CHAPTER 5

SEISMIC INTERPRETATION

CHAPTER 5.1

SEISMIC DATABASE

Seismic database

The seismic interpretation has been carried out on various 2D seismic surveys covering the whole study area and gathering **6400 km of 2D data**. These data acquired, processed and reprocessed during the thirty year long exploration history (from the 80s to present day) do not have the same quality.

In total, **5 2D surveys** were made available for the project. The seismic versions used for the project were the results of a preliminary data conditioning performed by RPS in 2009 in terms of time and phase shifts and in terms of seismic amplitude balancing.

On the study area **2 mains survey** have been used to do the interpretation: the **TGS** one which covers the entire Shelburne Sub-basin and the **JEBCO** survey which covers the Entire Yarmouth Arch.

The large-offset **NovaSPAN 2D seismic survey** have been integrated during the seismic interpretation of the Play Fairway Analysis as regional seismic lines.

Depending on the length of the structure and the distance to the seismic, the mapped horizon continuity is more or less certain. The map of Figure 1 illustrates the distance to the closest seismic data in order to give an idea on the uncertainty linked to the mapping.

Well database used for the seismic interpretation

The well to seismic tie was based primary on the three reference wells symbolized by a blue frame on the Figure 1. The two main wells (**Mohwak-B-93 and Bonnet-P-23**) have the complete set of data for the classical well to seismic tie (**checkshot survey, sonic and density logs**) but also the biostratigraphic results insuring the age of the seismic horizons picked. The **Cost G-2** well (located outside the study area) has only biostratigraphic data which is helpful to confirm the interpretation on the Yarmouth Arch.

The Figure 1 illustrates the distance to the closest well which has been tied to the seismic. It gives us a simple but direct idea of the "lateral uncertainty" linked to the seismic to well tie and depth conversion (far from the well, uncertainties raise).

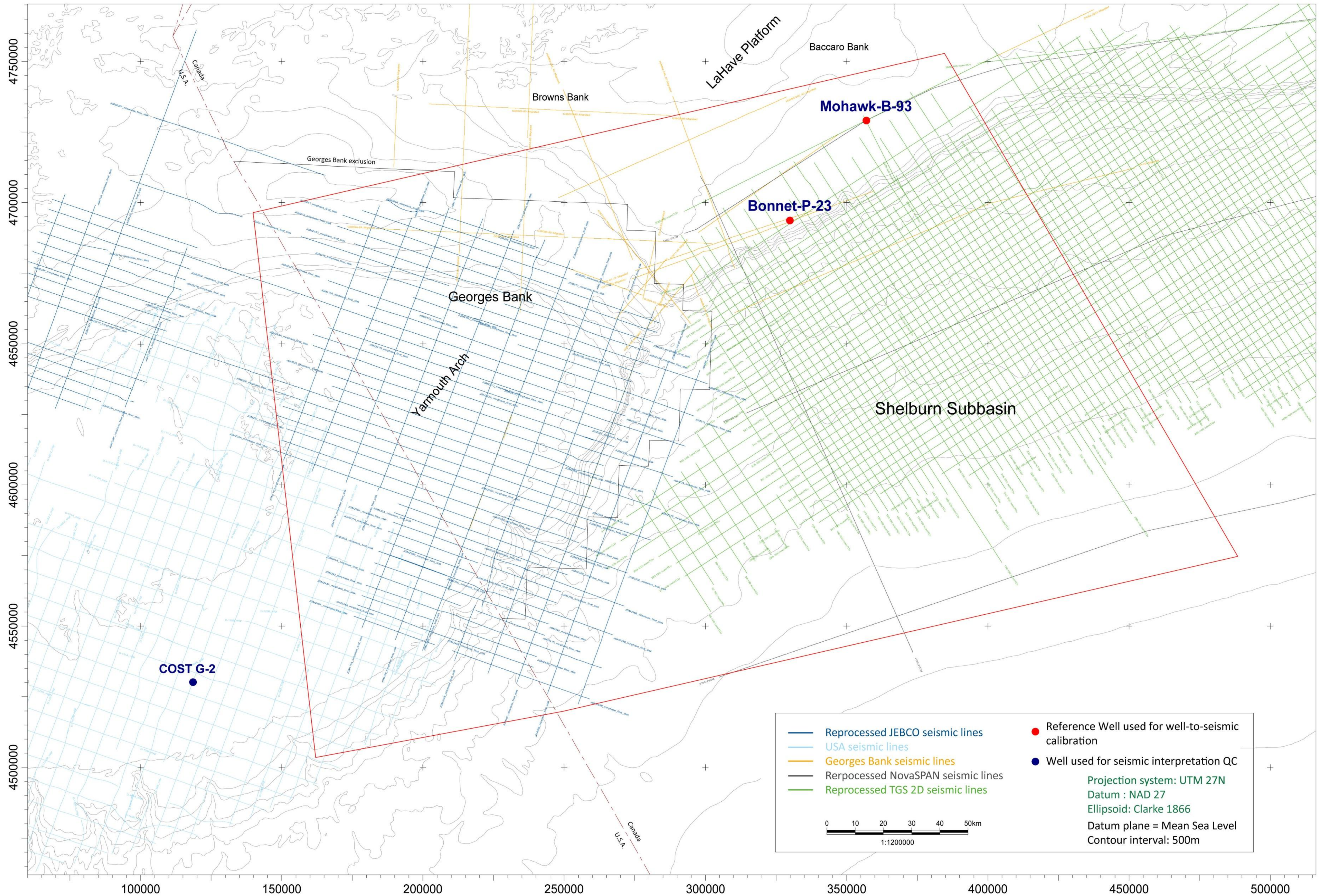
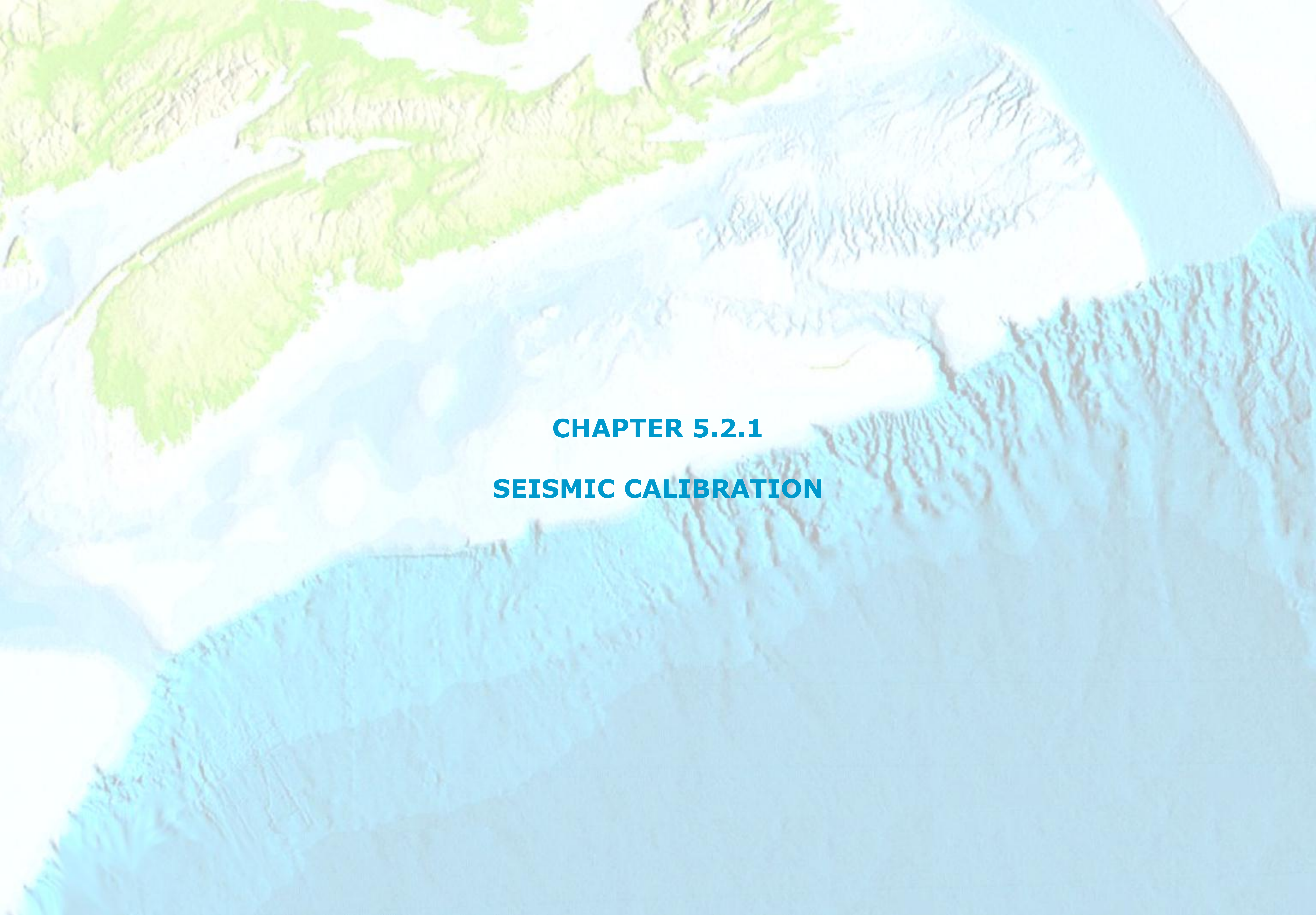


Figure 1: Seismic data density and well location map

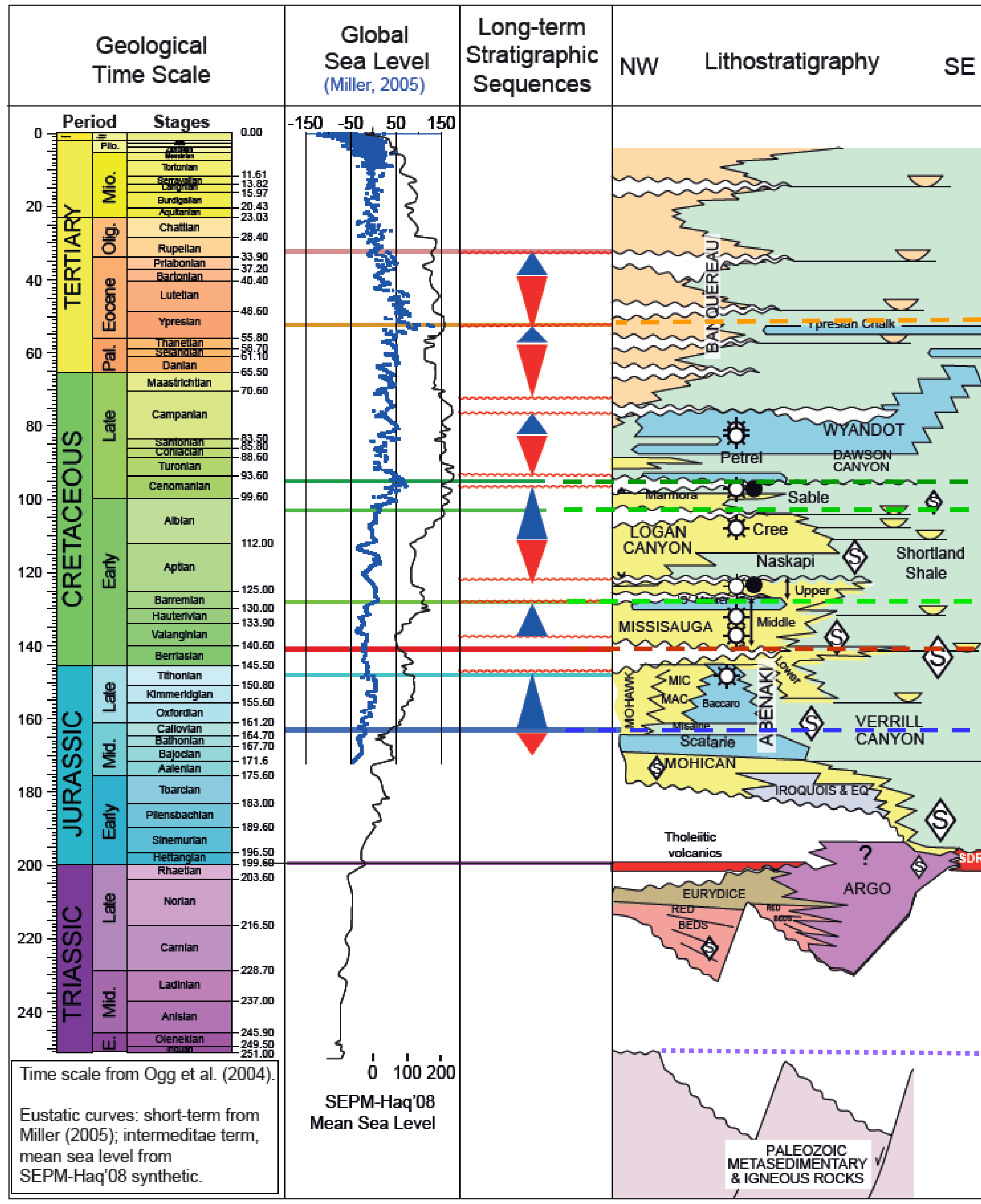


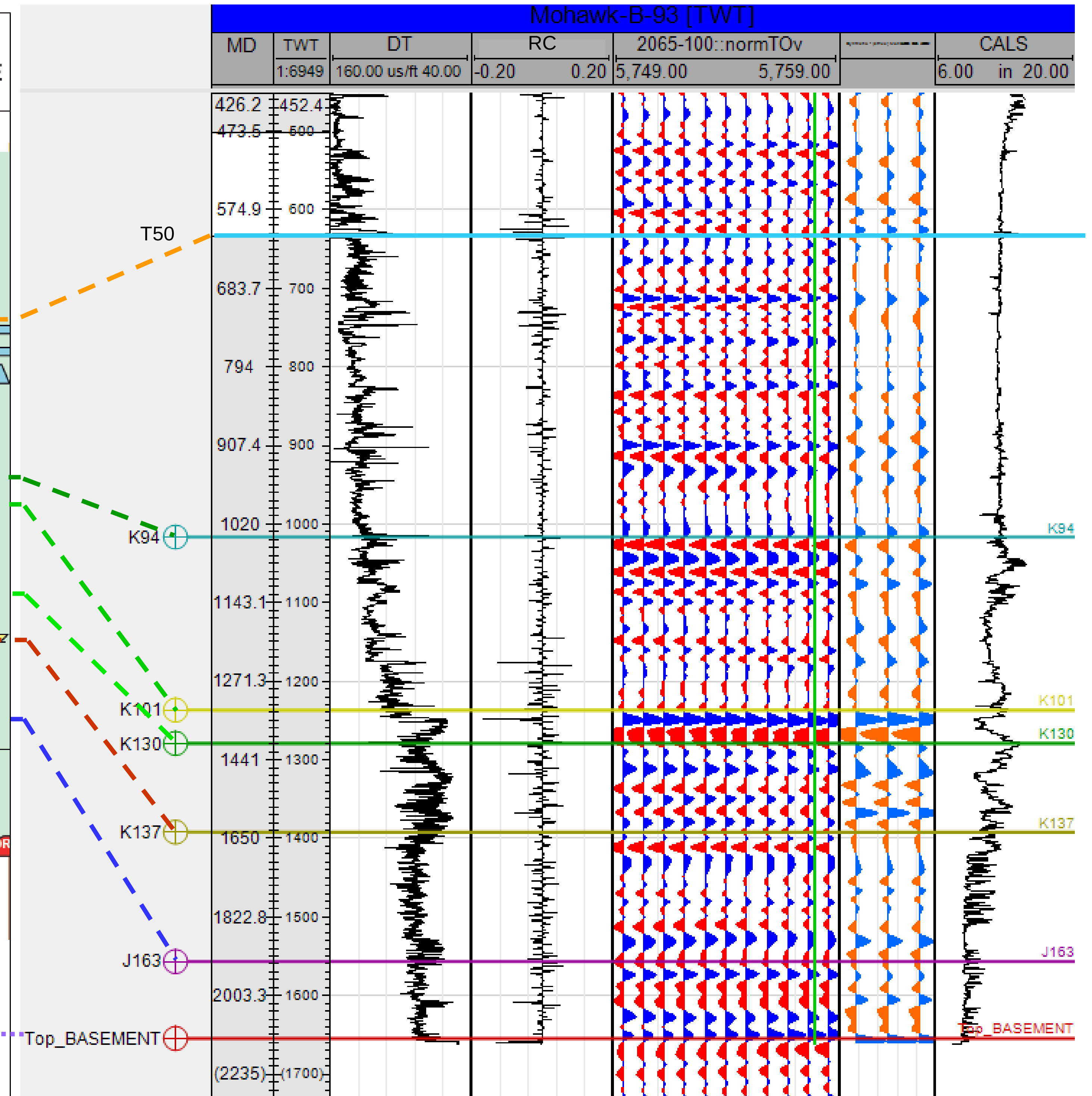
CHAPTER 5.2.1

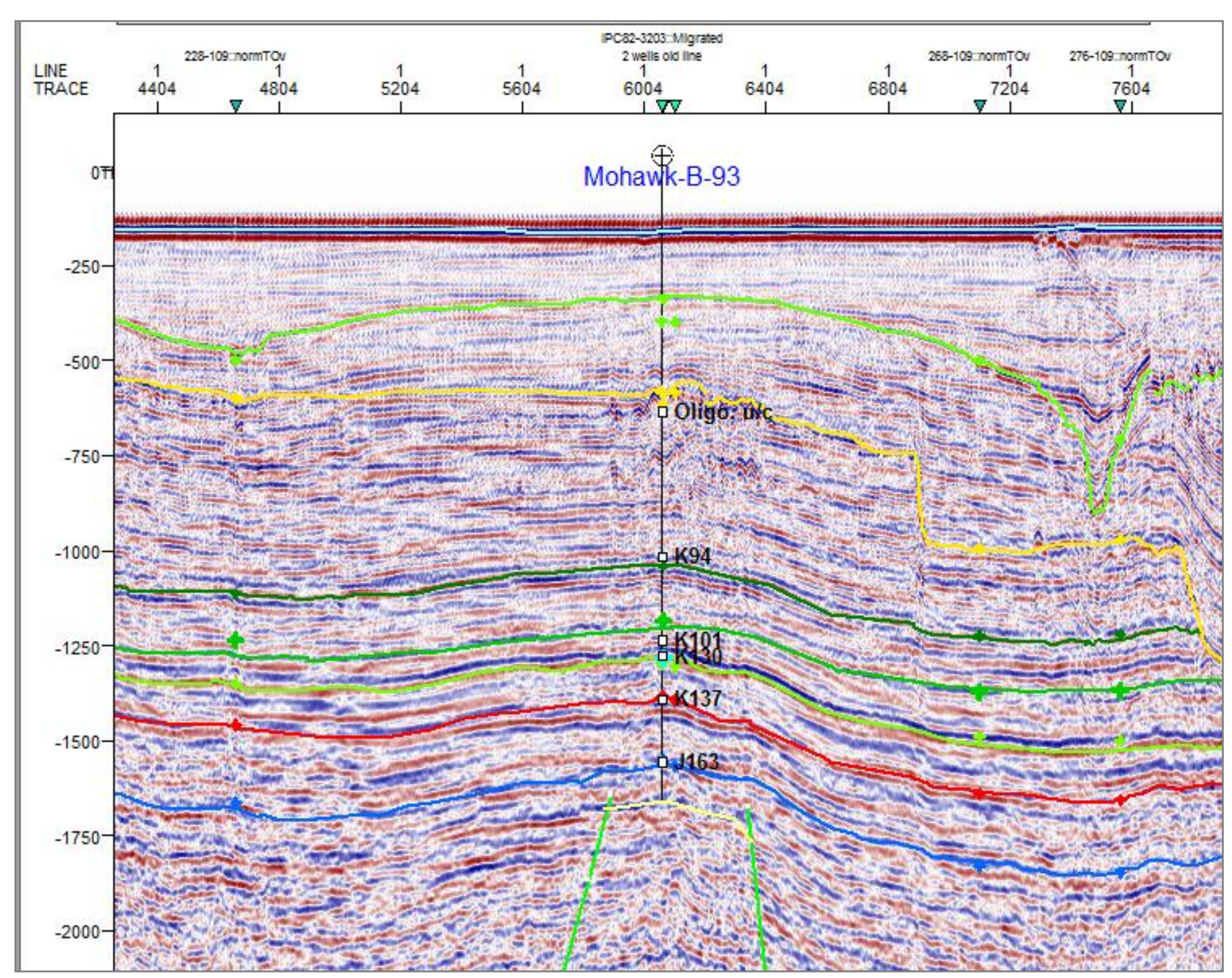
SEISMIC CALIBRATION

SEISMIC CALIBRATION AND VELOCITY MODEL

SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015







WELL HEADER		
Well Name	**Mohawk B-93**	
Rotary Table (R.T.)	31 m	
Total Depth (T.D.)	2126 m (R.T.)	
Geographic coordinates @surface	Lat: 42° 42' 10.52" N	Lon: 64° 43' 53.50" W
UTM coordinates (Zone 20N, NAD27, CL66)	X_{UTM} : 358182	Y_{UTM} : 4729065

BIOSTRATIGRAPHY	RPS Energy 2014

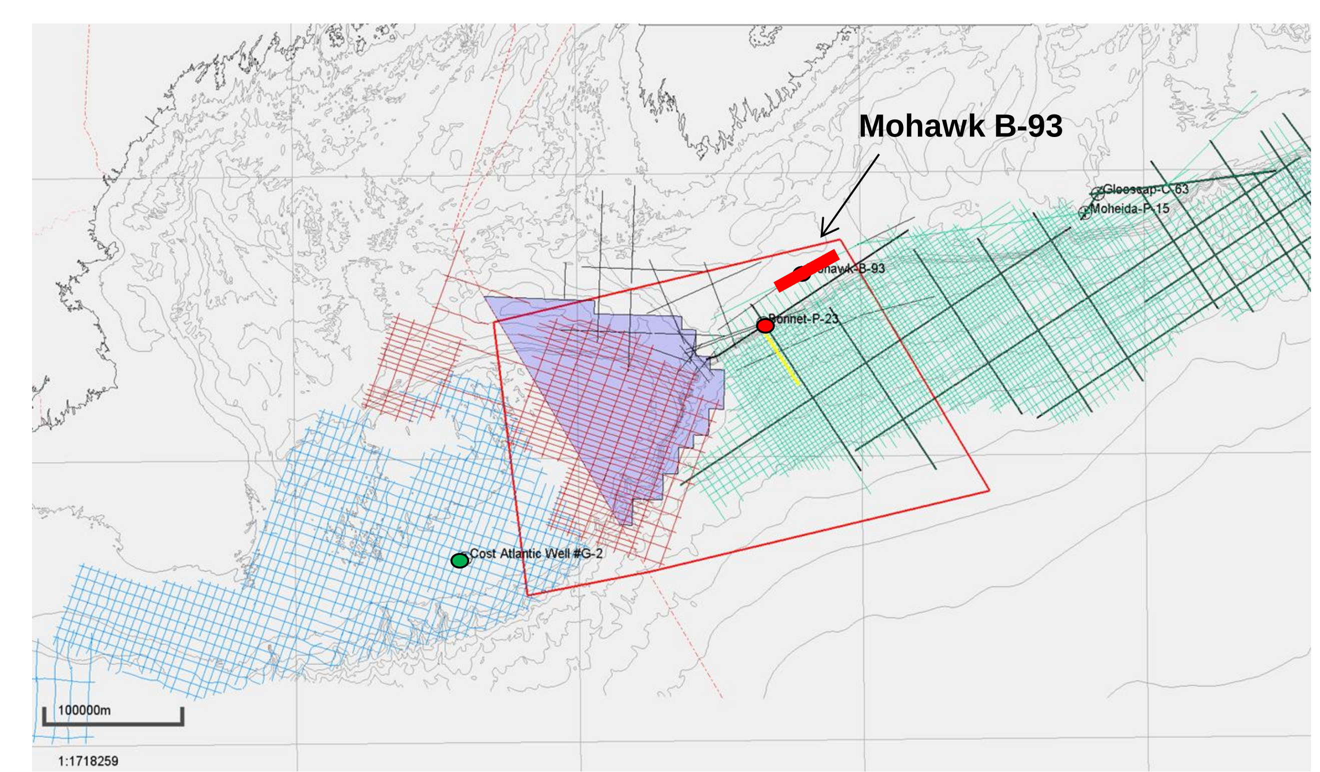
SEISMIC LOCATION	
Survey	Novaspan
Inline	5400
Trace	6060
Offset (m)	/

SEISMIC MARKERS

Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	134	117
T29	Mid-Oligocene Unconformity	n.d.	n.d.
T50	Ypresian Unconformity	635	581
K94	Turonian / Cenomanian Unconformity	1017	1009
K101	Late Albian Unc. (eq. Top Cree Mb)	1237	1293
K130	Hauterivian MFS (eq. Near "O" Marker)	1279	1373
K137	Berriasian / Valanginian Unconformity	1392	1604
J150	Tithonian MFS (eq. Top Baccaro Mb)	absent	absent
J163	Callovian MFS (eq. Top Scatarie Mb)	1557	1895
~J200	Breack-up Unconformity	absent	absent
	Top Basement	1659	2081

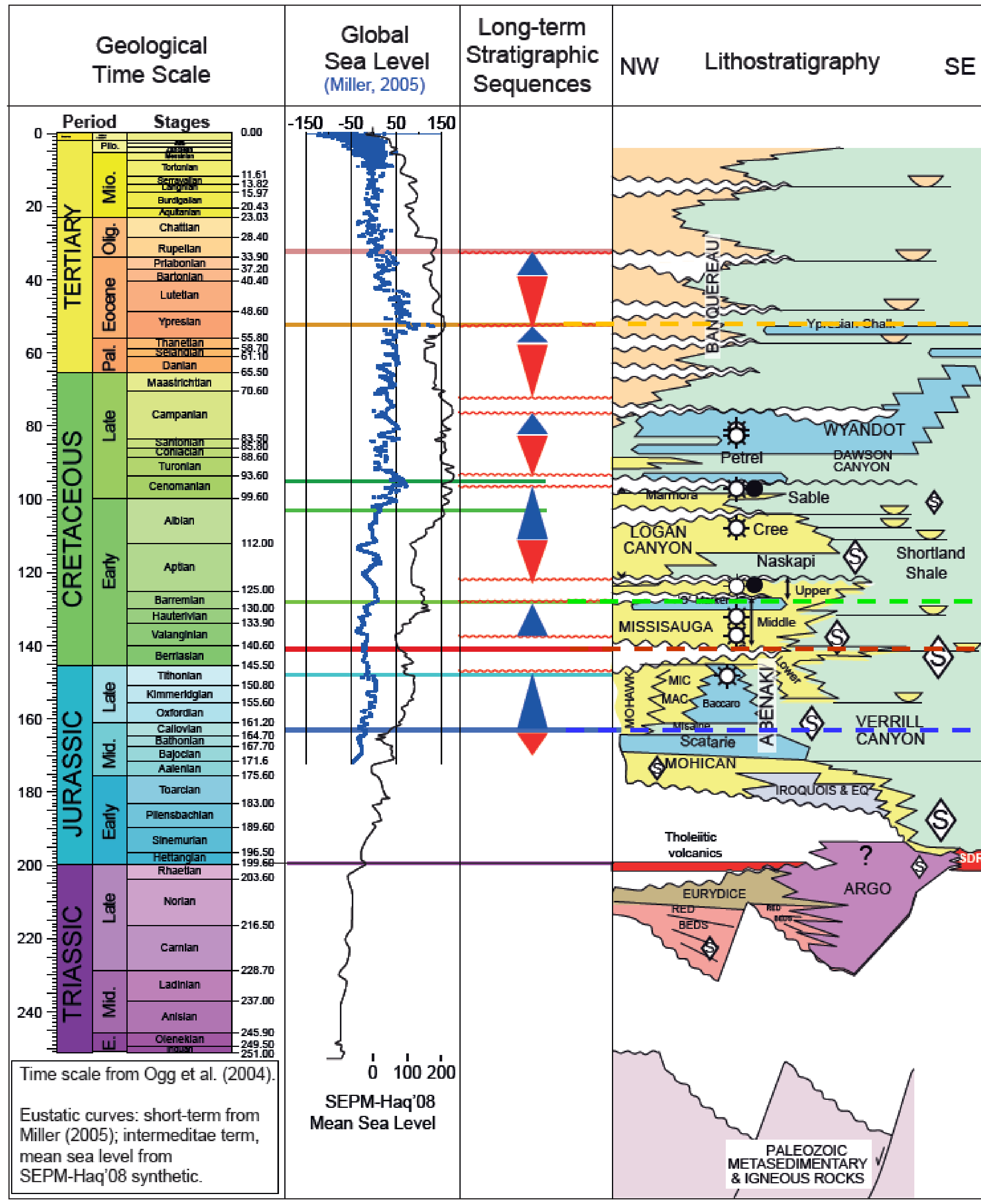
Mohawk B-93

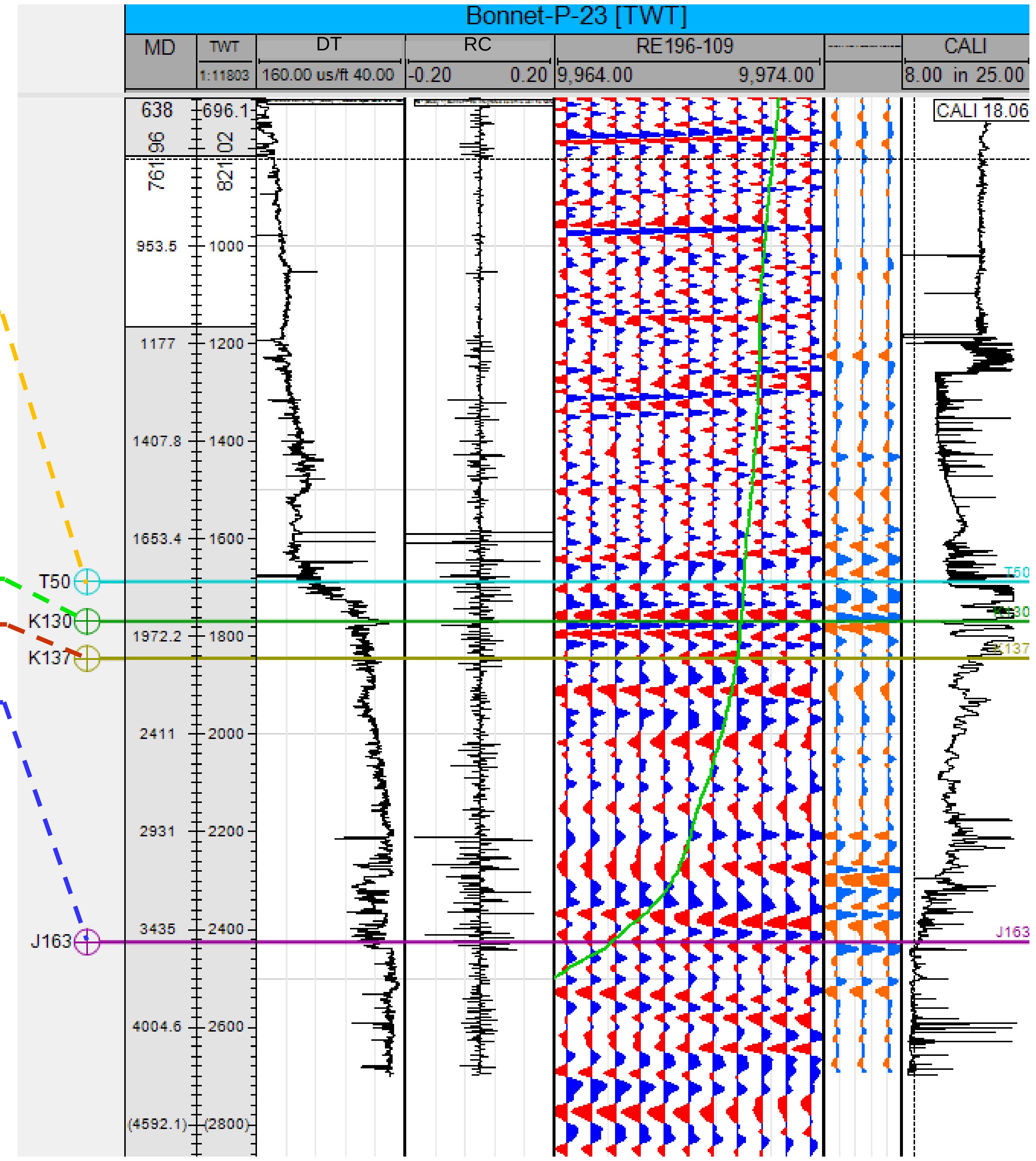
- Main well for the horizons calibration on the shelf (Mohawk Ridge, then extended to Georges Bank)
- Correlated with Bonnet P-23 & no correlation in deep water.
- Drilled in an particular location for the pre-Jurassic: basement high
- Very good calibration
- J150 not present on the shelf
- granitic basement at TD



SEISMIC CALIBRATION AND VELOCITY MODEL

SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015





WELL HEADER		
Well Name	Bonnet P-23	
Rotary Table (R.T.)	35 m	
Total Depth (T.D.)	4336 m (R.T.)	
Geographic coordinates @surface	Lat: 42° 22' 48.65" N	Lon: 65° 03' 01.89" W
UTM coordinates (Zone 20N, NAD27, CL66)	X_{UTM} : 331187	Y_{UTM} : 4693811

BIOSTRATIGRAPHY	RPS Energy 2011

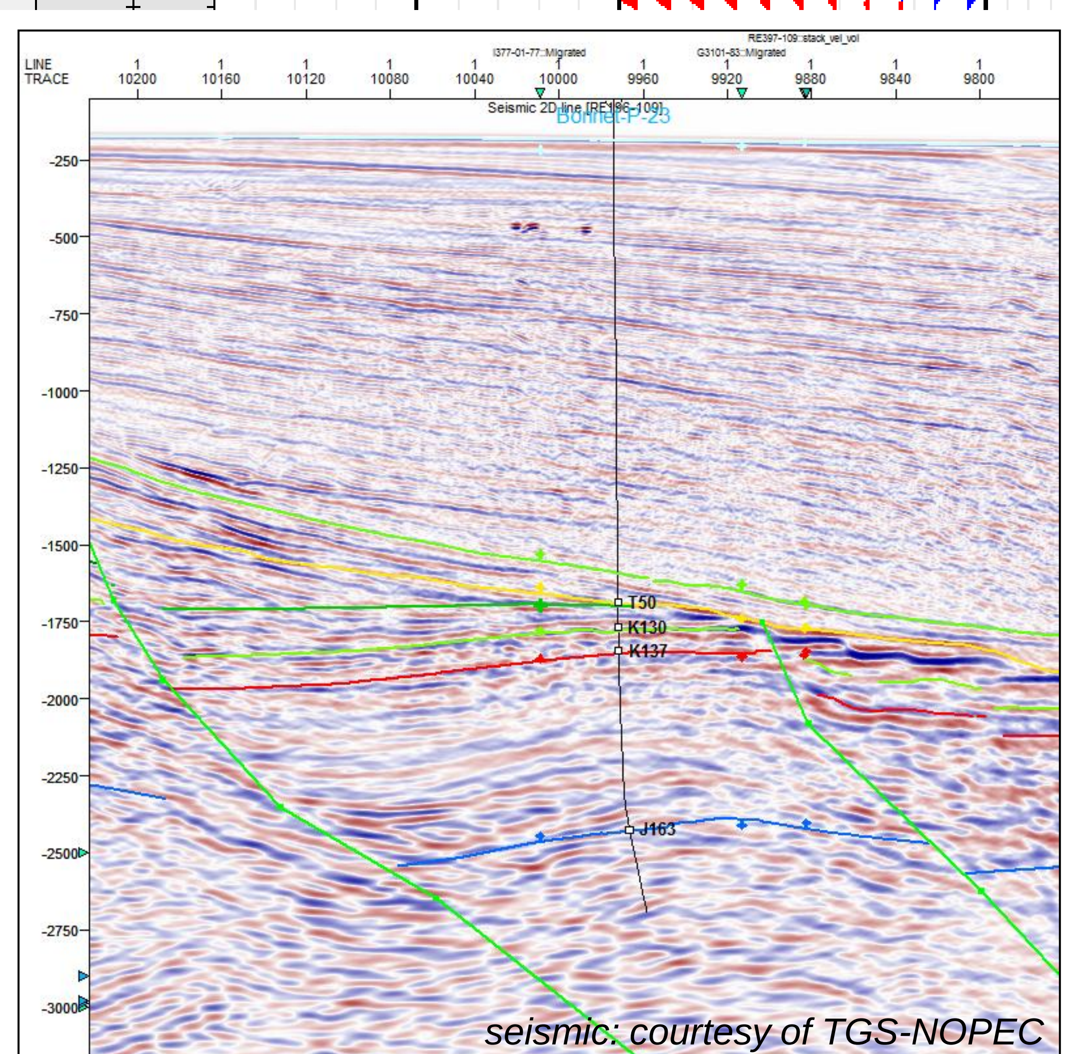
SEISMIC LOCATION	
Survey	2010 Repro. TGS
Inline	196-100
Trace	21950
Offset (m)	530

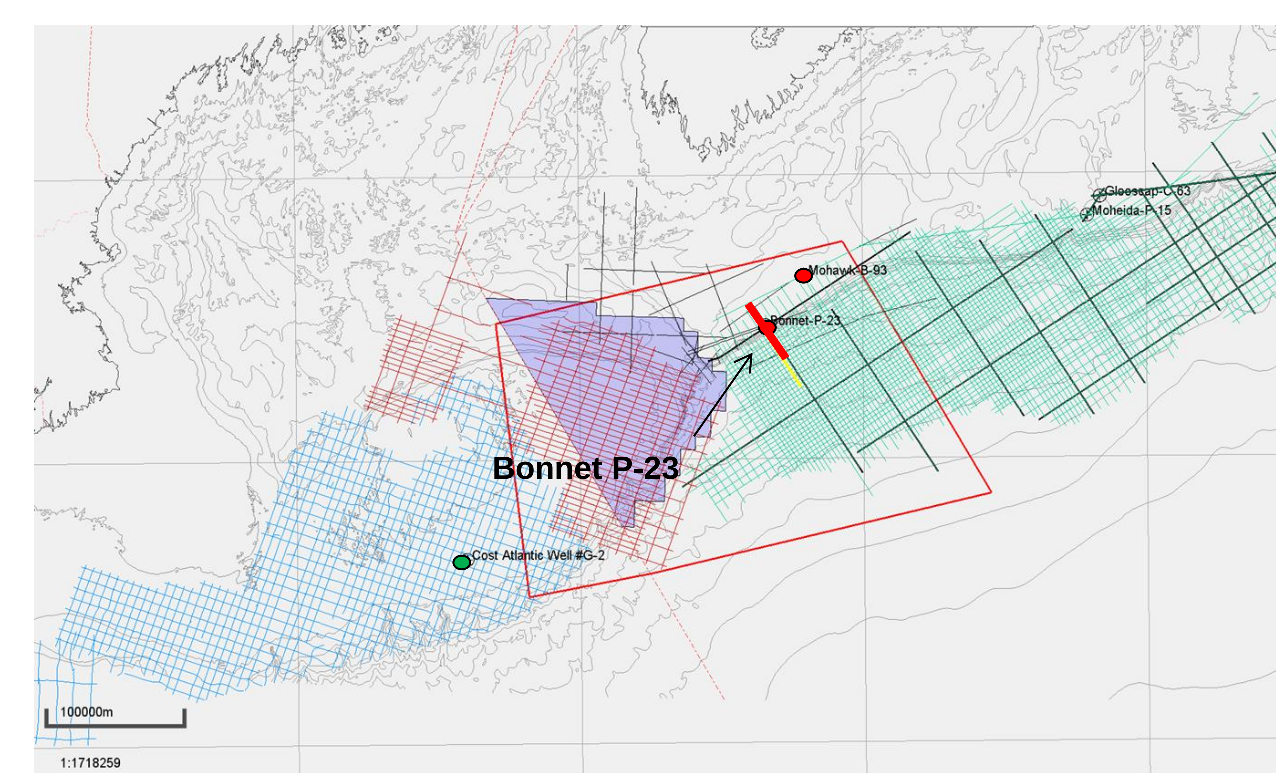
SEISMIC MARKERS

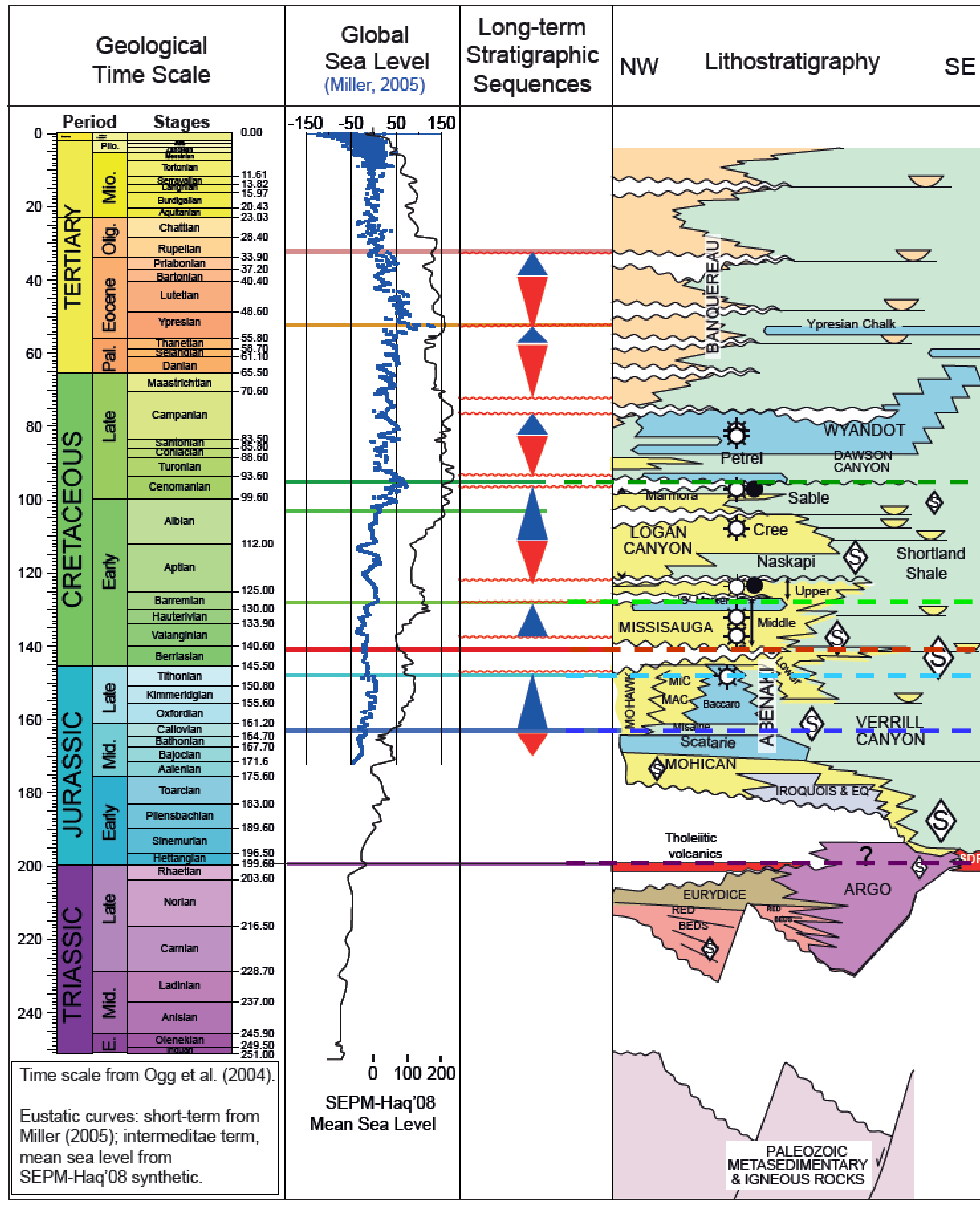
Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	212	133
T29	Mid-Oligocene Unconformity	1615	1637
T50	Ypresian Unconformity	1687	1728
K94	Turonian / Cenomanian Unconformity	absent	absent
K101	Late Albian Unc. (eq. Top Cree Mb)	absent	absent
K130	Hauterivian MFS (eq. Near "O" Marker)	1768	1868
K137	Berriasian / Valanginian Unconformity	1844	2030
J150	ithonian MFS (eq. Top Baccaro Mb)	absent	absent
J163	Callovian MFS (eq. Top Scatarie Mb)	2425	3456
~J200	Breack-up Unconformity	Not reached	Not reached

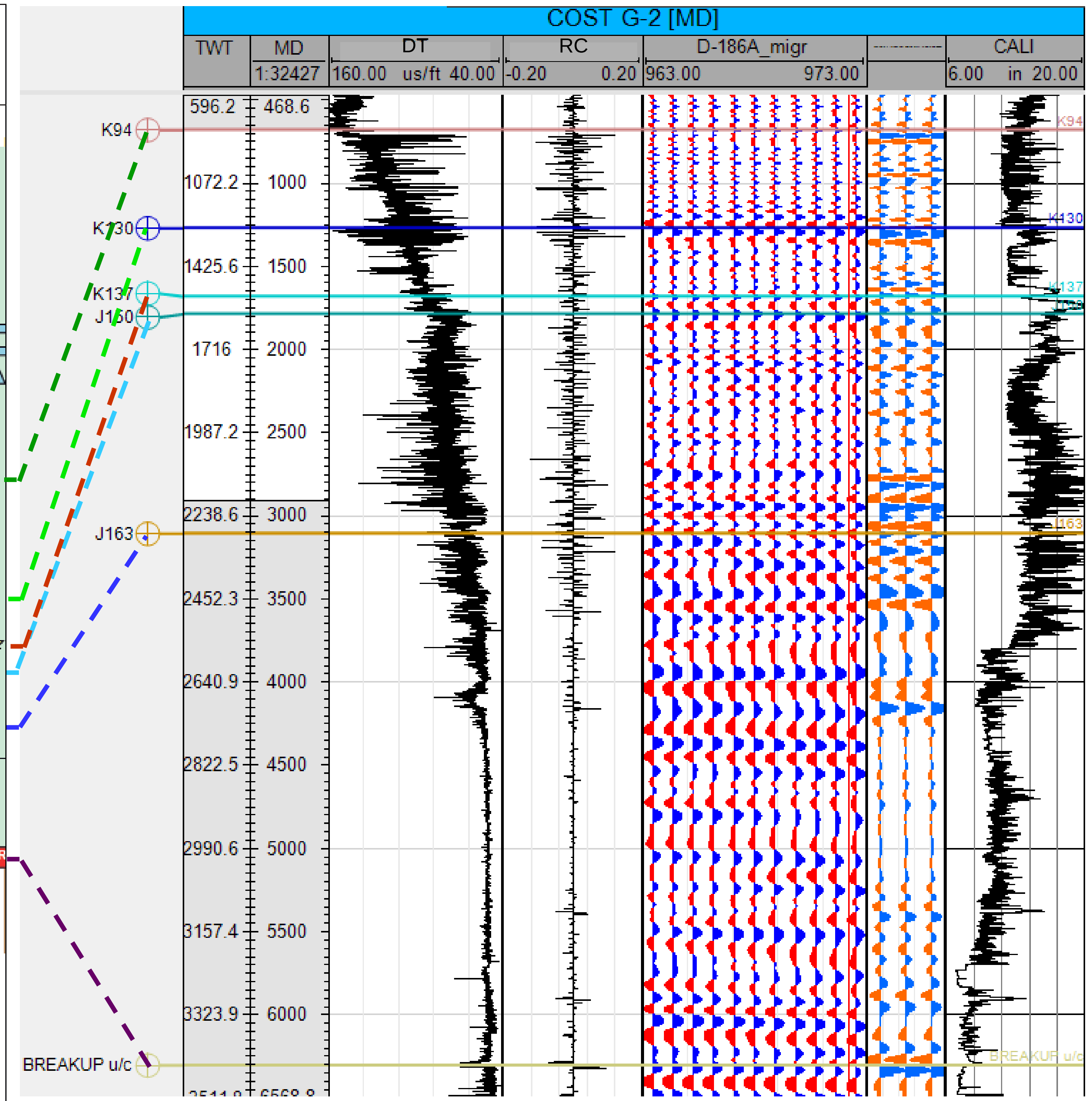
Bonnet P-23

- Shallow water well on La Have platform (no correlation in deepwater)
- Correlated with Mohawk B-23
- Drilled near shelf edge: U. Cretaceous & L. Paleogene eroded
- Lateral change of facies from Mohawk (growth fault system)
- Poor-to-fair calibration
- J150 not present on the shelf









WELL HEADER		
Well Name	COST G-2	
Rotary Table (R.T.)	24 m	
Total Depth (T.D.)	6660 m (R.T.)	
Geographic coordinates @surface	Lat: 40° 50' 11.4" N	Lon: 67° 30' 29.8" W
UTM coordinates (Zone 20N, NAD27, CL66)	X_{UTM} : 119844	Y_{UTM} : 4530186

BIOSTRATIGRAPHY	RPS Energy 2014

SEISMIC LOCATION	
Survey	US lines
Inline	D-186A
Trace	973
Offset (m)	/

SEISMIC MARKERS

Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	226	59
T29	Mid-Oligocene Unconformity	n.d.	n.d.
T50	Eocene Unconformity	n.d.	n.d.
K94	Turonian / Cenomanian Unconformity	802	653
K101	Late Albian Unc. (eq. Top Cree Mb)	n.d.	n.d.
K130	Hauterivian MFS (eq. Near "O" Marker)	1266	1243
K137	Berriasian / Valanginian Unconformity	1541	1654
J150	Near Tithonian MFS (eq. Top Baccaro Mb)	1602	1760
J163	Near Callovian MFS (eq. Top Scatarie Mb)	2283	3080
	Breakup Unconformity	3536	6616

COST G-2

Shallow water well on Georges Banks platform (isolated well with no correlation with other ones)

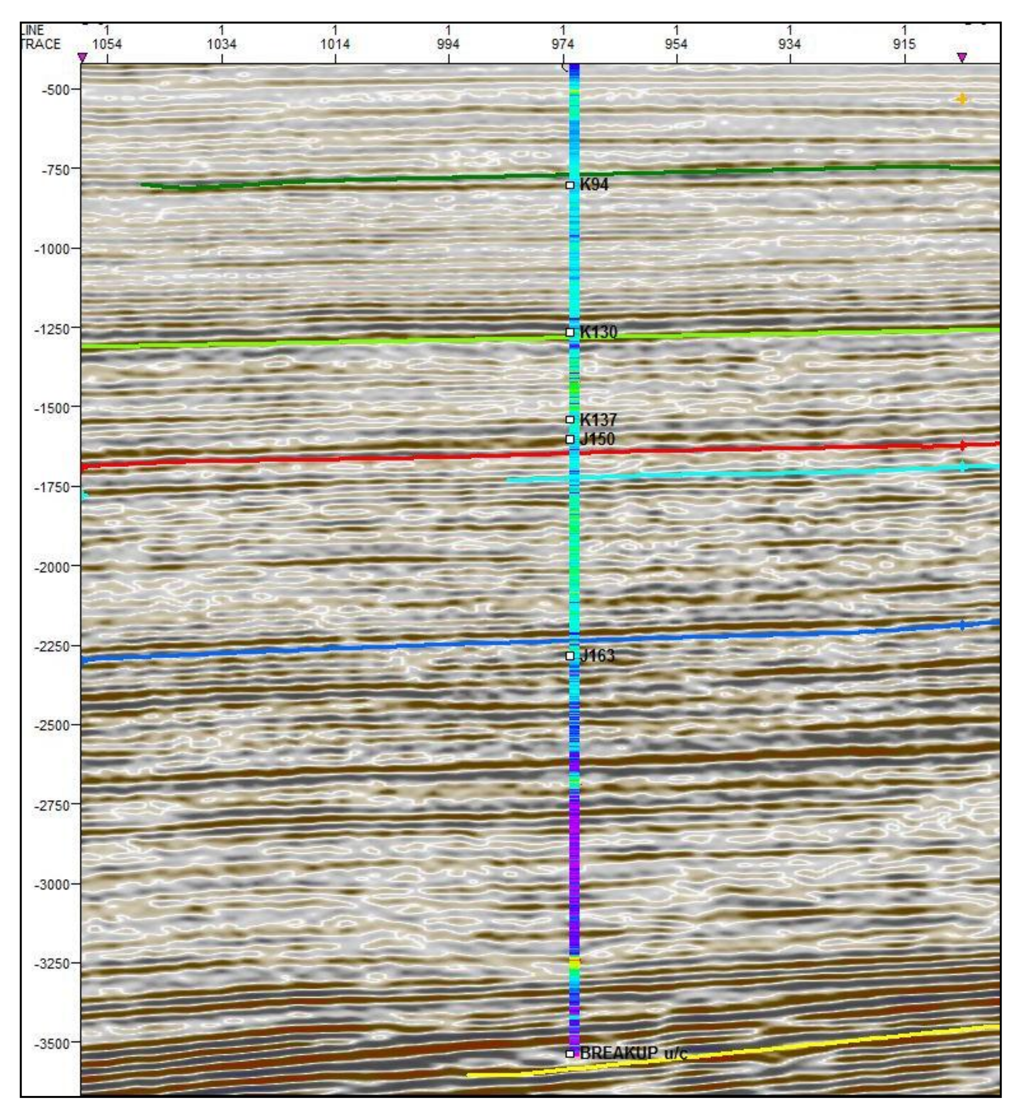
Three different issues raised during the calibration:

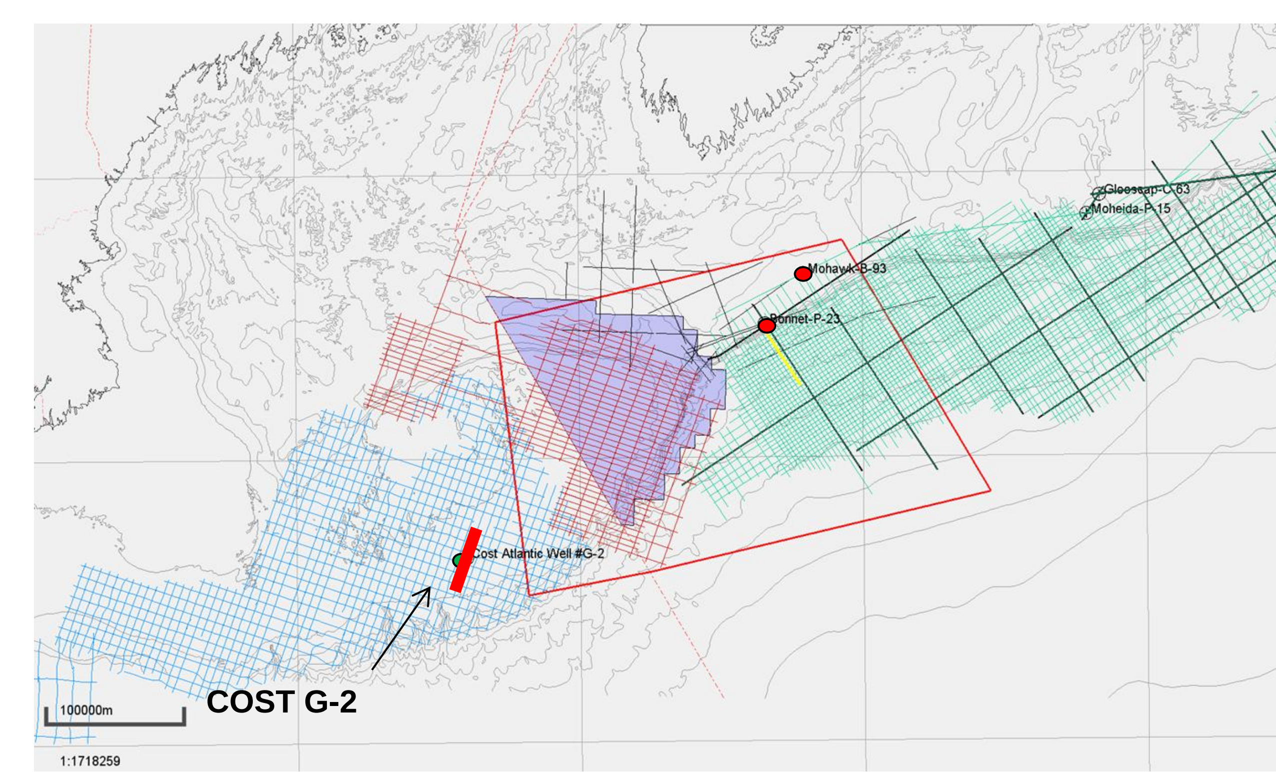
1) No checkshot data: the dynamic Time Depth Relationship (TDR) was created through the sonic integration (no sonic drift correction). However the caliper has considerable caving zones down the whole well : the absolute sonic values are likely to require correction, hence the TDR's is considerably uncertain.

2) The match synthetic/seismic is uncertain: the static part of the TDR was calibrated at the K130 strong amplitudes. A small stretch (20 ms) was applied at 3s to match a seismic event at ~ 4000 ft.

3) Some markers may also have uncertainties : the biostratigraphuc study in this well is not as strong as for the two main wells.

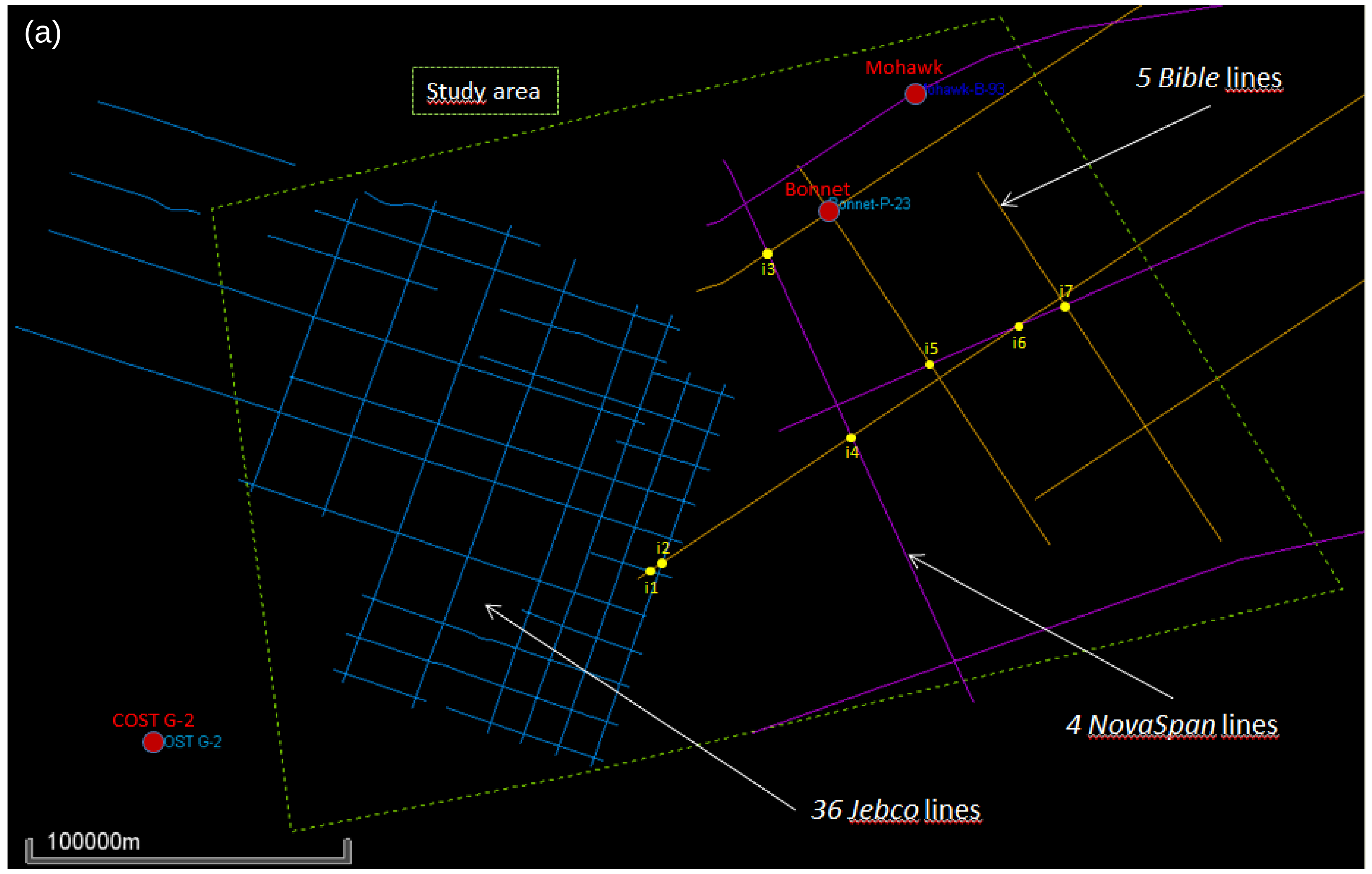
As a conclusion, G-2 cannot be taken as "hard" data for horizon calibration, but only as a secondary control.

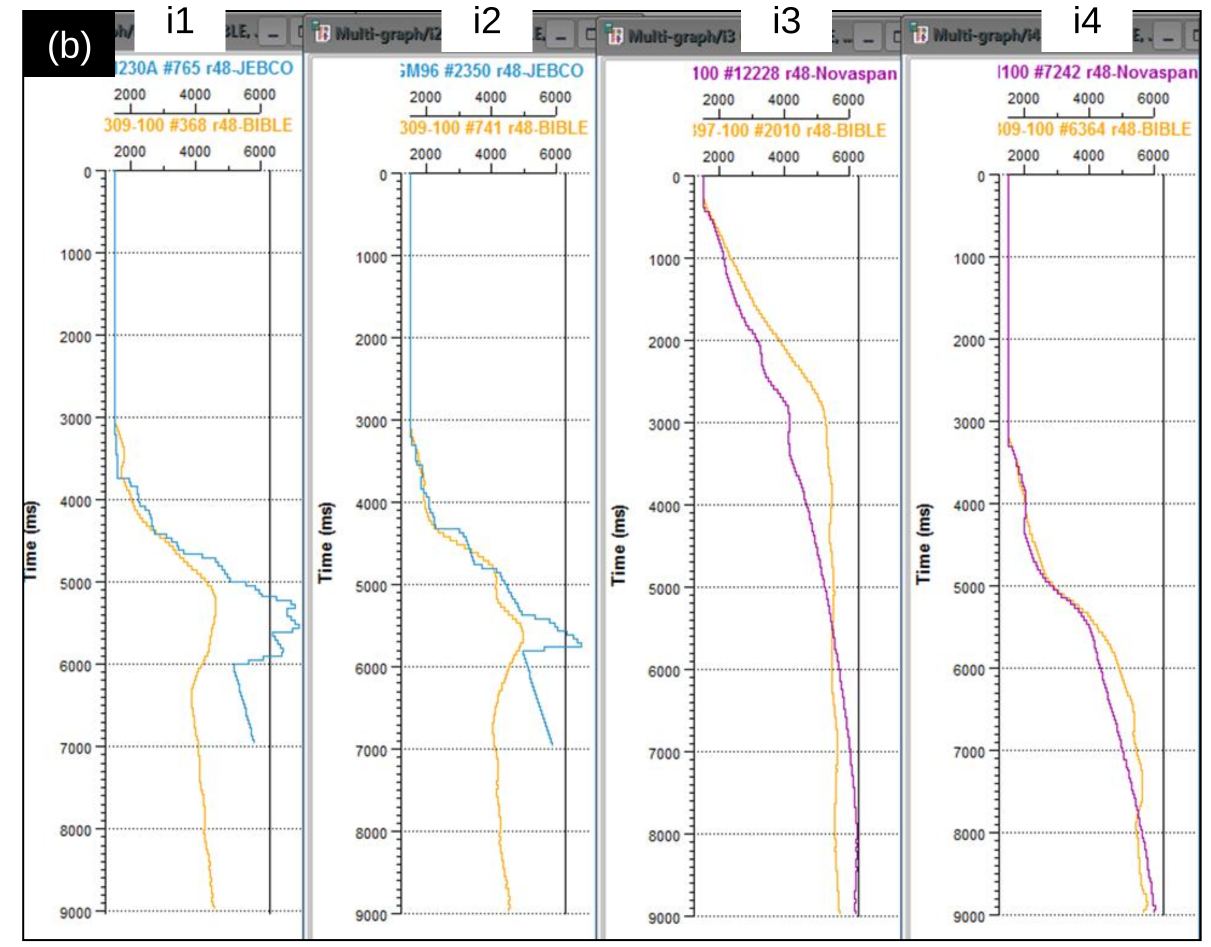




CHAPTER 5.2.2

VELOCITY MODEL
AND
TIME TO DEPTH CONVERSION





Seismic interval velocities at vintage intersections i1 to i4

Velocity modeling

A 3D velocity model was built within the Survey Area to get a conversion model from TWT to depth (Zss) domain. Only two wells are calibrated with confidence and are located in the shallow northern area: the velocity model had to be mainly based on the seismic velocities field. The Bonnet and Mohawk wells were used in a second step to calibrate the model for only shallow TWT.

First step: seismic velocities gridding

(a) The velocity model was built using Interval Velocities estimated from velocity analyses from 3 vintages of seismic: 5 TGS lines reprocessed in 2009-10, 4 NovaSpan lines reprocessed in 2009-10 and 36 Jebco lines reprocessed in 2009.

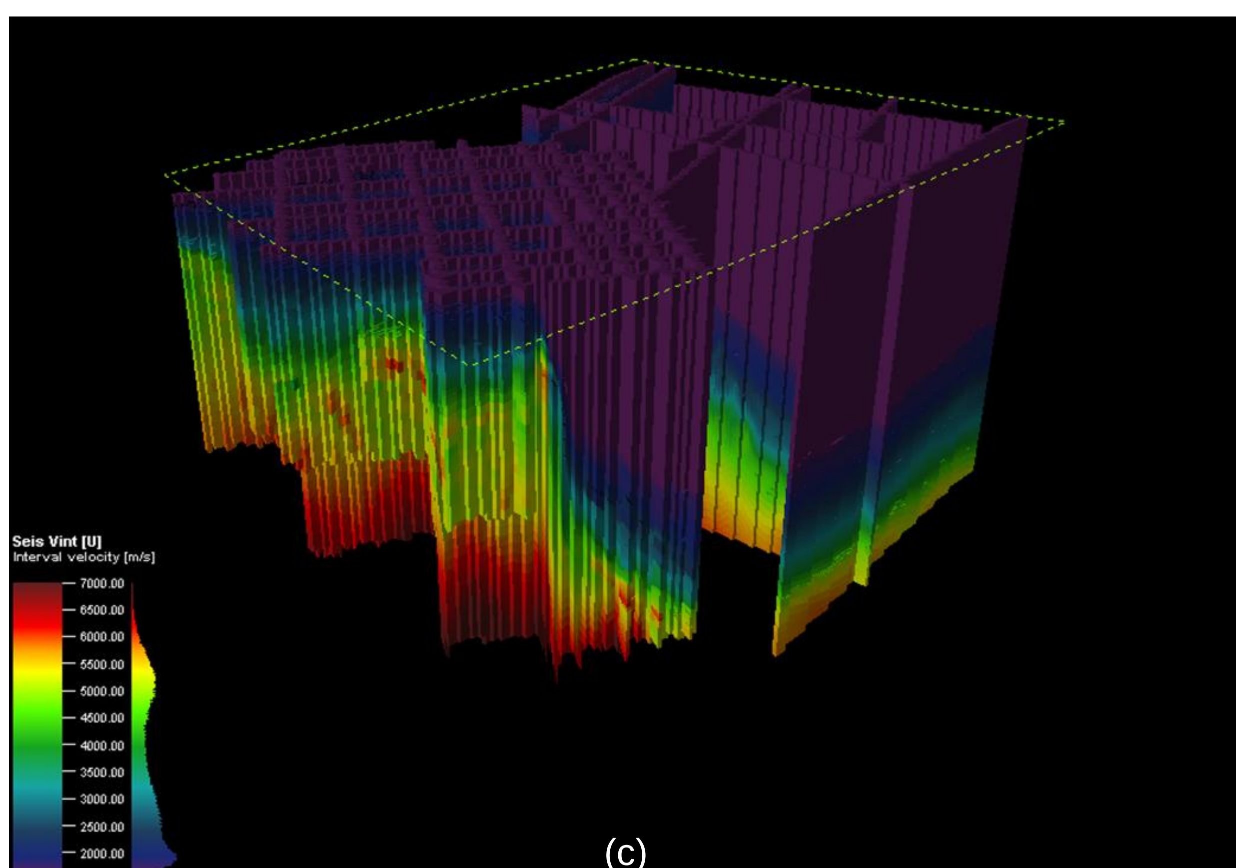
(b) Their Interval Velocity values having some differences at the intersections, a model with a large grid (2 x 2 km) was therefore built.

(c) The Interval Velocities were upscaled in it every 50 ms, then slightly smoothed.

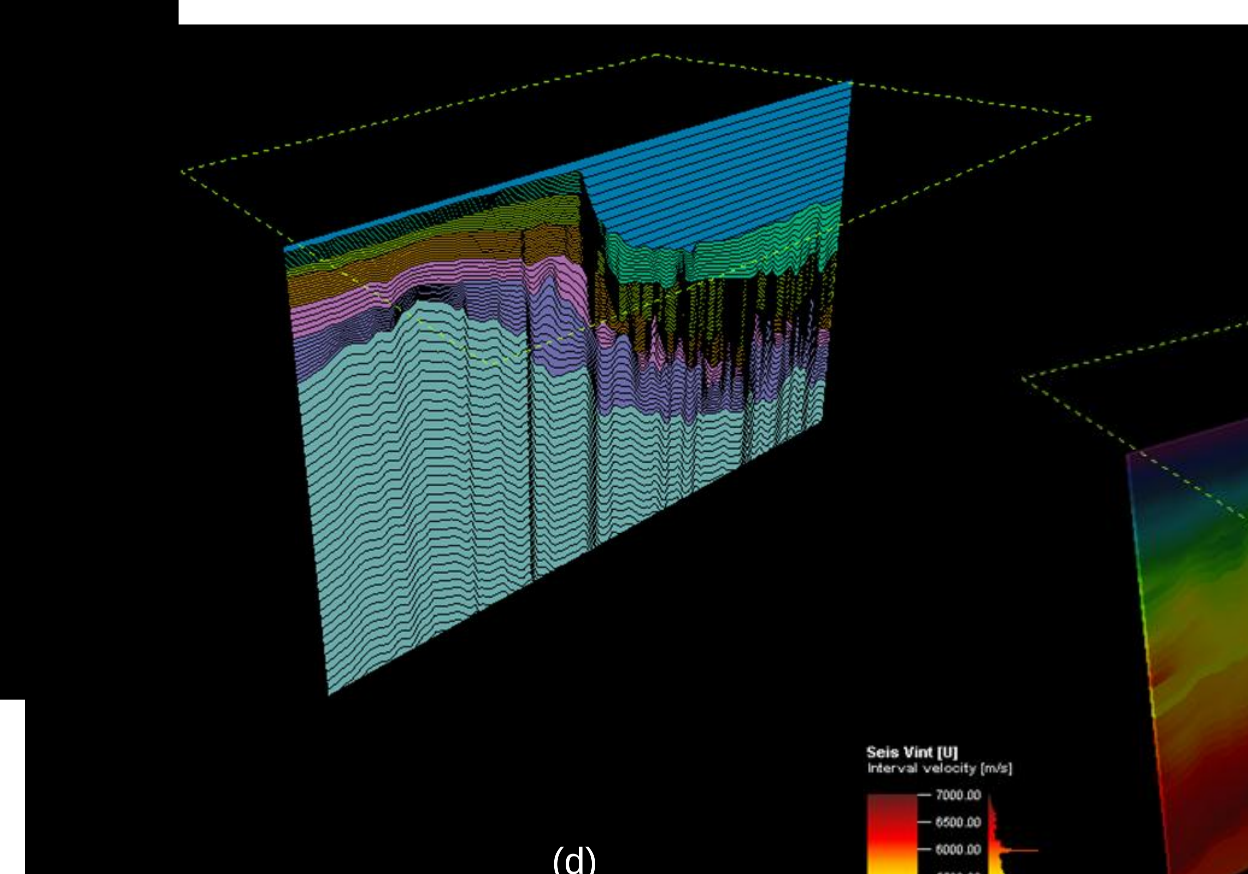
(d) An internal layering was defined from main horizons and two constant time slices: constant SRD, Sea bottom, T29, K94, K137, J163, Base Post-Rift, constant 9000 ms.

(e) This layering guided the 3D gridding of the Velocities.

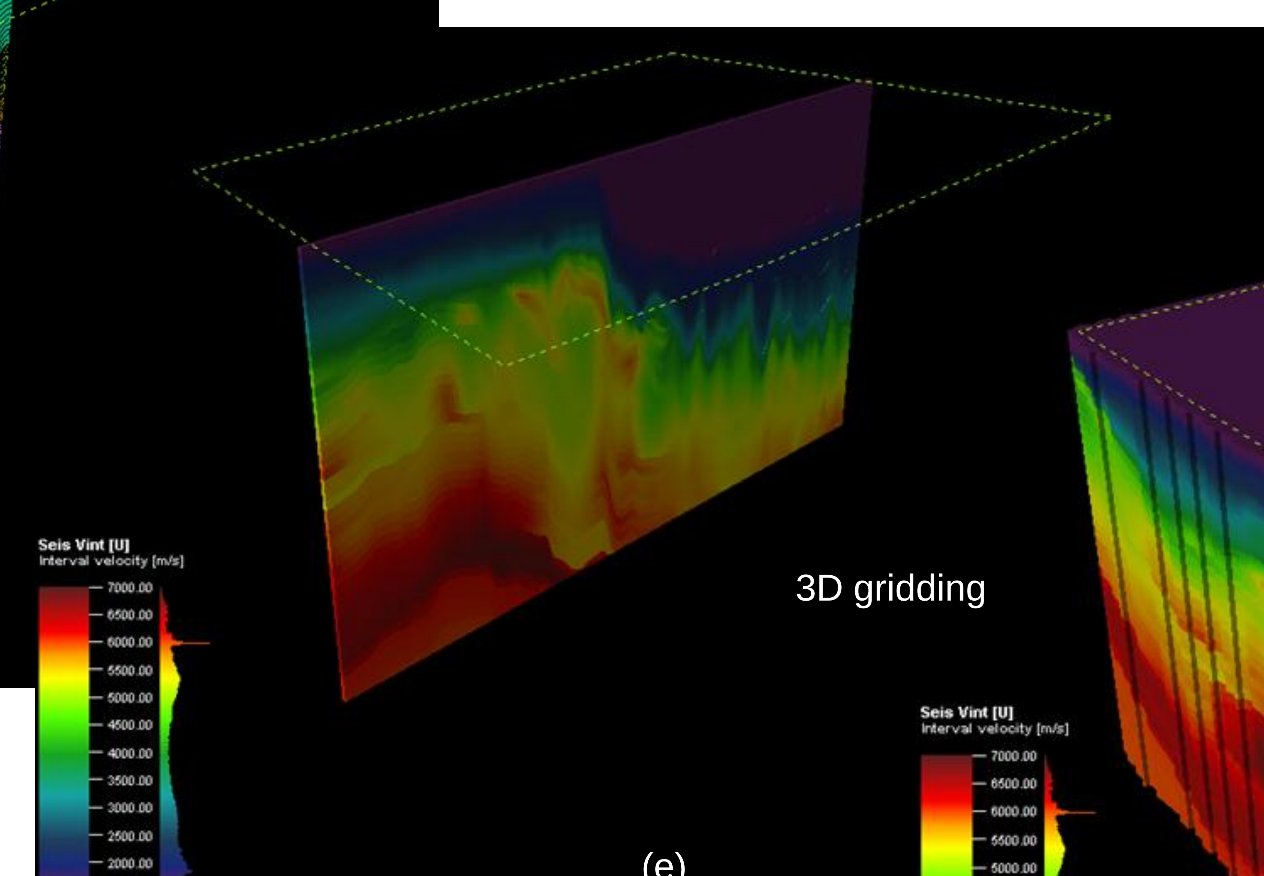
(f) This intermediary model – "without wells" – keeps good lateral variability, validating such approach.



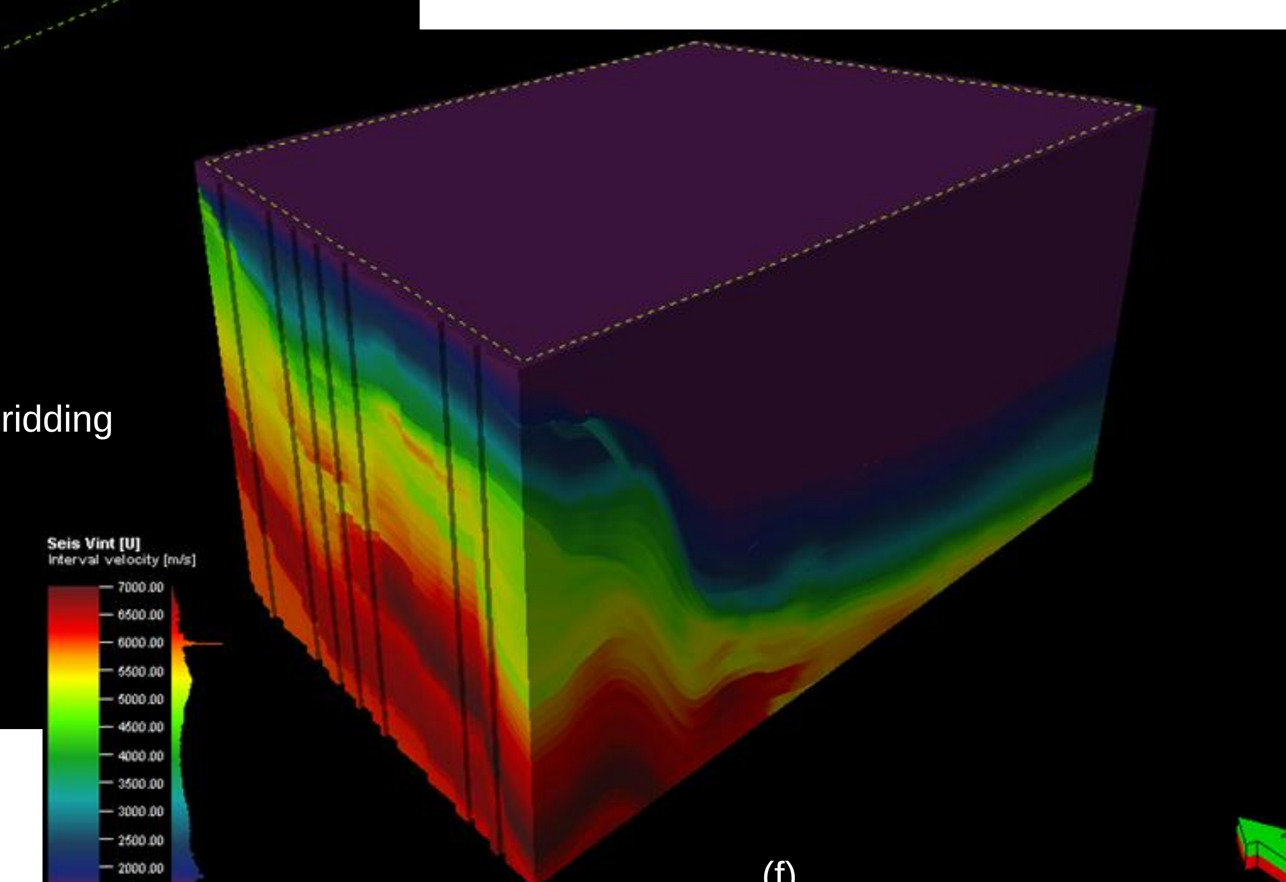
Upscaling of seismic velocities

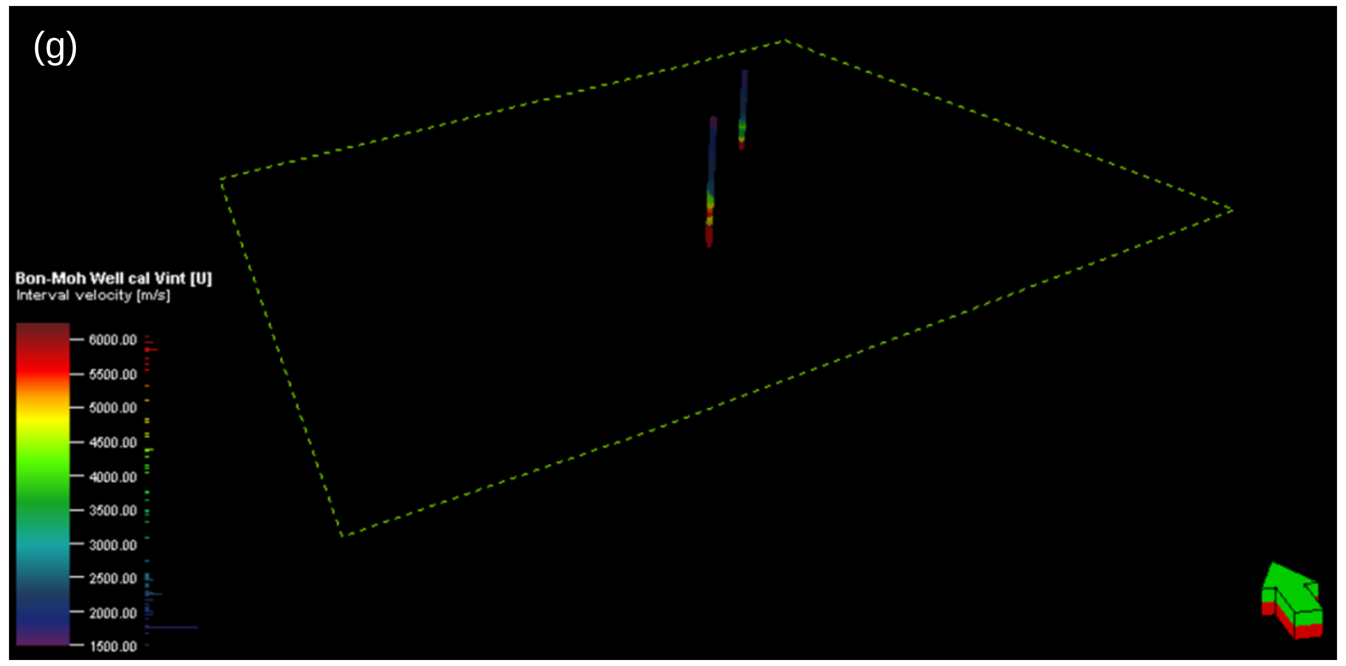


Layering

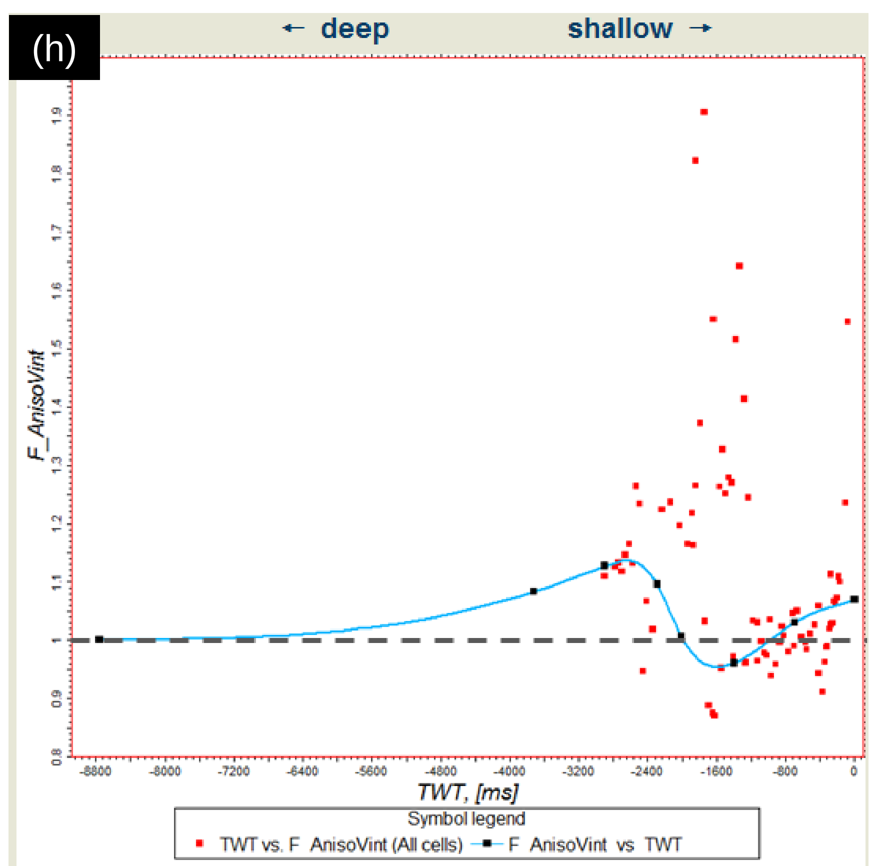


3D gridding





Upscaling of well velocities



TWT anisotropic factor

(i)		Z-value	Residual after anistropic correction	Residual after well correction
			(m SS)	
T29	Bonnet-P-23	-1636	-63	0
K94	Mohawk-B-93	-1009	25	0
	Bonnet-P-23	-1727	226	71
K137	Mohawk-B-93	-1604	-104	0
	Bonnet-P-23	-2029	9	-67
J163	Mohawk-B-93	-1895	-155	0
	Bonnet-P-23	-3453	-299	0

Velocity model correction from well markers

Second step: well adjustment for shallow TWT

(g) The calibrated Time-Depth Relationship in Bonnet and Mohawk wells were upscaled into the same 3D grid.

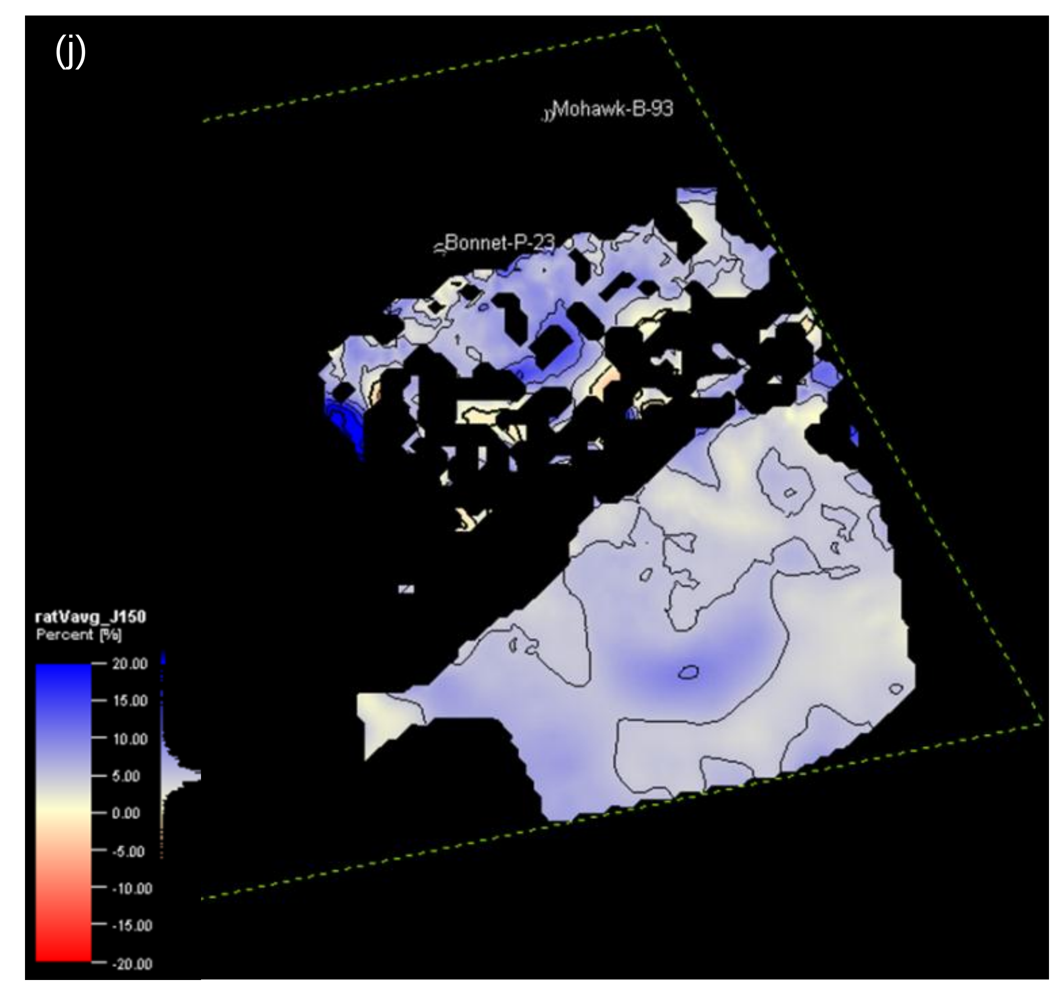
(h) A dynamic correction was applied to the grid: anisotropy values $V_{intwells}/V_{intseis}$ were estimated from both wells at every cell (red dots). A continuous Anisotropy Factor was then defined along the TWT axis (blue curve): mainly defined for the shallow times, it is reconnected to '1' for high times.

(i) The velocity errors at the wells were kriged and applied around them (range = 20 km), giving final residuals: null in Mohawk and close to 0 for Bonnet (below grid resolution at the T50/K94 erosion).

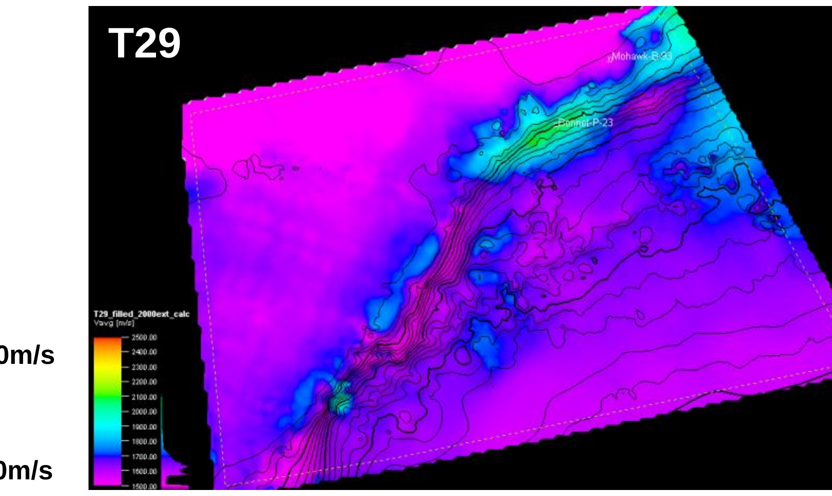
The main average velocity maps are displayed on the right side.

QC with PFA 2011 velocity model

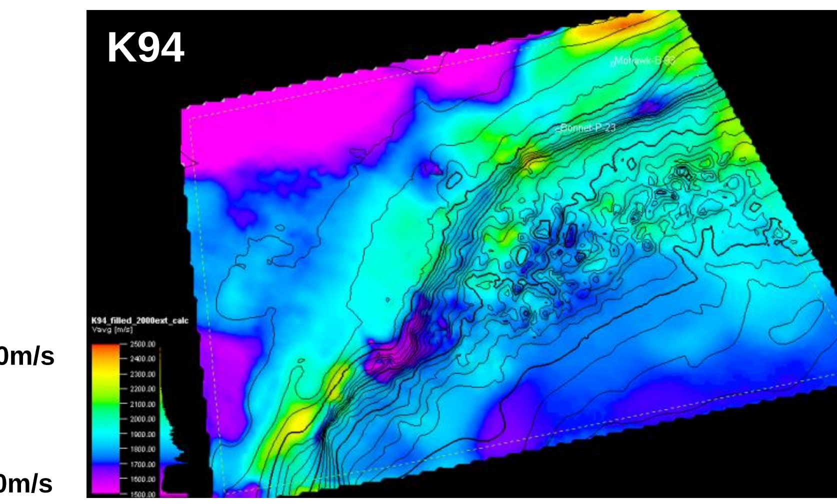
(j) Uncertainty analysis was not feasible (no control well). Only comparison with 2011 velocity model was possible. At the Jurassic levels, the horizons are ~ 5% deeper in average than the same surfaces produced for PFA 2011 maps. Such value remains in an acceptable range of uncertainty with regard to the lack of deep water wells.



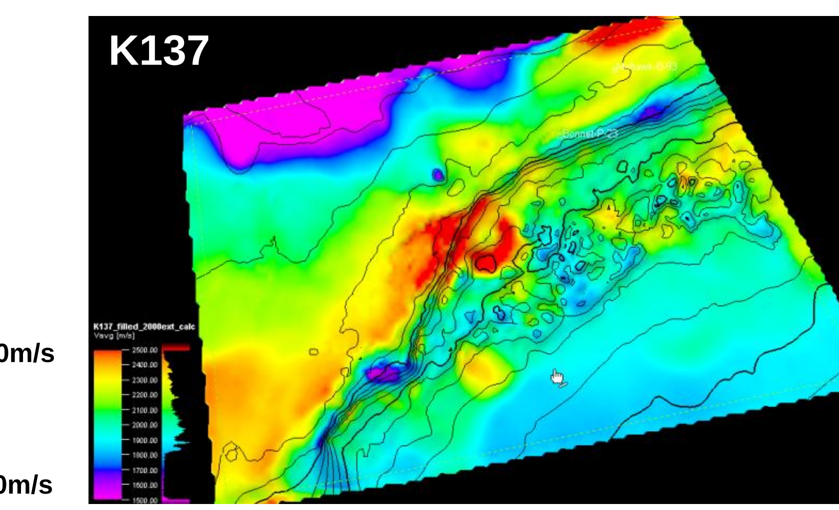
Vavg ratio 2015/2011 at J150



2500m/s
1500m/s



2500m/s
1500m/s



2500m/s
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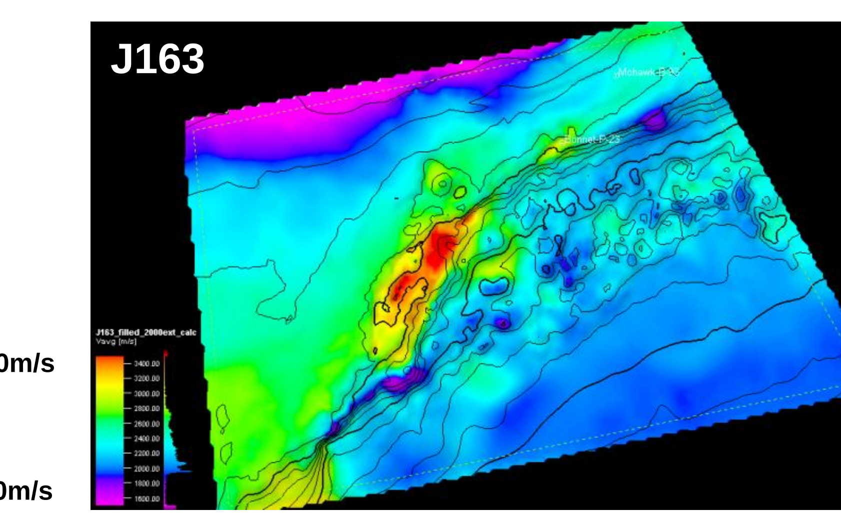
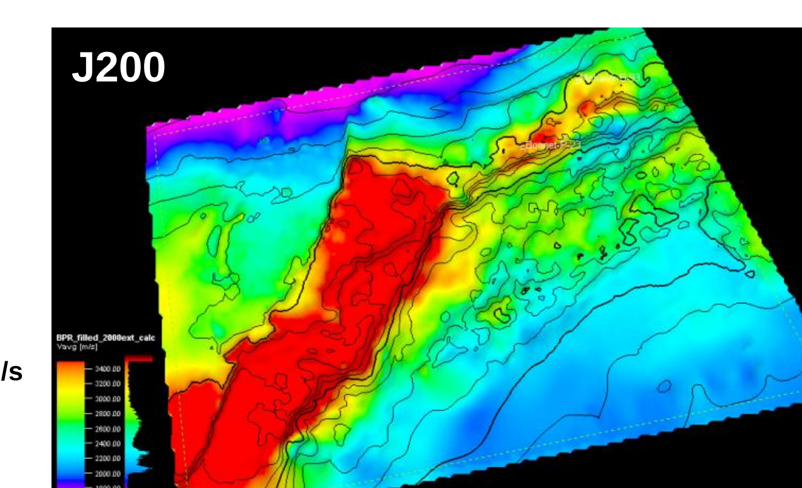


3500m/s
1500m/s



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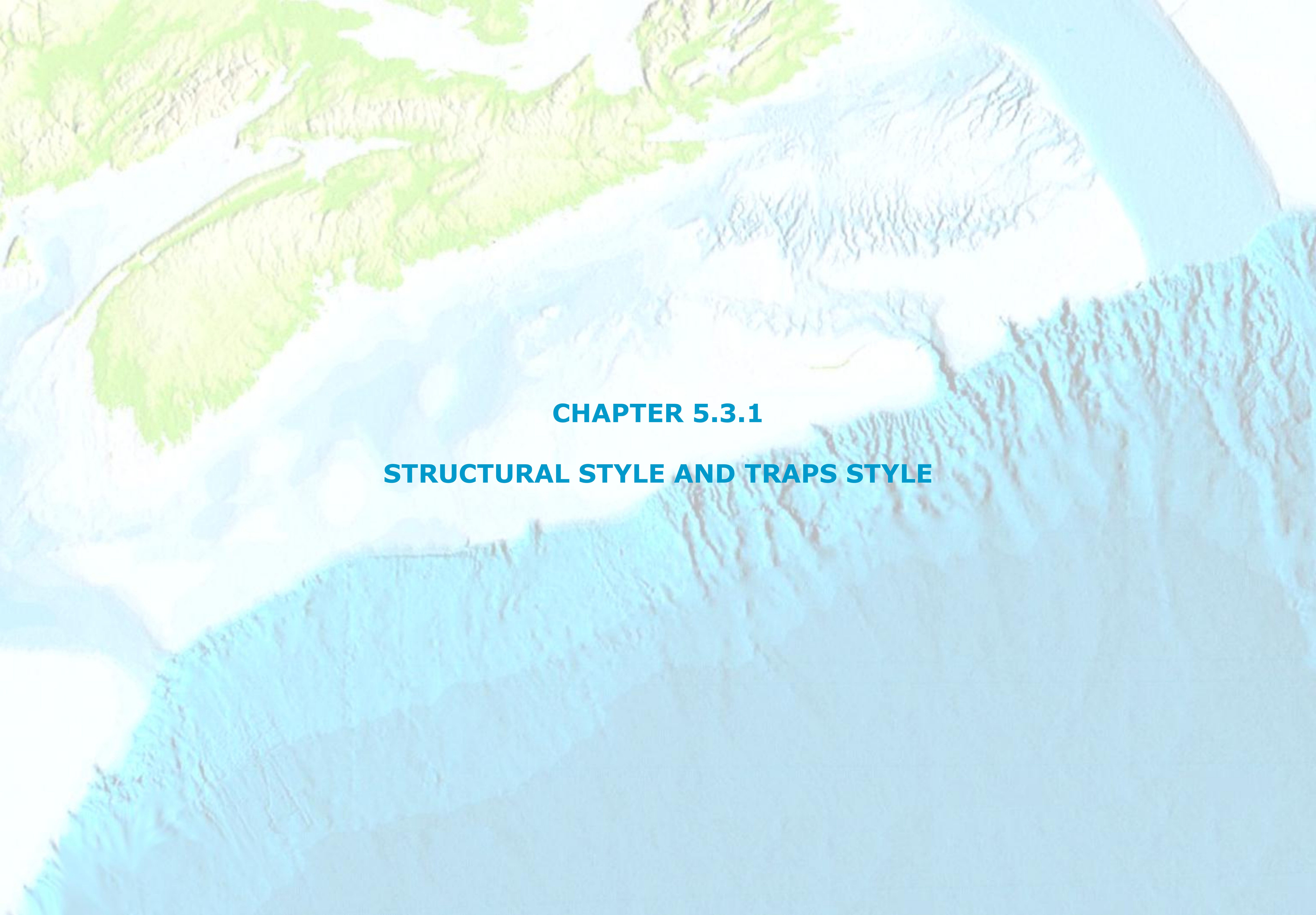


CHAPTER 5.3.1

STRUCTURAL STYLE AND TRAPS STYLE

SEISMIC INTERPRETATION – STRUCTURAL MAPPING

SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015

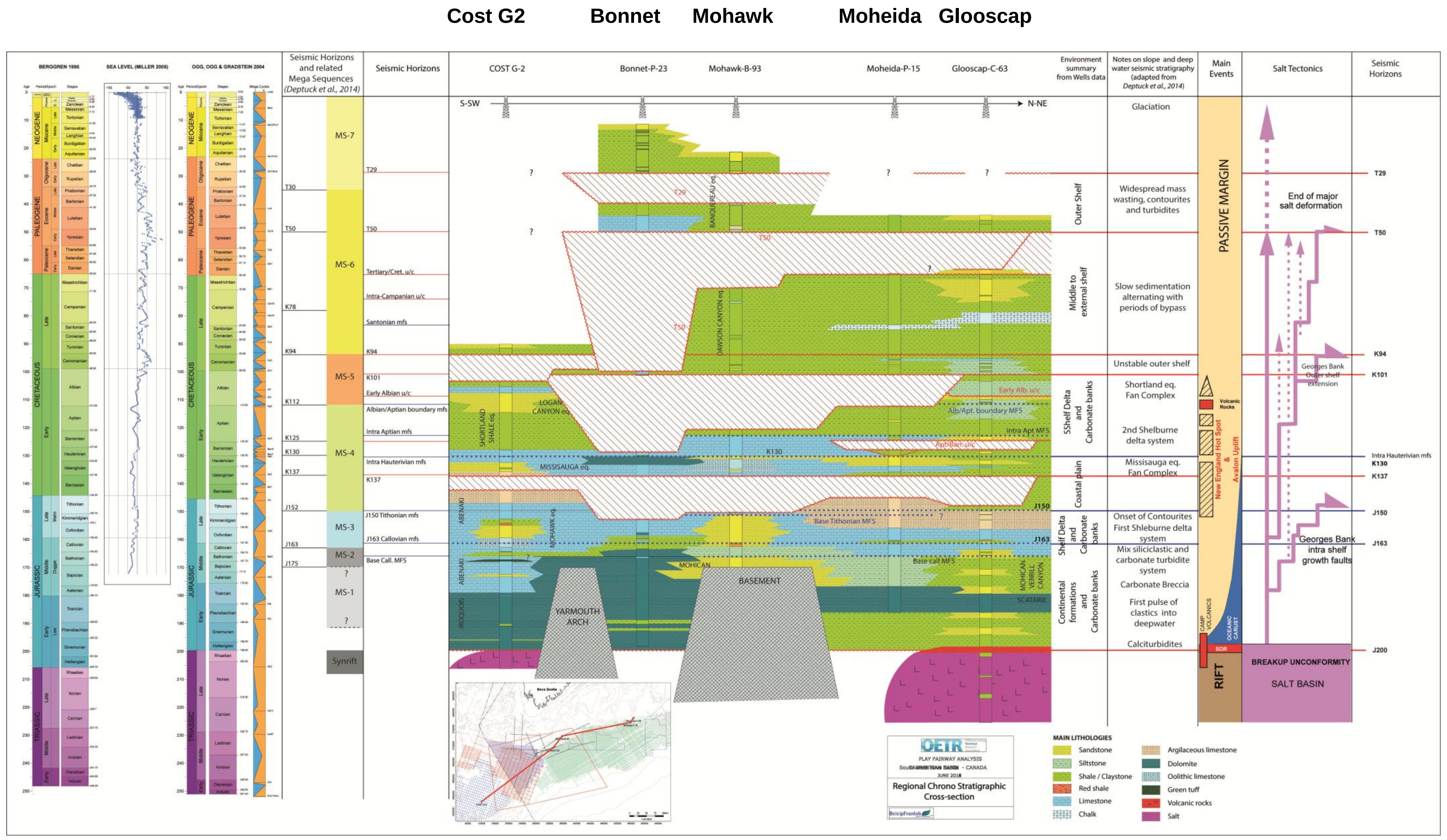


Figure 1 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

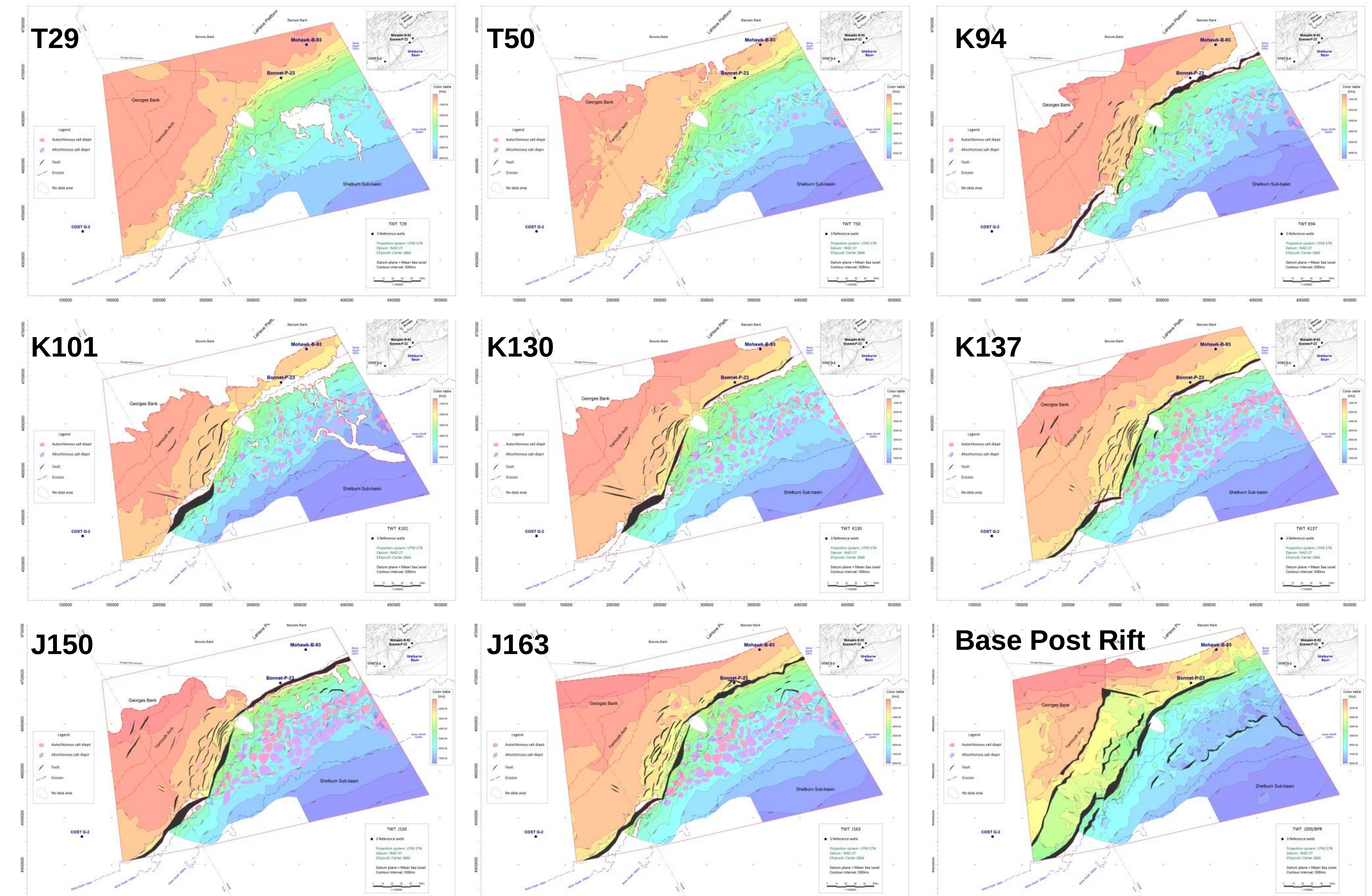


Figure 2 : TWT maps of the nine interpreted horizons (See TWT maps in attachment in full size resolution)

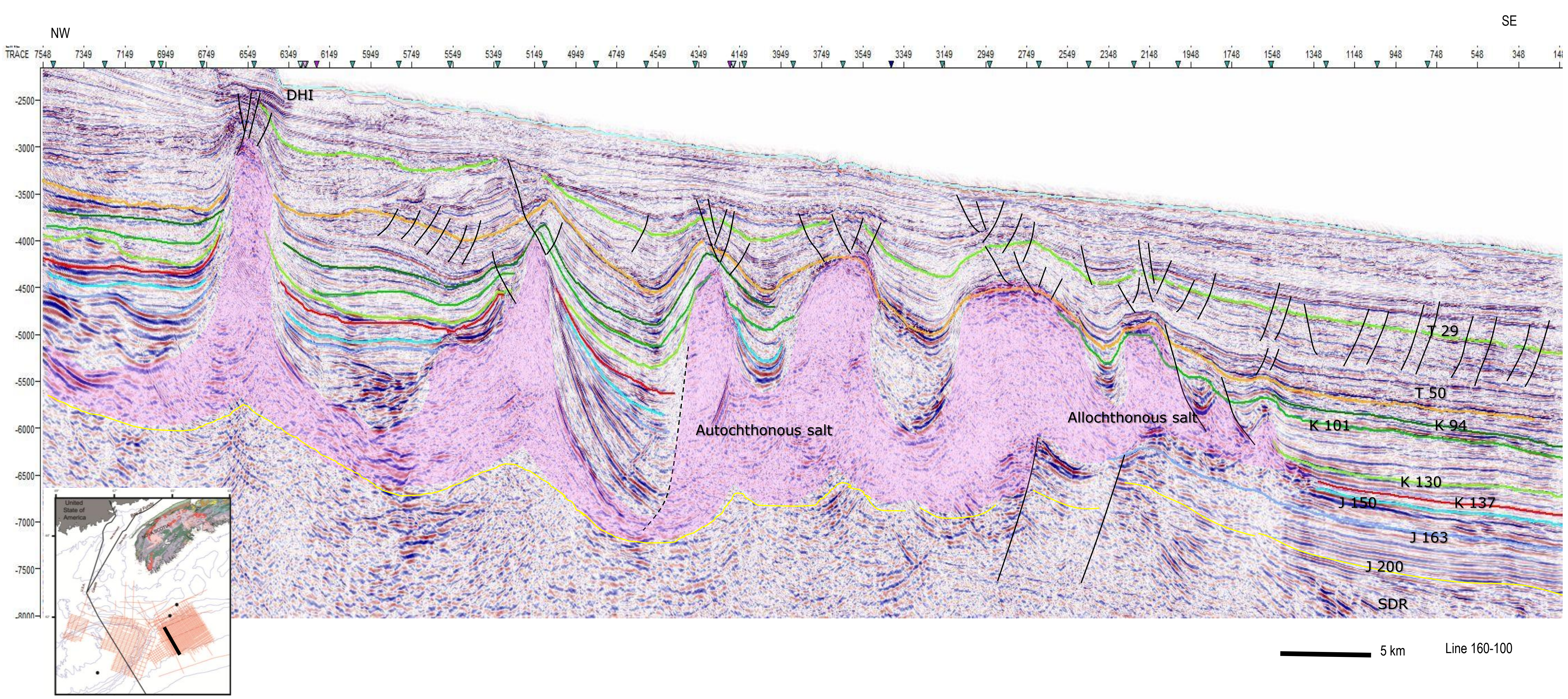


Figure 3 : Seismic cross-section in the Shelburne sub-basin. It shows the distribution of the different seismic events along the shelf breakdown (Mohawk fault zone), and the occurrence of autochthonous and allochtonous salt.

The results of the biostratigraphy study in parallel with the well-to-seismic tie and the seismic interpretation of isochronous surfaces constrained the identification of several key surfaces. In total 9 horizons were regionally mapped over the Georges Bank and Shelburne sub-basin in TWT (Two-Way-Time) domain. They are from top to bottom:

1. T29 (Mid Oligocene Unconformity)
2. T50 (Ypresian Unconformity)
3. K94 (Cenomanian Turonian Unconformity)
4. K101 (Late Albian Unconformity)
5. K130 (Hauterivian MFS)
6. K137 (Berriasian / Valanginian Unconformity)
7. J150 (Near Tithonian MFS)
8. J163 (Near Callovian MFS)
9. J200 Break-up Unconformity

Additional seismic horizons were regionally or locally picked to better understand the salt deformation (tops of autochthonous and allochthonous salt), to better constrain the time-to-depth conversion (Seabed).

The faults were interpreted on seismic cross-sections and laterally correlated to define the fault network of the different stratigraphic units. The same process has been applied to the salt diapirs and erosion areas.

N.B.: Each map (in time and depth) has its own color scale.

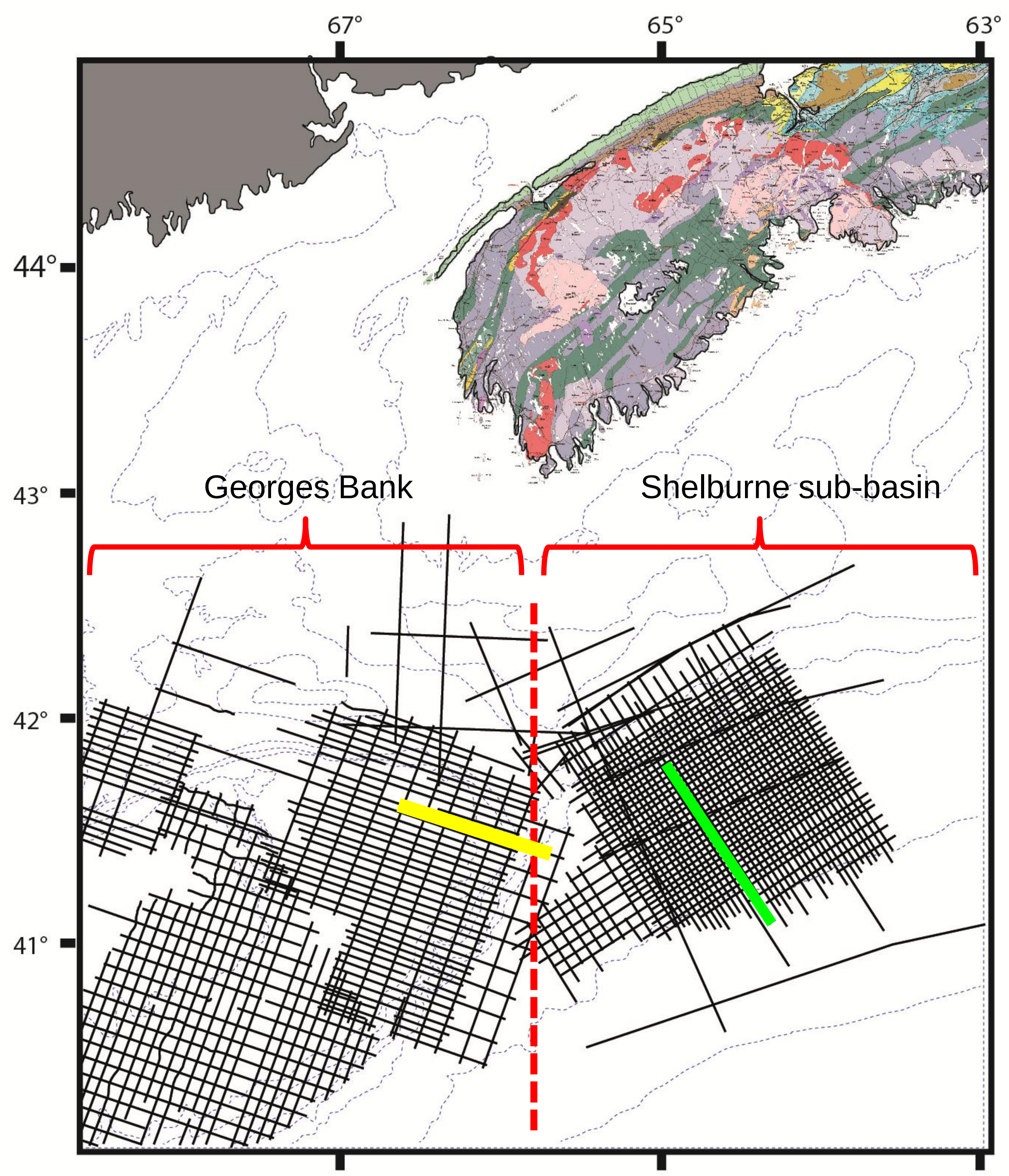


Figure 4 : Location map of the 2D seismic lines illustrating the geological provinces of the studied area: Georges Bank and Shelburne Basin areas.

The studied area can be divided *into* several areas:

- The Shelburne sub-basin, corresponding to an Atlantic-type volcanic passive margin with salt;
- The Georges Bank, corresponding mainly to a structural high (Yarmouth Arch), with some salt on each side (West Georges Bank and Shelburne sub-basin) and Early Jurassic volcanic seamounts (posterior to the Central Atlantic opening).

The eastern part of the Georges Bank corresponds to the Yarmouth sub-platform (Figure 4 and Figure 5). Autochthonous salt deposited during the Early Jurassic moved to the deepest part of the margin, (in the Shelburne sub-basin), allowing the sliding of the sediments toward the basin. Listric faults developed above this salt and are rooted directly inside (the largest ones are above the eastern side of the Yarmouth sub-platform). This salt is interpreted to be allochthonous in the basin and its motion may *create* some rafts of Jurassic sediments.

Two levels of salt are identified in the Shelburne sub-basin (Figure *5* and Figure 6): an autochthonous salt layer above the faulted "basement" which may have fed a shallower allochthonous salt layer. The autochthonous salt may have been evacuated through regional listric faults and counter-regional faults, on which the horizons K130, K137, J150 and J163 are folded and salt *welds* are expected. The allochthonous salt is mainly located in the deepest part of the basin close to the COB, above the SDR (Figure 6).

Listric faults developed on the autochthonous salt sheet and allowed the motion of Cenozoic and Cretaceous sediments (T29, T50 and K94) down the basin. Secondary diapirs seem to have been squeezed by shallow counter-regional listric faults, and it may be the result of the motion of all the sediments southward to the basin.

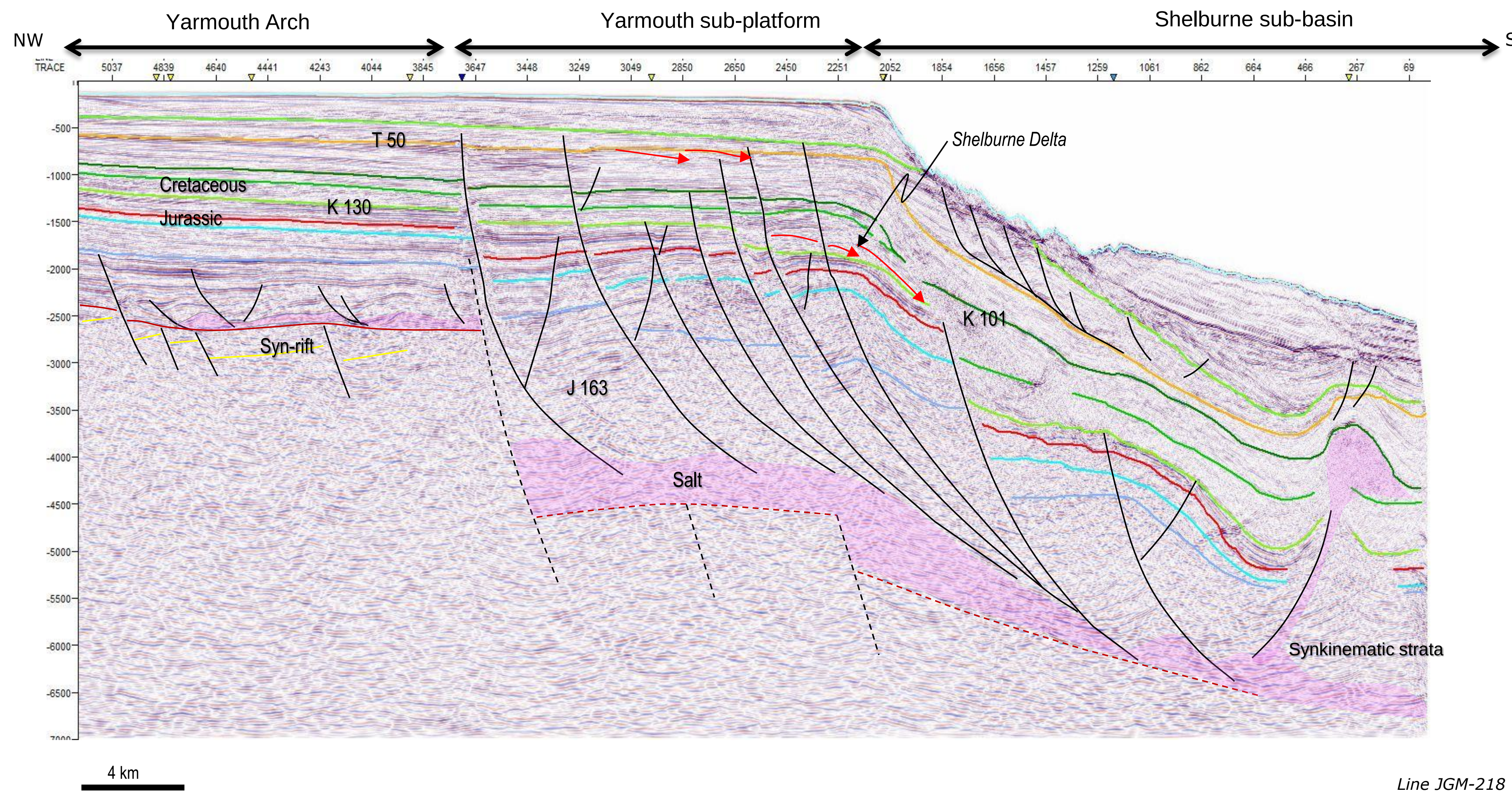


Figure 5 : Seismic section through the Georges Bank (Yellow line on the Figure 1). The motion of the salt nappe eastward is highlighted, as well as the synkinematic strata deposited above the salt (from J163 to T50).

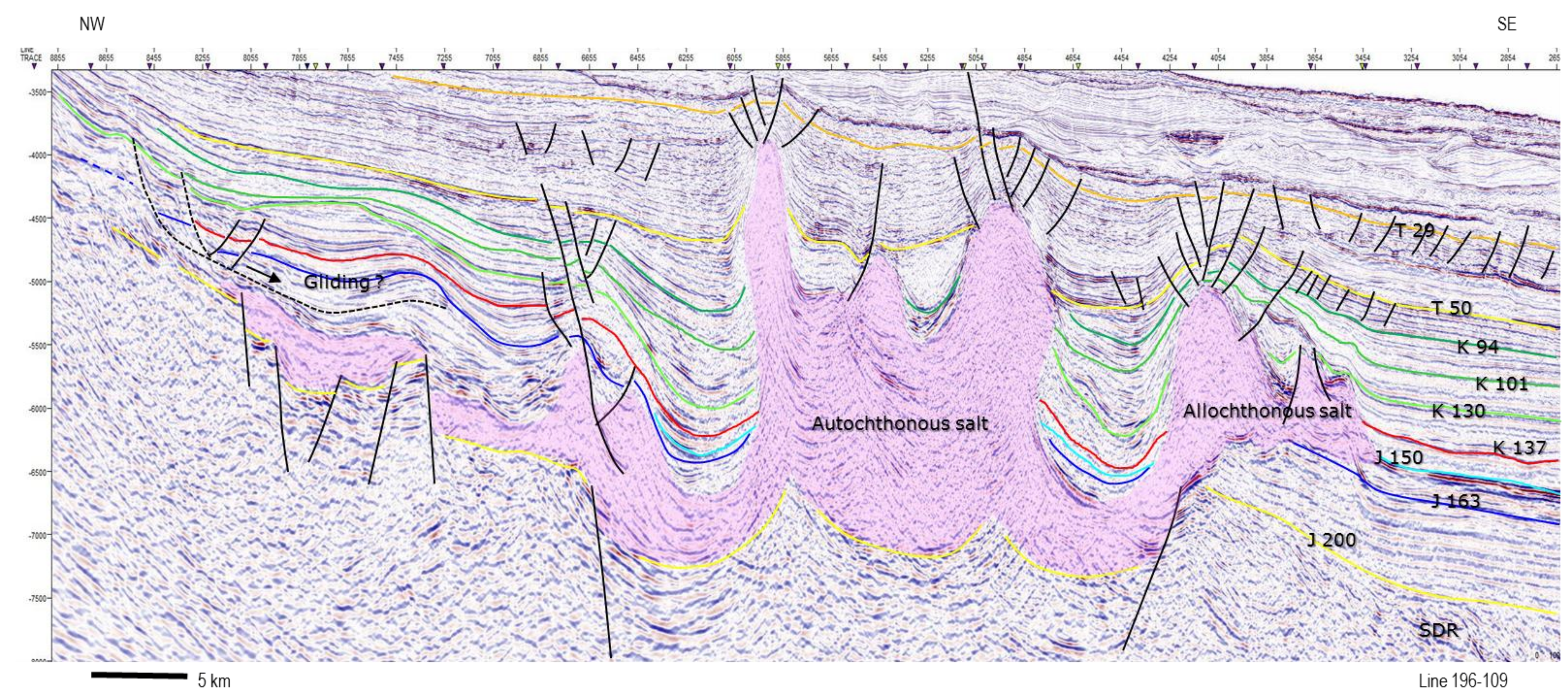


Figure 6 : Seismic section in the Shelburne basin (Green line). The autochthonous salt is creeping and forms some diapirs or is evacuated by counter-regional faults and forms a salt-sheet close to the boundary with the SDR area.

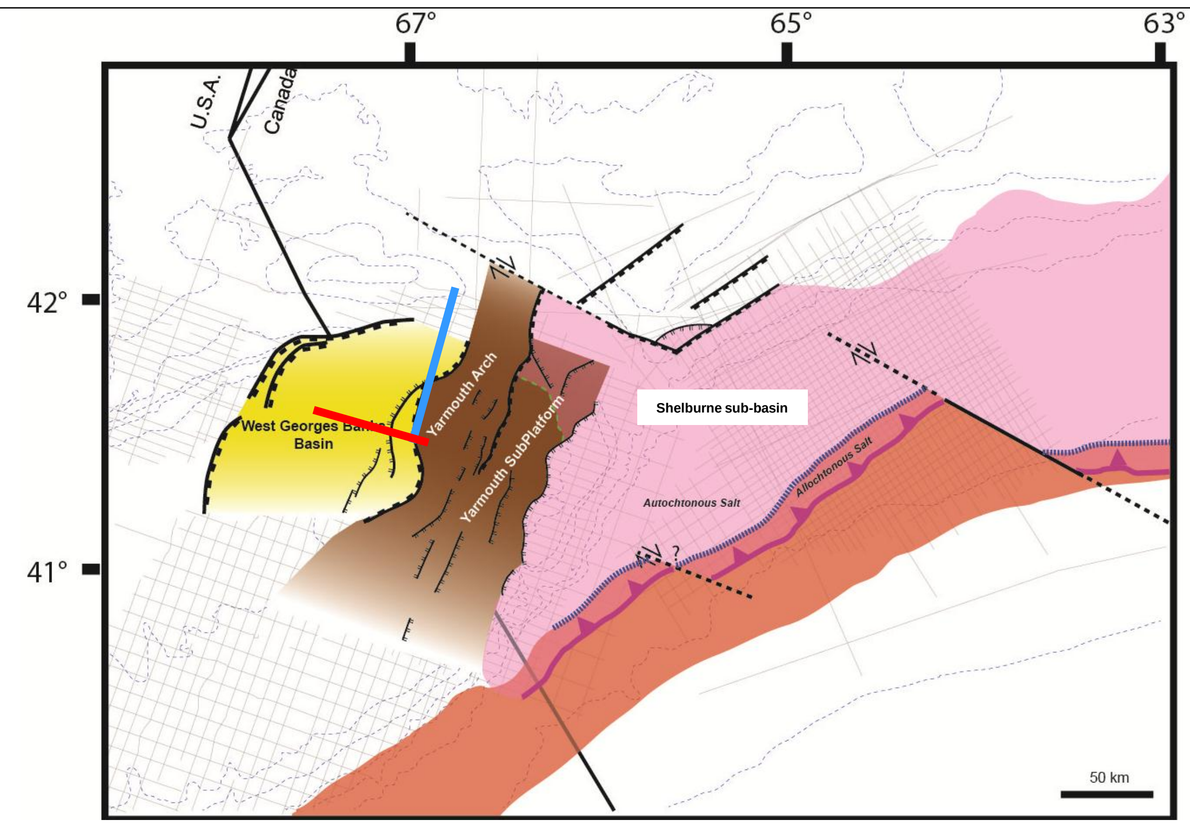


Figure 7: Structural map of the Georges Bank and the Shelburne sub-basin. The Georges Bank is dominated by a structural high created during the rifting of the Central Atlantic (Triassic horst) separating two basins: the West Georges Bank Basin on the West and the Shelburne sub-basin on the East

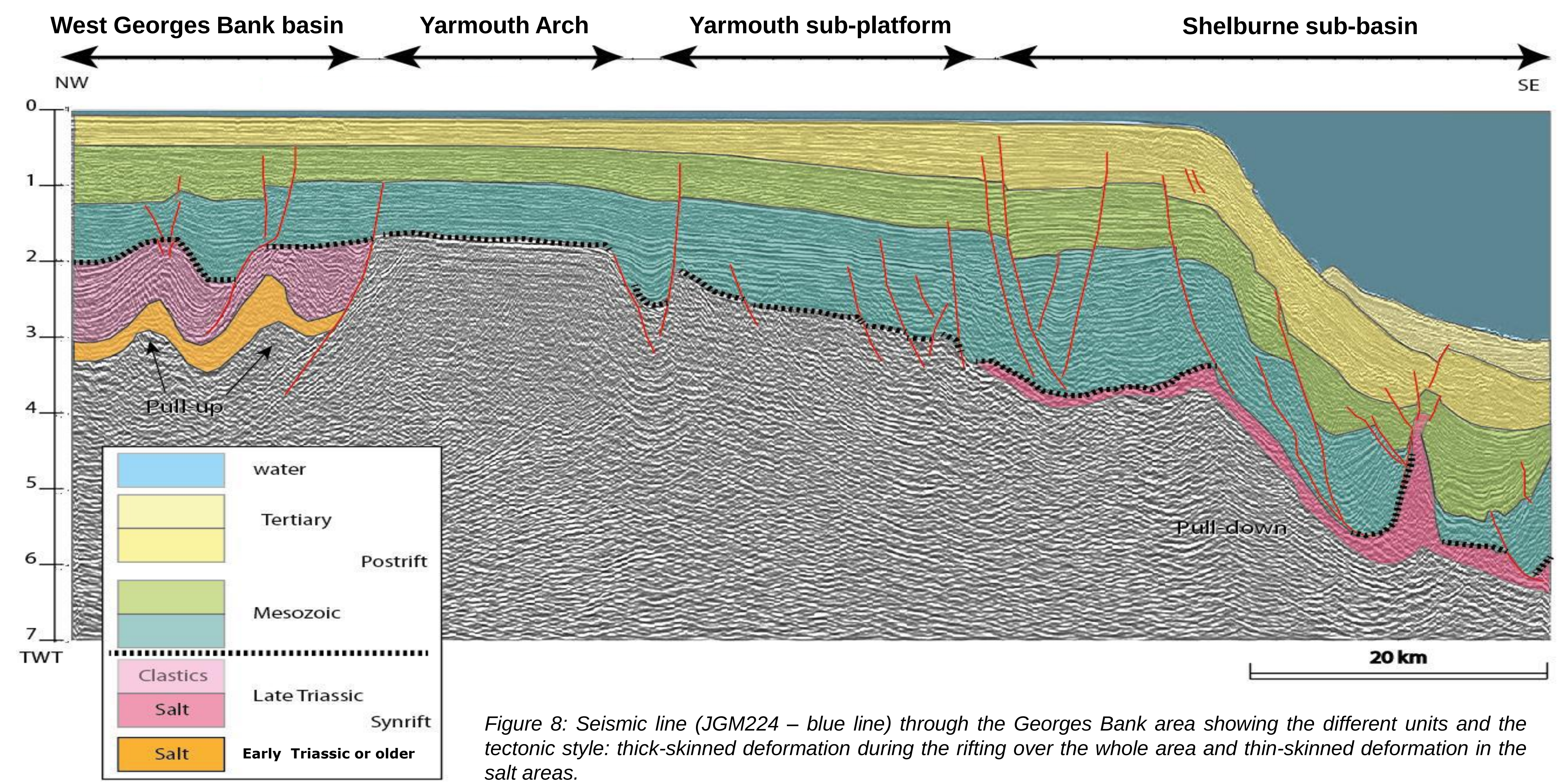


Figure 8: Seismic line (JGM224 – blue line) through the Georges Bank area showing the different units and the tectonic style: thick-skinned deformation during the rifting over the whole area and thin-skinned deformation in the salt areas.

The Shelburne sub-basin extends from the shelf to the south for almost 200 km. The basin is covered by a thick layer of salt which highlights different features: the transform fault trending NW-SE, the shelf edge and the boundary with the Georges Bank area (Figure 7). This salt is dated from the Early Jurassic and seems to seal the synrift event in the Shelburne sub-basin (Figure 7 & 8).

On the Georges Bank area, different units can be also delimited:

- The Yarmouth sub-platform is bounded to the East by the Shelburne sub-basin, and to the West by the Yarmouth Arch (Figures 7 & 8).
- The Yarmouth Arch is located between the Yarmouth sub-platform and the West Georges Bank basin. It is affected by a number of extensional faults (Figures 7 & 8).
- The West Georges Bank basin is at the extreme West of the study area (Figures 7 & 8). It seems to have opened during the rifting of the Central Atlantic. It is also characterized by a thick layer of salt at the at the base in contrast to the Shelburne sub-basin (Figures 9 & 10) where only a single salt layer is observed. The age of the salt on the West Georges Bank Basin is not clear. The biostratigraphic data review has dated from the Early Jurassic (possibly Hettangian) the oldest core in the well Cost G2 (See Plate 3.1.2).

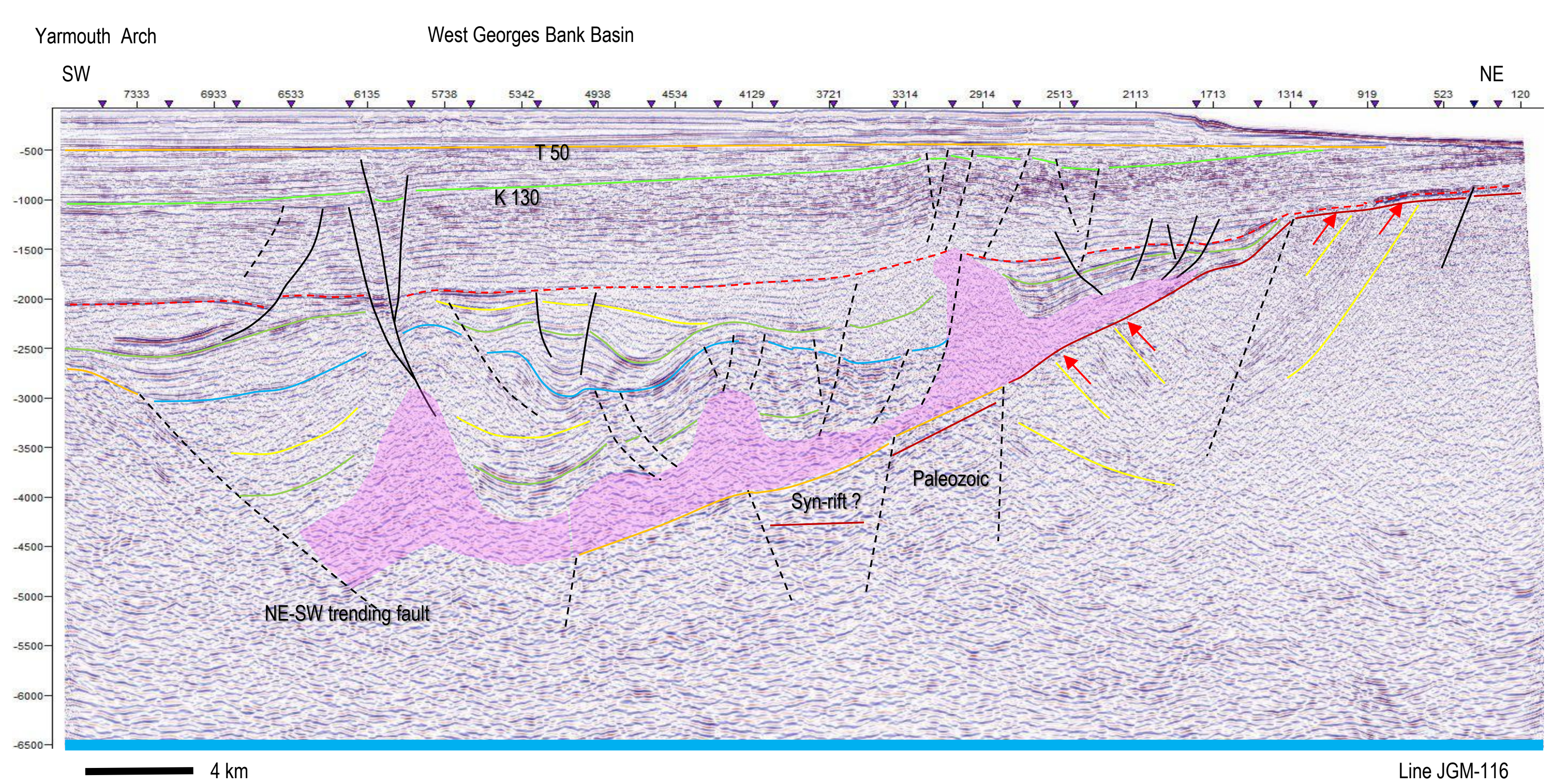


Figure 9: Seismic section (red line on Figure 1) through the Yarmouth Basin, showing the geometry of the salt and the tectonic style associated (thin-skinned faulting).

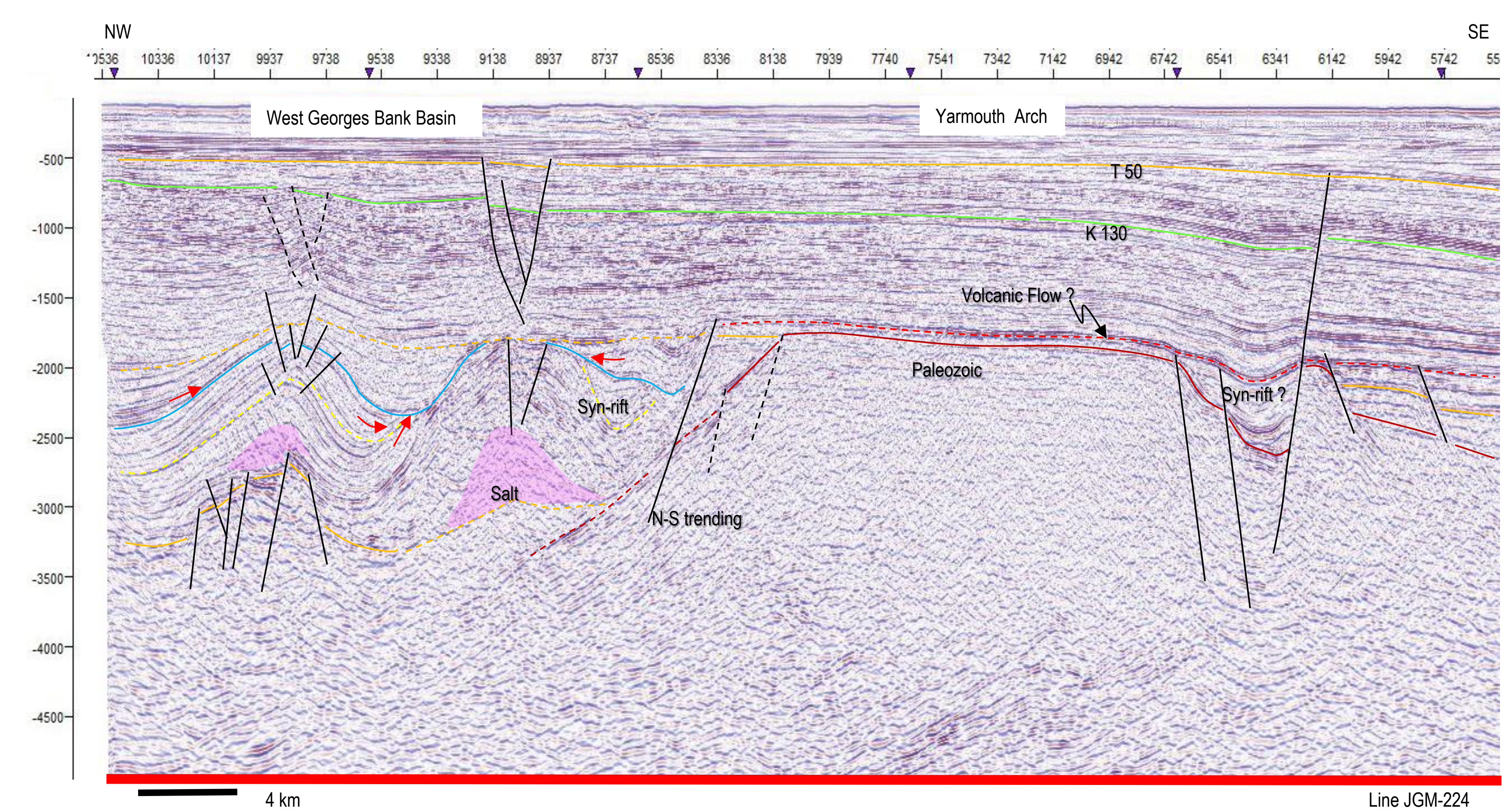
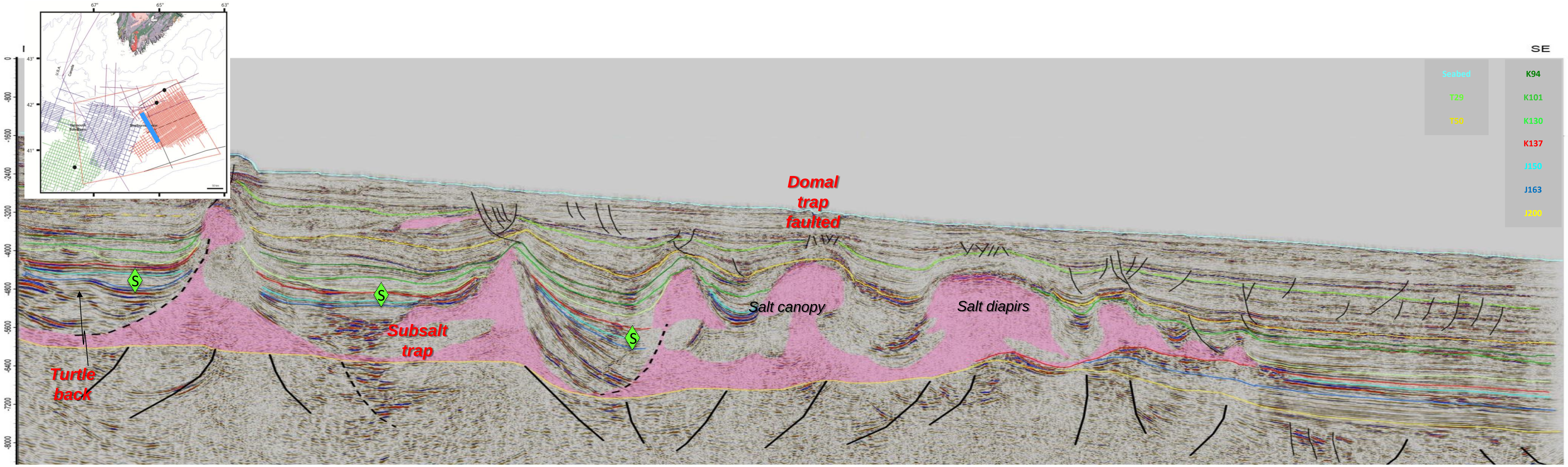


Figure 10: Seismic section through the Yarmouth Arch (JGM224 – blue line) and the Yarmouth Basin showing the tectonic style. The Yarmouth Arch is bounded by a steep fault to the Yarmouth Basin. The Salt is located at the bottom of the basin instead of the top as in the Shelburne Basin.



line 180-109

Figure 11 : Seismic line in the Shelburne Sub-Basin showing the different salt-related trap styles

Two types of traps are highlighted in the studied area:

- those related to salt tectonics (Figure 11 and Figure 12) which occur in the Shelburne sub-basin *mainly*
- those related to stratigraphic traps (Plate *5.3.1.5*) they are mainly located *against* the Yarmouth sub-platform *and the Scotian* shelf in the Shelburne sub-basin.

The salt-related traps are located mostly above the autochthonous salt in the Shelburne sub-basin, (Figure 11 and Figure 12). Potential traps may develop above and around diapirs as hydrocarbon sealed against the diapir flank, as a domal trap faulted or *unfaulted* trap above diapirs, turtle-back feature, and subsalt trap with reservoir beds pierced by diapirs and upturned to form a series of small stacked traps. Roll-over anticlines associated to listric faults close to the slope of the basin and faulted block (four-way dip closure) may also be of interest.

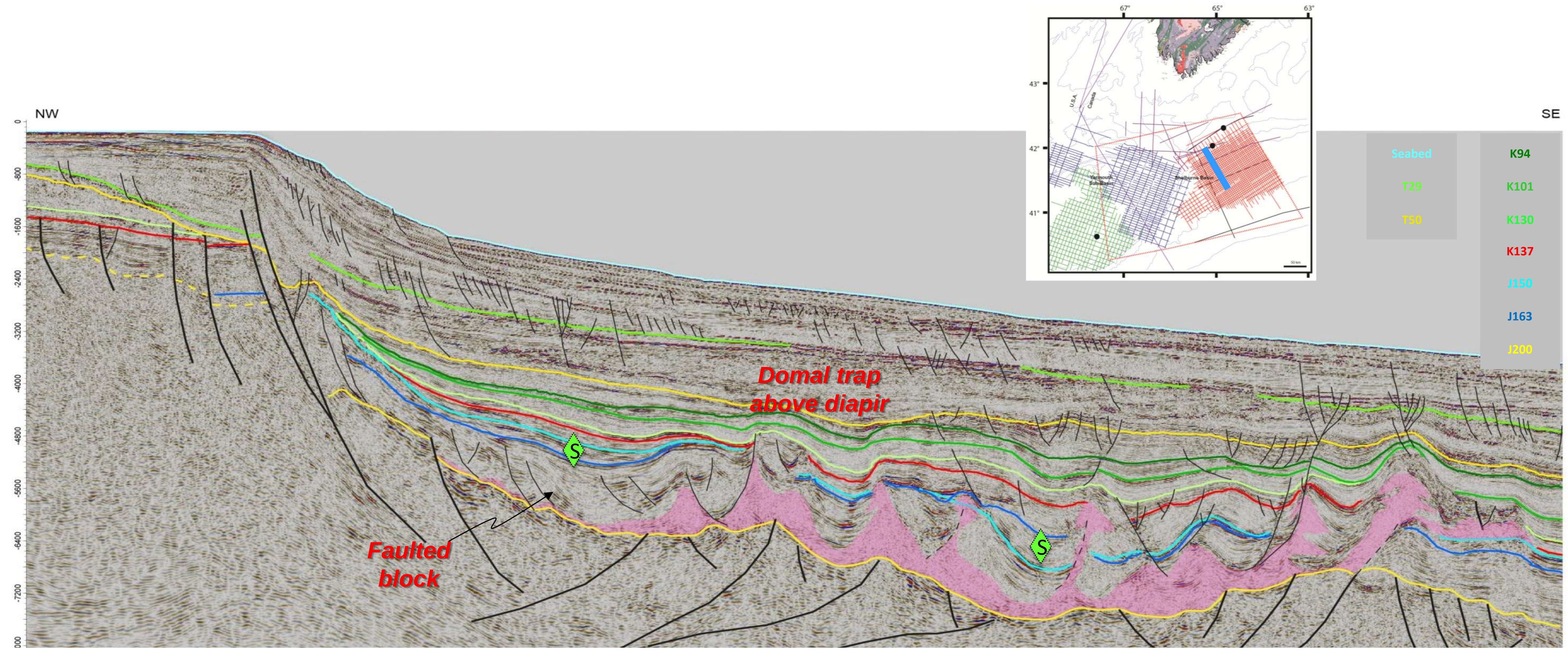


Figure 12: Seismic line in the Shelburne Sub-Basin showing the different salt-related trap styles

line 160-109

Trap Styles

Stratigraphic traps may occur in the Shelburne sub-basin but especially at the boundary with the Georges Bank margin. Indeed, this part of the margin shows complex depositional patterns such as turbidites, slope fans, basin floor fan, channels complex. Slope fans have been defined within the basin and above the carbonate platform on the shelf (Figure 13). Carbonate mounds are expected above basement high in the Shelburne Basin.
The Avalon Unconformity (associated to the horizon K137) is well extended on the shelf and on the slope where dipping Jurassic sediments were truncated and later buried by Early Cretaceous sediments and provides potential for stratigraphic trapping. The T29 and T50 horizons correspond also to unconformities which eroded Cenozoic and Late Cretaceous sandstones and shales, but they are mainly developed on the shelf edge where sediment layers are thin due to bypass or erosion above the Base Post Rift Sediment (Figure 1), and hence are less likely to lead to significant stratigraphic traps.

The most promising stratigraphic play is located in the southwestern side of the Shelburne sub-basin along the Yarmouth sub-platform and consists of pinch out traps in the Cretaceous turbidites (Figure 13).

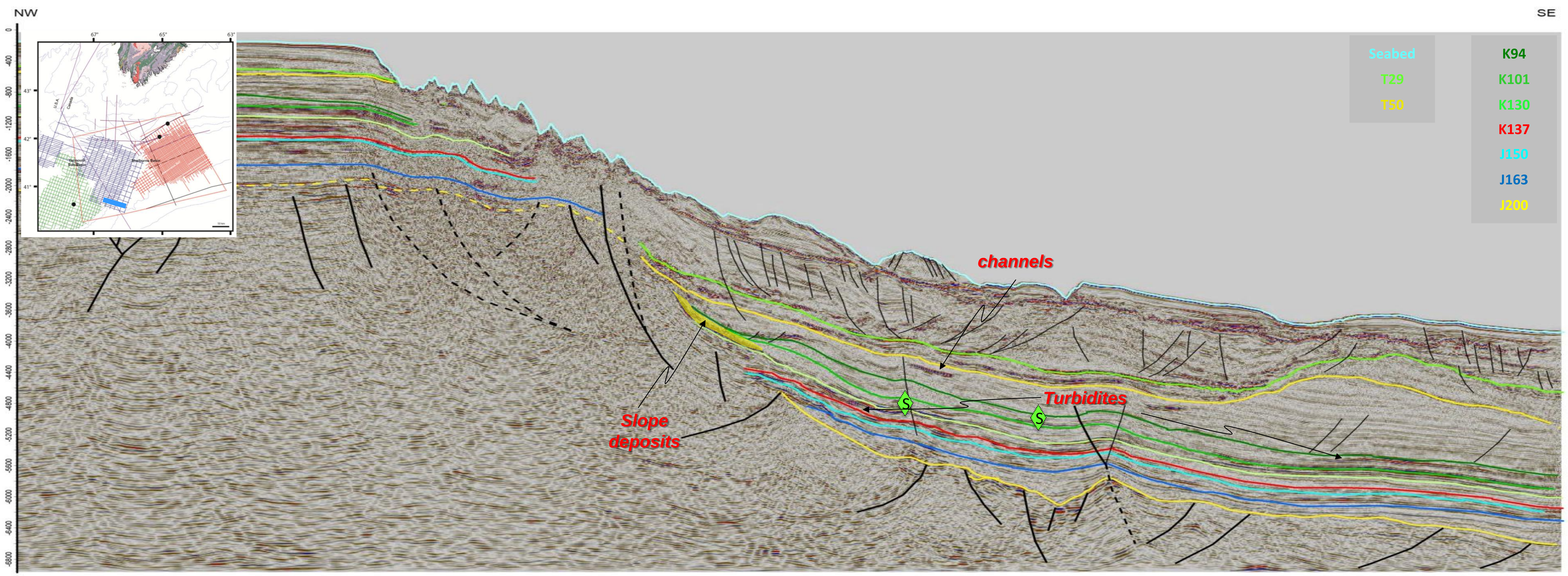


Figure 13 : Seismic line the Shelburne sub-basin showing stratigraphic trap styles

line JGM239

SEISMIC INTERPRETATION – STRUCTURAL MAPPING

Several potential seismic direct indicators of hydrocarbon have been spotted on the Shelburne Sub-Basin and in the Yarmouth SubPlatform.
There are 3 main indicators :
- the flat spots
- the bright spots
- The amplitude anomalies

Theses indicators are mainly observed in Cretaceous and Tertiary intervals.

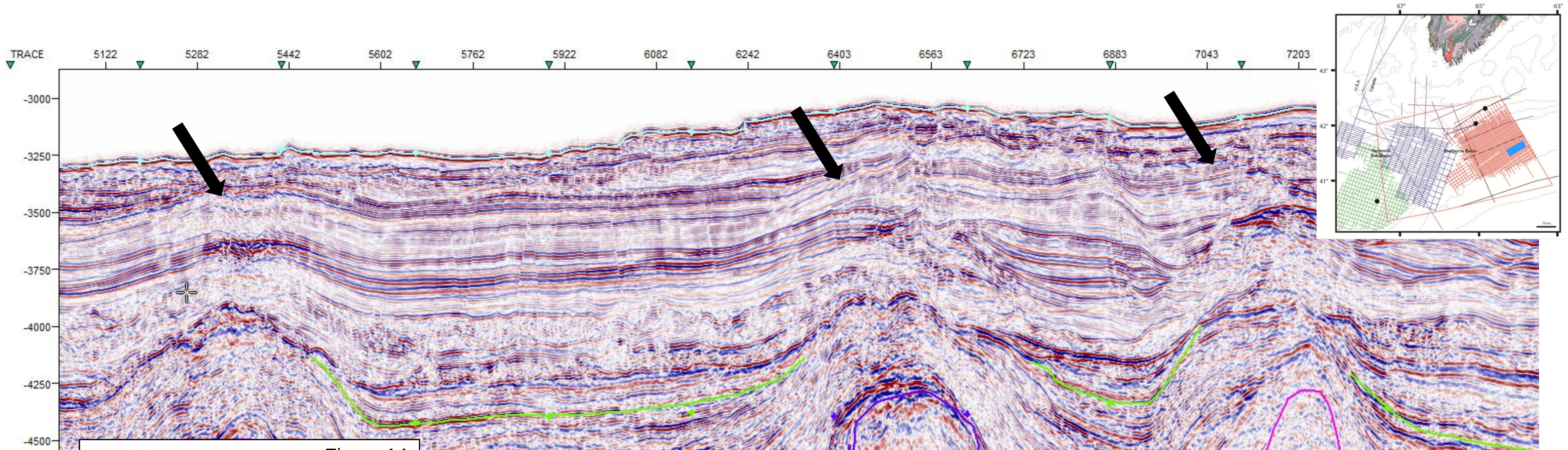


Figure 14

- *Bright spot*
- *Line TGS 297-109*
- *Interval: Above T29*
- *Reservoir: channels*
- *Trap style : Domal trap above salt*

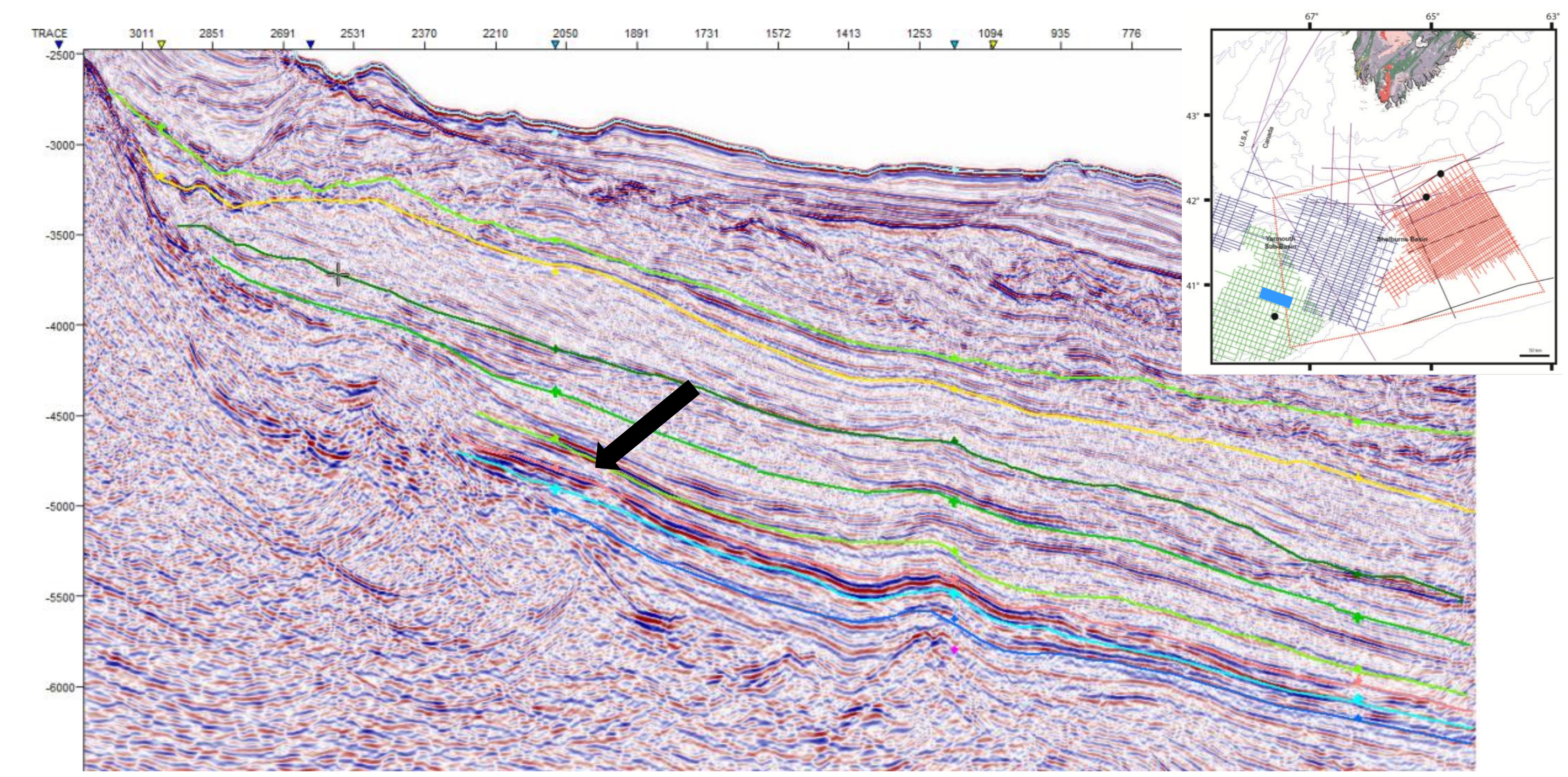


Figure 17

- *Bright spot*
- *Line JGM239B*
- *Interval: K130-J150*
- *Reservoir: silici-clastic turbidites fan*
- *Trap style : pinch out*

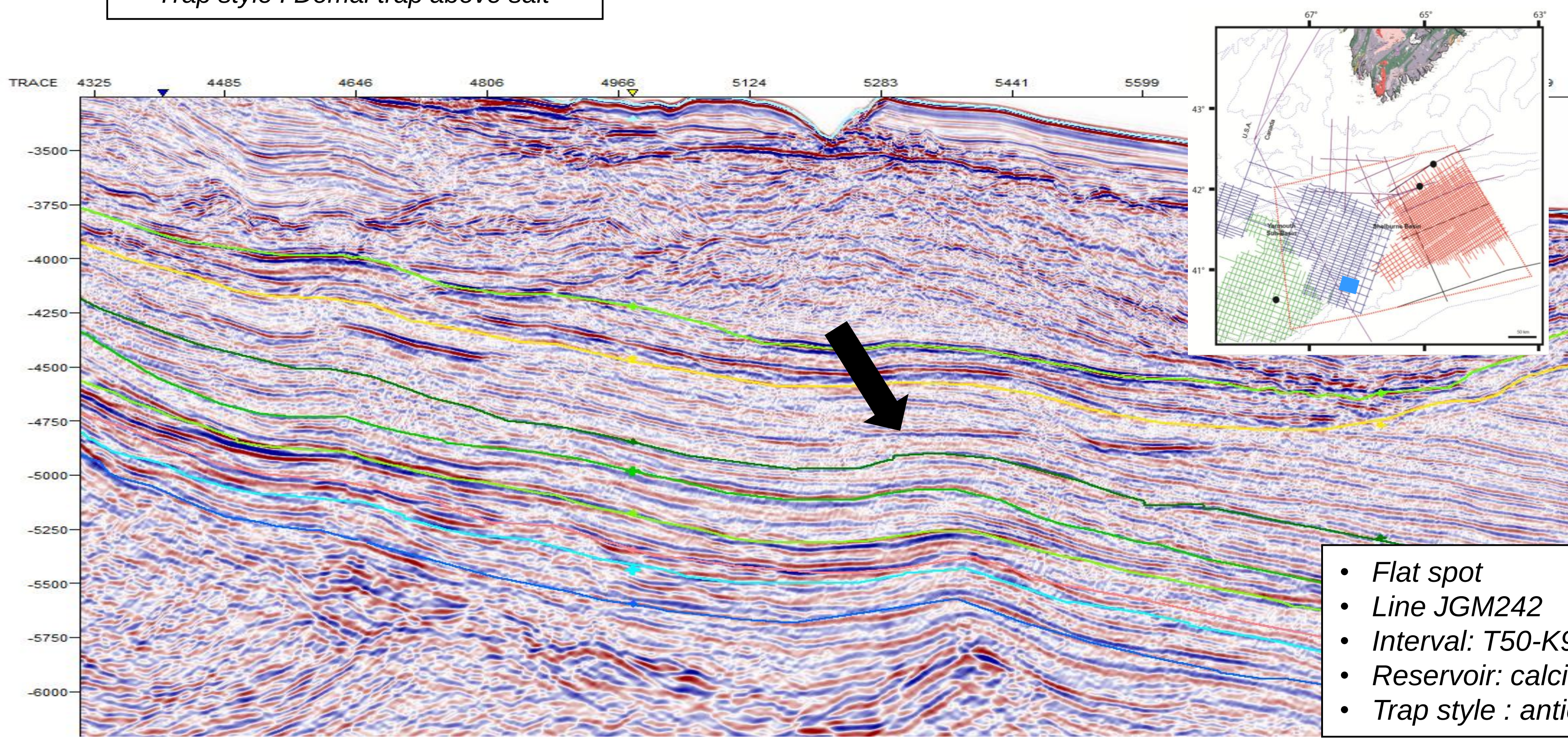


Figure 15

- *Flat spot*
- *Line JGM242*
- *Interval: T50-K94*
- *Reservoir: calci-turbidites*
- *Trap style : anticline*

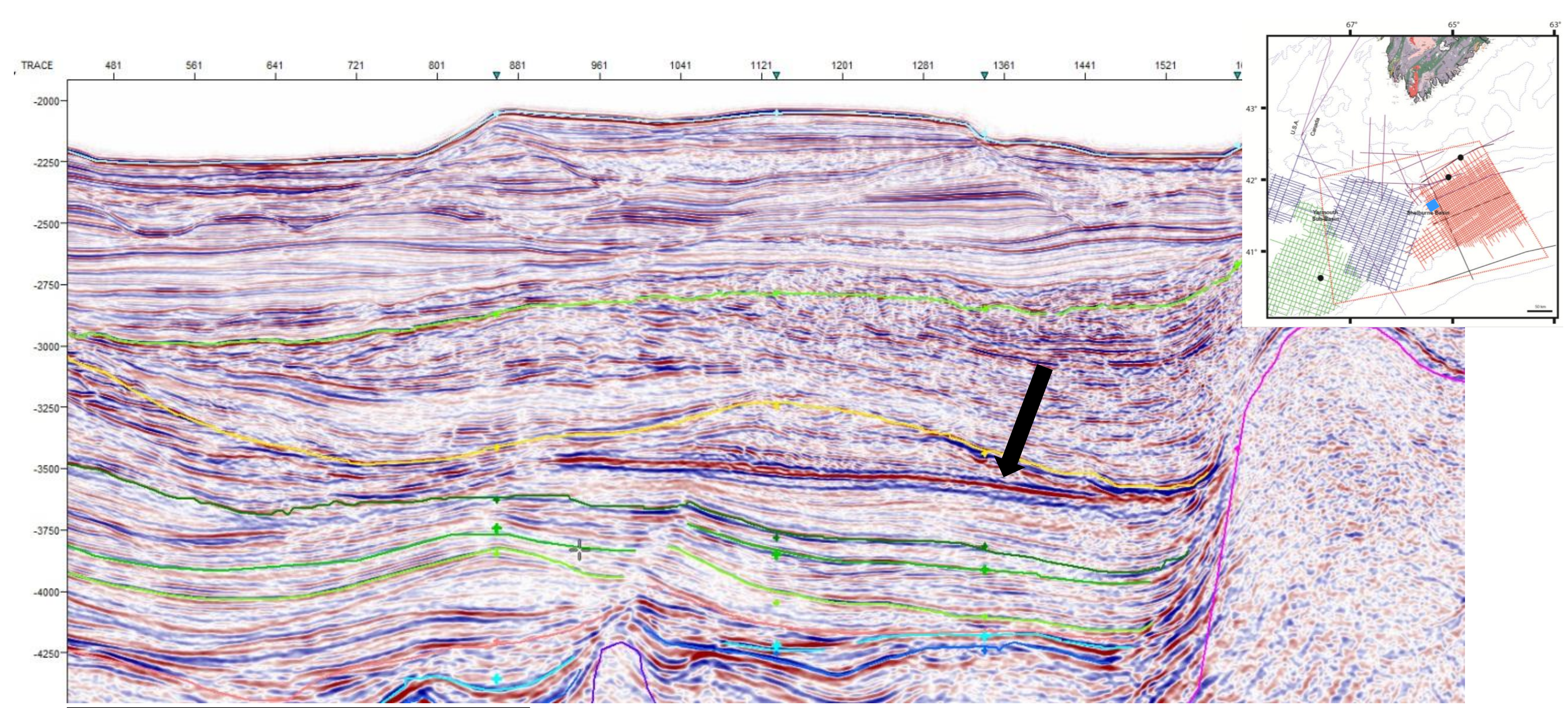


Figure 18

- *Amplitude anomaly*
- *Line TGS361-109*
- *Interval: T50-K101*
- *Reservoir: calci-turbidites (chalk)*
- *Trap style : pinch out*

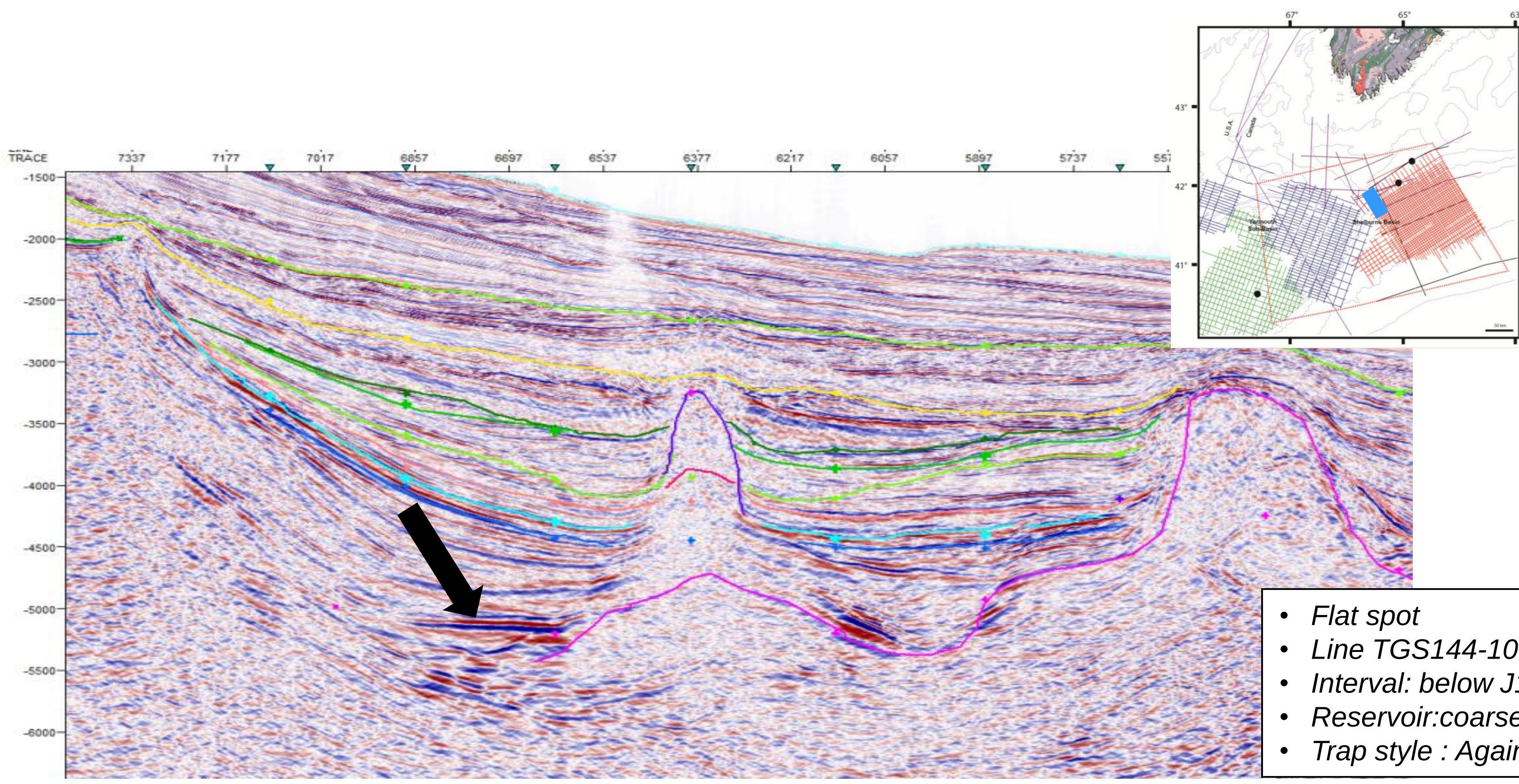
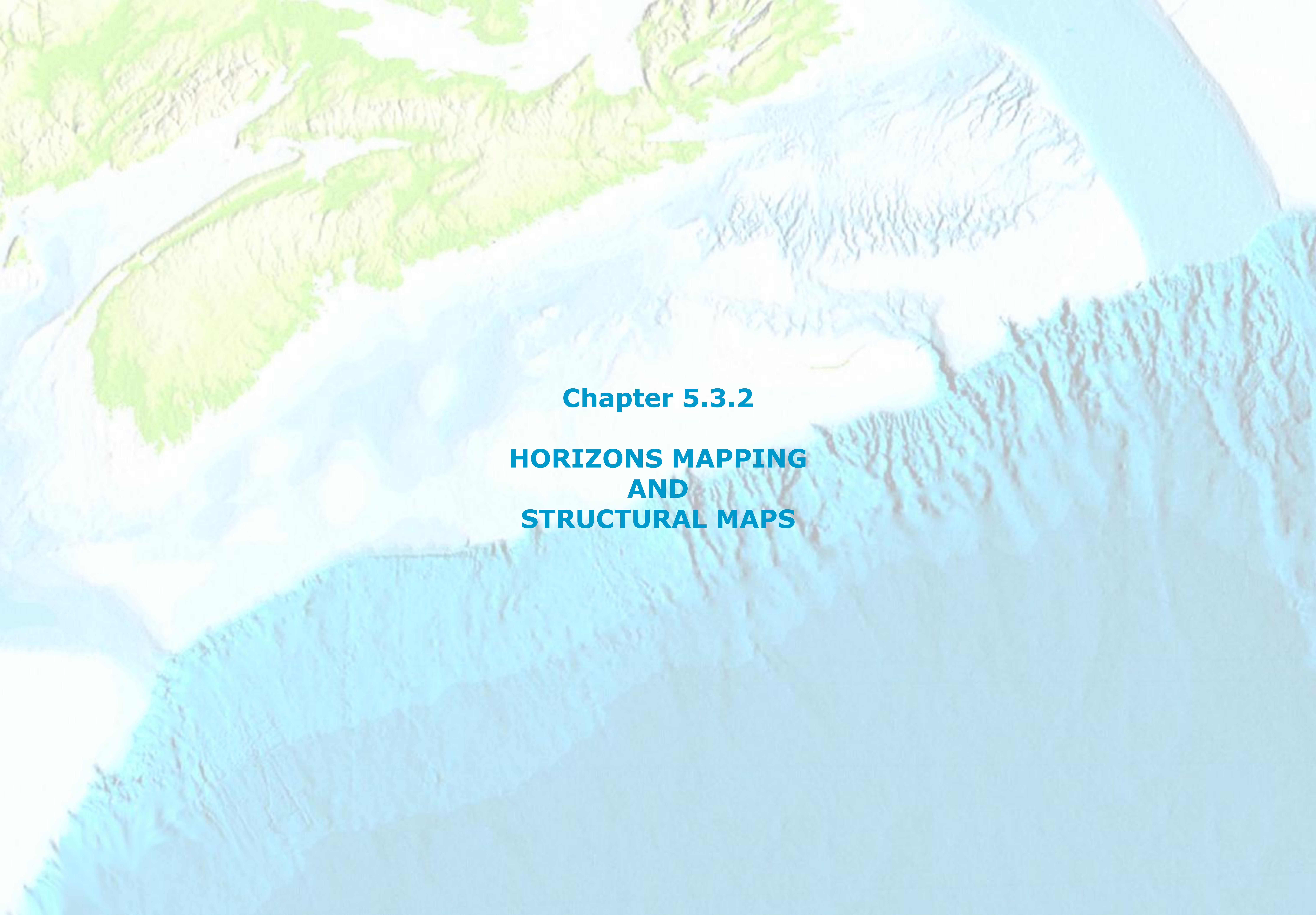


Figure 16

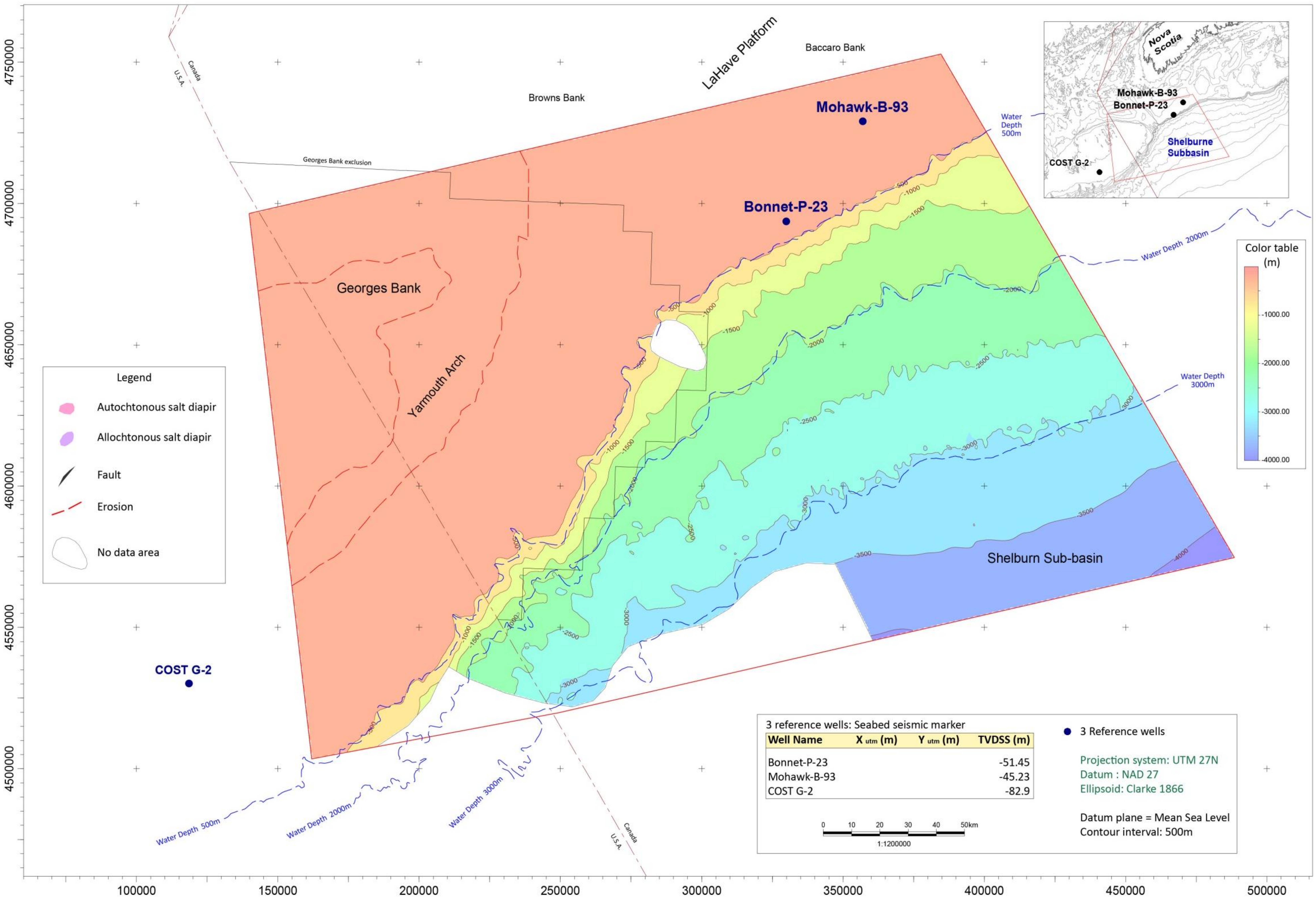
- *Flat spot*
- *Line TGS144-100*
- *Interval: below J163*
- *Reservoir:coarse calciturbidite*
- *Trap style : Again diapir*

Potential Hydrocarbon Indicators



Chapter 5.3.2

HORIZONS MAPPING
AND
STRUCTURAL MAPS



3 reference wells: Seabed seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23			-51.45
Mohawk-B-93			-45.23
COST G-2			-82.9

Seabed Depth Structural Map

Tectono-stratigraphical chart

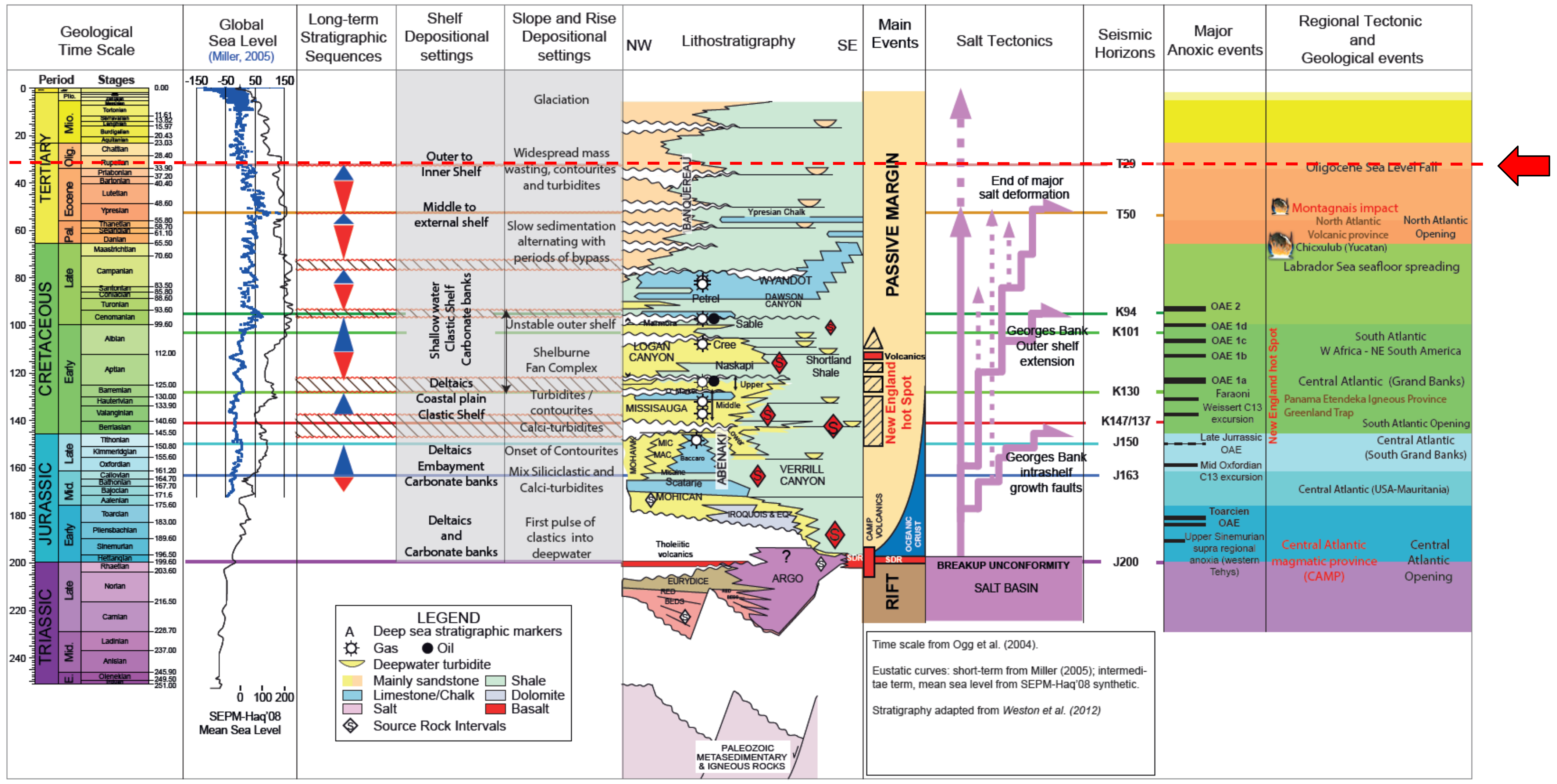


Figure 18 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

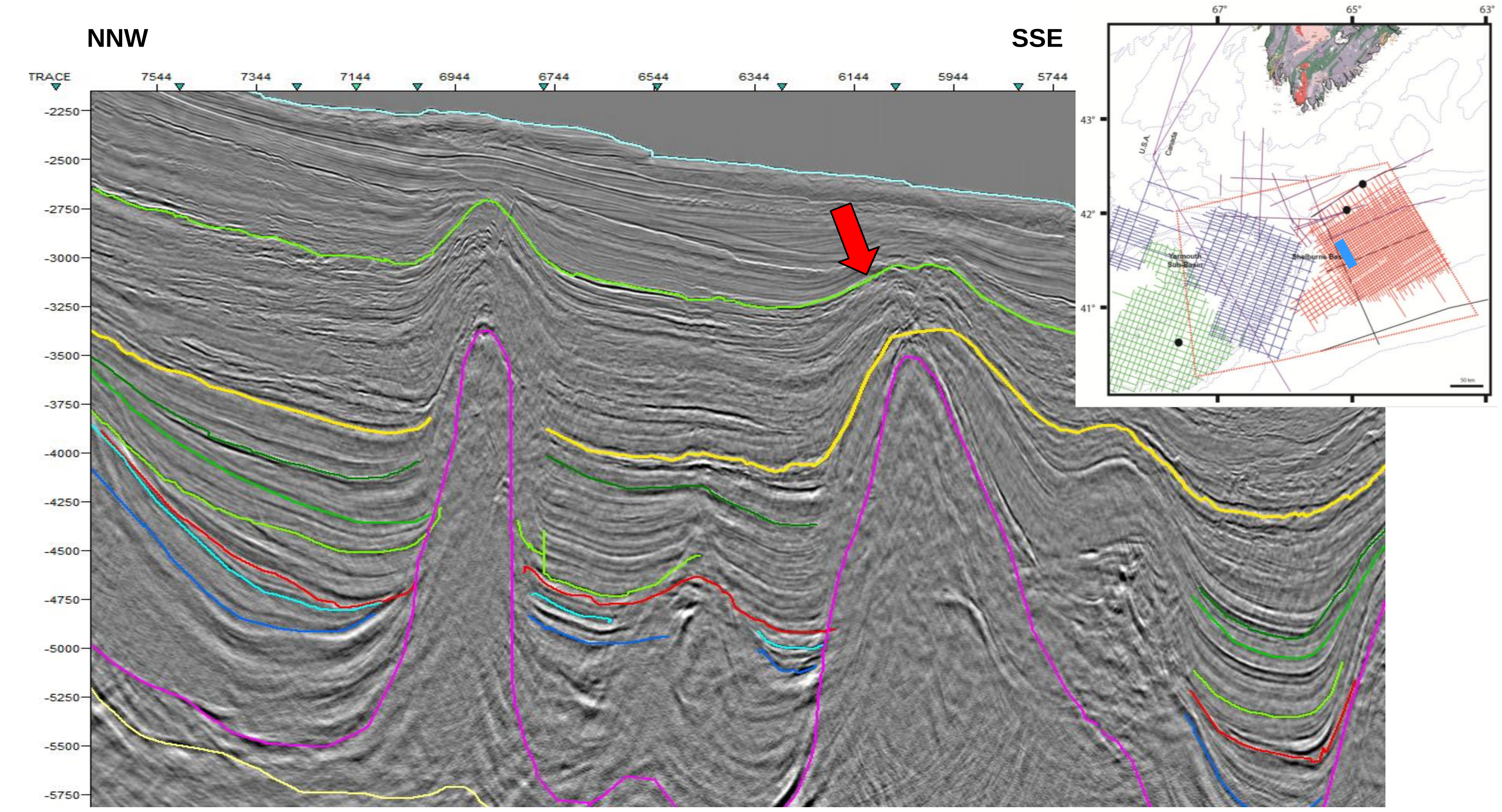


Figure 19 : Seismic line (TGS160-100) in Shelburne Sub-Basin showing T29 deformed by salt doming

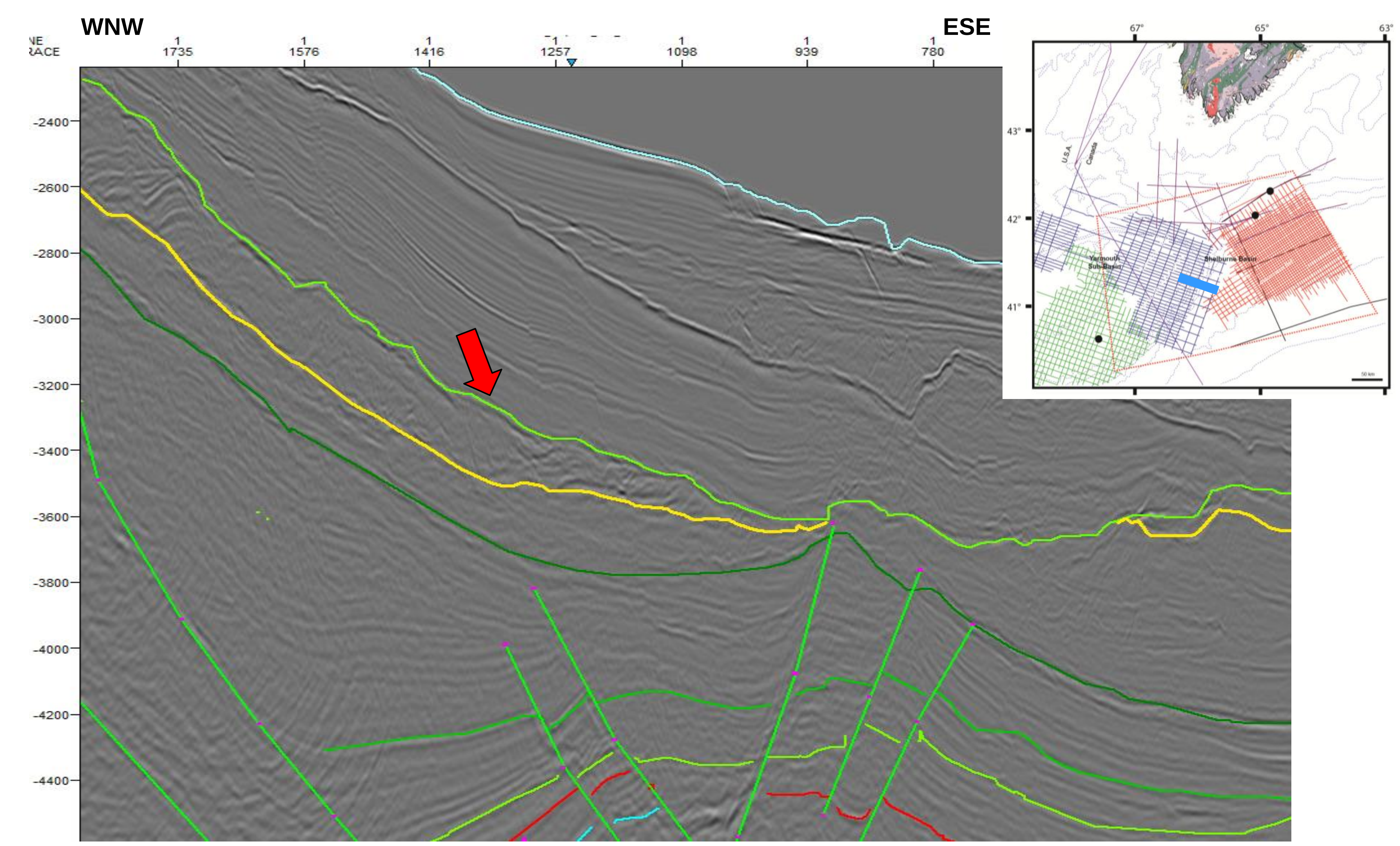


Figure 20 : Seismic line (JGM227E) in the slope of the Georges Bank Area showing truncation below T29

Horizon definition

The horizon named "Mid-Oligocene unconformity" (or T29) is the amalgamation of successive erosional surfaces corresponding to glacial episodes occurring from Rupelian to Priabonian times which removed a large amount of sediments from Tertiary to Late Cretaceous in age (incision can affect Cenomanian units along the slope of the basin). The attributed age of this surface has been estimated at 29 million years (Figure 18).

Well-to-seismic tying

No well marker is available in Bonnet or Mohawk wells; nevertheless it had been calibrated with Nova Scotia Play Fairway Analysis 2011 wells, and the picking was extended on the new lines. T29 does not have a typical acoustic signature but is reliably tied to the seismic through the seismic features (erosional truncations, Figures 19 & 20).

NB: concerning COST G-2 calibration, three uncertainties (no checkshot data, very bad synthetic/seismic match, uncertain well markers) prevents taking it as a reference well for any horizon adjustment. Its calibration was used only as a secondary control.

Seismic picking and uncertainty

The seismic correlation of such a timeline over the western extension of Georges Bank is uncertain (condensed layering). Nevertheless, the truncations are clear on the basin area and consistent at the study scale (Figure 19). T29 erosional surface is characteristic of the Oligocene glacial event and is buried by the Oligocene Neogene last phase of basin infilling.

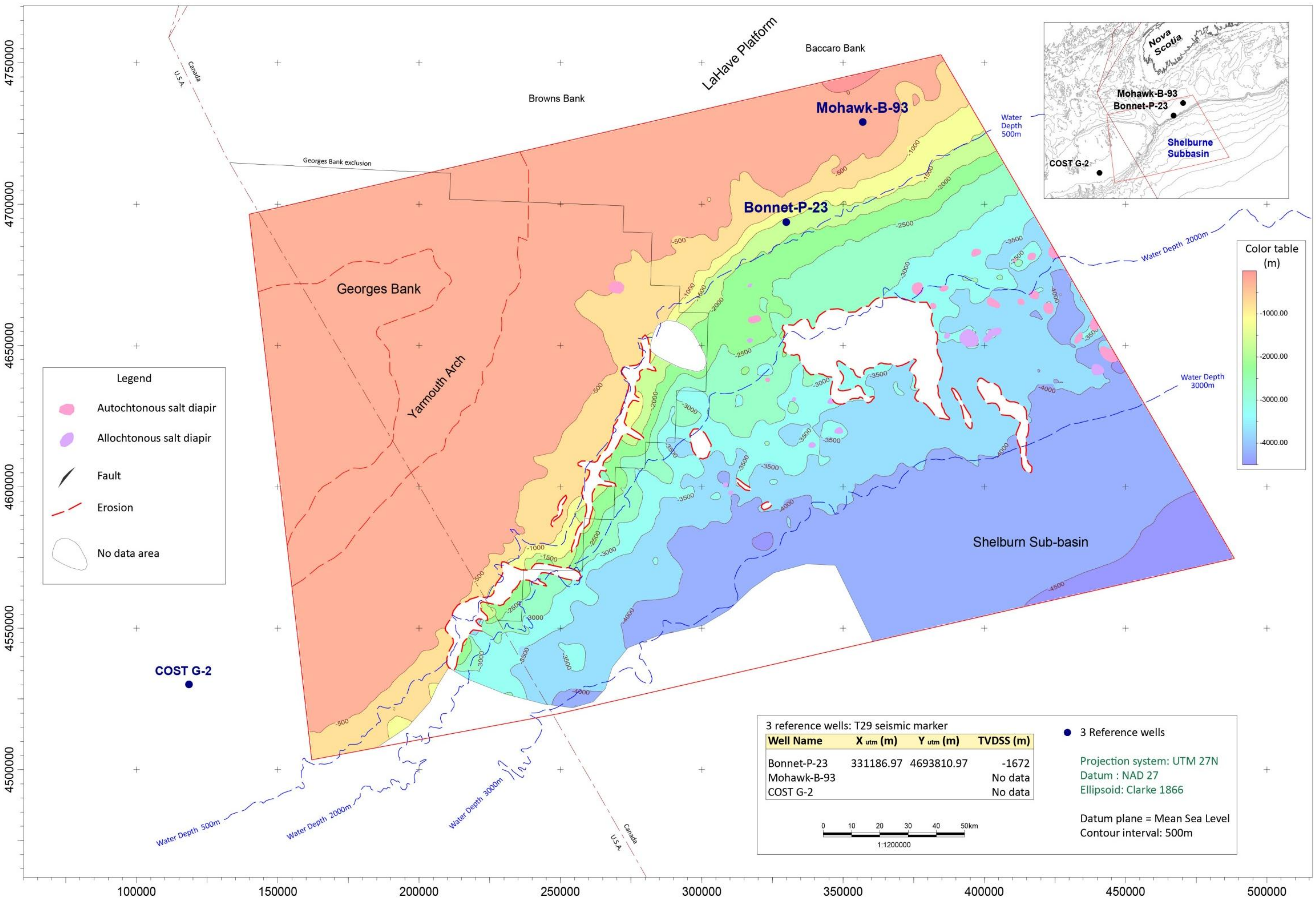
Structural description

T29 horizon is structurally close to the present day margin. No major structural fault has been observed (Figure 19).

On the slope, some erosion resulting from canyon incisions or gliding area is seen in the western part of it (against the Yarmouth sub-platform). An extended erosion is also present in the central part of the offshore area.

In the basin, several salt diapirs pierce T29, but folding of T29 is less pronounced than the deeper horizons (Figure 19). Westwards, on Georges Bank platform, no salt dome affects T29, except an isolated high – interpreted as salt piercement – located close to the slope direction change; this high will affect all the underlying horizons.

In the deep offshore where salt dome and seamount are absent, maximum depths are located in the Southeast of the study area.



3 reference wells: T29 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331186.97	4693810.97	-1672
Mohawk-B-93			No data
COST G-2			No data

T29 (Mid-Oligocene Unconformity) Depth Structural Map **PL. 5.3.2.3**

Tectono-stratigraphical chart

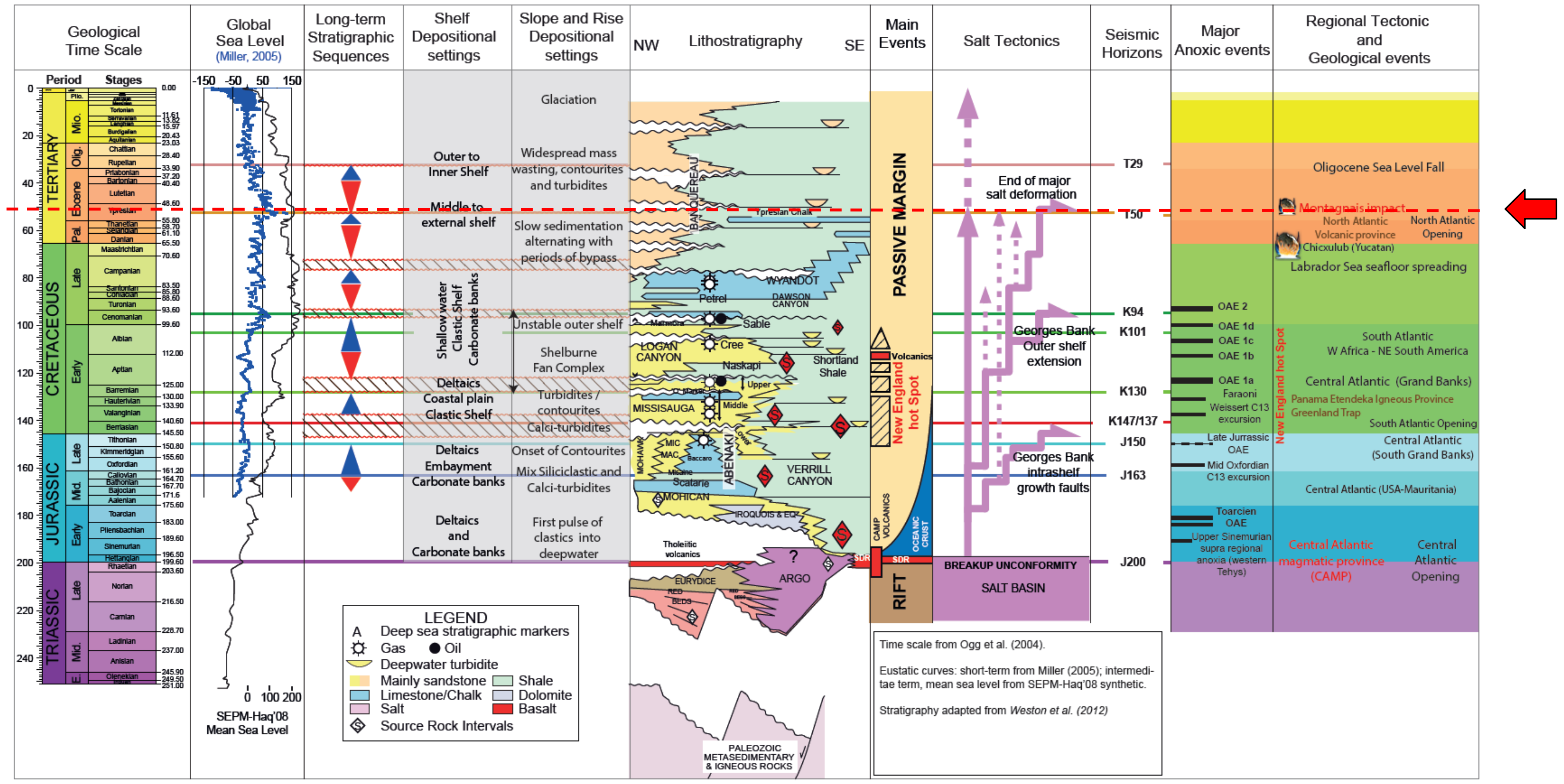


Figure 21 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

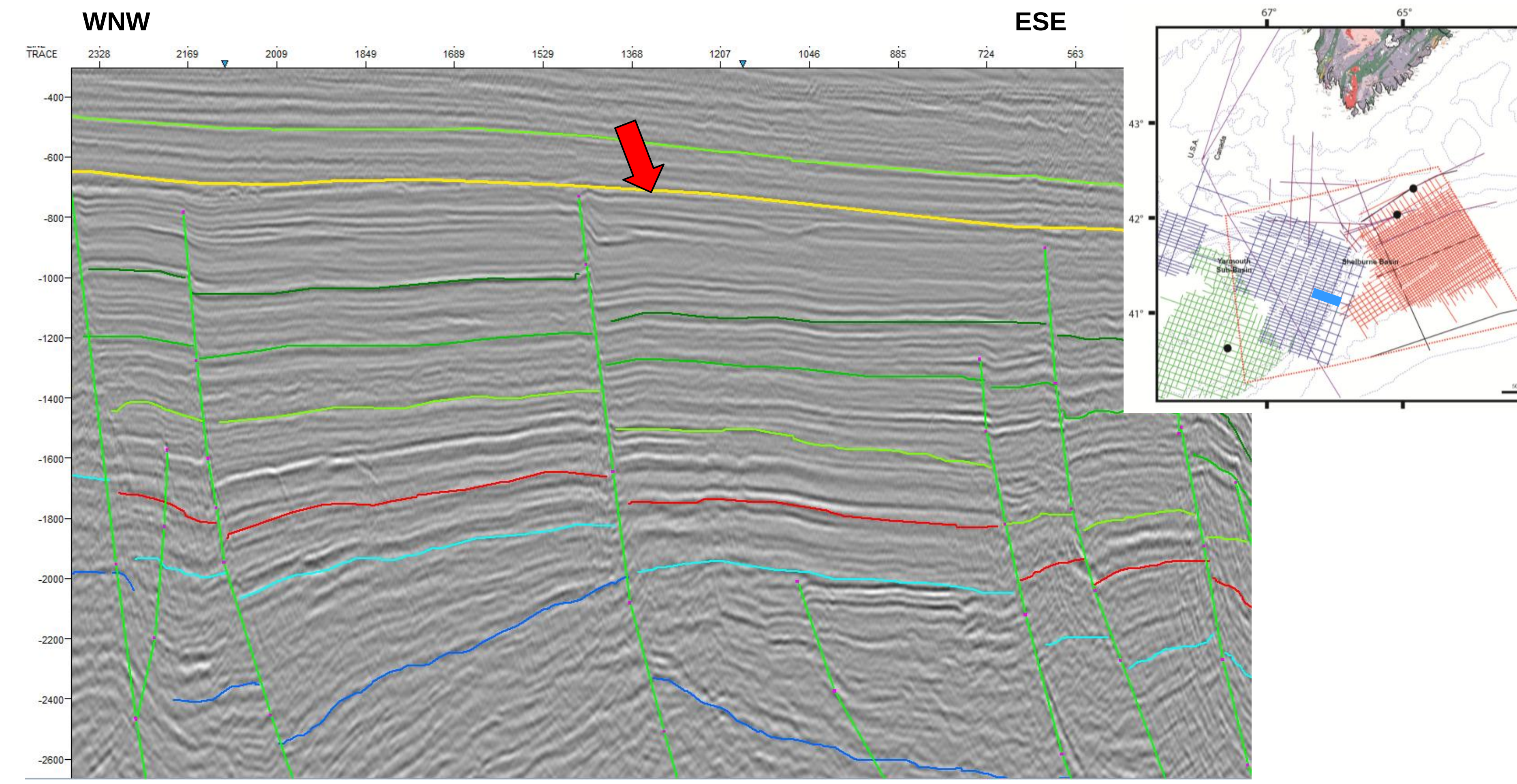


Figure 22 : Seismic line (JGM227E) in the Yarmouth sub-platform showing the faults sealed to T50

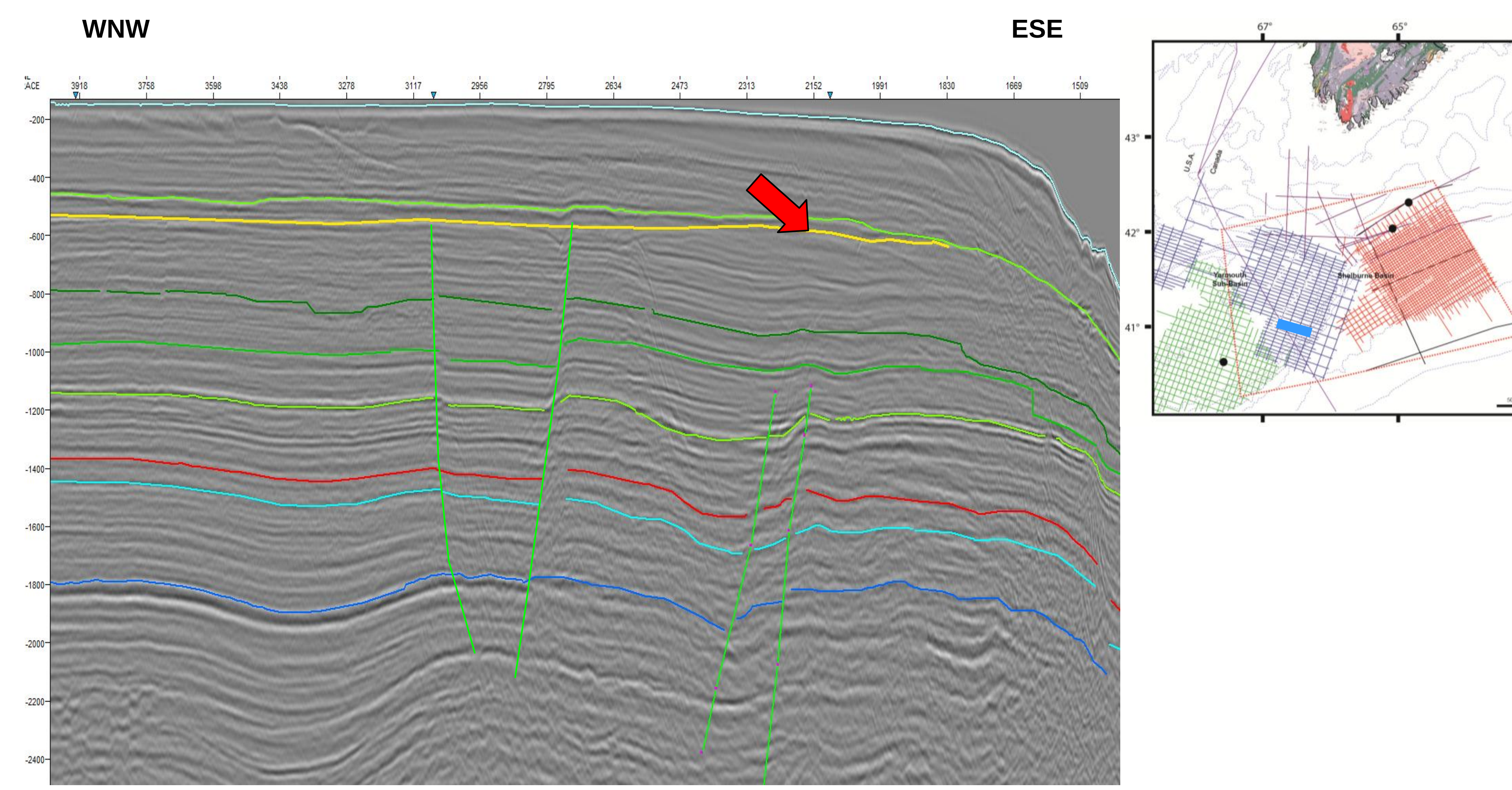


Figure 23 : Seismic line (JGM234B) in Shelf of the Yarmouth sub-platform showing erosion of T50 by T29

Horizon definition

The horizon named Ypresian Unconformity (or T50) affects the chalks deposited during early Tertiary times (Paleocene-Ecocene). It is confined to Ypresian in age and represents a major erosion recognized over most of the basin (Figures 21 & 22).

Well-to-seismic tying

The well-to-seismic tie is done on Bonnet well where the erosion has truncated a thick sequence of sediments until Aptian (no stratigraphic marker in the two other wells). T50 does not have a typical acoustic signature but is reliably tied to the seismic through the seismic features (erosional truncations) and, calibrated with 2011 Nova Scotia Play Fairway Analysis wells, its picking was extended on the new lines.

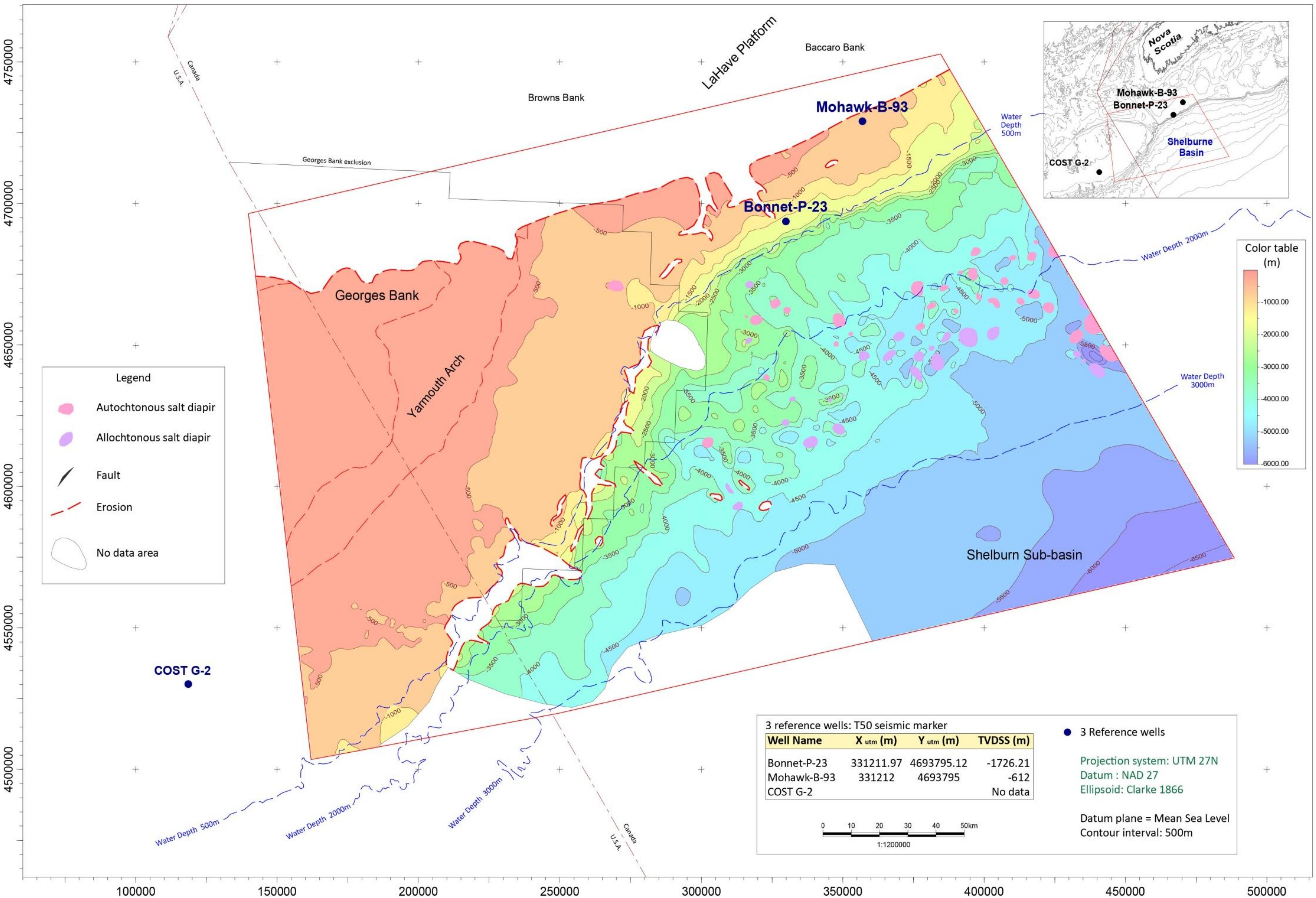
Seismic picking and uncertainty

The seismic correlation of such a timeline over the western extension of Georges Bank is uncertain (condensed layering). Nevertheless, the truncations are clear on the basin area and consistent at the study scale (Figures 22 & 23).

Structural description

T50 horizon is dipping as T29. The faults are sealed on the Yarmouth sub-platform. T50 is eroded by several Oligocene to Miocene in age incisions: T50 is bounded to the north by T29, as well as in the south-western corner.

The T50 erosion happens during the final stage of salt tectonics. Hence, it is generally pierced and is lying close to the top of the latest salt diapirs. The shelf is not directly affected by the salt tectonics except locally as in the Georges Bank area or along the Scotian shelf.



3 reference wells: T50 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331211.97	4693795.12	-1726.21
Mohawk-B-93	331212	4693795	-612
COST G-2			No data

● 3 Reference wells

Projection system: UTM 27N
Datum : NAD 27
Ellipsoid: Clarke 1866

Datum plane = Mean Sea Level
Contour interval: 500m

T50 (Base Ypresian Chalk) Depth Structural Map

Tectono-stratigraphical chart

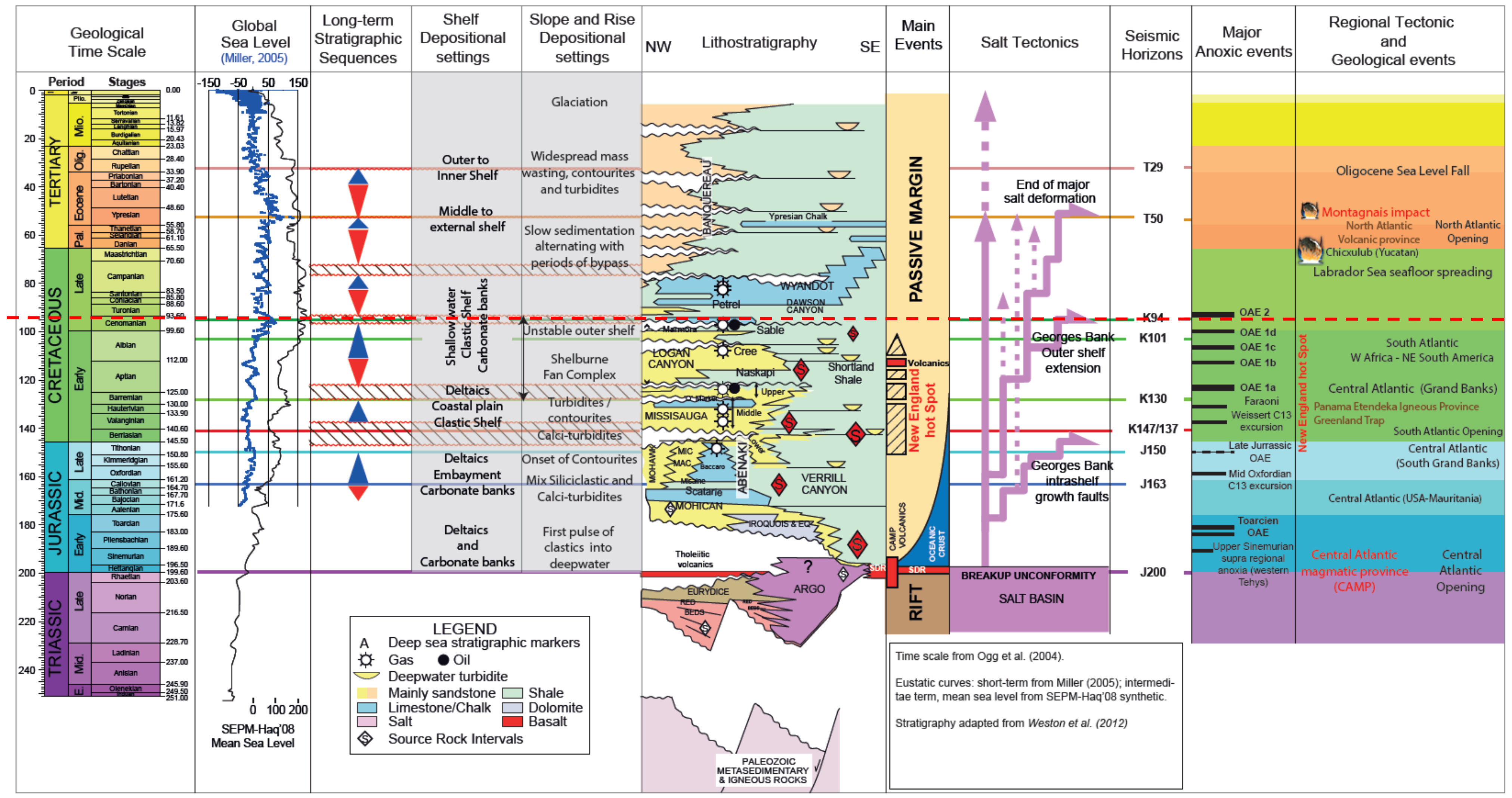


Figure 24 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

Horizon definition

The horizon named “Turonian Cenomanian unconformity” (or K94) mainly corresponds to an erosional surface equivalent to the base of the Petrel Member on the shelf. The Petrel Member is a regional seismic marker corresponding to a chalk unit deposited within the transgressive shale sequence of the Dawson Canyon Formation. It is the onset of the chalk production through the Late Cretaceous and is recognized over most of the Scotian Shelf. Basinwards, the Petrel Member thins and evolves into a more shaly facies (Figure 24).

Well-to-seismic tying

The well-to-seismic tying of the K94 horizon is done on Mohawk well. The signature of K94 is a sharp decrease of the sonic log and corresponds to a strong amplitude trough on the seismic. The result presents a good correlation.

Seismic picking and uncertainty

The K94 horizon corresponds to the base of the limestone Petrel Member, thickness of which is large on the shelf where it corresponds to a continuous reflector well-calibrated on the 2011 Nova Scotia Play Fairway Analysis wells. Basinwards, where the Petrel Member is thinning and starts to be more shaly or affected by salt tectonics or even eroded, the picking is more uncertain (Figure 25).

Structural description

In the shelf area, the Montagnais (Deptuck & Campbell, 2012) meteor impact lead to an erosional surface located at the west of the Mohawk well. On Georges Bank affected by growth faults with small throws that are hardly perceptible in the interpretation. Erosion exists also in the south-western corner, but the lack of lines and poor quality prevents knowing the exact layout (Figures 25 & 26).
On the shelf, K94 horizon is unaffected by salt tectonics. In the basin, numerous diapirs pierce K94. It is usually lying at the average depth of the allochthonous salt bodies in Shelburne Sub-Basin.

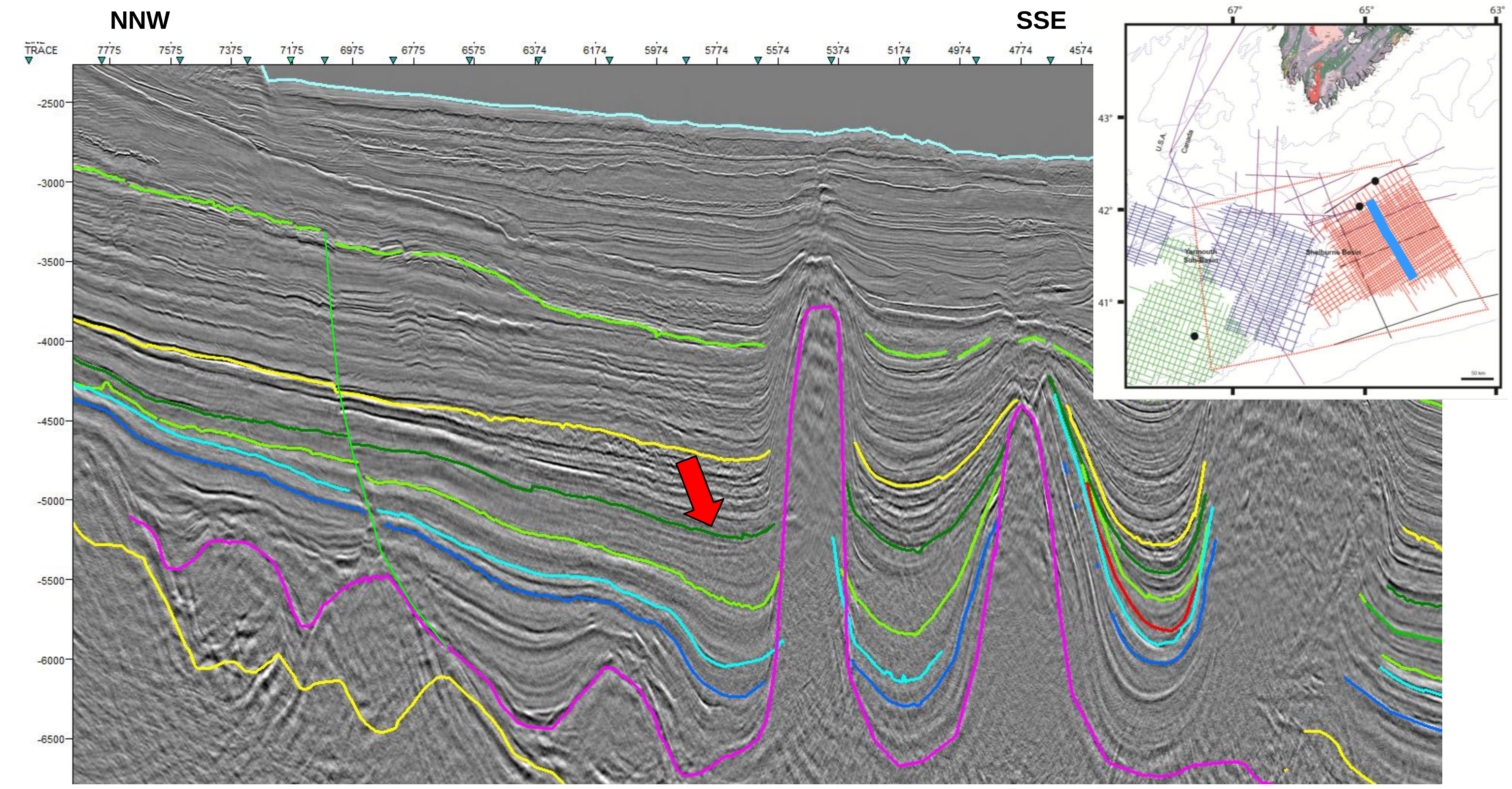


Figure 25 : Seismic line (TGS224-100) in the Shelburne sub-basin showing salt domes piercing K94

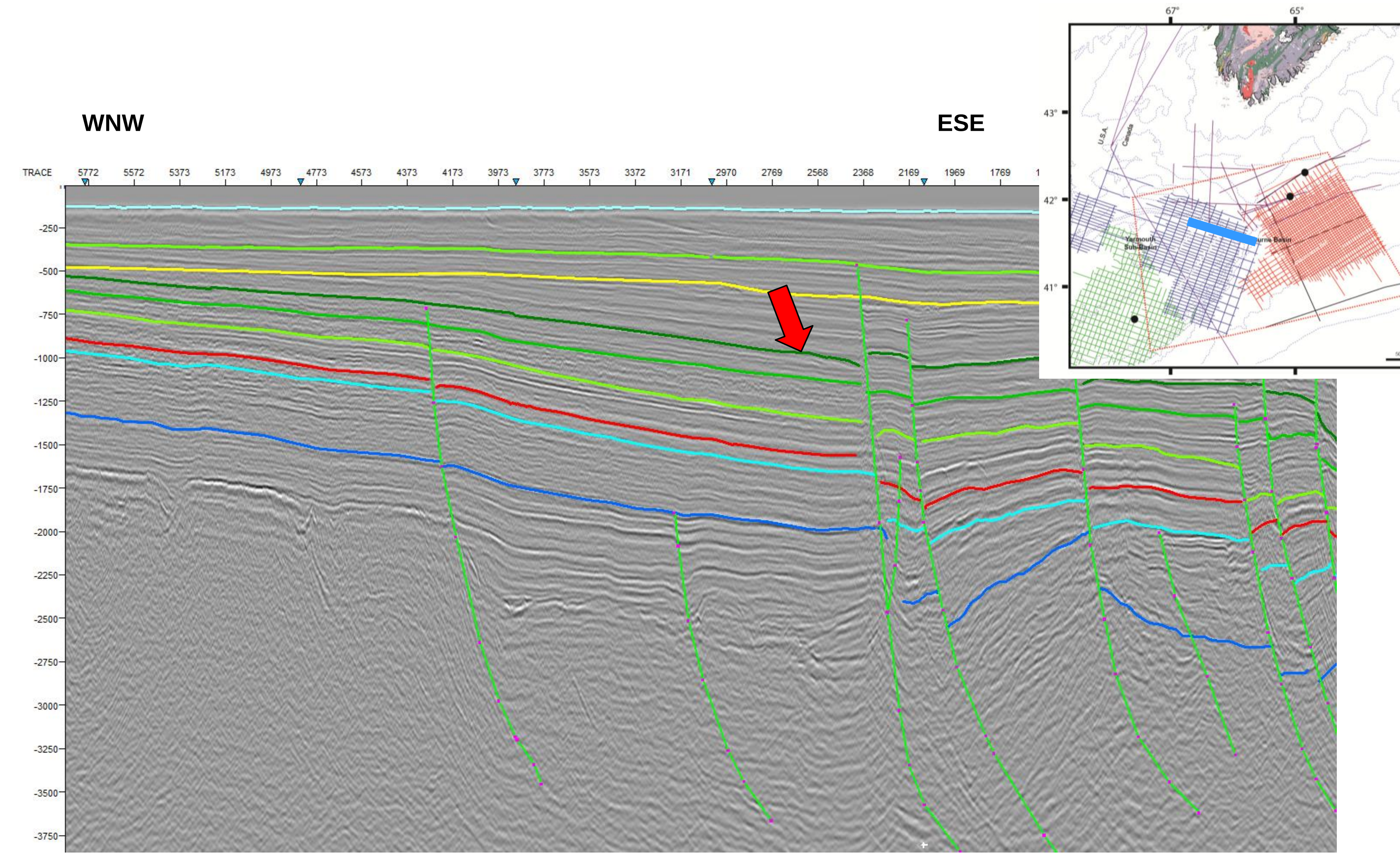
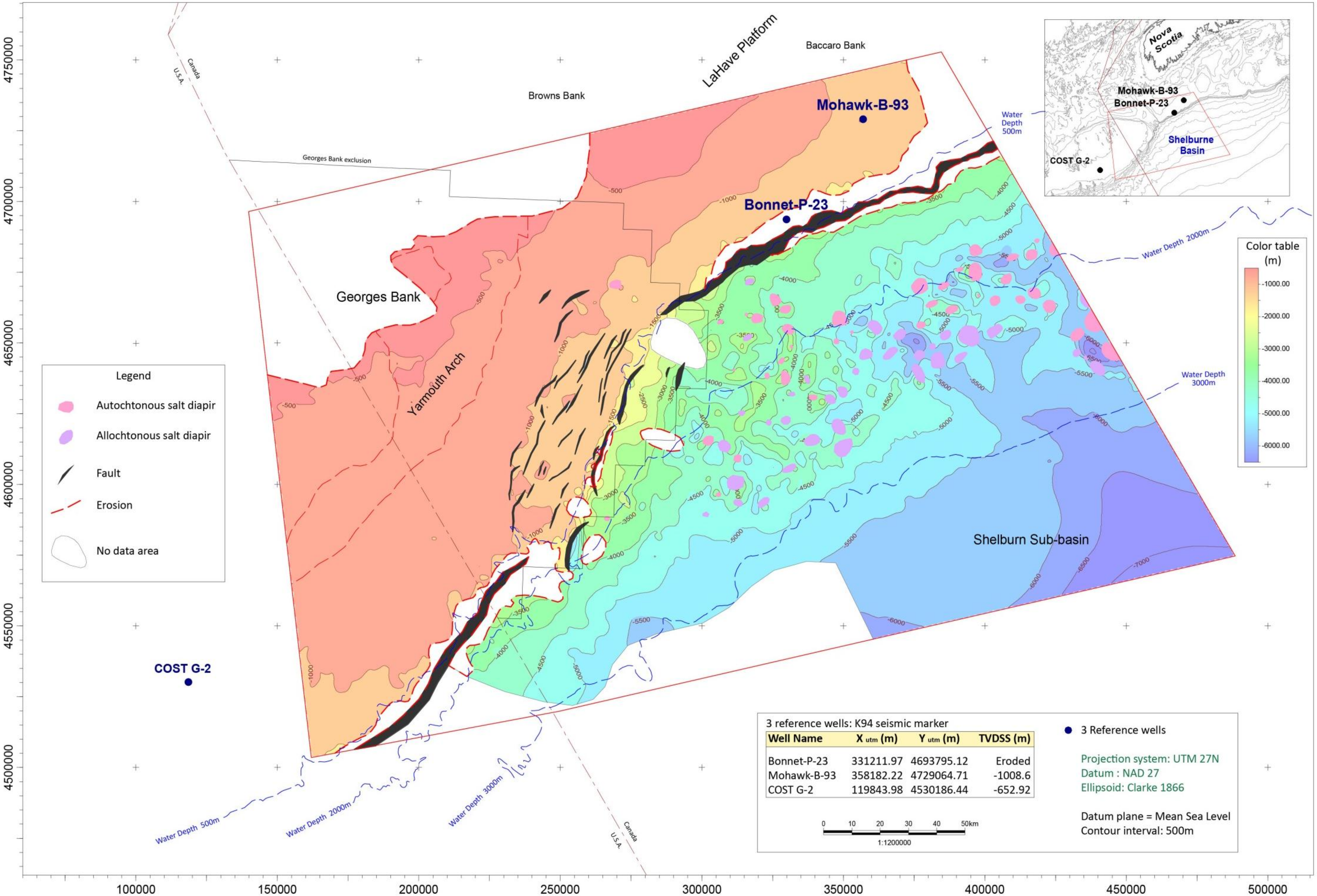


Figure 26 : Seismic line (JGM215) in the shelf of the Yarmouth sub-platform showing K94 affected by growth faulting

Deptuck, M.E. and Campbell, D.C. (2012) Widespread erosion and mass failure from the ~51 Ma Montagnais marine bolide impact off southwestern Nova Scotia, Canada, Canadian Journal of Earth Sciences, v. 49, p. 1567-1594

SEISMIC INTERPRETATION – STRUCTURAL MAPPING

SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015



3 reference wells: K94 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331211.97	4693795.12	Eroded
Mohawk-B-93	358182.22	4729064.71	-1008.6
COST G-2	119843.98	4530186.44	-652.92

K94 (Turonian Cenomanian Unconformity) Depth Structural Map

PL. 5.3.2.7

Tectono-stratigraphical chart

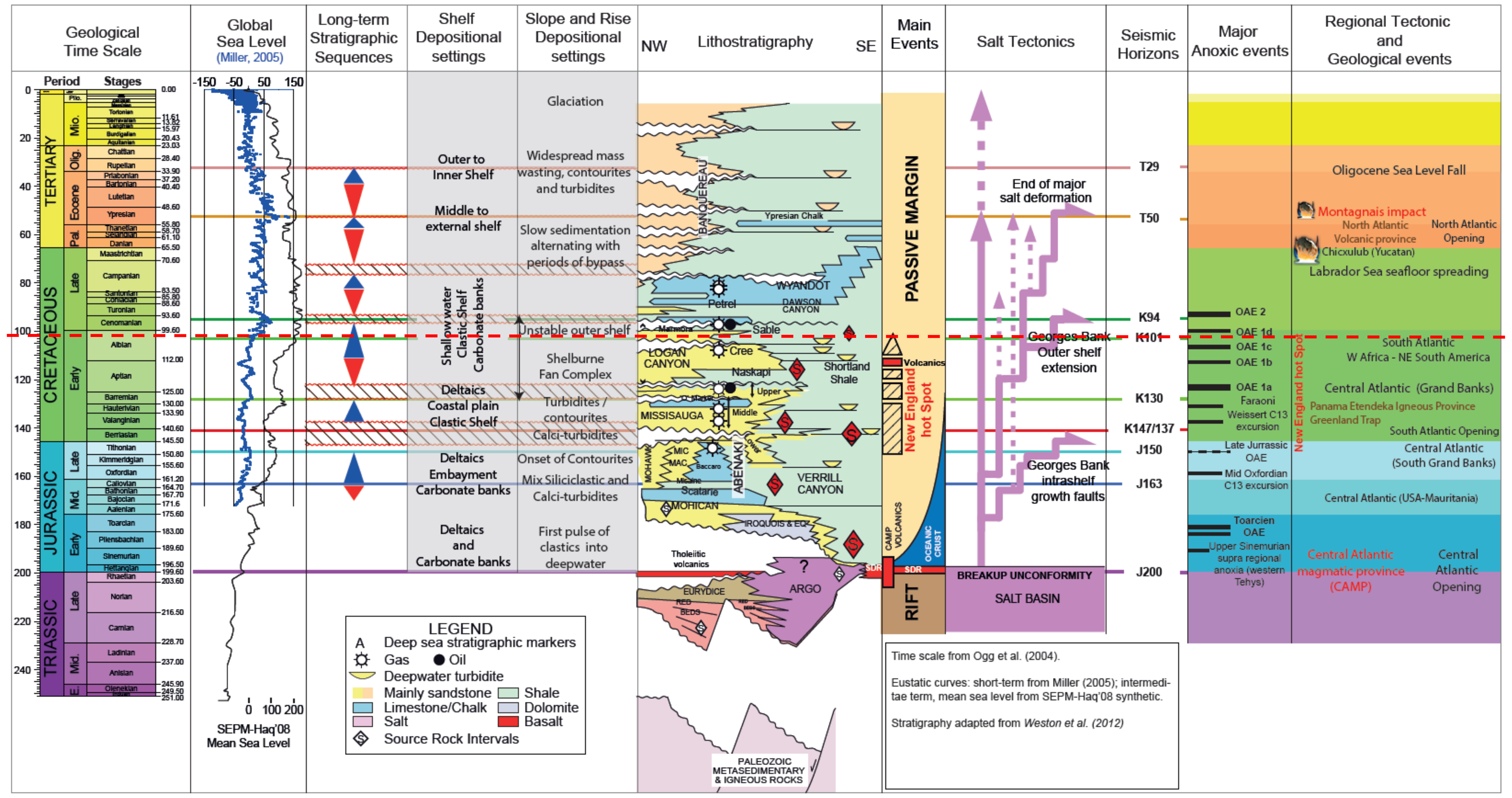


Figure 27 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

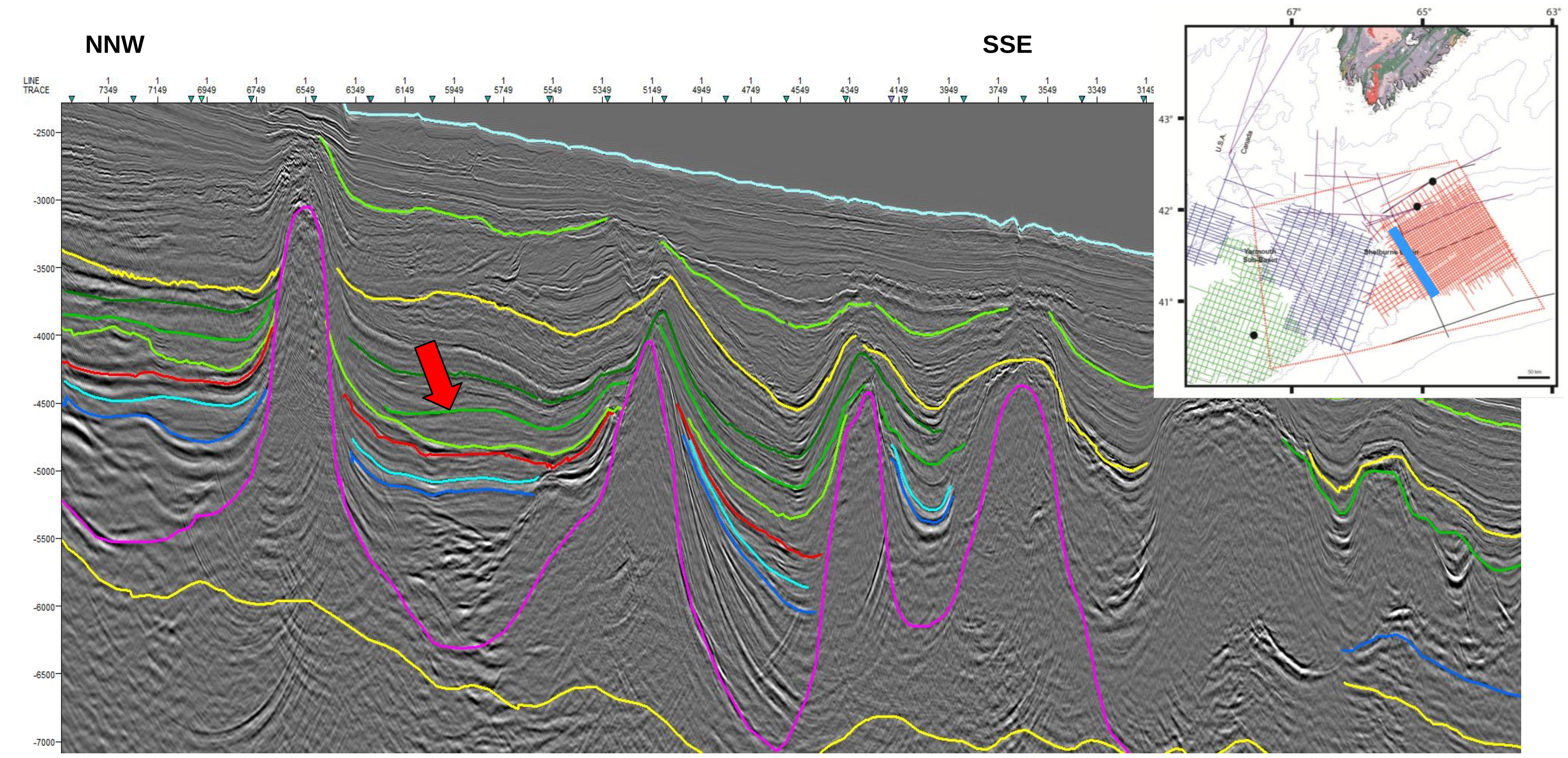


Figure 28 : Seismic line (TGS 152-100) in the Shelburne Sub-Basin showing salt domes piercing K101

Horizon definition

The horizon named "Late Albian unconformity" (or K101) is defined as a sequence boundary within the Logan Canyon Formation separating the Cree Member from the overlying Sable Member (Figure 27).

Well-to-seismic tying

The well-to-seismic tying of the K101 horizon is performed on Mohawk well. The well-to-seismic tie result presents a good correlation, improved by the integration of the Nova Scotia Play Fairway Analysis 2011 interpretation in the offshore part.

Seismic picking and uncertainty

On the shelf, the picking is based on the seismic facies and on the well-to-seismic calibration. Indeed, K101 corresponds to a strong energy package which is related to the transition between the shaly Sable Member and the fluvial sandstones of the Cree Member. On the slope, K101 can be eroded by K94, and an extended K94 canyon cuts the formation in the central part of the basin. There, the surface is difficult to pick (poor seismic character and salt dome occurrences), and the interpretation has been driven by the seismic recognition (Figure 28). Its picking is there more uncertain.

Structural description

The growth fault throws are still negligible in the Yarmouth sub-platform (Figure 29).
In the basin, numerous diapirs pierce it. K101 is deposited during the motion of the allochthonous salt, and is seated close to the salt diapirs.
All along the slope, K101 horizon has been removed by the regional gliding as a narrow strip *(Figure 3, Pl. 5.3.2.2)*, mainly due to K94 erosion, which also creates large canyons in the basin.

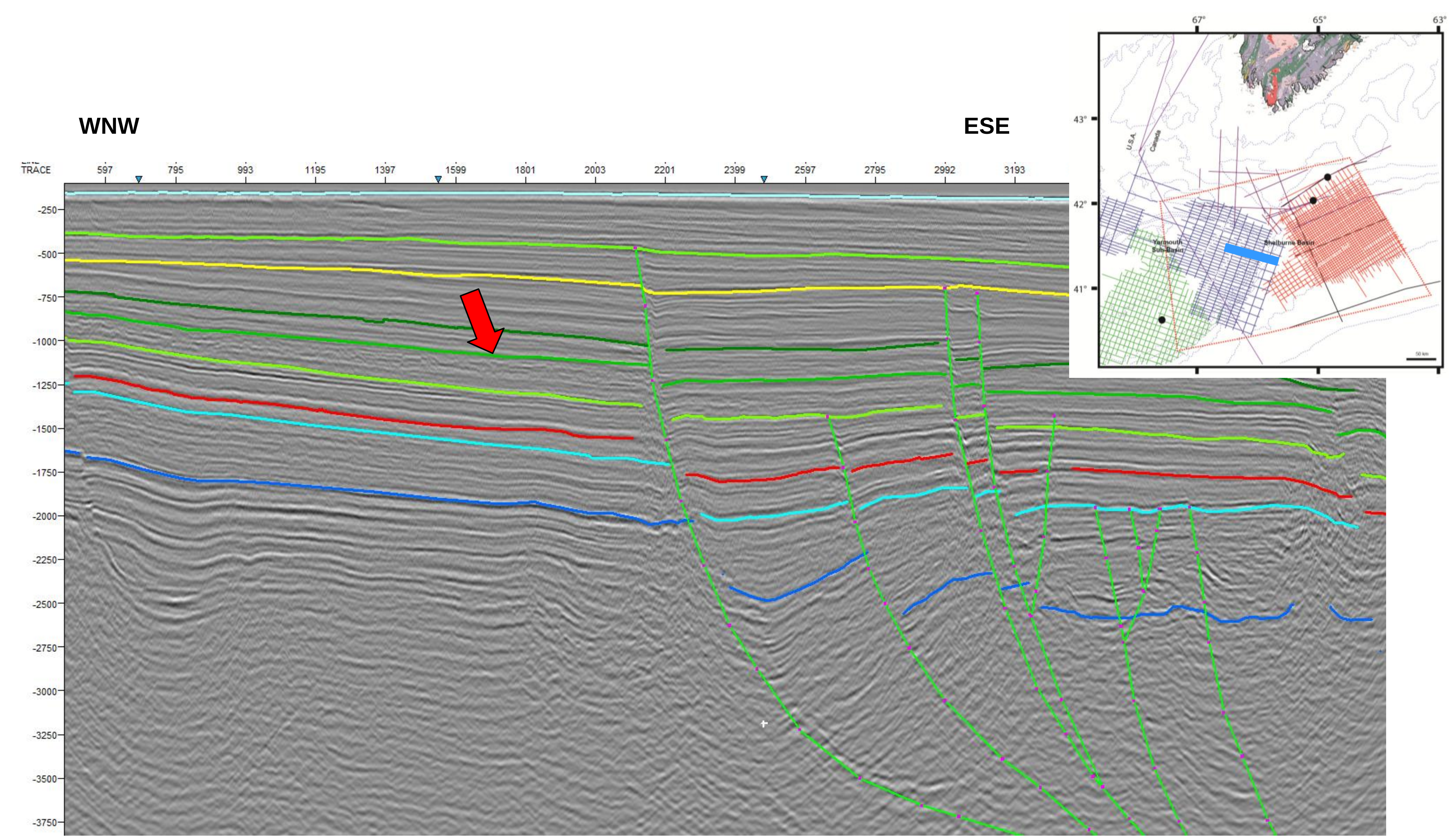
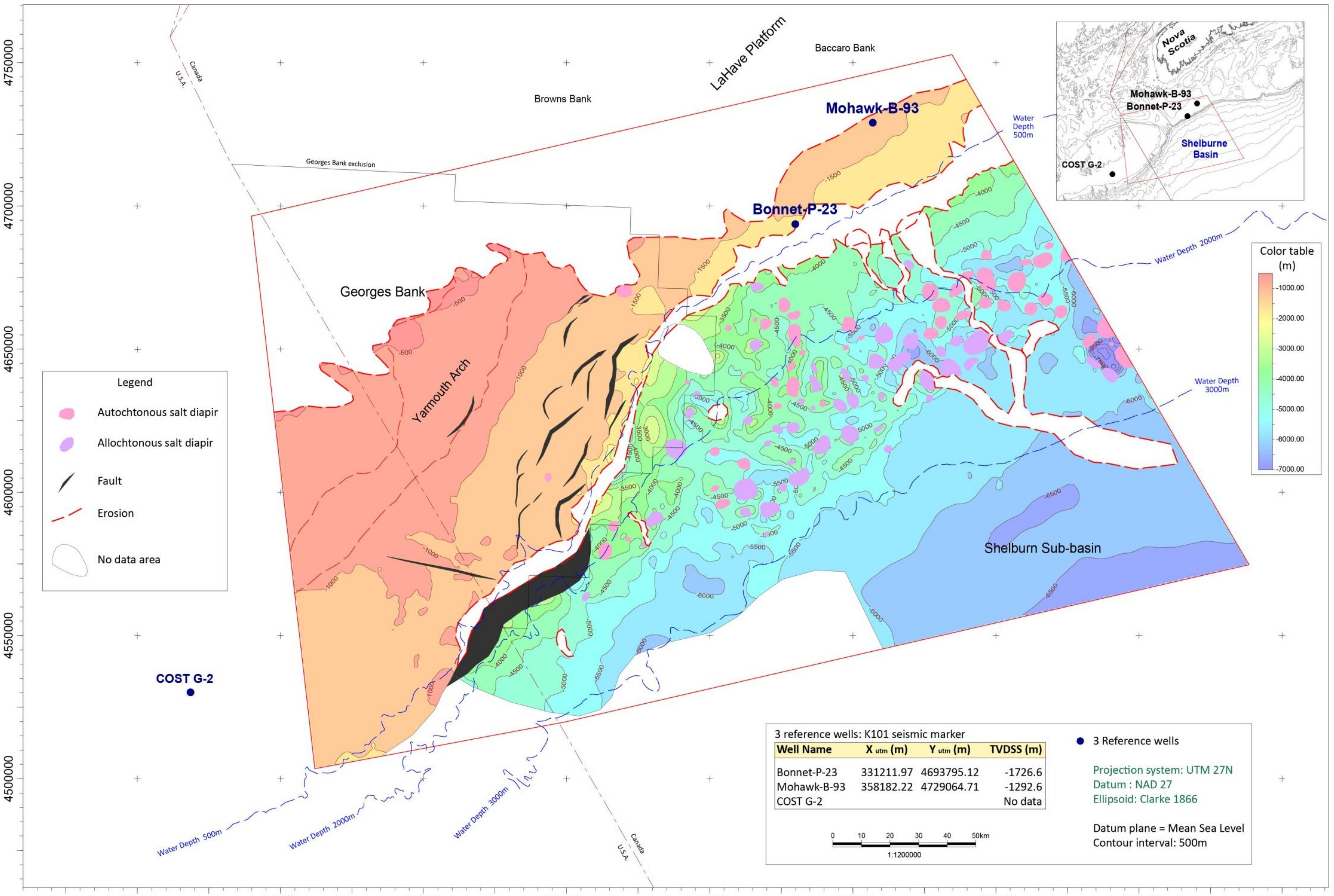


Figure 29 : Seismic line (JGM218) in the Yarmouth Subplatform showing K101 affected by growth faults

K101 (Late Albian Unconformity) Depth Structural Map



3 reference wells: K101 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331211.97	4693795.12	-1726.6
Mohawk-B-93	358182.22	4729064.71	-1292.6
COST G-2			No data

K101 (Late Albian Unconformity) Depth Structural Map

Tectono-stratigraphical chart

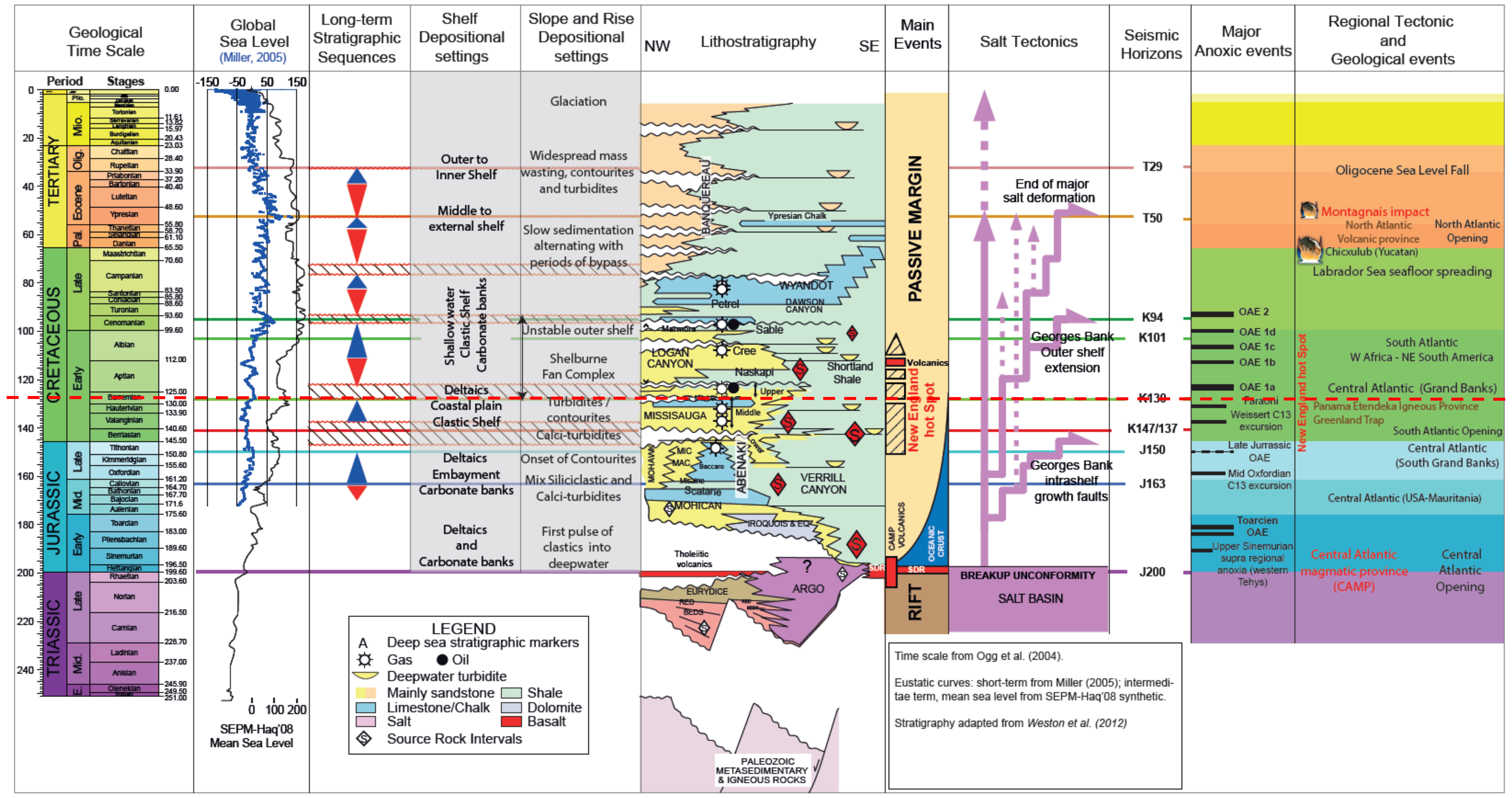


Figure 30 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

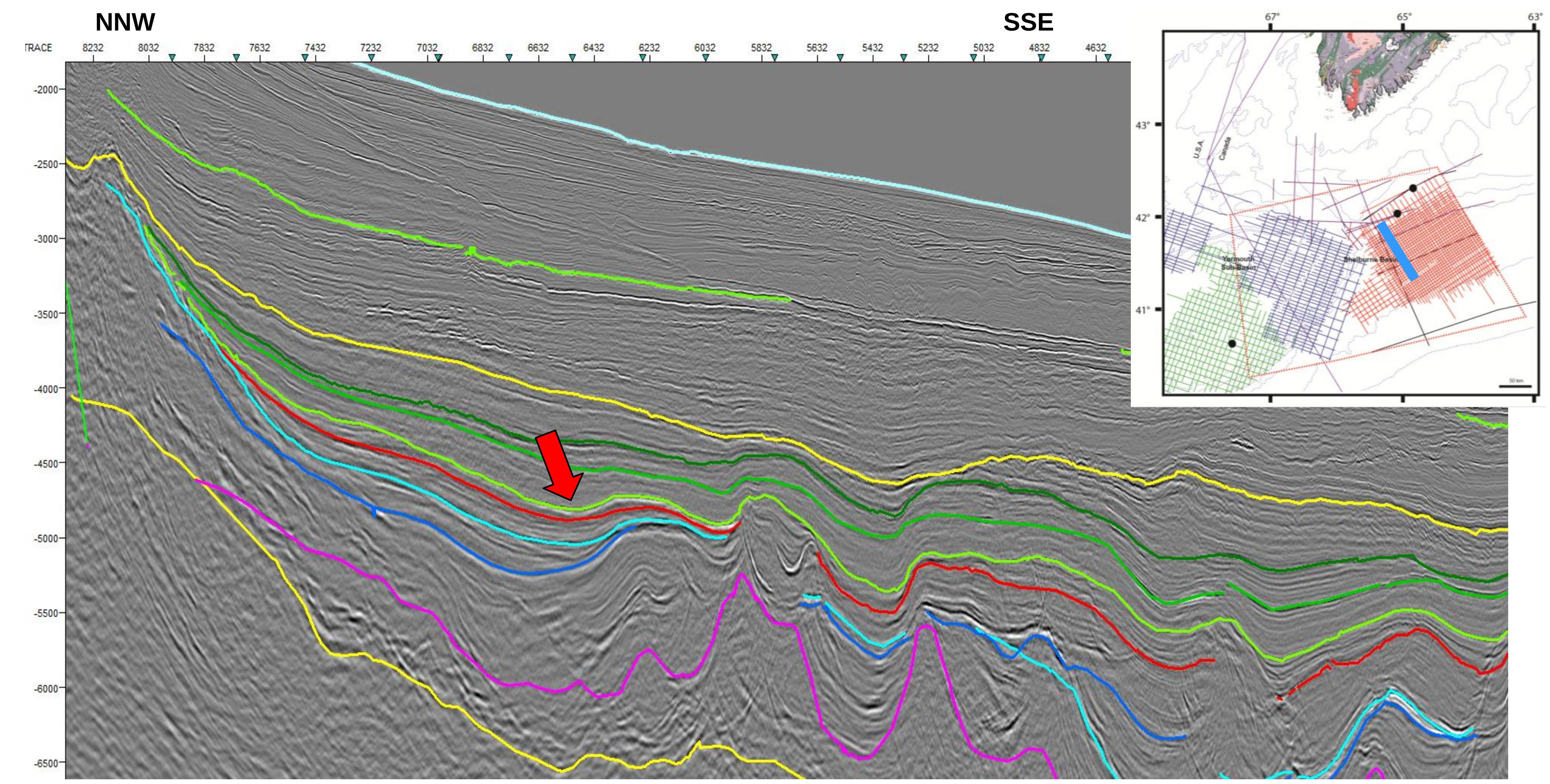


Figure 31 : Seismic line (TGS172-109) in the Shelburne sub-basin showing K130 eroded along the northern slope and affected by salt doming

Horizon definition

The horizon named "Hauterivian MFS" (or K130) corresponds to a regional maximum flooding surface (MFS) which occurred 130 Ma ago (Figure 30). It is approximately equivalent on the shelf to the so called "O" marker.

Well-to-seismic tying

The Hauterivian MFS was calibrated on the 3 wells. It is displayed as a fairly strong amplitude event at the onset of a mixed carbonate-terrigeneous platform in relation to a major drop in sediment supplies on the margin (Figure 31). More precisely, the seismic marker corresponds to the top of a relatively continuous carbonate layer with an increase of acoustic impedance due to high density and velocity carbonates. The well-to-seismic tie results present a good correlation only in Mohawk.

Seismic picking and uncertainty

K130 is picked confidently on the shelf of the Shelburne sub-basin, and was propagated to Georges Bank with confidence (Figures 31 & 32).

On the northern slope, K130 is locally eroded; otherwise the picking there is uncertain due to normal faulting. Within the basin, the picking is partly constrained by the more obvious and deeper position of the K137 unconformity where sub-salt imaging difficulties make the picking of the Hauterivian MFS more uncertain away from the far well ties done in 2011 Nova Scotia Play Fairway Analysis; both horizons are in this case often difficult to differentiate from each other.

Structural description

Erosion affects the horizon along the northern slope, and in the south-western corner.

Due to salt creeping we can observe a strong shelf edge fault activities along the western slope, whereas on the north-eastern corner we have a decrease of activity.

Basinwards, K130 is pierced by still numerous salt domes. It is the last horizon that is not affected by overlying salt detached sheets.

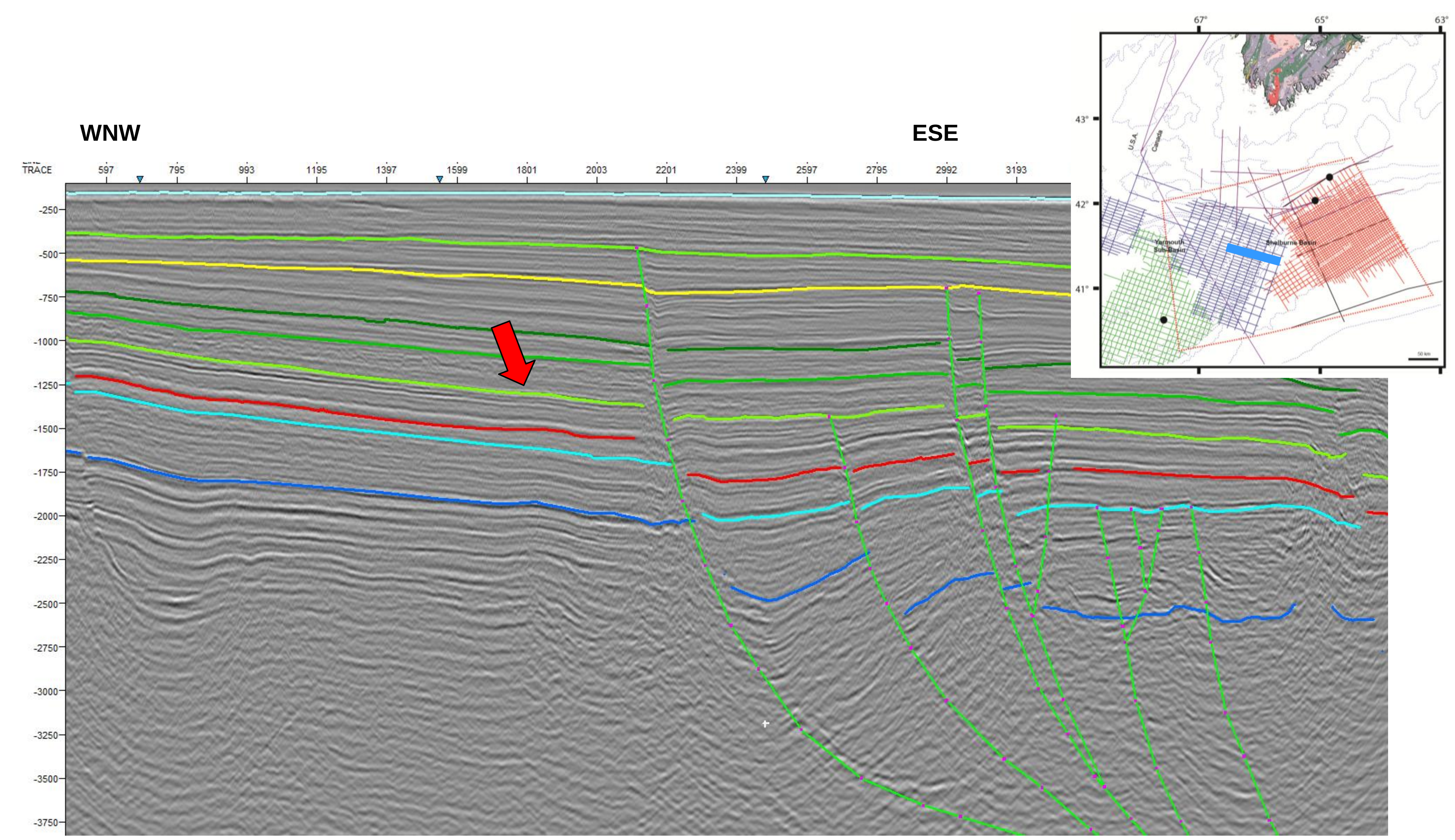
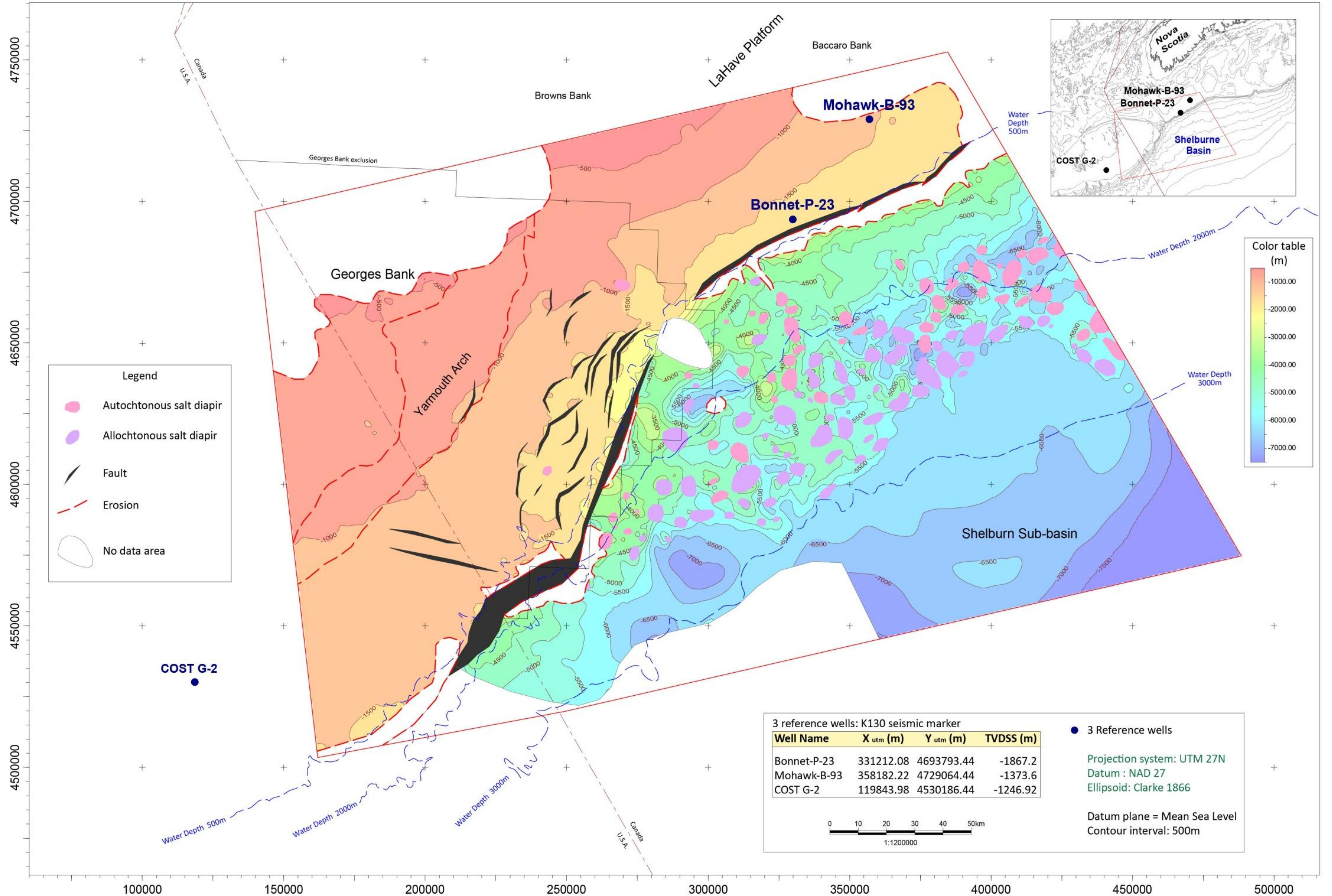


Figure 32: Seismic line (JGM220) in Yarmouth sub-platform showing K130 affected by growth faults



3 reference wells: K130 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331212.08	4693793.44	-1867.2
Mohawk-B-93	358182.22	4729064.44	-1373.6
COST G-2	119843.98	4530186.44	-1246.92

● 3 Reference wells

Projection system: UTM 27N
Datum : NAD 27
Ellipsoid: Clarke 1866

Datum plane = Mean Sea Level
Contour interval: 500m

1:1200000

K130 (Hauterivian MFS) Depth Structural Map

Tectono-stratigraphical chart

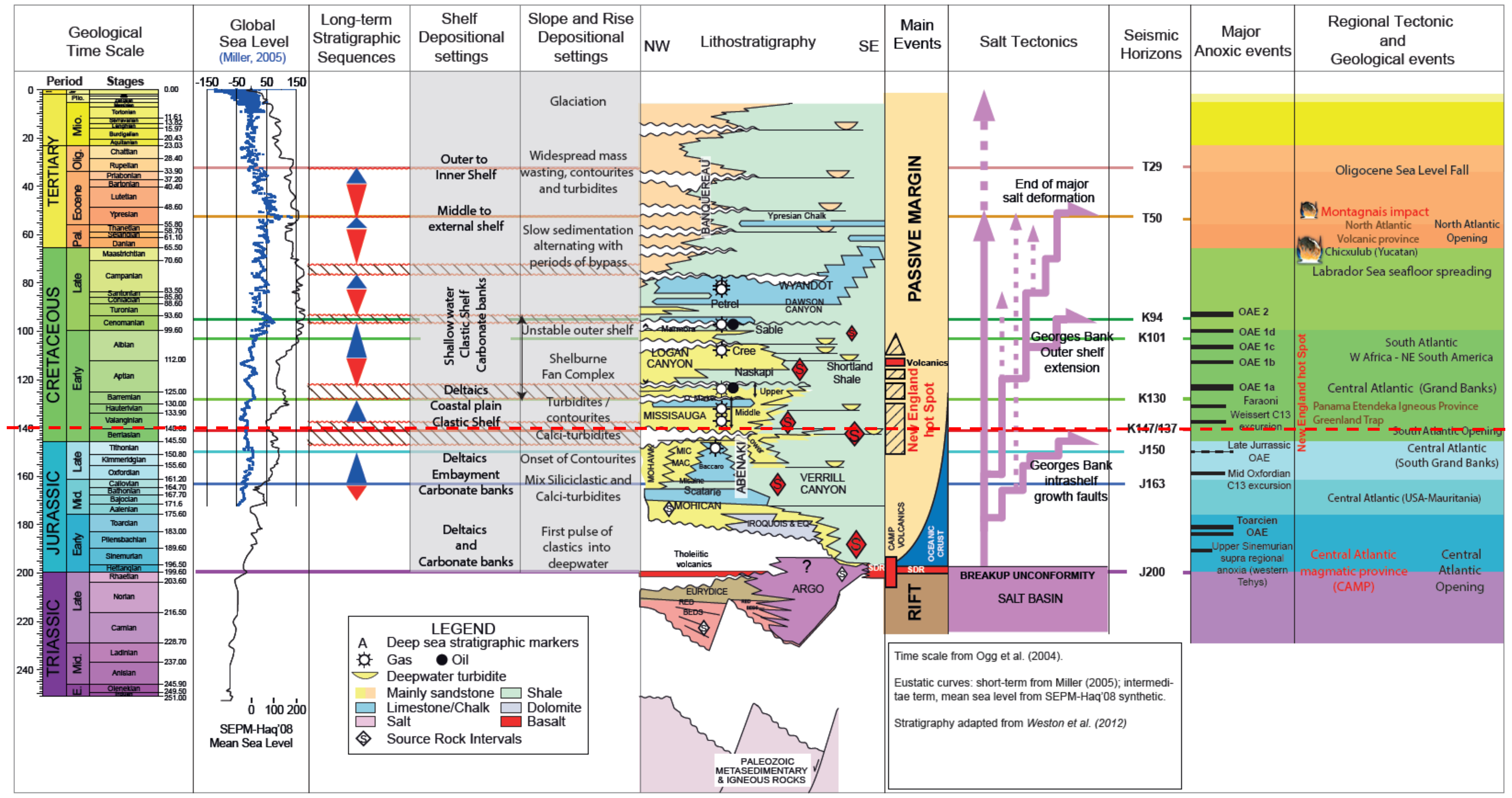


Figure 33 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

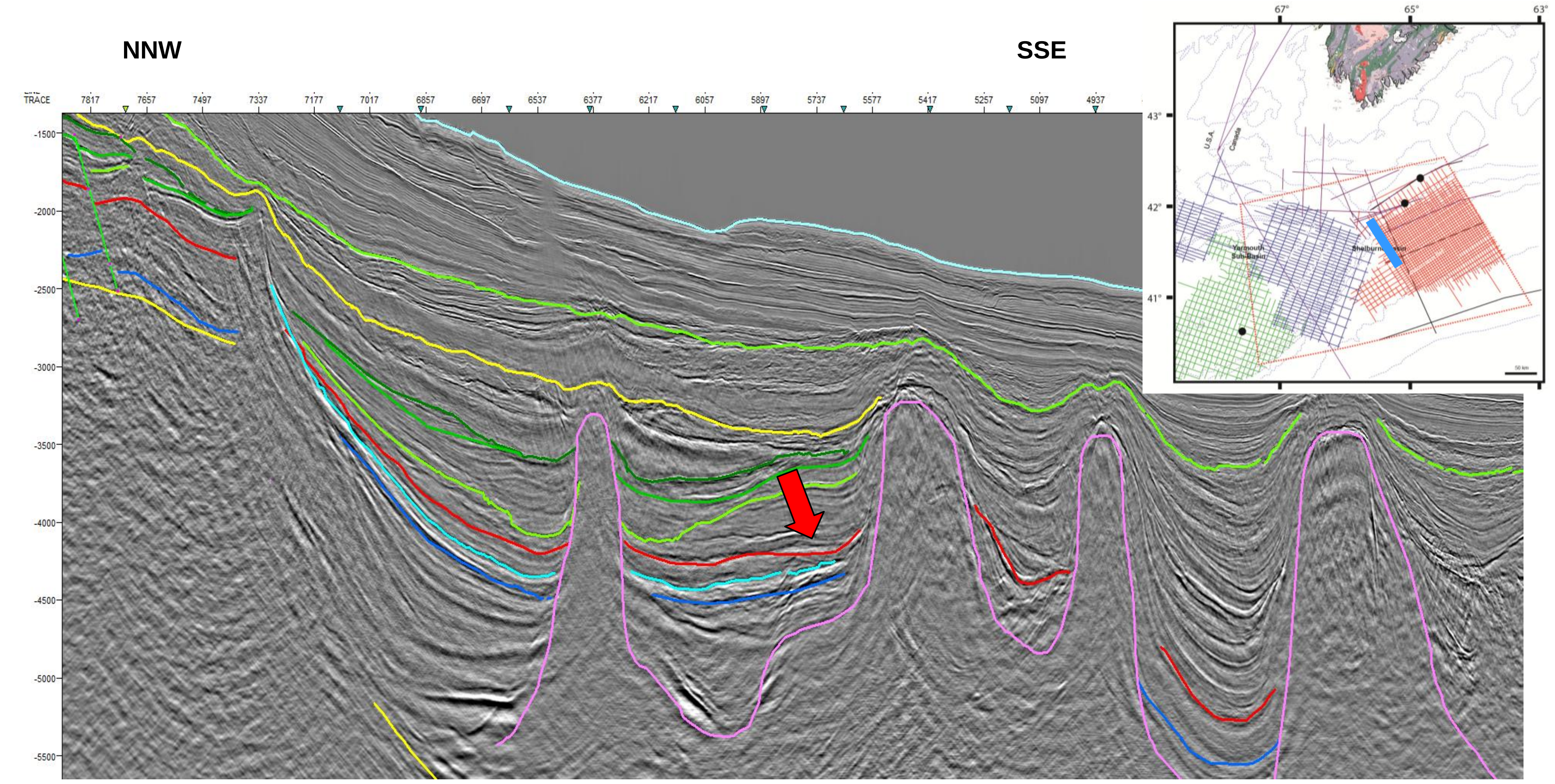


Figure 34: Seismic line (JGM148-109) in the Shelburne sub-basin showing salt piercing K137 and eroded along the northern shelf

Horizon definition

The seismic horizon named "Berriasian / Valanginian Unconformity" (or K137) corresponds to a regional unconformity which ranges from 147 Ma to 137 Ma in relation to a regional uplift coincident to the Avalon Uplift and Monteregian hotspot. On the shelf, it is interpreted as a sub-aerial unconformity (Figure 33).

Well-to-seismic tying

The well-to-seismic tie of the horizon K137 is possible in both the main shelf wells. It corresponds to the Berriasian / Valanginian unconformity. The well-to-seismic tie results present a very good correlation in Mohawk, poor in the Cost-G2.

Seismic picking and uncertainty

On the shelf, the picking of the Berriasian / Valanginian unconformity is relatively confident.
On the slope, the normal fault system and the average quality of the seismic make the picking uncertain (Figure 34). In the deep offshore area, the Berriasian / Valanginian unconformity is mainly based on the 2011' interpretation results, and extended to the base of the slope.

Structural description

The Berriasian / Valanginian unconformity is an erosional surface which is relatively conformable in the deep basin (correlative conformity).
Some erosion affects K137 on the slope in the northern area and a more limited extent in the south-western corner. The growth fault system is shifted from the inner shelf (Yarmouth sub-platform) to the outer shelf (Shelburne sub-basin). The shelf edge faults are more active with the erosional area (Figure 35).
Although K137 horizon is located frequently above the allochthonous salt sheets, salt welds, salt feeder (regional and counter-regional fault) and salt pillows affect this horizon in the basin.

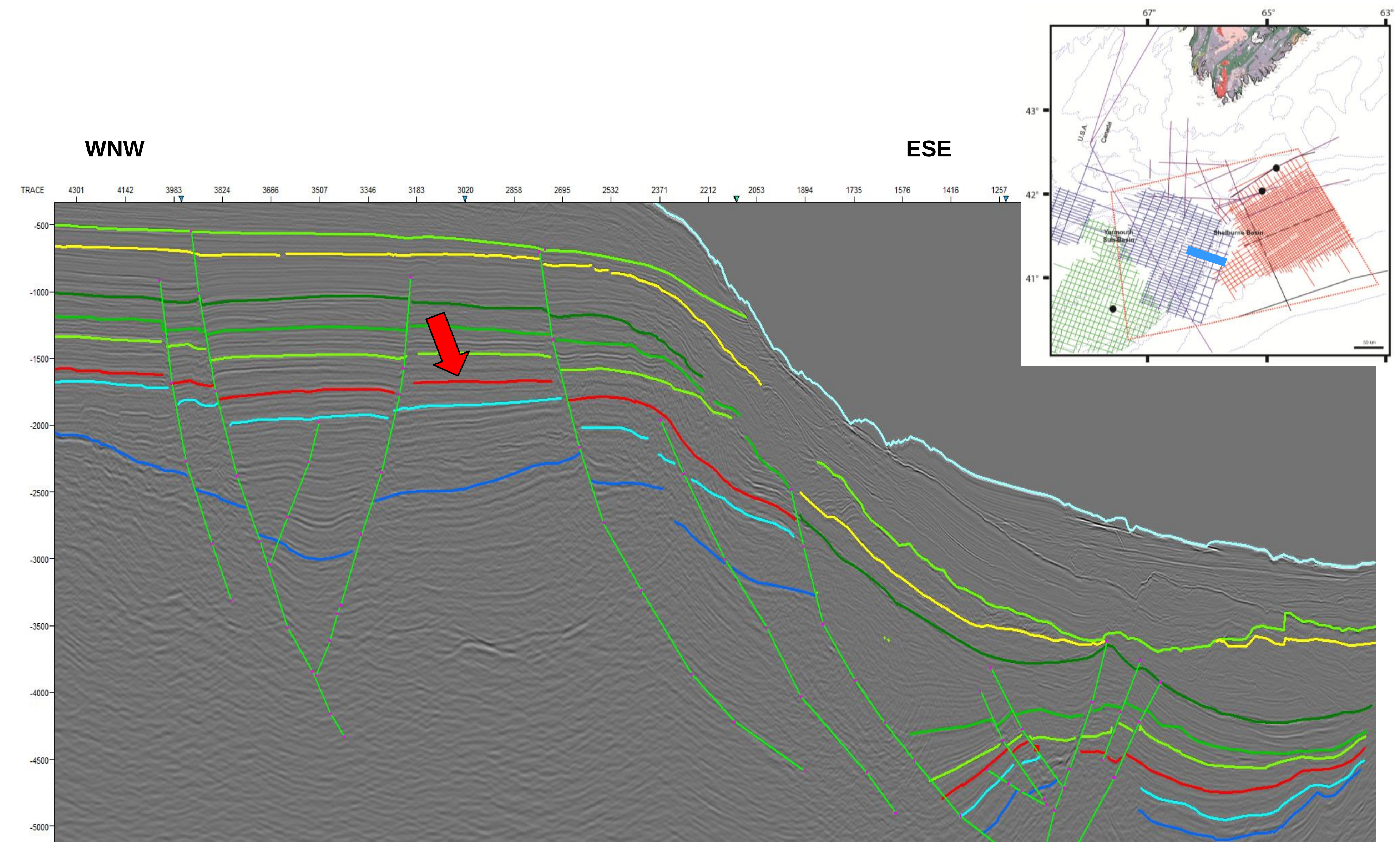
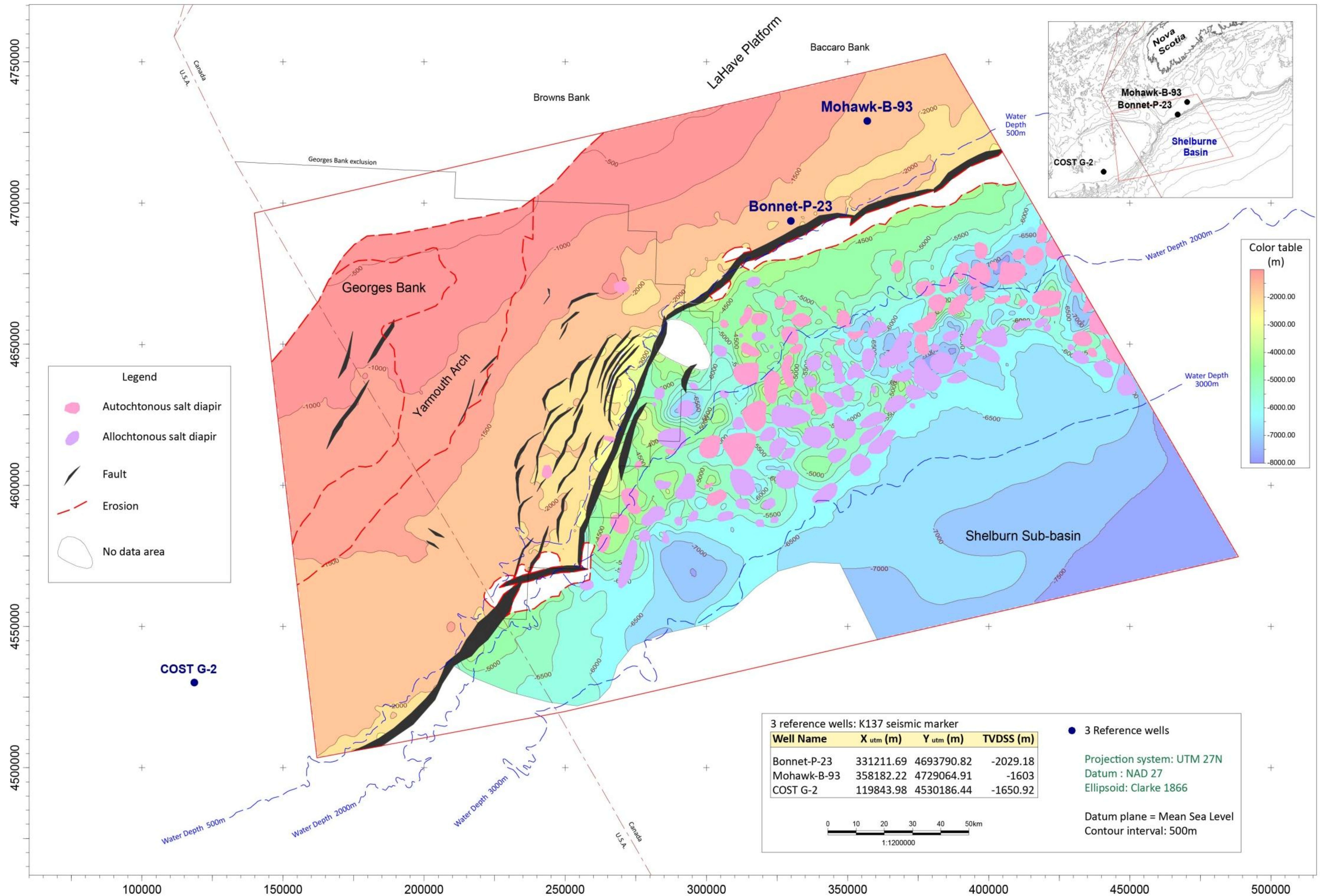


Figure 35: Seismic line (JGM 224) in the slope of the Yarmouth sub-platform showing the shift of the growth faults from inner to outer shelf at the K137.



3 reference wells: K137 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331211.69	4693790.82	-2029.18
Mohawk-B-93	358182.22	4729064.91	-1603
COST G-2	119843.98	4530186.44	-1650.92

● 3 Reference wells

Projection system: UTM 27N
Datum : NAD 27
Ellipsoid: Clarke 1866

Datum plane = Mean Sea Level
Contour interval: 500m

K137 (Berriasian / Valanginian Unconformity) Depth Structural Map PL. 5.3.2.13

Tectono-stratigraphical chart

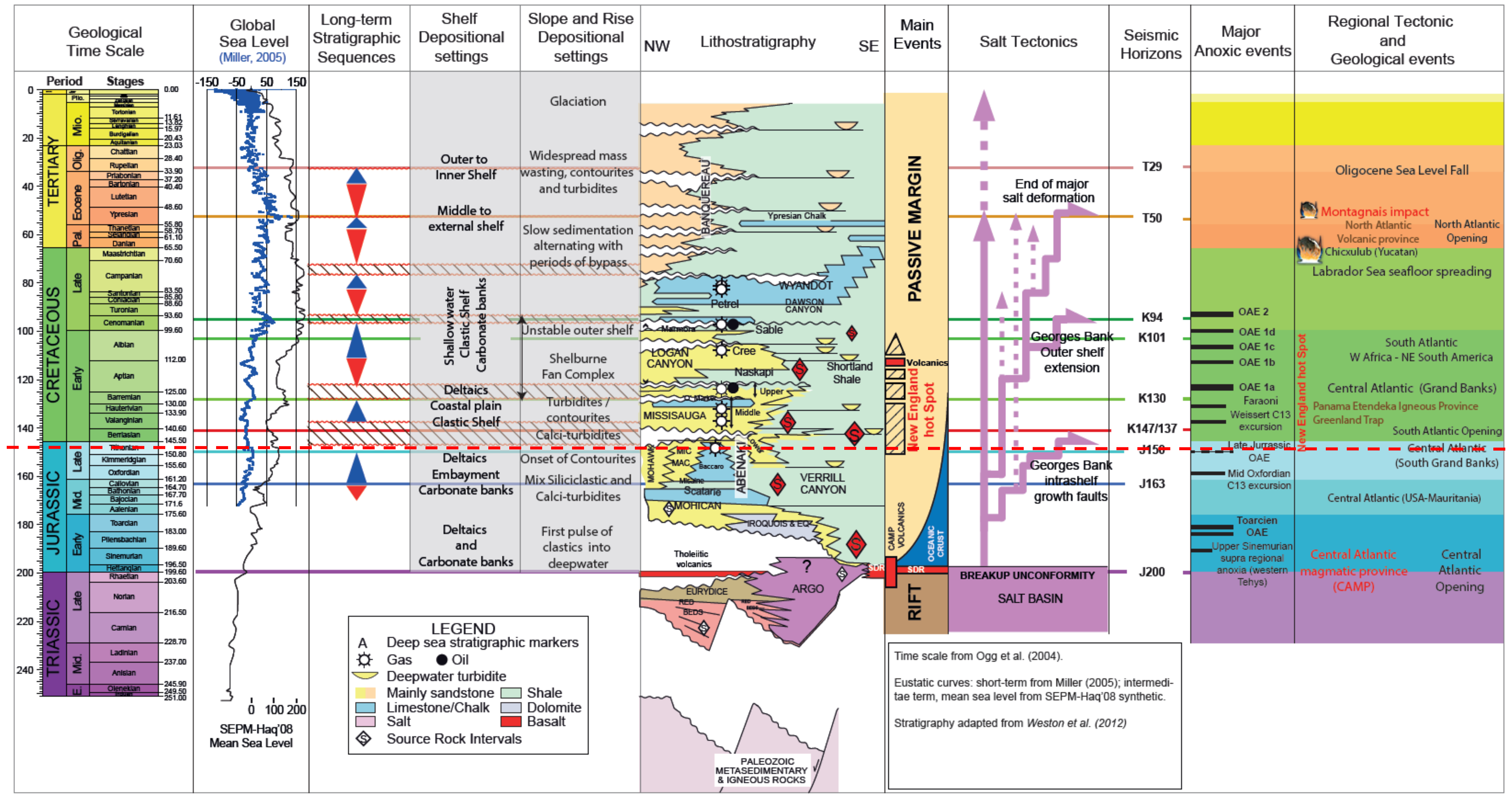


Figure 36 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

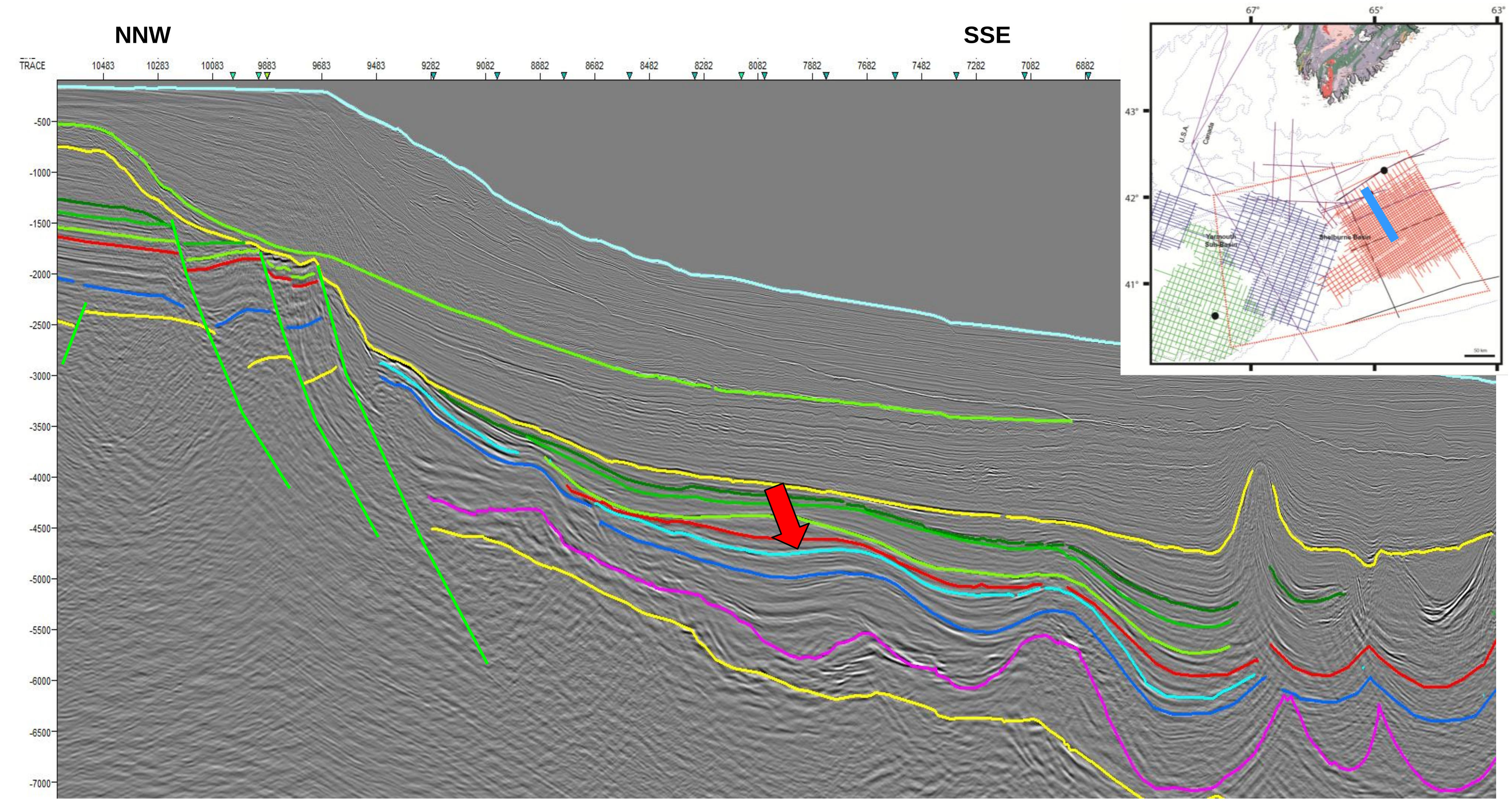


Figure 37: Seismic line (TGS 200-100) in the Shelburne Sub-Basin showing K150 eroded on the North shelf and deformed by the salt doming

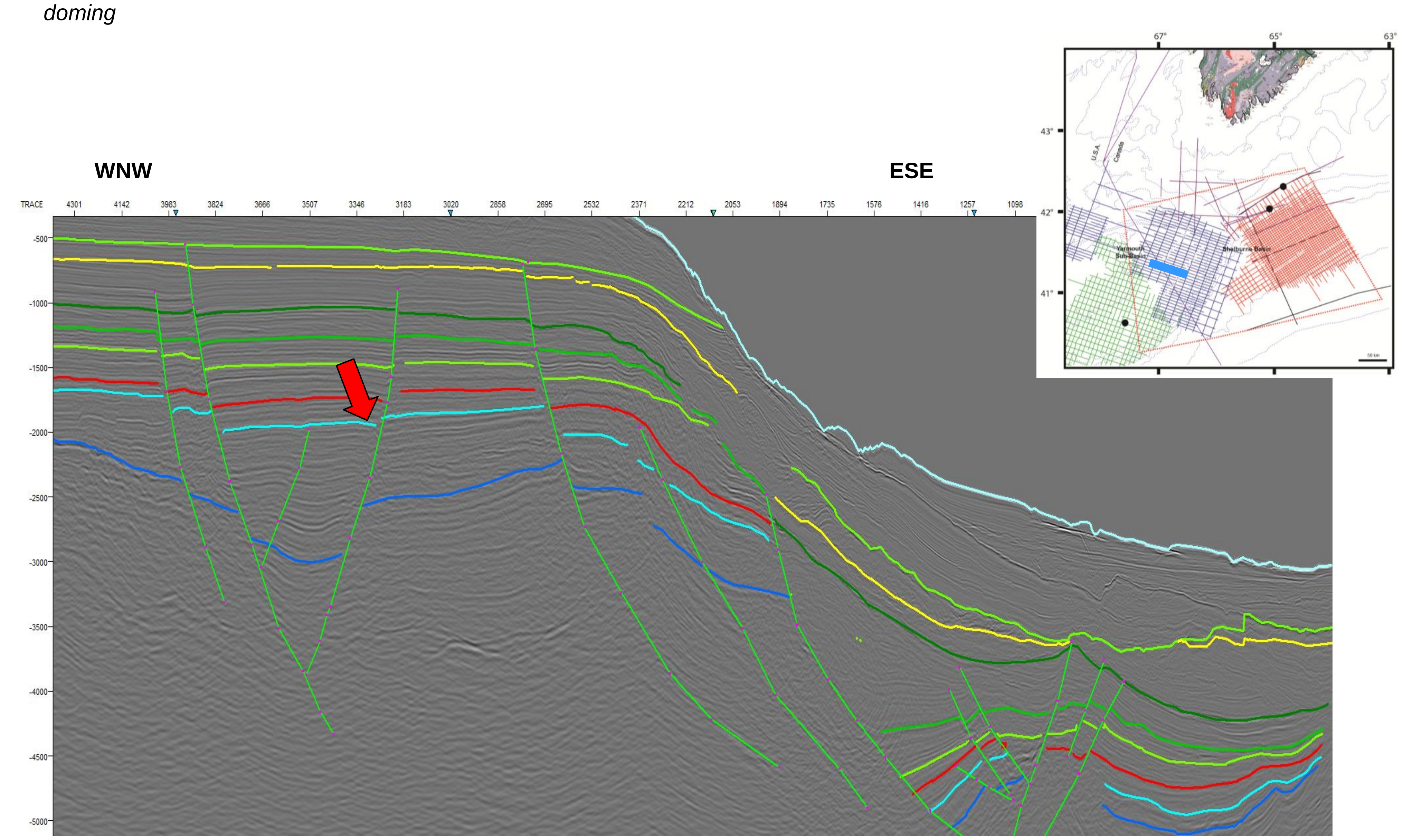


Figure 38: Seismic line (JGM228) in the Yarmouth SubPlatform showing the main activity of growth faults in the inner shelf at the J150.

Horizon definition

The J150 horizon corresponds to the Tithonian MFS defined by the biostratigraphic study. It corresponds to the Top Baccaro Member of the Abenaki Formation which ends the shallow marine carbonate platform in the western Nova Scotia Margin. To the eastern Laurentian Sub Basin and the South Whale Basin, where the carbonate system evolves into a deltaic system, the J150 horizon corresponds to the Top of the deltaic sandstones of the Mic-Mac formation. (Figure 36)

Well-to-seismic tying

The well-to-seismic tie of the horizon J150 is not possible on the reference wells except on Cost-G2 well, due to the impact of K137 erosion. Its assignment was done through a visual identification: strong MFS marker at the top of the Jurassic deltaic features as seen on JGM224 line. On the Northern side of the study area (LaHave platform) the J150 has been eroded by the K137 and is absent on the northern passage between the Shelburne sub-basin and the Georges Bank area whereas it is well observed more **to** the south-west (Georges Bank area).

In the offshore basin, it was extended and edited after 2011' interpretation.

Seismic picking and uncertainty

The poor seismic picking confidence is largely *to* the absence of the J150 marker in 2 reference wells. Nevertheless, its assignation in the Yarmouth sub-platform is in coherency with J163 and its proximity with K137, which erodes it towards the LaHave platform.

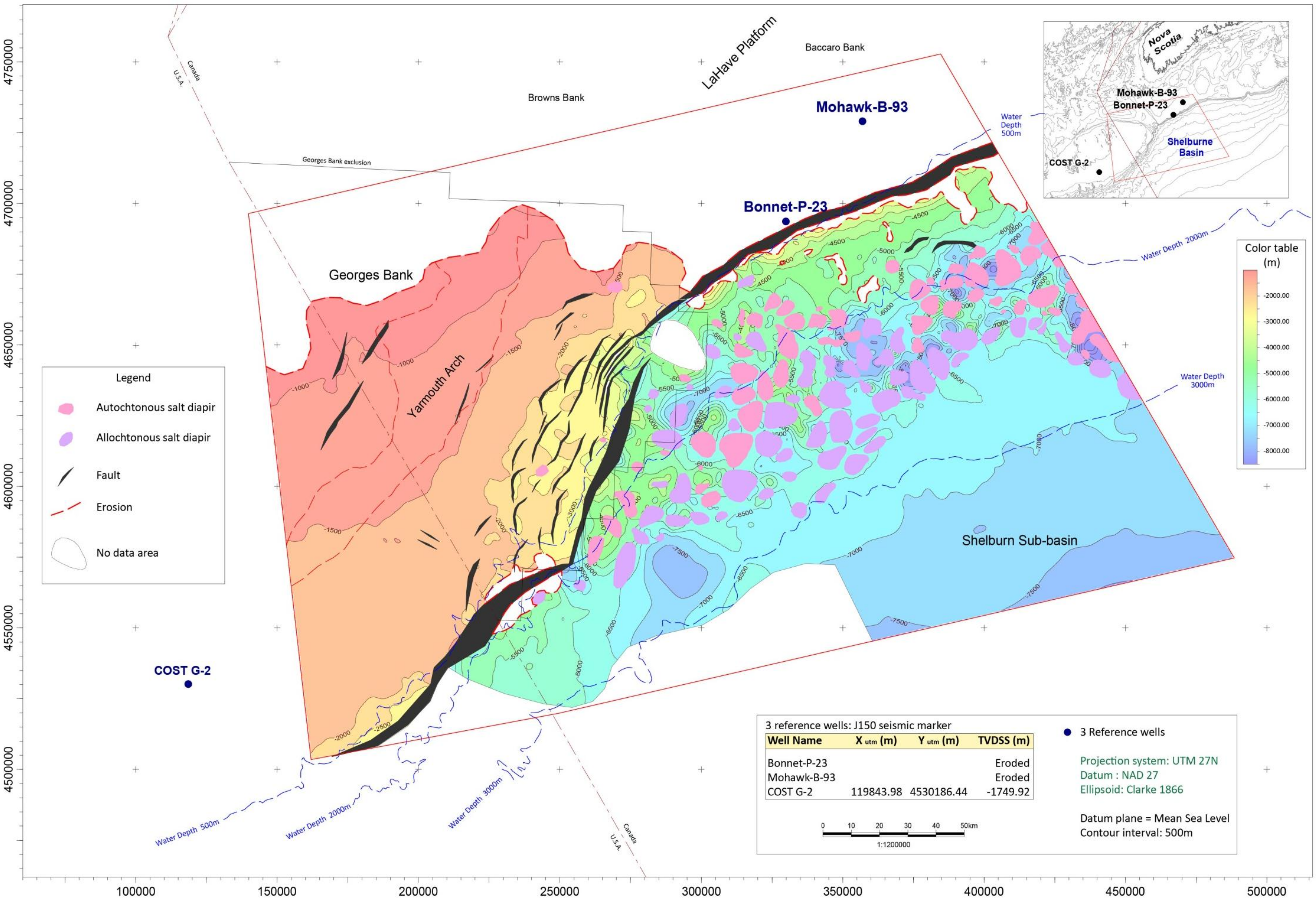
In the basin, the picking remains uncertain close to the salt bodies especially in the allochthonous salt province where highly complex structures are added to the subsalt image. In the deep offshore area in which salt is absent, the seismic quality is better and the interpretation becomes more confident despite the lack of well-to-seismic tie (Figures 37 & 38).

Structural description

From this horizon and afterwards, the growth faulting near the western slope are very active (inner shelf of Yarmouth sub-platform; Figure 38).

Along the northern slope, a shorter erosional strip is present, as well as in the south-western corner. To the North, there is no J150 due to K137.

In the basin, J150 horizon may be located below allochthonous salt sheets. The salt diapirs now fill more surface, making small sub-basins that should be connected by very narrow sediment "valleys" surrounded by high salt bodies.



3 reference wells: J150 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23			Eroded
Mohawk-B-93			Eroded
COST G-2	119843.98	4530186.44	-1749.92

J150 (Tithonian MFS) Depth Structural Map

PL. 5.3.2.15

Tectono-stratigraphical chart

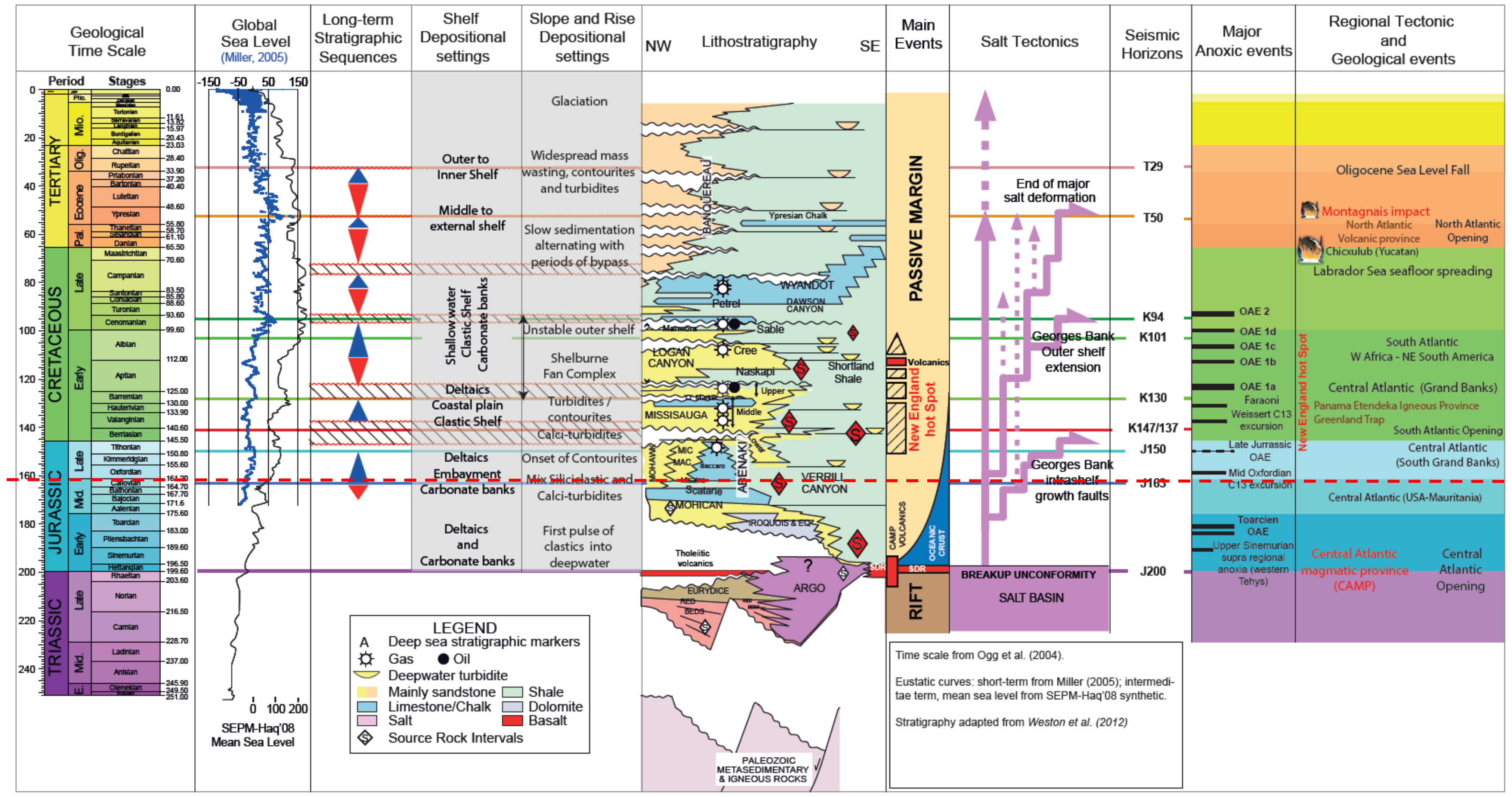


Figure 39 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

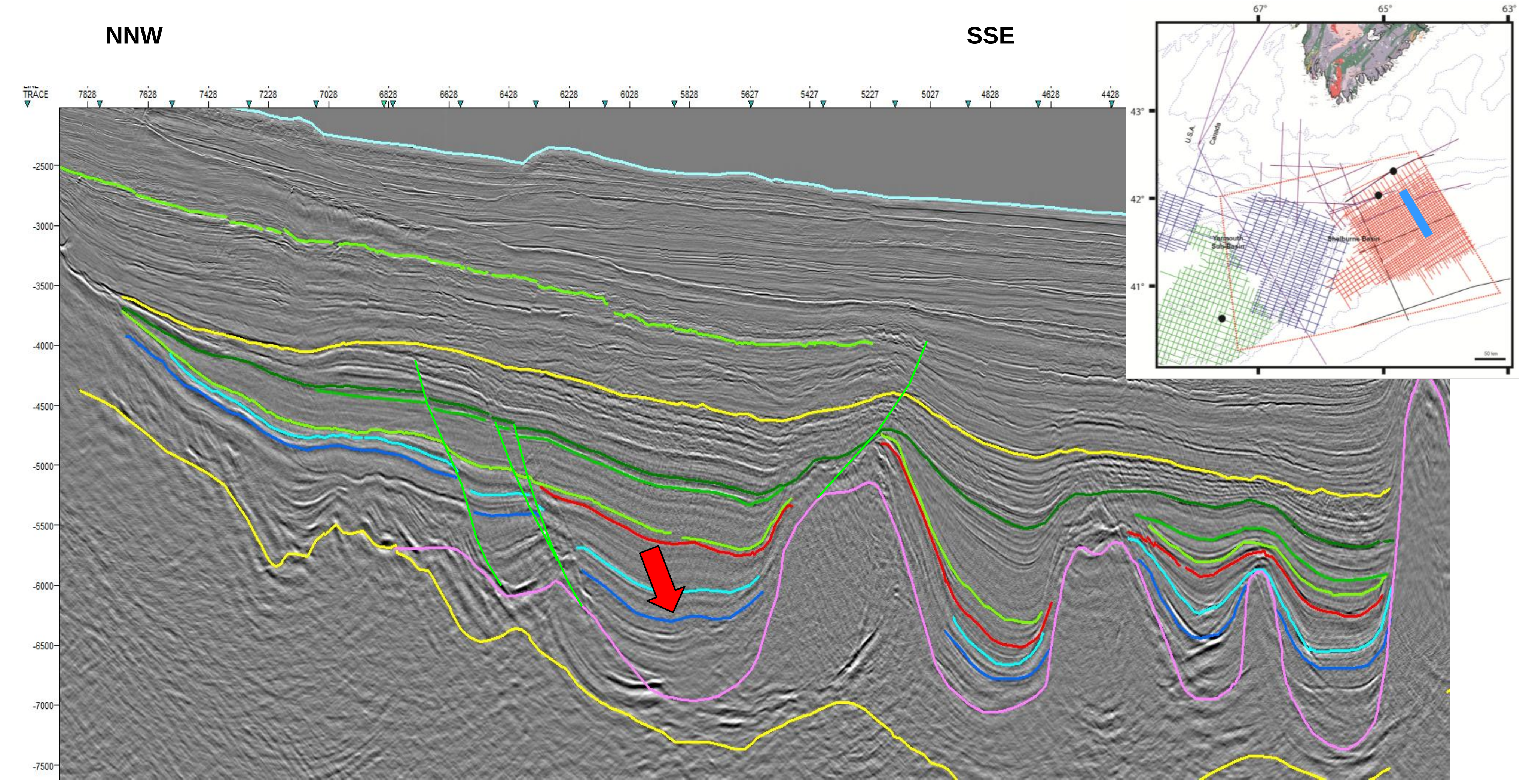


Figure 40: Seismic line (JGM 244-109) in the Shelburne sub-basin showing J163 geometry above the autochthonous salt (purple).

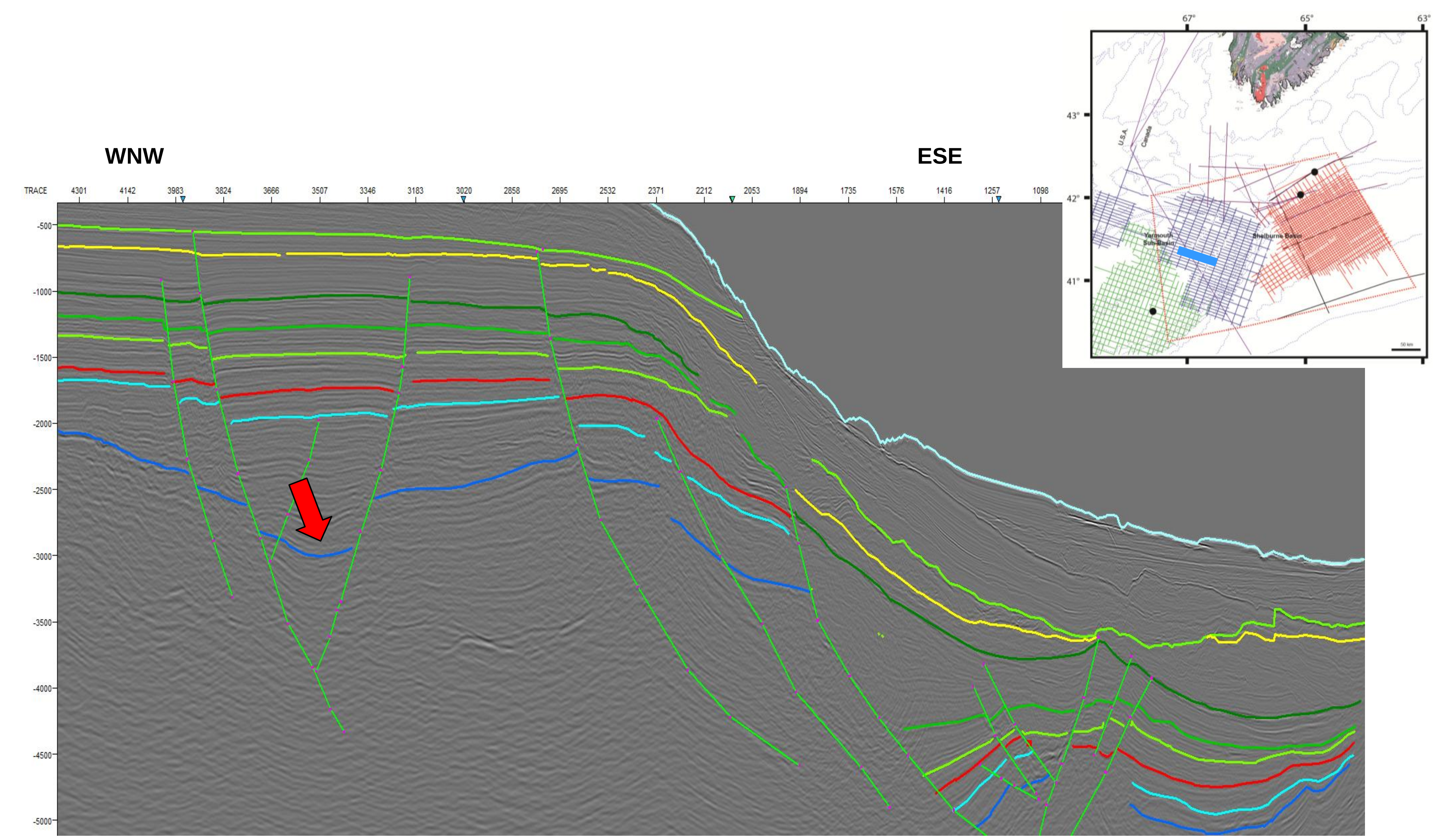


Figure 41: Seismic line (JGM228) in the Yarmouth sub-platform showing the main activity of growth faults in the inner shelf at the J163.

Horizon definition

The J163 seismic horizon correspond to the Callovian MFS identified in the biostratigraphic study. It corresponds to the Top of the Scatarie Member of the Abenaki Formation. It forms the shallow marine carbonate platform deposition (Figure 39).

Well-to-seismic tying

The well-to-seismic tie of the horizon J163 is possible on the 3 wells. Its extension towards the USA area is coherent with COST G-2 calibration. The horizon J163 is the transition between the shale of the Misaine Member and the carbonates of the Scatarie Member. Seismically, it corresponds to a positive peak as an increase of acoustic impedance creates a positive amplitude on zero-phase seismic in normal polarity according the SEG convention. The well-to-seismic tie results present a fair correlation.

Seismic picking and uncertainty

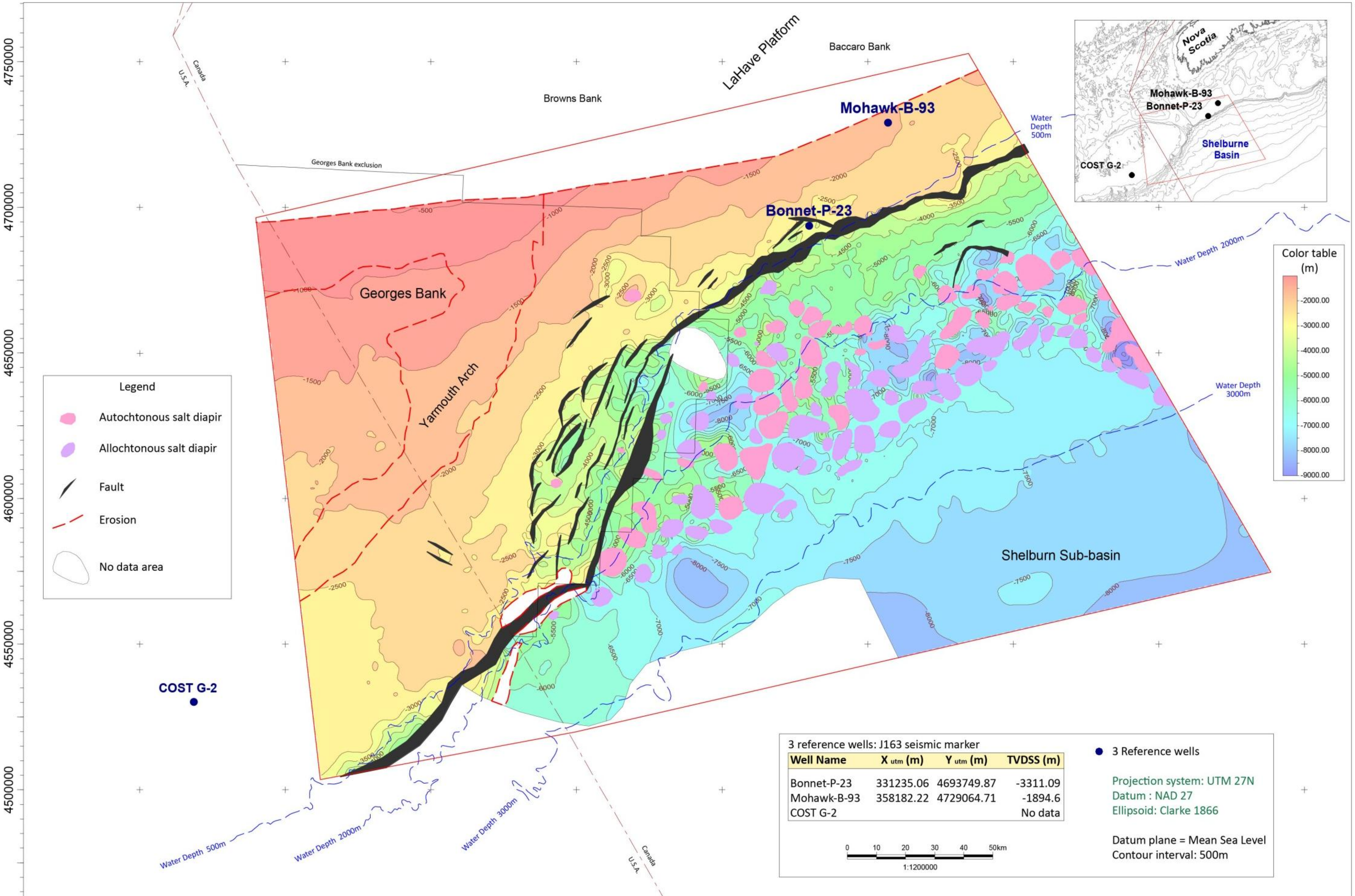
The seismic picking of the J163 horizon is good on the shelf area as it could also be defined using seismic geometries (below deltaic progradation on the Yarmouth sub-platform). The seismic imaging quality decreases on the slope and in the offshore area mainly due to salt tectonics (Figures 40 & 41). Indeed, the picking is very uncertain close to the salt bodies especially in the allochthonous zones where highly complex structures are added to the subsalt images. In the deep offshore area in which salt is absent, the seismic quality is better and the interpretation becomes more confident despite the lack of well-to-seismic tie. Note that in comparison to the 2011' study, J163 is deepened in this zone after seismic geometry considerations (within turbidite extensions).

Structural description

The growth fault system in the inner Yarmouth shelf is the most extended for this last Jurassic horizon (Figure 41). On either part of the slope, sedimentary draping allows it to be followed without difficulties (when salt is absent).

Erosion only remains in the south-western corner.

In the basin, J163 horizon may be located below allochthonous salt sheets. The salt diapirs have the most extensive surface, making small sub-basins that should be connected by very narrow sediment "valleys" surrounded by high salt bodies.



3 reference wells: J163 seismic marker

Well Name	X utm (m)	Y utm (m)	TVDSS (m)
Bonnet-P-23	331235.06	4693749.87	-3311.09
Mohawk-B-93	358182.22	4729064.71	-1894.6
COST G-2			No data

Tectono-stratigraphical chart

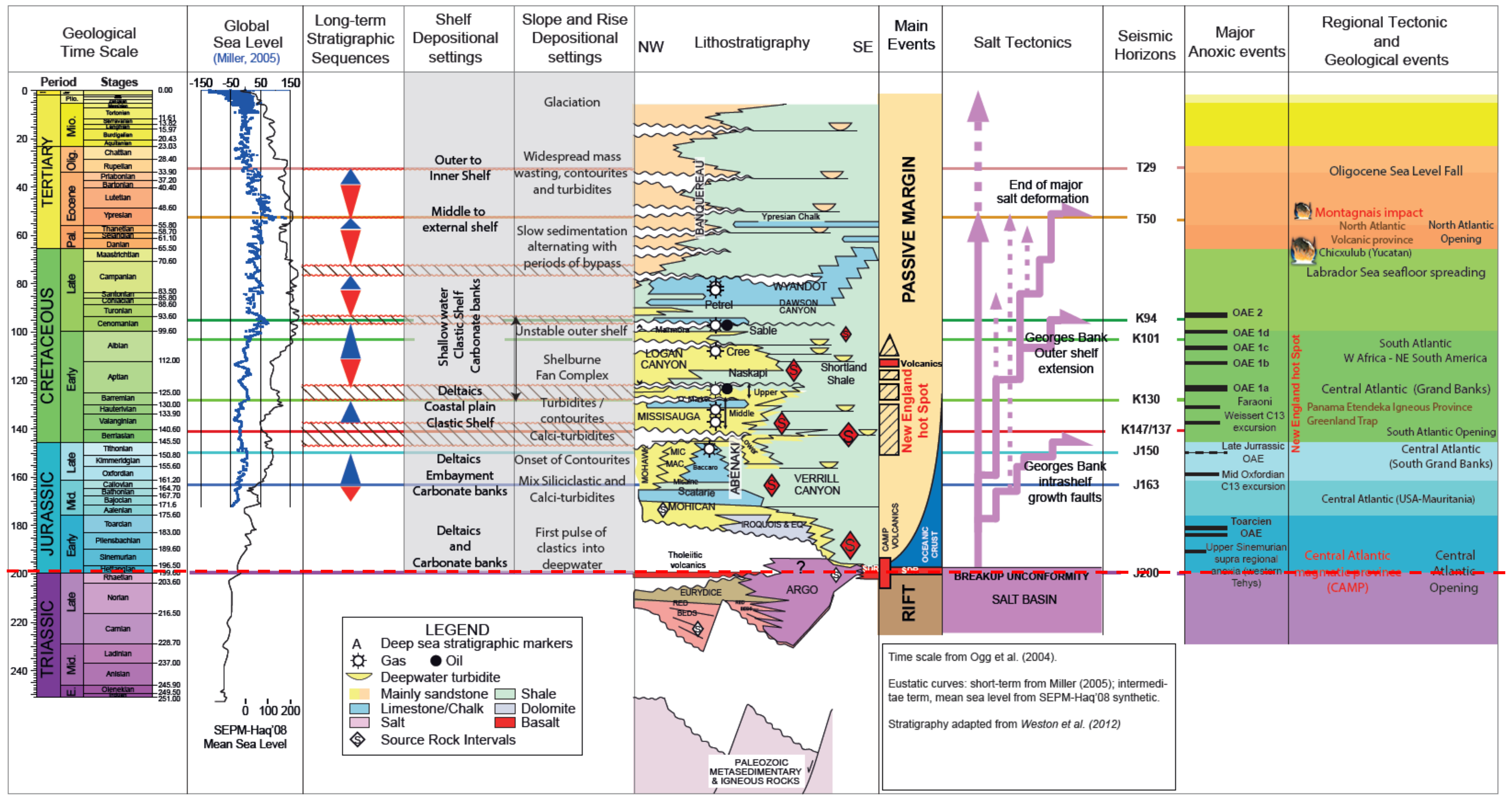


Figure 42 : Tectono-stratigraphical chart for the Georges Bank – Shelburne sub-basin.

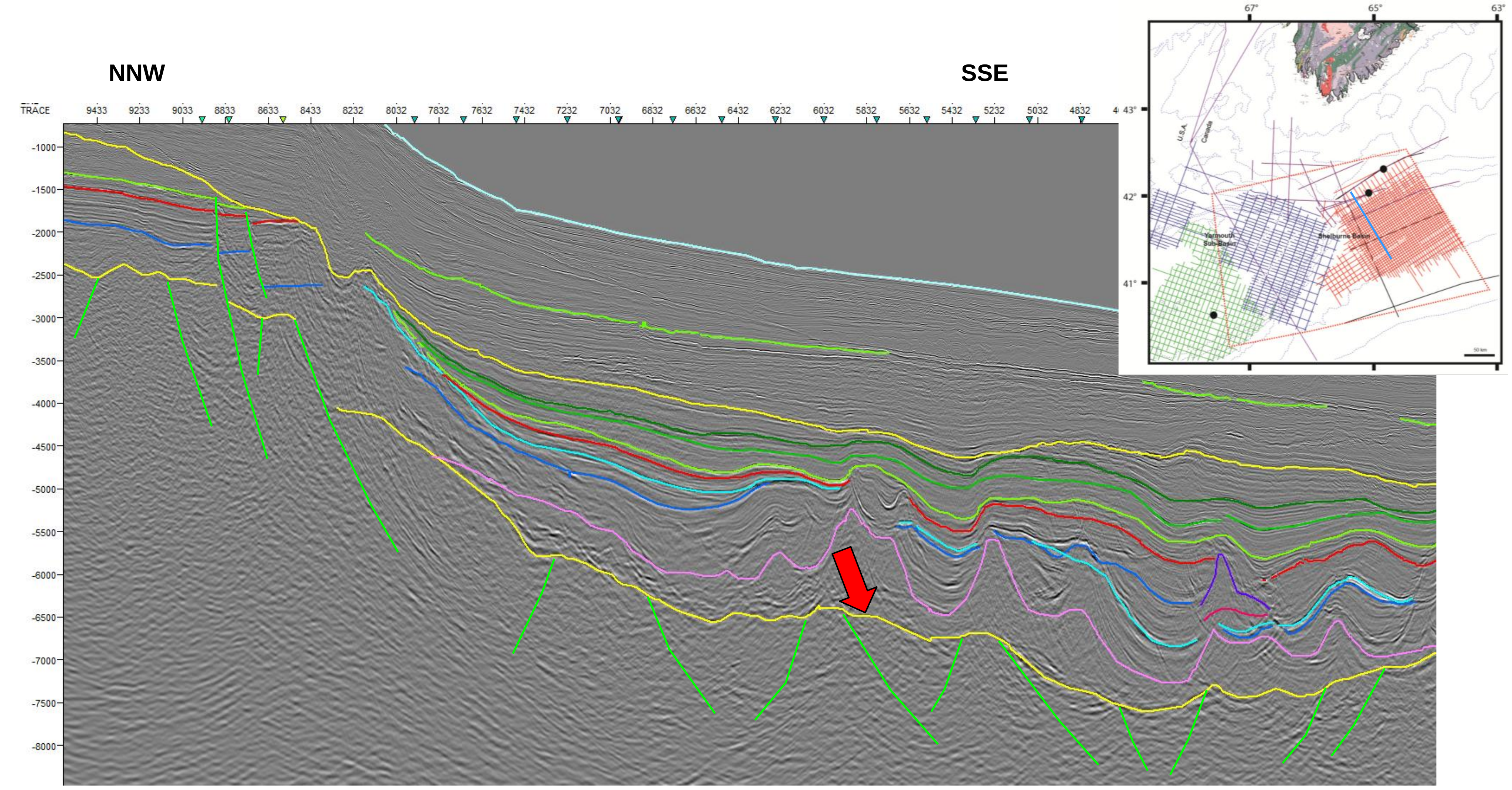


Figure 43: Seismic line (TGS176-100) in the Shelburne Sub-Basin showing the interaction between the Triassic faults and the overlying position of the salt diapirs

Horizon definition

The horizon named Break up Unconformity is the deepest horizon picked on seismic. On the continental shelf, it corresponds to the top of the Basement (undifferentiated Carboniferous or Triassic series) and the base of the Argo Salt when present in the sub-basins (Figure 42). On the slope, the horizon is also identified as the base of the Argo Salt in the Shelburne Sub-Basin. Seawards, in the deep offshore area, the horizon has been picked at the top of seaward dipping reflectors (SDRs) when occurring, and equivalent top of Oceanic Crust.

Well-to-seismic tying

In the studied area, The Break-up Unconformity is penetrated only in the Cost-G2 well. But due to poor quality of the seismic lines (USA line) it's difficult to propagate it correctly over the whole of the Georges Bank area. Thus, over the Shelburne sub-basin, the interpretation is speculative, and based on seismic facies, on the correlation with Nova Scotia Play Fairway Analysis 2011 (Figures 43 & 44).

Seismic picking and uncertainty

The structural complexity (normal faulting with large throw) and the poorly imaged seismic interval (e.g. below the salt diapirs) makes the picking uncertain. The uncertainty is increased by the absence of any well penetrating the Break up Unconformity on the Shelburne sub-basin (Figure 43). The seismic event is characterized by an average to poor seismic reflection with poor lateral seismic continuity. From the continental shelf into the slope, the seismic interpretation of this horizon is speculative, and is only constrained locally by the base of the Argo Salt on the shelf and, in the basin, by also the base of the Argo Salt or some stronger reflections or even by SDRs interpreted as the top of the Oceanic Crust (Figure 43). On the Georges Bank area, the seismic interpretation is based on a strong reflectors corresponding to the CAMP volcanic event (Figure 44).

Structural description

The Break-up Unconformity is dipping gently Southeast in the Shelburne sub-basin and Georges Bank area. At the boundary of these two zones, it dipping abruptly to the Northeast.
On the Georges Bank area it dips to the North and is bounded by a transform fault on the north side of the Yarmouth sub-platform. Thus, between the Yarmouth Arch and the Yarmouth sub-platform the fault becomes steeper to the North.
Between the Yarmouth sub-platform and the Shelburne sub-basin, the fault dips abruptly (Figure 44).
Extensive faults oriented Northeast / Southwest affect the slope of the Shelburne sub-basin and delimit clearly the shelf from the basin. On the Georges Bank, two directions are registered: a NNE-SSW corresponding to inherited structures and a NE-SW corresponding to the Atlantic rifting.
In the deepest part of the Shelburne Sub-Basin, the J200 sediments is broken by a basement high (horst) corresponding to the boundary with the SDRs.

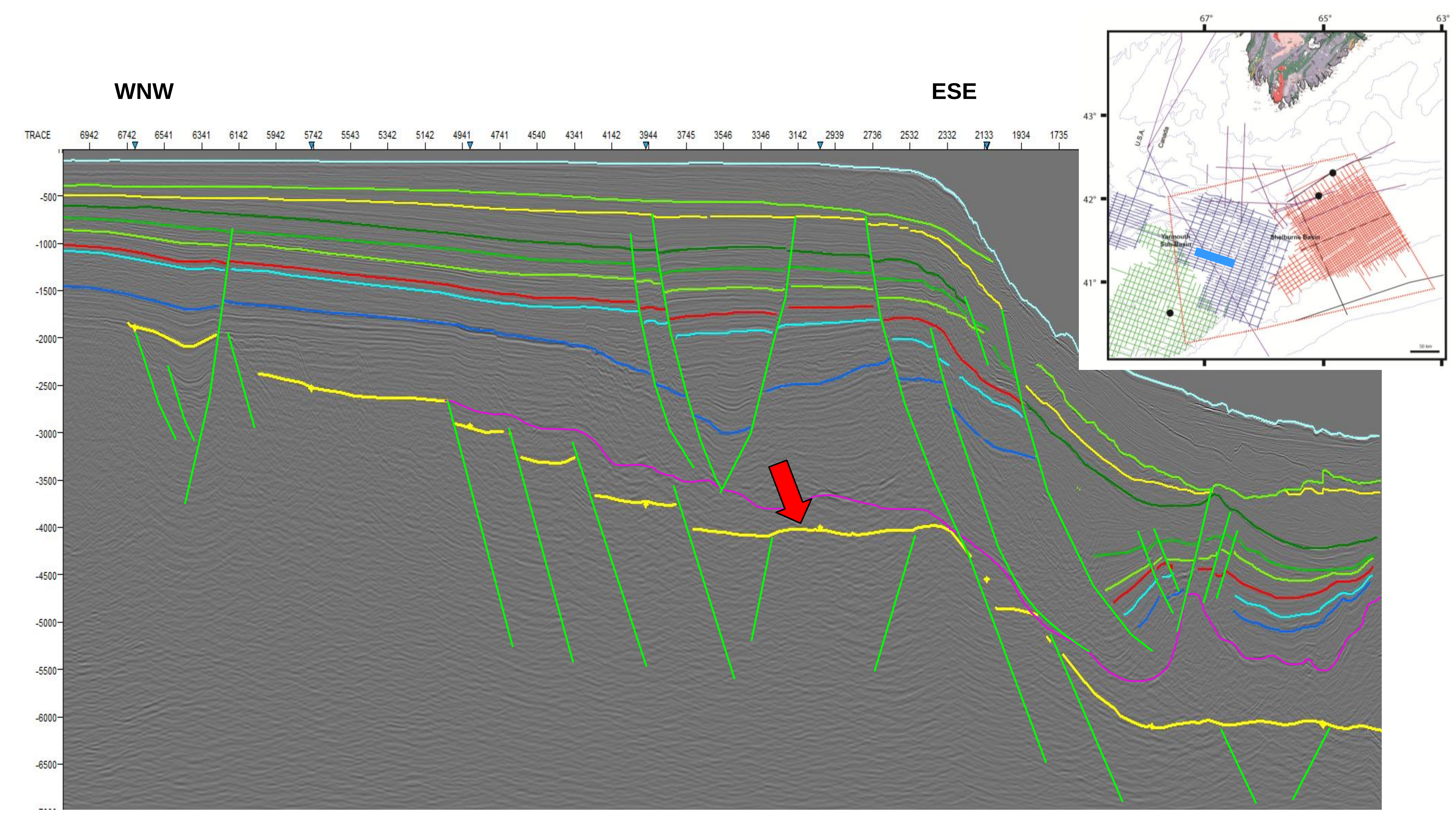
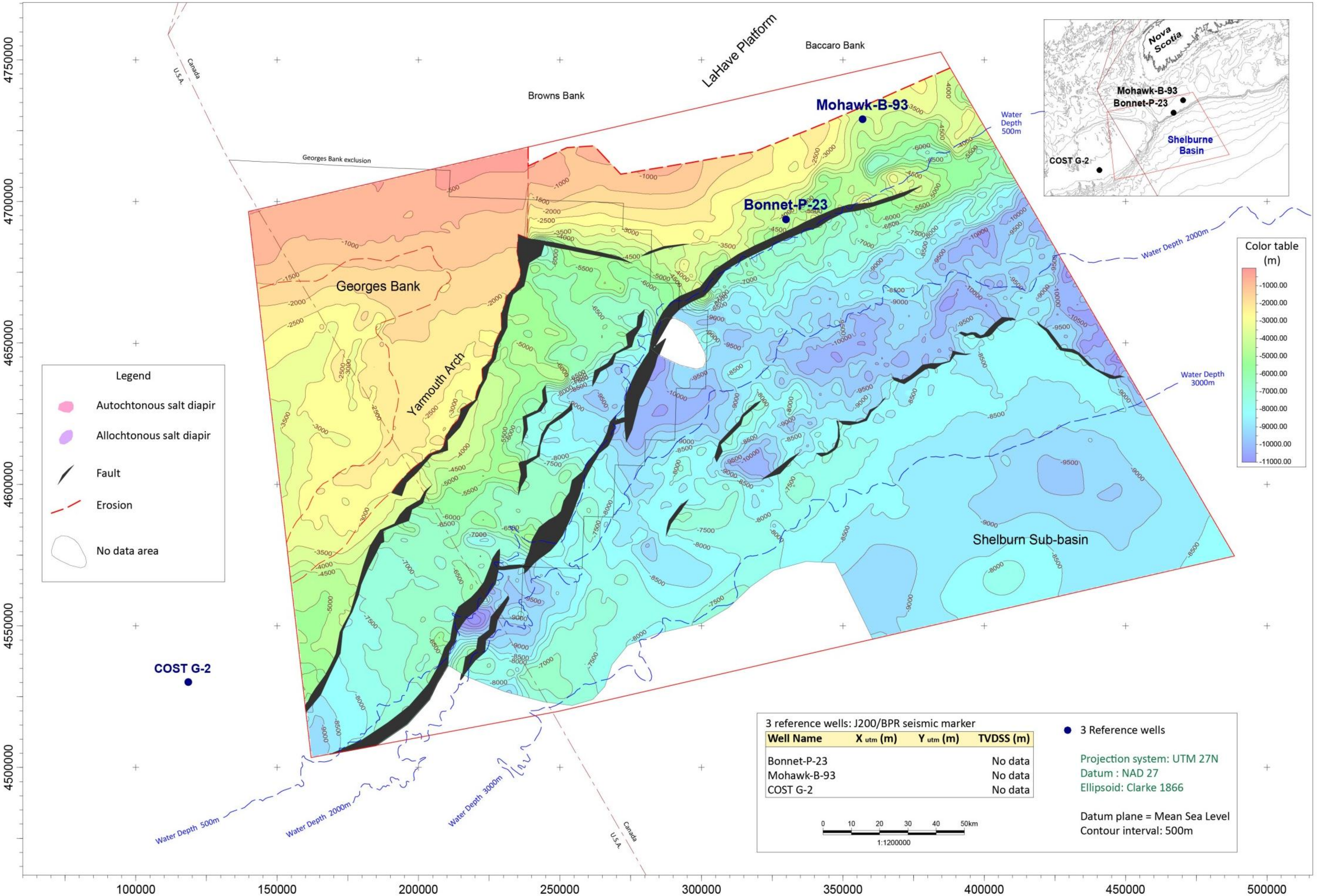


Figure 44: Seismic line (JGM228) from the Yarmouth Arch to the Shelburne sub-basin showing the evolution of the Break-up Unconformity

J200 (Break-up Unconformity) Depth Structural Map

SEISMIC INTERPRETATION – STRUCTURAL MAPPING

SOUTH WEST NOVA SCOTIA EXTENSION - CANADA - June 2015



3 reference wells: J200/BPR seismic marker

Well Name	X_{utm} (m)	Y_{utm} (m)	TVDSS (m)
Bonnet-P-23			No data
Mohawk-B-93			No data
COST G-2			No data

J200 (Break-up Unconformity) Depth Structural Map

PL. 5.3.2.19