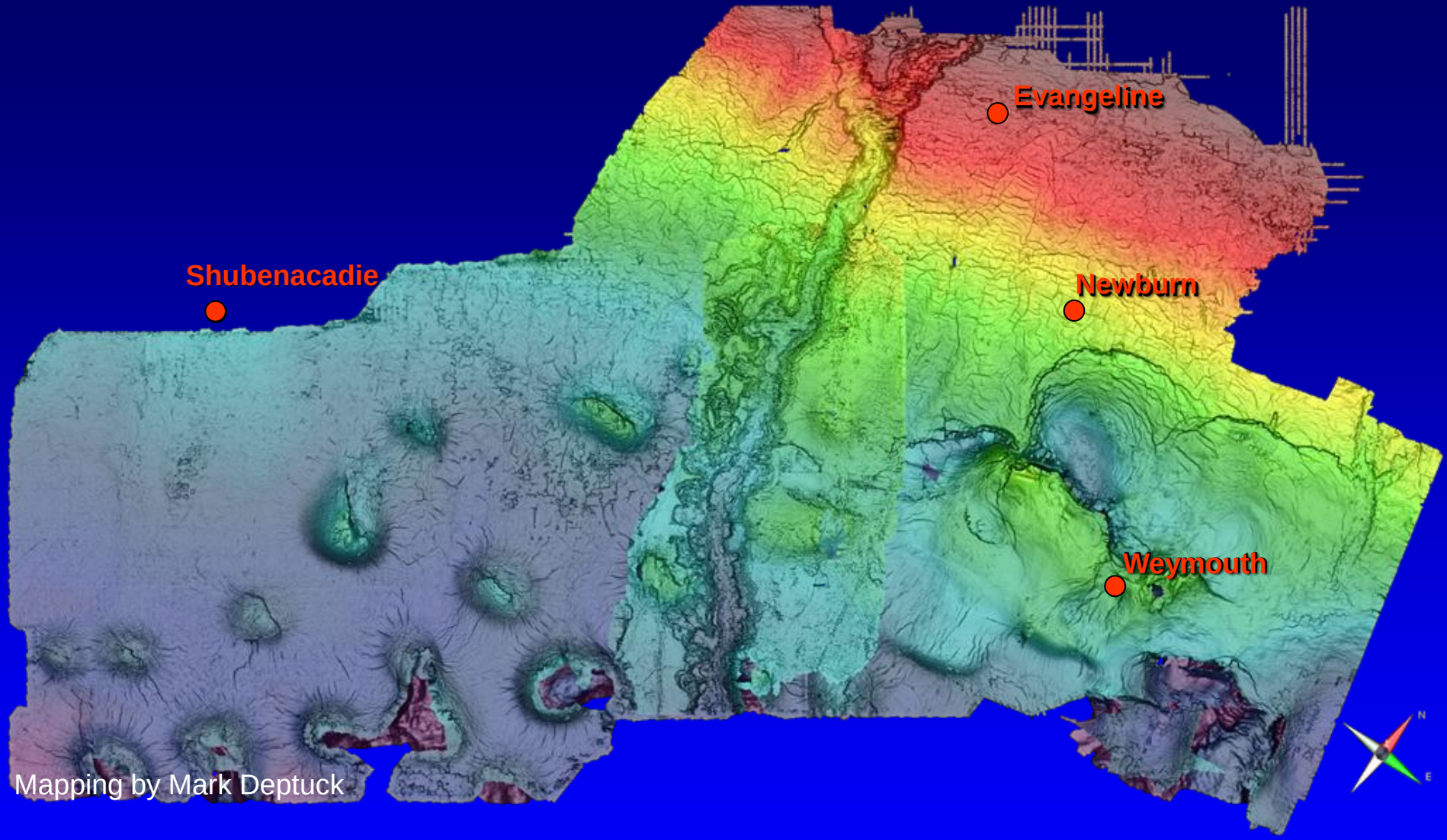
- minibasin ‘thicks’ in parcels 1, 2, 3, and 4
- DHI’s above numerous salt diapirs
- potential turbidite onlap plays in parcels 6, 7, 8
- potential for Upper Cretaceous to Eocene chalk reservoirs (as found in Eagle and Primrose)
- multple regressive periods in Eocene-Oligocene shelf succession, especially east of Montagnais



- Widespread folding of strata above many diapirs in the ASM Province -

Some of these young structures could be viable targets if, as proposed in the OETR 2011 PFA, the timing of Pleinsbachian source rock maturity is also young. Requires deposition of a viable reservoir (turbidites or chalk?) before diapirs were squeezed.

Middle Miocene marker

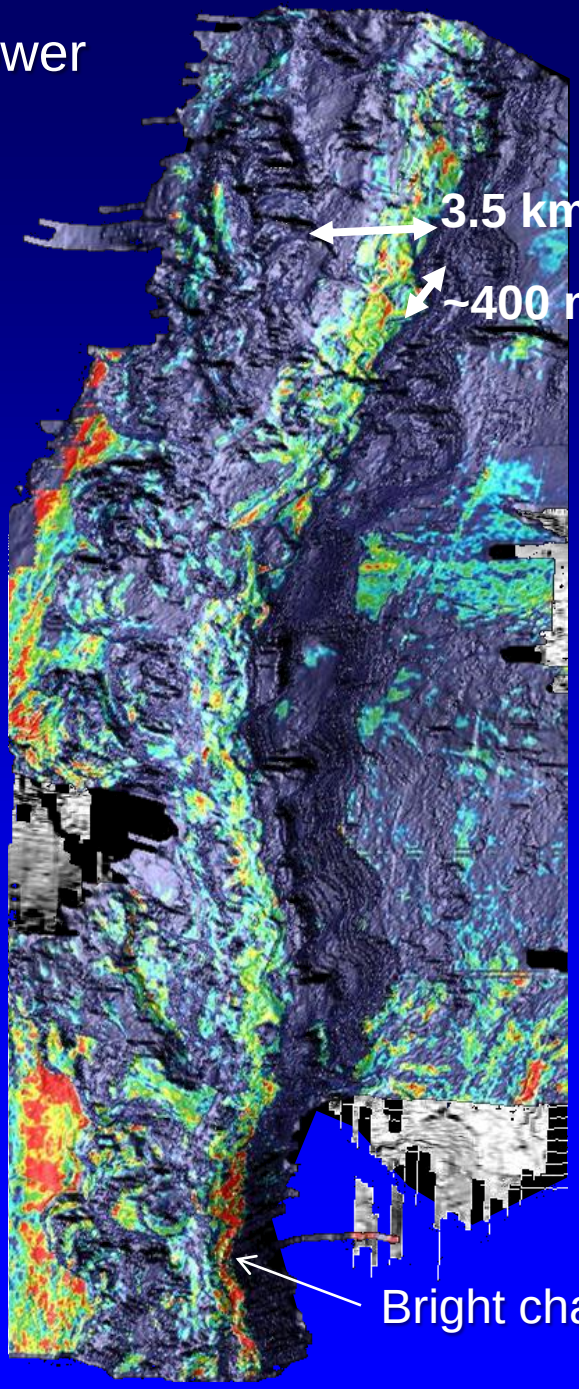


Sandy channels in the lower fill of the canyon

Channels at base are 50-200 m wide

Mapping by Mark Deptuck

Sandy channels in the lower fill of the canyon



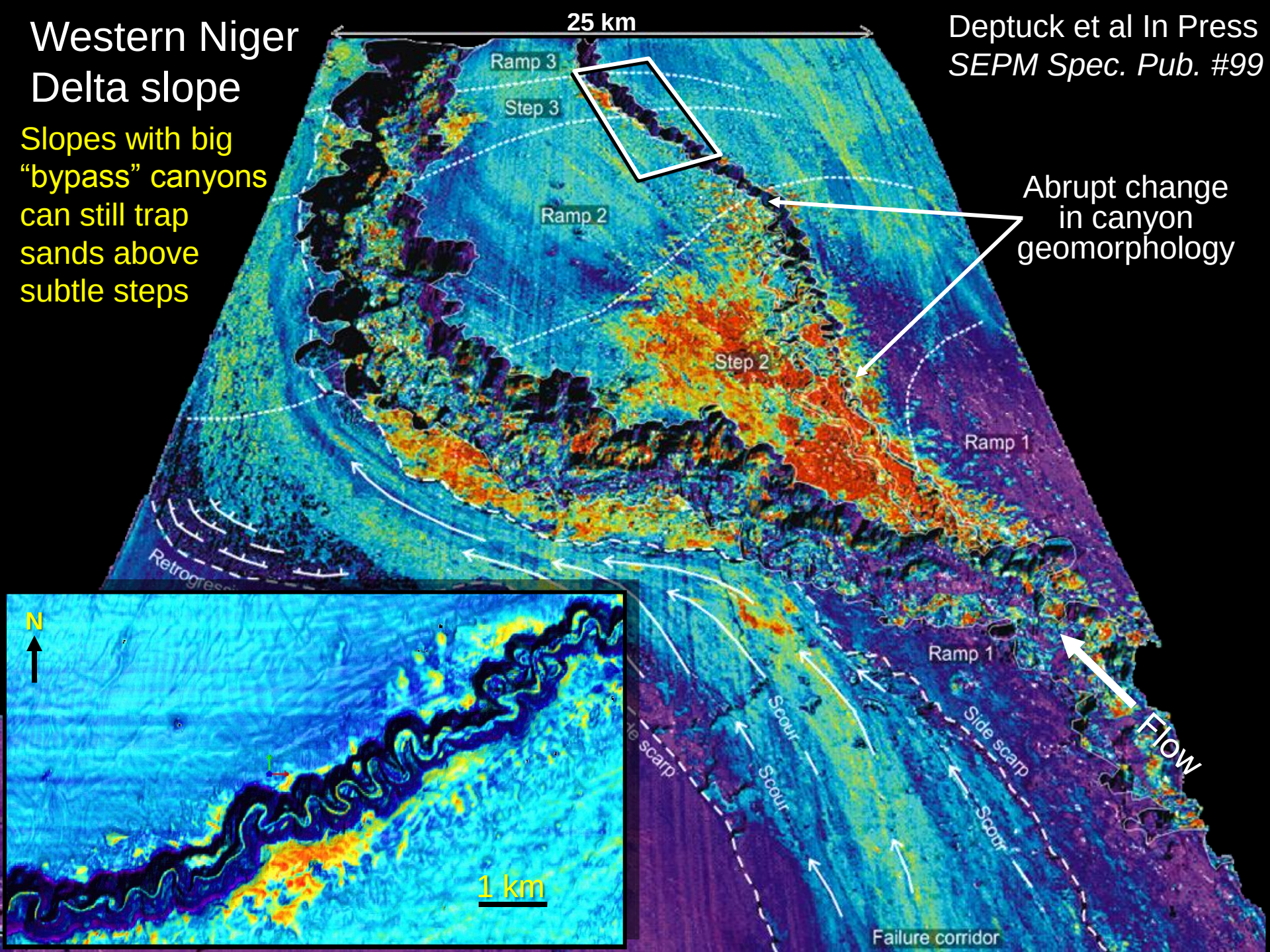
Channels at base are 50-200 m wide

Mapping by Mark Deptuck

Western Niger Delta slope

Slopes with big “bypass” canyons can still trap sands above subtle steps

Deptuck et al In Press
SEPM Spec. Pub. #99



Thank you!

For more about slope morphology and its impact on reservoir architecture and distribution see:

Application of Seismic Geomorphology Principles to Continental Slope and Base-of-Slope Systems: Case Studies from Seafloor and Near-Seafloor Analogues

Edited by: Bradford E. Prather, Mark E. Deptuck, David Mohrig, Berend van Hoorn, and Russell B. Wynn

This Special Publication volume is based on the 2009 SEPM Research Conference of the same title held in Houston, TX. This volume is planned as digital online and CD version. Shell sponsorship will make the online version free access at www.sepmonline.org. The CD version will contain the full resolution version of all images. This book is in the final editing stages and should be out by Fall, 2011.