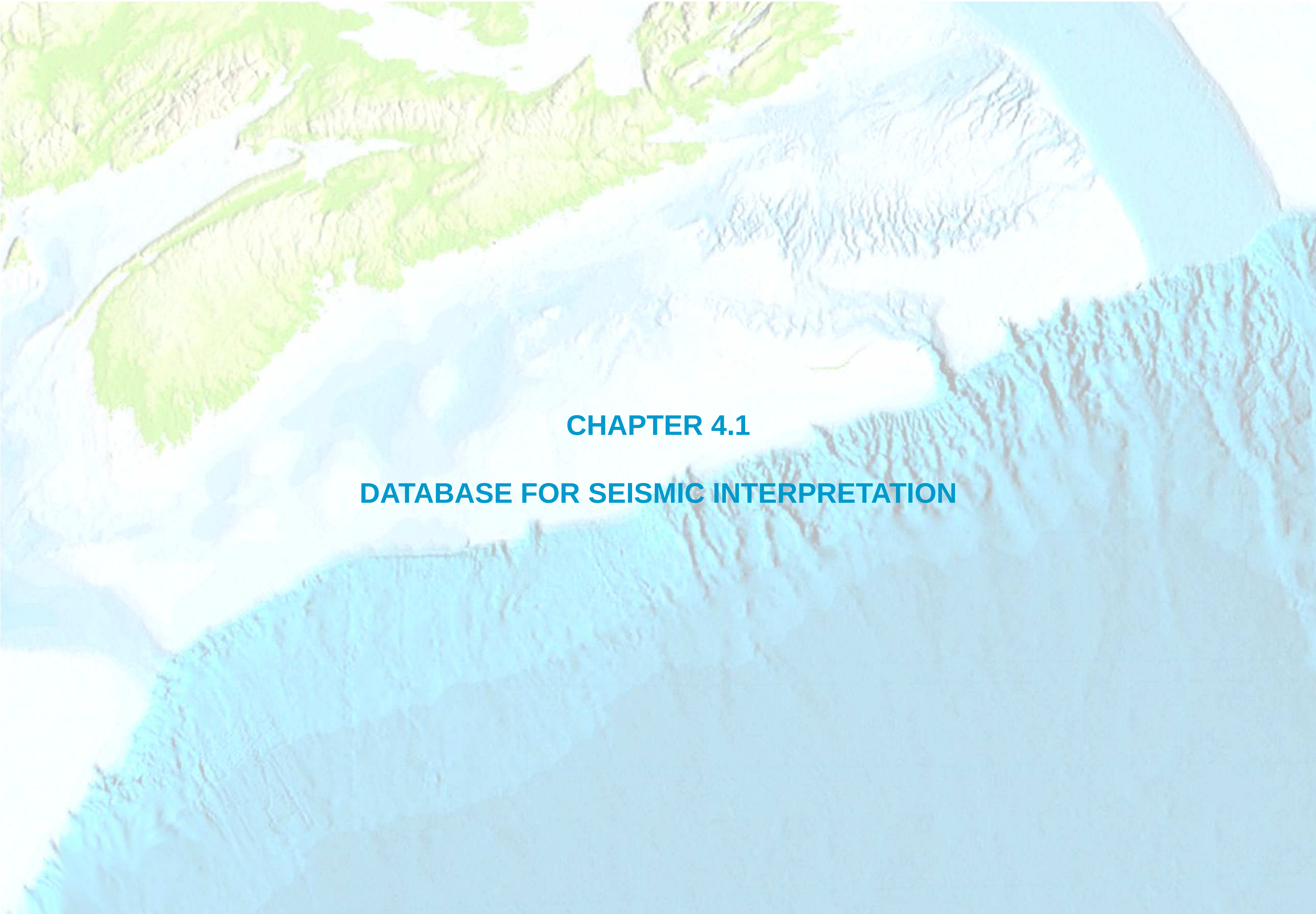
# CHAPTER 4

# SEISMIC INTERPRETATION



# CHAPTER 4.1

# DATABASE FOR SEISMIC INTERPRETATION

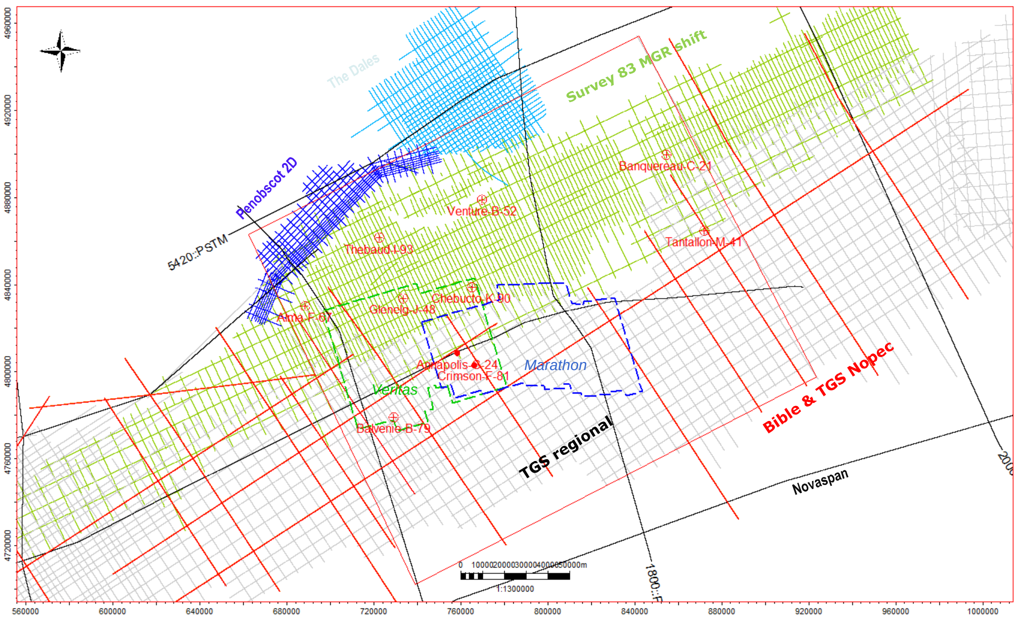



Figure 1: Location map of the seismic surveys.

### Seismic database

The seismic interpretation has been undertaken on various 2D seismic surveys located on the central shelf and slope of the Scotian Margin.

In total, seven 2D seismic surveys and two 3D seismic surveys were made available for the project as shown in Figure 1. They surveys are listed below.

### 2D lines

(a) 10 Novaspan 2D (with RMS velocity data): long lines
(b) Bible (with RMS velocity data): Novaspan re-processed
(c) 298 TGS regional 2D: Dense gridding
(d) 333 Survey 83 MGR shift: Dense gridding, cover the platform
(e) 62 The Dales: Dense gridding, cover the platform
(f) 25 TGS Nopec
(g) 64 Penobscot 2D

### 3D seismic cubes

(a) Marathon (3838Km²)
(b) Veritas (3980Km²)

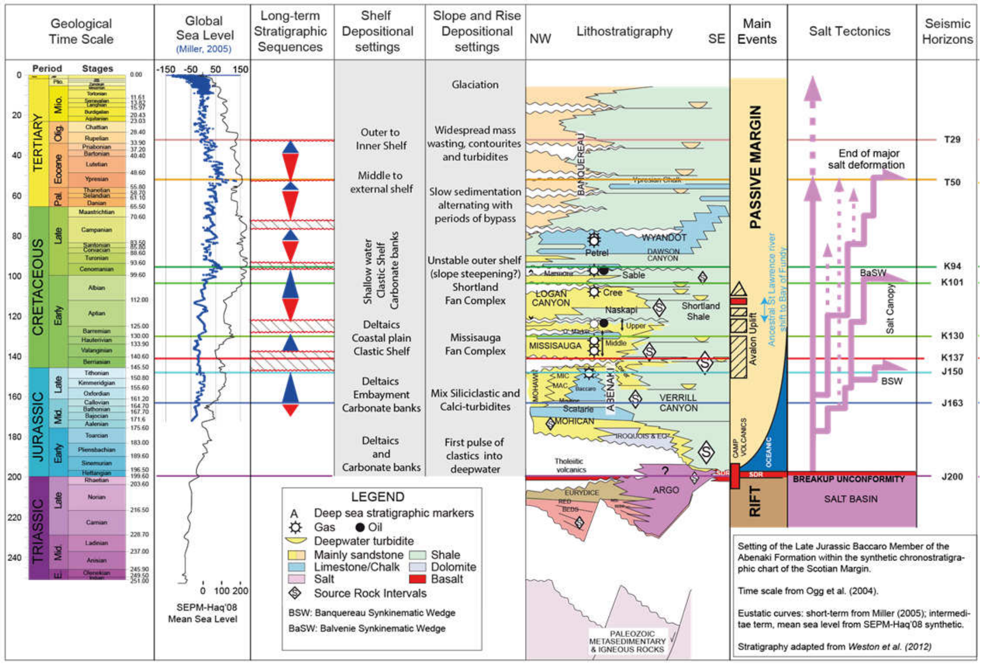



Figure 2: Stratigraphic chart of the Central Scotian Margin, Nova Scotia.

### Seismic horizons

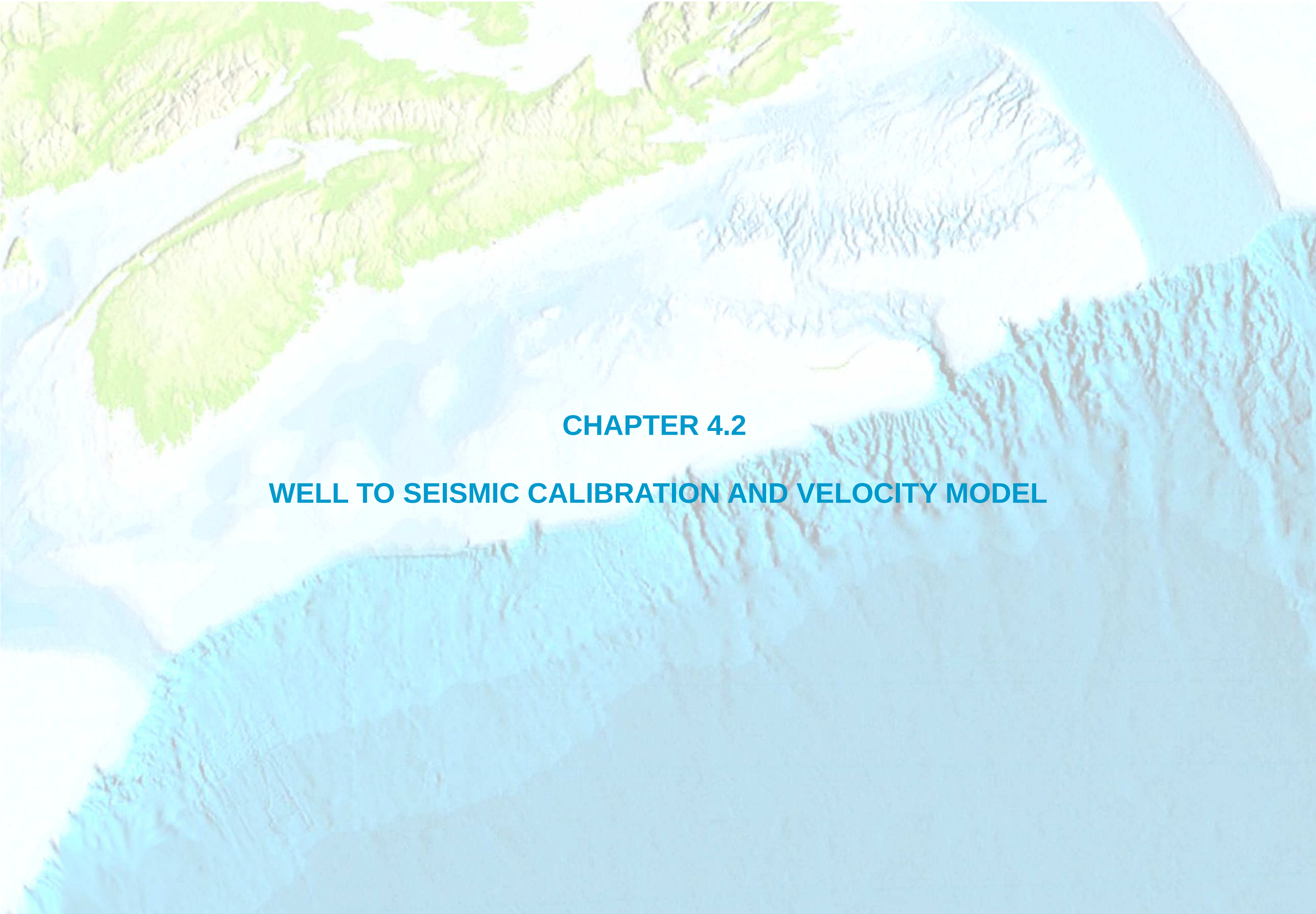
The following nine horizons displayed in the last column of Figure 2 are used in the present study. Two horizons, namely K137 and J150, were reinterpreted according to a new interpretation produced by the CNSOPB (Deptuck et al., 2014). Four horizons, namely K94, K101, K130 and J163 were updated from the previous 2011 PFA study and are consistent with new interpretations of the K137 and J150 horizons.

- T29 (interpreted in 2011)
- T50 (interpreted in 2011)
- K94 (interpreted in 2011) Updated
- K101 (interpreted in 2011) Updated
- K130 (interpreted in 2011) Updated
- K137 (interpreted in 2011) New interpretation
- J150 (interpreted in 2011) New interpretation
- J163 (interpreted in 2011) Updated
- J200 (interpreted in 2011)

Figure 3 presents the seismic phase computed during the seismic-to-well calibration for each of the nine stratigraphic markers.

| Stratigraphic Marker | Stratigraphic surface | Phase |
|---|---|---|
| T29 | Unconformity | Positive |
| T50 | Unconformity | Negative |
| K94 | Unconformity | Negative |
| K101 | Unconformity | Positive |
| K130 | MFS | Positive |
| K137 | Unconformity | Negative |
| J150 | MFS | Positive |
| J163 | MFS | Positive |
| J200 | BUU | Negative/Positive |

Figure 3 : Seismic phase for each stratigraphic marker



# CHAPTER 4.2

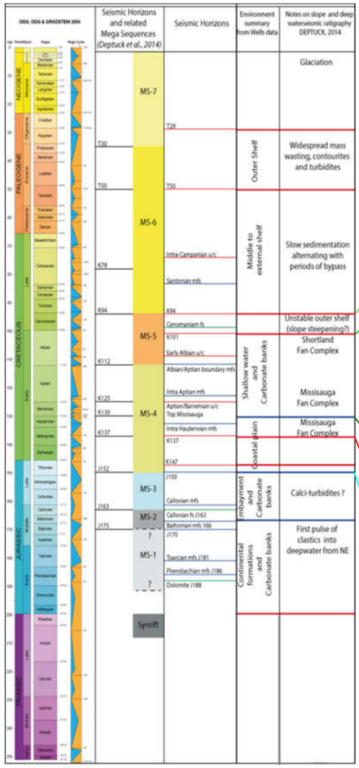
# WELL TO SEISMIC CALIBRATION AND VELOCITY MODEL

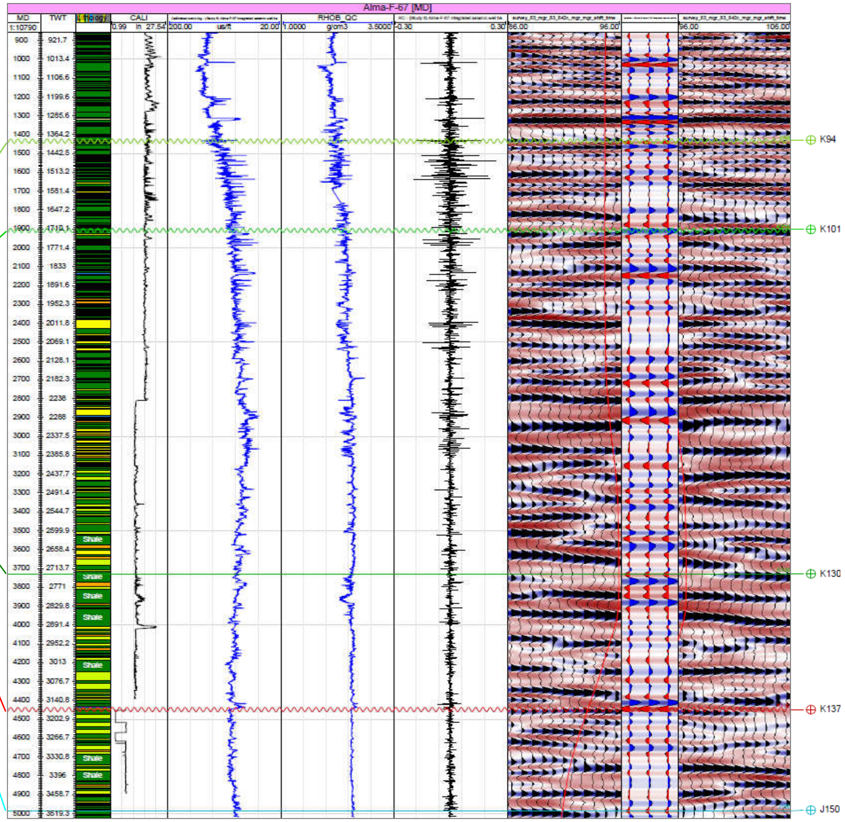
# CHAPTER 4.2.1

# SECTION CALIBRATION

# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION






| WELL HEADER | | |
|---|---|---|
| Well Name | **Alma F-67** | |
| Rotary Table (R.T.) | 24.4 m | |
| Total Depth (T.D.) | 5054 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 36' 17.98" N | Lon: 60° 39' 56.29" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 688396 | $Y_{UTM}$ : 4830450 |

| BIOSTRATIGRAPHY | RPS Energy 2010 |
|---|---|

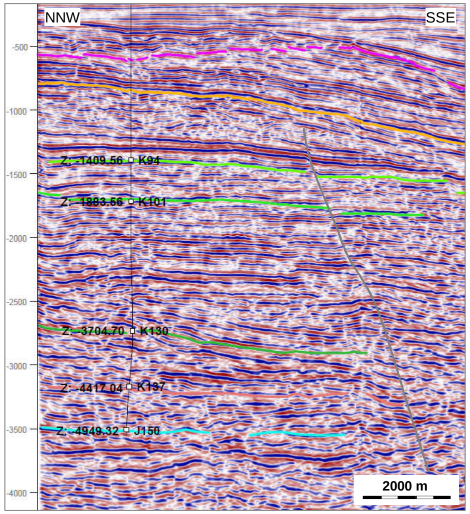
| SEISMIC LOCATION | |
|---|---|
| Survey | Survey 83 |
| Line | 83_842c |
| Trace | 95 |
| Offset (m) | 335 |

**SEISMIC MARKERS**

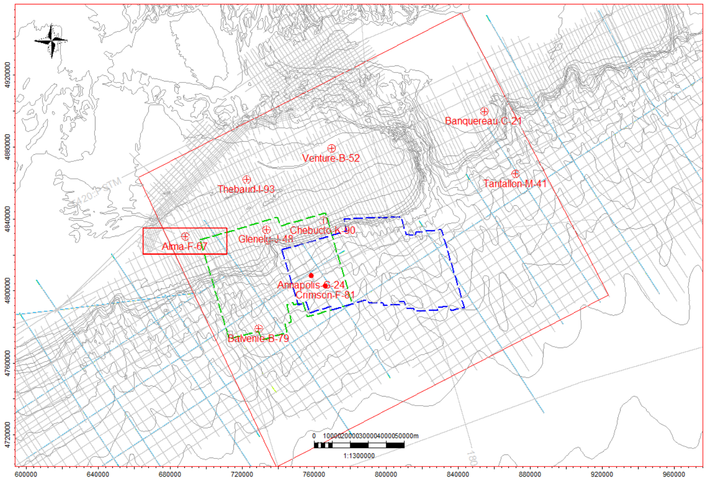
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 119 | 68 |
| T29 | Mid-Oligocene Unconformity | No data | No data |
| T50 | Base Ypresian Chalk | No data | No data |
| K94 | Turonian / Cenomanian Unconformity | 1398 | 1408 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 1725 | 1855 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 2739 | 3751 |
| K137 | Berriasian / Valanginian Unconformity | 3173 | 4417 |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | 3512 | 5018 |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 4900 | Not reached |

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |

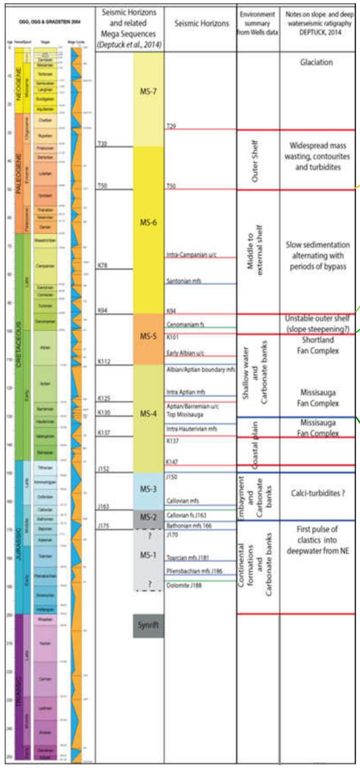


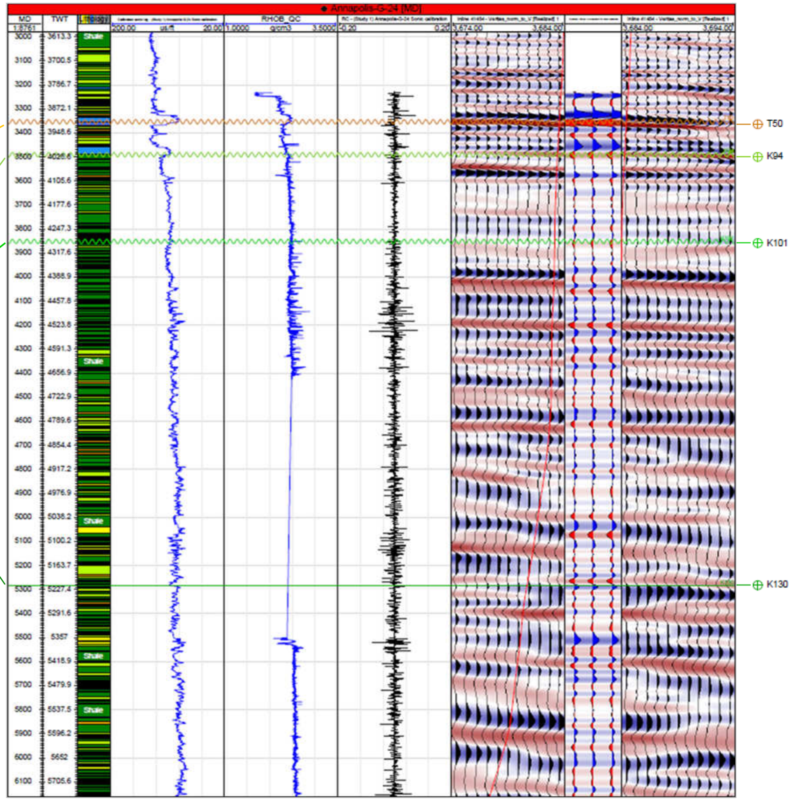

***Survey 83 MGR – line 83_842c***
*Time Shift = 0 ms*



# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Central Scotian Slope Study– CANADA – July 2016




**WELL HEADER**

| | | |
|---|---|---|
| Well Name | **Annapolis G-24** | |
| Rotary Table (R.T.) | 36 m | |
| Total Depth (T.D.) | 6182 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 23' 22.94" N | Lon: 59° 48' 29.19" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 758530 | $Y_{UTM}$ : 4808827 |

| | |
|---|---|
| **BIOSTRATIGRAPHY** | RPS Energy 2010 |

**SEISMIC LOCATION**

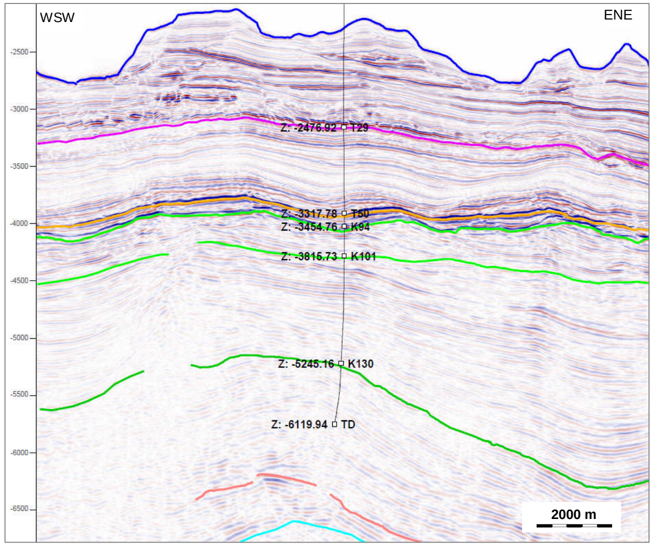
| | |
|---|---|
| Survey | Marathon 3D |
| Inline | 3700 |
| Trace | 2170 |
| Offset (m) | 235 |

**SEISMIC MARKERS**

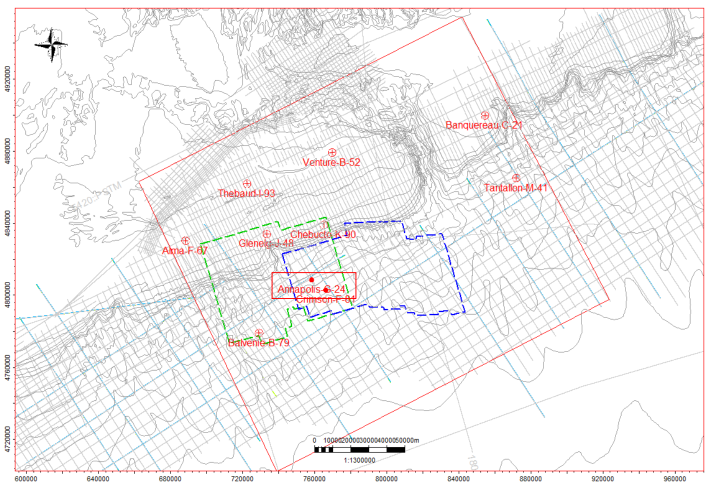
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 2276 | 1678 |
| T29 | Mid-Oligocene Unconformity | 3160 | 2477 |
| T50 | Base Ypresian Chalk | 3918 | 3318 |
| K94 | Turonian / Cenomanian Unconformity | 4029 | 3455 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 4291 | 3816 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 5245 | 5285 |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 9000 | Not reached |

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |



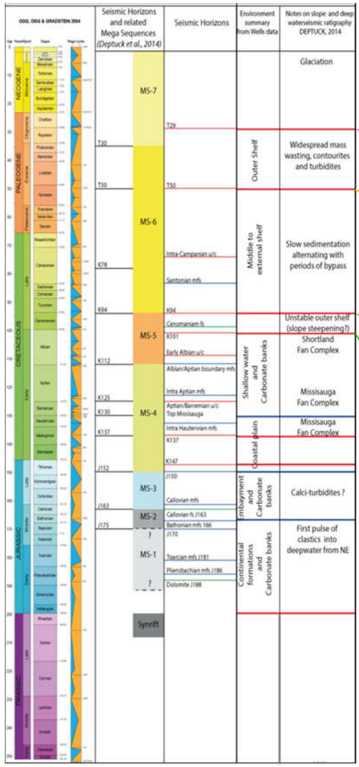

*Marathon 3D – Inline 3700*
*Time Shift = 0 ms, Phase shift = 0°*




 **Annapolis G-24**

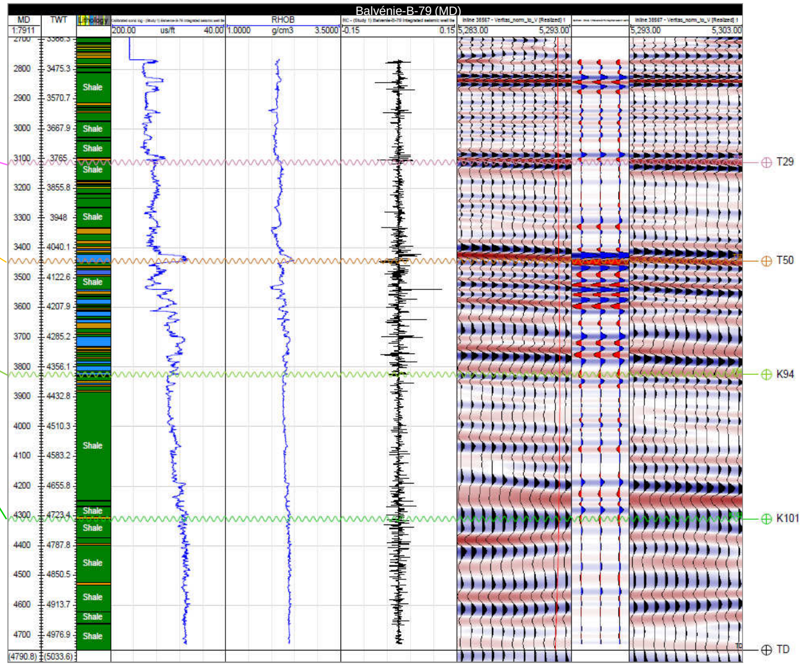
# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

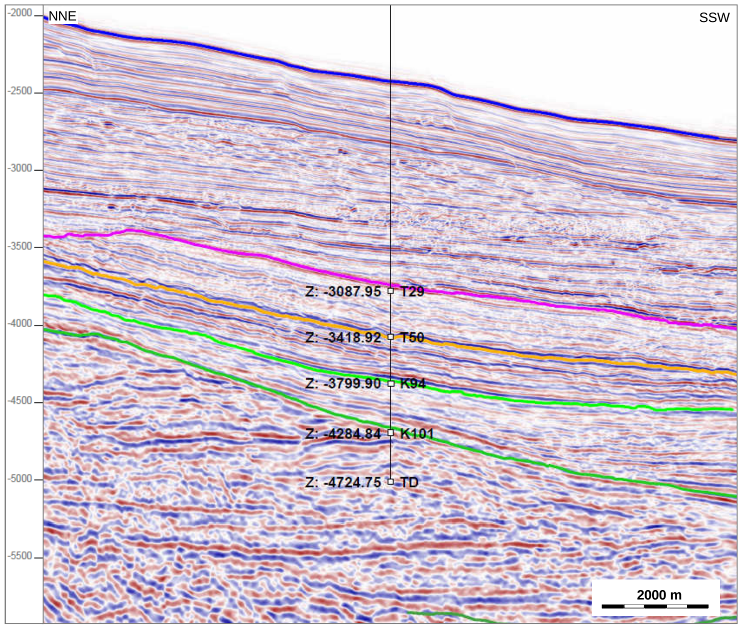




Key:

| | | | |
|---|---|---|---|
| Claystone | | T29 | |
| Shale | | T50 | |
| Siltstone | | K94 | |
| Sandstone | | K101 | |
| Limestone | | K130 | |
| Marl | | K137 | |
| Chalk | | J150 | |
| | | J163 | |
| | | J200 | |




*Veritas 3D – Inline 38600*
*Time Shift = 0 ms, Phase shift = 0°*

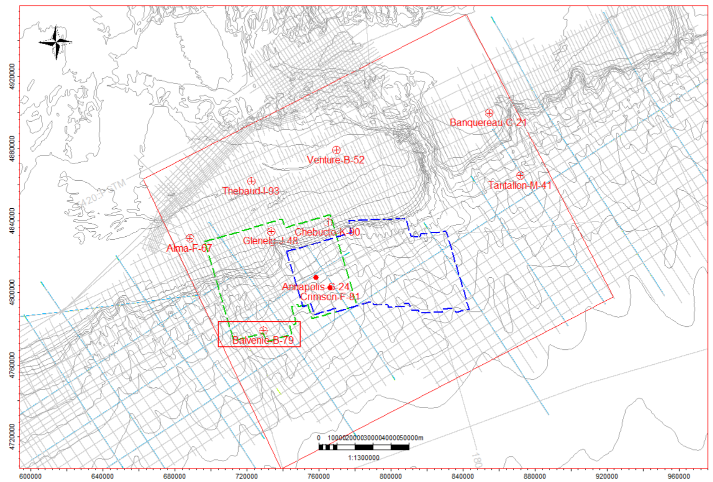
| WELL HEADER | | |
|---|---|---|
| Well Name | **Balvenie B-79** | |
| Rotary Table (R.T.) | 25 m | |
| Total Depth (T.D.) | 4750 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 08' 01.29" N | Lon: 60° 10' 56.84" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 729167 | $Y_{UTM}$ : 4779300 |

| BIOSTRATIGRAPHY | RPS Energy 2010 |
|---|---|

| SEISMIC LOCATION | |
|---|---|
| Survey | Veritas 3D |
| Inline | 38600 |
| Trace | 5295 |
| Offset (m) | 440 |

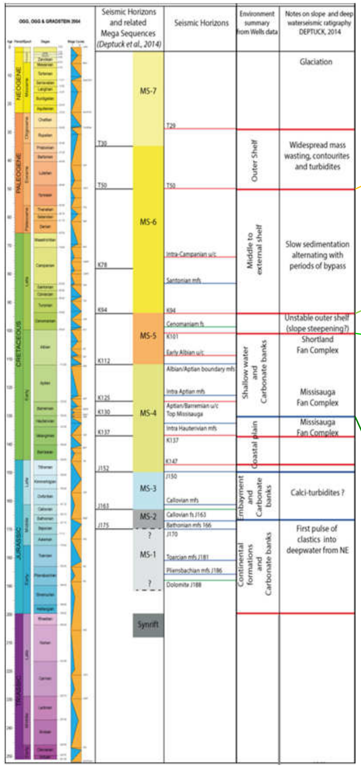
**SEISMIC MARKERS**

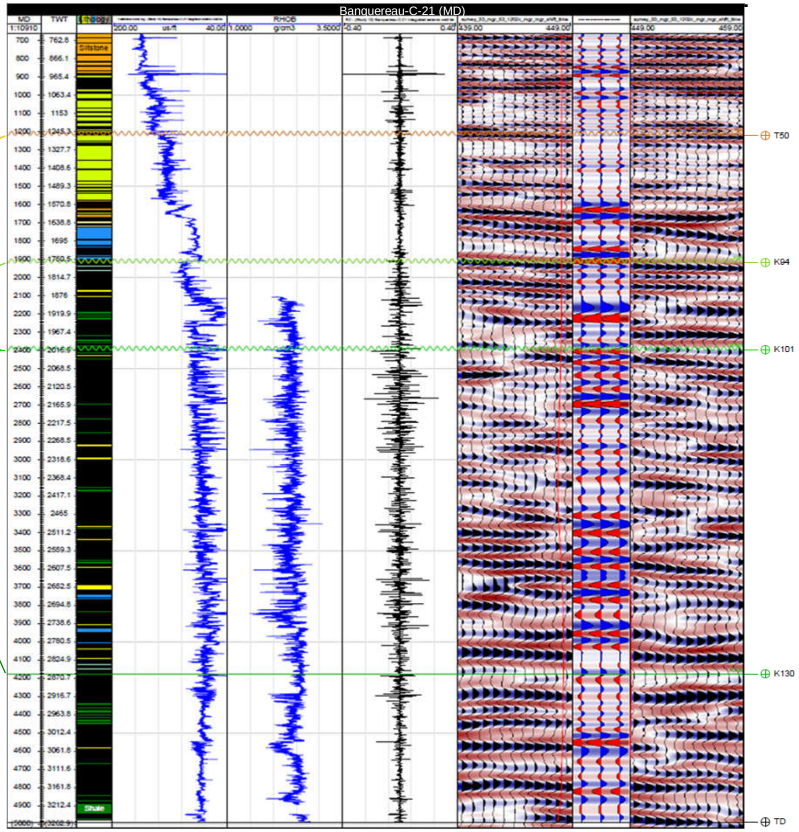
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 2372 | 1803 |
| T29 | Mid-Oligocene Unconformity | 3771 | 3088 |
| T50 | Base Ypresian Chalk | 4063 | 3419 |
| K94 | Turonian / Cenomanian Unconformity | 4362 | 3800 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 4721 | 4285 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | Not reached | Not reached |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 8500 | Not reached |



# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

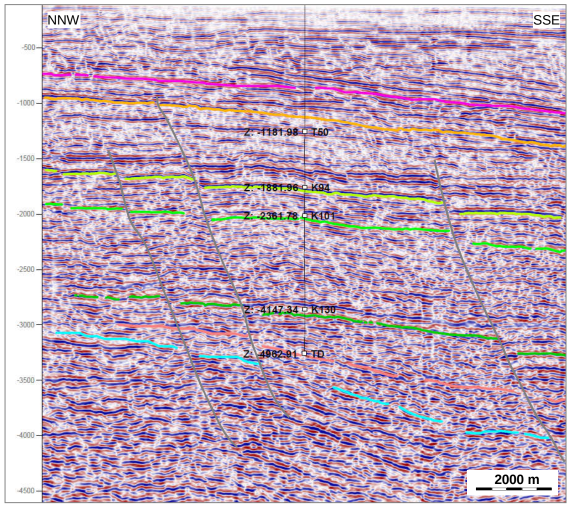
Central Scotian Slope Study– CANADA – July 2016




Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |



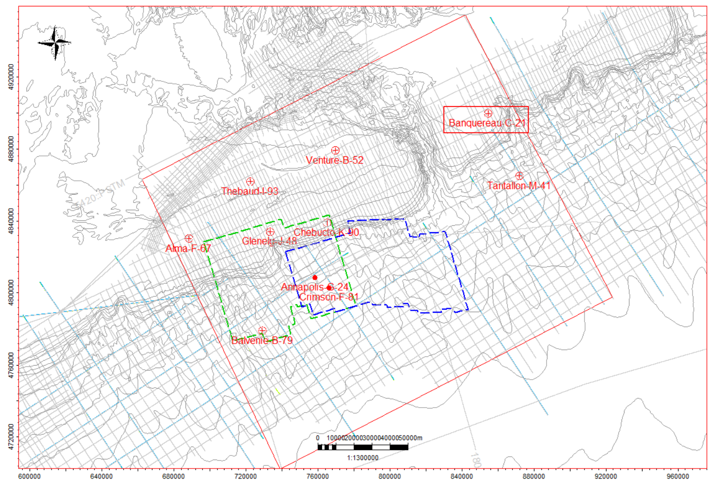

*Survey 83 MGR - line 83_1202c*
*Time Shift = 0 ms*

| WELL HEADER | | |
|---|---|---|
| Well Name | **Banquereau-C-21** | |
| Rotary Table (R.T.) | 27 | |
| Total Depth (T.D.) | 4991 | |
| Geographic coordinates @surface | Lat: 44°10'07.52" | Lon: 58°34'00.24' |
| UTM coordinates (Zone **20N, NAD27**) | $X_{UTM}$ : 854445,11 | $Y_{UTM}$ : 4899964,38 |

| BIOSTRATIGRAPHY | RPSEnergy /PFA 2011 |
|---|---|

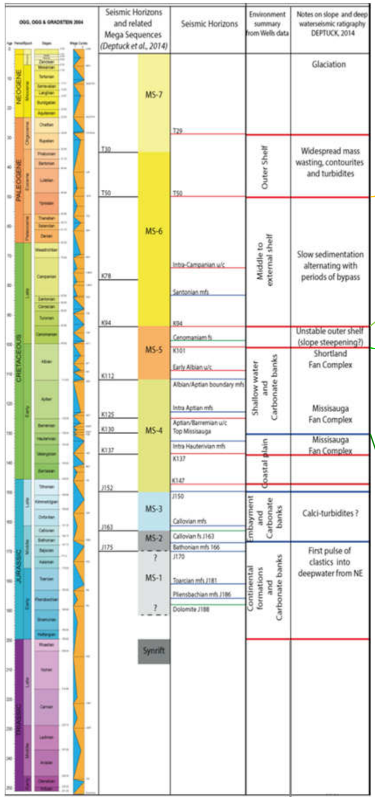
| SEISMIC LOCATION | |
|---|---|
| Survey | 83 MGR |
| Line | 1202c |
| Trace | |
| Offset (m) | 604 |

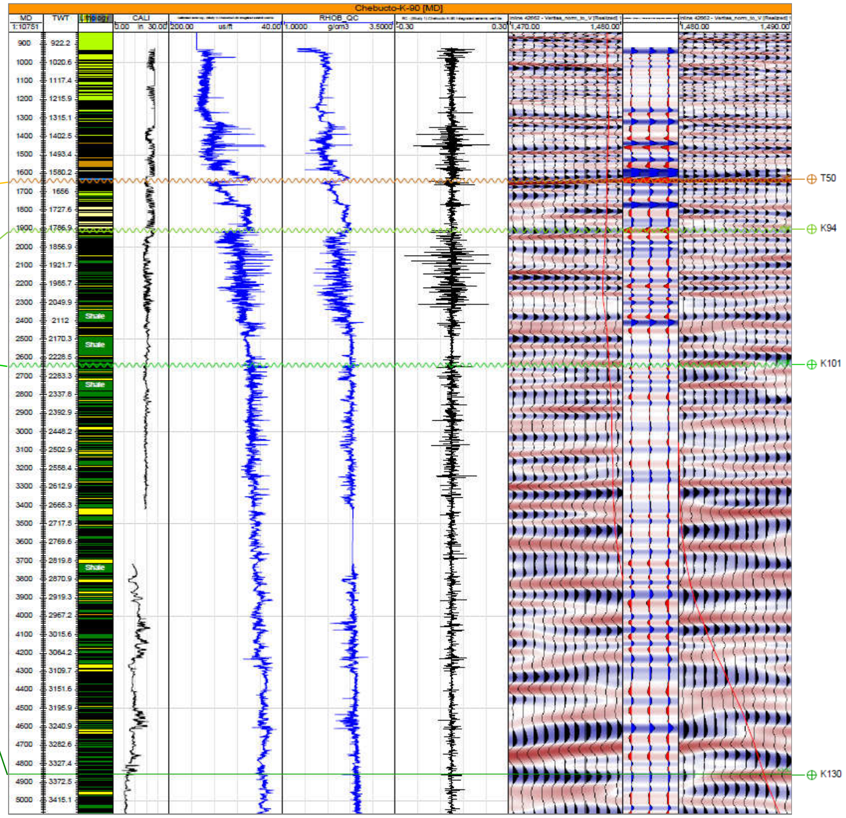
| SEISMIC MARKERS | | | |
|---|---|---|---|
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
| 0 | Seabed | 95 | 83 |
| T29 | Mid-Oligocene Unconformity | No data | No data |
| T50 | Base Ypresian Chalk | 1253 | 1182 |
| K94 | Turonian / Cenomanian Unconformity | 1755 | 1882 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 2013 | 2362 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 2860 | 4147 |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | Not reached | Not reached |



# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Central Scotian Slope Study– CANADA – July 2016




## WELL HEADER

| | | |
|---|---|---|
| Well Name | **Chebucto K-90** | |
| Rotary Table (R.T.) | 22.8 m | |
| Total Depth (T.D.) | 5235 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 39' 44.74" N | Lon: 59° 42' 52.05" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 764931 | $Y_{UTM}$ : 4839413 |

| | |
|---|---|
| **BIOSTRATIGRAPHY** | RPS Energy 2010 |

## SEISMIC LOCATION

| | |
|---|---|
| **Survey** | **Veritas 3D** |
| **Inline** | 42662 |
| **Trace** | 1480 |
| **Offset (m)** | 185 |

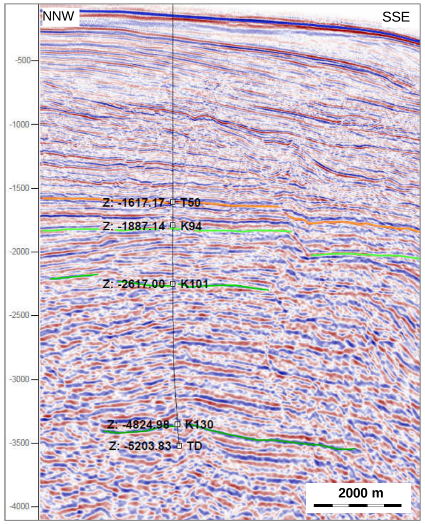
## SEISMIC MARKERS

| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 85 | 86 |
| T29 | Mid-Oligocene Unconformity | 1338 | 1302 |
| T50 | Base Ypresian Chalk | 1605 | 1617 |
| K94 | Turonian / Cenomanian Unconformity | 1792 | 1887 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 2251 | 2617 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 3352 | 4825 |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 6500 | Not reached |

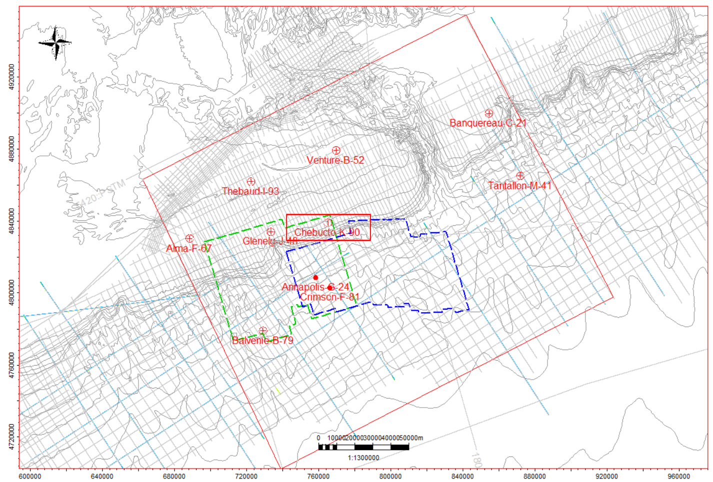
Key:

- Claystone
- Shale
- Siltstone
- Sandstone
- Limestone
- Marl
- Chalk

- T29
- T50
- K94
- K101
- K130
- K137
- J150
- J163
- J200

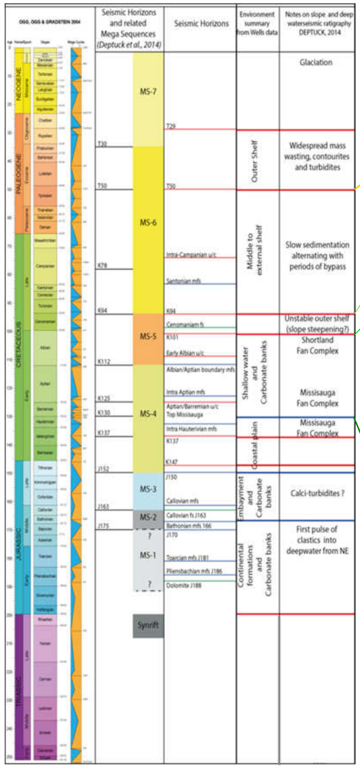


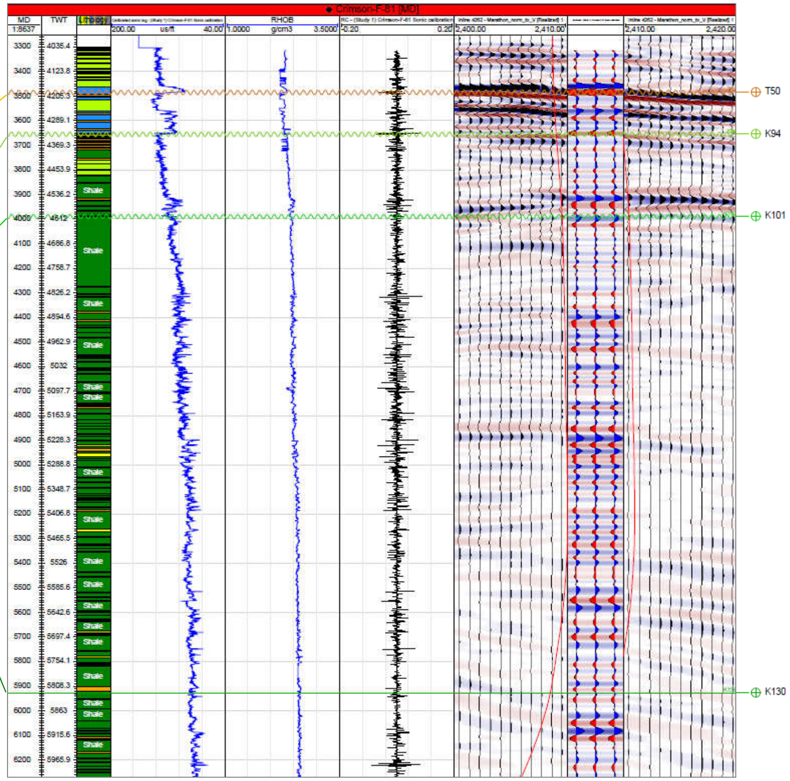

*Veritas 3D – Inline 42662*
*Time Shift = 0 ms, Phase shift = 0°*



# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Central Scotian Slope Study– CANADA – July 2016





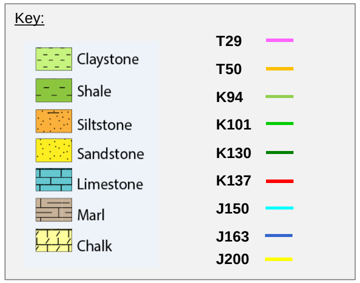

| WELL HEADER | | |
|---|---|---|
| Well Name | **Crimson F-81** | |
| Rotary Table (R.T.) | 21.4 m | |
| Total Depth (T.D.) | 6676 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 20' 22.29" N | Lon: 59° 42' 57.03" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 766218 | $Y_{UTM}$ : 4803555 |

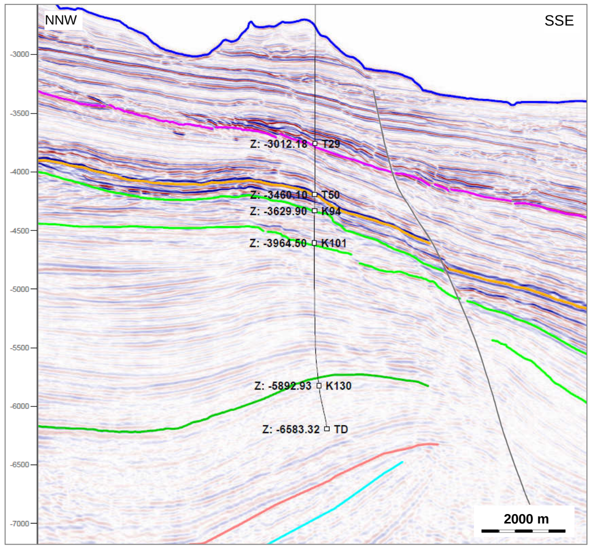
| BIOSTRATIGRAPHY | RPS Energy 2010 |
|---|---|

| SEISMIC LOCATION | |
|---|---|
| Survey | Marathon 3D |
| Crossline | 2400 |
| Trace | 4262 |
| Offset (m) | 200 |

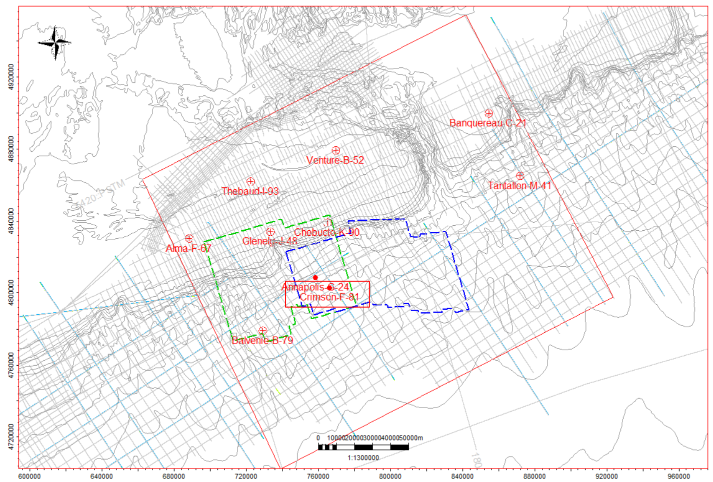
**SEISMIC MARKERS**

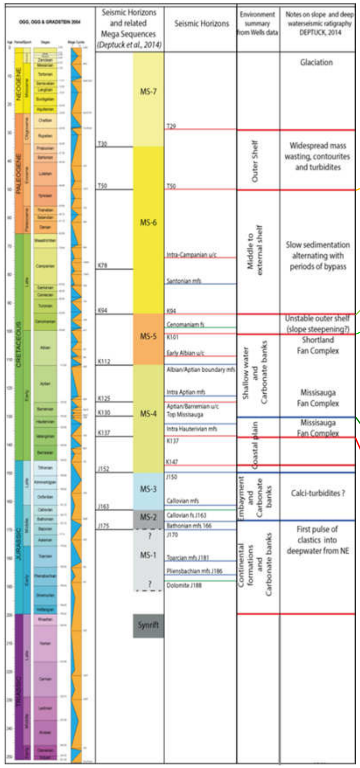
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 2787 | 2091 |
| T29 | Mid-Oligocene Unconformity | 3758 | 3012 |
| T50 | Base Ypresian Chalk | 4192 | 3460 |
| K94 | Turonian / Cenomanian Unconformity | 4330 | 3630 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 4605 | 3965 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 5823 | 5893 |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 8750 | Not reached |

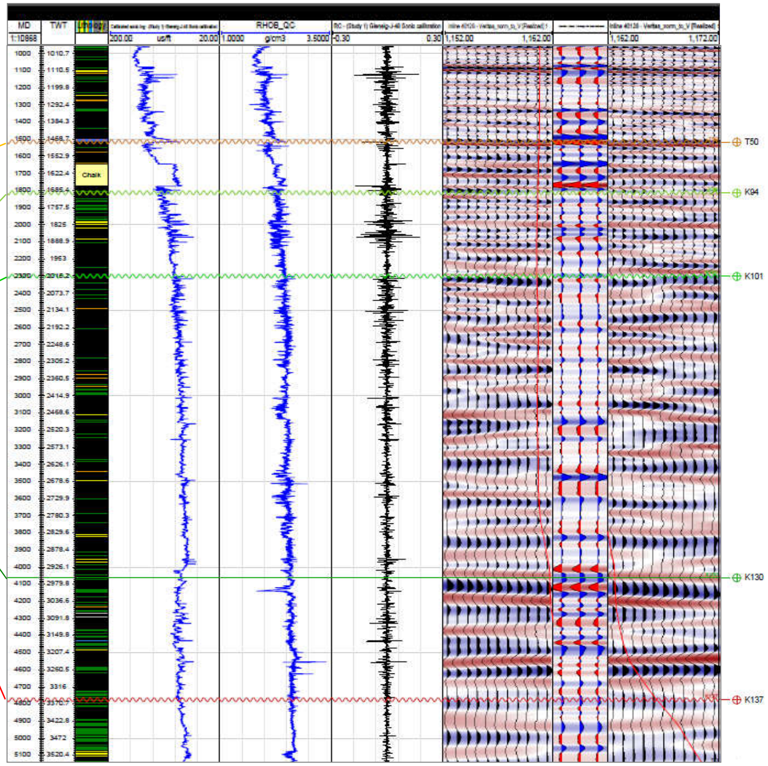



*Marathon 3D – Crossline 2400*
*Time Shift = 0 ms, Phase shift = 0°*







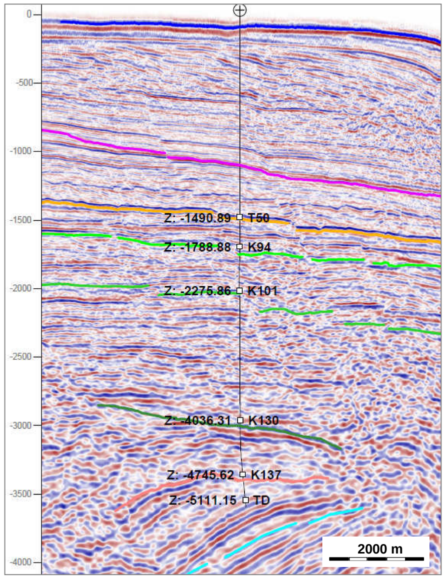

| WELL HEADER | | |
|---|---|---|
| Well Name | **Glenelg J-48** | |
| Rotary Table (R.T.) | 24.1 m | |
| Total Depth (T.D.) | 5148 m (R.T.) | |
| Geographic coordinates @surface | Lat: 43° 37' 38.57" N | Lon: 60° 06' 24.84" W |
| UTM coordinates (Zone 20N, NAD27, CL66) | $X_{UTM}$ : 733410 | $Y_{UTM}$ : 4834340 |

| BIOSTRATIGRAPHY | RPS Energy 2010 |
|---|---|

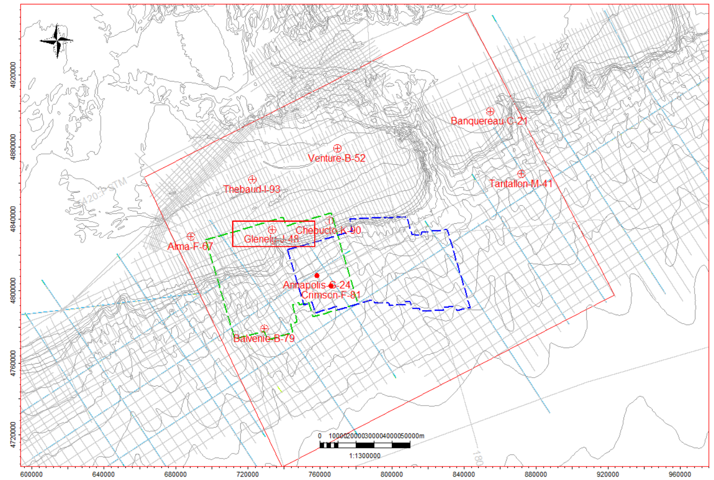
| SEISMIC LOCATION | |
|---|---|
| Survey | Veritas 3D |
| Inline | 40100 |
| Trace | 1163 |
| Offset (m) | 320 |

**SEISMIC MARKERS**

| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 112 | 84 |
| T29 | Mid-Oligocene Unconformity | 1092 | 1054 |
| T50 | Base Ypresian Chalk | 1481 | 1491 |
| K94 | Turonian / Cenomanian Unconformity | 1695 | 1789 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 2016 | 2276 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 2963 | 4036 |
| K137 | Berriasian / Valanginian Unconformity | 3360 | 4746 |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | 6950 | Not reached |




*Veritas 3D – Inline 40100*
*Time Shift = 0 ms, Phase shift = 0°*

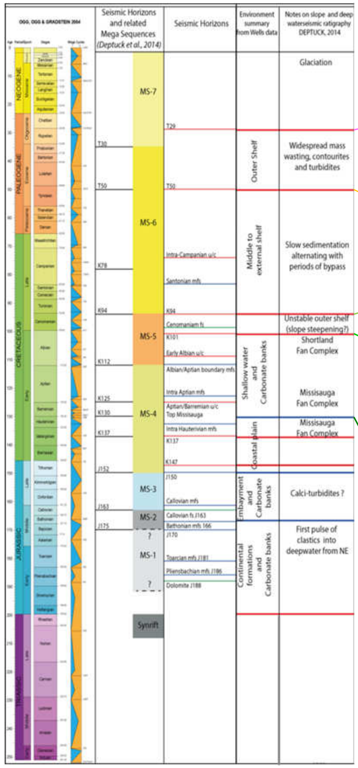


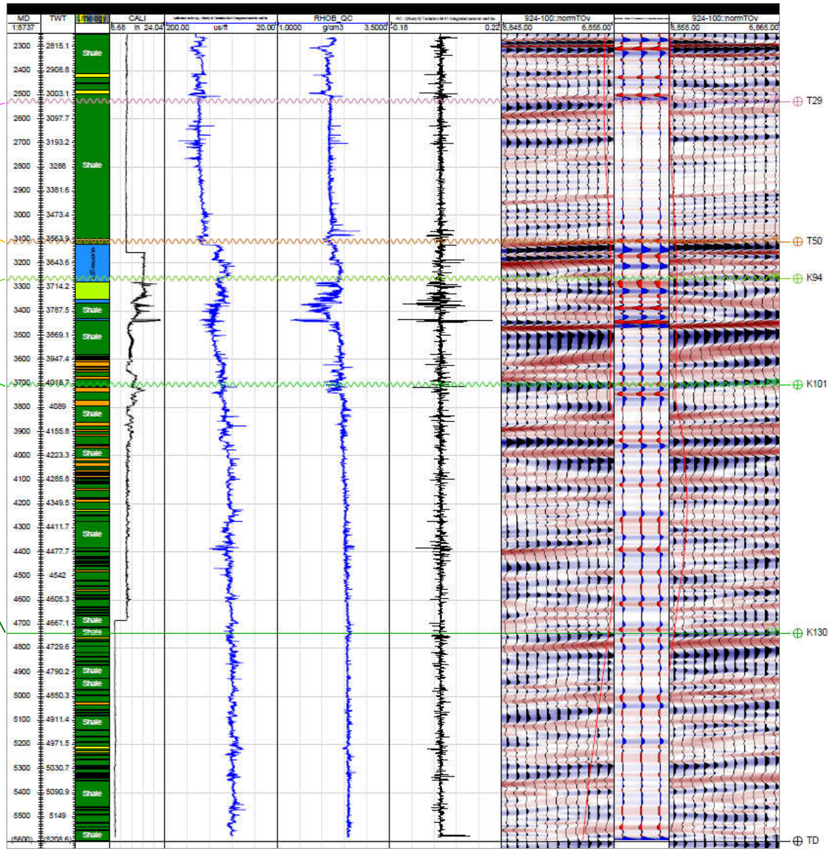

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |

# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Central Scotian Slope Study– CANADA – July 2016






| WELL HEADER | | |
|---|---|---|
| Well Name | Tantallon M-41 | |
| Rotary Table (R.T.) | 24 | |
| Total Depth (T.D.) | 5602 | |
| Geographic coordinates @surface | Lat: 43°50'55.96" | Lon: 58°22'23.99" |
| UTM coordinates (Zone **20N, NAD27**) | $X_{UTM}$ : 871898,03 | $Y_{UTM}$ : 4865286,04 |

| BIOSTRATIGRAPHY | RPSEnergy /PFA 2011 |
|---|---|

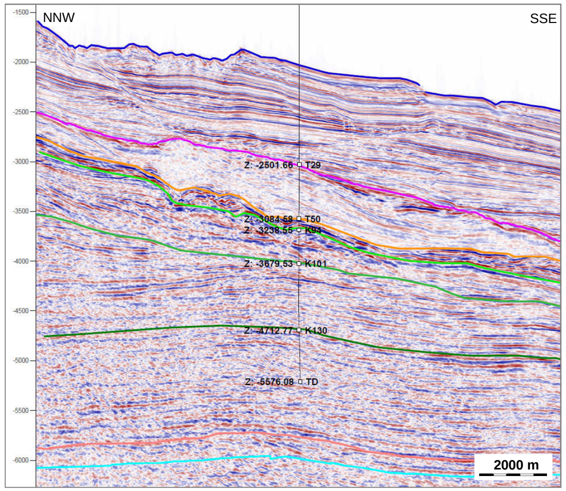
| SEISMIC LOCATION | |
|---|---|
| Survey | 2D line **TGS** |
| Line | 924-100::normTov |
| Trace | |
| Offset (m) | 500 |

**SEISMIC MARKERS**

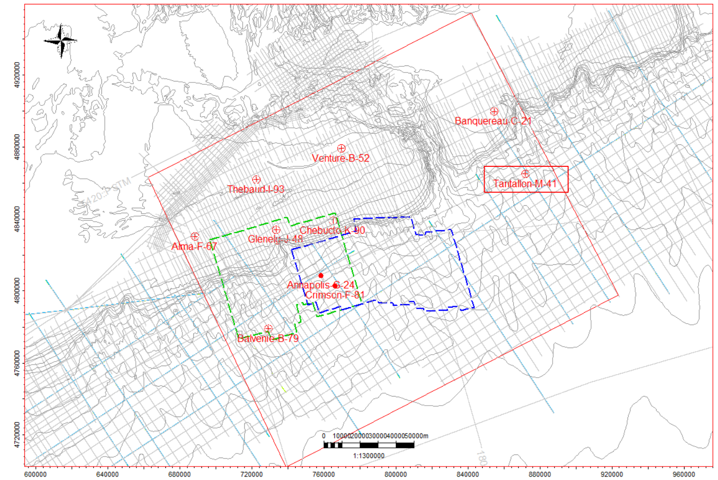
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | 1955 | 1516 |
| T29 | Mid-Oligocene Unconformity | 3031 | 2502 |
| T50 | Base Ypresian Chalk | 3577 | 3085 |
| K94 | Turonian / Cenomanian Unconformity | 3690 | 3239 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 4024 | 3680 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 4692 | 4713 |
| K137 | Berriasian / Valanginian Unconformity | Not reached | Not reached |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | Not reached | Not reached |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | Not reached | Not reached |

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |



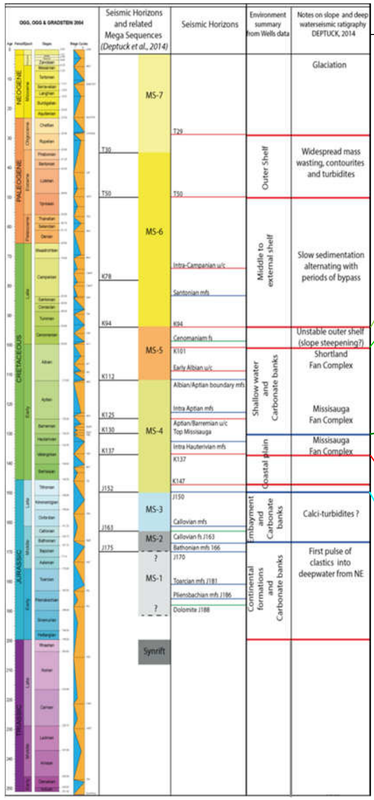

***Line 2D TGS*** 924-100::normTov
*Time Shift = 0 ms*

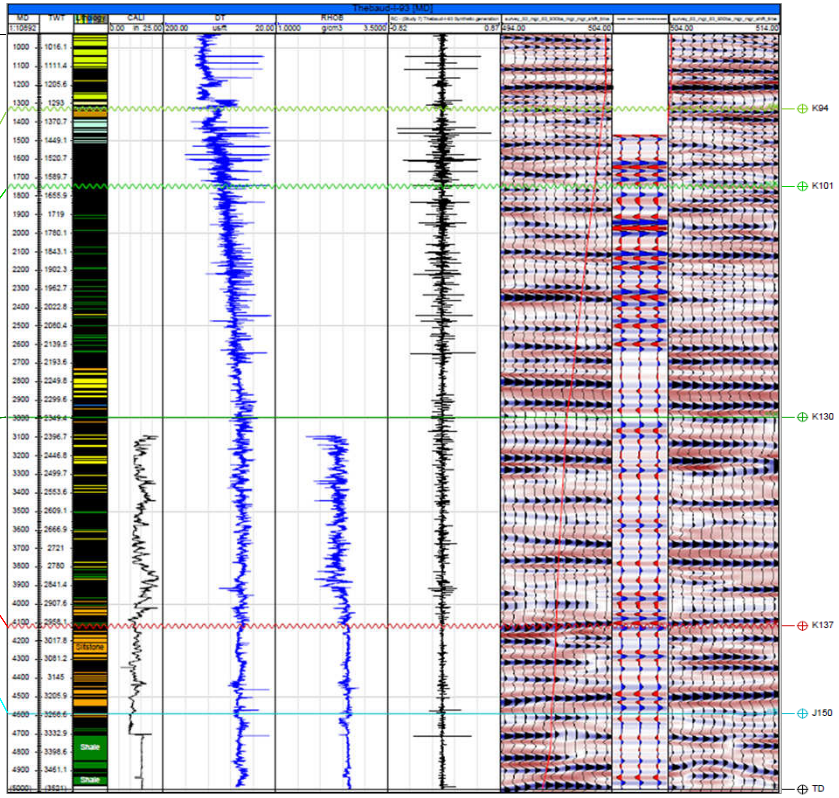



**PL. 4.2.1.8** **Tantallon M-41**

# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION






| WELL HEADER | | |
|---|---|---|
| Well Name | **Thebaud I-93** | |
| Rotary Table (R.T.) | 37 | |
| Total Depth (T.D.) | 5166 | |
| Geographic coordinates @surface | Lat: 43°52'44.54" | Lon: 60°13'50.94" |
| UTM coordinates (Zone **20N, NAD27**) | $X_{UTM}$ : 722477,31 | $Y_{UTM}$ : 4861950,09 |

| BIOSTRATIGRAPHY | RPSEnergy /PFA 2011 |
|---|---|

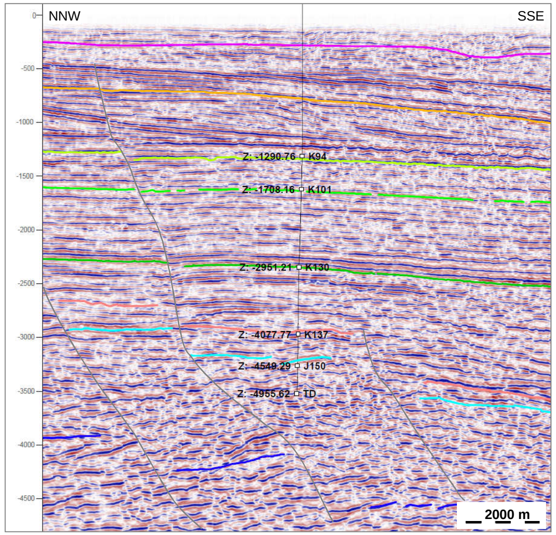
| SEISMIC LOCATION | |
|---|---|
| Survey | 83 MGR |
| Line | 930ba |
| Trace | |
| Offset (m) | 218 |

**SEISMIC MARKERS**

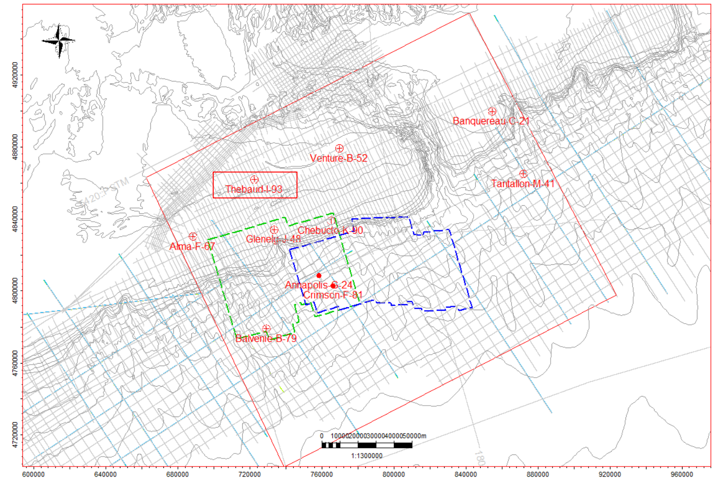
| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | No data | No data |
| T29 | Mid-Oligocene Unconformity | No data | No data |
| T50 | Base Ypresian Chalk | No data | No data |
| K94 | Turonian / Cenomanian Unconformity | 1365 | 1291 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 1664 | 1709 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 2370 | 2952 |
| K137 | Berriasian / Valanginian Unconformity | 2922 | 4078 |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | 3164 | 4549 |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | Not reached | Not reached |

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |

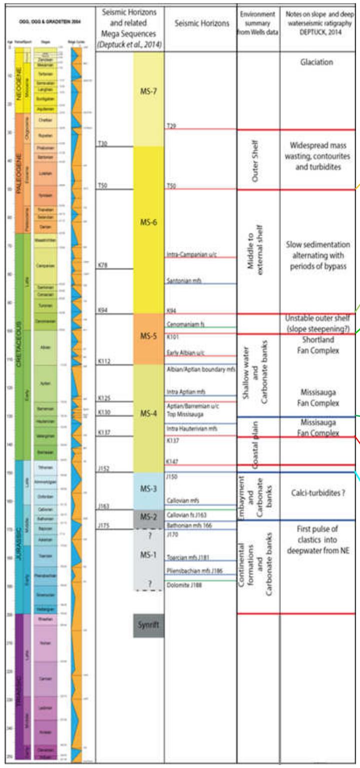


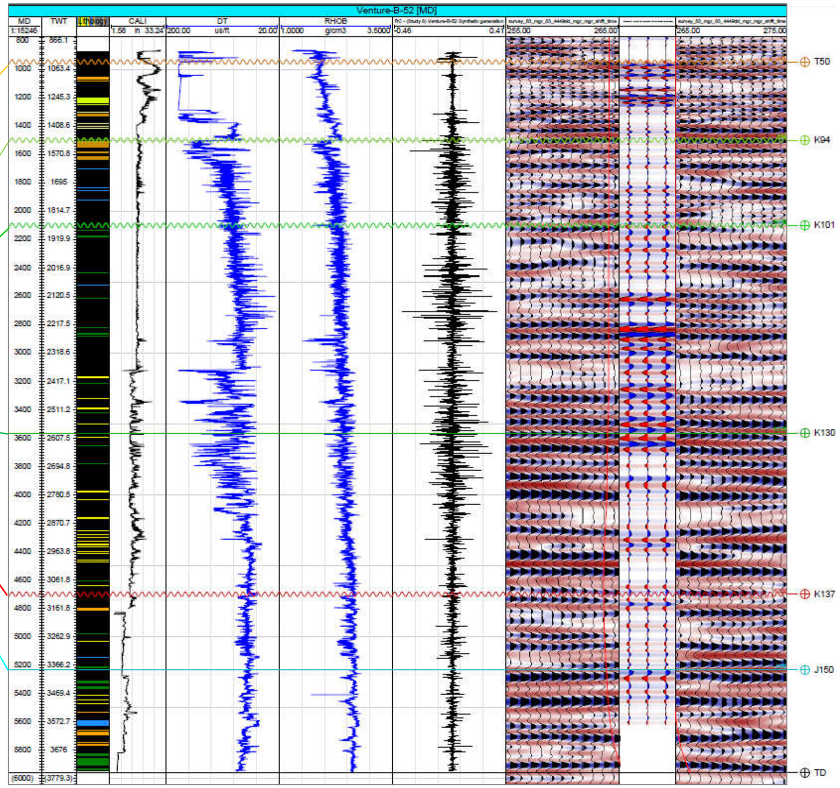

***Line 83 MGR*** 930ba
*Time Shift = 0 ms*

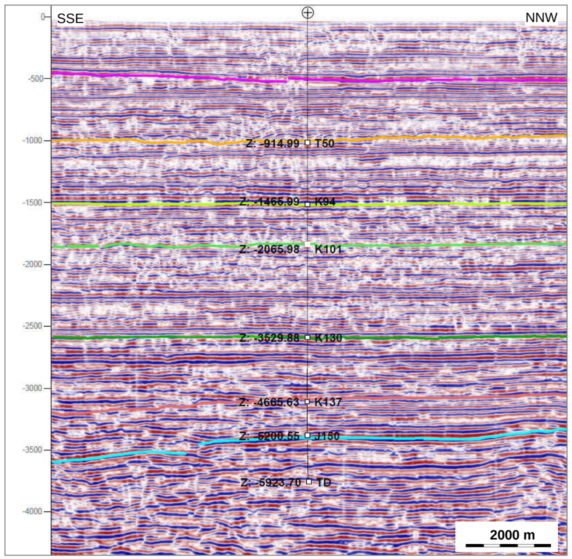


# SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION






*Line 83 MGR* 4449dd
*Time Shift = 0 ms*

Key:

| | |
|---|---|
| Claystone | T29 |
| Shale | T50 |
| Siltstone | K94 |
| Sandstone | K101 |
| Limestone | K130 |
| Marl | K137 |
| Chalk | J150 |
| | J163 |
| | J200 |

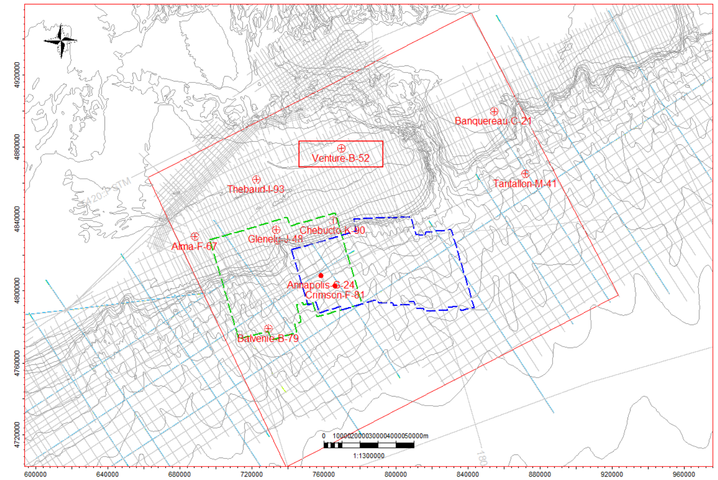
| WELL HEADER | | |
|---|---|---|
| Well Name | Venture B-52 | |
| Rotary Table (R.T.) | 34 | |
| Total Depth (T.D.) | 5960 | |
| Geographic coordinates @surface | Lat: 44°01'12.88" | Lon: 59°38'07.76" |
| UTM coordinates (Zone **20N, NAD27**) | $X_{UTM}$ : 769668,23 | $Y_{UTM}$ : 4879410,5 |

| BIOSTRATIGRAPHY | RPSEnergy /PFA 2011 |
|---|---|

| SEISMIC LOCATION | |
|---|---|
| Survey | 83 MGR |
| Line | 83_4449dd |
| Trace | |
| Offset (m) | 116 |

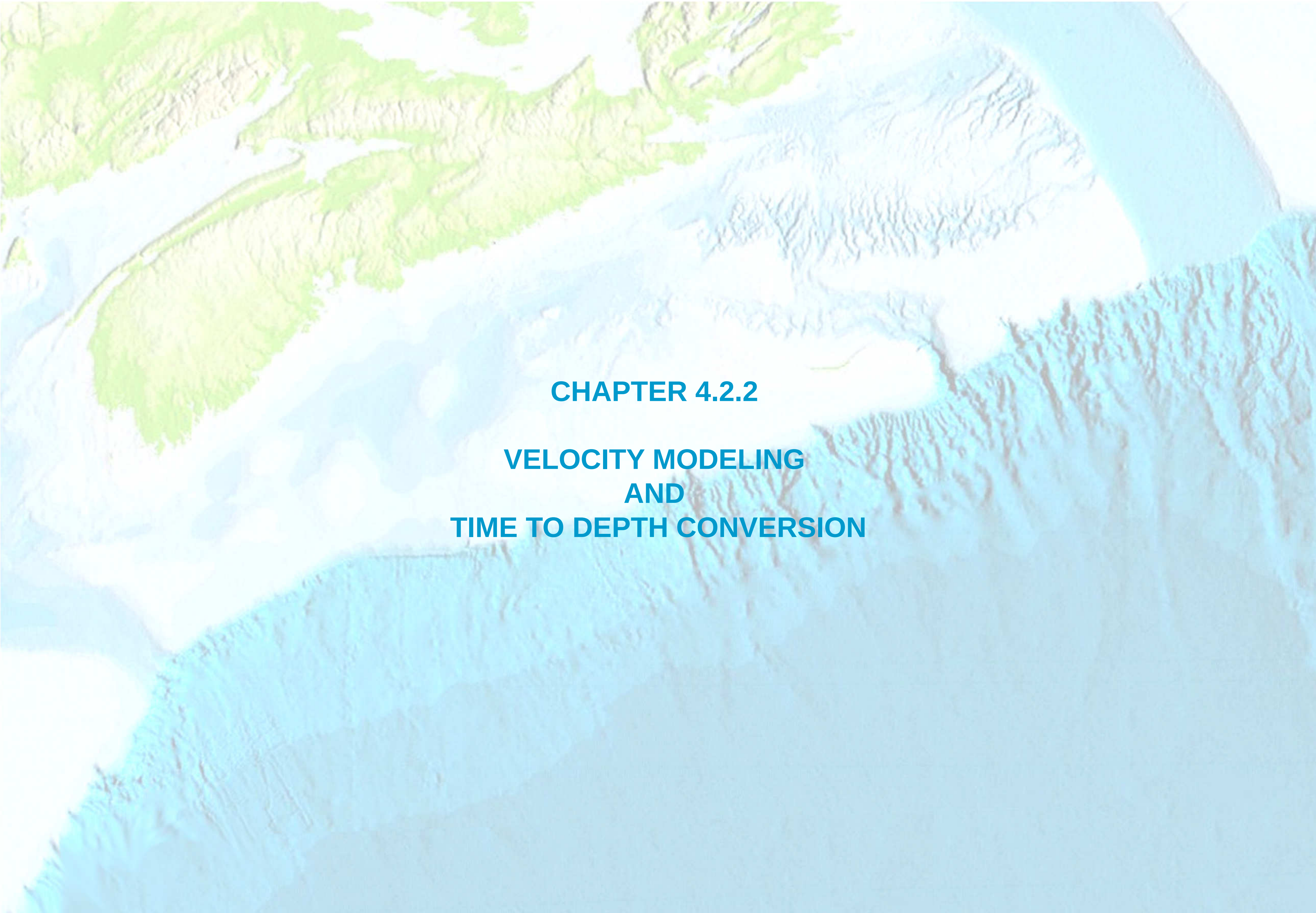
**SEISMIC MARKERS**

| Age (Ma) | Name | ms (TWT) | m (TVDSS) |
|---|---|---|---|
| 0 | Seabed | No data | No data |
| T29 | Mid-Oligocene Unconformity | No data | No data |
| T50 | Base Ypresian Chalk | 766 | 915 |
| K94 | Turonian / Cenomanian Unconformity | 1326 | 1466 |
| K101 | Late Albian Unc. (eq. Top Cree Mb) | 1636 | 1873 |
| K130 | Hauterivian MFS (eq. Near "O" Marker) | 2602 | 3530 |
| K137 | Berriasian / Valanginian Unconformity | 3111 | 4434 |
| J150 | Near Tithonian MFS (eq. Top Baccaro Mb) | 3463 | 5201 |
| J163 | Near Callovian MFS (eq. Top Scatarie Mb) | Not reached | Not reached |
| ~J200 | Top Autochthonous Salt | Not reached | Not reached |
| | Post Rift Base (eq. Top Eurydice Fm.) | Not reached | Not reached |






**Venture B-52**



# CHAPTER 4.2.2

# VELOCITY MODELING
# AND
# TIME TO DEPTH CONVERSION

## Velocity Modeling

A 3D velocity model was built within the survey area to obtain a conversion model from two-way time (TWT) to depth (Zss) domain. Ten wells are calibrated with confidence; the velocity model is primarily based on seismic velocities. The wells are used in a second step to calibrate the model on the platform.

### First Step: Seismic Velocity Gridding

(a) The velocity model was built using seismic velocities estimated from the velocity analysis of two seismic datasets: 10 TGS lines (Bible lines) reprocessed in 2009-10, four NovaSpan lines reprocessed in 2009-10 (Figure 4). The 2D lines are distributed over the entire area, including the deeper part of the study area where wells are absent;

(b) The kriging of the dataset was done with Isatis® resulting in a seismic velocity map for each horizon;

(c) These intermediary maps – “without well constraint” – maintain a good lateral variability, which in turn validates this approach. The main seismic velocity maps (in $m.s^{-1}$) are displayed below on the left side (Figure 5).

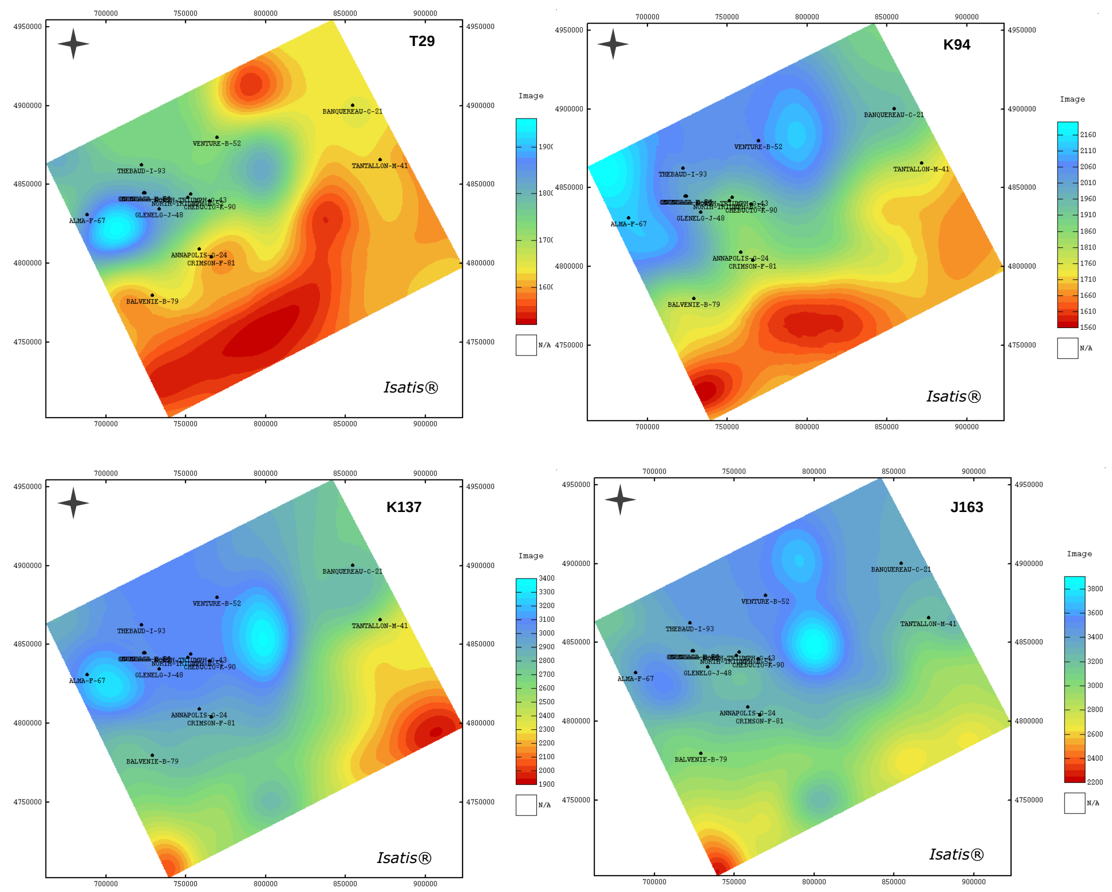



*Figure 5: Example of seismic velocity maps extracted from Isatis® for T29, K94, K137 and J163.*

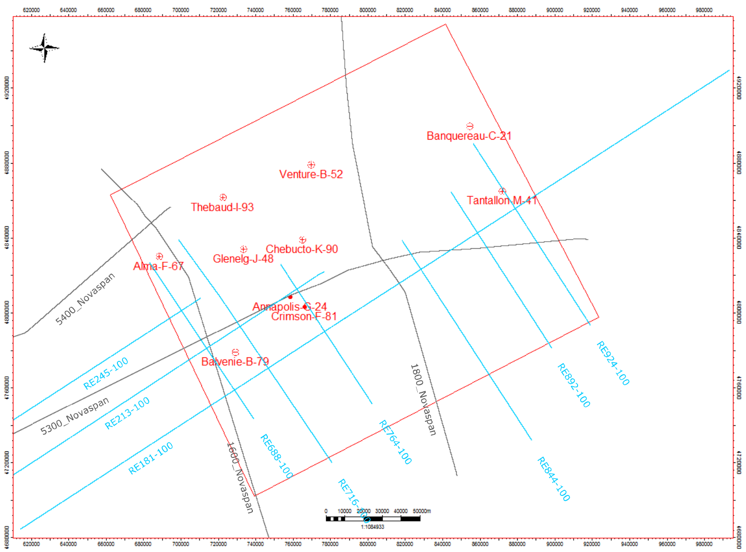



*Figure 3: Available data used for the velocity model: in blue the Bible velocity lines, in grey the Novaspan velocity lines, in red the wells available over the area and having a Time-Depth curve.*

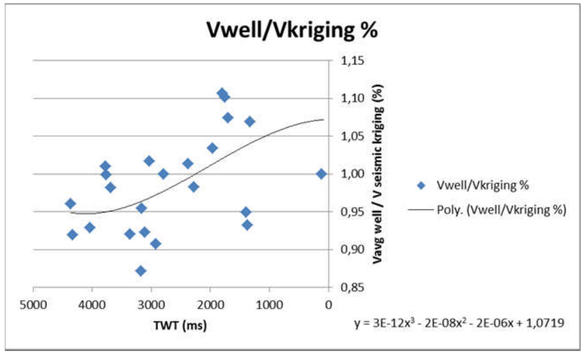
### Second Step: Global Correction of the Seismic Velocity Maps

(a) A dynamic correction was applied to each seismic velocity map: anisotropy values $V_{AvgWells}/V_{Seis}$ were estimated from each well;

(b) The distribution of the $V_{AvgWells}/V_{Seis}$ along the TWT is good: differences are </= 10% (Figure 6);

(c) Differences obtained between seismic velocities and average velocities from the wells allow estimates of the average anisotropy factor for each horizon (cf table);

(d) The average calculated anisotropy factors were applied on each seismic velocity map. This allows adjustment of seismic velocities with average velocities obtained from wells in order to compute the average velocity map for each horizon.




**Correction to apply to seismic velocity map for each horizon (%)**

| Horizons | Average AF |
|---|---|
| T29 | 0,995 |
| K94 | 1,002 |
| K137 | 0,906 |
| J163 | 0,900 |
| J200 | 0,900 |

*Figure 6: Distribution of anisotropy factor as a function of time (TWT). A distribution close to 1 indicates that well and seismic velocities are well correlated.*

**Third Step: Computation of Interval Velocity Maps**

(a) Computation of interval velocity maps from the average velocity maps;
(b) Interval velocity map editing.

**Fourth Step: Computation of the Velocity Model**

(a) Computation of the velocity model using the following horizons: Seabed, T29, K94, K137, J163 and J200 in Petrel®;
(b) The velocity model has been filled with interval velocities and constrained with interval velocities at well;
(c) Interval velocity maps have been quality controlled and re-edited, especially for the deeper horizons in the transition area ~~of~~ between the continental and oceanic crusts (COB);
(d) The velocity model allows conversion of all the horizons into the depth domain;
(e) For quality control the average velocity maps have also been re-calculated from the time maps and the newly depth-converted maps;
(f) The main average velocity maps (in $m.s^{-1}$) are shown on the right side.

**Fifth Step: Uncertainties of the Velocity Model**

(a) Calculation of the initial velocity model without well constraint;
(b) Plotting of the difference between the $\text{depth}_{\text{velocity model without well}}$ and the $\text{depth}_{\text{well marker}}$ vs its frequency to estimate the prediction error of the initial model (Figure 7);
(c) The graph below represents this distribution for all the horizons: 90% of the depth values show less than 8% of error.

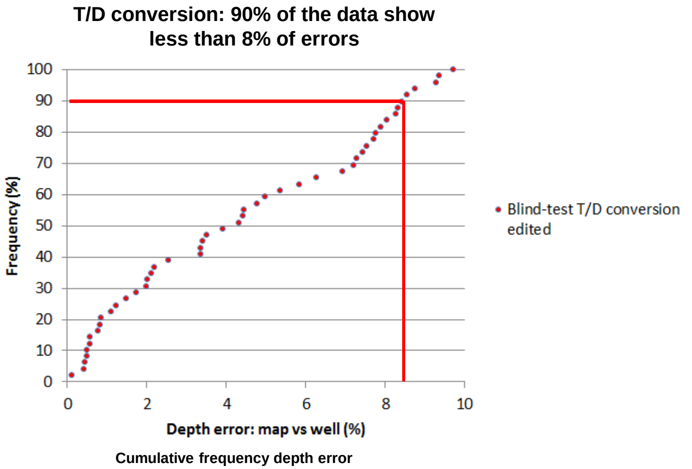



*Figure 7: Error distribution vs frequency.*

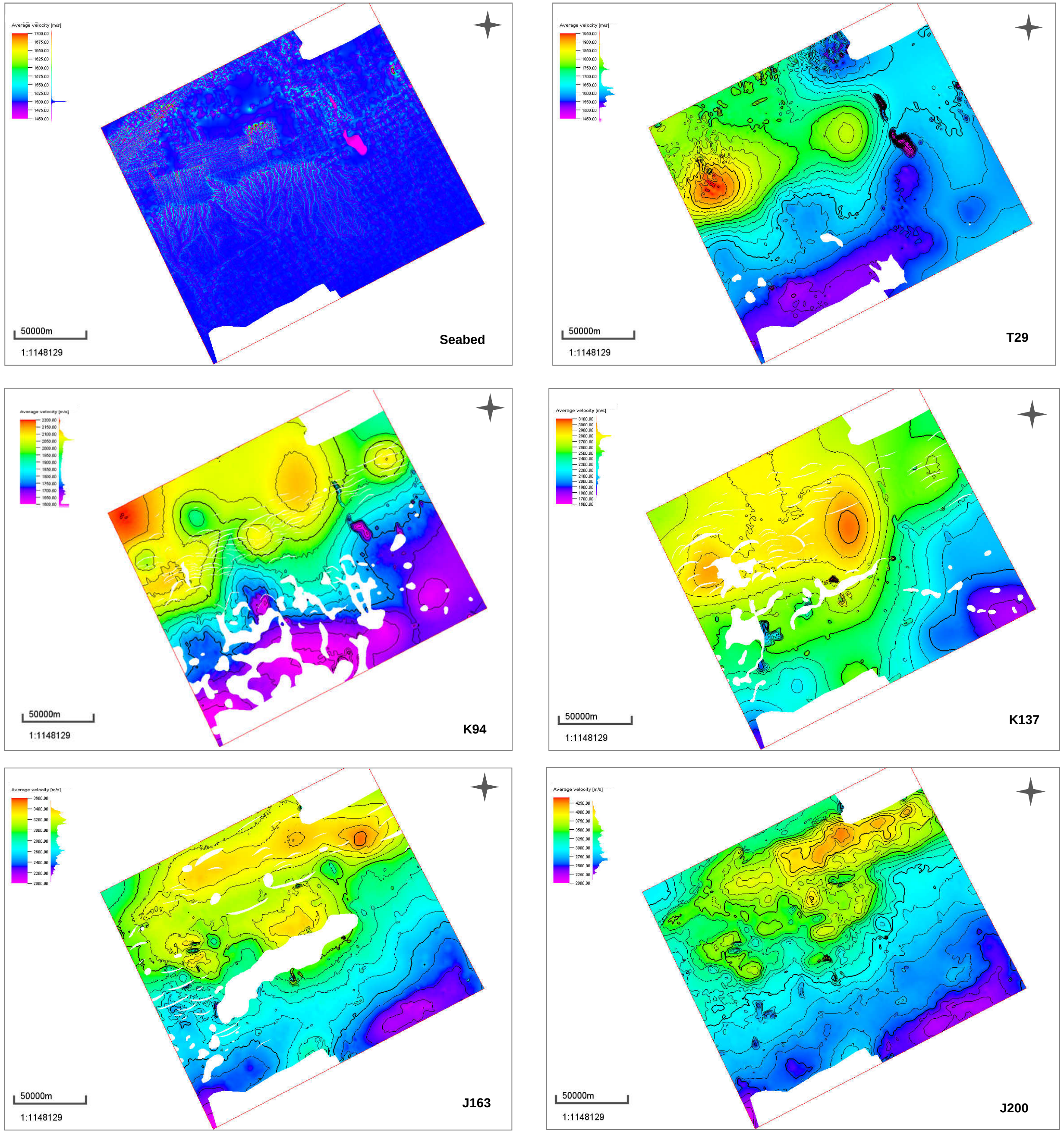



*Figure 8: Average velocity maps (m/s) along the 6 horizons used for the velocity model.*

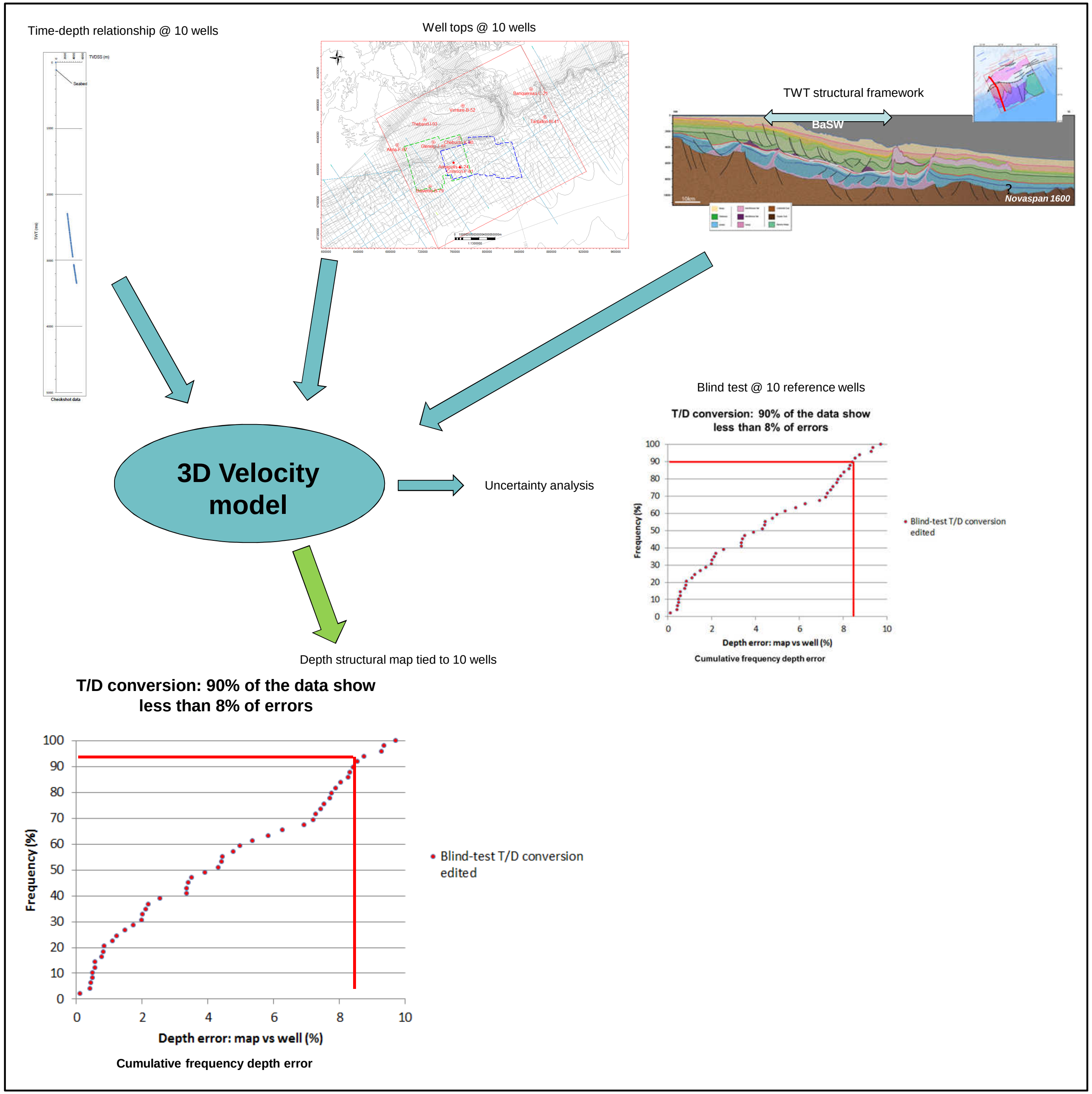



*Figure 9 : Time-to-depth conversion workflow with its uncertainty analysis*

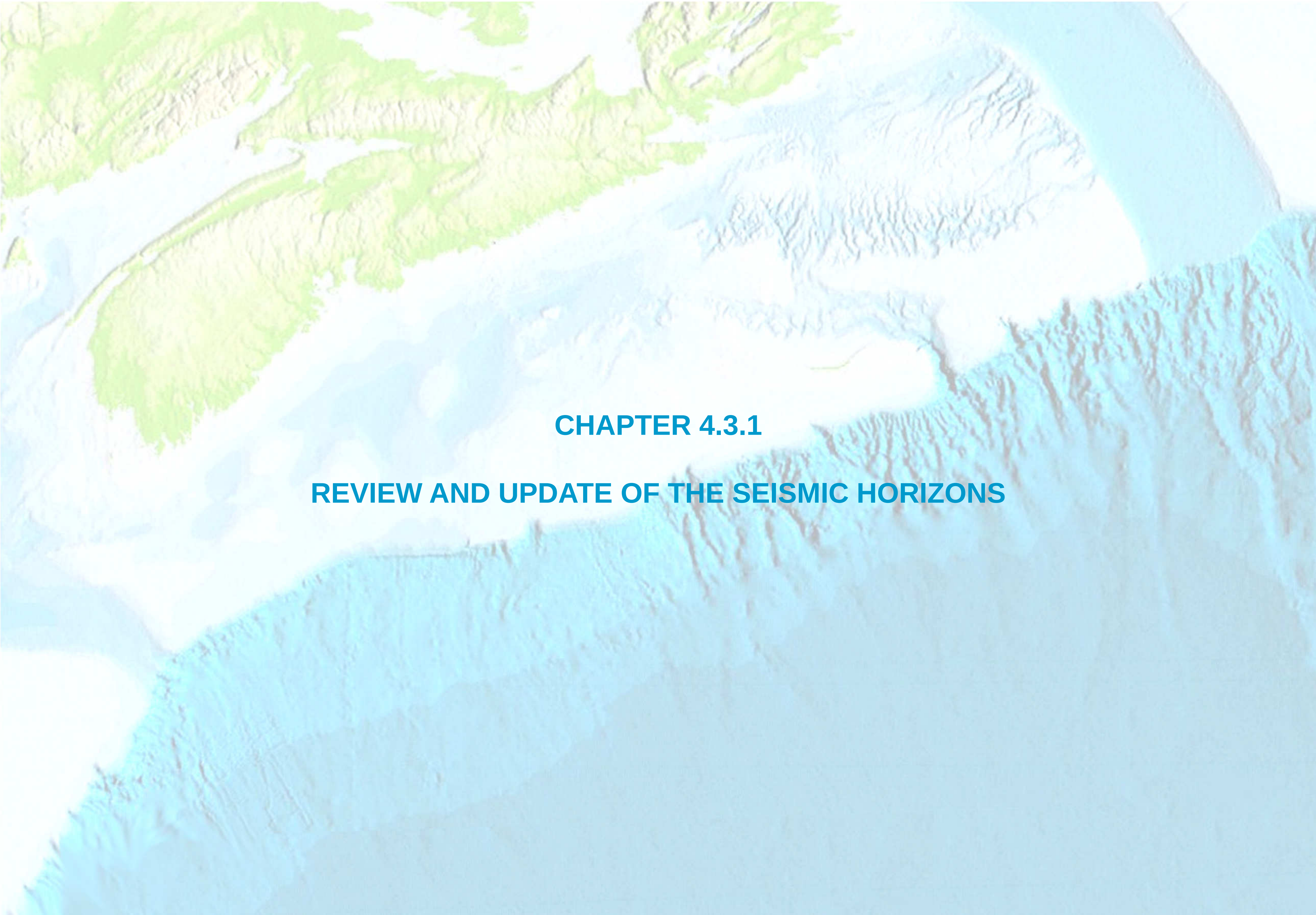
A 3D velocity model was built for the Annapolis Sub-basin, to depth convert the TWT surfaces resulting from the seismic interpretation of the 2D and 3D seismic datasets (see Section 4.2). Time-depth relationships from the calibration were used to constrain the time to depth conversion. The well tops of the 10 reference wells in the study area allow control of the velocity law at each interpreted horizon, and to estimate and predict the velocity error (Figure 9).

The final depth maps tie to the geological tops of the 10 reference wells. They are from top to bottom:

1. Seabed
2.T29 (Mid Oligocene Unconformity)
3. T50 (Base Ypresian Chalk)
4. K94 (Cenomanian Turonian Unconformity)
5. K101 (Late Albian Unconformity)
6. K130 (Hauterivian MFS)
7. K137 (Berriasian / Valanginian Unconformity)
8. J150 (Near Tithonian MFS)
9. J163 (Near Callovian MFS)
10. Base of Post-Rift sediment (J200)

# CHAPTER 4.3

# STRUCTURAL MAPPING



# CHAPTER 4.3.1

# REVIEW AND UPDATE OF THE SEISMIC HORIZONS

**Review and Modifications of the Seismic Interpretation**

This area was mapped as part of the 2009-2011 PFA study. Since then a need has arisen to re-interpret the J150 horizon in light of a new interpretation proposed by the CNSOPB in 2014 (PL 4.3-2).

Revision of the seismic interpretation of the J150 and K137 horizons, and updates where needed of the 9 other horizons was undertaken on the Veritas Speculative 3-D survey, the Marathon Exclusive survey and the available 2-D lines (approximately 2500 km of 2D lines are located within the study area).

The new mapping was based on the interpretation carried out by Beicip-Franlab in 2011 in accordance with the formation tops, stratigraphic packages and sequences identified at the wells.

Local updates were performed on some horizons, especially for the K94, K101 and K130, to improve and complete the picking when necessary (Figure 1).

The major improvements were realized on Veritas and Marathon 3D seismic cubes and in the area between the 3D and 2D data to improve the link between both interpretations.

Moreover, in 2011, interpretation was not undertaken in the area of poor seismic data coverage (Figure 2). To improve the interpretation and avoid crossing horizons when extrapolating between two points without data, horizon interpretation was propagated.

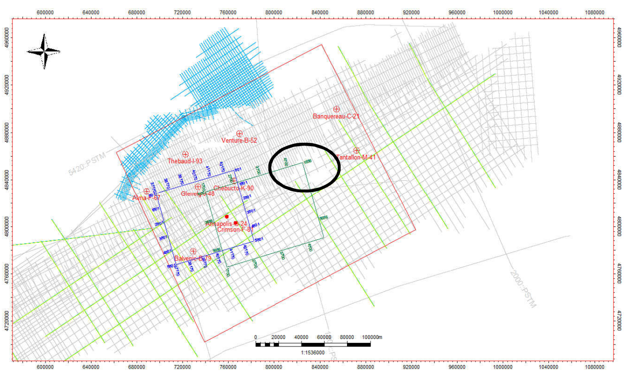


*Figure 2: Seismic coverage on the study area (2D and 3D data). The black circle shows the area of poor seismic data coverage.*

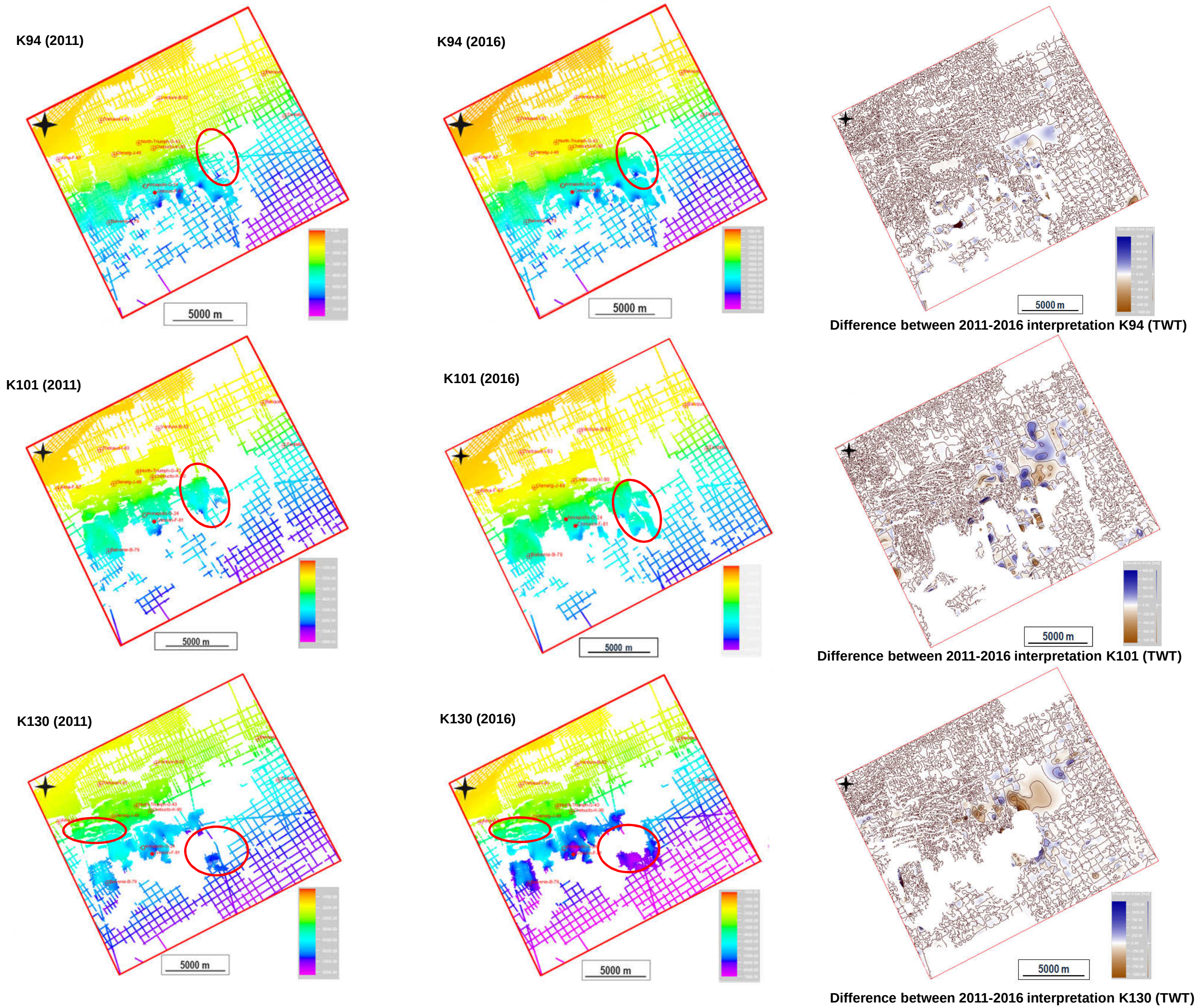



*Figure 1: Update and review of the 2011 interpretation for three Cretaceous horizons (K94, K101 and K130) and maps of differences in time between 2011 and 2016 interpretations (the areas with no interpretation represent salt).*

**Interpretation of J150 by CNSOPB (2014) Deptuck et al., 2014**

Two interpretations of the J150 were made in 2011, a "deep pick" for OETR (PFA 2011) and a "shallow pick" by CNSOPB (Deptuck et al., 2014). The first change regarding the interpretation of J150 was induced by the choice of timing of the Banquereau Synkinematic Wedge (BSW). Two different interpretations have been proposed for its timing. The first scenario was proposed by OETR in 2011 with "*the BSW as a Berriasian feature that is largely time-equivalent to the lower parts of the Missisauga Formation. With this timing, the near top Jurassic marker (J150) is carried below the BSW, and the BSW is largely synchronous with the Avalon Uplift*".

*"In contrast,* CNSOPB *interpret the BSW as a primarily Middle to Upper Jurassic element that is time-equivalent to the Mic-Mac Formation. In this scenario, the top Jurassic marker is correlated above the BSW, and the BSW largely pre-dates the later Jurassic development of the Avalon uplift"* (Deptuck et al., 2014). Since 2014, the latter scenario is favored, and the near top Jurassic marker is interpreted above the BSW (as interpreted in the transect below, Figure 6).

Moreover, the OETR 2011 interpretation induces some important variations in thickness between the Jurassic and Cretaceous intervals, not justifiable according to the geological history and the filling of the deep Annapolis Sub-basin. Both thickness maps presented on the right side of this slide show the thickness variations between the Jurassic and Cretaceous intervals with the 2014 CNSOPB interpretation (Figure 4 and 5). These two maps are consistent with the thickness variations linked to the BSW and Balvenie Wedge and filling of Sable Sub-basin.

Following from these observations, Beicip-Franlab proposed a new interpretation of the J150 horizon, consistent with the 2014 CNSPOB interpretation in order to homogenize the interpretation along all the sub-basins and to be consistent with the proposed geological history Figure 3).

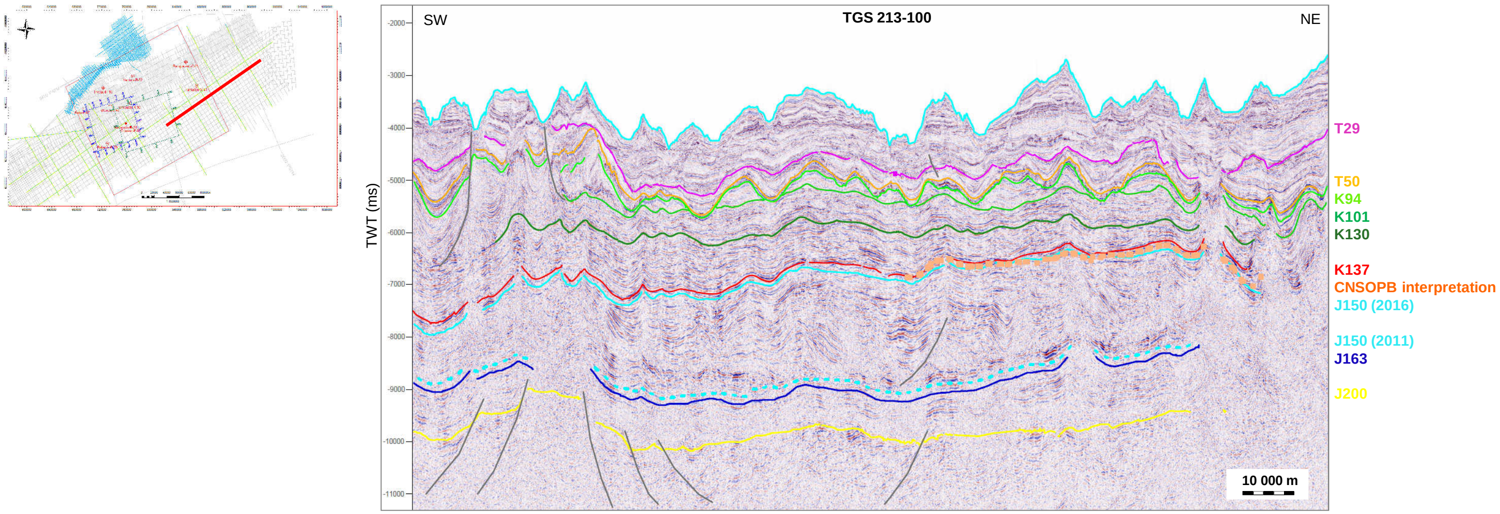



*Figure 3: Profile crossing the BSW and showing J150 CNSOPB interpretation vs J150, 2011 Beicip-Franlab interpretation* ***(TGS 213-100).***

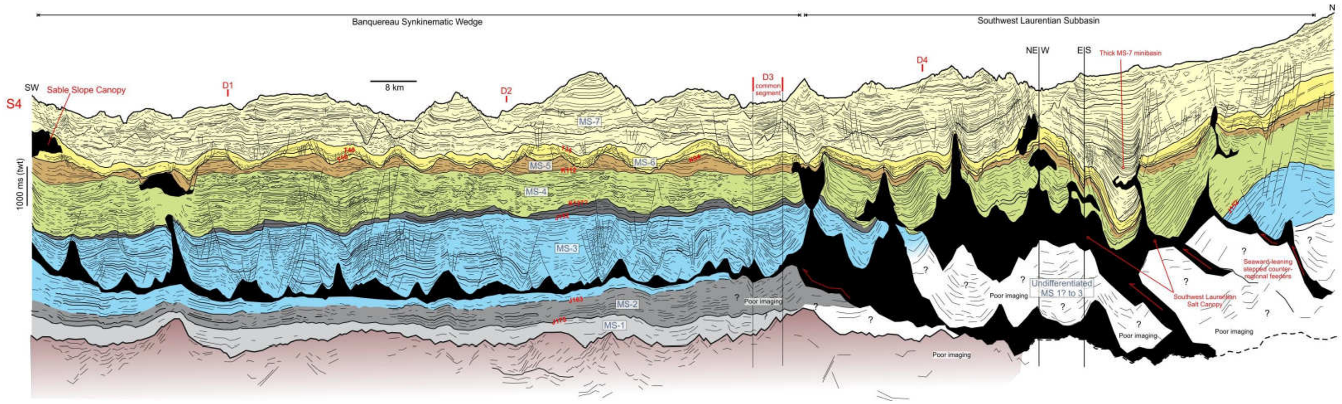



*Figure 6: Profile crossing the BSW and passing through the southwest Laurentian Sub-basin (Figure 12 from Deptuck et al., 2014).*

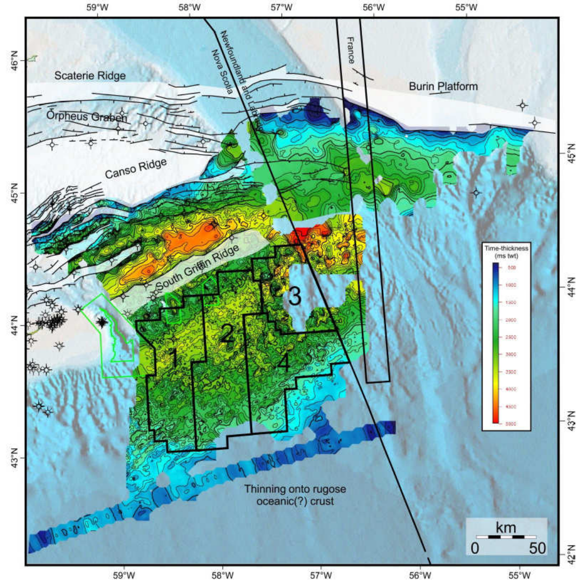



*Figure 4: Time thickness map, "on the shelf, the map is between the J152 marker and a marker correlated near the top of synrift succession; on the slope, the map is between the J152 marker and the top of the rugose basement" (Deptuck et al., 2014).*

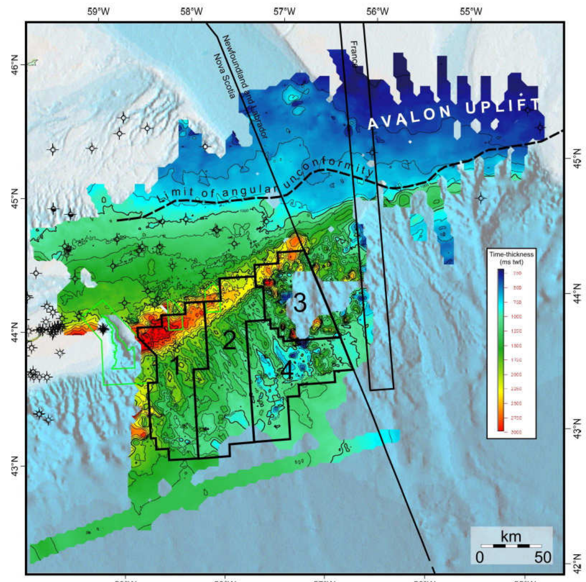


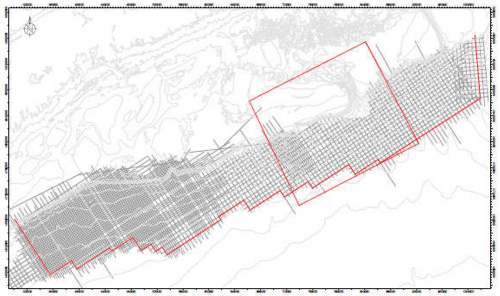

*Figure 5: Time thickness map between the J152 and K94 markers (Deptuck et al., 2014).*

**Interpretation of J150**

**Seismic picking**

A wide transect was generated, crossing the entire Nova Scotia Margin from Shelburne Sub-basin to Laurentian Sub-basin in the deeper part to avoid the salt canopy impact (Figure 7). This transect was used as a base to perform the new interpretation of J150, to homogenize the entire area and to obtain a regional understanding.
The new interpretation of J150 was performed in order to:

- Homogenize the J150 interpretation with Shelburne and Laurentian Sub-basins completed by Beicip-Franlab in 2014 and 2015, in accordance with the J150 interpretation proposed by CNSOPB;
- Be more consistent in terms of thickness (Figure 8). The 2011 Beicip-Franlab interpretation of J150 resulted in thickness anomalies between the Cretaceous and Jurassic, while the deeper Annapolis Sub-basin presented significant sediment deposits.
- Please note the approximate location on the map of where the 2011 J150 agrees with the 2016 J150. This will clearly show the area of the change.



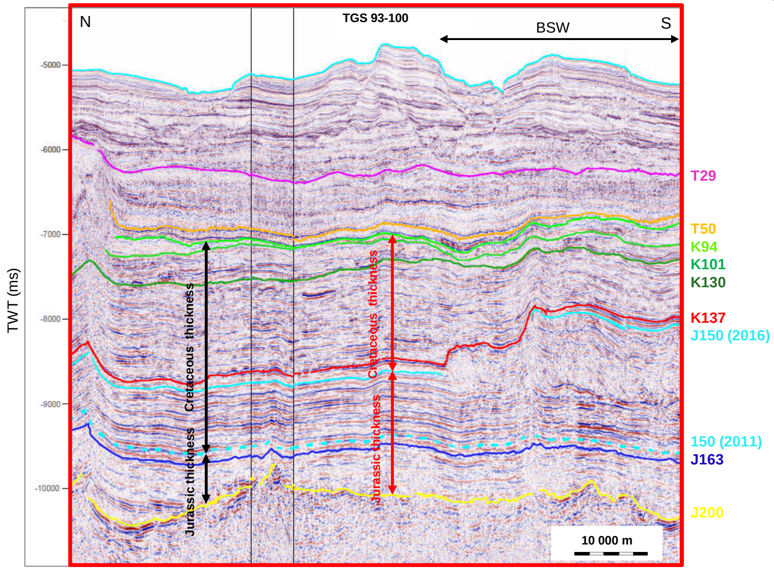



*Figure 8: Profile crossing the BSW and Annapolis Sub-basin with new J150 interpretation and its impact on the thickness variations between the Cretaceous and Jurassic intervals.*

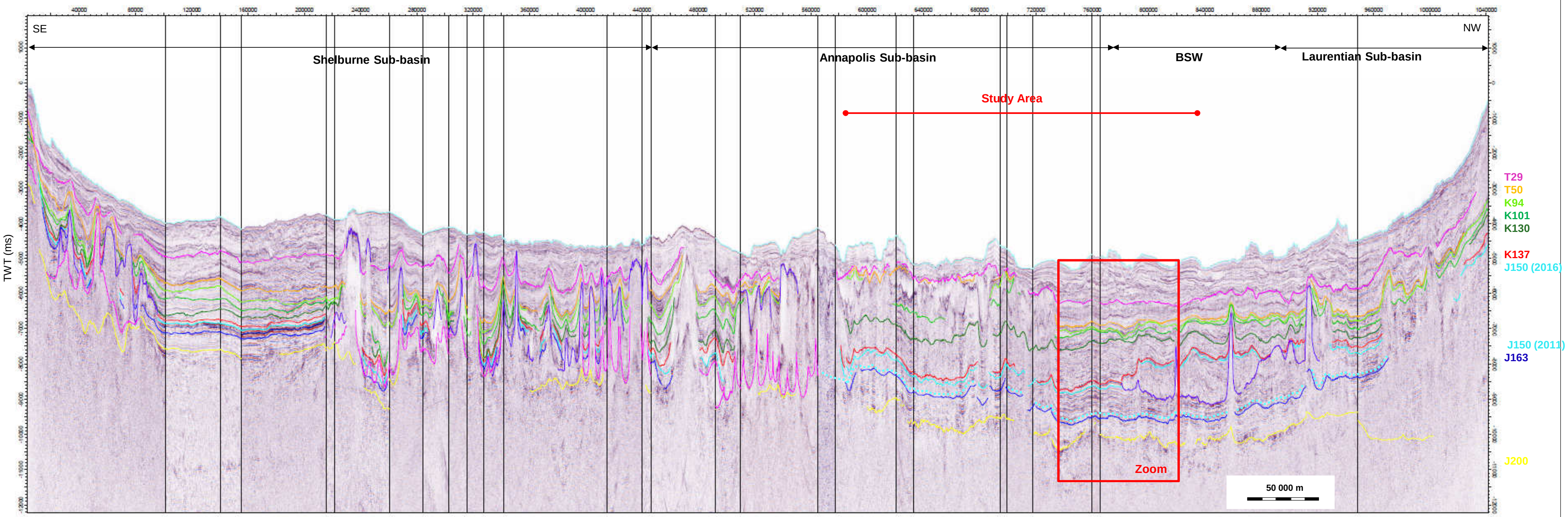



*Figure 7: Transect crossing the margin from Shelburne sub-basin to Laurentian sub-basin giving a global overview of the new seismic interpretation of J150.*

### Interpretation of J150

**Seismic picking**

According to the transect (Figure 7), the new interpretation was performed along the Annapolis Sub-basin and in the BSW area.

Figure 9 presents a transect in the central part of the study area. The 2011 and 2016 the J150 interpretations have not been changed on the shelf because they are controlled by wells. In 2016, Beicip-Franlab decided to increase the thickness of the Jurassic interval in the deeper slope area and homogenize the interpretation with the shelf domain.

In the BSW area (Figure 10), the new J150 interpretation is located above the BSW implying a change in the timing of deformation. The BSW produced a thickening of the series linked to the gliding of the sediments. Therefore, the change from a picking of the J150 below the gliding surface to a picking of the J150 in the upper part of the BSW results in an important difference of thicknesses between 2011 and 2016 maps, as shown by the Figure.

The entire interpretation of the J150 horizon has been changed except on the shelf and upper slope areas, which as noted is controlled by wells. The difference map between the 2011 and 2016 interpretations (Figure 11) shows the major discrepancies located especially in the BSW and Balvenie Wedge areas. In the Balvenie area, the changes are linked to a new interpretation of the Balvenie Synkinematic Wedge.

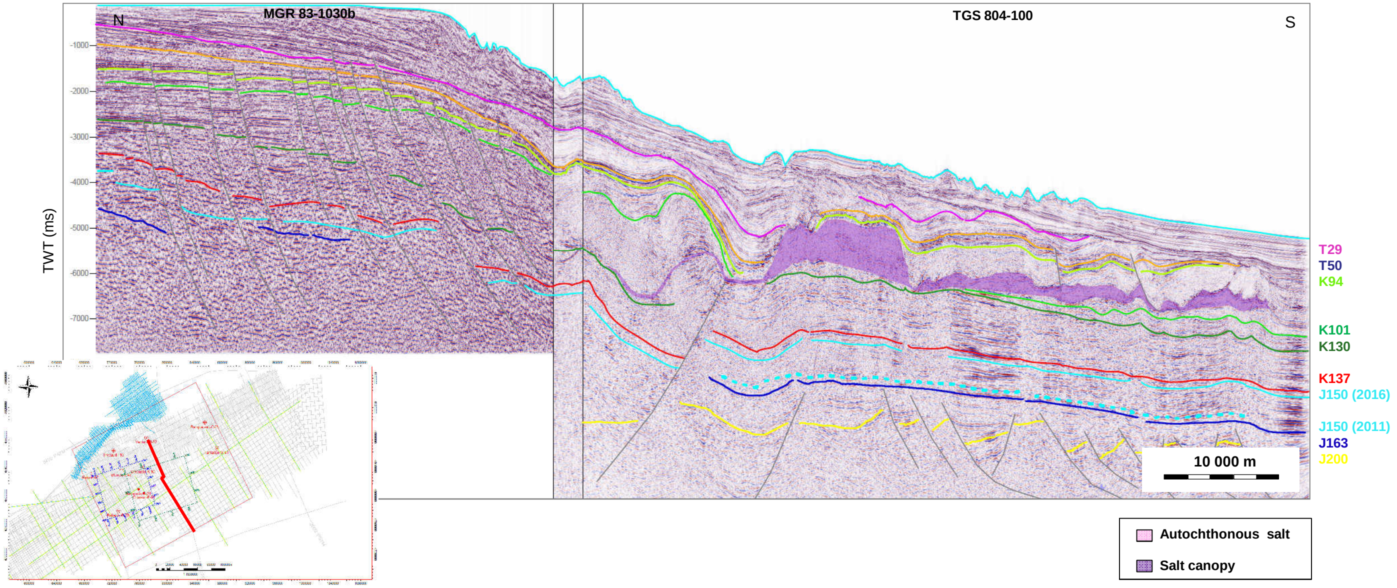



*Figure 9: Transect crossing the margin from the shelf to the deep basin in the central part of the study area, and comparing the 2016 J150 interpretation with the 2011 interpretation.*

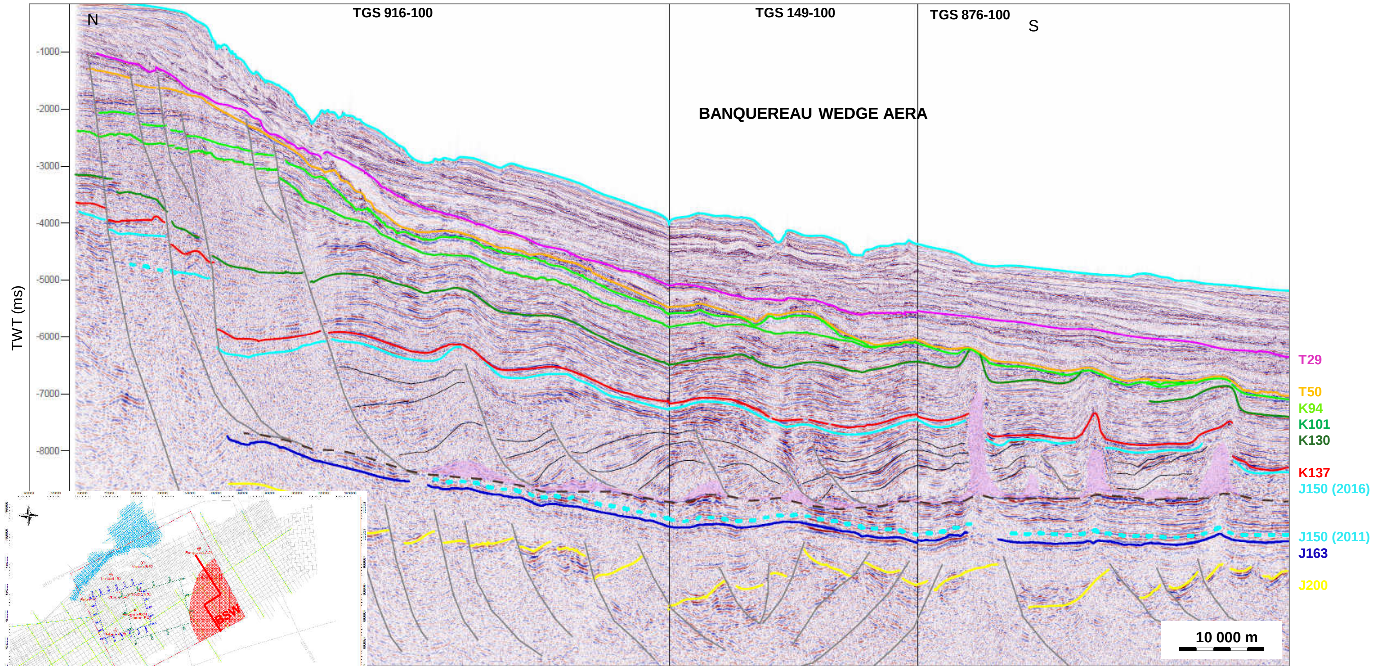



*Figure 10: Transect crossing the Banquereau Synkinematic Wedge in the western part of the study area.*

Allochthonous salt

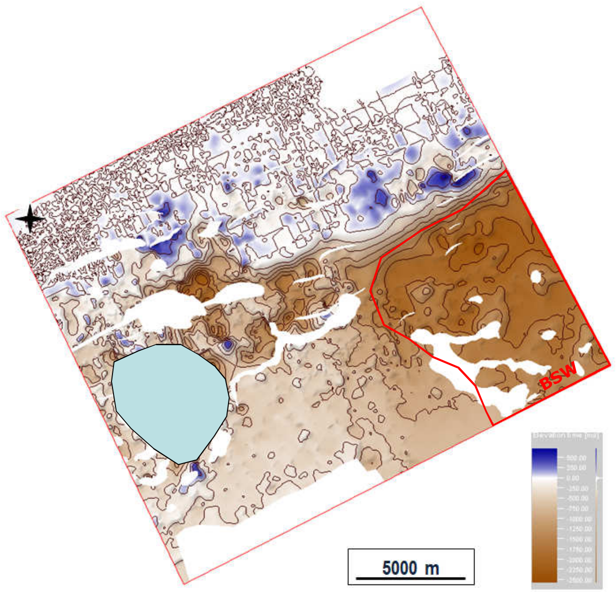



*Figure 11: Thickness (time) difference between 2011-2016 interpretation of J150.*

# Comparison of Depth Maps from 2011 vs 2016

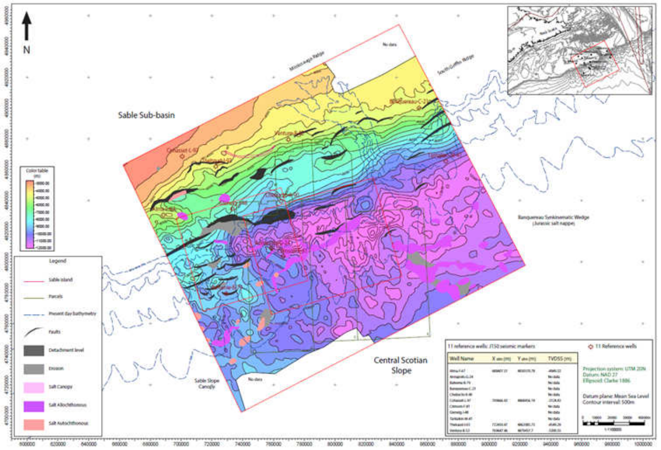



*Figure 12: Depth maps of J150 horizon in 2011 (Top Tithonian - in meters).*

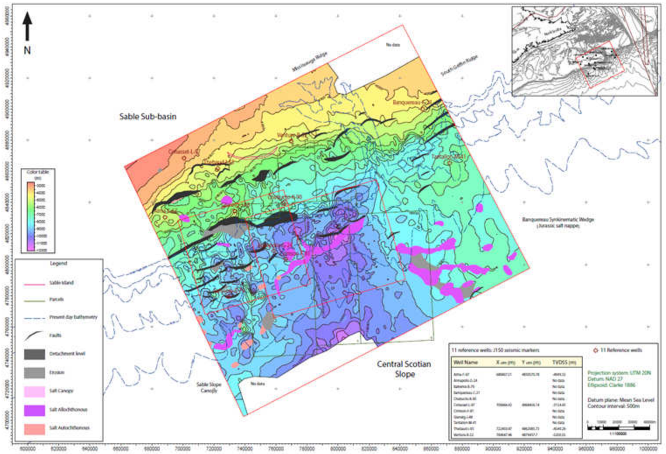



*Figure 13: Depth maps of J150 horizon in 2016 (Top Tithonian - in meters).*

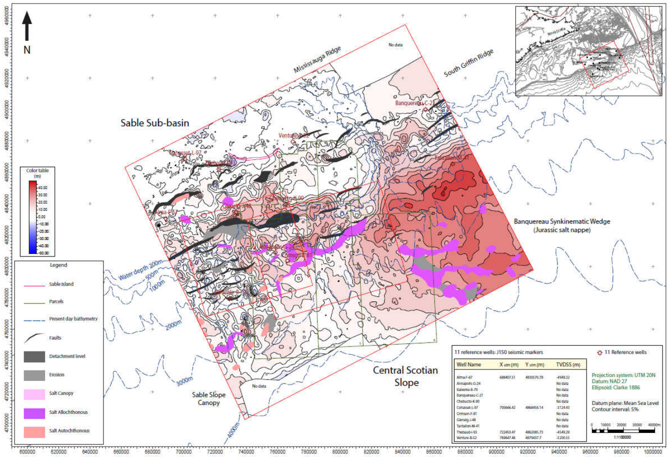



*Figure 14: Thickness difference between 2011-2016 interpretation of J150 (in meters).*

### K137 and J163 Interpretations

Interpretation of J150 requires updating and adjusting the 2011 interpretation of the two bounding horizons: K137 and J163. Figures 15 and 16 present the 2011 vs 2016 interpretation highlighting the improvement of the picking and a better understanding of the Balvenie Synkinematic Wedge geometry and timing. Most of the changes for both horizons have been done in the Veritas cube in the Balvenie Wedge area, as shown on Figure 17 which presents maps of difference between the 2011 and 2016 interpretations for both the K137 and J163 horizons.

In 2011, in the Balvenie Wedge area, the K137 (Valanginian) was merged with an important detachment level (Figure 18) and the horizons below this detachment missed the tilted blocks geometry. In the new interpretation the K137 is below the detachment level and shows tilted fault block structures. In some areas, the K137 is deformed by the Balvenie slide sediments (above the detachment level) and so interpretation is not possible. This 2016 interpretation is in agreement with geological features (faults and detachment). The horizons on top of the detachment are affected by growth faults induced by downslope sediment movement.

The J163 (Callovian) was not interpreted in the Veritas 3D seismic cube, except on a few lines. The 2011 interpretation did not respect the faults and did not follow the geometry of the reflections. In this study, horizon interpretation was corrected and propagated over the entire cube, respecting the seismic reflectors and the “fishbone” geometry.

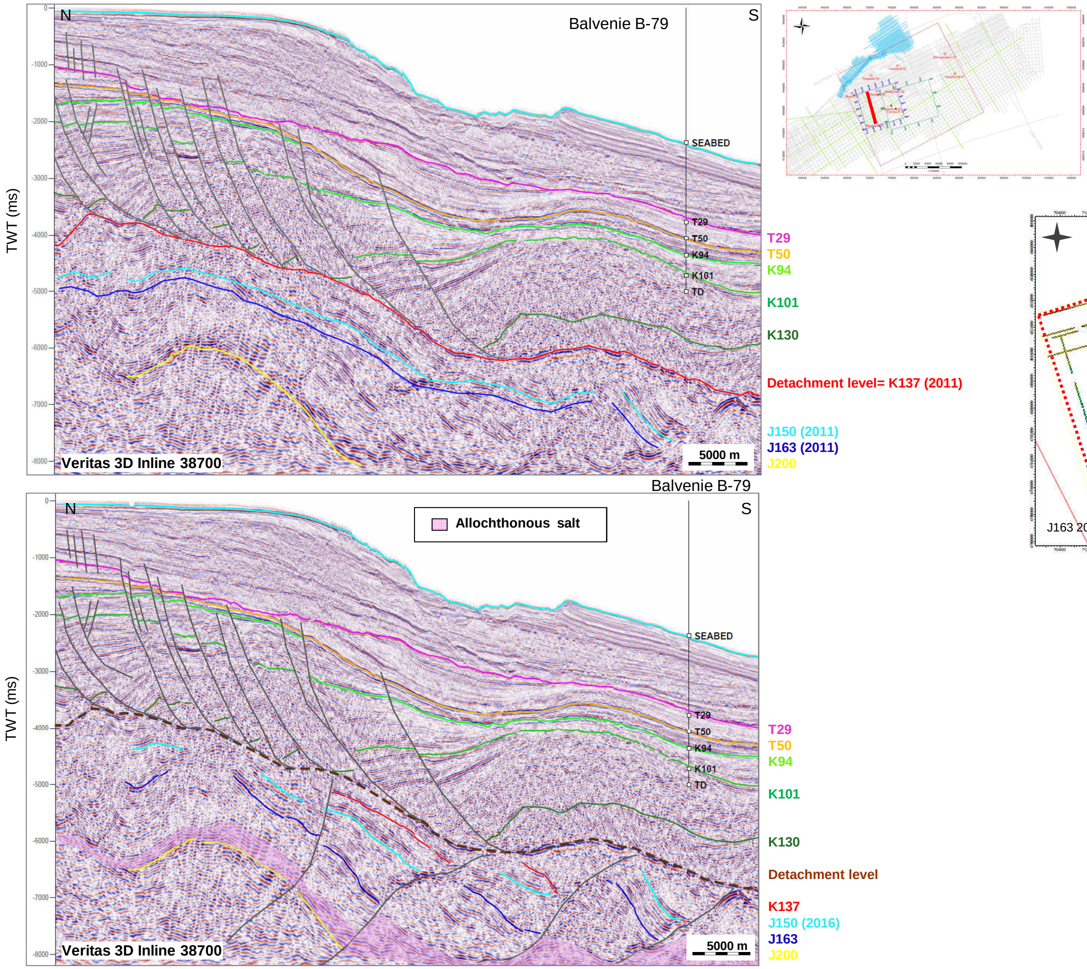



*Figure 18: Comparison between 2011 and 2016 interpretations for K137, J150 and J163 horizons in the Balvenie Wedge area.*

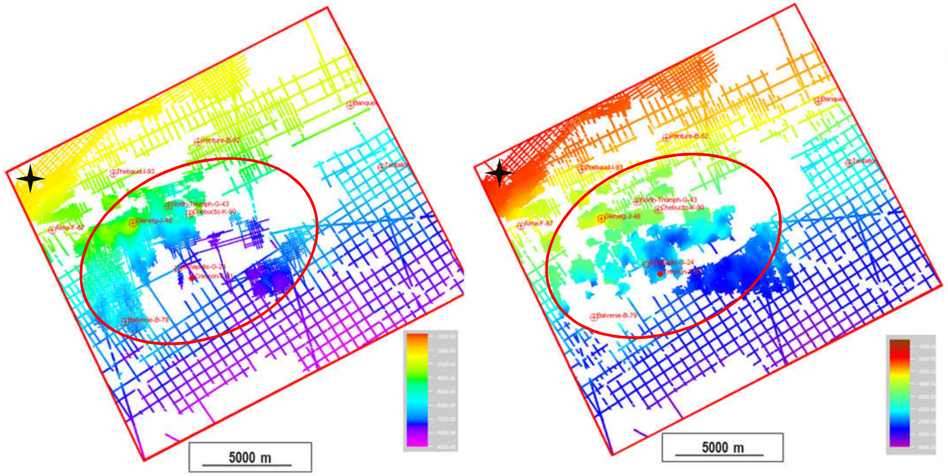



*Figure 15: Update and review of the 2011 interpretation for K137 horizon (TWT).*

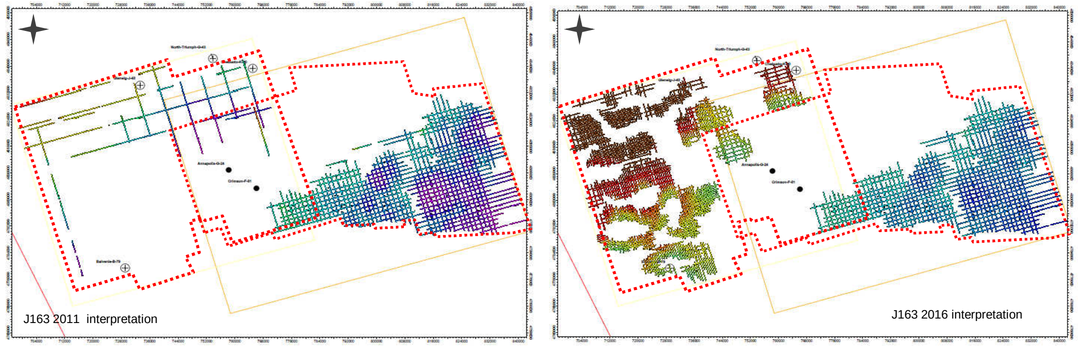
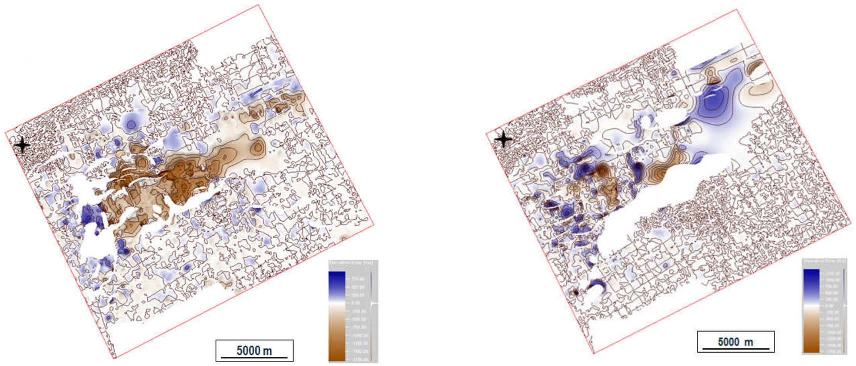



*Figure 16: Update and review of the 2011 interpretation for K163 horizon (TWT).*

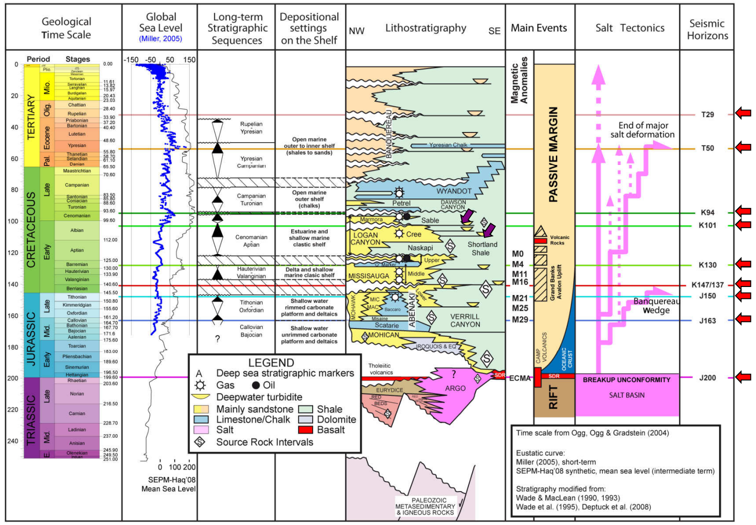



**Difference map between 2011-2016 interpretation K137**

**Difference map between 2011-2016 interpretation J163**

*Figure 17: Maps of differences in Two Way Time (TWT) between 2011 and 2016 interpretations.*

**Tectono-Stratigraphical Chart**



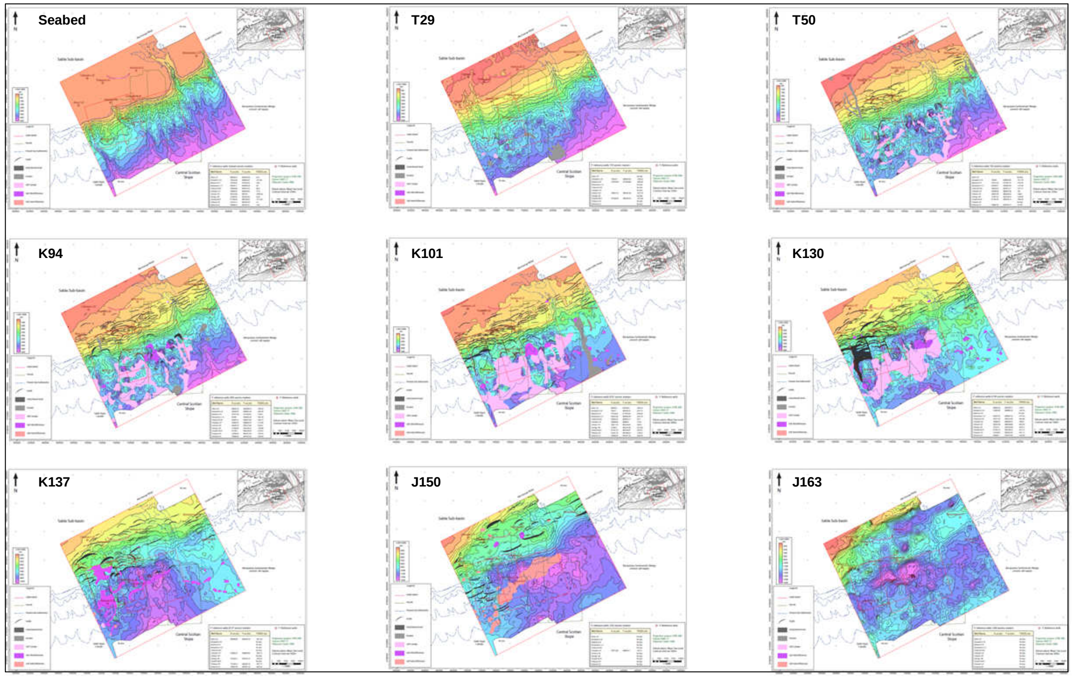




*Figure 19: Tvdss map of the interpreted horizons.*

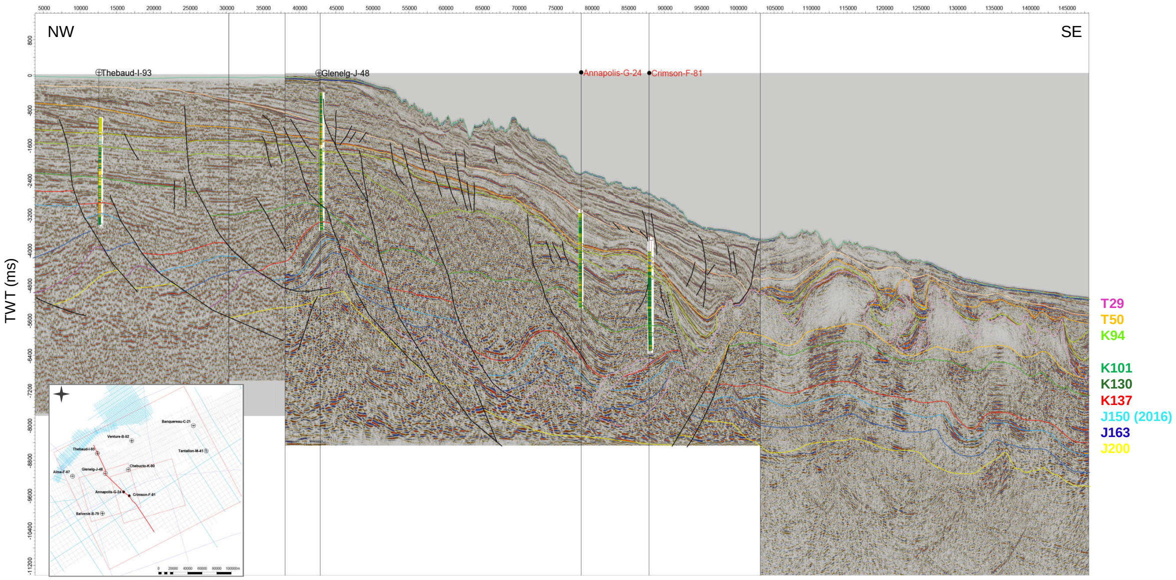
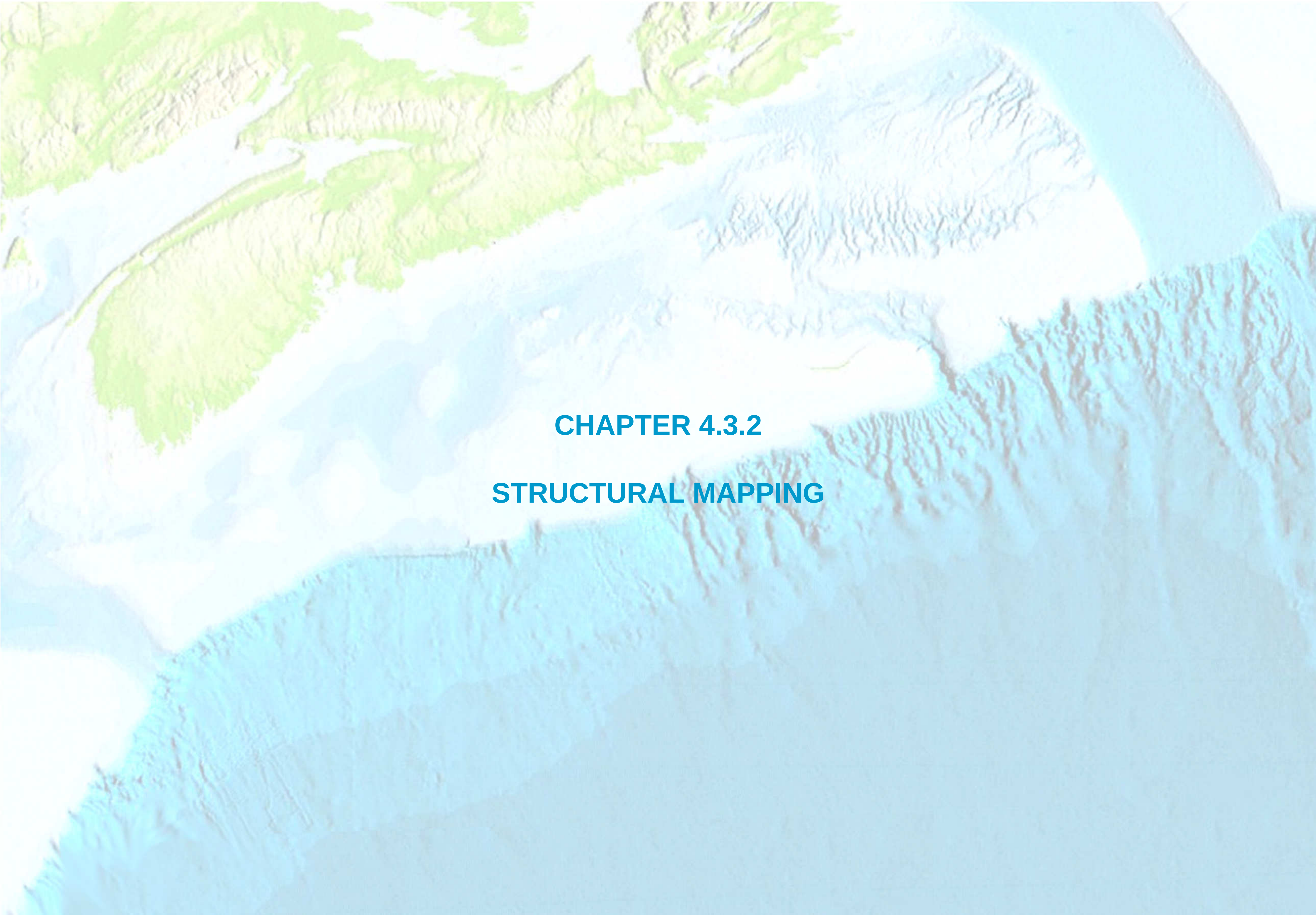



*Figure 20: Transect in the central part of the study area showing all interpreted horizons.*

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 (unconformities and MFS) which defined the stratigraphic breakdown of the margin. In total, 13 horizons were regionally mapped over the entire margin in the two-way time (TWT) domain (Figure 19 and 20). They are from top to bottom:

1. Seabed
2. T29 (Mid Oligocene Unconformity)
3. T50 (Base Ypresian Chalk)
4. K94 (Cenomanian Turonian Unconformity).
5. K101 (Late Albian Unconformity)
6. K130 (Hauterivian MFS)
7. K137 (Berriasian / Valanginian Unconformity)
8. J150 (Near Tithonian MFS)
9. J163 (Near Callovian MFS)
10. Top Allochthonous Salt
11. Top Autochthonous Salt
12. Top Salt Canopy
13. J200 (Top Autochthonous Salt) - Base of Post-Rift Sediments

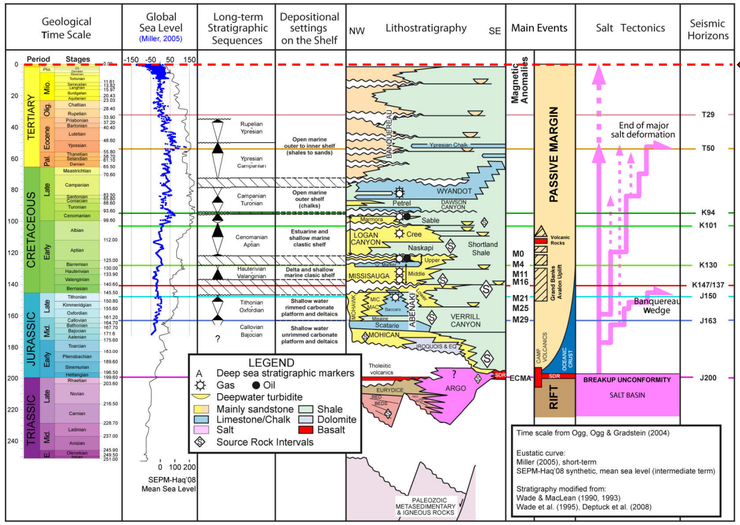
The faults were interpreted on seismic and laterally correlated to define the fault network of the different stratigraphic units.

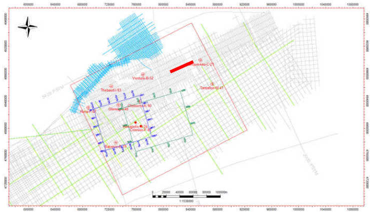


# CHAPTER 4.3.2

# STRUCTURAL MAPPING

### Tectono-Stratigraphical Chart



### Seismic Picking and Uncertainty

The Seabed horizon was picked over the margin using the available 2D and 3D seismic databases.

The seismic picking confidence is excellent on the slope and the deep offshore, with a sharp positive reflection. On the shelf where water becomes shallower, the seismic image becomes poorer with loss of seismic amplitude (shallow mute) and the seabed seismic interpretation becomes less controlled.

### Structural Description

The Seabed structural map ranges from 0 to 4000 m below mean sea level (PL 4-3-10). The Seabed depth structural map shows a relatively shallow continental shelf bounded to the east by a major canyon: the Gully Canyon (Figure 22 et 23). The continental shelf break approximately follows the 150 water depth contour. The Seabed exhibits numerous canyons and slope incisions along the margin (Figure 24 ).

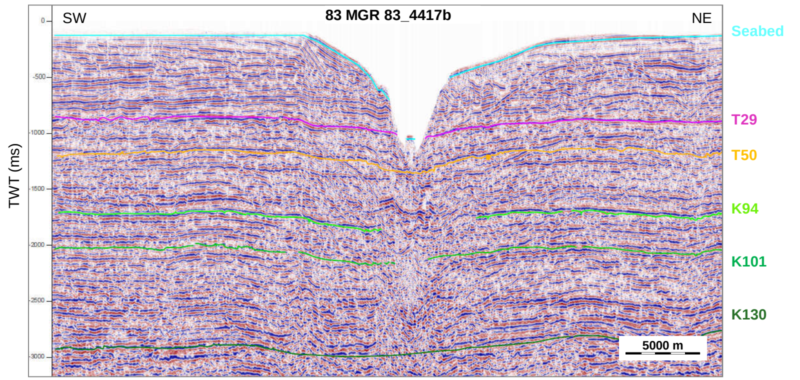



*Figure 23: Seabed, the Gully canyon on the shelf, on survey 83 MGR line 83_4417b.*

### Horizon Definition

The Seabed seismic horizon has been picked as the first positive reflection observed on seismic sections. Indeed, the seafloor is a physical interface of increasing impedance and corresponds to a positive peak of amplitude on zero-phase seismic in normal polarity according to the SEG convention (i.e. an increase in acoustic impedance creates a positive amplitude). However, no log data in the shallow section of the wells could be used to create a confident well to seismic tie.

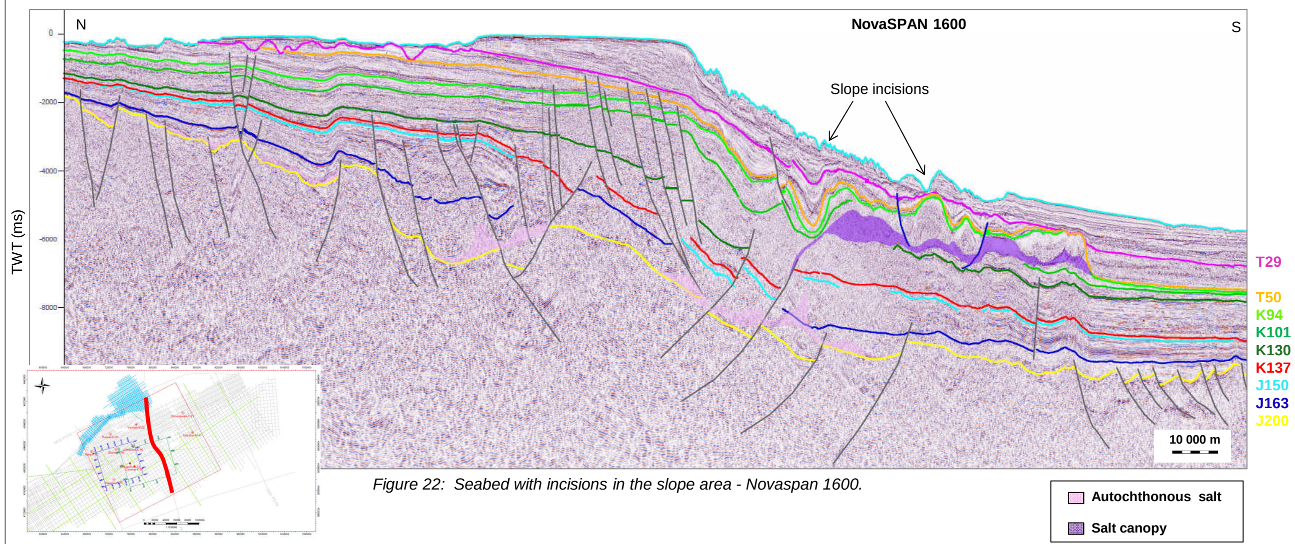



*Figure 22: Seabed with incisions in the slope area - Novaspan 1600.*

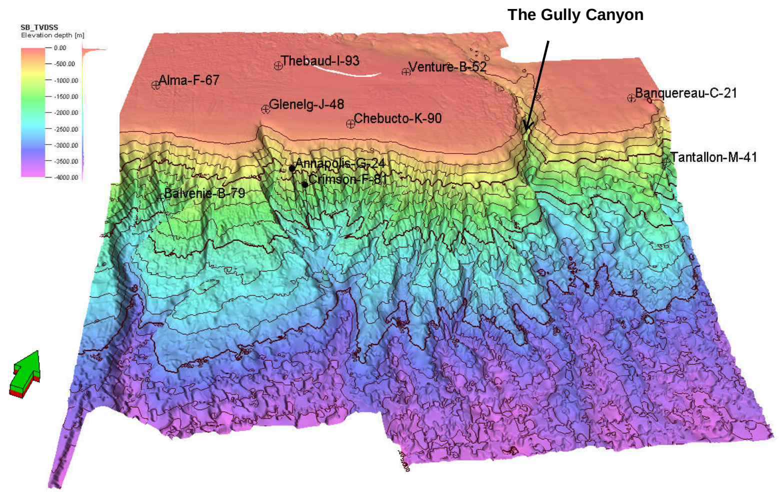
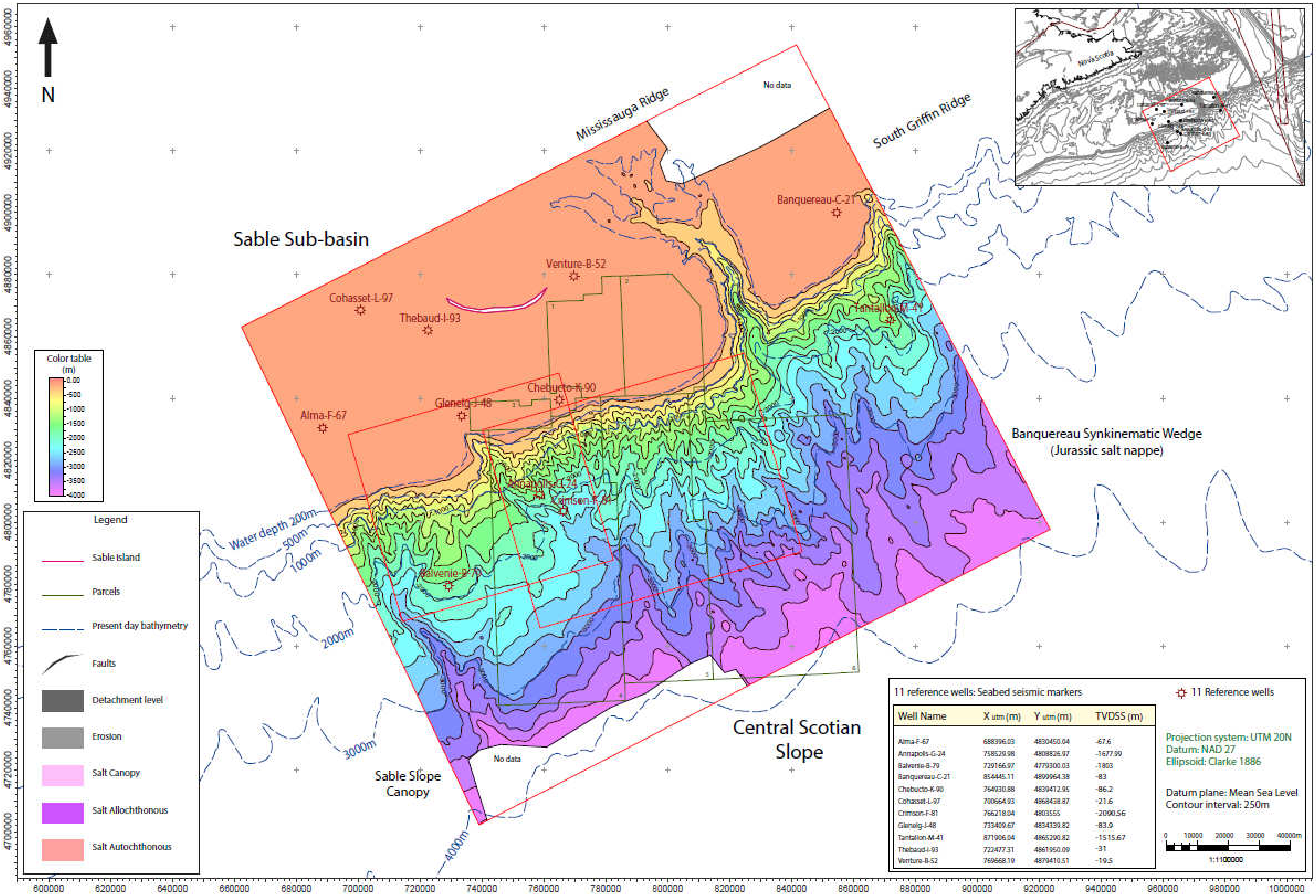



*Figure 24: Seabed structural TVDSS map in 3D.*

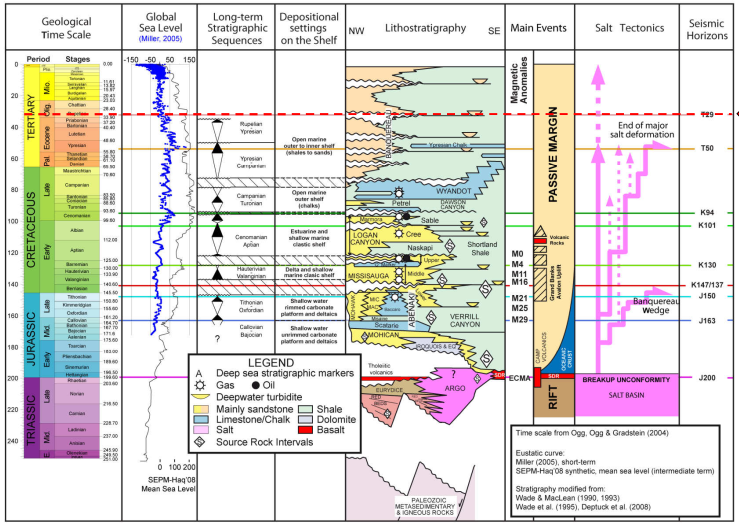



11 reference wells: Seabed seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688396.03 | 4830450.04 | -67.6 |
| Annapolis-G-24 | 758529.98 | 4808826.97 | -1677.90 |
| Balvenie-B-79 | 729166.97 | 4779300.03 | -1803 |
| Banquereau-C-21 | 854445.11 | 4899964.38 | -83 |
| Chebucto-K-90 | 764030.88 | 4839412.95 | -86.2 |
| Cohasset-L-97 | 700664.93 | 4868438.87 | -21.6 |
| Crimson-F-81 | 766218.04 | 4803555 | -2090.56 |
| Glenelg-J-48 | 733409.67 | 4834139.82 | -83.9 |
| Tantallon-M-41 | 871906.04 | 4865290.82 | -1515.67 |
| Thebaud-I-93 | 722477.31 | 4861950.09 | -31 |
| Venture-B-52 | 769668.19 | 4879410.51 | -19.5 |

**PL. 4.3.2.2** **Seabed Depth Structural Map**

### Tectono-Stratigraphical Chart



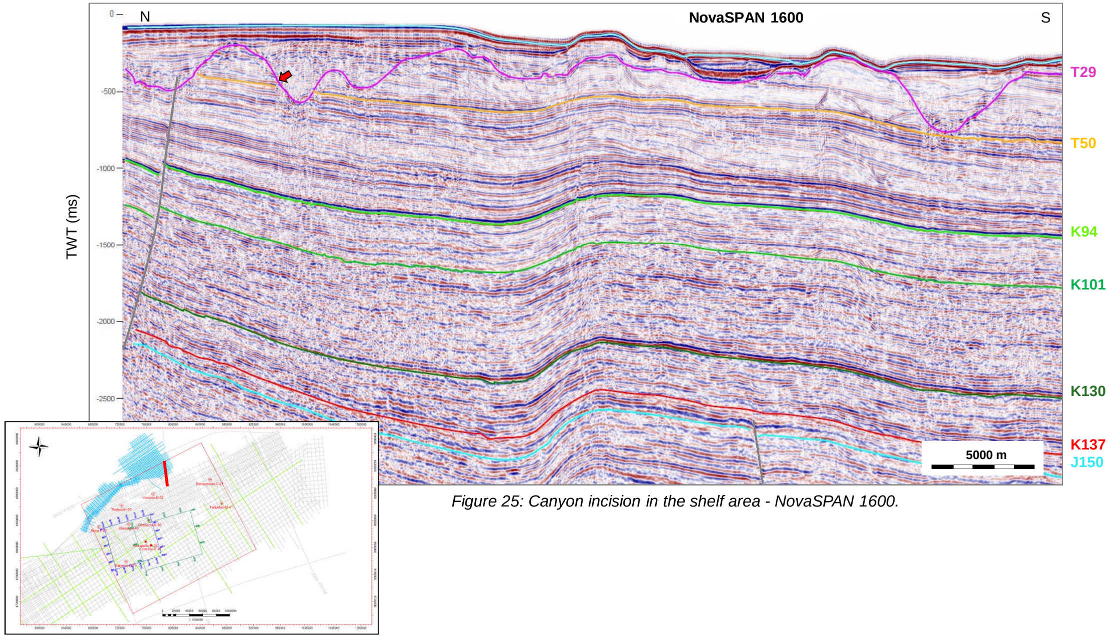




Figure 25: Canyon incision in the shelf area - NovaSPAN 1600.

### Horizon Definition

The horizon named "Mid-Oligocene Unconformity" (or T29) is an amalgamation of successive erosional surfaces corresponding to glacial episodes occurring from Rupelian to Priabonian times, which removed a large amount of Tertiary to Late Cretaceous sediments (the incision also affects older Cenomanian units in the Mohican I-100 well). The age of this surface has been estimated at 29 million years.

### Well to Seismic Tie

The well to seismic tie is done on four of the ten key wells. T29 does not have a typical acoustic signature but is reliably tied to the seismic through the correlation between the biostratigraphic results and the seismic features (biostratigraphic unconformities versus erosional truncations). The well to seismic tie results present a fairly good correlation (reference well: Tantallon M-41, PL 4.2.1.8).

### Seismic Picking and Uncertainty

Due to the lack of biostratigraphic results in the shallower sediments, the seismic correlation of such a timeline over the margin is uncertain. Nevertheless, the truncations are clear on the seismic and consistent at the basin scale. The T29 erosional surface is characteristic of the Oligocene glacial event and is buried by the Oligocene Neogene last phase of basin infilling.

### Structural Description

The T29 structural map ranges from 500 to 6000 m below mean sea level (PL. 4.3.2.4). The maximum depth of 5000 m from sea surface is reached in the eastern corner of the study area.

T29 dips southeast uniformly and is generally conformable to the seafloor. No major structural faults have been observed.

Along the margin, T29 shows two major canyon incisions located in the southwest portion of the study area, near Balvenie B-79 and close to Tantallon M-41. The width of these canyons can reach three kilometers (Figure 25). This horizon shows the emergence of the current canyon and infilling of the other canyon to the southeast.

T29 is also expressed by shallow and numerous channels on the Sable Sub-basin (Figure 26).

In the basin, several salt diapirs pierce T29 in the Annapolis Sub-basin. T29 is later than the canopy systems as it covers the canopies in the Annapolis and Laurentian Sub-basins.

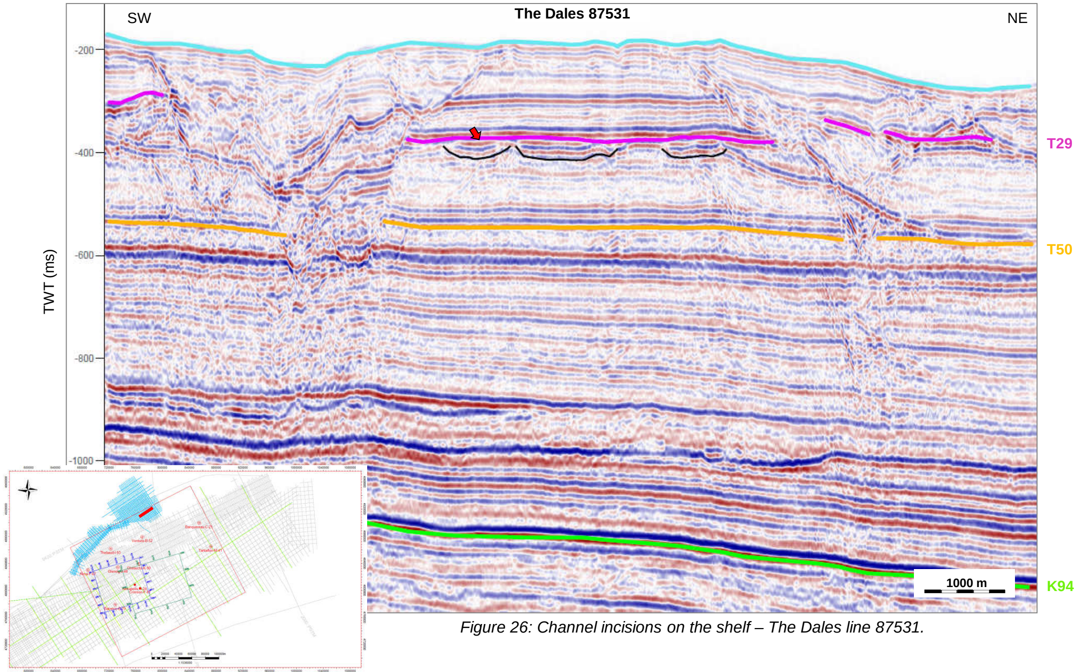
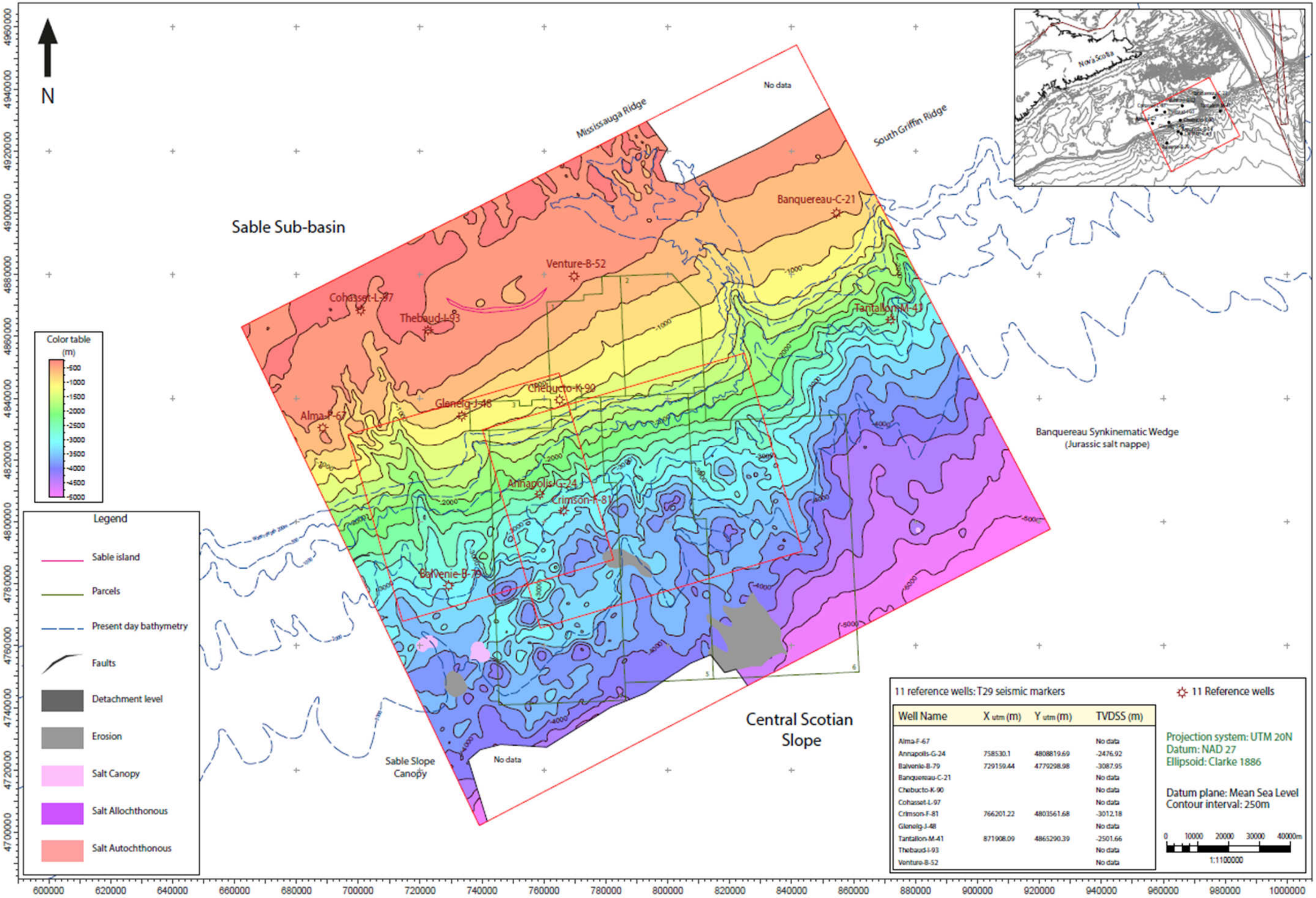



Figure 26: Channel incisions on the shelf – The Dales line 87531.



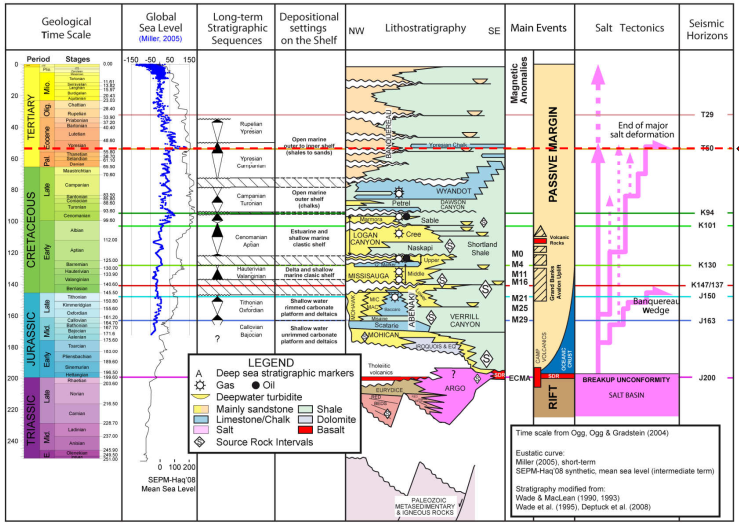

11 reference wells: T29 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | | | No data |
| Annapolis-G-24 | 758530.1 | 4808819.69 | -2476.92 |
| Balvenie-B-79 | 729159.44 | 4779298.98 | -3087.95 |
| Banquereau-C-21 | | | No data |
| Chebucto-K-90 | | | No data |
| Cohasset-L-97 | | | No data |
| Crimson-F-81 | 766201.22 | 4803561.68 | -3012.18 |
| Glenelg-J-48 | | | No data |
| Tantallon-M-41 | 871908.09 | 4865290.39 | -2501.66 |
| Thebaud-I-93 | | | No data |
| Venture-B-52 | | | No data |



**T29 Depth Structural Map**

### Tectono-Stratigraphical Chart




### Horizon Definition

The horizon named "Base of the Ypresian chalks" (or T50) is the last episode of the prolific chalk deposition that occurred through Late Cretaceous and Tertiary times. It is Ypresian in age and represents a maximum flooding surface recognized over most of the Scotian Shelf as well as in the southern Grand Banks. Landward, T50 evolves into a more proximal facies.

### Well to Seismic Tie

The well to seismic tie of the T50 horizon is done on eight of the ten keys wells. The acoustic log signature of the Ypresian chalks has a sharp base with a gradational top evolving from chalk to shale facies. The formation is usually too thin to distinguish the seismic top from the base. Consequently, the best choice for tying the unit is its base, which corresponds to a strong amplitude trough on the seismic profile. The results present a very good correlation (reference well: Chebucto K-90, PL. 4.2.1.5).

### Seismic Picking and Uncertainty

T50 is picked as a trough over the entire area using available 2D and 3D seismic databases (see PL 4-3-14). The picking and its uncertainties are dependent on the data but also on the thickness of the series which separate the Ypresian chalks from the Wyandot chalks. When these series are thick (primarily on the shelf), the picking is based on a seismic stratigraphy approach. On the slope and the basin where the series becomes thin, the picking is mainly driven by the seismic facies and is thus less accurate. There, T50 is defined as the top of a strong energy package containing chalk deposits of the Late Cretaceous and Tertiary and is usually overlaid and underlain by a transparent seismic facies related to shale from Middle Eocene and Cenomanian (Figure 28).

### Structural Description

The T50 structural map ranges from 500 to 5500m below mean sea level (Plate 4-3-14).

T50 dips southeast, with a slope domain between 2000 and 4000m TVDSS (present day depth). It is affected on the shelf by northeast / southwest trending normal listric faults dipping southeast.

T50 was deposited during the final stages of salt tectonics. Thus, it is generally lying on top of the latest canopies in the Annapolis Sub-basin. The shelf is not strongly affected by the salt tectonics but it is affected by diapirs in the Banquereau Wedge area and by salt canopies in the canopy province, inducing some pounded mini-basins in the central part of the study area. These pounded basins are created by salt movements. The margin is cut by numerous canyons and the slope is eroded by incisions. In some areas, the T29 unconformity erodes the T50 (Figure 28).

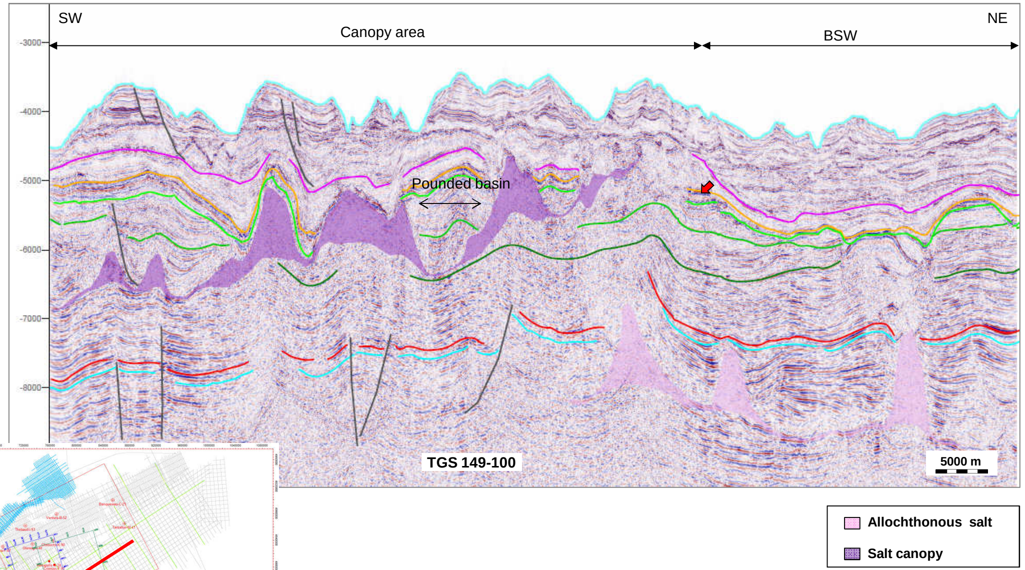



*Figure 27: T50 horizon – Interpretation of T50 in canopies area showing examples of pounded basins creating positive structures and salt impact on the interpretation – TGS 157b-100.*

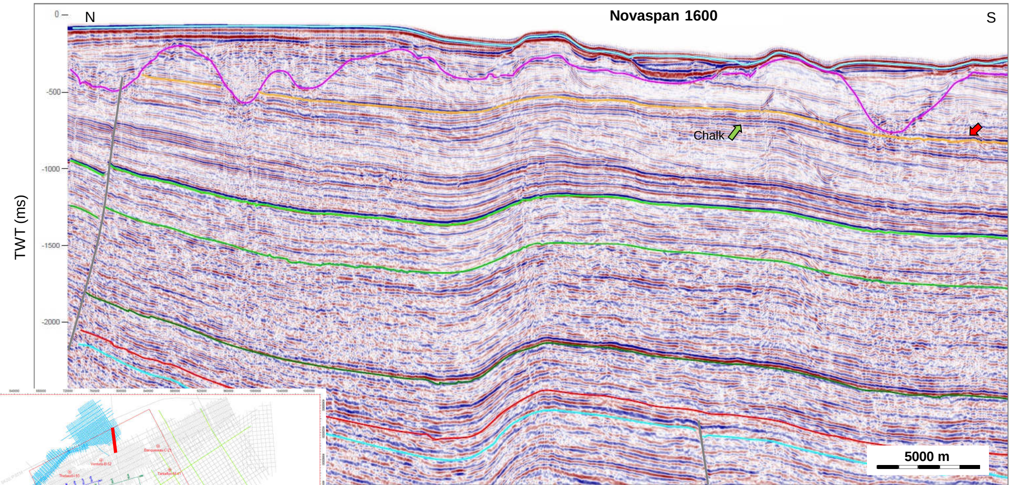
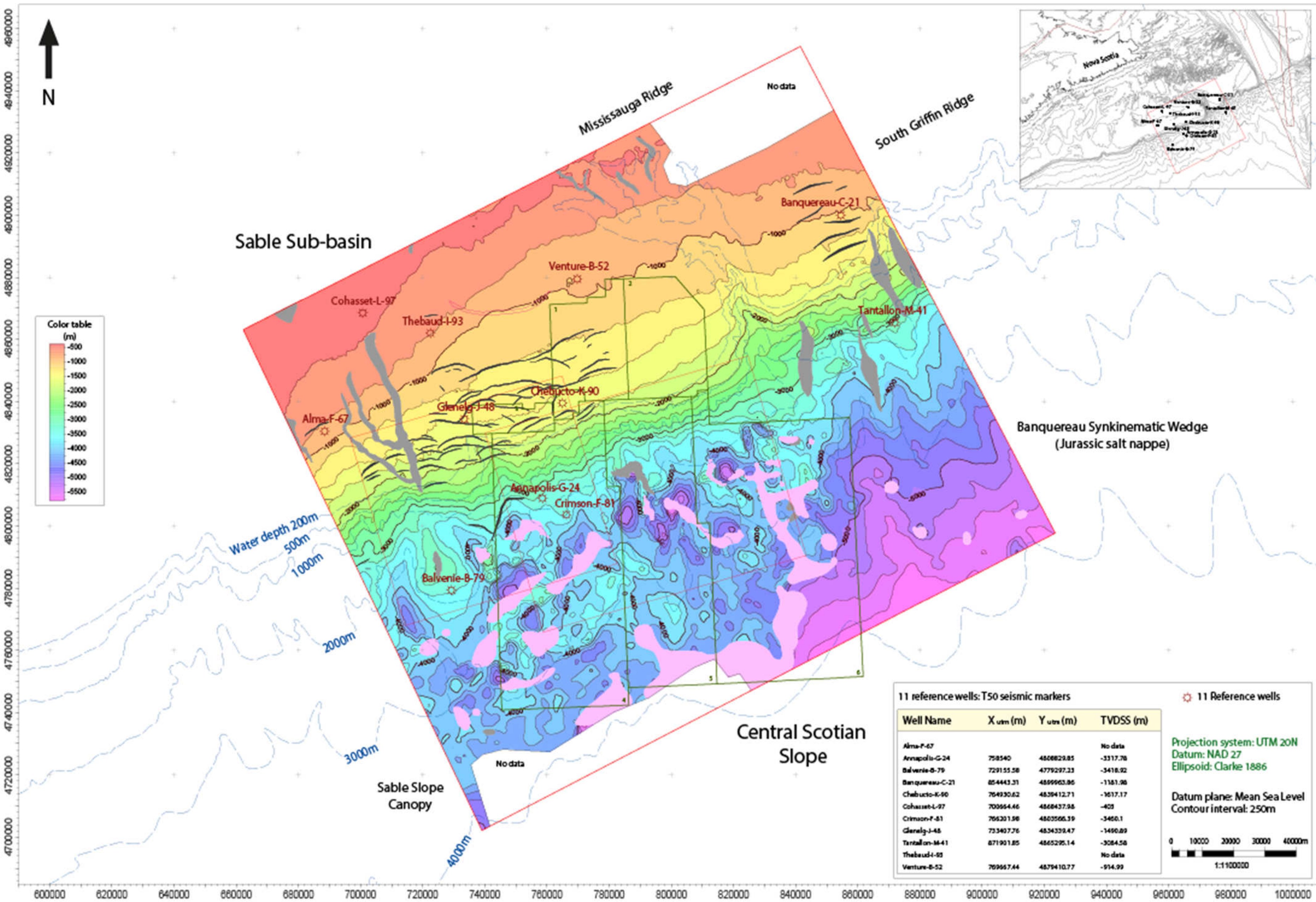



*Figure 28: T50 seismic horizon – Shelf area – Erosion of T50 horizon by the T29 unconformity- Novaspan 1600.*



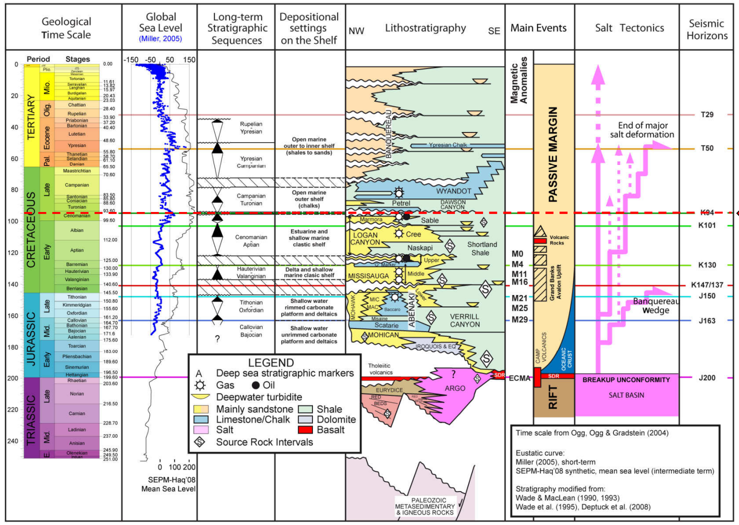

11 reference wells: T50 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | | | No data |
| Annapolis-G-24 | 758540 | 4808829.85 | -3317.78 |
| Balvenie-B-79 | 729155.58 | 4779297.23 | -3418.92 |
| Banquereau-C-21 | 854443.31 | 4899963.86 | -1181.98 |
| Chebucto-K-90 | 764930.62 | 4839412.71 | -1617.17 |
| Cohasset-L-97 | 700664.46 | 4868437.98 | -403 |
| Crimson-F-81 | 766201.98 | 4803566.39 | -3460.1 |
| Glenelg-J-48 | 733407.76 | 4834339.47 | -1490.89 |
| Tantallon-M-41 | 871901.85 | 4865295.14 | -3084.58 |
| Thebaud-I-93 | | | No data |
| Venture-B-52 | 769667.44 | 4879410.77 | -914.99 |

PL. 4.3.2.6

## T50 Depth Structural Map

## Tectono-Stratigraphical Chart




### Horizon Definition

The horizon named "Turonian Cenomanian Unconformity" (or K94) mainly corresponds to a submarine 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 shales of the Dawson Canyon Formation. It represents the onset of chalk production through the Late Cretaceous and is recognized over most of the Scotian Shelf as well as in the southern Grand Banks. Basinward, the Petrel Member thins and evolves into a more shaly facies.

### Well to Seismic Tie

The well to seismic tie of the K94 horizon is possible on the ten keys wells. The signature of K94 is a sharp decrease of the sonic log and corresponds to a strong amplitude trough on the seismic profile. The Petrel Member is usually too thin to distinguish its top from its base using the seismic data. It can be directly overlaid by the chalks of the Wyandot (Crimson F-81). The results present a good correlation (reference well: Chebucto K-90, PL 4.2.1.5).

### Seismic Picking and Uncertainty

The K94 horizon is picked as a trough in the Annapolis Sub-basin using available 2D and 3D seismic databases. The picking and its uncertainties are dependent on the data but also on the thickness of the Petrel Member and its petrophysical properties. On the shelf where the Petrel member is a thick limestone, the seismic to well tie is reliable. Basinwards, where the Petrel Member thins and starts to become more shaly, the few well ties are more uncertain. Truncations are visible on the seismic data (Figure 29).

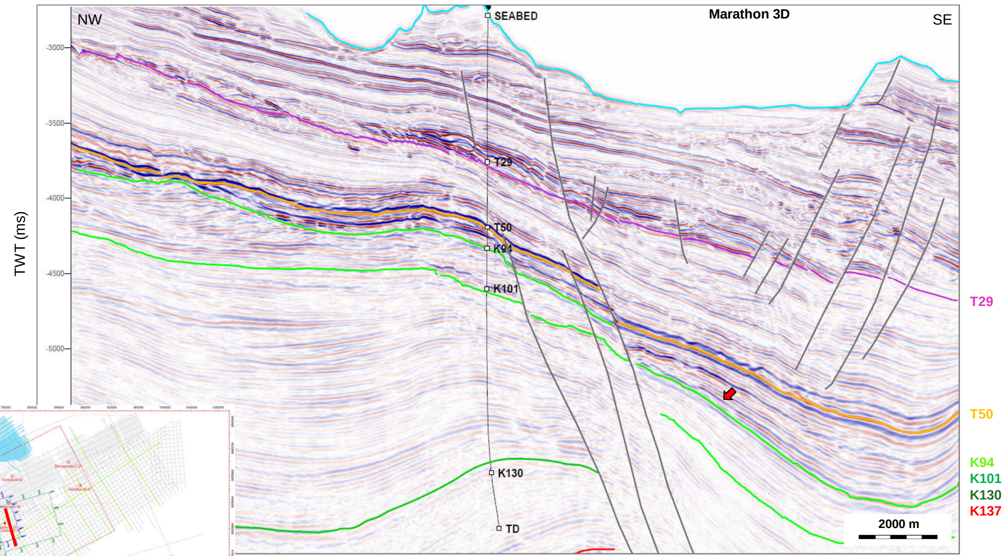
### Structural Description

The K94 structural map ranges from 500 to 6000m below mean sea level (Plate 4-3-15).

In the shelf area, K94 dips gently southeast and is affected by normal listric fault networks trending northeast / southwest and dipping southeast. Moreover, the formation of two major faults is observed.

In the basin, numerous diapirs pierce K94 in the Annapolis Sub-basin. In the canopy area, it is affected by a complex system of pounded mini basins partly isolated by salt diapirs induced by salt dynamics (Figure 30).

The continental shelf domain of K94 (northwest of the paleo shelf-break) presently ranges from 1500 to 2500 m TVDSS. In the basin, its maximum depth reaches more than 6000 m TVDSS. The slope is well developed and progresses into the basin. This Upper Cretaceous period corresponds to the end of the Balvenie Synkinematic Wedge.



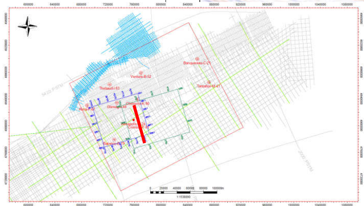
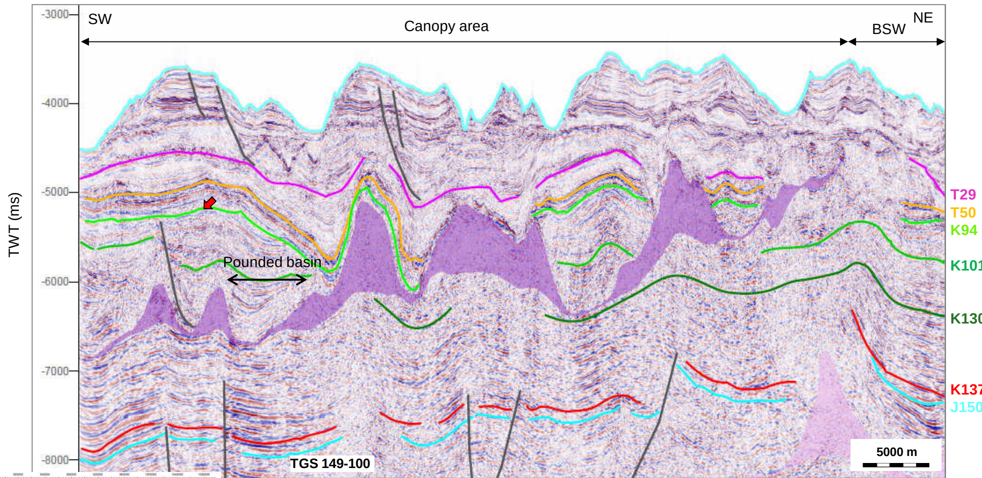
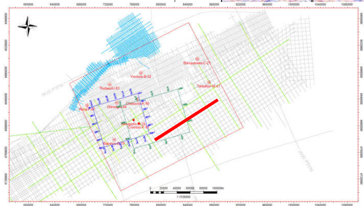



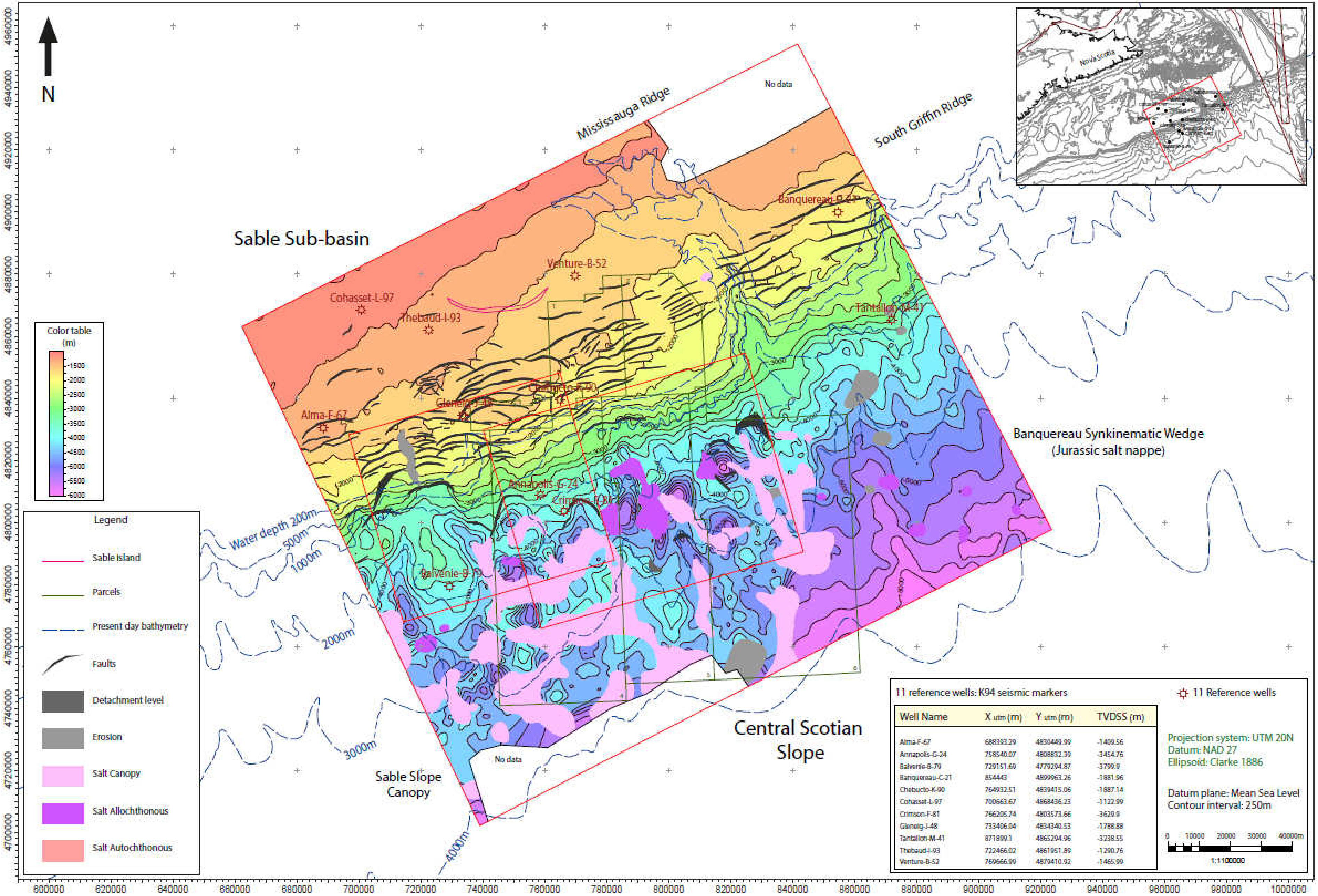
*Figure 29: K94 horizon – Interpretation of K94 in Crimson area showing examples of truncations along the unconformable surface – Marathon 3D seismic cube.*



Salt canopy

*Figure 30: K94 horizon – Interpretation of K94 in the canopies area showing examples of pounded basins and salt tectonic effects along the unconformable surface – TGS 149-100.*




11 reference wells: K94 seismic markers

| Well Name | $X_{utm}$ (m) | $Y_{utm}$ (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688393.29 | 4830448.99 | -1409.56 |
| Annapolis-G-24 | 758540.07 | 4808832.39 | -3454.76 |
| Balvenie-B-79 | 729151.69 | 4779204.87 | -3799.9 |
| Banquereau-C-21 | 854443 | 4899963.26 | -1881.96 |
| Chebucto-K-90 | 764932.51 | 4839415.06 | -1887.14 |
| Cohasset-L-97 | 700663.67 | 4868436.23 | -1122.99 |
| Crimson-F-81 | 766205.74 | 4803573.66 | -3629.9 |
| Glenelg-J-48 | 733406.04 | 4834340.53 | -1788.88 |
| Tantallon-M-41 | 871899.1 | 4865294.96 | -3238.55 |
| Thebaud-I-93 | 722466.02 | 4861951.89 | -1290.76 |
| Venture-B-52 | 769666.99 | 4879410.92 | -1465.99 |

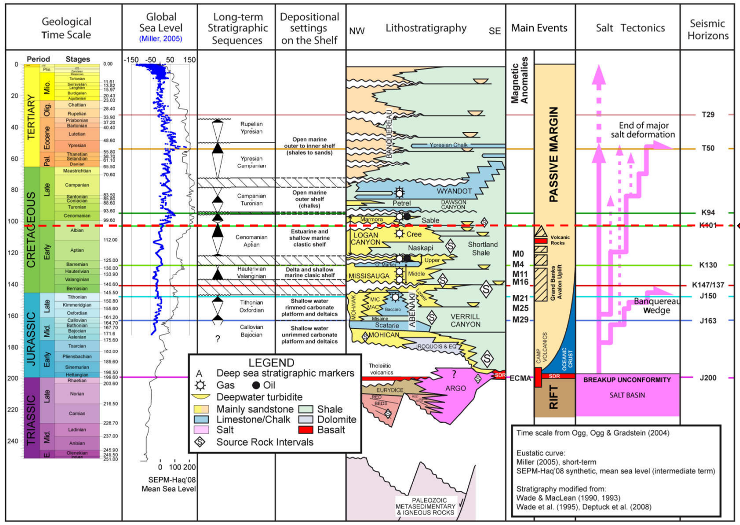


K94 Depth Structural Map

# SEISMIC INTERPRETATION - STRUCTURAL MAPPING

Central Scotian Slope Study – CANADA – July 2016

## Tectono-Stratigraphical Chart



### 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.

### Well to Seismic Tie

The well to seismic tie of the K101 horizon is possible on the ten key wells. K101 does not have a regional acoustic signature but is reliably tied to the seismic through the biostratigraphic results (unconformities) and the seismic features (erosional truncations). The well to seismic tie results present an average to good correlation (reference well: Balvenie B-79, PL. 4.2.1.3).

### Seismic Picking and Uncertainty

On the shelf, the picking is mainly based on seismic facies. Indeed, K101 corresponds to a strong energy event, which is related to the transition between the shaly Sable Member and the fluvial sandstones of the Cree Member. On the slope, especially in the eastern part, K101 has an erosional pattern clearly shown by truncations on the seismic (Figure 31) and proven by biostratigraphic results as in the Tantallon M-41 well. In the basin, the surface is difficult to follow, especially in the canopy area and so the interpretation has been driven by seismic facies correlation.

### Structural Description

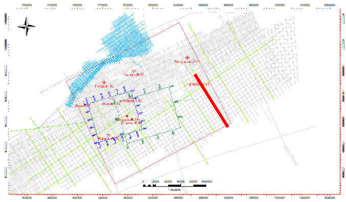
The K101 structural map ranges from 1500 to 7000m below mean sea level (Plate 4-3-18).

On the shelf margin the K101 horizon is affected by several canyons. The K101 horizon is characterized by truncations highlighted on Figure 31 and used to identify the horizon.

On the shelf, the K101 horizon dips southeast and is affected by numerous normal listric fault networks, oriented northeast/southwest and dipping southeast; it is not affected by salt tectonics.

In the basin, numerous diapirs pierce K101 (Figure 32). Because K101 ~~is~~ was deposited during the growth of the canopy system, it is encountered in an allochthonous context. For example, K101 is affected by the salt canopy in the south of the 3D seismic cubes (Figure 33).

The Late Albian times correspond to the filling of the Balvenie Synkinematic Wedge. On the slope and in the deep basin, K101 forms a complex system of pounded mini basins partly isolated by salt diapirs. Salt movement affected sediment transport pathways between the salt diapirs. The continental shelf domain of K101 ranges presently from 1500 to 3500 m TVDSS. In the basin, its maximum depth reaches 8000 m TVDSS.



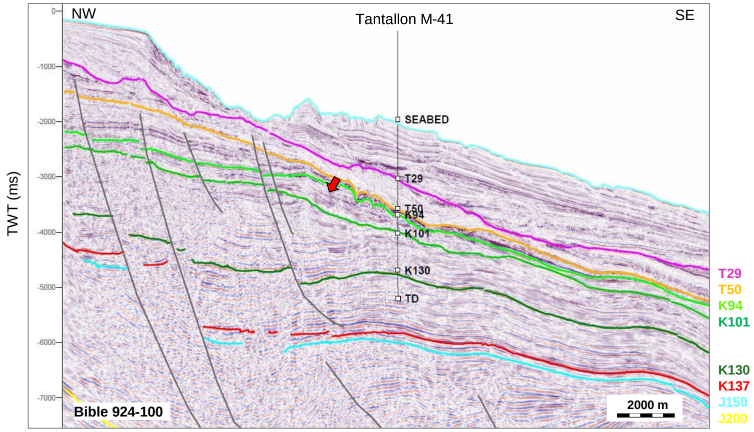



*Figure 31: Truncations on K101 – 2010 reprocessed Bible 924-100– TWT (ms).*

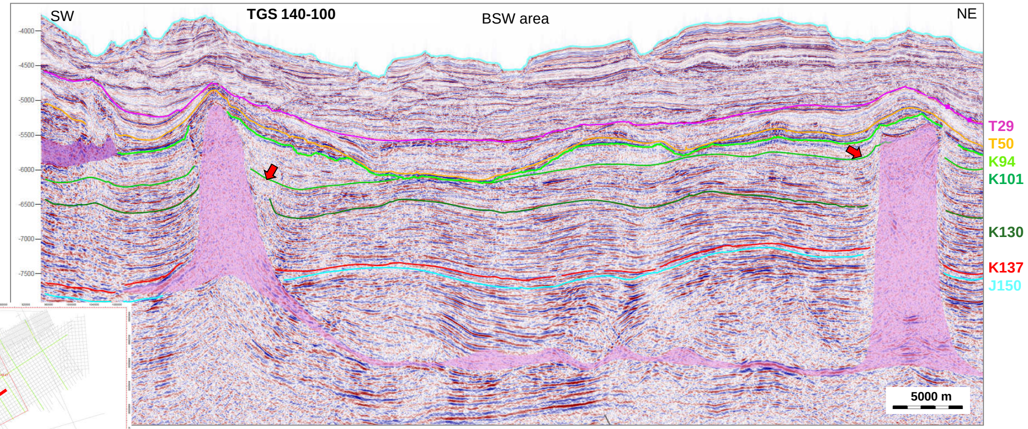



*Figure 32: K101 in its allochthonous salt context affected by diapirs in the BSW area – TGS line 149-100.*

Allochthonous salt

Salt canopy

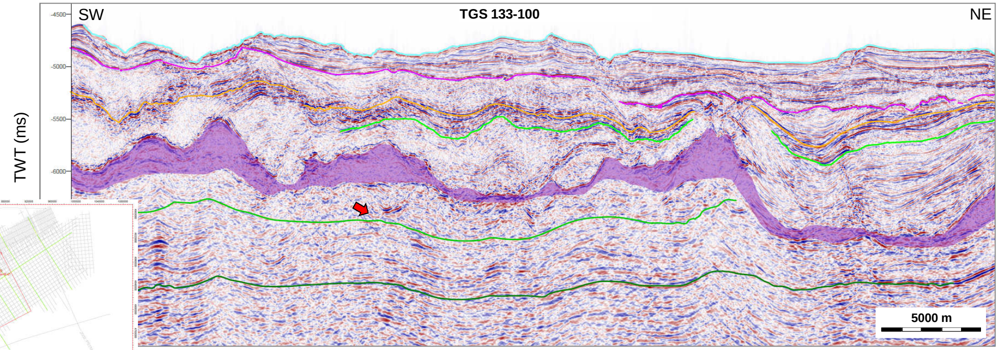
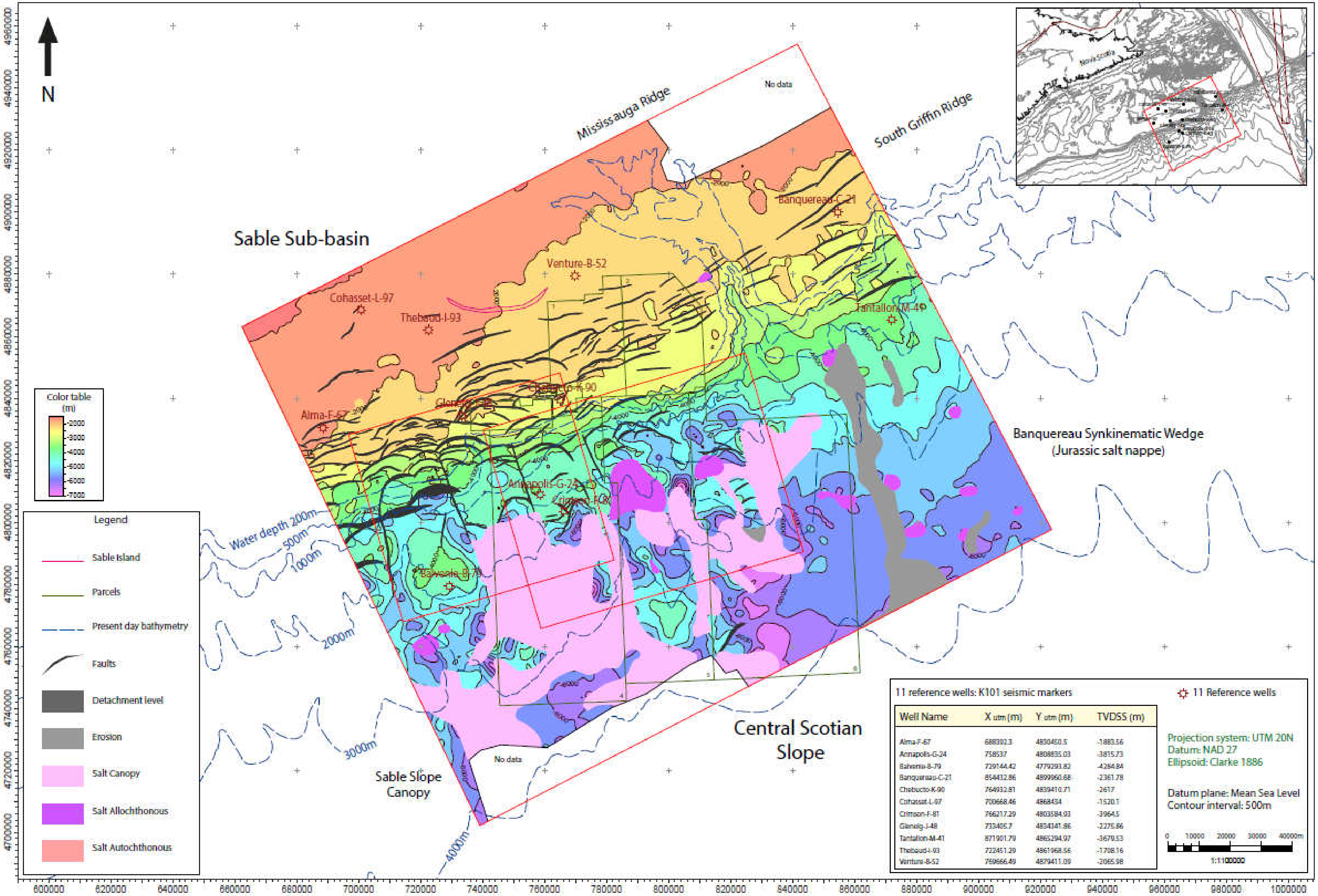



*Figure 33: K101 in its allochthonous salt context affected by salt canopy – TGS line 133-100.*

Salt canopy

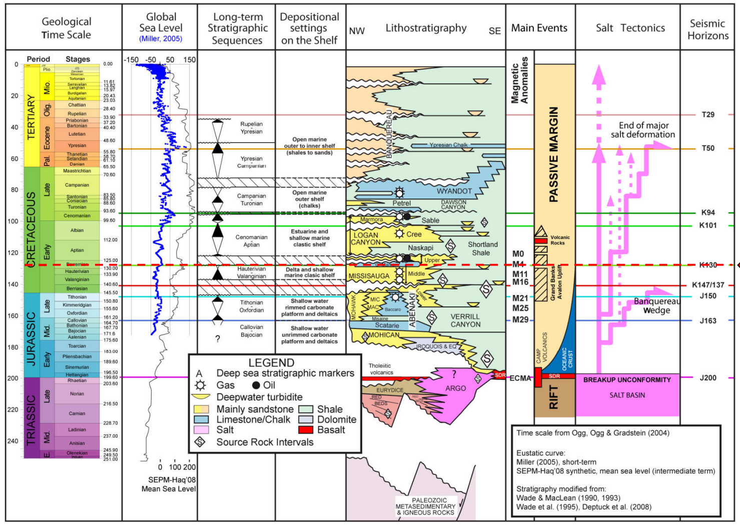


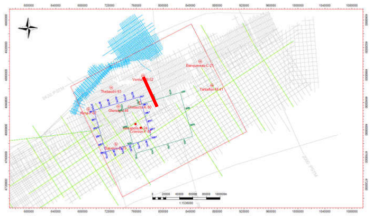

11 reference wells: K101 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688392.3 | 4830450.5 | -1883.56 |
| Annapolis-G-24 | 758537 | 4808835.03 | -3815.73 |
| Bahenia-B-79 | 729144.42 | 4779293.82 | -4284.84 |
| Banquereau-C-21 | 854432.86 | 4899960.68 | -2361.78 |
| Chebucto-K-90 | 764932.81 | 4839410.71 | -2617 |
| Cohasset-L-97 | 700668.46 | 4868434 | -1520.1 |
| Crimson-F-81 | 766217.29 | 4803584.93 | -3964.5 |
| Glenelg-J-48 | 733405.7 | 4834341.86 | -2275.86 |
| Tantallon-M-41 | 871901.79 | 4865294.97 | -3679.53 |
| Thebaud-I-93 | 722451.29 | 4861968.56 | -1708.16 |
| Venture-B-52 | 769666.49 | 4879411.09 | -2065.98 |

PL. 4.3.2.10 **K101 (Late Albian Unconformity) Depth Structural Map**

### Tectono-Stratigraphical Chart



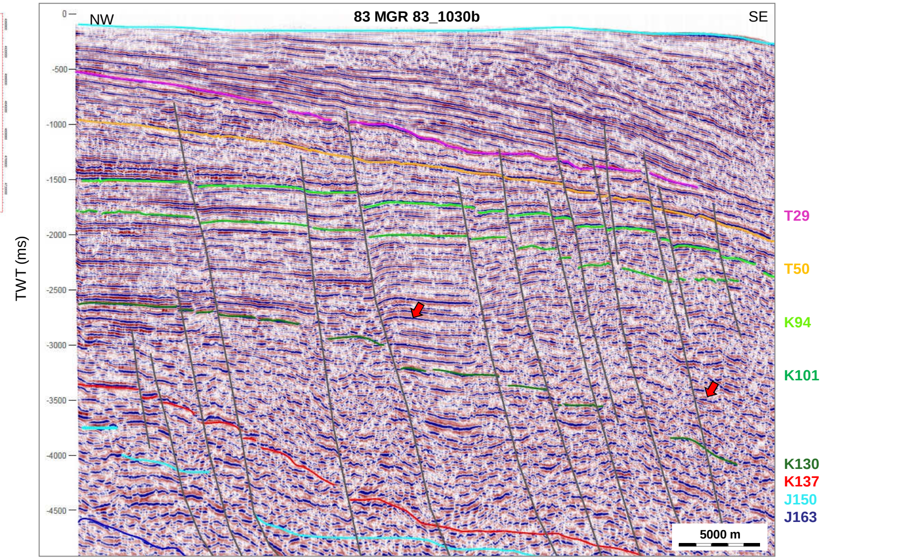



*Figure 34: K130 seismic horizon – Shelf area – Survey 83 MGR line 83_1030b.*

### Horizon Definition

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

### Well to Seismic Tie

The Hauterivian MFS was encountered by nearly all the wells on the shelf and by most of the wells in the deep offshore, except Balvenie B-79. On the shelf, the Hauterivian MFS is displayed as a strong amplitude event at the onset of a mixed carbonate-terrigenous platform (Cohasset L-97) in relation to a major drop in sediment supplies on the margin. 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. In the deep offshore area, the Hauterivian MFS is displayed as a weaker seismic event but is still higher in amplitude than the surrounding seismic reflections (Tantallon M-41).

### Seismic Picking and Uncertainty

The Hauterivian MFS was picked over the entire margin using available 2D and 3D seismic databases. On the shelf, this surface is picked with high confidence especially in the central and eastern part of the margin. Existing interpretation of the "O" Marker on the northern part of the shelf has been added to the map (Wade and MacLean, 1990). This interpretation shows an erosional edge of the K130 surface to the north.

On the slope, the growth fault system and sub-salt imaging difficulties make the picking of the Hauterivian MFS more uncertain away from the well ties.

### Structural Description

The K130 structural map ranges from 2000 to 9000m (Plate 4-3-20).

In the shelf domain, the K130 horizon uniformly dips to the southeast and is affected by listric faults oriented SW-NE (Figure 34). Sediments prograde along the margin and shelf edge. Above the K130, the horizons are not affected by autochthonous salt. On the shelf, the Hauterivian MFS is represented by a gentle monocline with faults. The slope (a clastic dominated passive margin) is affected by a series of growth faults (SW-NE) due to allochthonous salt remobilization from sediment loading during Late Cretaceous times.

The deep offshore area can be subdivided into different domains. The western area is characterized by the gliding of sediments on a detachment level at the base of the Balvenie Synkinematic Wedge. The horizon is affected by large listric faults (Figure 35) with an important throw (SW-NE). Allochthonous salt evolves into a canopy in the central slope. Thus the central area is affected by diapirism and forms a complex system of pounded mini basins partly isolated by salt diapirs. Large salt sheets were expelled to the surface during the Cretaceous. They formed a large discontinuity between the slope basins northwest of the salt canopies and the deep offshore area in front of the canopies.

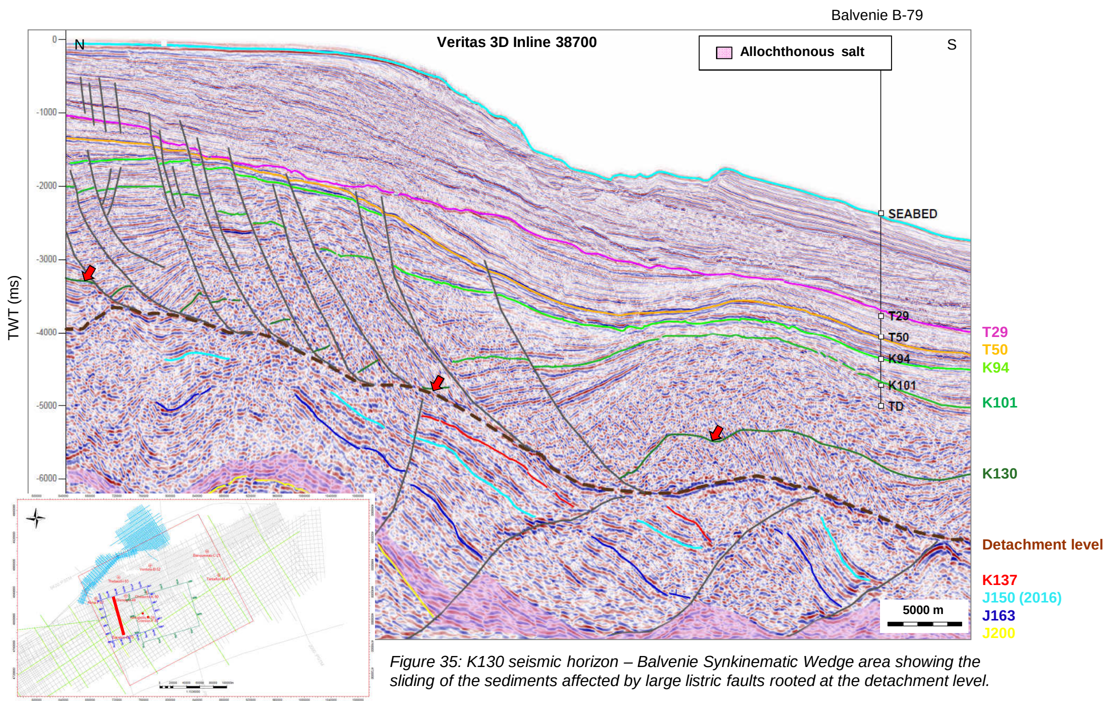
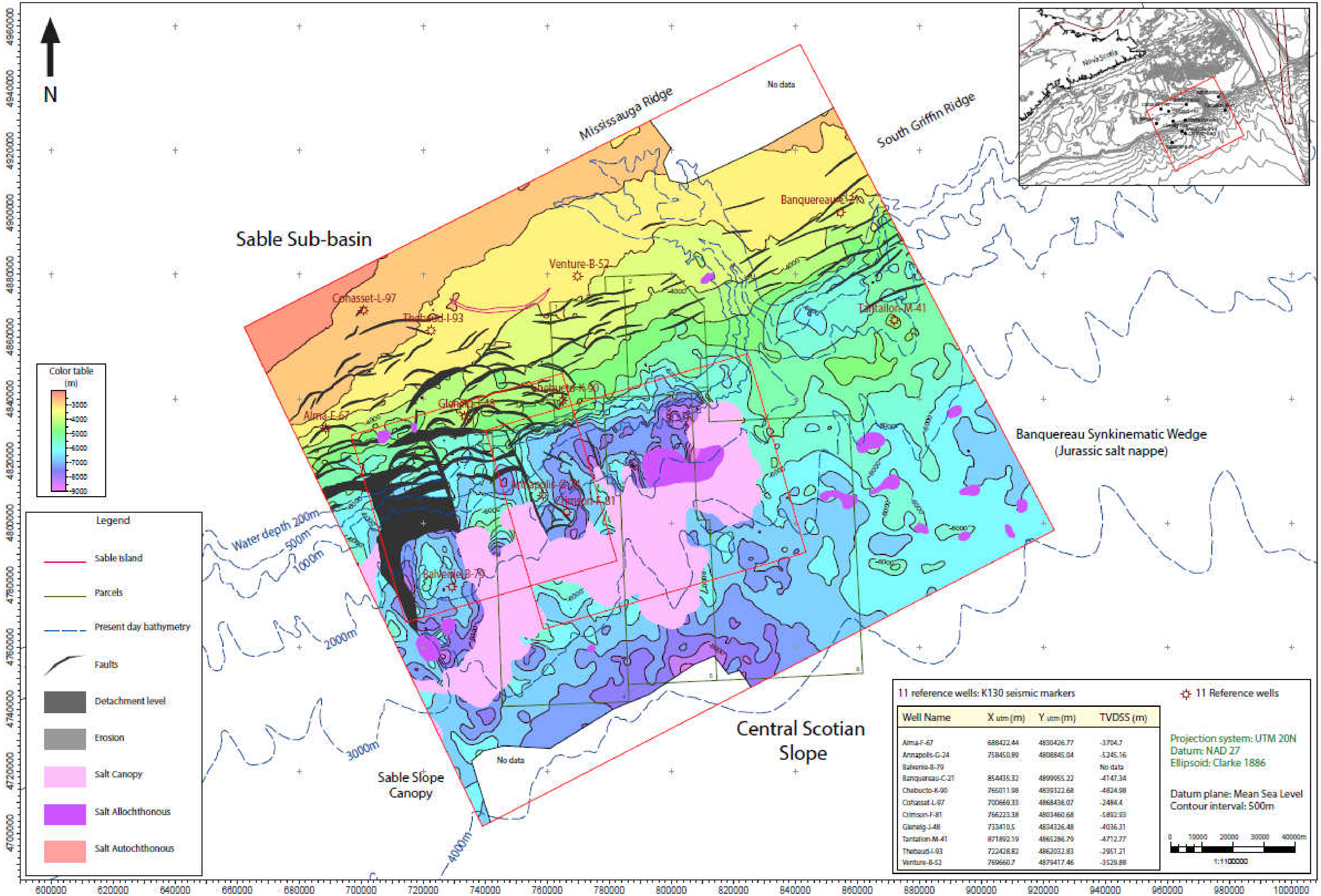



*Figure 35: K130 seismic horizon – Balvenie Synkinematic Wedge area showing the sliding of the sediments affected by large listric faults rooted at the detachment level.*



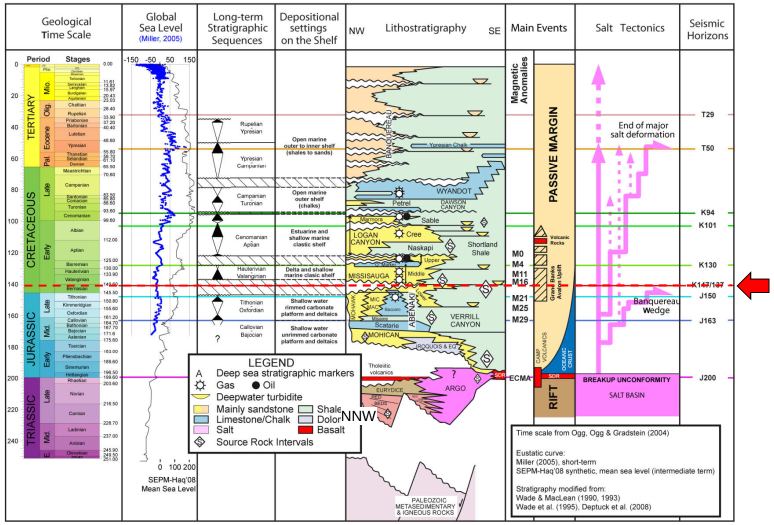

11 reference wells: K130 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688422.44 | 4830426.77 | -3704.7 |
| Annapolis-G-24 | 758450.89 | 4808845.04 | -5245.16 |
| Balvenie-B-79 | | | No data |
| Banquereau-C-21 | 854435.32 | 4899965.22 | -4147.34 |
| Chebucto-K-90 | 765011.98 | 4839322.68 | -4824.98 |
| Cohasset-L-97 | 700669.33 | 4868436.07 | -2484.4 |
| Crimson-F-81 | 766223.38 | 4803460.68 | -5892.93 |
| Glenelg-J-48 | 733410.5 | 4834326.48 | -4036.31 |
| Tantallon-M-41 | 871892.19 | 4865286.79 | -4712.77 |
| Thebaud-I-93 | 722428.82 | 4862032.83 | -2951.21 |
| Venture-B-52 | 769660.7 | 4879417.46 | -3529.88 |



K130 Depth Structural Map

### Tectono-Stratigraphical Chart



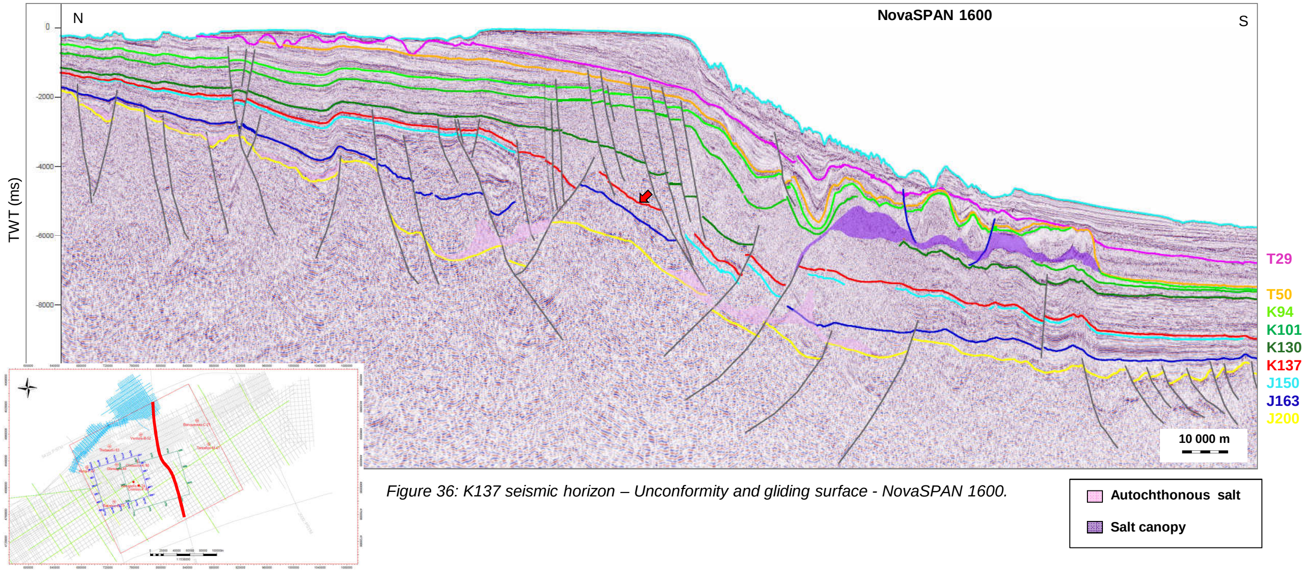




*Figure 36: K137 seismic horizon – Unconformity and gliding surface - NovaSPAN 1600.*

### Horizon Definition

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

### Well to Seismic Tie

Four wells in the study area reach the K137. In the lower slope and deep offshore areas, no well has penetrated deep enough to reach the Berriasian / Valanginian Unconformity. The seismic response varies in accordance with the nature and thickness of sediments preserved / deposited around the unconformity.

### Seismic Picking and Uncertainty

The Berriasian / Valanginian Unconformity was picked over the study area using available 2D and 3D seismic databases. On the shelf, the picking of this surface is relatively confident. Where the Tithonian to Berriasian interval is reduced or absent, the K137 marker interferes with the underlying J150 seismic reflection. On the slope, the growth fault system and the average quality of the seismic data makes the picking uncertain away from well ties. In the deep offshore area, the Berriasian / Valanginian Unconformity is based only on seismic facies changes, between the overlying higher amplitude shallow marine terrigenous deposits and the underlying low amplitude Tithonian shales, as well as on the reflection terminations and marks of erosion, especially in the BSW area. It is marked as an average to good minimum amplitude (red trough).

### Structural Description

The K137 structural map shows depths ranging from 1800 to 10500m below mean sea level (Plate 4-3-22).

In the shelf domain, the K137 depth structural map uniformly dips to the center of the study area (Plate 4-3-22). The shelf is affected by NW-SE listric faults, which have been interpreted as differential gliding zones (Figure 36). In the Sable Sub-basin, an increase of the number of listric faults is observed compared to the overlying horizons. The central area corresponds to the Salt Canopy Province and is affected by a large syncline structure. It marks the beginning of canopies and associated pounded basins. The K137 is cross-cut by allochthonous salt, in the central part, while autochthonous salt diapirs are still active.

The K137 drapes the J150, except in the shelf area because of the active growing fault system (Figure 37). In the Balvenie area, a detachment level cross-cuts and deforms the horizon. In the SW part of the Balvenie, the formation has partially been subsumed into the sliding of sediments; this effect is not represented on the map.

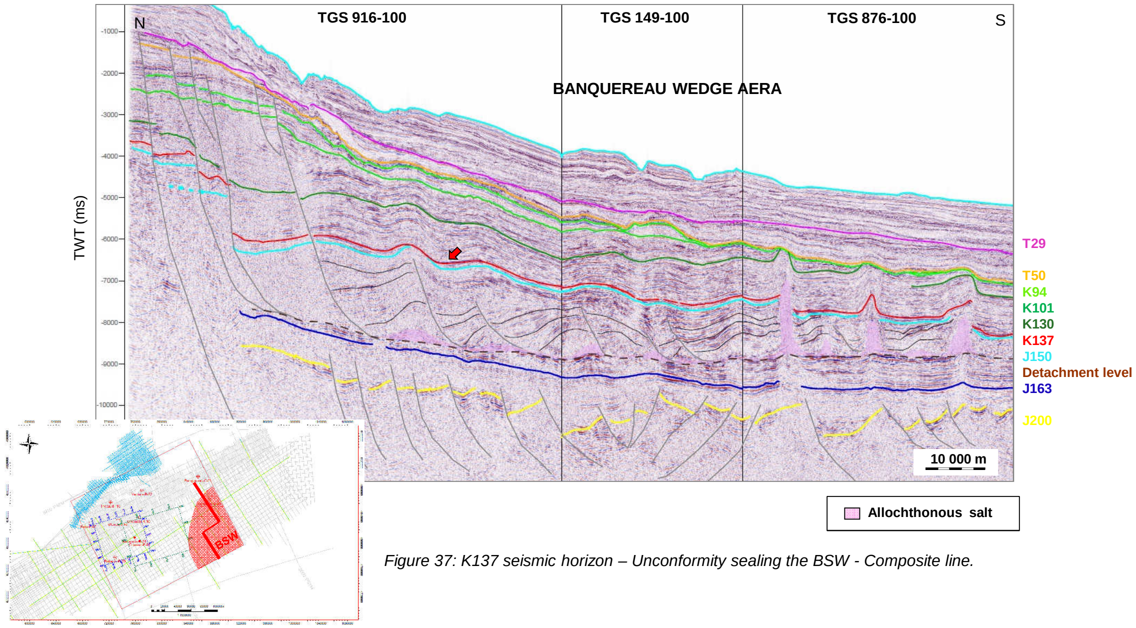
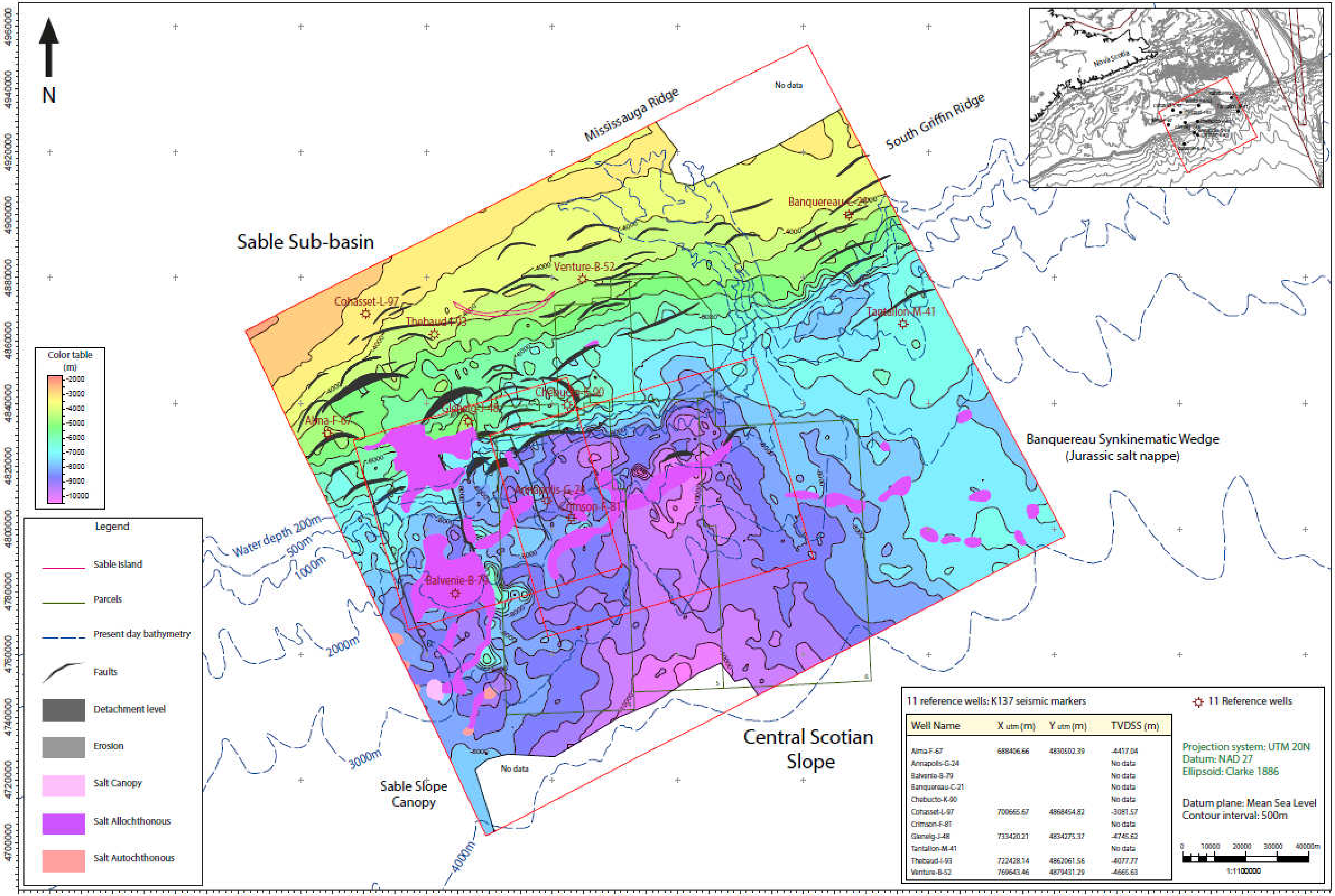



*Figure 37: K137 seismic horizon – Unconformity sealing the BSW - Composite line.*

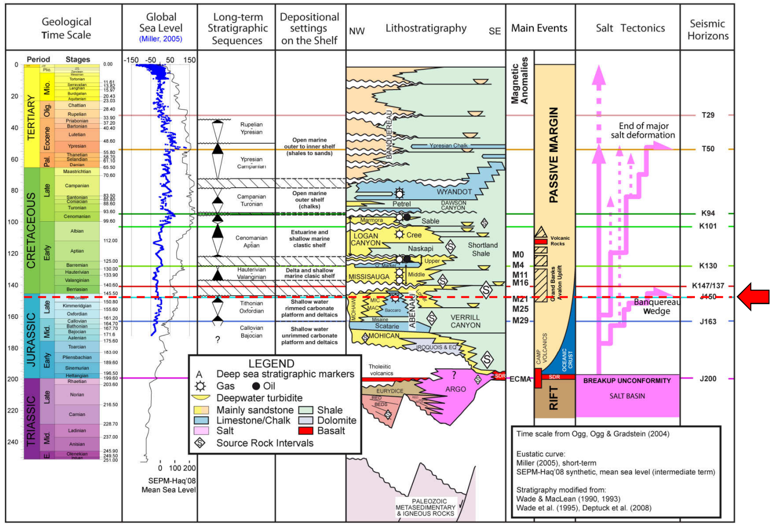



11 reference wells: K137 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688406.66 | 4830502.39 | -4417.04 |
| Annapolis-G-24 | | | No data |
| Balvenie-B-79 | | | No data |
| Banquereau-C-21 | | | No data |
| Chebucto-K-90 | | | No data |
| Cohasset-L-97 | 700665.67 | 4868454.82 | -3081.57 |
| Crimson-F-81 | | | No data |
| Glenelg-J-48 | 733420.21 | 4834275.37 | -4745.62 |
| Tantallon-M-41 | | | No data |
| Thebaud-I-93 | 722428.14 | 4862061.56 | -4077.77 |
| Venture-B-52 | 769643.46 | 4879431.29 | -4665.63 |

**PL. 4.3.2.14** **K137 Depth Structural Map**

## Tectono-Stratigraphical Chart




### Horizon Definition

The J150 horizon is near and below 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 margin. To the east, where the carbonate system evolved into a deltaic system, the J150 horizon corresponds to the top of the deltaic sandstones of the Mic-Mac Formation.

### Well to Seismic Tie

Three of the ten key wells reach the J150 horizon. All of these wells are located on the shelf. On the slope, the seismic picking is based only on the seismic facies. In terms of lithology, J150 is usually the transition from clastic deposits to the carbonates of the Baccaro Mb. It corresponds on the seismic to a peak, as an increase of acoustic impedance creates a positive amplitude on zero-phase seismic in normal polarity, according to the SEG convention.

### Seismic Picking and Uncertainty

The J150 seismic horizon was picked over the Annapolis Sub-basin using available 2D and 3D seismic databases (PL 4.3.2.16). In order to propagate the mapping on the Annapolis Sub-basin in accordance with the Shelburne and Laurentian Sub-basins, the interpretation of the J150 by CNSOPB (2014) was used as a guide to homogenize the interpretation. The seismic picking confidence is excellent on the shelf, with a sharp positive reflection and good well controls. Seismic quality decreases towards the slope as the Jurassic interval is strongly affected by early salt tectonics in the Annapolis Sub-basin. The picking is very uncertain close to the salt bodies, especially in the salt canopy province where highly complex structures are added to the subsalt imaging issues. In the offshore, seismic quality is better and the interpretation becomes more confident despite the lack of seismic calibration (no well control).

### Structural Description

The J150 structural map shows depths ranging from 2500 to 12000m below mean sea level (Plate 4-3-24).

After having filled the Sable Sub-basin, sediments continued to prograde into the deep basin along the margin (Figure 38). This period corresponds to the end of the Banquereau Synkinematic Wedge deformation; the J150 sealed the wedge. Diapirs cut the BSW and affect the horizon (Figure 39). In the central part, the vertical movements of allochthonous salt pierce the J150 which is not directly affected by the salt canopy. In the western part, the main listric/detachment faults are established in the Balvenie Wedge area. The J150 horizon is affected by diapirs originating from autochthonous salts.

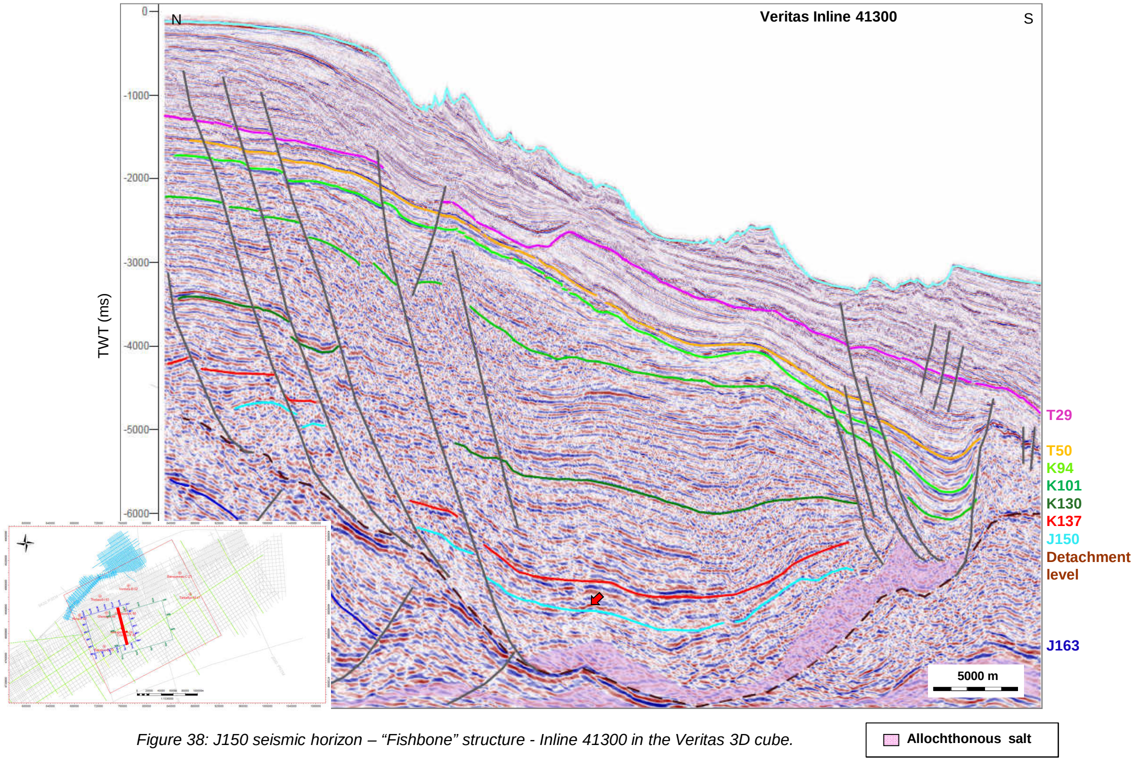



*Figure 38: J150 seismic horizon – "Fishbone" structure - Inline 41300 in the Veritas 3D cube.*

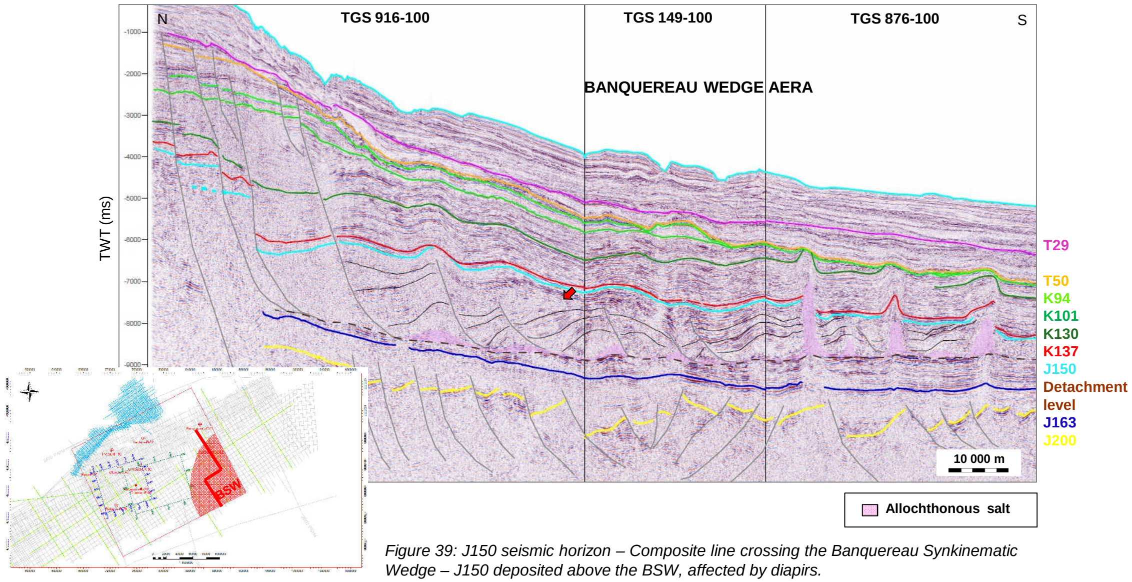
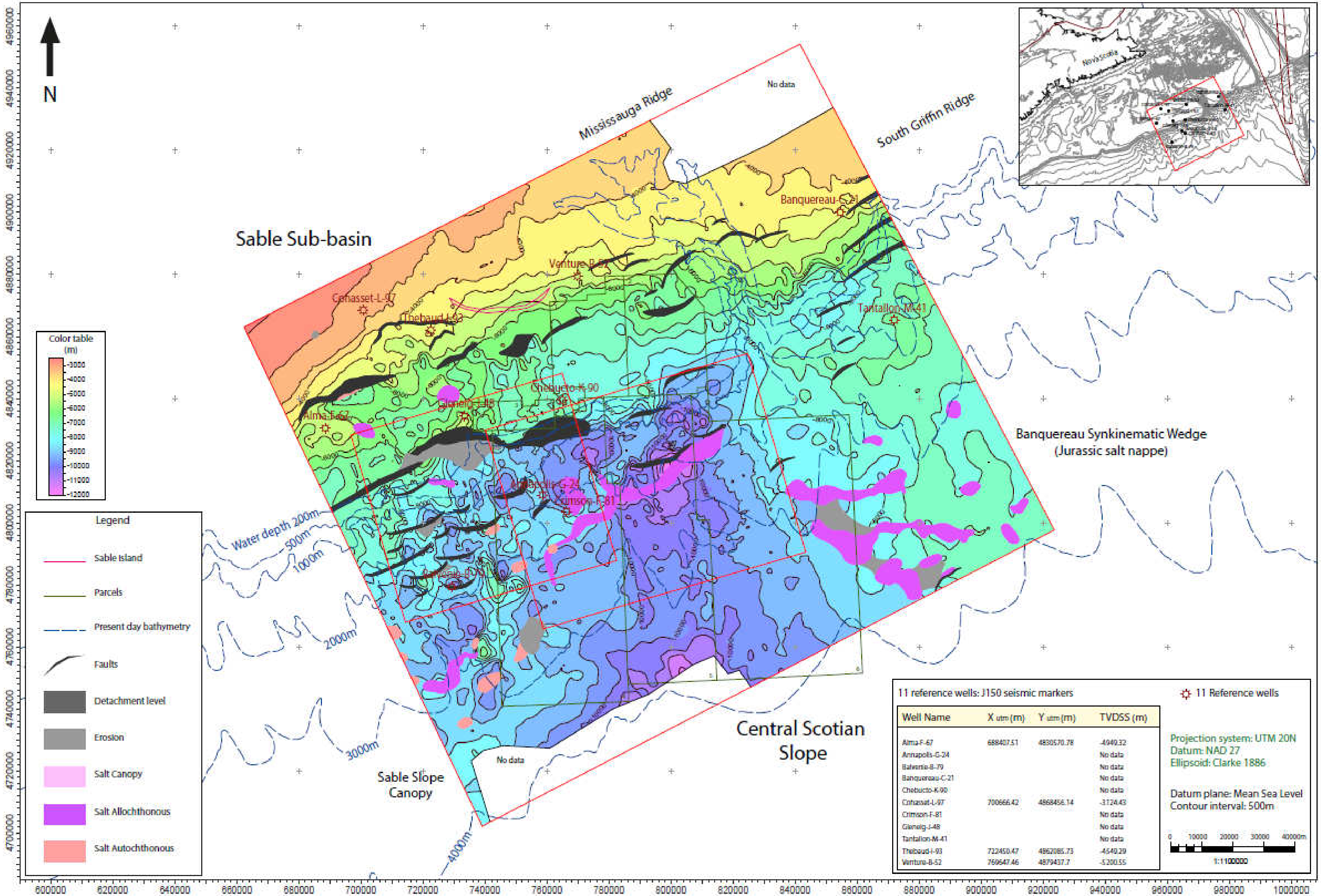



*Figure 39: J150 seismic horizon – Composite line crossing the Banquereau Synkinematic Wedge – J150 deposited above the BSW, affected by diapirs.*



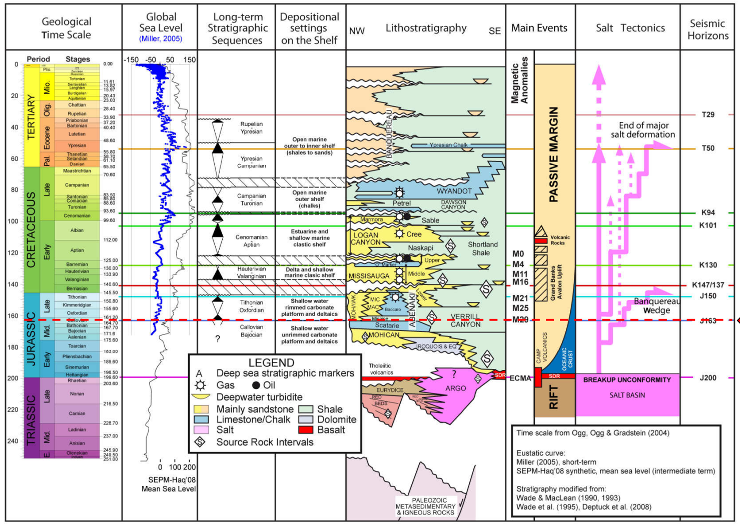

11 reference wells: J150 seismic markers

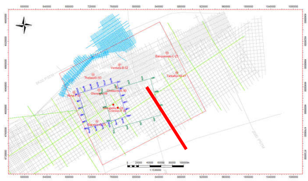
| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | 688407.51 | 4830570.78 | -4949.32 |
| Annapolis-G-24 | | | No data |
| Balvenie-B-79 | | | No data |
| Banquereau-C-21 | | | No data |
| Chebucto-K-90 | | | No data |
| Cohasset-L-97 | 700666.42 | 4868456.14 | -3124.43 |
| Crimson-F-81 | | | No data |
| Glenelg-J-48 | | | No data |
| Tantallon-M-41 | | | No data |
| Thebaud-I-93 | 722450.47 | 4862085.73 | -4549.29 |
| Venture-B-52 | 769647.46 | 4879437.7 | -5200.55 |



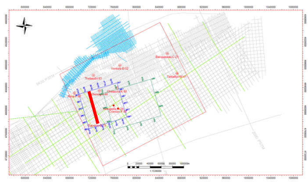
J150 Depth Structural Map

**Tectono-Stratigraphical Chart**

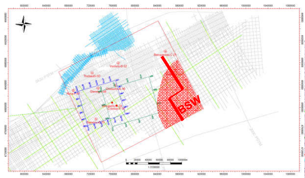


Salt canopy



Allochthonous salt



Allochthonous salt

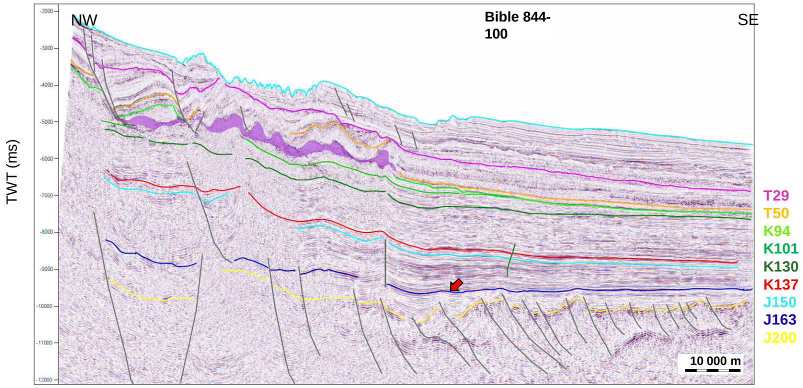



*Figure 40: J163 seismic horizon – Bible line 844-100.*

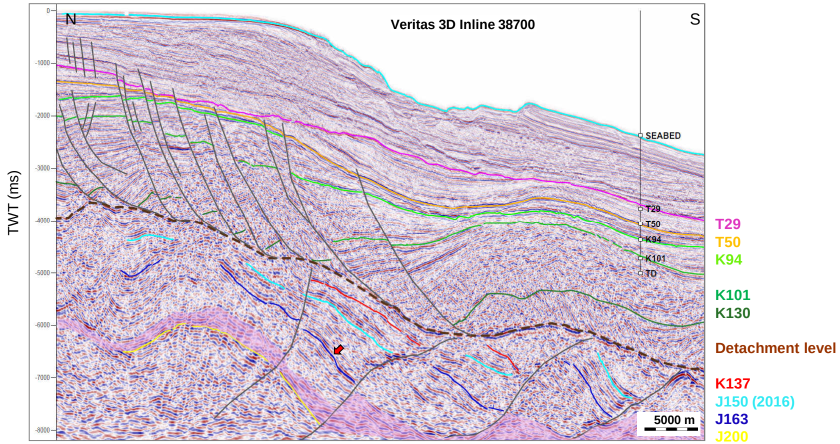



*Figure 41: J163 seismic horizon – Line in Veritas 3D cube – Geometry of titled blocks affecting the J163 horizon.*

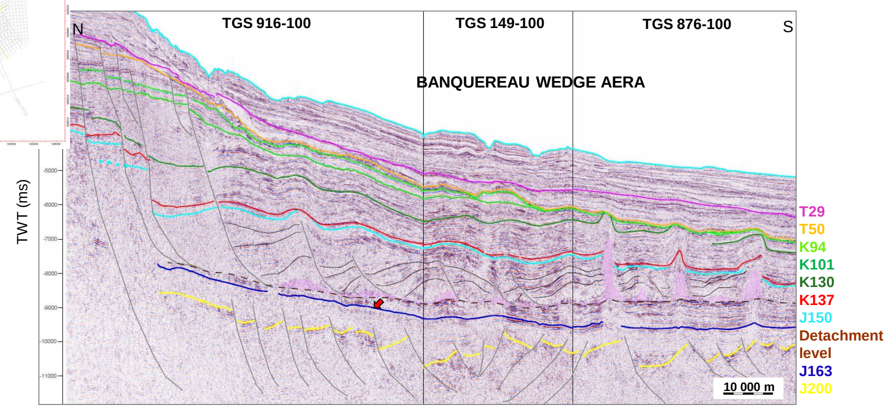



*Figure 42: J163 seismic horizon – BSW area, composite line.*

**Horizon Definition**

The J163 seismic horizon is close to the Callovian MFS identified in the biostratigraphic study. It corresponds to the top of the Scatarie Mb of the Abenaki Formation. It forms the onset of the shallow marine carbonate platform deposition.

**Well to Seismic Tie**

In terms of lithology, the J163 horizon is the transition between the shales of the Misaine Mb. and the carbonates of the Scatarie Mb. On the seismic, it corresponds to a positive peak as an increase of acoustic impedance creates a positive amplitude on zero-phase seismic in normal polarity, according to the SEG convention. All of these calibrated wells are located in the shelf area and so the well tie is only valid on the shelf. Outside of this zone, the interpretation of the J163 horizon is speculative and based only on seismic facies.

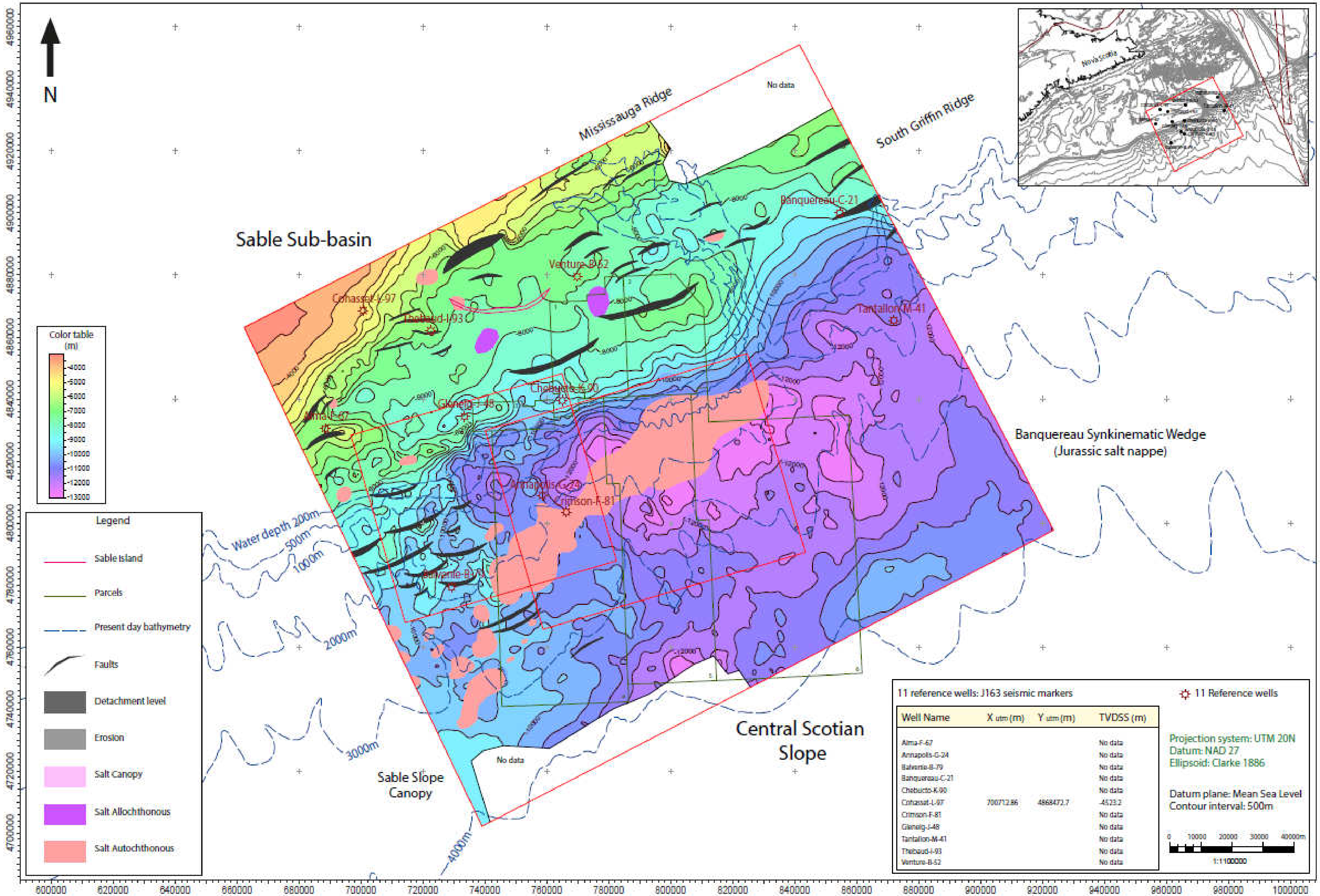
**Seismic Picking and Uncertainty;**

The J163 seismic marker was picked over the margin using available 2D and 3D seismic databases (PL4.3.2.17). The seismic picking confidence is excellent on the shelf with a sharp positive reflection. Seismic imaging quality decreases on the slope and in the deep offshore, mainly because of early salt tectonics in the Annapolis Sub-basin. The picking is very uncertain close to the salt bodies especially in the salt canopy province where highly complex structures add to the subsalt imaging issues. In the deep offshore area, outside of the salt diapir and salt canopy provinces, seismic quality is better and the interpretation becomes more confident despite the lack of seismic calibration (no well control).

**Structural Description**

The J163 depth structural map ranges from 3000 to 13000 m below mean sea level (Plate 4-3-26).

At the early Late Jurassic, sediment input is already well established and the passive margin architecture starts to develop. Thus, in the deepest part of the basin, it erases the geometry of J200. J163 is not affected by the deformation of J200 in the oceanic part (Figure 40); the sediments infill the Sable Sub-basin and prograde on the margin. In the main part of the study area, significant vertical migration of autochthonous salt affects the J163. In the western part, significant deformations are observed, corresponding to tilted blocks induced by the deformation of the Balvenie Synkinematic Wedge (Figure 41). In the eastern part of the slope, a portion of the J163 sediments are remobilized in the BSW (Figure 42).



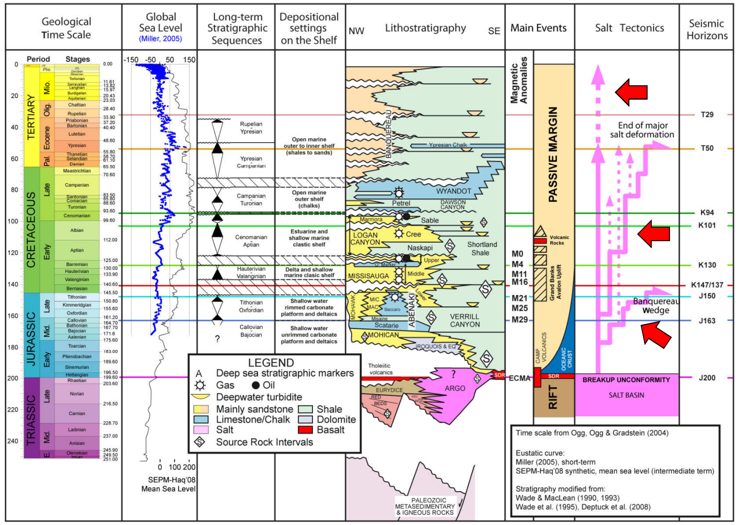

11 reference wells: J163 seismic markers

| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | | | No data |
| Annapolis-G-24 | | | No data |
| Balvenie-B-79 | | | No data |
| Banquereau-C-21 | | | No data |
| Chebucto-K-90 | | | No data |
| Cohasset-L-97 | 700712.86 | 4868472.7 | -4523.2 |
| Crimson-F-81 | | | No data |
| Glenelg-J-48 | | | No data |
| Tantallon-M-41 | | | No data |
| Thebaud-I-93 | | | No data |
| Venture-B-52 | | | No data |



J163 Depth Structural Map

**Tectono-Stratigraphical Chart**



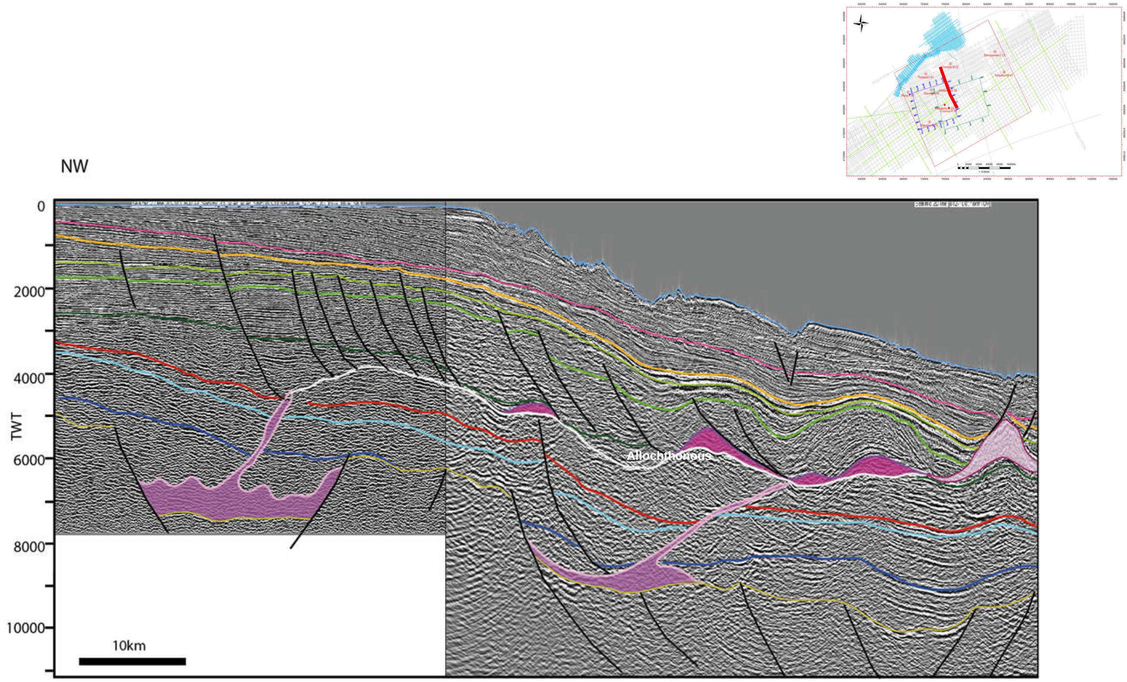




*Figure 43: Allochthonous salt – Banquereau detachment wedge zone – composite 2D line (83-1030B mgr & 812-100 NormTov).*

**Horizon Definition**

The horizon “Top Allochthonous Salt” corresponds to the various salt bodies which result from the remobilization and diapirism of the Late Triassic to Early Jurassic autochthonous salt. Generally related to vertical movement, it is distinguished from the Top Salt Canopy horizon, which is related to salt that mainly spreads laterally.

**Well to Seismic Tie, Seismic Picking and Uncertainty**

Allochthonous salt has been penetrated by a few wells on the margin (ex: Onondaga E-84, Primrose A-41, Wenonah J-75) located outside of the study area (PFA, 2011). On seismic data, it is displayed as an average to strong amplitude event at the interface between the overlying sediments and the higher velocity salt body. The picking of the allochthonous salt is relatively confident on the margin, on the slope and deep offshore areas, except in the Sable Sub-basin where only old vintage 2D seismic data of poor quality were available for seismic interpretation. It is also guided by overlying salt related structures and/or underlying pull-up effects due to the high velocity of the salt bodies.

**Structural Description**

The present day image of the allochthonous salt is the result of various phases of salt remobilization during subsequent sediment loading and gravity gliding. Two major provinces can be described:

- The growth fault and roll-over province of the Sable and Annapolis Sub-basins. In these provinces, salt domes and tongues are created in relation to the prograding and gravity-gliding systems of the Jurassic and Early Cretaceous intervals. Autochthonous salt was pushed out of the Sable Sub-basin to flow in Annapolis Sub-basin (Figure 43);
- The Banquereau Synkinematic Wedge zone. This zone shows regional scale salt detachment and associated syn-kinematics sediments (Ings and Shimeld, 2006), which occurred during Jurassic times. The detachment layer is interpreted as a thin layer of salt or a possible welded zone with small triangular salt remnants (rollers) and sparse diapirs at the front of the detachment (Figure 44).

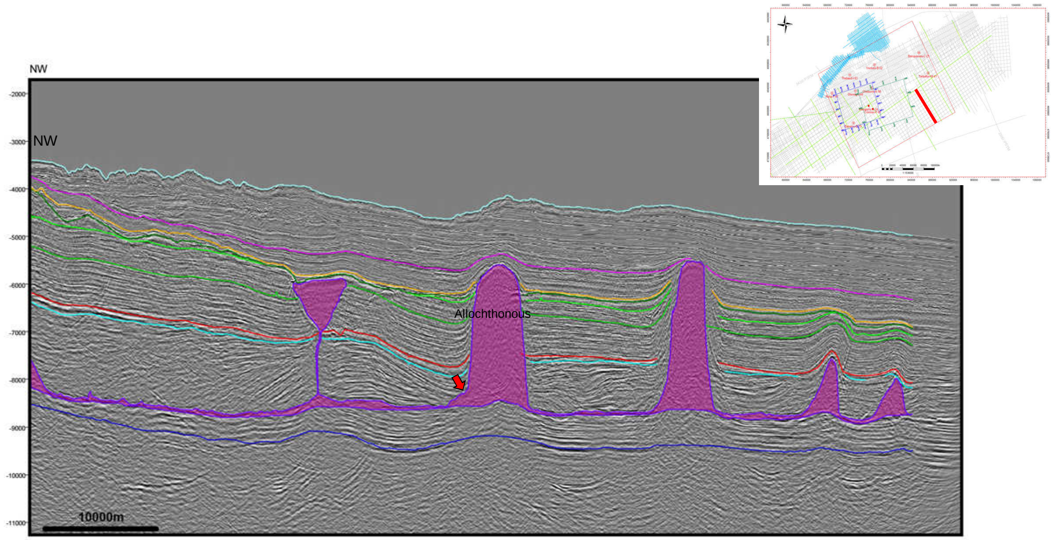
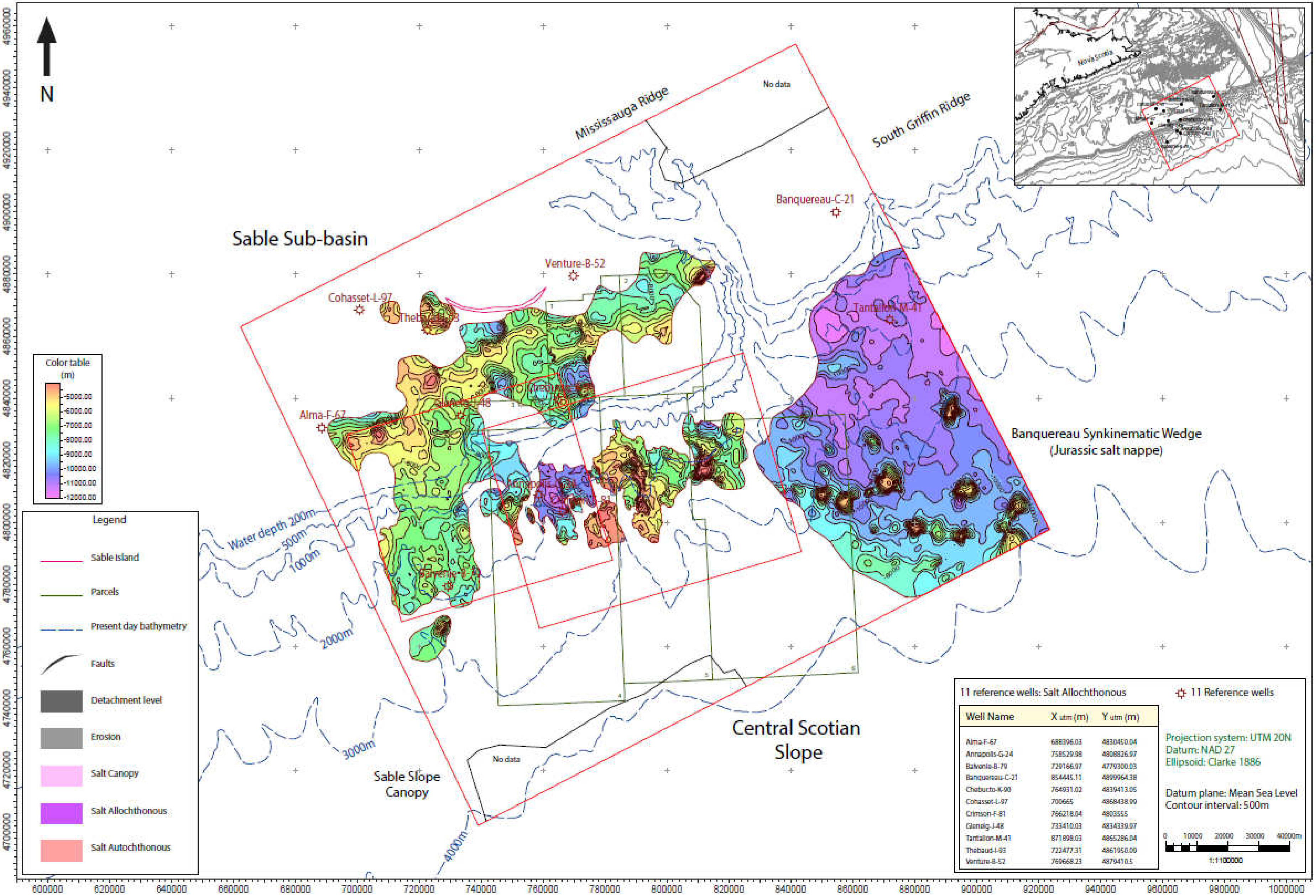



*Figure 44: Allochthonous salt – Banquereau detachment wedge zone – 2007 reprocessed TGS 884-100 2D line.*




11 reference wells: Salt Allochthonous

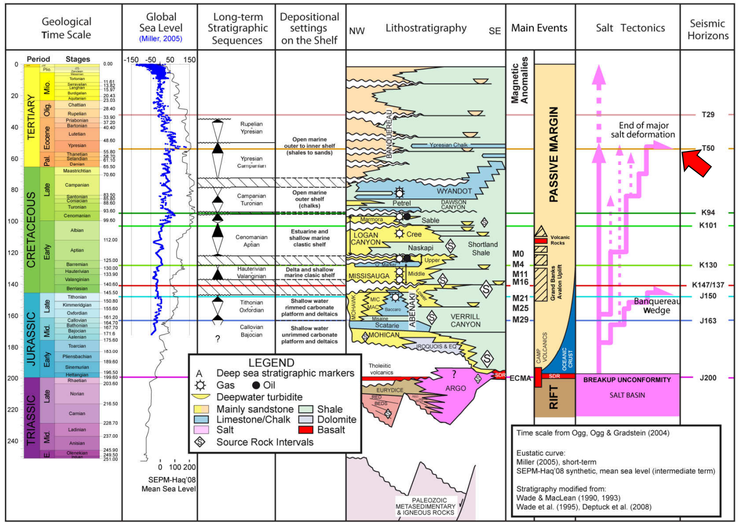
11 Reference wells

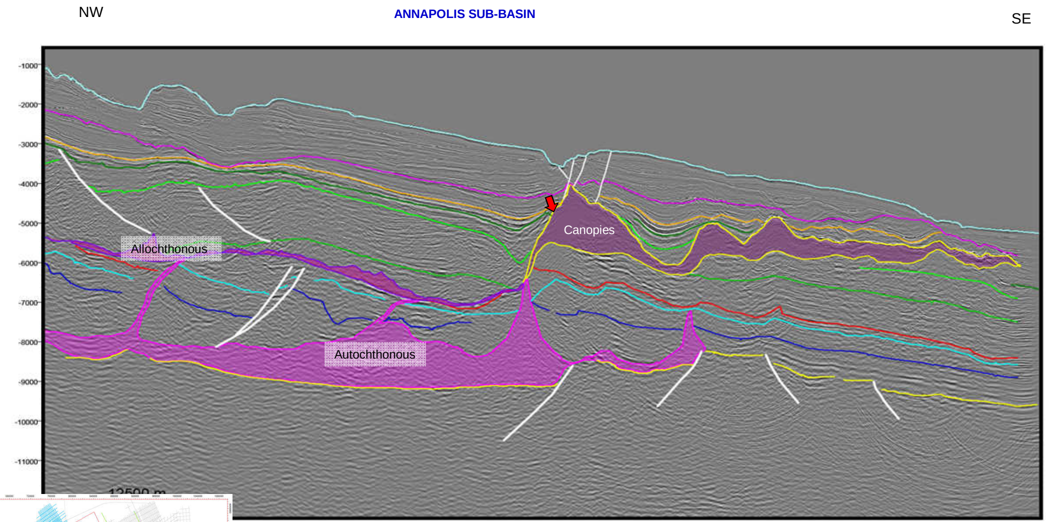
| Well Name | X utm (m) | Y utm (m) |
|---|---|---|
| Alma-F-67 | 688396.03 | 4830450.04 |
| Annapolis-G-24 | 758529.98 | 4808826.97 |
| Balvenie-B-79 | 729166.97 | 4779300.03 |
| Banquereau-C-21 | 854445.11 | 4899964.38 |
| Chebucto-K-90 | 764931.02 | 4839413.05 |
| Cohasset-L-97 | 700665 | 4868438.99 |
| Crimson-F-81 | 766218.04 | 4803555 |
| Glenelg-J-48 | 733410.03 | 4834339.97 |
| Tantallon-M-41 | 871898.03 | 4865286.04 |
| Thebaud-I-93 | 722477.31 | 4861950.09 |
| Venture-B-52 | 769668.23 | 4879410.5 |

PL. 4.3.2.20

**Top Allochthonous Salt Depth Structural Map**

**Tectono-Stratigraphical Chart**



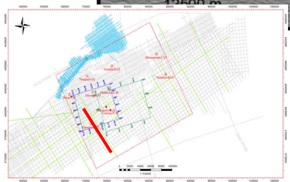
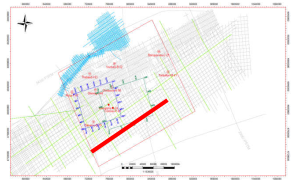



*Figure 45: Salt Canopy Province – Dip line across Annapolis sub-basin – 708-100 NormTov.*



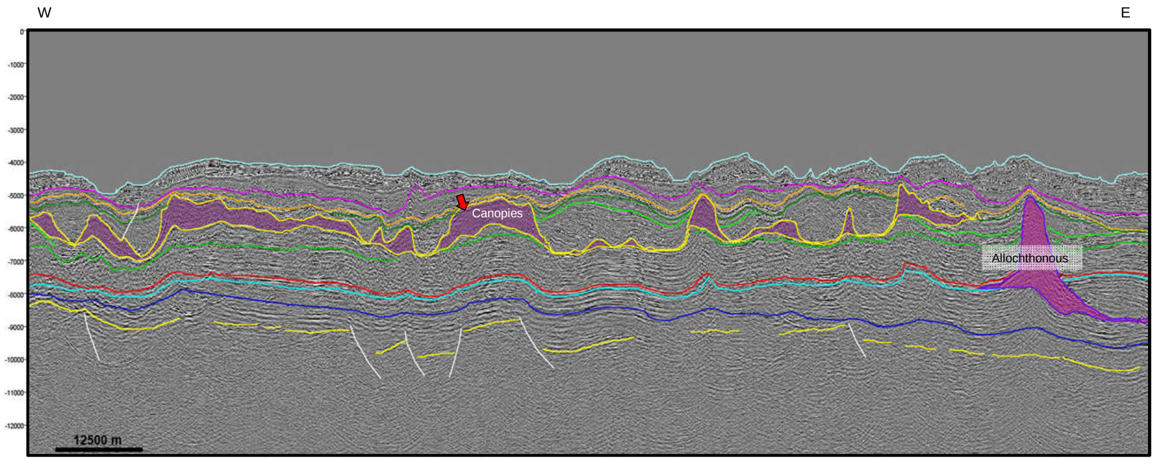



*Figure 46: Salt Canopy Province – Strike line along Annapolis sub-basin – 149-100 Norm Tov.*

**Horizon Definition**

The horizon "Top Salt Canopy" corresponds to the top of a complex set of salt bodies resulting from the remobilization of earlier salt tongues in a passive continental margin due to sediment loading and salt expelled seaward (Gemmer et al., 2005; Ings and Shimeld, 2006; Vendeville, 2005).

**Seismic Picking and Uncertainty**

On seismic data, the salt canopy body is characterized by the absence of seismic reflections in an interval delimited:

- By a strong positive amplitude at the top of the salt (positive contrast of impedance due to the high velocity of the salt);
- By a weak to average amplitude event at the bottom of the salt body (negative contrast of impedance).

The picking of the Top Salt Canopy is relatively confident and mainly controlled by 3D seismic surveys. The picking of the base of the salt canopy is more difficult due to sub-salt imaging problems. The 2010 pre-stack 2D reprocessing improved the quality of the sub-salt interval.

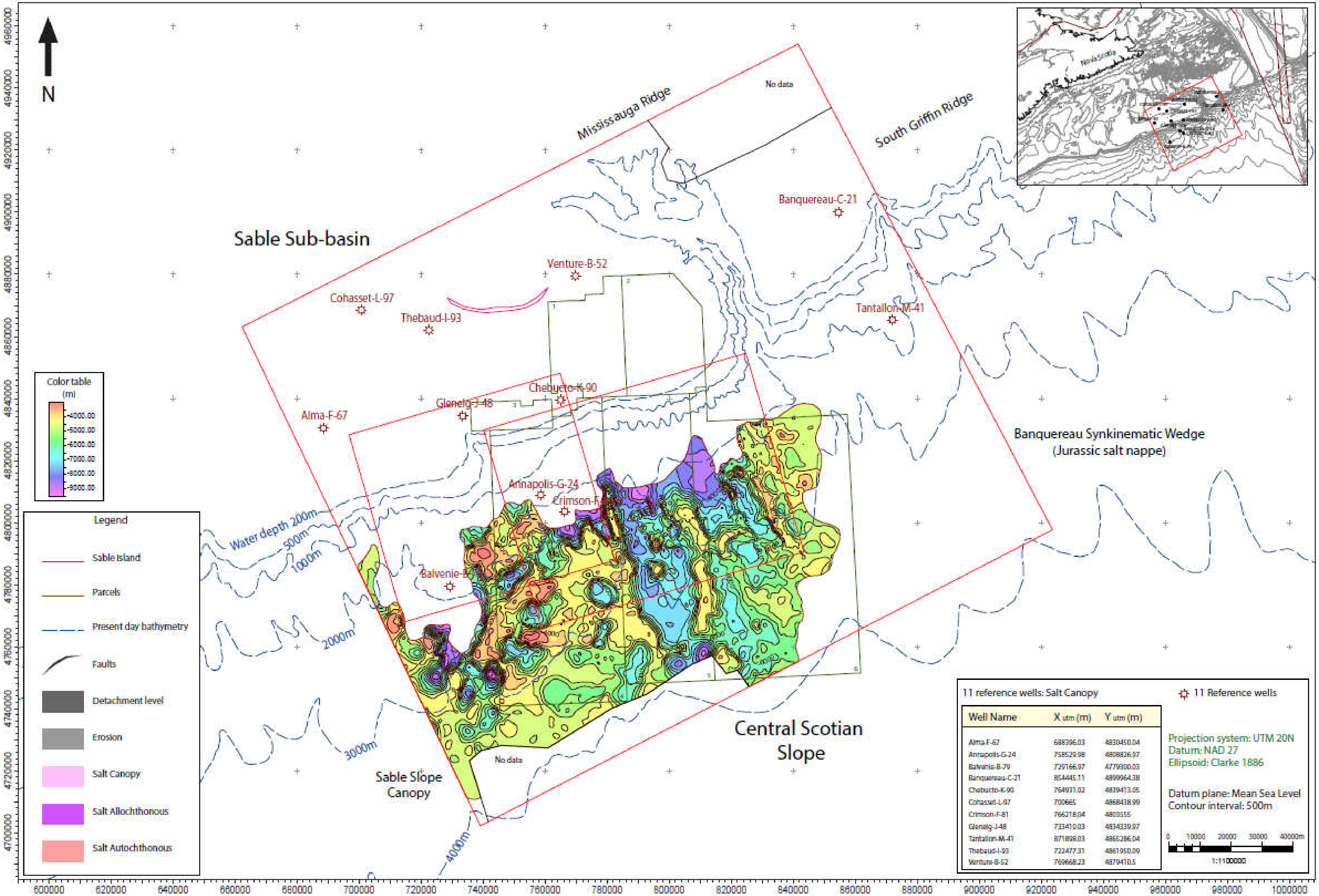
**Structural Description**

Salt canopies characterize the Sable Salt Canopy province (PL 2-18) located at the southern edge of the Annapolis Sub-basin in front of the major sedimentary supply. It is the result of long-term salt tectonics mainly controlled by sediment progradation and aggradation into the Scotian Basin (Ings et al., 2009).

The Top Salt Canopy generally shows an irregular topography in relation to later local salt withdrawals and rises. The Canopy extends seaward over a large distance (i.e. 100 km) and is delimited laterally by sharp flanks, which could be connected to deeper transverse faults.

The base of the salt canopies can be subdivided into two parts: a steep ramp in relation to the syn-sedimentary motion of the salt body and a flat ramp related to rapid flowage during low sedimentation rate episodes.

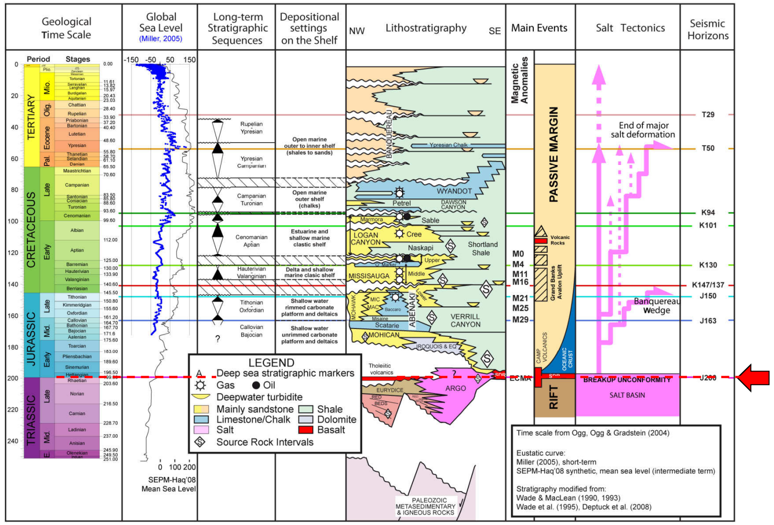
The canopy is fed by allochthonous and autochthonous salt through a system of feeders also called a Roho System (PL 2-14).




| Well Name | X utm (m) | Y utm (m) |
|---|---|---|
| Alma-F-67 | 688396.03 | 4830450.04 |
| Annapolis-G-24 | 758529.98 | 4808826.97 |
| Balvenie-B-79 | 729166.97 | 4779300.03 |
| Banquereau-C-21 | 854445.11 | 4899964.38 |
| Chebucto-K-90 | 764931.02 | 4839413.05 |
| Cohasset-L-97 | 700665 | 4868438.99 |
| Crimson-F-81 | 766218.04 | 4803555 |
| Glenelg-J-48 | 733410.03 | 4834339.97 |
| Tantallon-M-41 | 871898.03 | 4865286.04 |
| Thebaud-I-93 | 722477.31 | 4861950.09 |
| Venture-B-52 | 769668.23 | 4879410.5 |

PL. 4.3.2.22 **Top Salt Canopy Depth Structural Map**

**Tectono-Stratigraphical Chart**



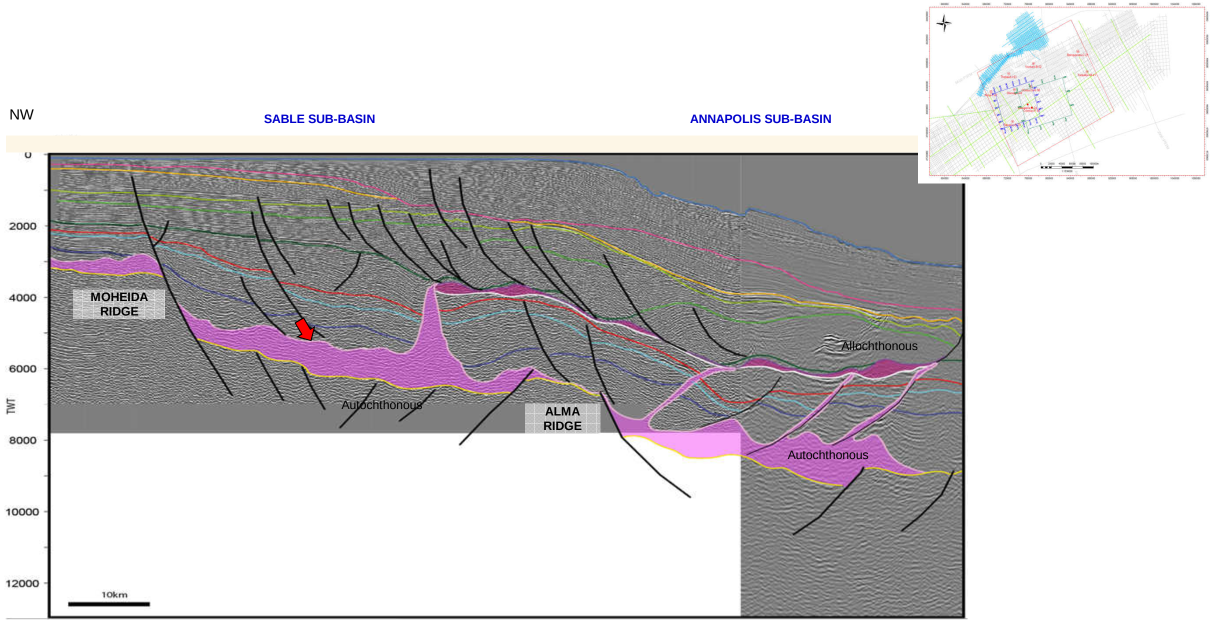




*Figure 47: Allochthonous Salt - Sable Sub-basin – 2010 reprocessed GXT NovaSPAN 2D line 1600 – PSTM.*

**Horizon Definition**

The horizon "Top Autochthonous Salt" corresponds to the salt sheet deposited from Late Triassic to possibly Early Jurassic times on top of existing rift topography and which remained during subsequent deformational events in its autochthonous basin. It differs from the Allochthonous Salt and the Salt Canopy bodies, which evacuated either vertically or laterally from their autochthonous basins.

**Well to Seismic Tie, Seismic Picking and Uncertainty**

The Top Autochthonous Salt has only been penetrated on the continental shelf by the well Glooscap C-63. In the well, the Top Autochthonous Salt is mainly characterized by a sharp decrease in impedance due to the low salt density ($d_{salt}$ = 2 g/cm$^3$) interbedded with denser sediments. On seismic, it is generally displayed as a negative seismic event with poor lateral continuity. In the absence of well control, the seismic interpretation of the Top Autochthonous Salt remains uncertain and is mainly guided by overlying salt related structures and/or underlying pull-up effects due to the high velocity of the salt bodies. In the deepest part of the basin, the autochthonous salt interpretation is very speculative due to poor quality seismic imaging.

**Structural Description**

The present day image of the salt is the result of various phases of salt remobilization due to sediment loading and gravity gliding. Autochthonous salt is present in all the early inherited rift basins of the Nova Scotia Margin such as the Sable and Annapolis Sub-basins. The salt basins are generally limited by normal faults; basement structural highs such as the Alma and South Griffin Ridges are free of salt deposits. The southern limit of the autochthonous salt basin is associated with the basement step observed along a positive magnetic anomaly (corresponding to the East Coast Magnetic Anomaly – the ECMA), which separates the continental crust from the serpentinized mantle or oceanic crust.

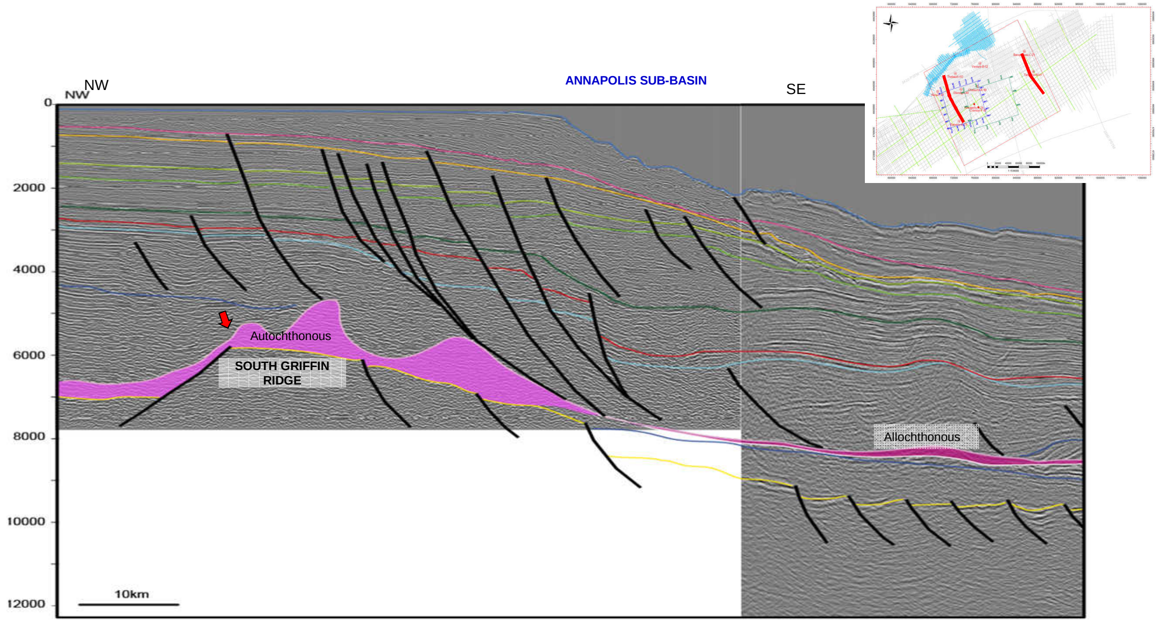
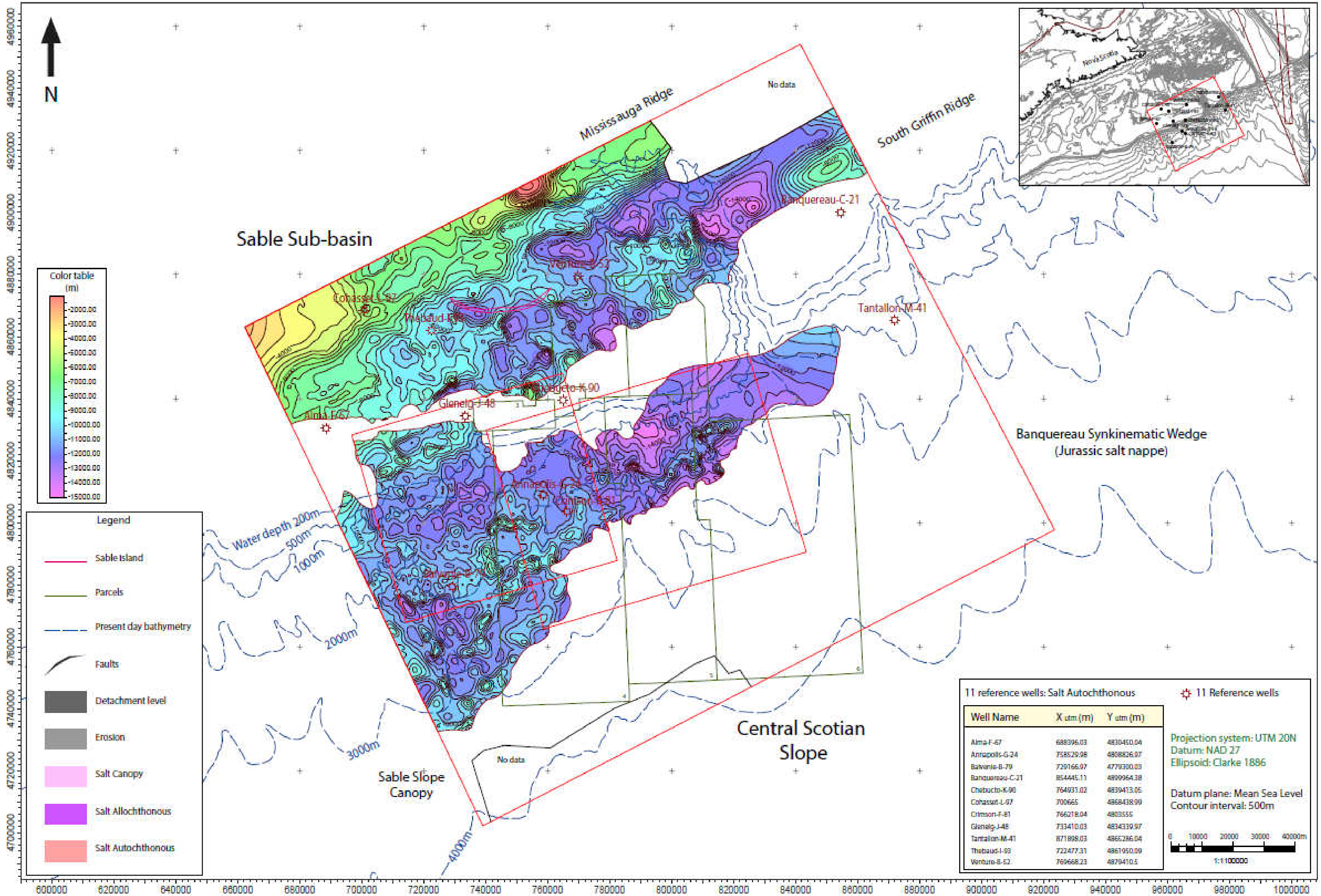


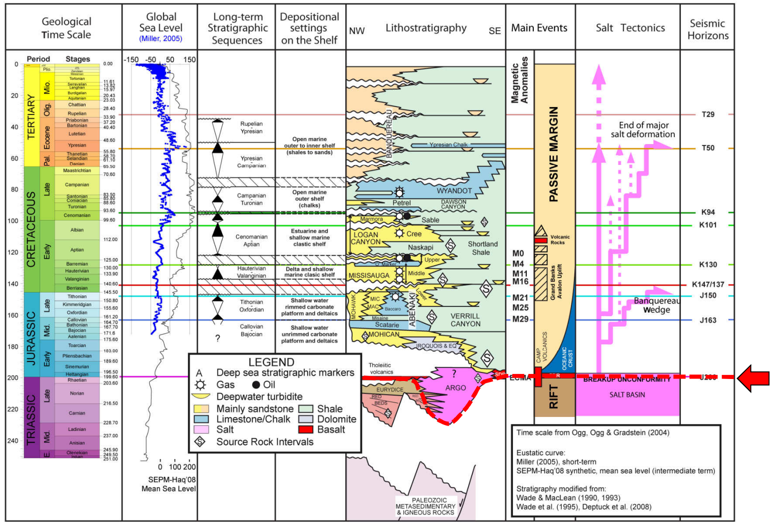

*Figure 48: Salt Canopy Province – Dip line across Annapolis sub-basin – 708-100 NormTov.*




| Well Name | X utm (m) | Y utm (m) |
|---|---|---|
| Alma-F-67 | 688396.03 | 4830450.04 |
| Annapolis-G-24 | 758529.98 | 4808826.97 |
| Balvenie-B-79 | 729166.97 | 4779300.03 |
| Banquereau-C-21 | 854445.11 | 4899964.38 |
| Chebucto-K-90 | 764933.02 | 4839413.05 |
| Cohasset-L-97 | 700665 | 4868438.99 |
| Crimson-F-81 | 766218.04 | 4803555 |
| Glenelg-J-48 | 733410.03 | 4834339.97 |
| Tantallon-M-41 | 871898.03 | 4865286.04 |
| Thebaud-I-93 | 722477.31 | 4861950.09 |
| Venture-B-52 | 769668.23 | 4879410.5 |

PL. 4.3.2.24 Top Autochthonous Salt Depth Structural Map

## Tectono-Stratigraphical Chart




### Horizon Definition

The horizon named "Base of the Post-rift Sediments" 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 to the basement of the Argo Salt, when present on the slope and in the distal basin. Seawards in the deep offshore area, the horizon has been picked at the top of the exhumed/serpentinized mantle or oceanic crust.

### Well to Seismic Tie

The well to seismic tie is limited to a single well on the Moheida Ridge, which penetrated deep enough in the Triassic series (reference well: Glooscap- C63; PFA 2011). Outside of this zone, the interpretation of the Base of the Post-rift Sediments is speculative and based only on seismic facies.

### Seismic Picking and Uncertainty

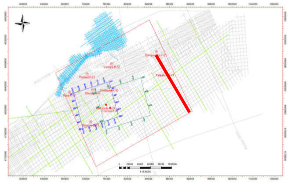
The "Base of the Post-rift Sediments" horizon was picked over the study area using available 2D and 3D seismic databases (PL. 4.3.2.26).

The structural complexity and the poorly imaged seismic interval make picking very uncertain. The seismic event is characterized by an average to poor seismic reflection with poor lateral seismic continuity (Figure 49). Outside of the continental shelf into the slope, seismic interpretation of this horizon is very speculative (Figure 50). In the deep offshore, seismic interpretation becomes more confident with the interpretation of the top of the exhumed/serpentinized mantle or oceanic crust (Figure 50).

### Structural Description

The "Base of the Post-rift Sediments" structural map shows 3 domains:

- The continental crust composed of alternating sharp and elongated highs (NE-SW) and wide troughs (Sable and Annapolis Sub-basins). These troughs correspond to the autochthonous salt basins;
- The southern edge of the continental crust is marked by a major basement step associated with the East Coast Magnetic Anomaly (ECMA). It is believed to represent a "volcanic ridge" which makes the transition between the continental and the exhumed/serpentinized mantle domain (or oceanic crust ?). It also corresponds to the end of the autochthonous salt basin;
- The serpentinized/exhumed mantle domain (or oceanic crust) located in the southeast portion of the study area. No majors features such as structural highs or troughs are observed, but a series of tilted, rotated fault blocks are visible. This domain is separated from the continental domain by the Continental Oceanic Boundary (COB).



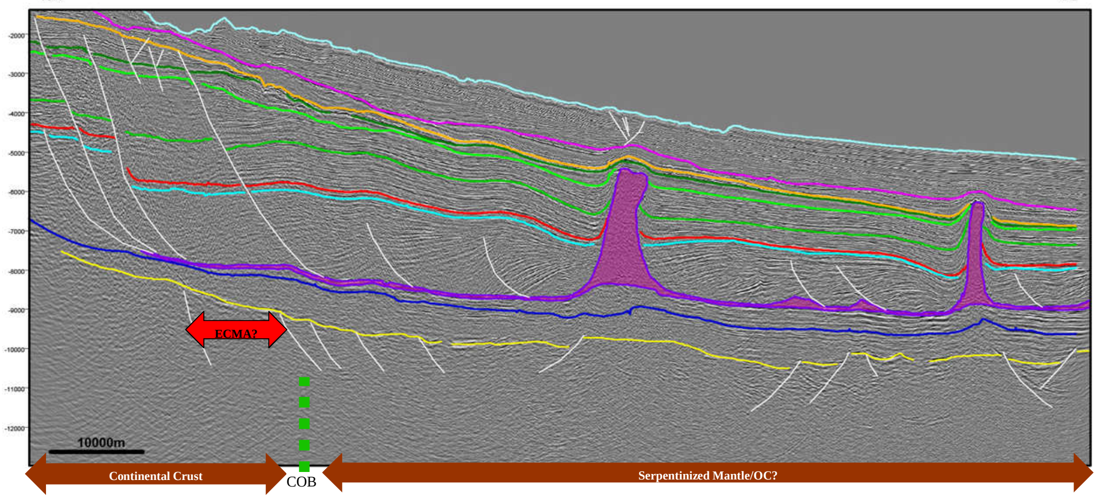
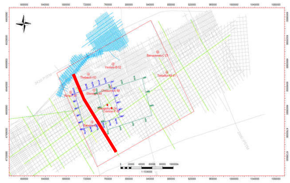



*Figure 49: Base of Post-Rift Sediments – Banquereau Synkinematic Wedge area – 924-100 Norm Tov.*



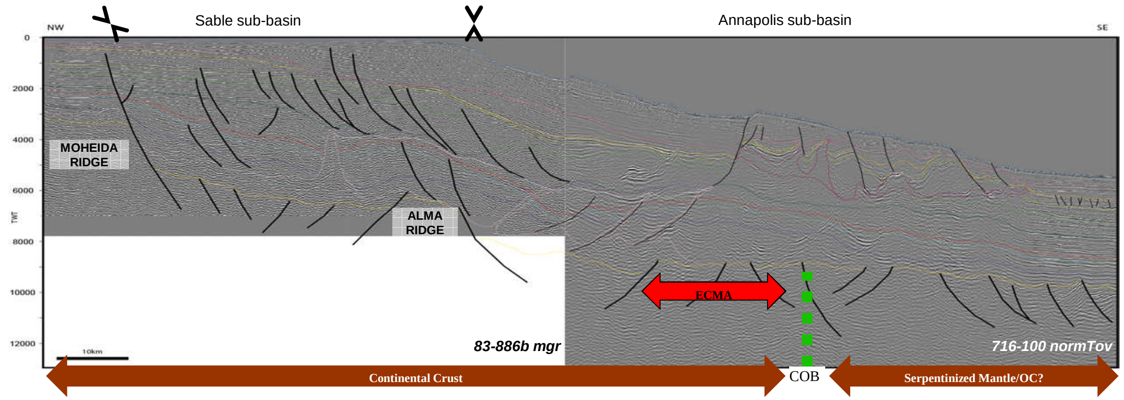
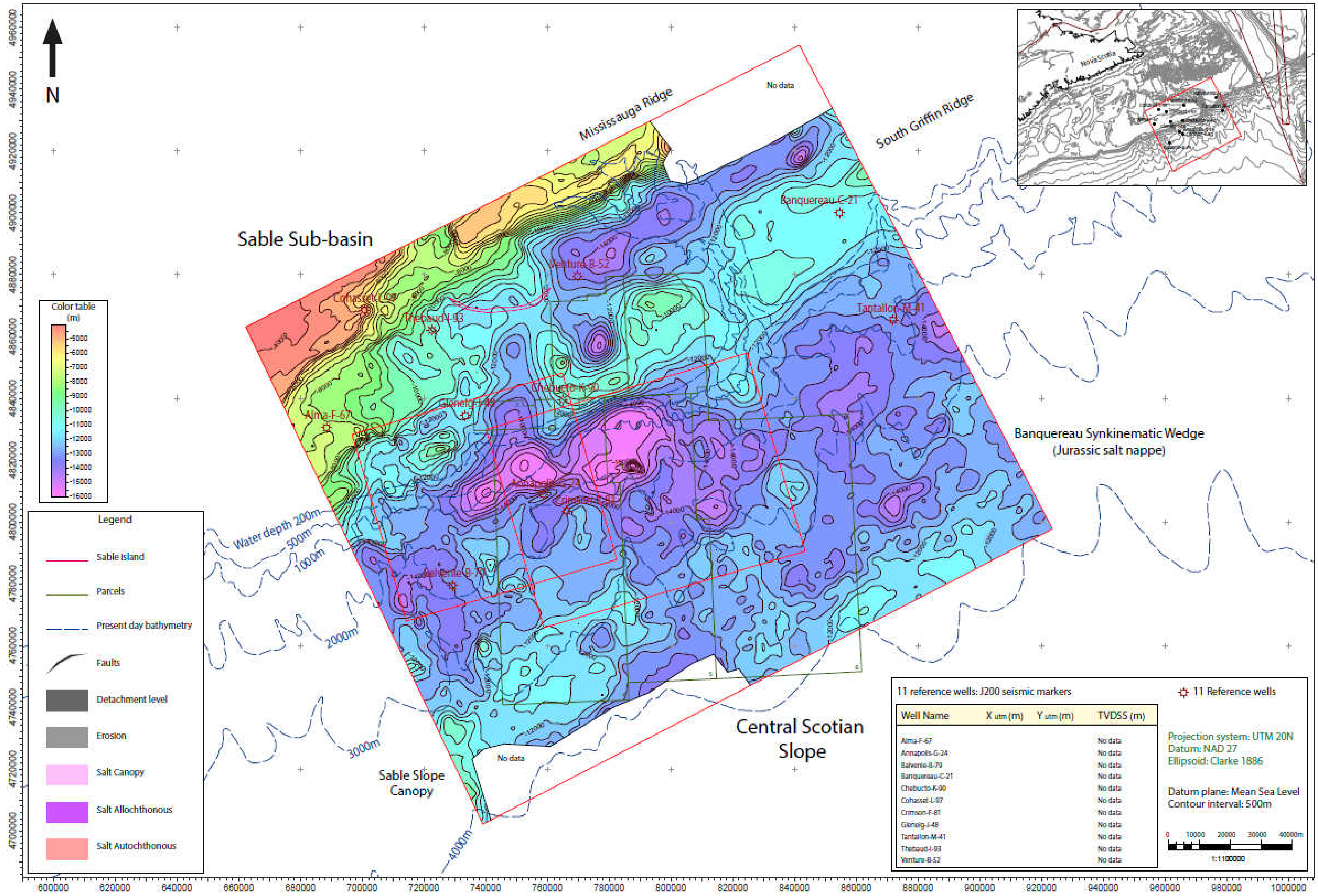



*Figure 50: Base of Post-Rift Sediments_ transition between continental and oceanic crust.*




| Well Name | X utm (m) | Y utm (m) | TVDSS (m) |
|---|---|---|---|
| Alma-F-67 | | | No data |
| Annapolis-G-24 | | | No data |
| Balvenie-B-79 | | | No data |
| Banquereau-C-21 | | | No data |
| Chebucto-K-90 | | | No data |
| Cohasset-L-97 | | | No data |
| Crimson-F-81 | | | No data |
| Glenelg-J-48 | | | No data |
| Tantallon-M-41 | | | No data |
| Thebaud-I-93 | | | No data |
| Venture-B-52 | | | No data |

PL. 4.3.2.26 **Base of Post-Rift Sediments Depth Structural Map**

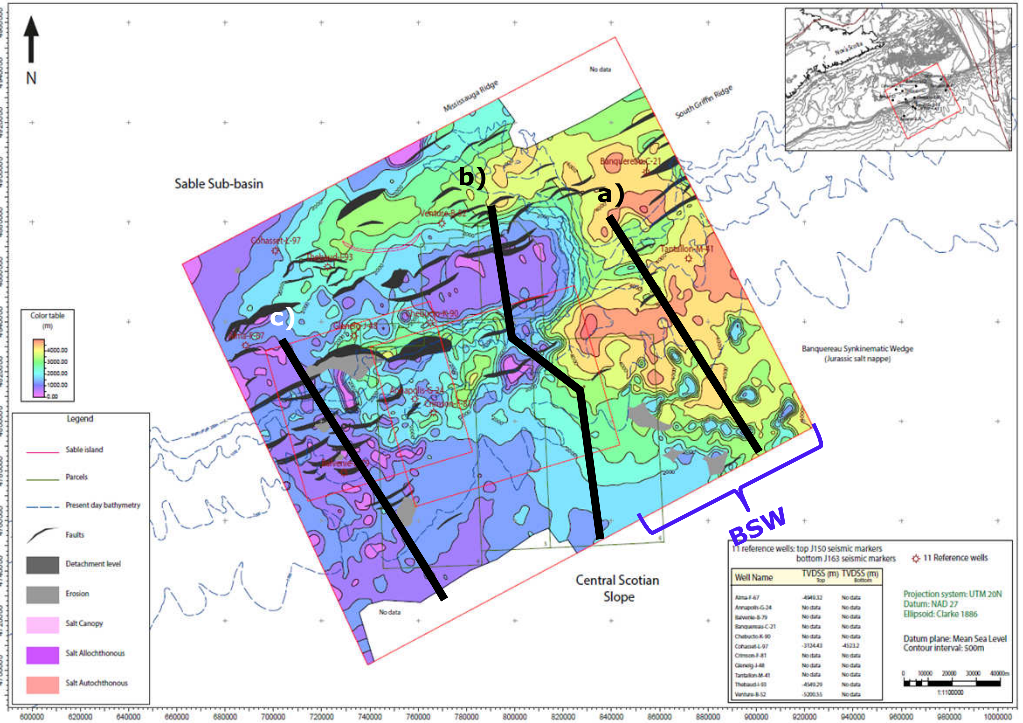



*Figure 50: Thickness map between J163-J150.*

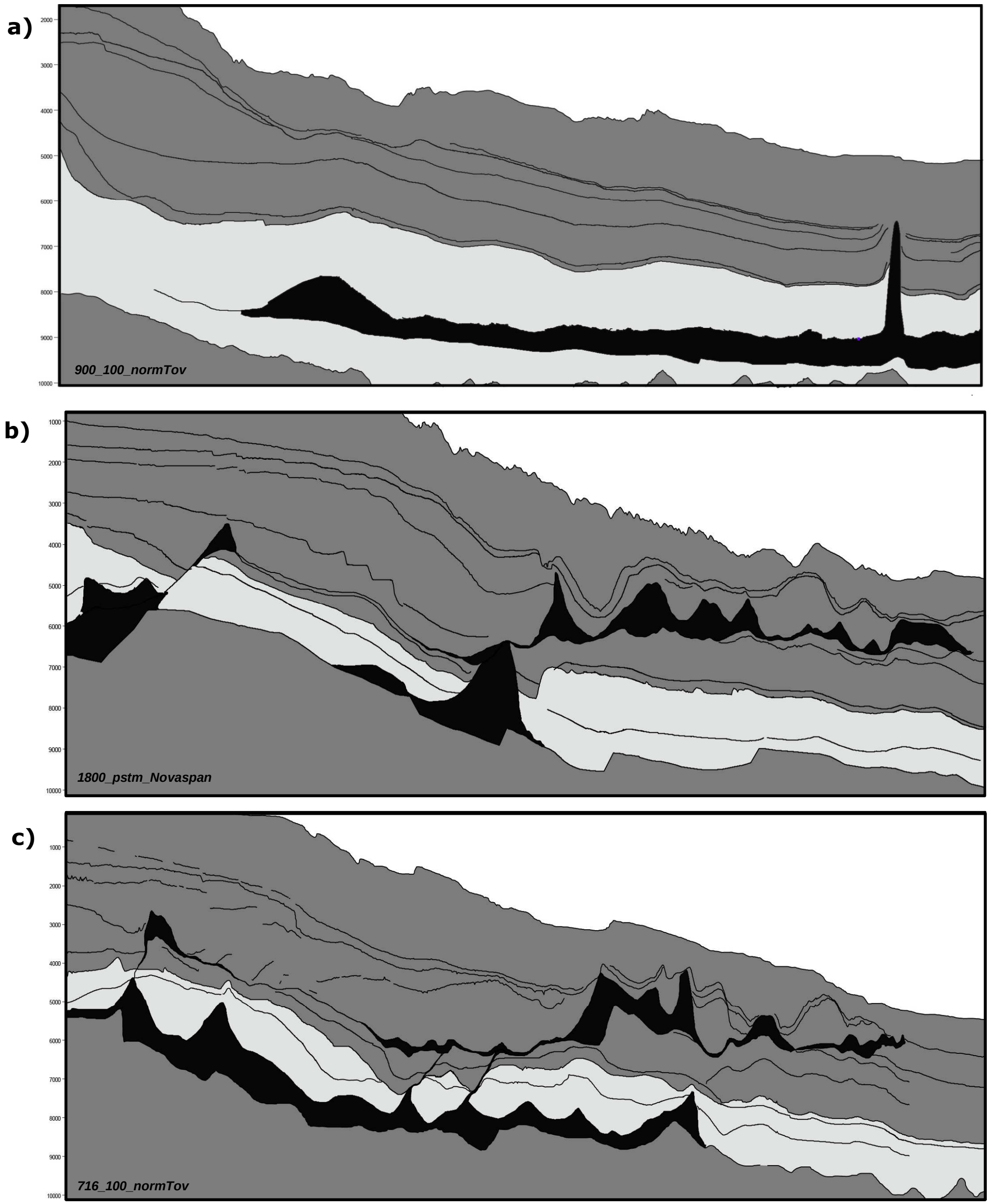



*Figure 51: Three seismic lines across the study area: a) Line in the BSW area; b) line in the central part; c) line in the BaSW area. The Jurassic series is shown in light grey.*

The following maps and figures (Figures 50, 51, 52 and 53) result from the mapping and highlight the sedimentary evolution in different parts of the basin over time.

During the Jurassic from 200 to 150Ma, the main depocenters were located on the eastern side of the study area (Figure 50).

As shown by the sedimentary study (PL 2-21), sediment input during the Jurassic was from the northeast and the deposits filled the Sable Sub-basin and ~~the~~ Banquereau area (Plate 2-21). As described in the tectonic setting (PL 2-21) the salt overpassed the South Griffin Ridge and spread into the Banquereau area.

Thus the sedimentary wedge developed and its thickness reached an average of 5km, whereas in the other parts of the study area such as the Annapolis Sub-basin) it only attained 1 to 1.5 km in thickness (Figures 50 and 51).

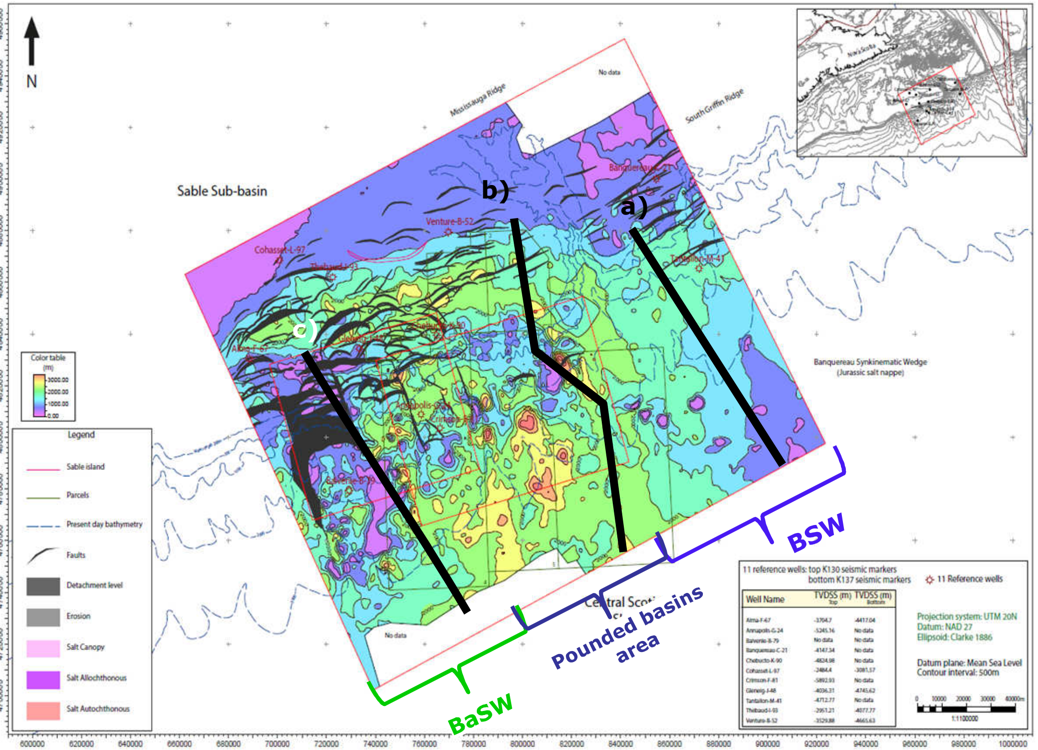



*Figure 52: Thickness map of the units between K137-K130.*

During the Cretaceous, from 145 to 94 Ma, a switch of depocenters from the northeast (Sable Sub-basin and BSW) to the southwest (Annapolis Sub-basin) is observed (Figure 52).

The main sedimentary input migrates to the central part of the Sable Sub-basin (Figures 52 and 53b). Three main depocenters are observed: the shelf, the slope and the distal basin (Figure 52).

As for the BSW, the sedimentary overloading drives the Sable Sub-basin autochthonous salt creeping over the Alma Ridge and spreading in the western side of the study area. At the same time, a set of growth faults develops on the shelf edge and traps the sediments. The salt creeping increases also in the central slope (resulting in canopy development) and several pounded basins form. The average thickness reaches 2.5 km in the central and western areas whereas it is less important on the BSW (1km average; Figure 53).

In the late Early Cretaceous the BaSW forms in the eastern part of the study area.

In the Late Cretaceous the sedimentary input decreases and deposits are mainly trapped on the shelf edge particularly in the central and western areas.

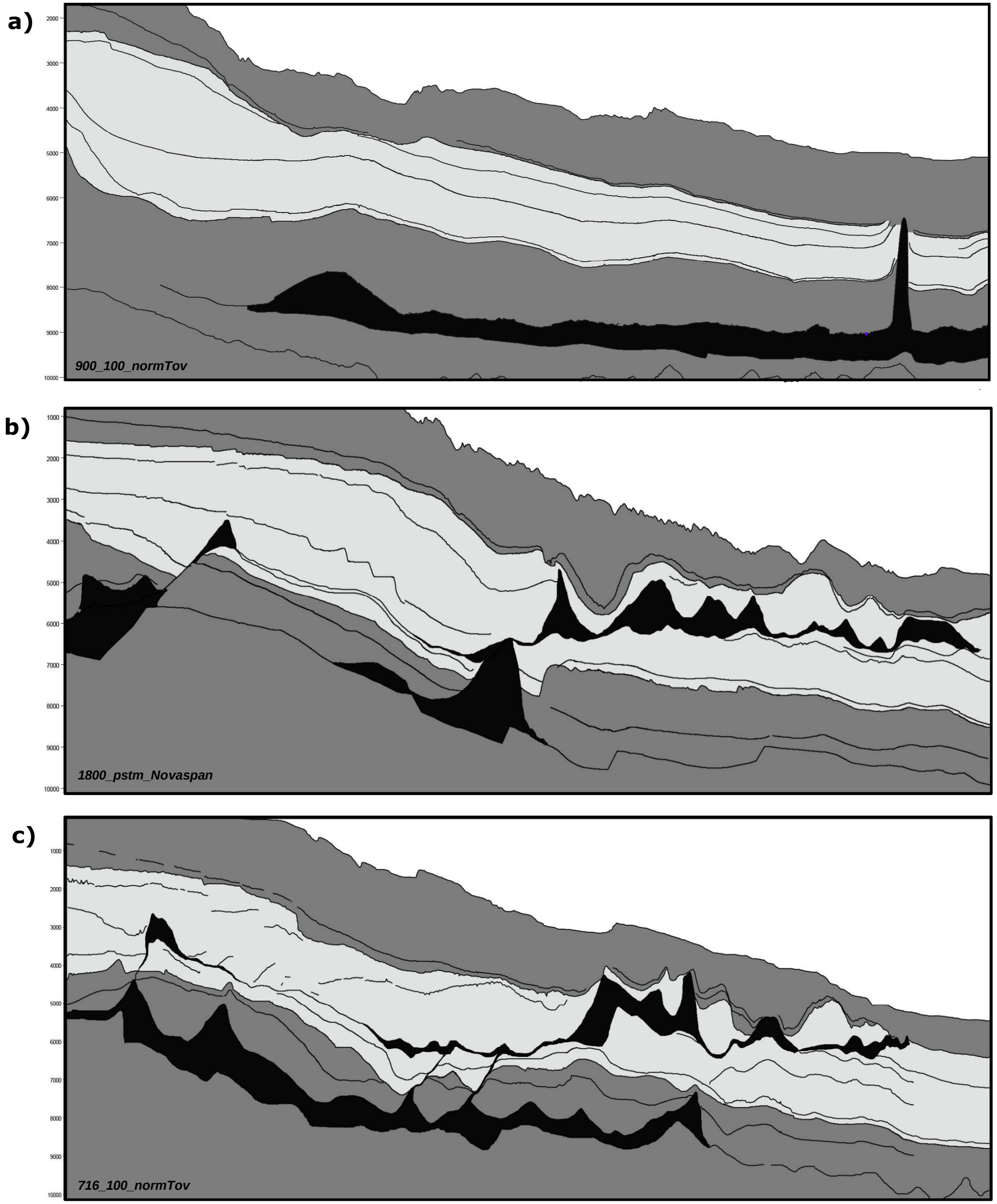



*Figure 53: Three seismic lines across the study area: a) Line in the BSW area; b) line in the central part; c) line in the BaSW area. The Cretaceous series is shown in light grey.*



## Thickness Map between K137 to K130

**References:**

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Gemmer L., Beaumont C., Ings, S.J., 2005. Dynamic modeling of passive margin salt tectonics: effects of water loading, sediment properties and sedimentation patterns, Basin Research, (2005) 17, 383-402.

Ings S.J., Shimeld J.W., 2006. A new conceptual model for the structural evolution of a regional salt detachment on the northeast Scotian margin, offshore eastern Canada, AAPG Bulletin, V.90, N° 9 (September 2006), pp. 1407-1423.

Ings S.J., Gemmer L., Beaumont C., 2009. Passive Margin Salt Tectonics: Effects of Margin Tilt, Sediment Progradation, and Regional Extension.

Vendeville B.C., 2005. Salt tectonics driven by sediment progradation: Part I – Mechanics and kinematics, AAPG Bulletin, V.89, N° 8 (August 2005), pp. 1071-1079.

Wade, J.A., and MacLean, B.C., 1990. The geology of the southeastern margin of Canada (chapter 5), in Keen, M.J., and Williams, G.L., eds, Geology of the continental margin of eastern Canada: Geological Survey of Canada, Geology of Canada, no.2, p.190-238