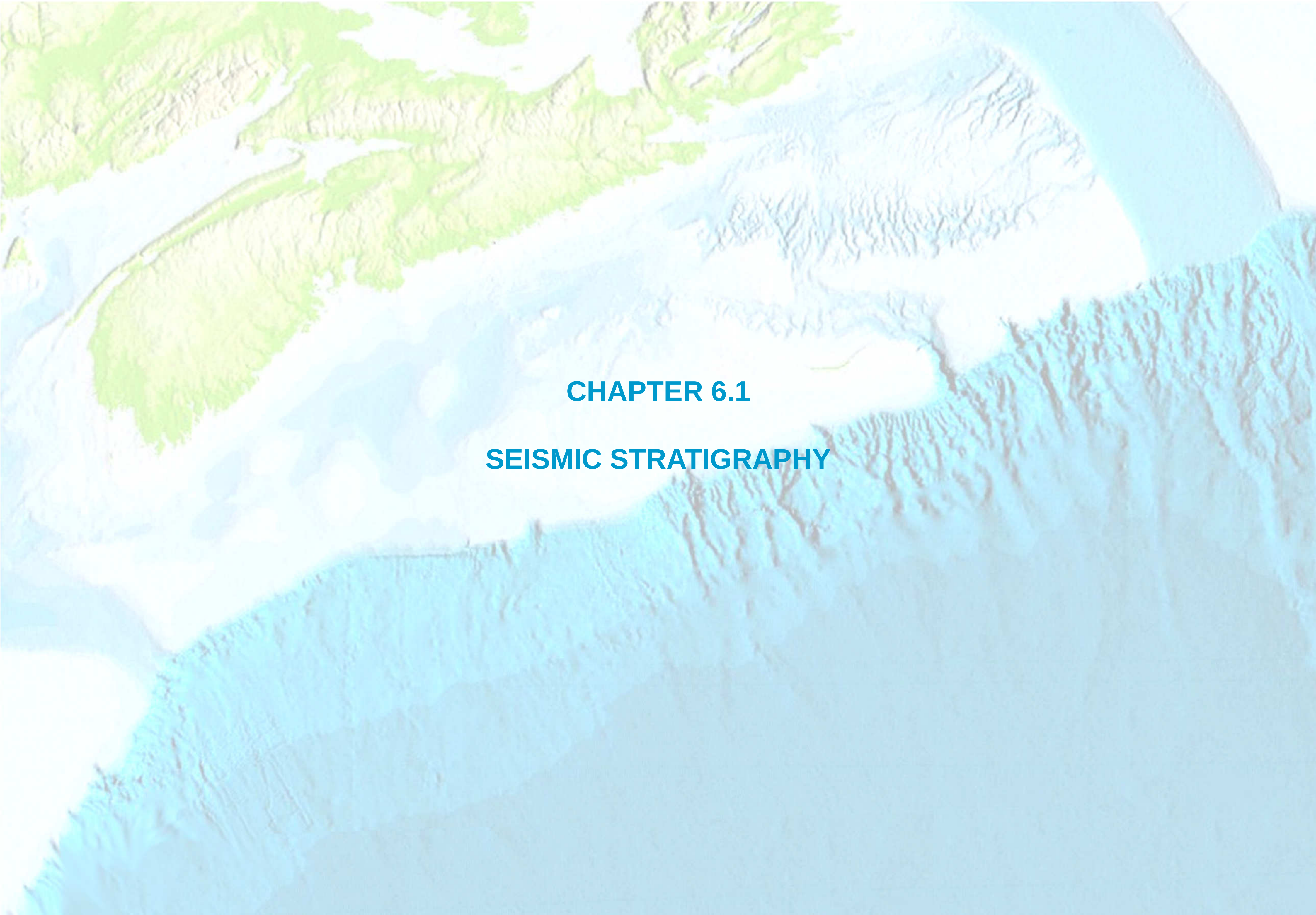
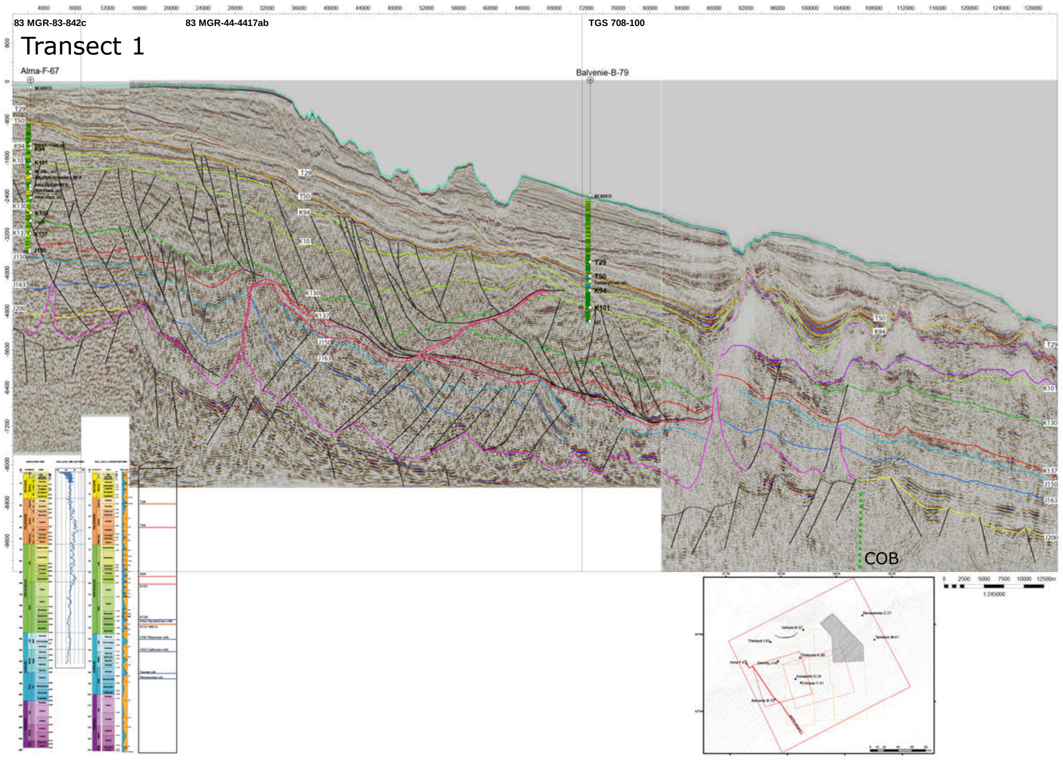
# CHAPTER 6

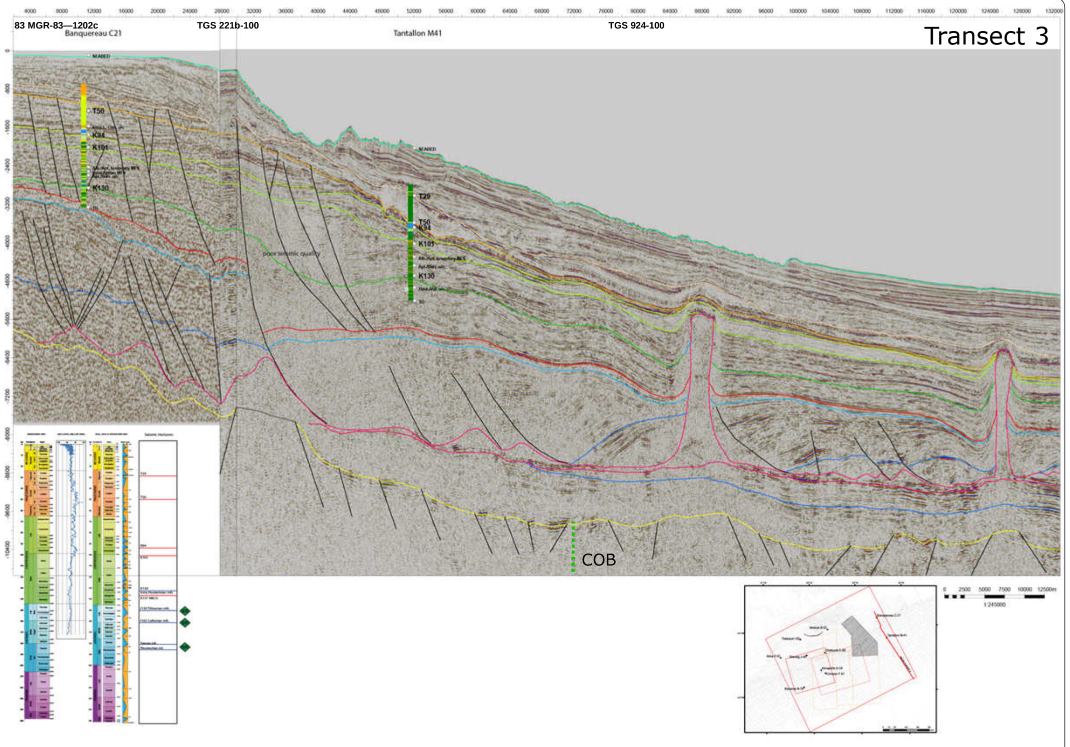
# SEISMIC STRATIGRAPHY
# AND
# GROSS DEPOSITIONAL ENVIRONMENT MAPPING

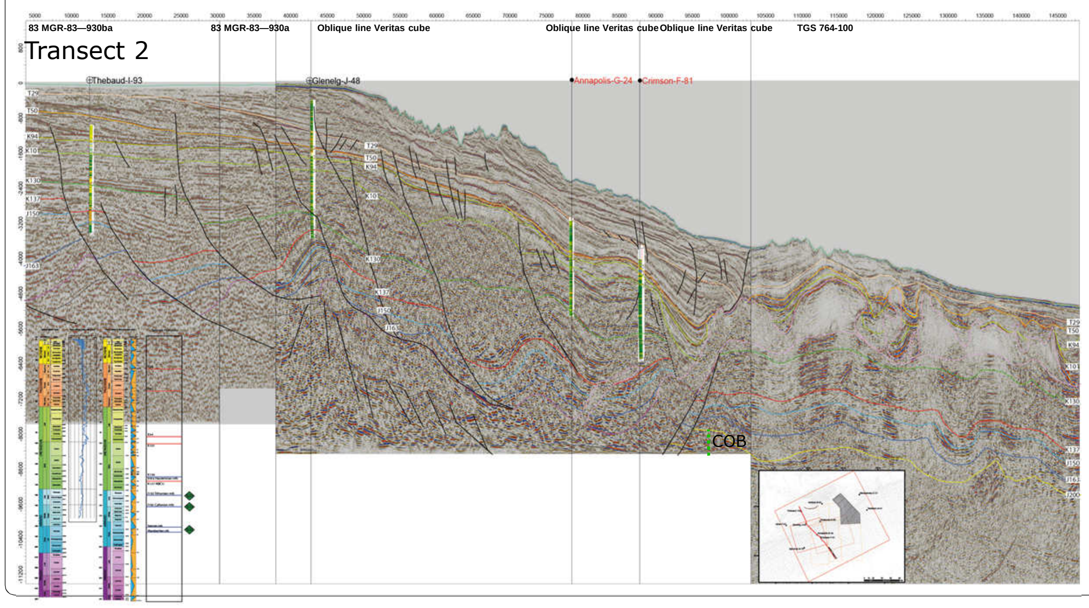


# CHAPTER 6.1

# SEISMIC STRATIGRAPHY



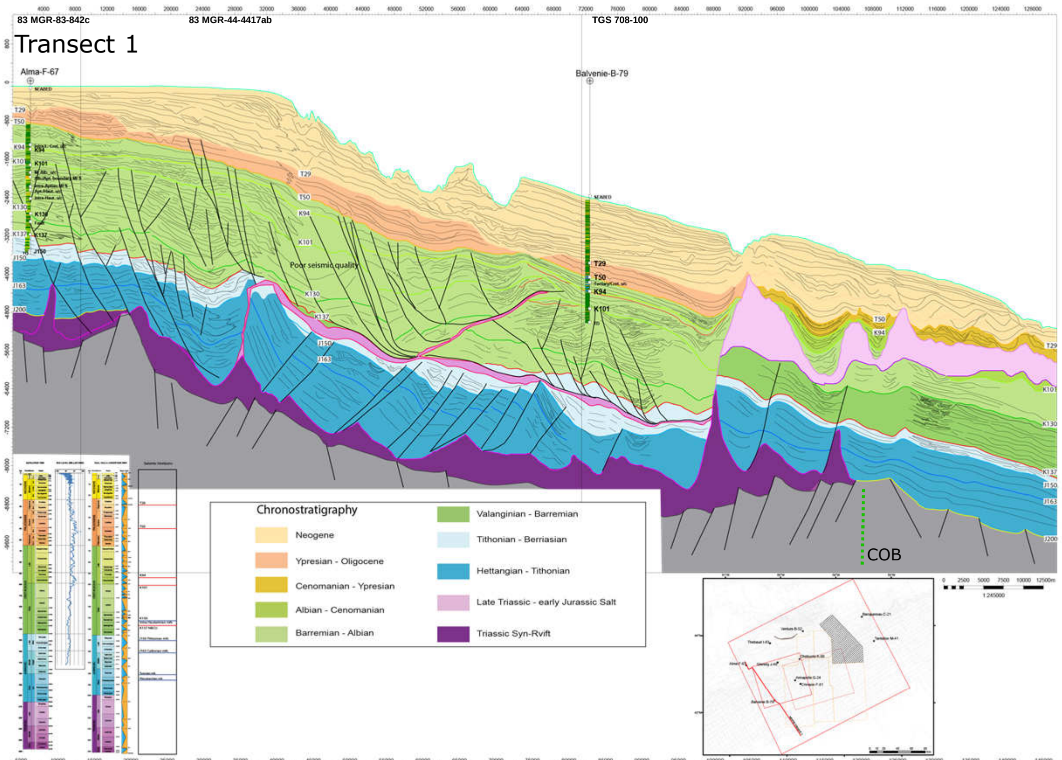



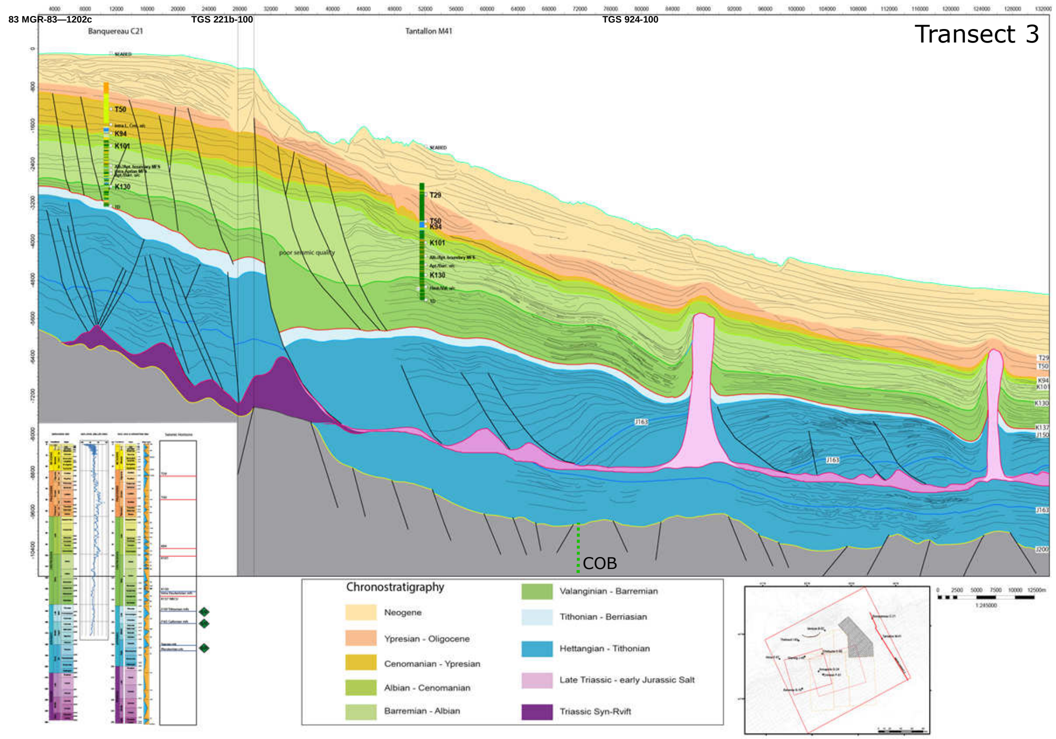

These three dip sections across the Sable Sub-basin illustrate the variability and complexity in structural and sedimentary architecture of the Central Scotian Margin since the Breakup Unconformity (J200). Salt tectonics is the key feature as it controls the majority of the faulting systems, as well as sediment distribution and the resulting architecture. The main structures observed are:

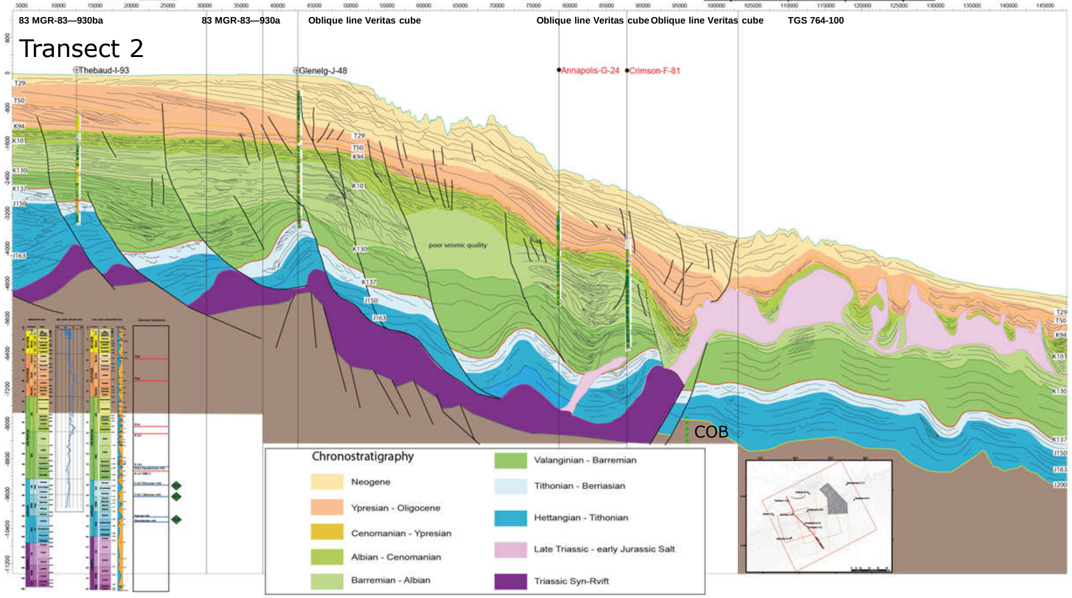
- Growth faults system rooted to the top of salts;
- Synkinematic wedges (Transects 1 and 2) characterized by extension in the upper part and compression in the downward part (rafted structures, turtle back structures);
- A roho system with autochthonous salt feeders (Transect 1);
- Salt canopy in Transects 1 and 2 as well as diapirs in Transect 3.

Transect 1 shows a large extension of the autochthonous salt, which tends to decrease northeast of Transect 3. Decreases in the size of the salt basin coincides with changes in salt tectonic styles, with changes occurring rapidly along the 200 km of the study area. The southwestern part of the area, which is represented by Transect 1, shows Cretaceous age fishbone architectures and a Roho system. Toward the central part of the Sub-basin, the extent of the autochthonous salt decreases and the area is characterized by a deeply rooted growth fault system. Vertical sediment movement is significant, and the associated deformation generates major structures, such as in Glenelg J-48, or large a vertical space for sediment accommodation, such as that found between Glenelg J-48 and Annapolis G-34. To the northeast, the salt extent is reduced to the back of the Alma Ridge (Transect 3). The main structure corresponds to the Banquereau Synkinematic Wedge (BSW): its internal structure shows landward tilted blocks. The BSW is related to the collapse of the margin during the Jurassic due to the migration of the autochthonous salt over the Alma Ridge (Deptuck et al., 2014). Post Jurassic deformation is related to mechanical readjustment of the BSW in response to sediment loading during the Early to Mid Cretaceous, but this part of the basin does not show the same complexity as other parts of the study area. Additionally, the deformation across the margin is passively controlled by large structures inherited from the rifting, such as the Alma Ridge, and the main growth faults always develop in association with these prominent regional structures.

In summary, the study area is divided into three distinct structural zones. It appears that where the autochthonous salt is more extensive, the deformation is more complex and therefore numerous trapping systems are created. In the Annapolis area where the salt is more restricted, deformation is more localized creating small deep basins. To the northeast in proximity to the BSW deformation is less developed because of the limited amount of salt and (except for the BSW itself), geometries are smoother and longer wavelength, leading to fewer trapping systems.



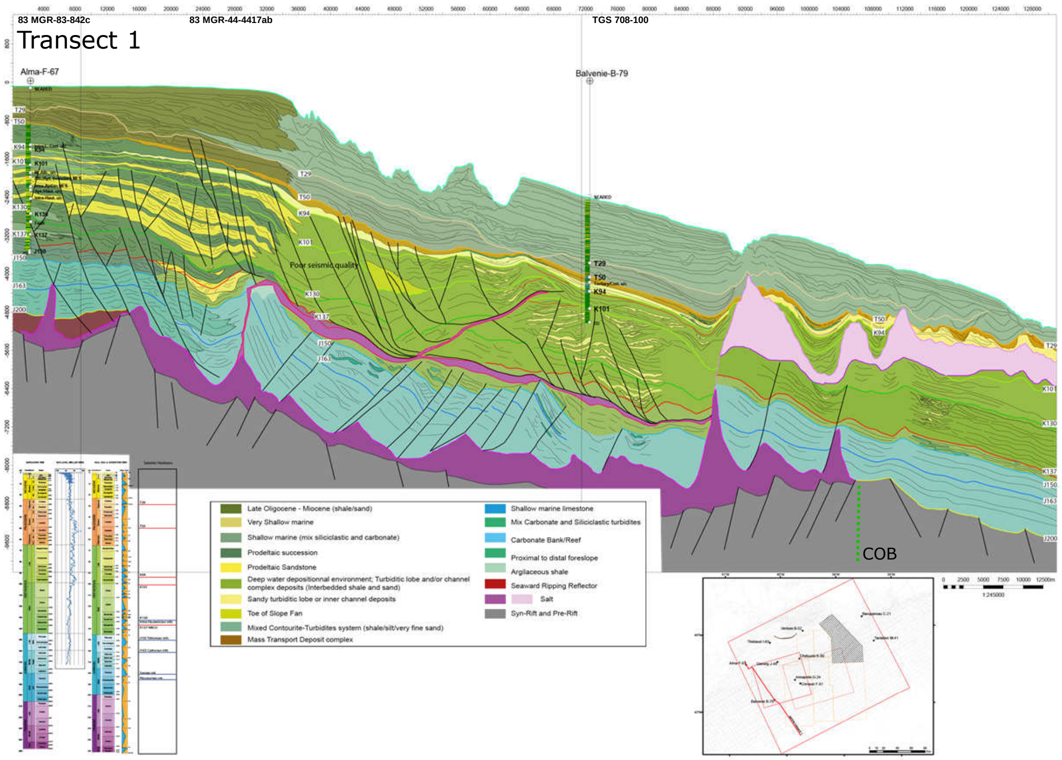

These three sections show the typical chronostratigraphic succession of the Sable Sub-basin.

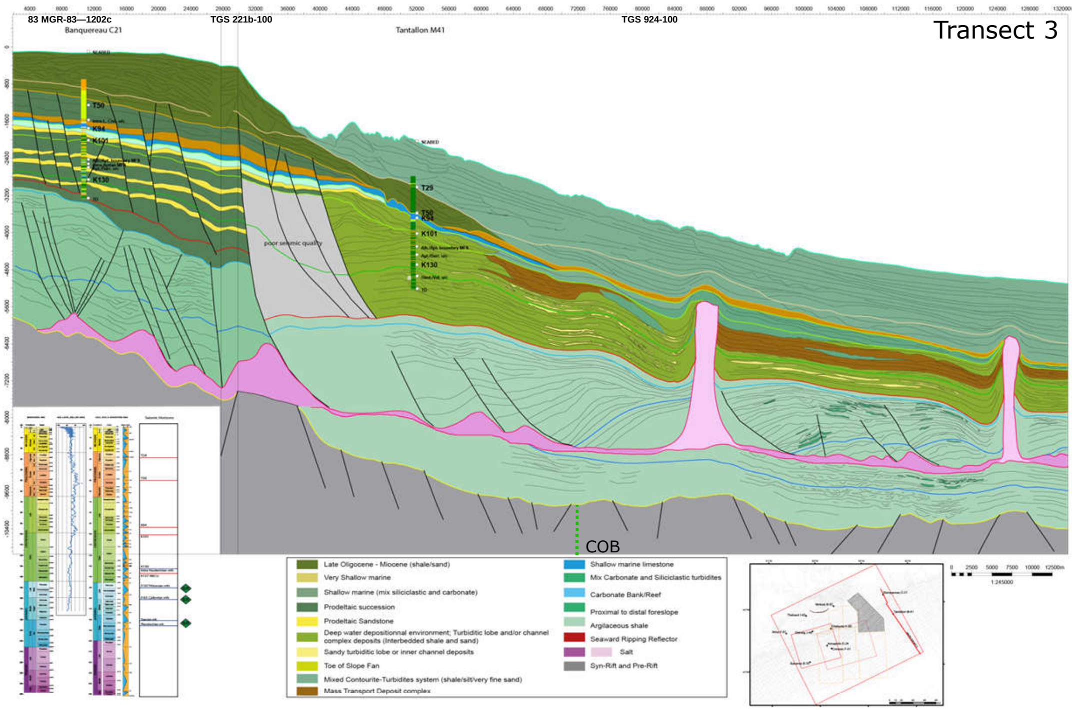
The deepest part of the sections shows the autochthonous salt identified above the basement and early syn-rift sediments. At the Early Jurassic (200 Ma), rifting ceases and the Scotian Margin begins to Subside. Salt deposited in the rifted Sable Sub-basin starts to be overloaded by Jurassic sediment.

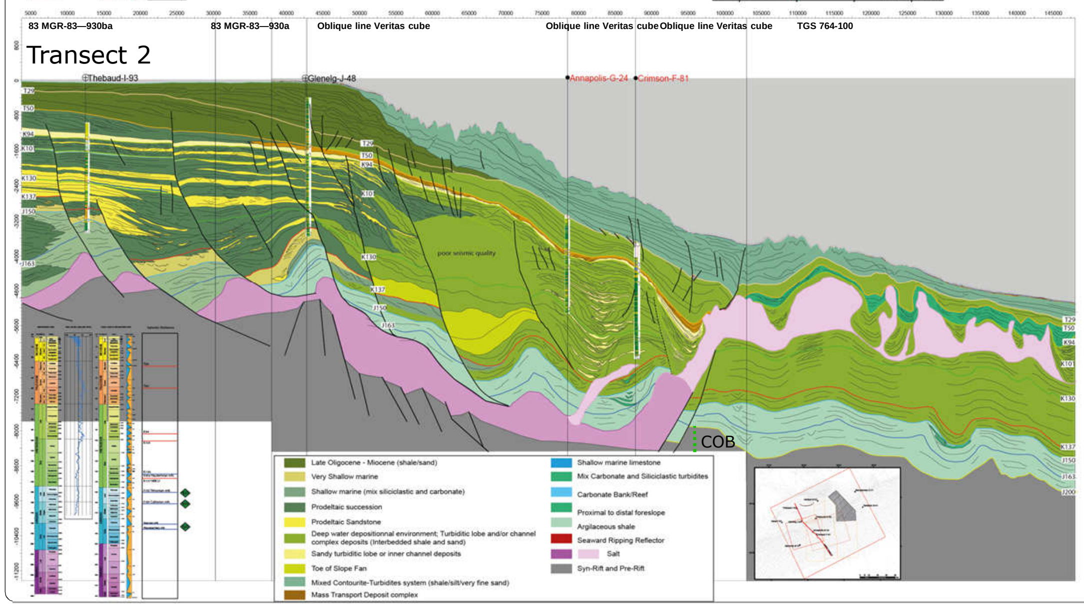
The three dip sections show thick Jurassic succession on the shelf, but sediment thickness varies basinward, with a thicker offshore accumulation in the Balvenie area (Transect 1) and a decreasing trend to the Banquereau area (Transect 3). This difference is the result of the impact of the Alma Ridge, which prevents sediment from reaching the deepest part of the basin and forces sediment toward Annapolis and Balvenie areas (see also thickness maps Appendixes 2.4.8 and 2.4.9). Between the Callovian and Tithonian interval (J163 – J150), autochthonous salt starts to migrate over the Alma Ridge as sediment piles up on the back side of the Sub-basin. This rapid change in salt behavior coincides with the loading of Mic-Mac sediment in the area. Salt migration over the Ridge occurs within a very short time (much less than 7 MY), and leads to the creation of the Banquereau Synkinematic Wedge (BSW). A particular aspect of the event is that it duplicated the Lower to Middle Jurassic sequences, giving the illusion of a particularly thick Jurassic accumulation (Transect 3; see also PL. 2.1.19 for a mechanical reconstitution of the event).

Salt deformation across the study area is diachronous. In the Balvenie and Annapolis areas, salt deformation starts at the end of the Jurassic and intensifies shortly after the base Cretaceous unconformity (K137). The increase in salt deformation coincides with deposition of the thick Missisauga Fm. Cretaceous successions are thicker in the Balvenie and Annapolis areas than in the Banquereau area, particularly the Barremian – Albian interval (K130 – K101). In Banquereau area, post BSW mechanical adjustment allows the accumulation of a thick Valanginian – Hauterivian (K137 – K130) interval against the main listric fault. However, overall the Cretaceous successions remain less important there than in the Annapolis and Balvenie areas. Salt canopies start to form during the Aptian and last until the Albian – early Cenomanian. In the meantime, in the Balvenie area, a large roho system develops. Development of salt canopies during the Albian – early Cenomanian coincides with the Logan Canyon Fm. The significant sediment loading over the salt canopy leads to the formation of numerous short lived intra salt mini-basins. In the Banquereau area, sedimentation is only impacted by vertical migration of salt diapirs.

Post Cenomanian, salt deformation decreases but continues until the Ypresian. The deformation is marked primarily in the salt canopy area and is much reduced on the shelf. Salt tectonics terminated around the Eocene – Oligocene period. Nonetheless, local vertical salt movement in response to sediment overload may have occurred until the late Tertiary.



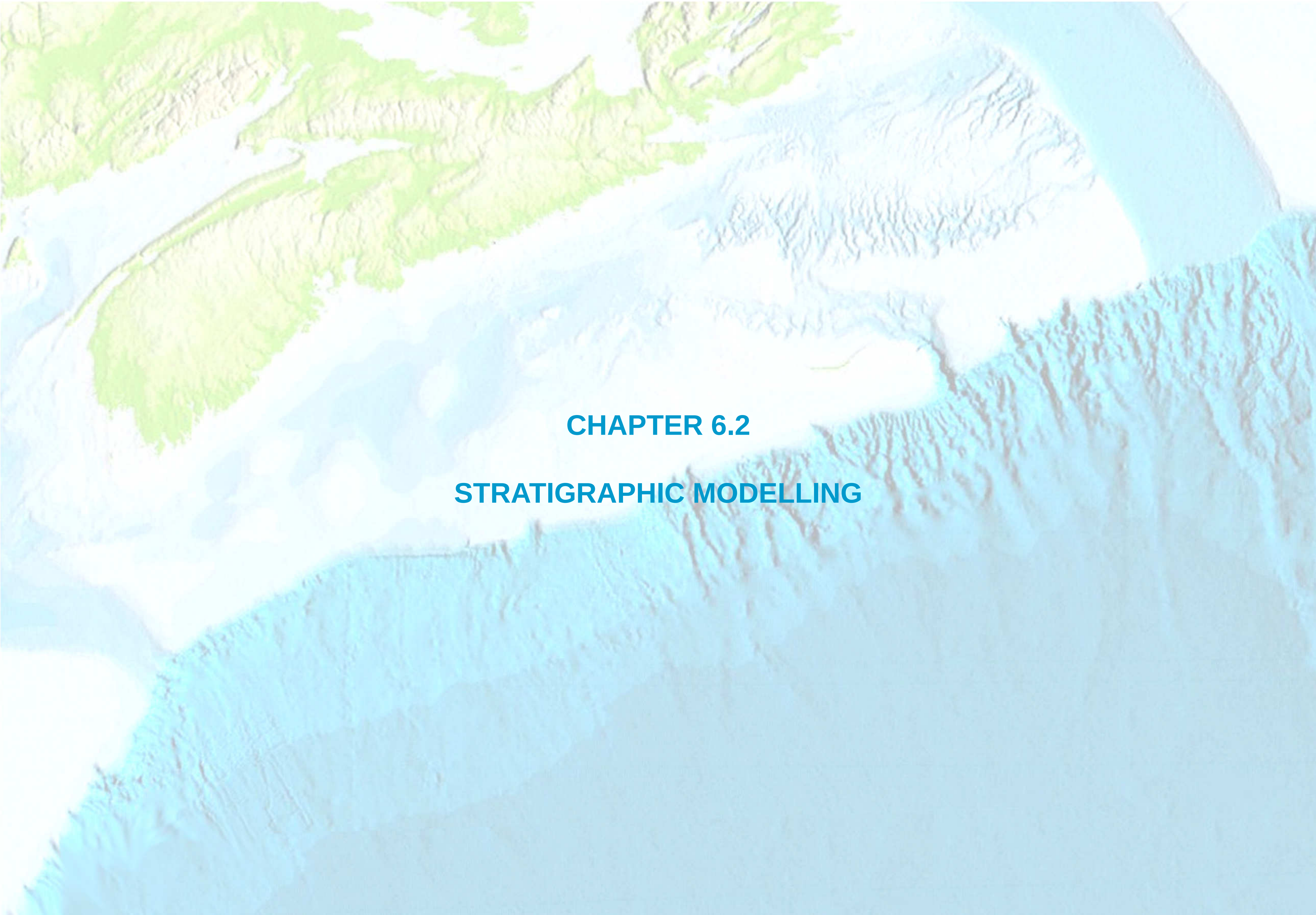




These three sections show the typical lithostratigraphic succession of the Sable Sub-basin. The lower series between the J200 and J150 (Hettangian – Tithonian) is essentially composed of mixed carbonate – clastic sediment. Thick carbonate banks accumulate on the inner part of the shelf, which is not captured on the different transects here. The clastic portion is first represented by the Mohican equivalent Fm until the Mid Jurassic, and then the MicMac Fm until the Kimmeridgian – Tithonian. The sediment of this period is generally representative of shallow water deposition, with the clastic portion corresponding to the progradation of deltaic and prodeltaic sediments on the paleo shelf feeding early turbidite systems on the basin slope and rise. Calciturbidites or calcareous rich turbidites are inferred to be significant in deep water during the Early to Mid Jurassic as well as during the J150 – K137 interval due to the significant reworking of carbonate products landward. Before the initiation of significant salt movement, sediment transfer from shelf to basin is assumed to correspond to a simple model of direct and classic source to sink system, with widespread turbidites. Near the top Jurassic, the sedimentation is dominated by clastic sediments and marine shale related to the rapid development of the Sable River and associated deltaic plain.

Sediment accumulation during the Cretaceous is dominated by fluvial and deltaic sediment, but limestone remains present until the end of the Cretaceous. The basin is dominated by clastic turbidites and marine shale. At that time, clastic input increased significantly, resulting in an increase of the salt deformation. Sediment conduits evolve and complexity within the sediment delivery system appears. For instance, the formation of the BSW has a significant impact in sediment distribution to the basin since it acts as a topographic high and forces the sediment toward the central part of the study area. On the shelf, well correlation to seismic data allows interpretation of the extension of sand rich sediment layers. The three transects show a rapid decrease in sand content towards the shelf edge (particularly in Transect 2). Sand distribution is controlled by the topography resulting from salt tectonics. Thus, in the Balvenie area sand easily reaches the shelf edge and consequently is more likely to be transferred to the basin slope. In the Annapolis area, a significant amount of sand seems to be trapped mid shelf during the Early Cretaceous due the large depression caused by salt movement. In the Banquereau area, less sand is present on the shelf during the Cretaceous interval, but transport to the shelf edge seems to be more efficient.

During the Hauterivian – Barremian transition and up to the Cenomanian, there is an increase in sand content toward the shelf edge. Nonetheless, based on wells only, this trend is not recorded in deep water. In fact, Annapolis G-24 and Crimson F-41 wells show a maximum sand content for the Berriasian – Hauterivian interval and a continuous increase in shale content until the Late Cretaceous. This discrepancy is the direct result of salt control on the sediment delivery system. As salt moves and mini–basins evolve, sediment pathways also migrate. Additionally, several mini–basins appear to form on the upper slopes, which would then tend to trap sands early on. Unfortunately, seismic data is often poor on the upper slope, partly due to the significant faulting systems that perturb the seismic signal, making it difficult to image seismic facies.

During the Turonian to the Campanian – Maastrichtian interval, data show the existence of a widespread chalky limestone and marl sediments corresponding to the Petrel Fm. The Mid to Late Eocene sees the appearance of mixed contourite – clastic system with an abrupt intensification of the contourite record since the Oligocene.



# CHAPTER 6.2

# STRATIGRAPHIC MODELLING

# Objectives of the DionisosFlow® Forward Stratigraphic Modeling

1. To provide a 4D geological reconstruction of the Central Scotian Margin (Sable Sub-basin) in the Lower Cretaceous (130.5 - 101 Ma) using forwards stratigraphic modeling approaches (Figures 1 and 2).

2. To evaluate the impact of salt kinematics and associated syn-sedimentary listric faulting on the margin and basin morphology, sediment pathways as well as facies lateral and vertical variations.

3. To provide a probable distribution of expected reservoir facies in the basin as well as their sedimentary architectures with regards to the diverse depositional settings.

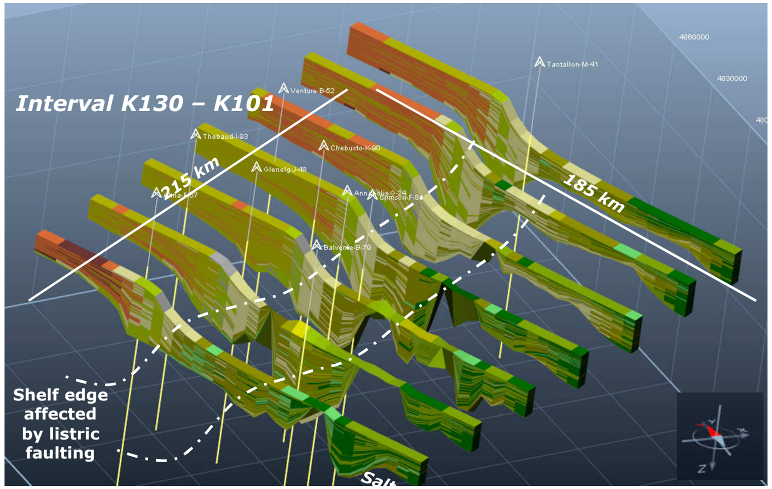
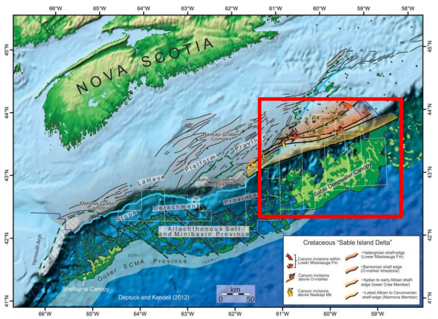



*Figure 1: Simulated forward Stratigraphic Model of the Sable Sub-basin underlining the main sedimentary facies vertical and lateral variations.*

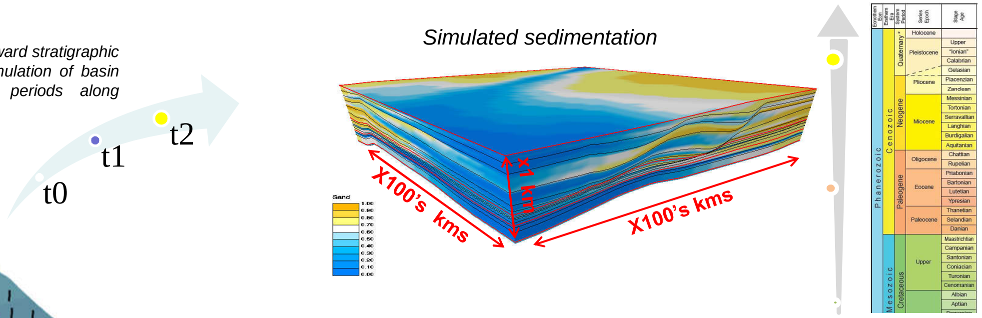


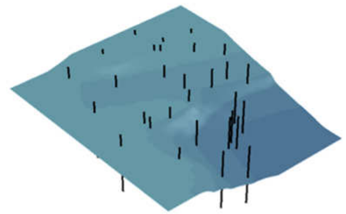

**Sedimentary Facies**

- Fluvio-Deltaic/ Estuarine (sand >30%)
- Fluvio-Deltaic/ Estuarine (sand<30%)
- Fluvio-deltaic channels
- Inner neritic sand
- Middle outer neritic sand
- Sandy turbidites
- Fine turbidites
- Mixed turbidites (shale & silt dominated)
- Mixed lobes (sand>20%)
- Mixed lobes (sand<20%)
- Basinal Shale

*Figure 2: Location map of the Sable Sub-basin and surrounding basins and salt provinces (Kendell and Deptuck, 2012).*

*Figure 3: DionisosFlow forward stratigraphic model workflows allow simulation of basin infill through geological periods along regional scales.*




**DionisosFlow** is a deterministic process-based tool that reproduces interaction between the main mechanisms driving sedimentation (i.e., subsidence, bathymetry, sediment transport/in situ production, erosion, eustasy).

***Multi-disciplinary and multi-scale approaches***

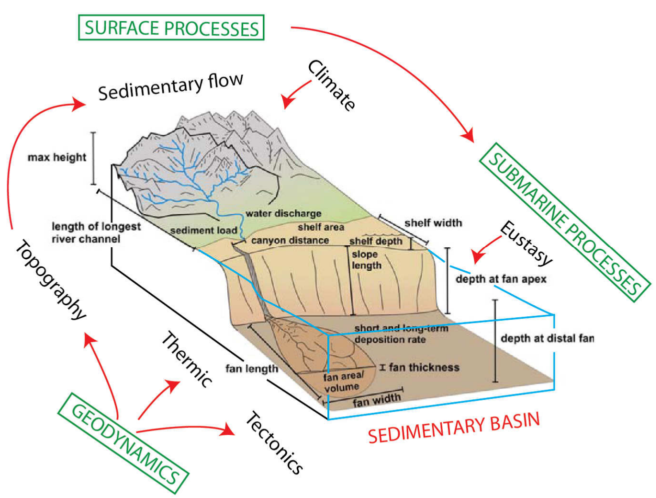


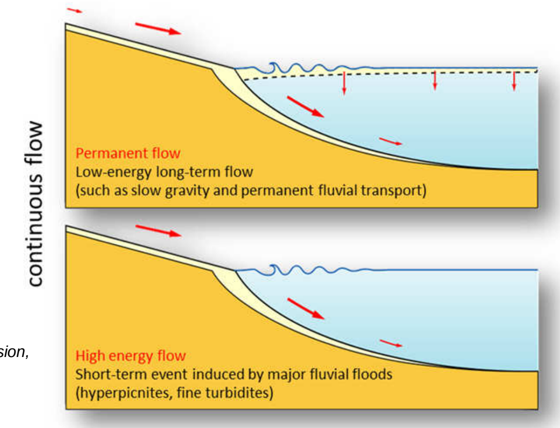

*Figure 4 Diagrams showing the interaction of several processes regarding sedimentary erosion, transport and deposition.*

***Modified from Martinsen et al., 2010; Hawie et al., 2015***

**The transport rate is proportional to basin slope and water discharge:**

$$Q_s = K\, Q_w\, S$$

- Qs = sediment inflow
- Qw= Water flow
- S = depositional slope degree
- K = Diffusive coefficient



# DionisosFlow® Forward Stratigraphic Modeling Workflow

**Forward stratigraphic modeling using DionisosFlow allows to:**

- Integrate multidisciplinary and multi-scale datasets
- Validate geological & facies models
- Study large-scale sedimentary processes (carbonate & siliciclastic)
- Delineate petroleum systems elements (i.e., reservoirs, seals, source rocks)
- Assess the impact of deformation (e.g., salt, listric faulting) on sedimentary pathways)
- Improve basin models (P-T and migration simulations) through refined facies modeling

Forward simulations of sedimentary processes are conducted in 4D in a sequence stratigraphic framework where Subsidence and eustasy drive accommodation (Figure 5)

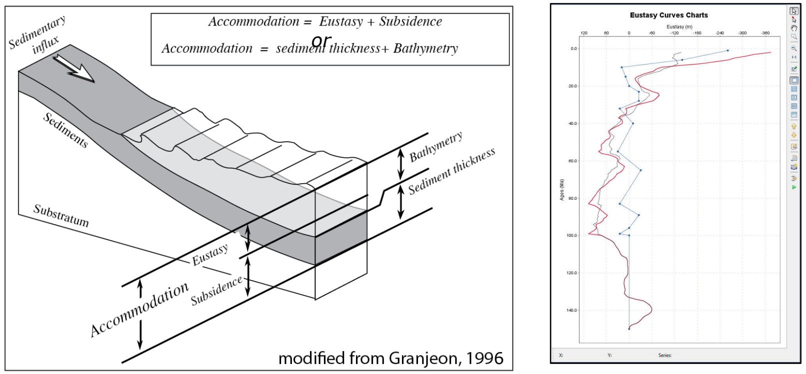



*Figure 5: Calculation of accommodation in DionisosFlow software.*

Transport is simulated through diffusive equations and is dependent on slope, water discharge, sediment load, lithology. grain size and the paleo-environments.

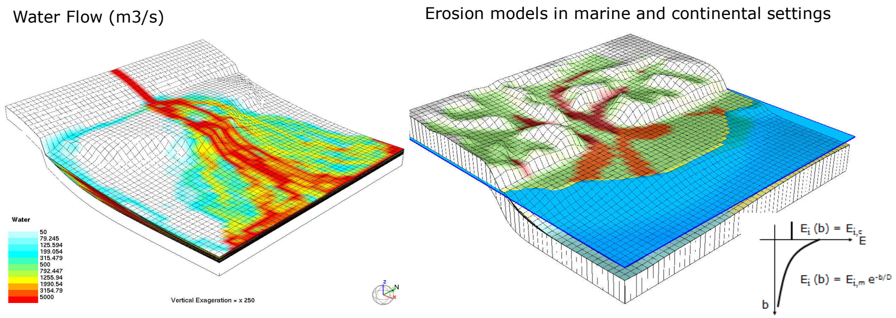



*Figure 6: Examples of simulated models showing sediment transport and erosion in continental and marine realms.*

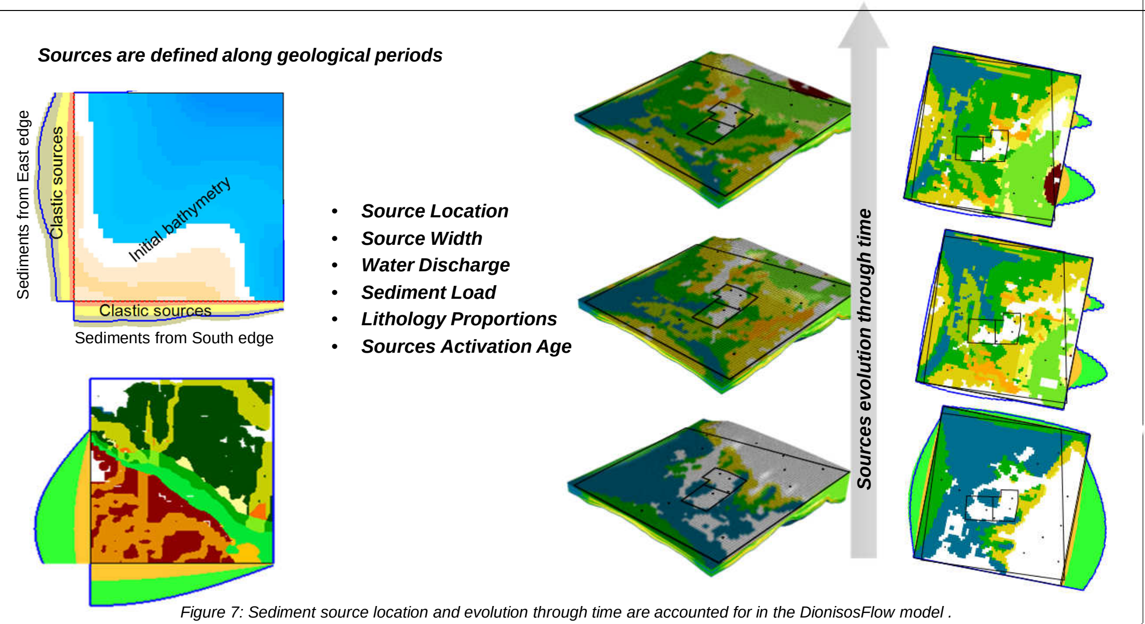



*Figure 7: Sediment source location and evolution through time are accounted for in the DionisosFlow model .*

Forward stratigraphic modeling using a **DionisosFlow loop workflow** allows testing multiple scenarios of basin deformation and infill in order to generate high resolution stratigraphic models allowing a better characterization of the petroleum system elements (i.e., reservoir, seal, source rock, stratigraphic trapping).

***Outputs***

*Depositional environment properties*
- *Paleobathymetries*
- *Water flow*
- *Wave energy*
- *Slope*

*Lithological information*
- *Thickness maps*
- *Sediment concentrations*
- *NTG maps*
- *Body connectivity*

*Facies model*
- *Detailed facies maps*
- *Reservoir/seal quality*

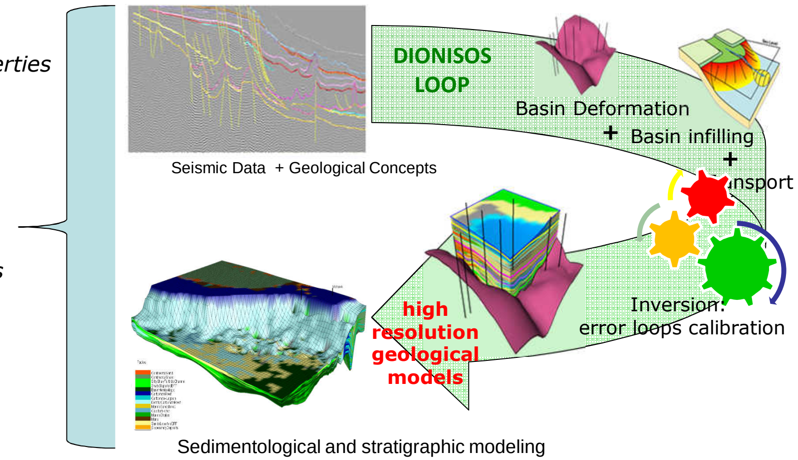



*Figure 8: DionisosFlow forward stratigraphic modeling workflow loop and consequent output.*

# DionisosFlow® Modeling Framework and Results

## Overall stratigraphic and sedimentological assessment

The Scotian Basin represents a passive Mesozoic-Cenozoic continental basin located in offshore Nova Scotia. The studied Lower Cretaceous rock succession comprises fluvio-deltaic and shelf sediments of the Missisauga (Berriasian to Barremian- Williams et al., 1990) and Logan Canyon Formations (Cummings and Arnott, 2005) passing laterally seawards to a much shalier Shortland Member (Piper et al., 2010).

Following the progradation and onset of thick sedimentary piles, loading resulted in salt deformation and growth faulting which controlled shelf and deeper basinal depocenters (Shimeld, 2004; Ings and Shimeld, 2006).

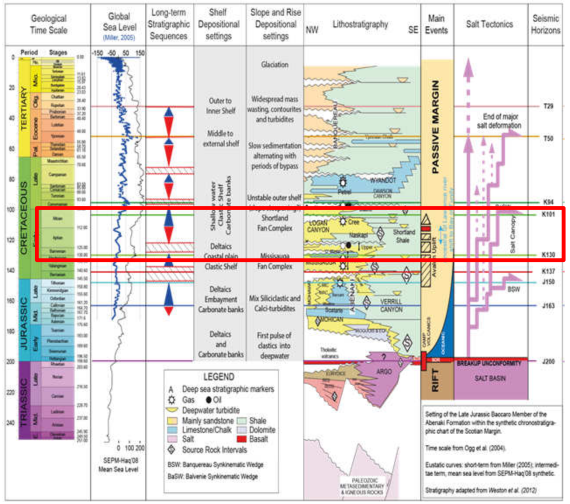


Figure 9: Tectono-stratigraphic chart of the Sable Sub-basin.

## Seismic stratigraphic and facies analysis

Seismic stratigraphic interpretation of the Central Scotian Basin was conducted and supported by seismic facies analysis permitting a better understanding of the overall unit thicknesses as well as the expected depositional environments and sedimentary geometries of the K130-K101 interval (e.g. shelf progradation and clinoforms).

The impact of salt kinematics and syn-sedimentary listric faulting on the Shelf-Basin architecture was also assessed through the seismic interpretation.

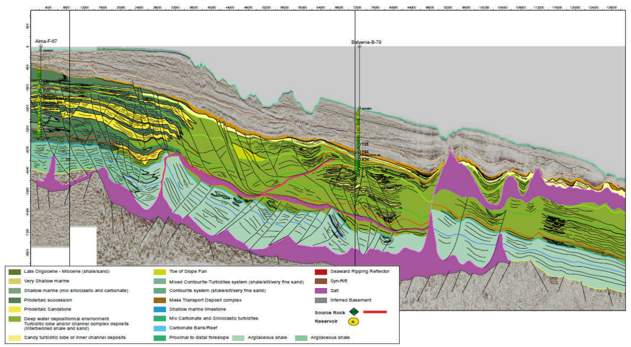


Figure 10: Seismic facies analysis of the Alma (shelf) - Balvenie (basin) section.

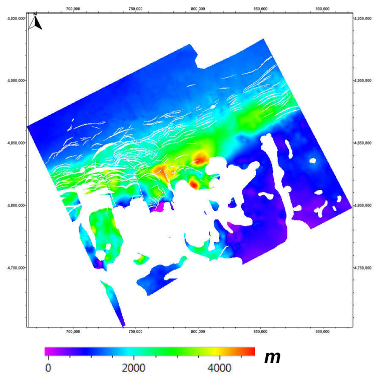



Figure 11: Thickness of the K130-K101 interval.

## Modeling specifications

- **Model Size**: 185 km x 215 km
- **Cell Size**: 4x4 km
- **Time Steps**: 500 kyrs
- **Period**: 130,5 to 101 Ma
- **Eustatic curve**: Miller et al., 2005

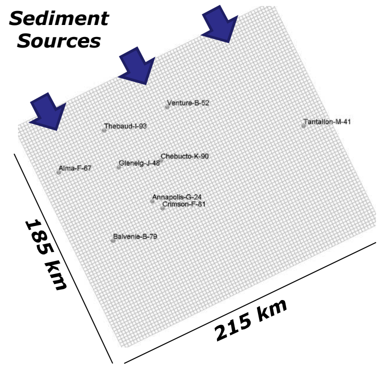
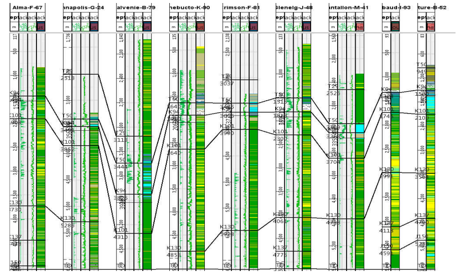


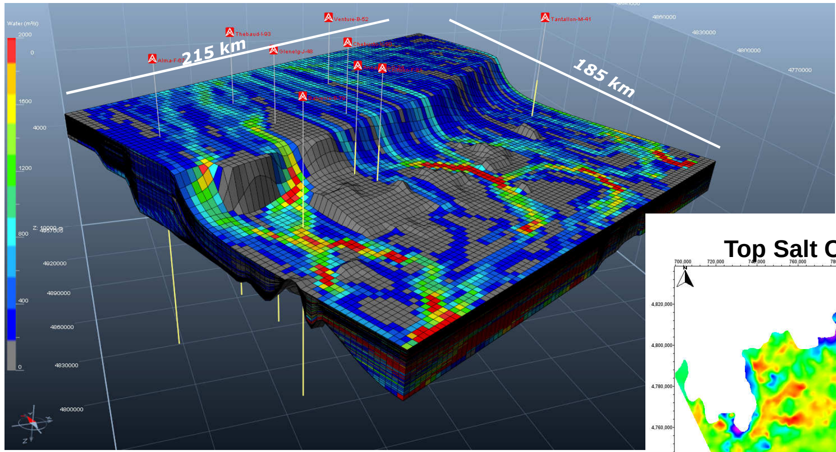

Figure 12: DionisosFlow model framework, tested source locations as well as available well data.

**9 wells used for overall lithology and facies tendencies**



## Results

Main sedimentary pathways driving sediments from the shelf towards the basin are diverted around salt domes and canopies. Deposition of sediments is thus localized along the shelf, in mini-basins generated from salt kinematics as well as deeper in the basin.



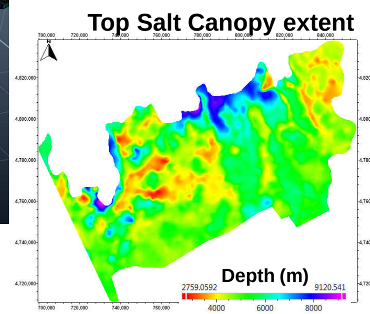




Figure 13: DionisosFlow model simulation showing the diversion of water pathways around salt domes and canopies.

# DionisosFlow® Modeling Results

## Sedimentation rate results

High sedimentation rates are mainly localized in sectors affected by listric faulting/ salt kinematics.

The highest rates of sediment accommodation occurs around the rapidly prograding shelf (mainly impacted by listric faulting) as well as well as around the mini basins (evolving as a result of salt flow).

The diversion of sedimentary pathways between evolving salt domes and canopies leads to a further sediment transfer into the deeper basin.

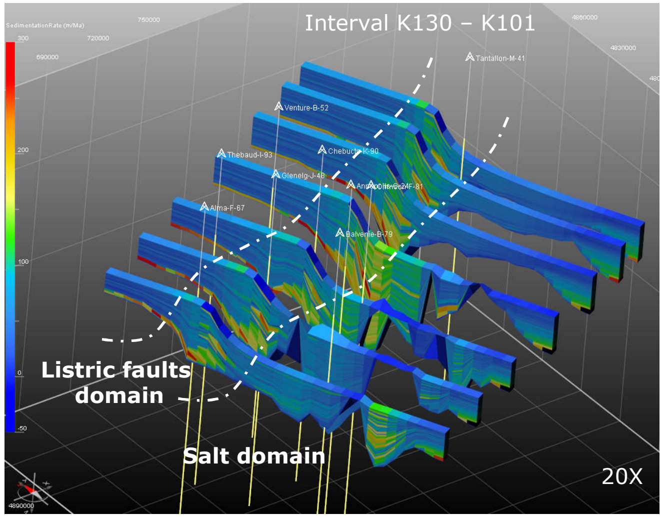



*Figure 14: Modeled sedimentation rates along the Sable Sub-basin*

## Bathymetry modeling

Bathymetric modeling generated from the forward stratigraphic simulations supports the proposed geological model with deltaic/estuary to shallow marine settings towards the margin that develops rapidly into deep marine settings towards the southern offshore (up to more than 2000 m of water depth).

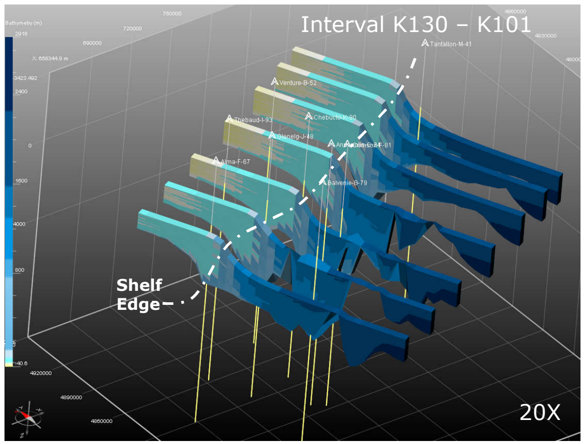



*Figure 15 Modeled bathymetries along the Sable Sub-basin.*

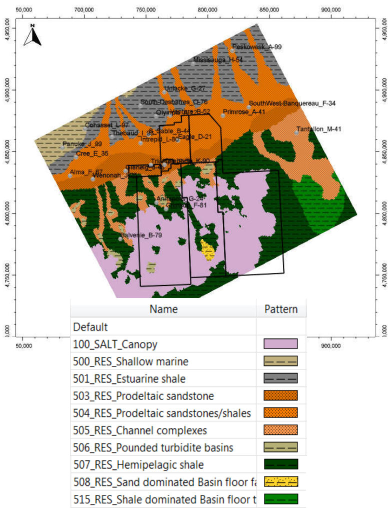



*Figure 16: Gross Depositional Environment map.*

## Reservoir architectures

Reservoir architectures have been assessed in order to explore the unit's vertical connectivity and lateral extent.

Along the shelf, more than 35-45% of the sand is deposited in a fluvio-deltaic setting.

The sand content diminishes along the slope (20-25%) as does the connectivity of the reservoir facies (mixed sand, shale and silt).

Intercalations of mixed fine grained turbidites are expected in the basin, fed by pathways diverted away from salt domes and canopies.

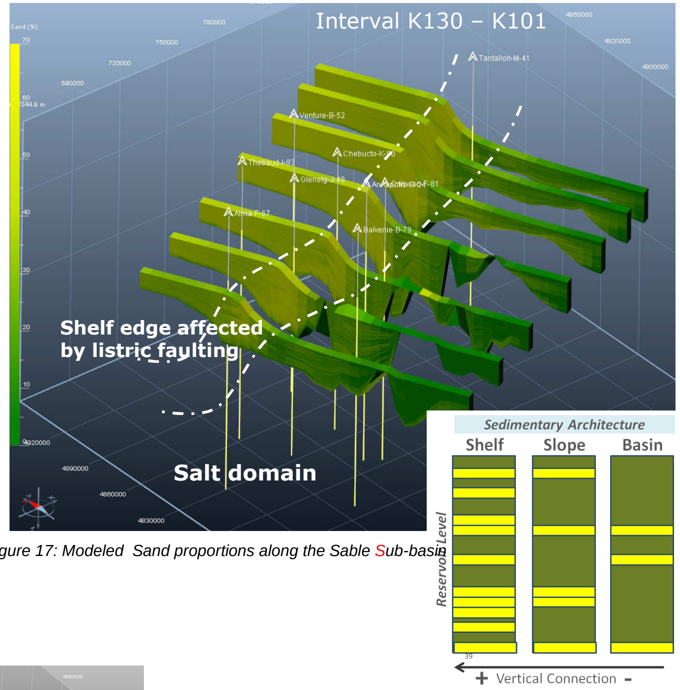



*Figure 17: Modeled Sand proportions along the Sable Sub-basin*

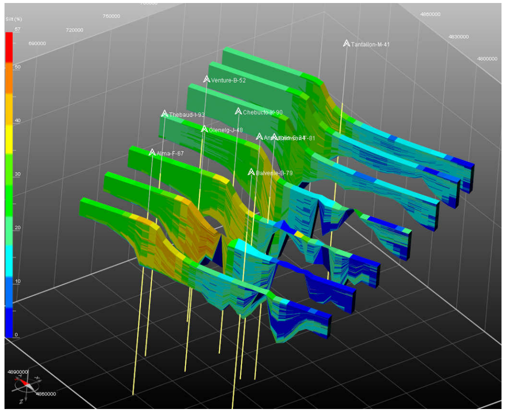


*Figure 18: Modeled silt proportions along the Sable Sub-basin.*

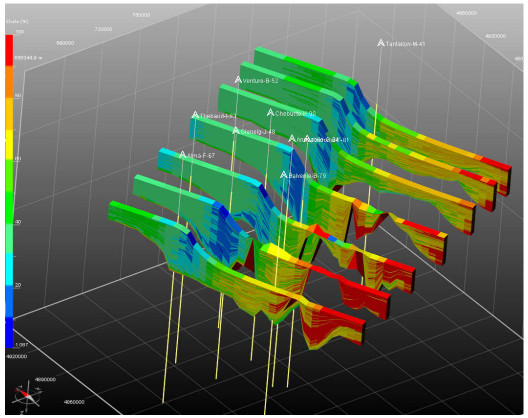


*Figure19: Modeled Shale proportions along the Sable Sub-basin.*

# DionisosFlow® Modeling Conclusions

The sandstone facies extends from shelf to basin and preferentially accumulated in depocenters formed by active faulting and salt deformation.

A still undrilled sandstone rich belt appears to be present along the outer shelf area filling the listric fault's depocenters.

Sandstone rich lobes appear to be present in the basin, primarily filling mini-basins and corridors between salt domes.

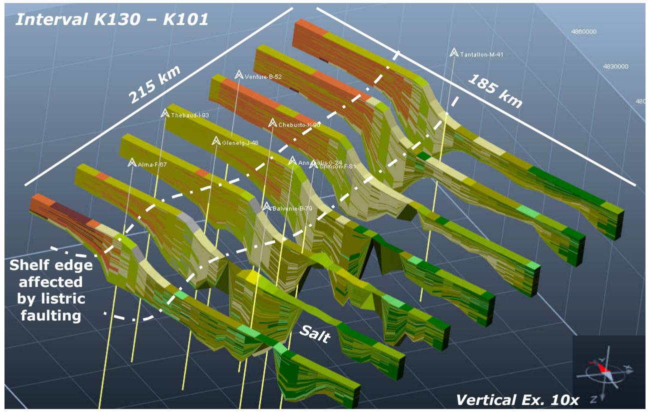
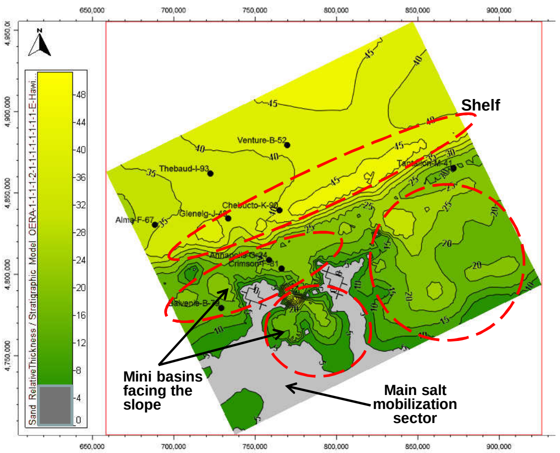
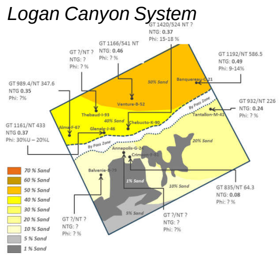



*Figure 20: Simulated forward Stratigraphic Model of the Sable Sub-basin underlining the main sedimentary facies.*

*Overall sand proportion tendencies fit well with the proposed geological and petrophysical interpretation (35-40% towards the western shelf (e.g. Alma-F67; Glenelg-J-46; Chebucto-K-90) and gradually increase eastwards to reach 40-50% (e.g., Venture). Sand proportions decrease southwards towards the toe of slope (10 and 25%) in the salt induced mini-basins (e.g. Balvenie B-79; Annapolis G-24). In the eastern part of the offshore, more extensive sand deposits appears to be draped over gentle deformation and sand proportions vary from 20-25% along the studied interval (e.g. Tantallon-M-41).*



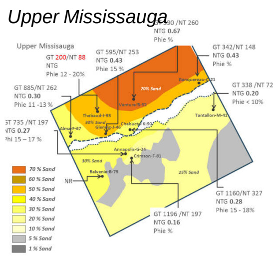




*Figure 21: Weighted average sand proportion map for the K130- K101 interval compared to the Logan Canyon and Upper Mississauga units*

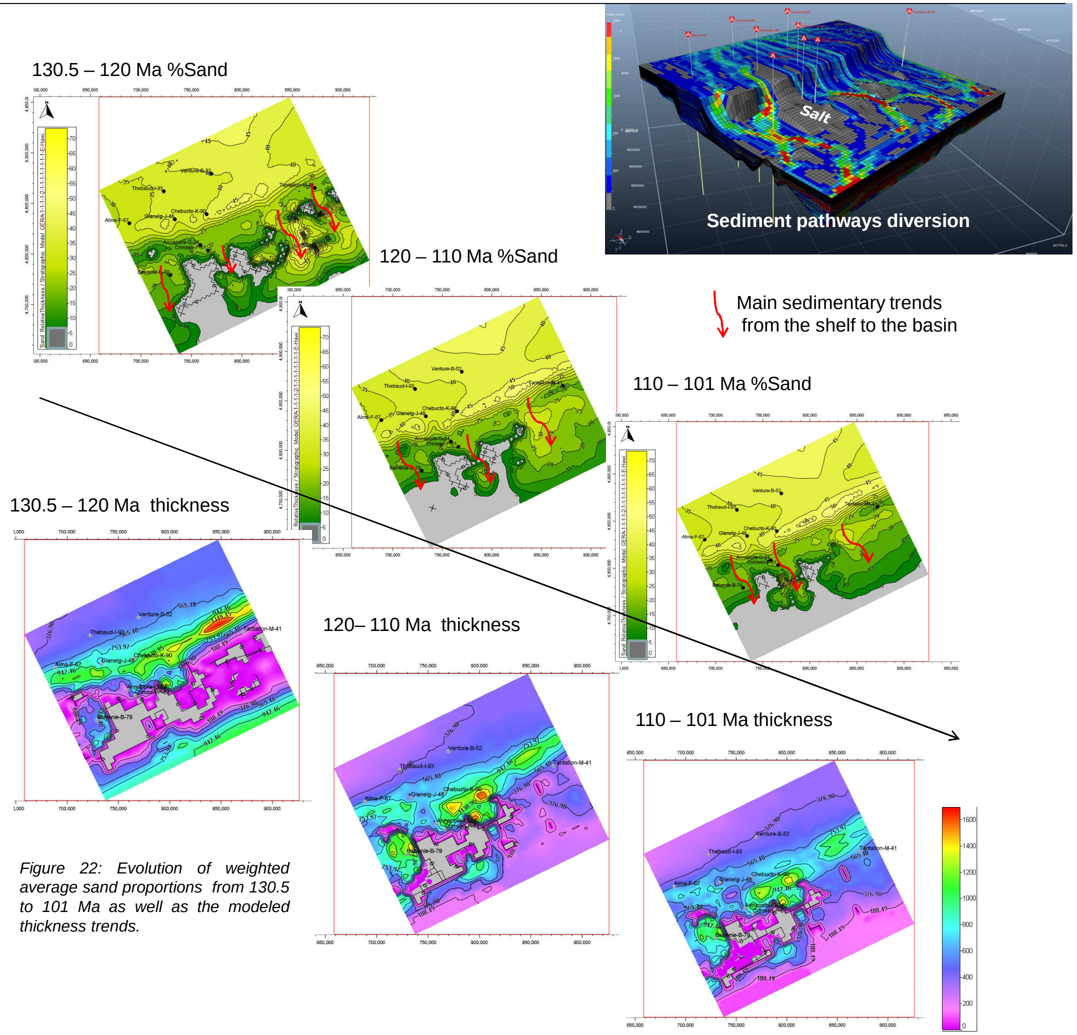



*Figure 22: Evolution of weighted average sand proportions from 130.5 to 101 Ma as well as the modeled thickness trends.*

**Finally, the thickness trends also support the hypothesis of three main trapping domains:**

- a major shelf progradation affected by listric faulting (major thicknesses at the shelf edge);
- mini basin development due to salt deformation proximal to the slope and deeper in between salt domes and canopies (note that the main salt deformation occurs in the SW);
- sediment transfer and draping on top of salt in the deeper basinal setting.

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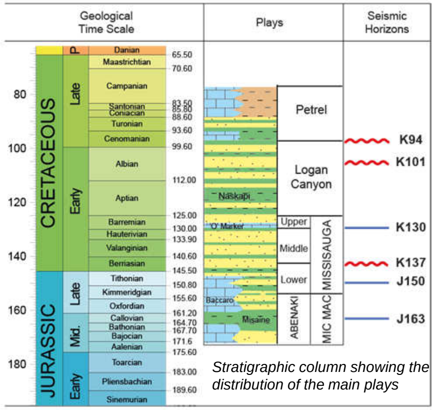
# CHAPTER 6.3

# GROSS DEPOSITIONAL ENVIRONMENT MAPPING

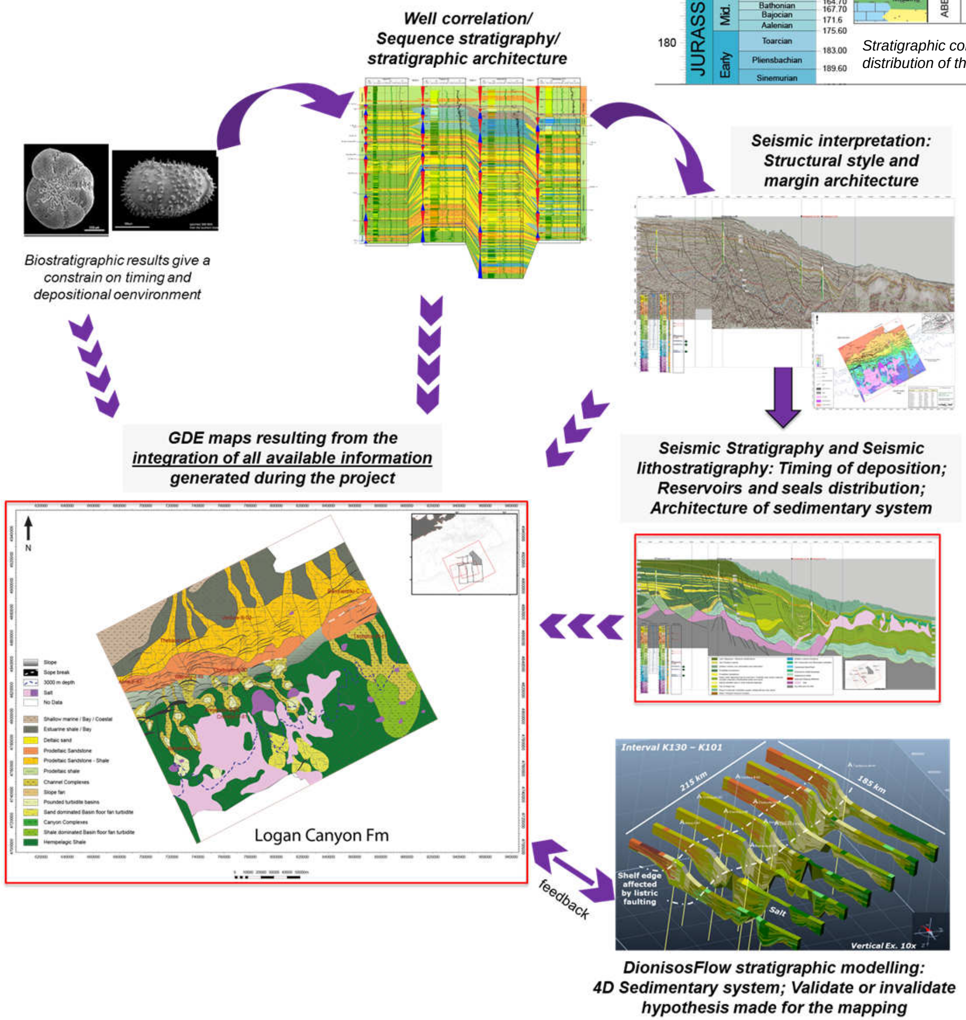
## Gross Depositional Environment (GDE) workflow

Gross Depositional Environment maps have been draw for each interval from J200 to K94 as well as for the three main reservoir intervals. The objective of the GDE mapping is to provide a rapid overview of the stratigraphic framework in support of the petroleum system assessment. GDE maps allow for a more reliable prediction of reservoir distribution than a correlation between sparsely distributed wells, and a better representation of sediment distribution systems from shelf to deep water.

The methodology used for making the GDE maps is detailed below:




*Stratigraphic column showing the distribution of the main plays*




## Gross depositional environments from Early Jurassic (J200) to Early Eocene

**J200 (Rhaetian to Hettangian; GDE map J200, PL. 6.3.4)**

The J200 boundary (GDE J200, PL. 6.3.2) corresponds to the base of post rift sediment and is of late Triassic to early Jurassic age (Rhaetian to Hettangian). As for the rest of the margin, the depositional environment corresponds to shallow marine conditions with sediments characteristic of continental to shallow water environments.

**J200 – J163 (Early to Middle Jurassic; Reservoir intervals: Scatarie and Mohican; GDE maps Scatarie and J163, PL. 6.3.5 and 6.3.6)**

During the Early Jurassic, sediments begin to infill the inherited rift basins and overlay the autochthonous salt (Figures 1-5-6). The thickness map (Figure 4) shows thick accumulations between the Alma and Missisauga Ridges. On seafloor highs, thick carbonate platforms developed in shallow water environments, whereas the rapid basin subsidence createed favorable conditions for the development of early turbidite systems (Figures 5-6). Because of the Alma Ridge, sediments are directed to the southwest. The first pulses of clastic sediment are associated with the development of the proto Sable River (proto St Lawrence river). By the middle Jurassic salt tectonics is already active and controls sediment distribution.

**J163 – J150 (Callovian to Tithonian; Reservoir intervals: Abenaki and MicMac; GDE maps Abenaki/MicMac and J150, PL. 6.3.7 and 6.3.8)**

On the shelf, depositional environments evolved from unrimmned carbonate banks to a rimmed shallow-marine carbonate platforms (1). Because of structural inheritance and the development of the Sable River (Figures 1-5-6), carbonate banks stop following the shelf edge, as it was the case southward of the area, and take a northwestward direction with a more landward position. Sediment inputs tend to increase and led to the formation of the Banquereau Synkinematic Wedge, which will reshape the morphology of the basin. The J150 time frame corresponds to a flooding period corresponding to the Tithonian MFS which is interpreted as being one of the major source rocks on the margin.

**J150 – K137 (Tithonian to Valanginian; Reservoir interval: lower Missisauga; GDE maps lower Missisauga and K137, PL. 6.3.9 and 6.3.10)**

The Tithonian – Valanginian interval corresponds to the opening of the northern Atlantic with the separation between Europe and Newfoundland. This event is associated with a major uplift episode called the Avalon Uplift, characterized by a major regressive sequence that formed the Lower Missisauga Berriasian sands. Accumulation on the shelf is restricted and sediment accumulation in the basin is low compared to the previous and following intervals. The sediment delivery system has slightly shifted southward from its initial position.

**K137 – K130 (Valanginian to base Barremian; Reservoir interval: middle Missisauga: GDE maps middle Missisauga and K130, PL. 6.3.11 and 6.3.12)**

During the Valanginian to base Barremian interval, sediment input increases drastically. This change in sediment supply is related to major changes occurring within the river's drainage area in response to the Avalon Uplift. The Sable River (the proto St Lawrence River) is well developed and formed a very large delta on the shelf. During the Valanginian – Hauterivian transition, a transgressive phase occurs ending with the formation of the Hauterivian MFS (K130). Slightly diachronous from the K130, a short-lived oolitic platform developed on the shelf (the O' marker) and marks the transition to the next regressive phase. In the basin, salt tectonics are particularly active in response to the rapid sediment load, and numerous mini basins begin to form. The initiation of a salt canopy by the Hauterivian time disrupts the sediment supply to deeper part of the basin, and sediment starts to pile up ahead of the salt wall.

**K130 – K101 (Barremian to top Albian; Reservoir intervals: upper Missisauga and Logan Canyon; GDE maps Upper Missisauga/Logan Canyon and K101. PL. 6.3.13 and 6.3.14)**

During this time, the sedimentary system has started to evolve with a continuous increase in shale content until the Naskapi Fm (Aptian). The deltaic system remains as wide as during the Middle Missisauga but the size of the river tributaries have decreased. The depositional environment is more open to marine influences, with sediments characteristic of estuarine and/or tide dominated river deltas. Because of the intense salt tectonics, canyons do not last very long and therefore sediment conduits are perpetually evolving. Additionally, due to the dense network of growth faults at the shelf edge, mini-basins develop upslope creating potentially efficient sand trapping systems. In order to better understand sands distribution from shelf to basin during this time frame, a stratigraphic modelling was performed (see chapter 6.2). Results show a broad distribution of sandstone across the basin, but with a significant amount of sand trapped at the shelf edge and in the upper slope in mini-basins.

A major transgressive event occurs during the Aptian leading to the formation of the Naskapi Mbr. This event is related to a drastic shift of the proto St Lawrence River to the Bay of Fundy leading to a cut in sediment supply to Sable Sub-basin (Figures 3-4). The event lasted approximately the entire Aptian and the margin was starved of sediment. By the end of the Aptian, the proto St Lawrence river returned to its former location as drainage areas are reorganized in response to the subsidence following the end of the Avalon Uplift. Sedimentation resumes as it was during the Barremian – Aptian.

**K101 – K94 (Albian to Cenomanian; Reservoir interval: Upper Logan Canyon (Cree Mbr); GDE map K94, PL. 6.3.15)**

The K101 – K94 interval is associated with a Late Albian shallow marine regressive episode before a flooding event at the onset of the Cenomanian. Shale content continuously increases from the Albian to the Cenomanian (Figures 1-4-5-6). The salt canopy has stopped evolving after the K101 and sediment accumulates within numerous intra-salt mini-basins. A stable connection between the shelf, slope and rise occurs and well developed turbidite systems are formed.

## Main reservoir characteristics

Petrophysical parameters used as an input for the GDE mapping originate from the PFA (2011) and data compiled by CNSOPB (Kidson et al., 2002; Kidson et al., 2007).

**The wells used are considered to be representative of the study area:**

- Central Shelf: Alma F67, Cohasset L97, Glenelg J48, Chebucto K90
- Central slope: Annapolis G24, Crimson F81, Tantallon M41

**Reservoir facies and characteristics were obtained from:**

- The integration of sequence stratigraphy and lithostratigraphic breakdown from the 10 key wells.
- Logs signature and interpreted lithological columns.
- Vertical facies distribution from the wells for each main sequence in reservoir and non reservoir units (Gross reservoir and Gross shale results).
- Cross plots based on Neutron Density and GR and tied to the standard regression lines of basic lithologies: anhydrite, dolomite, limestone, sandstone.
- Porosity results from previous reservoir studies (Kidson et al., 2002; Kidson et al., 2007; OETR, 2011).

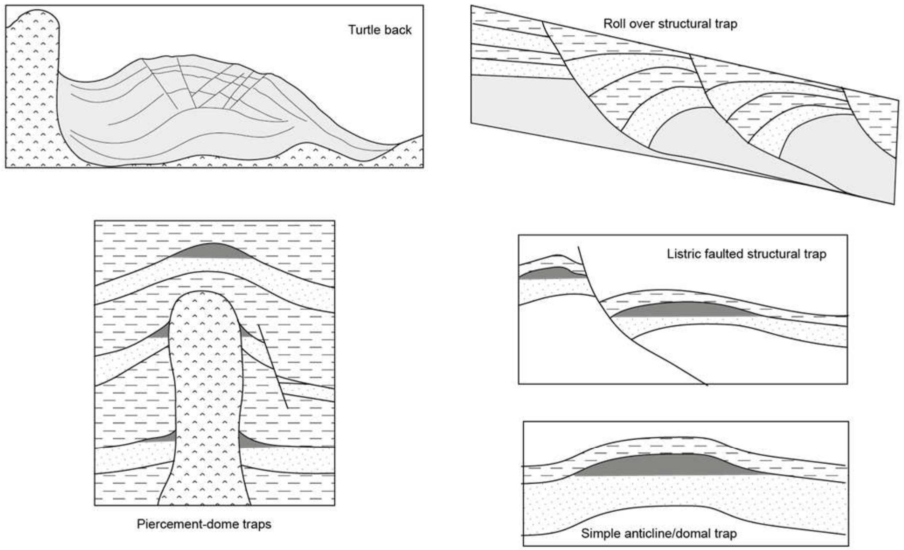
**Reservoir characteristics from key wells for the main play intervals:**

- Baccaro Mbr: up to 1200m thick, predominantly limestone with minor shale intervals. Weak porosity in carbonates, nonetheless reaching 10-12 % when oolithic or dolomitic facies are present.
- Mic Mac Formation: thick Late Jurassic delta complex. Good reservoir quality with 15 - 18% porosity on ~~in~~ average. The shale content is mainly attributed to the Misaine Member.
- Lower Missisauga (Tithonian - Berriasian): lower unit mostly sandy, some limestone intervals; upper unit shaly; average porosity of 15%.
- Middle Missisauga (Berriasian - Hauterivian): Thick section of sandstone with average porosity of 15%.
- Upper Missisauga (Hauterivian - Barremian): Predominantly sandy sequence, some shales and limestone intervals. Average porosity of 18%, limestones are tight.
- Logan Canyon Formation (Aptian – Cenomanian): sandy sequence, some shale and limestone intervals. Reservoir types: estuarine, swallow marine clastic, turbidites sandstones. Average porosity of 23%. Limestones are tight.

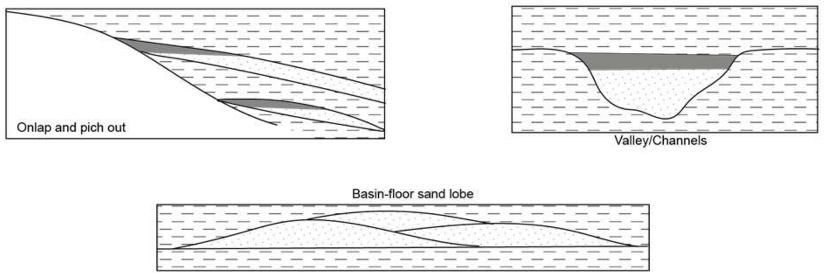
| | Lithology | Depositional Environment | Porosity Range (%) | Average Porosity (%) |
|---|---|---|---|---|
| **Mic-Mac/Baccaro** | Mixed clastic-carbonate facies. Interbedded sandstone, siltstone and shale; limestone facies. | Delta front; carbonate platform and reef margin | 3 to 24 | 15% in clastic sand |
| **Lower Missisauga** | Fine to coarse sand and sandy shale; poorly to well sorted. Calcitic and siliceous sedimentation. Calcareous shale and oolitic limestone | Deltaic fluvial channels and strandplain-shoreface | 8 to 20 | 15 |
| **Middle Missisauga** | Fine to coarse sand and sandy shale, sometimes intraclast conglomerate; poorly to well sorted; carbonate corresponds to oolitic limestone. | Deltaïc fluvial channels and strandplain-shoreface | 12 to 32 | 15 |
| **Upper Missisauga** | Very fine to coarse grained sand (occasionally pebbly). Moderate to well sorted sediment. Calcitic and siliceous sedimentation. Presence of authigenic grain-coating chlorite. Interbedded shale and silt. Carbonate corresponds to skeletal and oolitic wackestone to packstone, tight limestone and marl | Deltaïc fluvial channels and strandplain-shoreface; | 11.4 to 28 | 18 |
| **Logan Canyon** | Very fine to fine sandstone with noticeable quantities of carbonaceous material and kaolinite. Sediment poorly to very well sorted. Sandstone interbedded with shale. | Delta front and strandplain-shoreface; lagoonal shale. | 12 to 24 | 23 |

## Main trap styles

Structural traps




Stratigraphic traps

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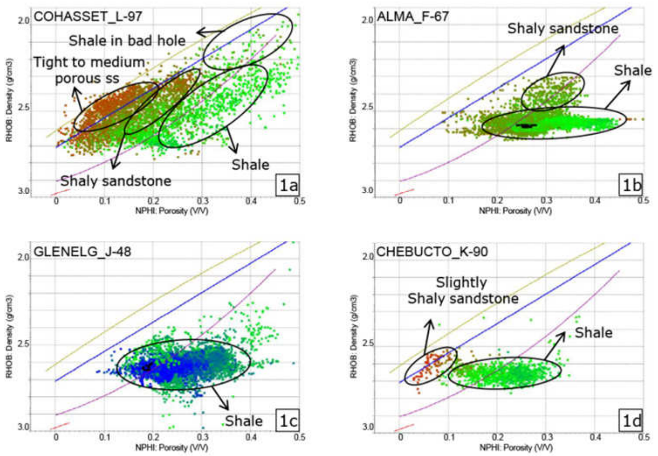
http://www.offshoreenergyresearch.ca/OETR/OETRPlayFairwayProgramMainPage/tabid/402/Default.aspx

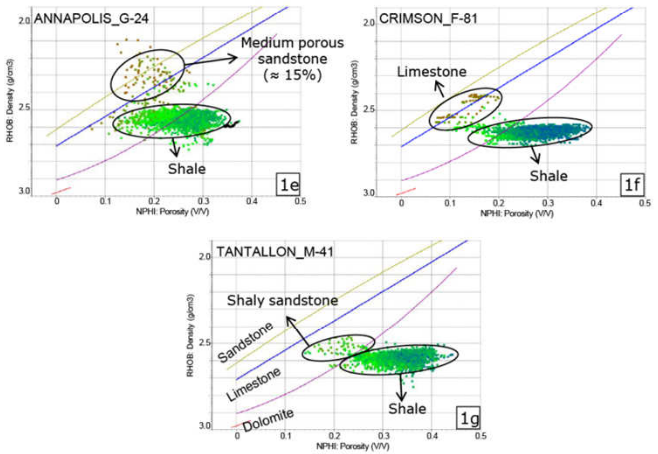
## Lithologies from cross - plot Neutron/Density - Gama-Ray of the key wells. Data and cross - plots from PFA, 2011

### TITHONIAN - BERRIASIAN SEQUENCE - Lower to Middle Missisauga Fm

#### Central Shelf

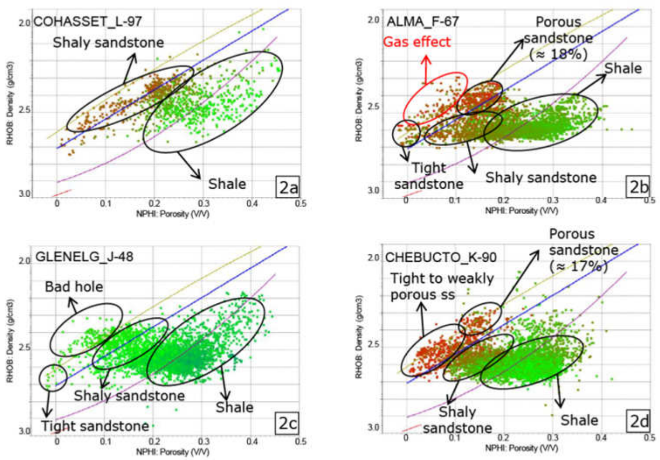



#### Central Slope

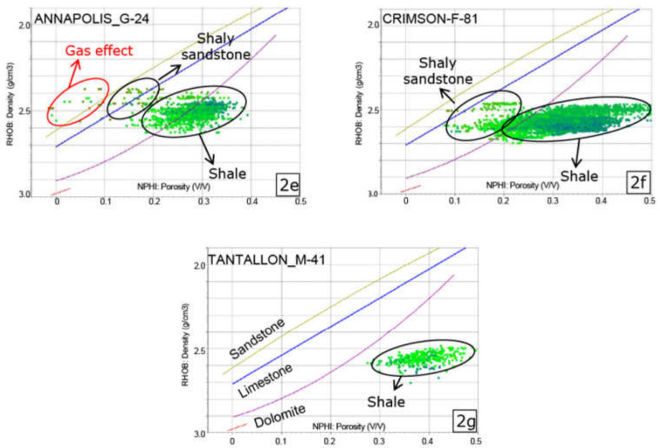



### BERRIASIAN - APTIAN SEQUENCE - Upper Missisauga Fm

#### Central Shelf

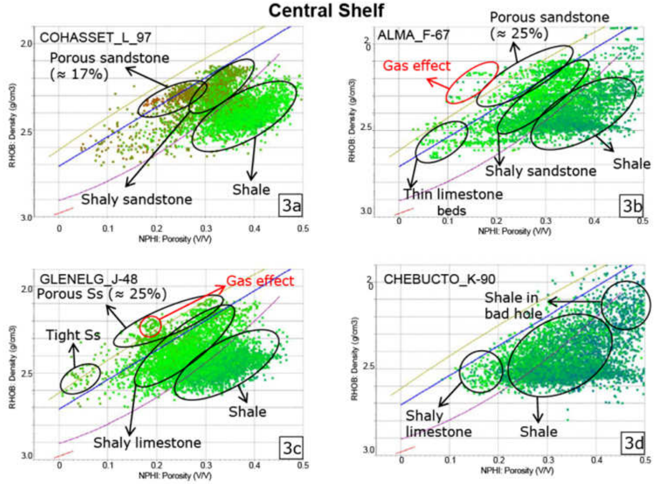



#### Central Slope

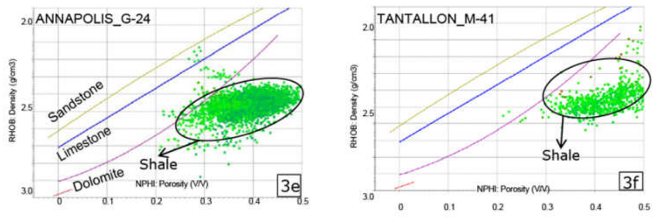



### CENOMANIAN SEQUENCE - Logan Canyon Fm

#### Central Shelf




#### Central Slope




**GENERAL RESERVOIR CHARACTERISTICS OF THE LOGAN CANYON Fm based on available data**

**Central Shelf**: Sedimentary facies for this interval is homogeneous in the western part of the shelf (3a, b, c). It is characterised by the presence of porous sandstones, shaly sandstones and shale. The eastern part (3d) is shale dominated. Gas is noted in Alma F-67 and Glenelg J-48 (3b and c).

**Central Slope**: The shale facies is predominant, but porous limestone may locally be present (3e and f)

**GENERAL RESERVOIR CHARACTERISTICS OF THE LOWER AND MIDDLE MISSISAUGA Fm based on available data**

**Central Shelf**: The interval is mainly composed of shale, shaly sandstones and minor sandstones. The shale proportion increases towards the shelf-slope transition (1b, c, d)

**Central Slope**: The interval is mainly composed of shale. Nonetheless minor sandstones and limestones are present (1e, f, g)

**GENERAL RESERVOIR CHARACTERISTICS OF THE UPPER MISSISAUGA Fm based on available data**

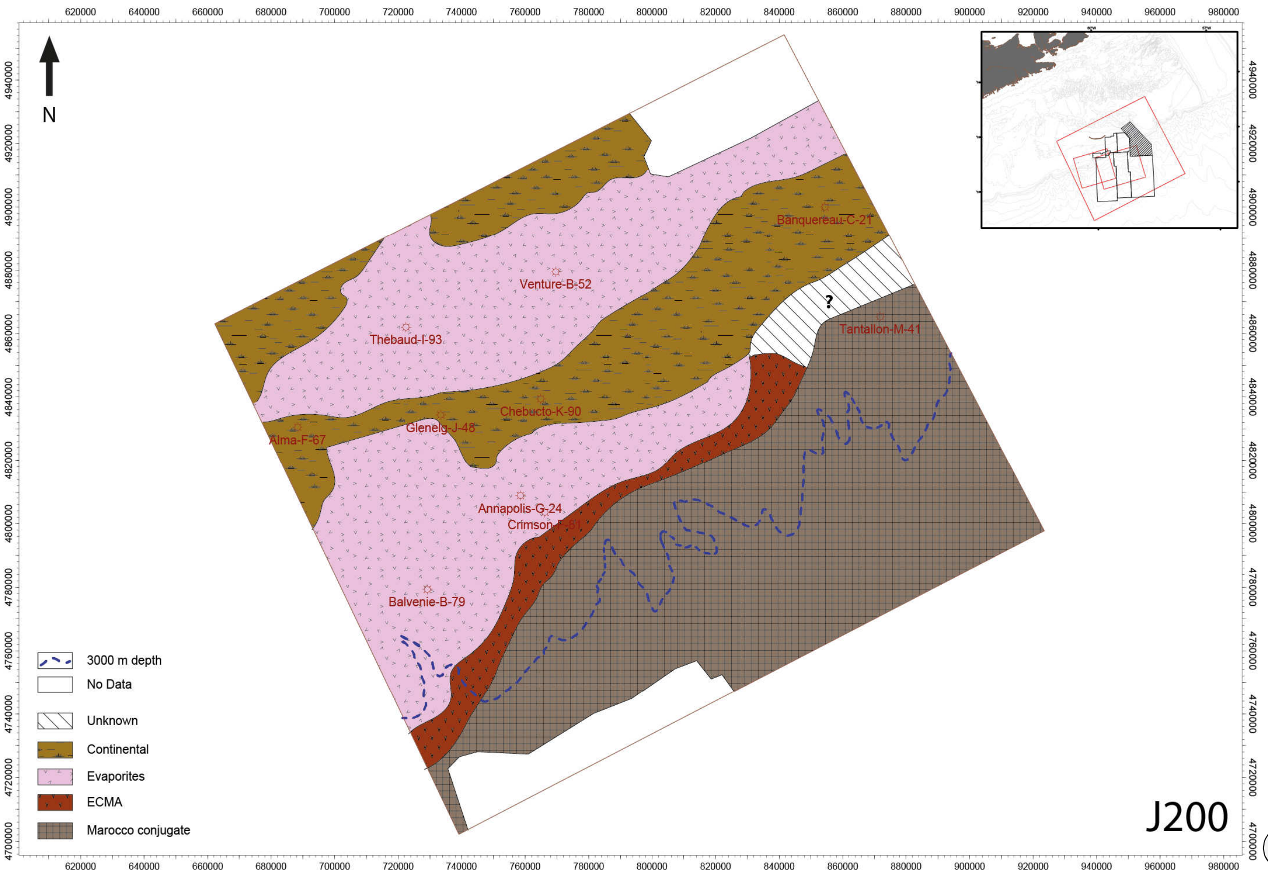
**Central Shelf**: The interval is mainly constituted of tight-to-porous sandstones, shaly sandstones and shale. Porous sandstones are mainly observed in Alma F-67 and Chebucto K-90 (2b and d), while in Glenelg J-48 (2c) at the shelf-slope transition, shale is the predominant facies. Gas is noted in Alma F-67 (2b).

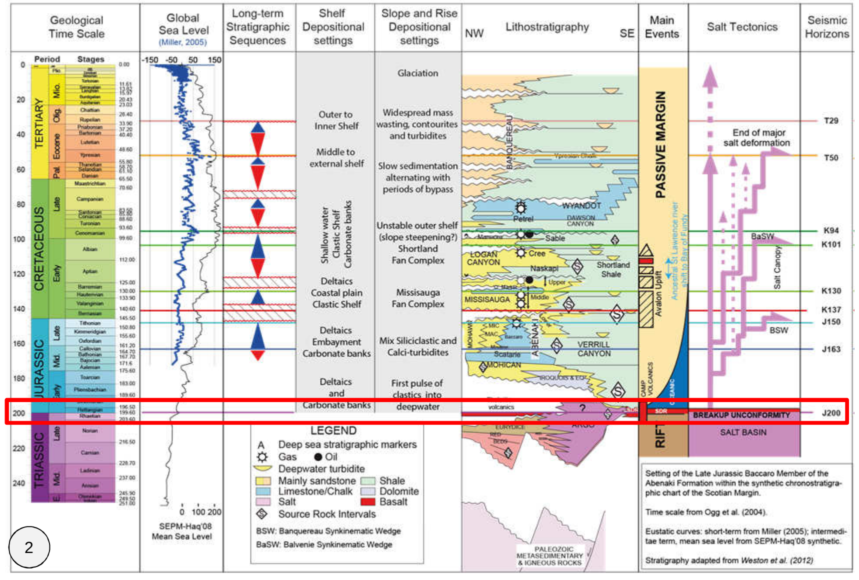
**Central Slope**: The interval is mainly composed of shale with minor shaly sandstones (2e, f, g)

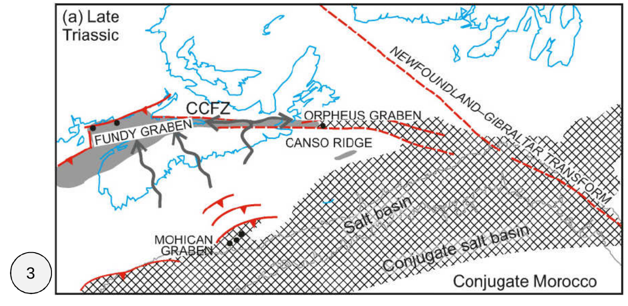
**Matrix lines***
- Sandstone
- Limestone
- Dolomite

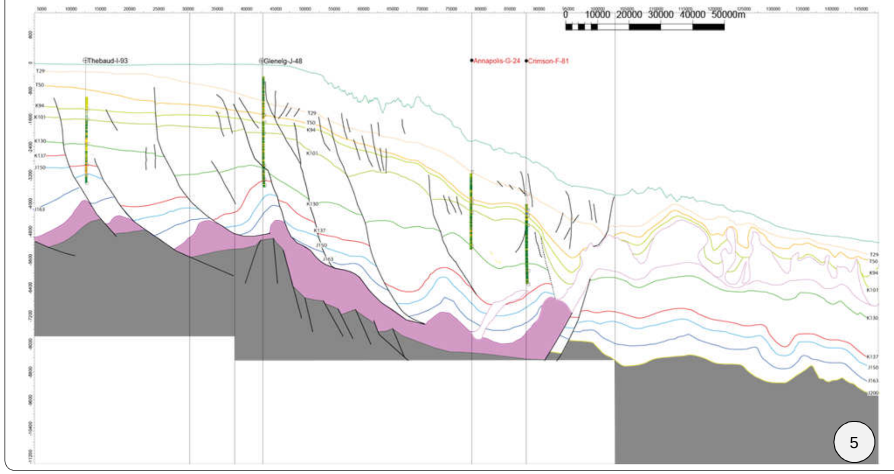
* Schlumberger (1997)
Log Interpretation Charts; SMP-7006; charts of type CP-1, CP-22, CP-23.

Gamma Ray (API)



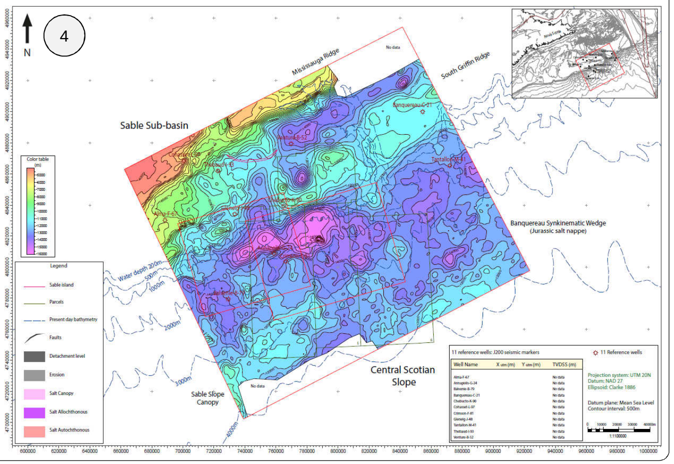
1- Gross Depositional Environment Map at J200

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

3- Sediment source distribution along the Scotian and South Newfoundland Margins during the late Triassic

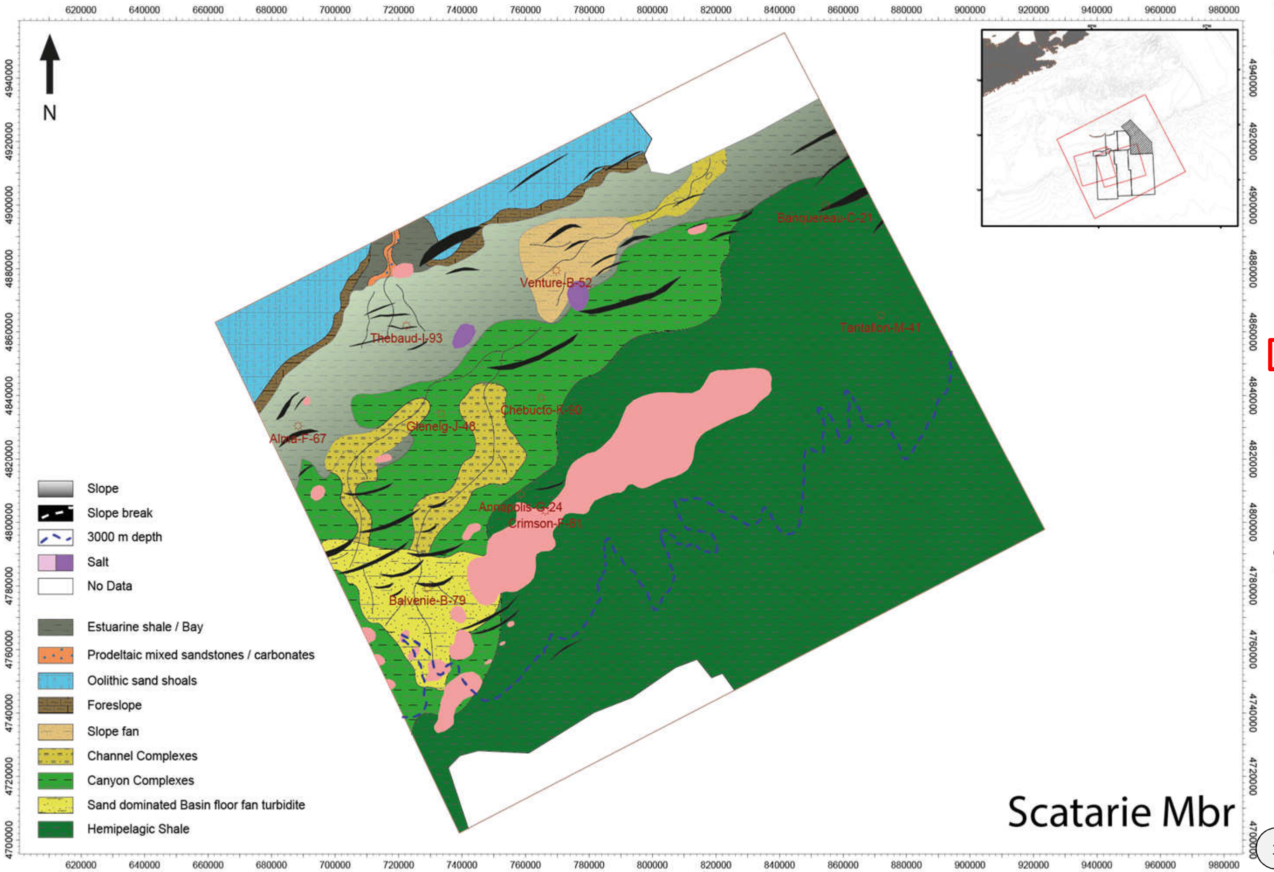
4- J200 Structure Map

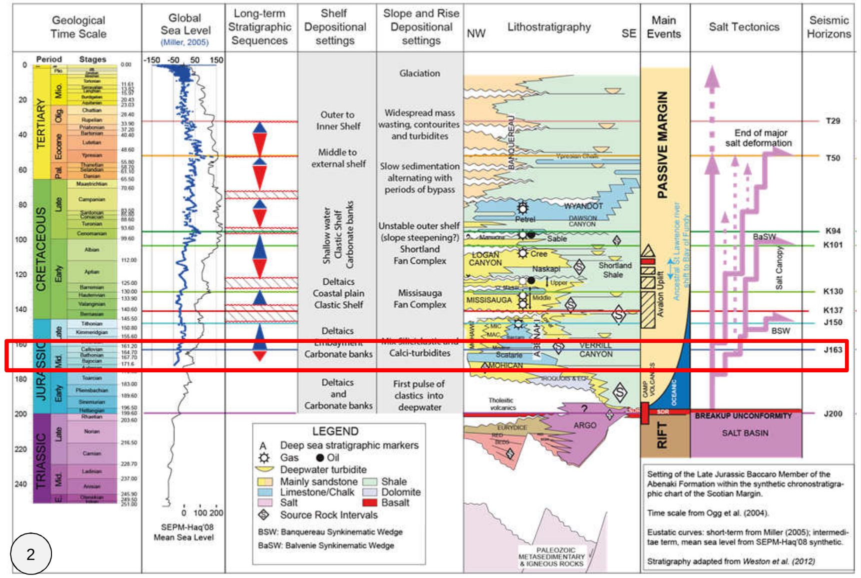
5- J200 Interval in Annapolis Cross-section

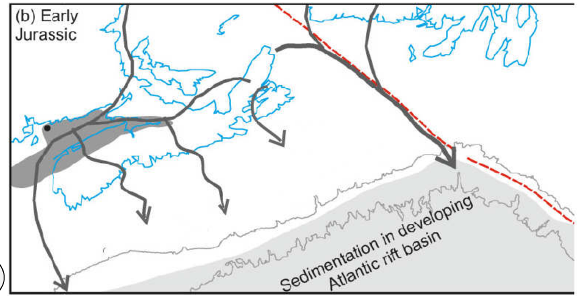


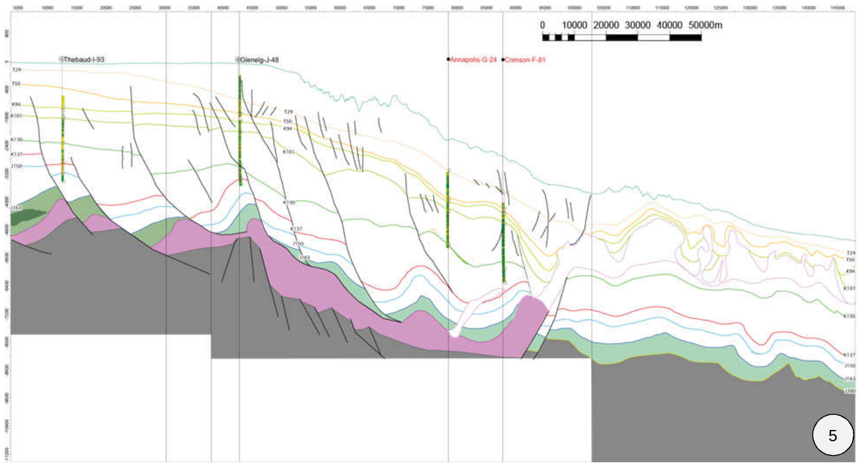

## PL. 6.3.4

## J200 GDE Map



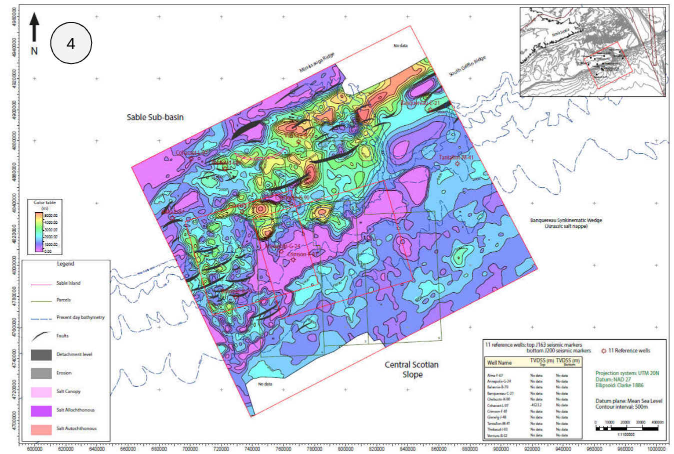

1- Gross Depositional Environment Map for the Scatarie Mbr interval

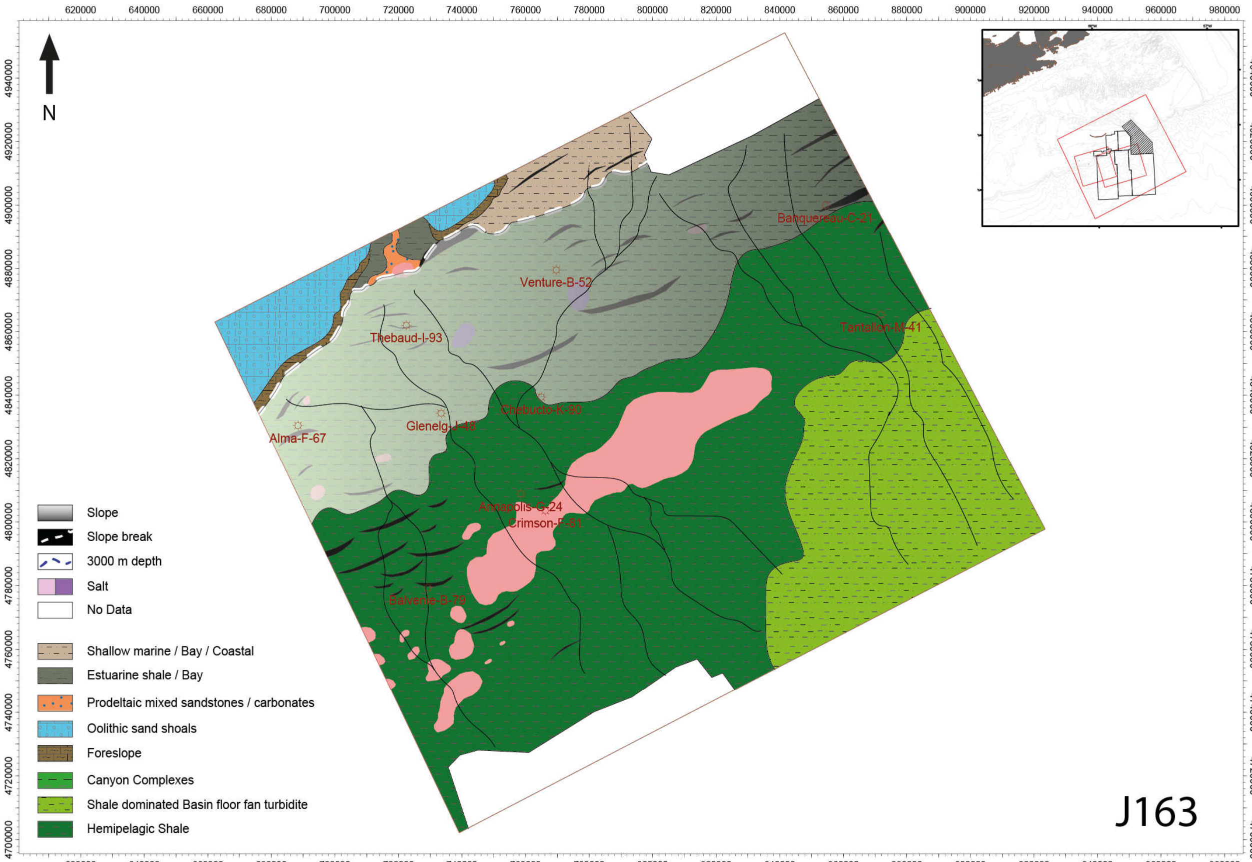
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

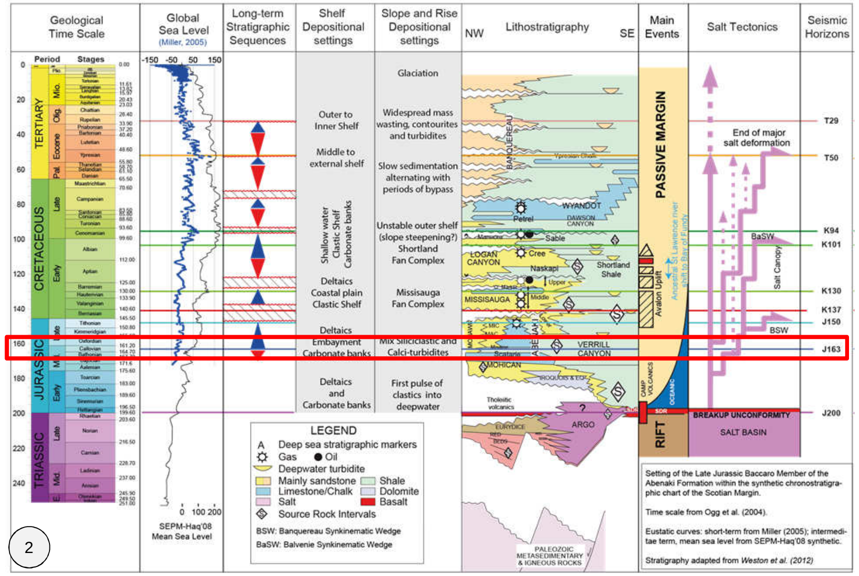
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the early Jurassic

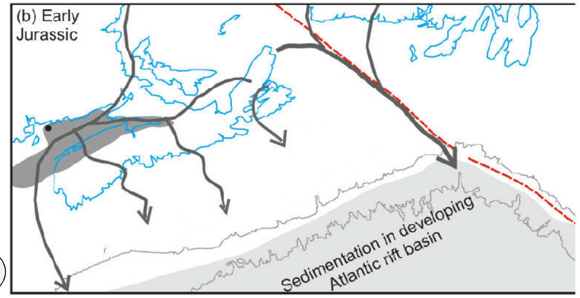
4- J 163 – J200 Thickness Map

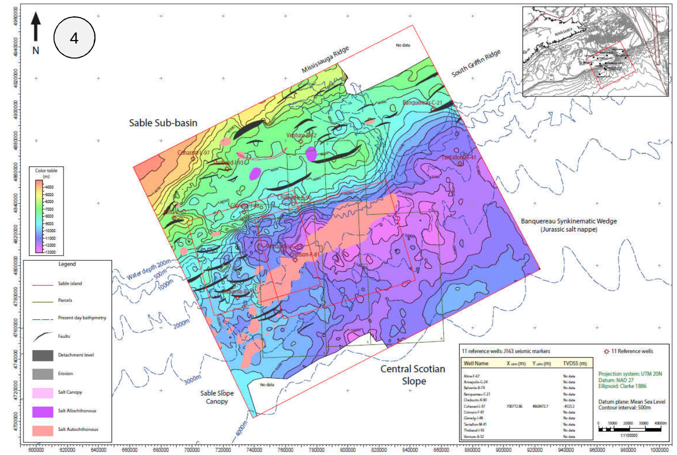
5- J163 – J200 Interval in Annapolis Cross-section

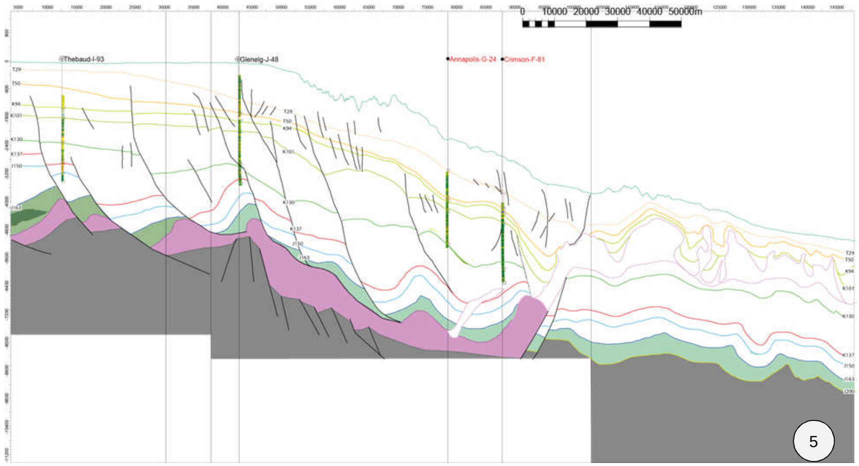




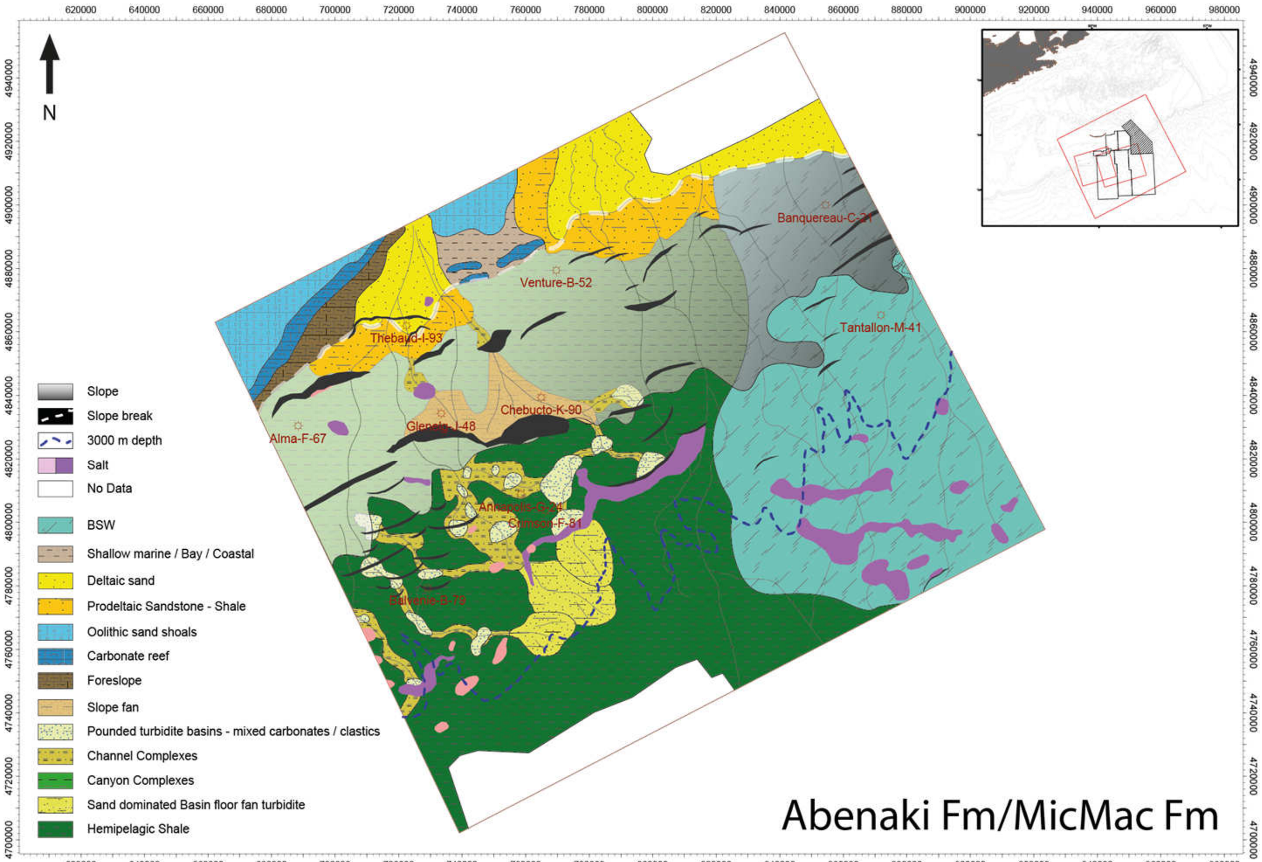

1- Gross Depositional Environment Map at J163

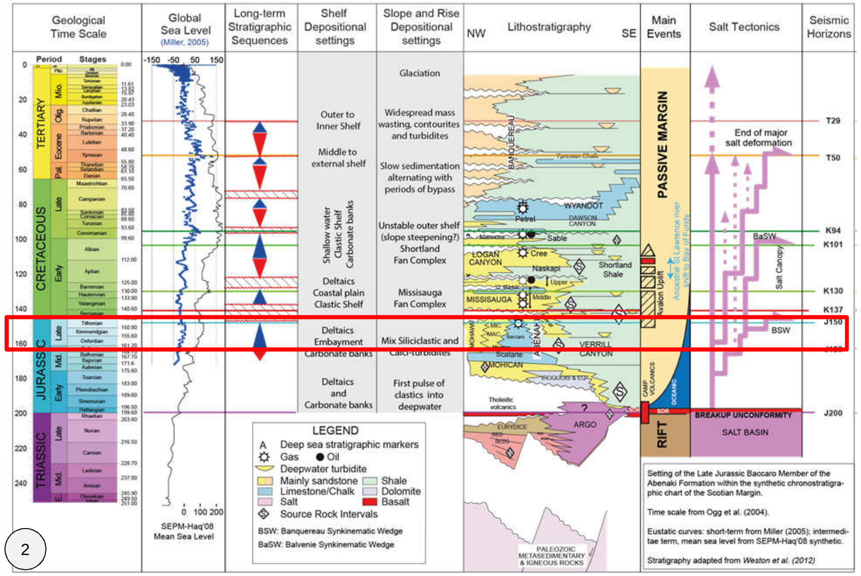
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

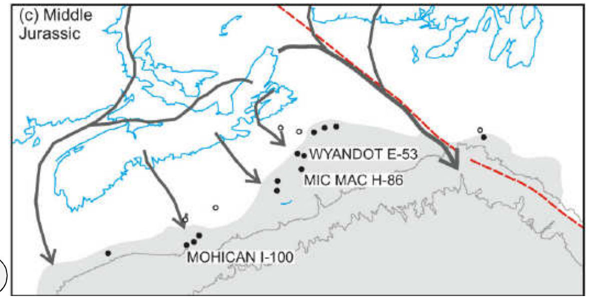
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the early Jurassic

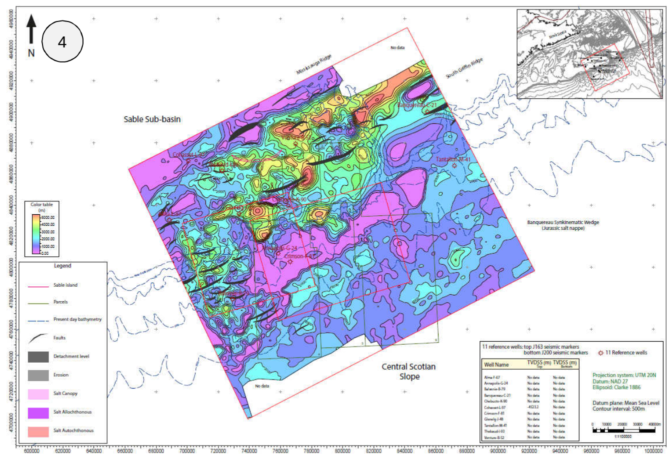
4- J163 Structure Map

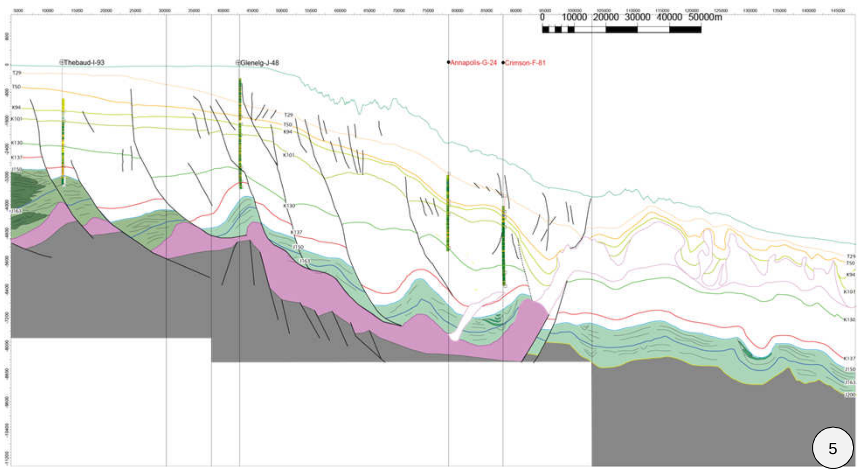
5- J163 – J200 Interval in Annapolis Cross-section




1- Gross Depositional Environment Map for the Abenaki/MicMac interval

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

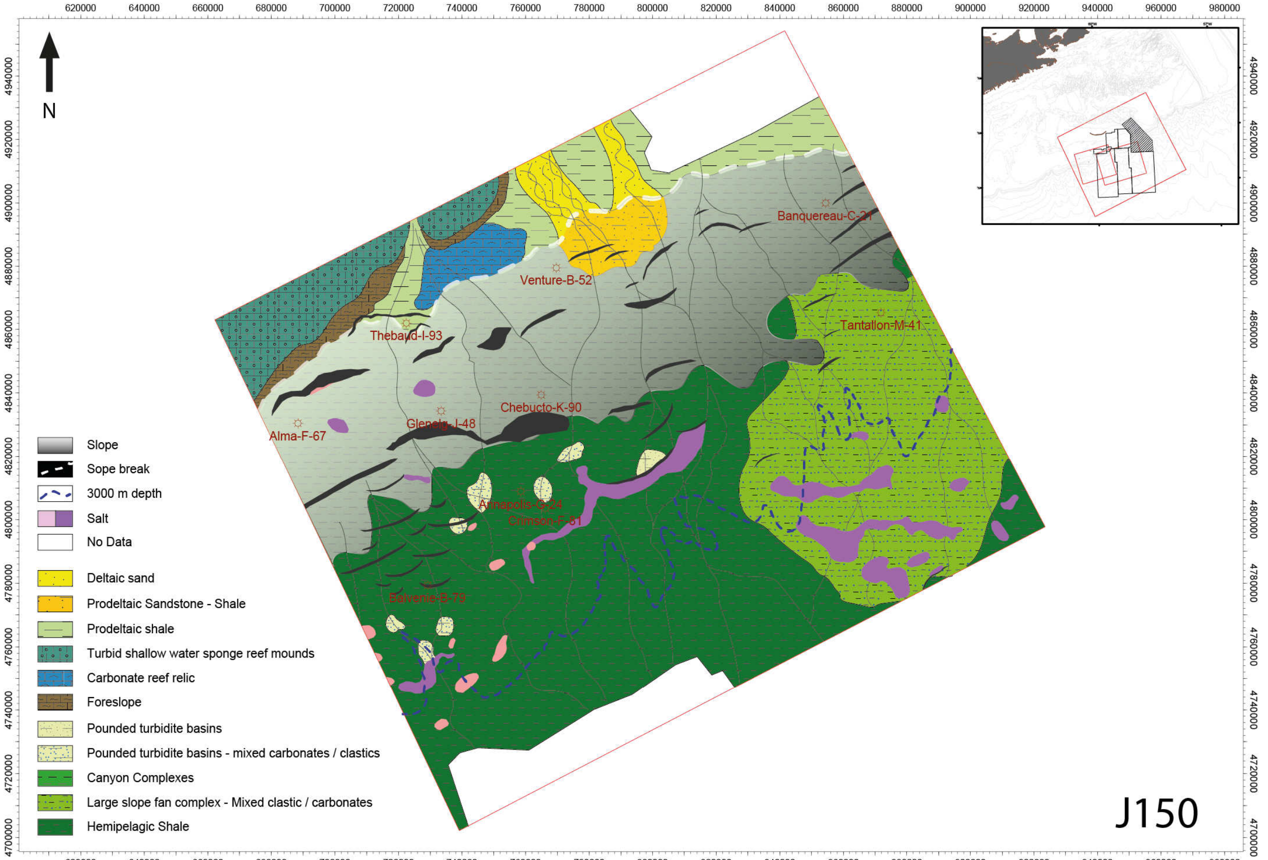
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the Middle Jurassic

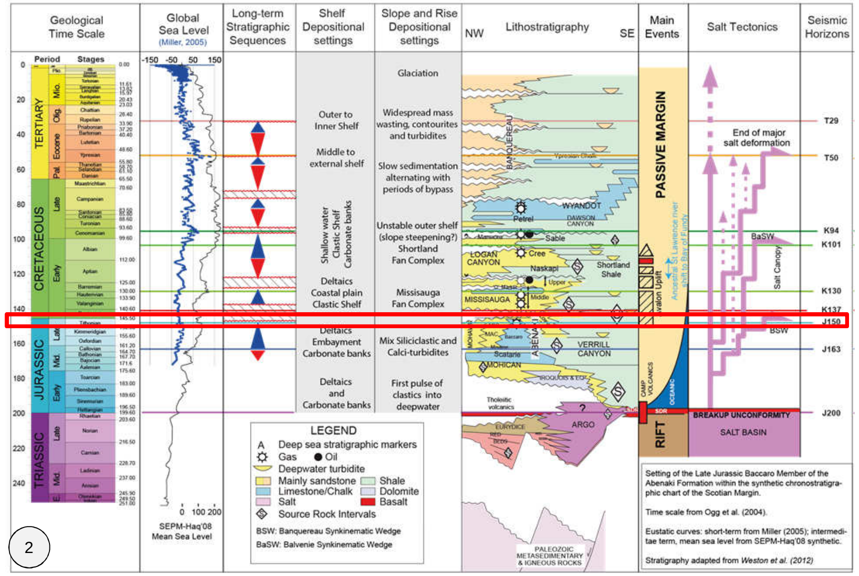
4- J 150 – J150 Thickness Map

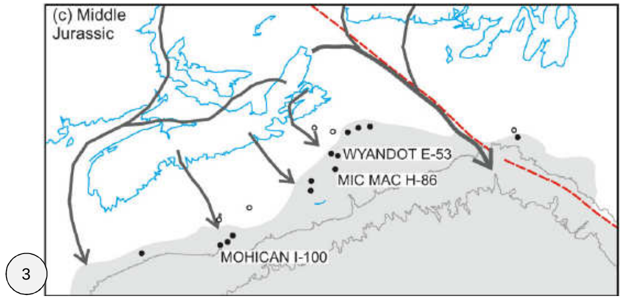
5- J150 - J163 Interval in Annapolis Cross-section

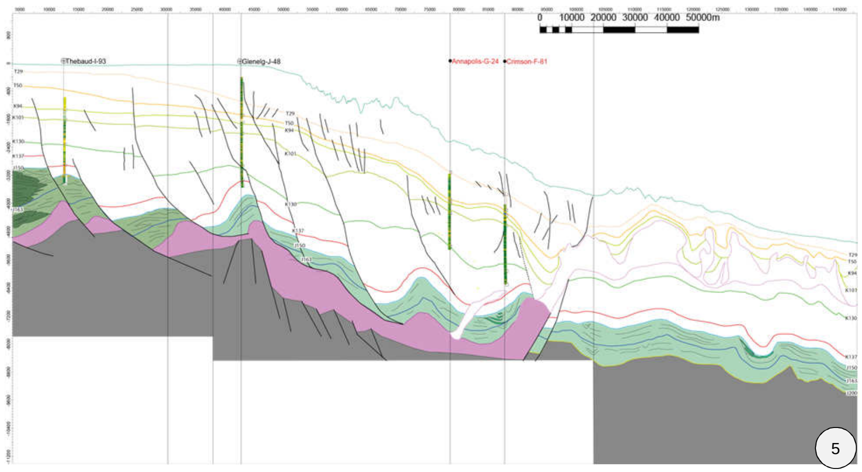
# GDE MAPPING

Central Scotian Slope Study– CANADA – July 2016



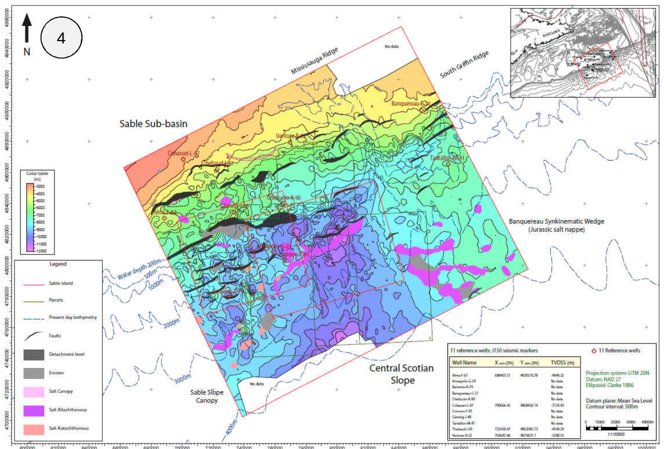

1- Gross Depositional Environment Map at J150

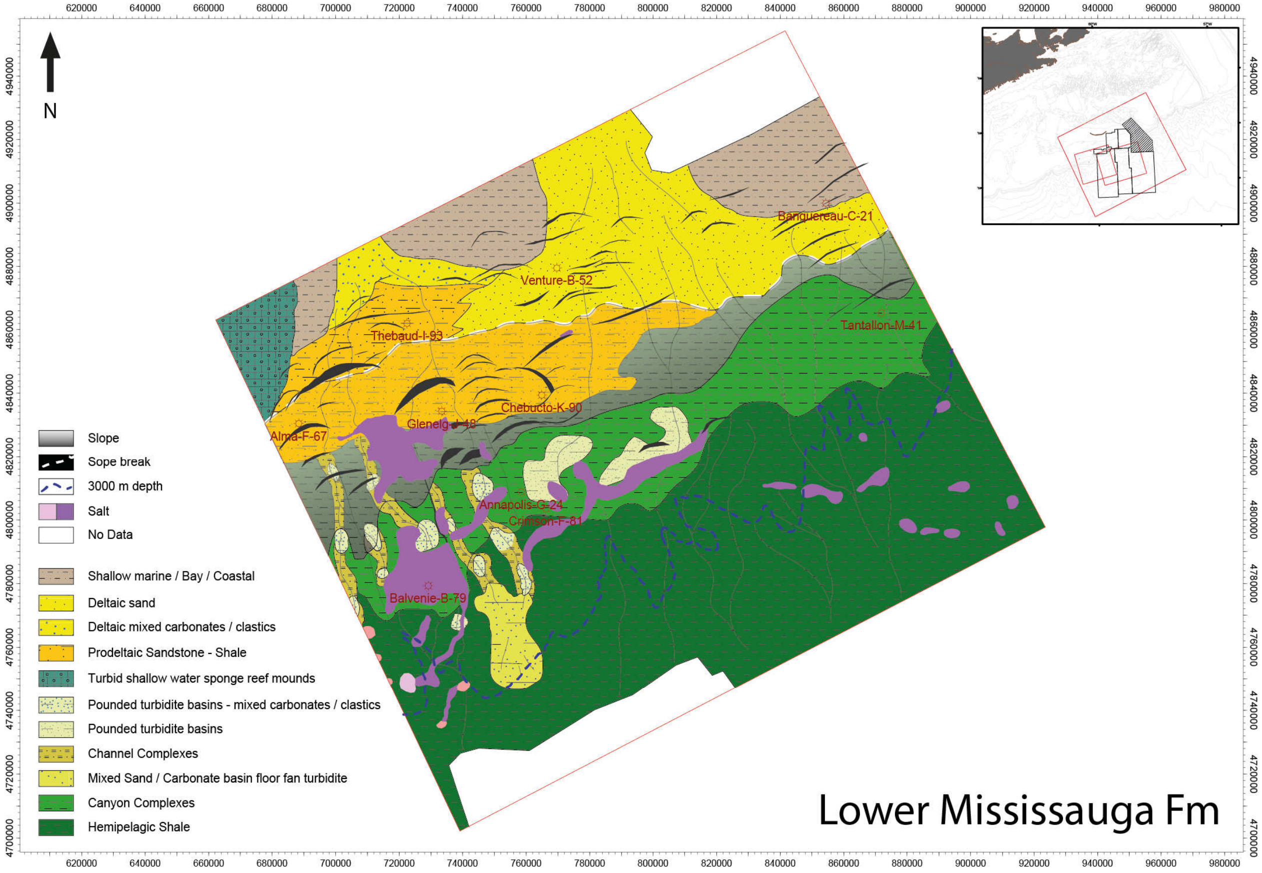
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

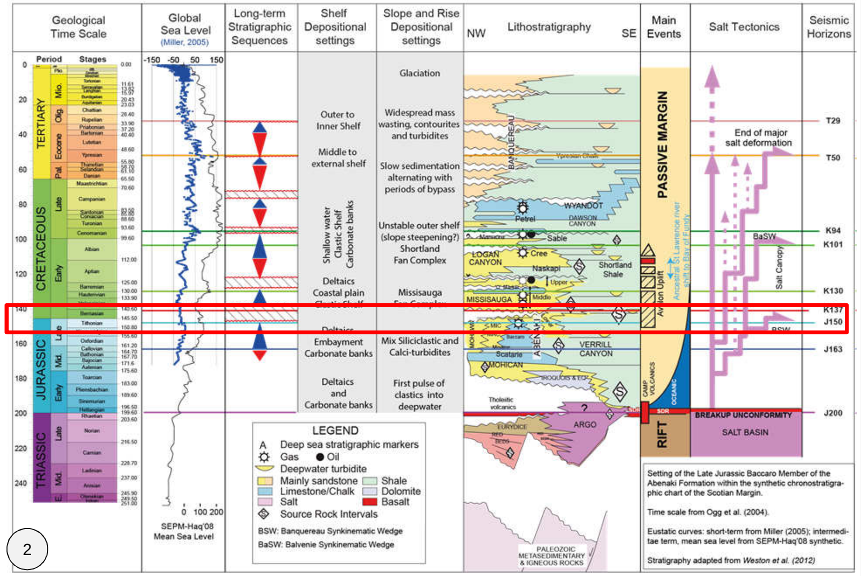
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the Middle Jurassic

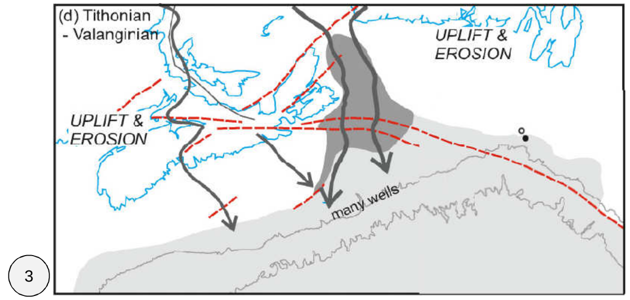
4- J150 Structure Map

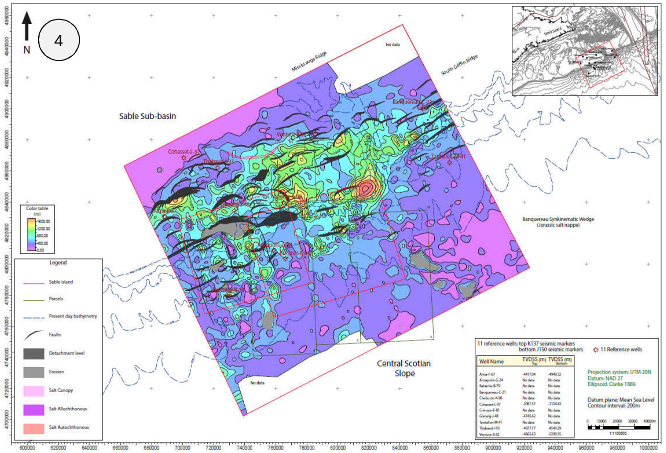
5- J150 - J163 Interval in Annapolis Cross-section

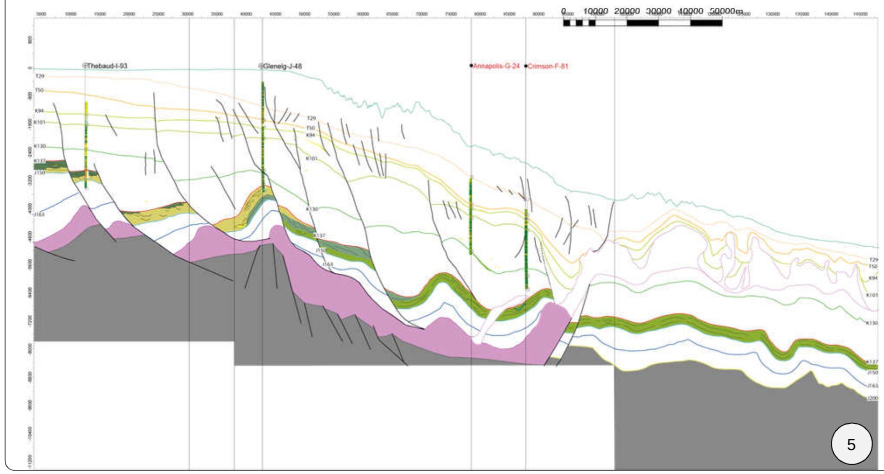




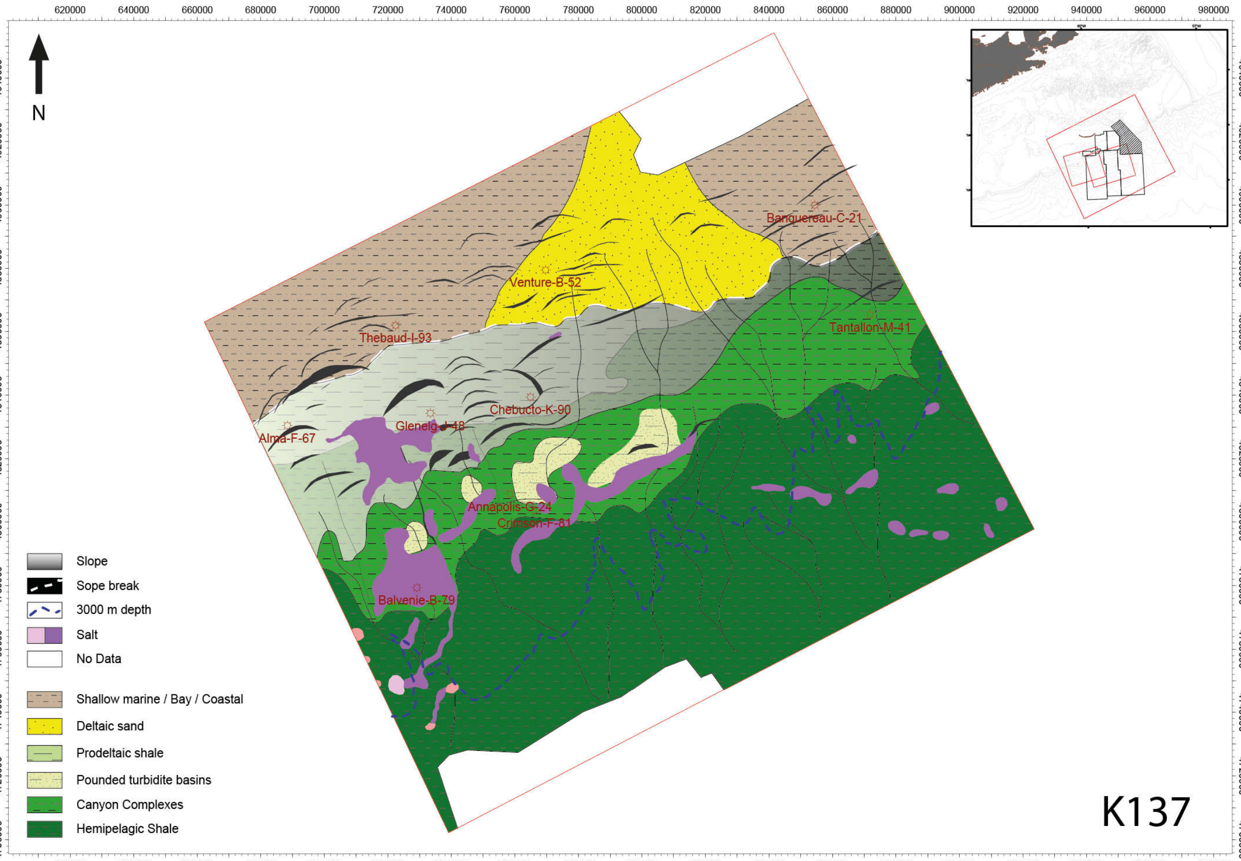

1- Gross Depositional Environment Map for the Lower Missisauga interval

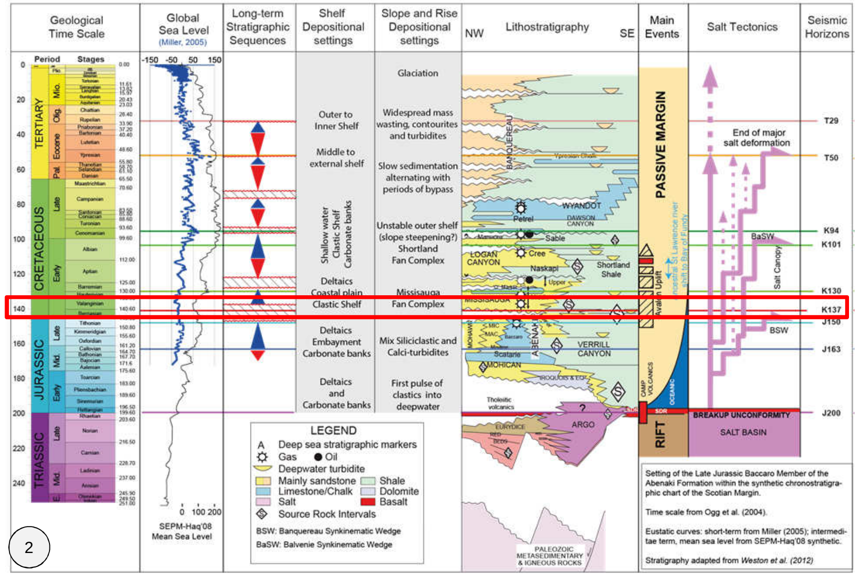
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

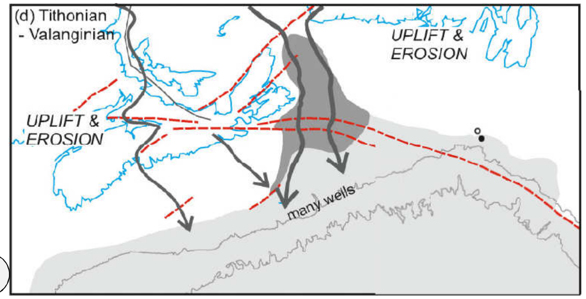
3- Sediment source distribution along the Scotian and South Newfoundland Margin during the Late Jurassic – Early Cretaceous

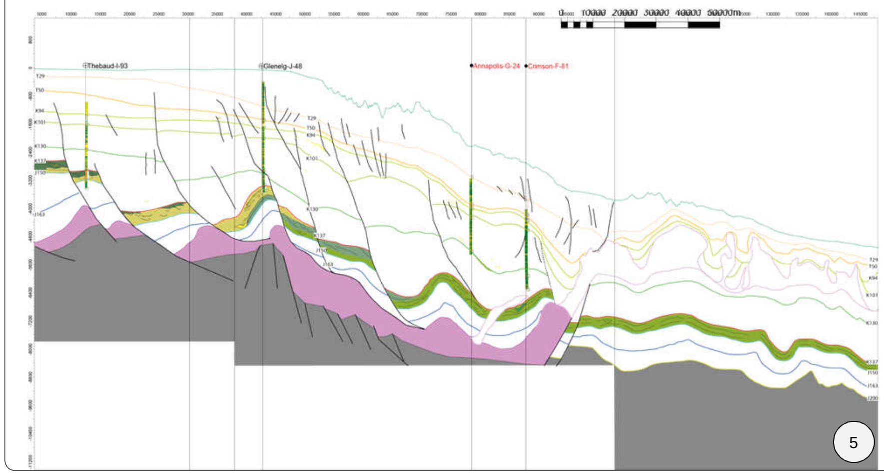
4- K 137 – J150 Thickness Map

5- K137 - J150 Interval in Annapolis Cross-section



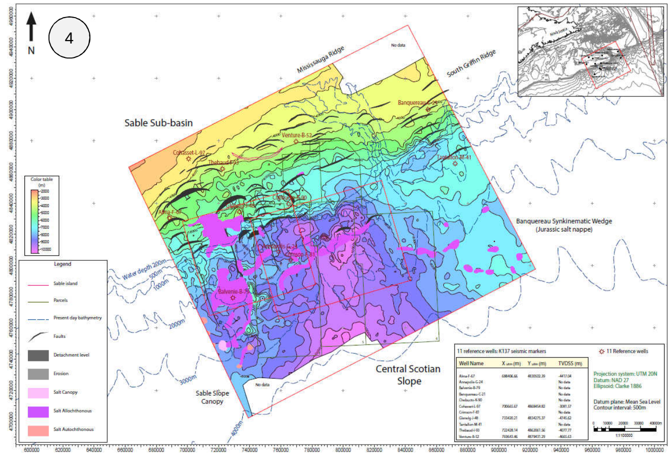

1- Gross Depositional Environment Map at K137

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

3- Sediment source distribution along the Scotian and South Newfoundland Margin during the Late Jurassic – Early Cretaceous

4- K 137 Structure Map

5- K137 - J150 Interval in Annapolis Cross-section

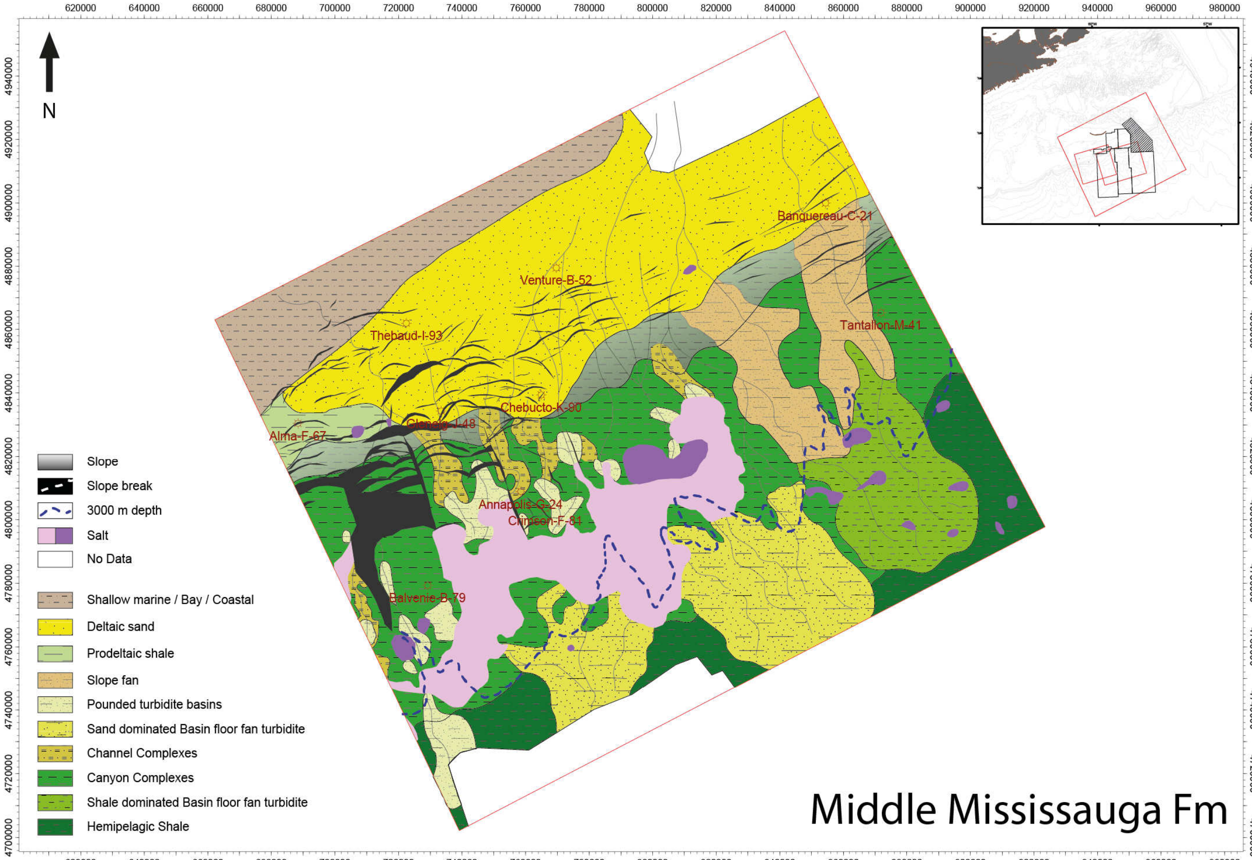


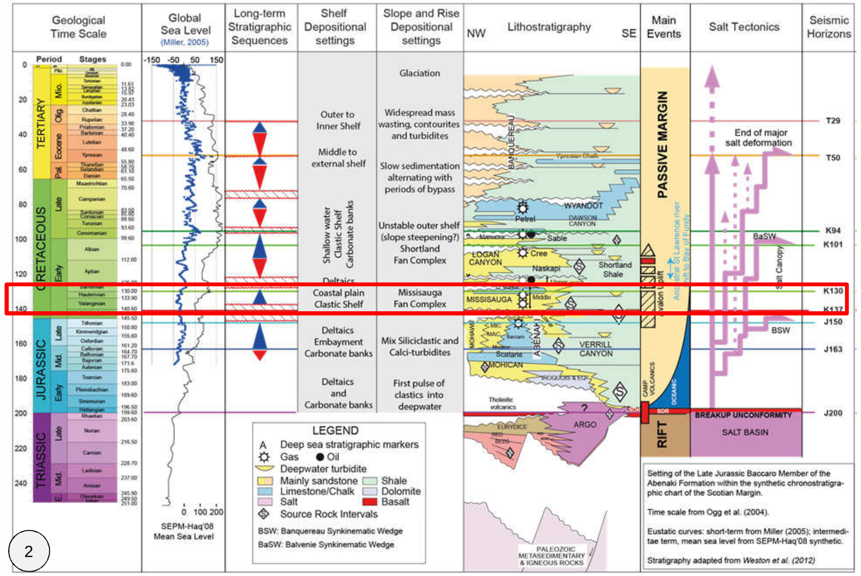


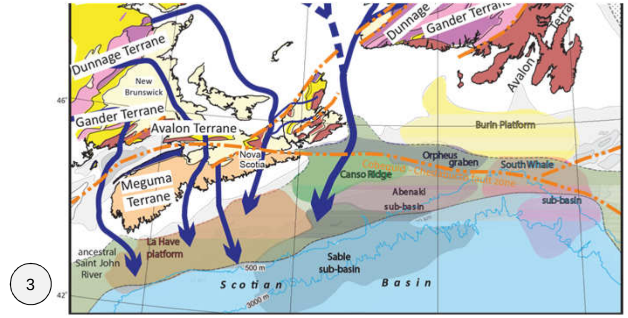

## K137 GDE Map

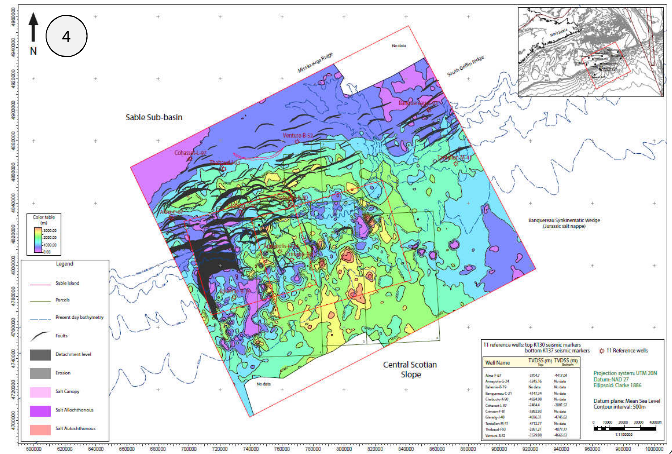
# SEISMIC STRATIGRAPHY

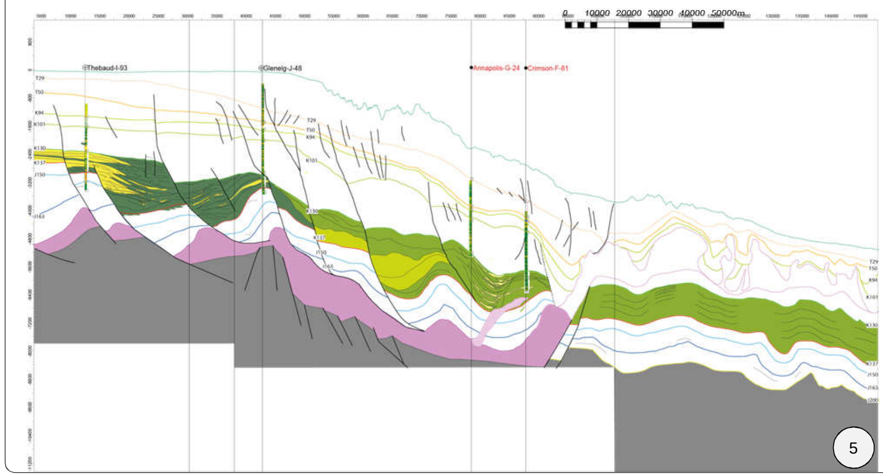
Central Scotian Slope Study– CANADA – July 2016




1- Gross Depositional Environment Map for the Middle Missisauga interval

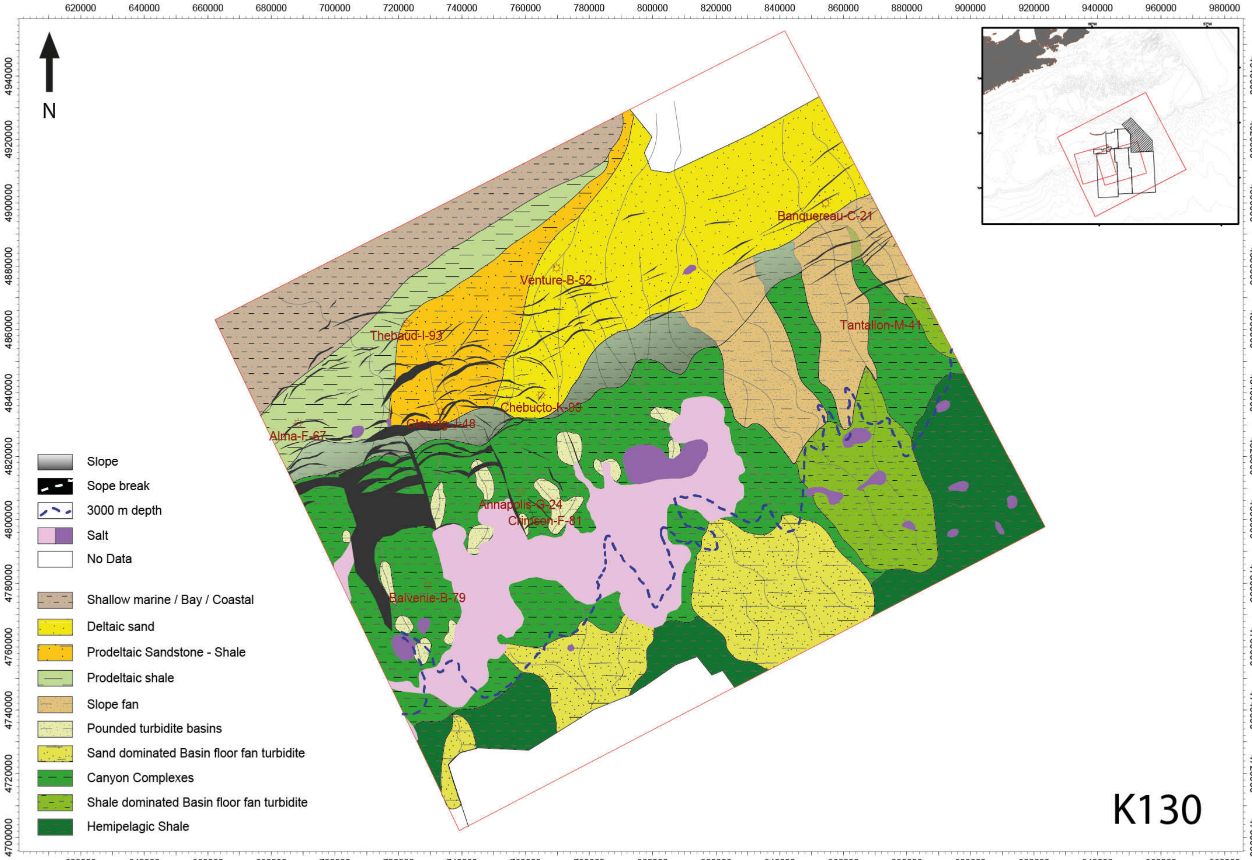
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

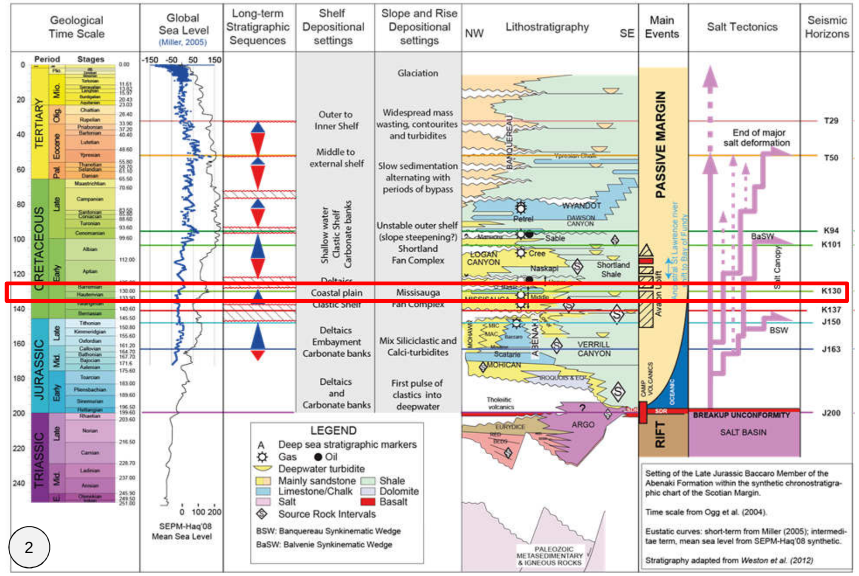
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the Early Cretaceous

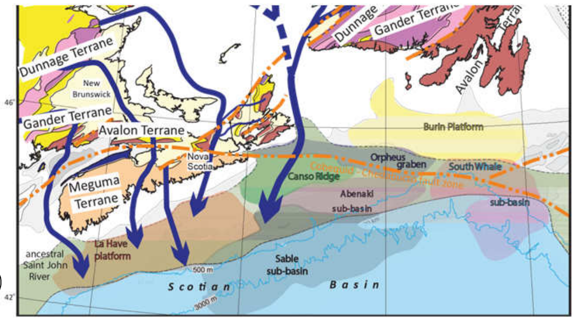
4- K 130 – K137 Thickness Map

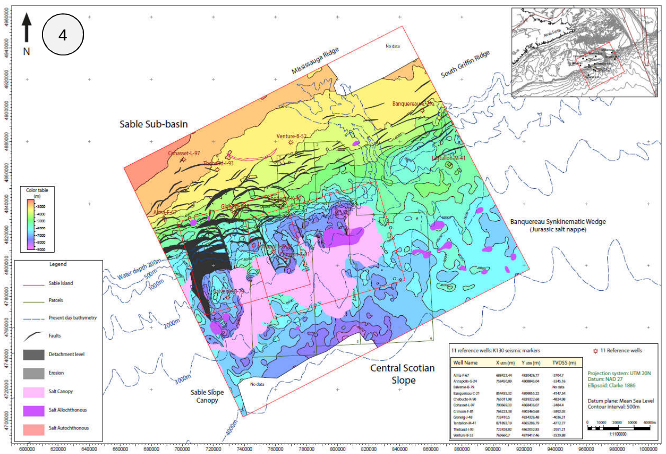
5- K130 - K137 Interval in Annapolis Cross-section

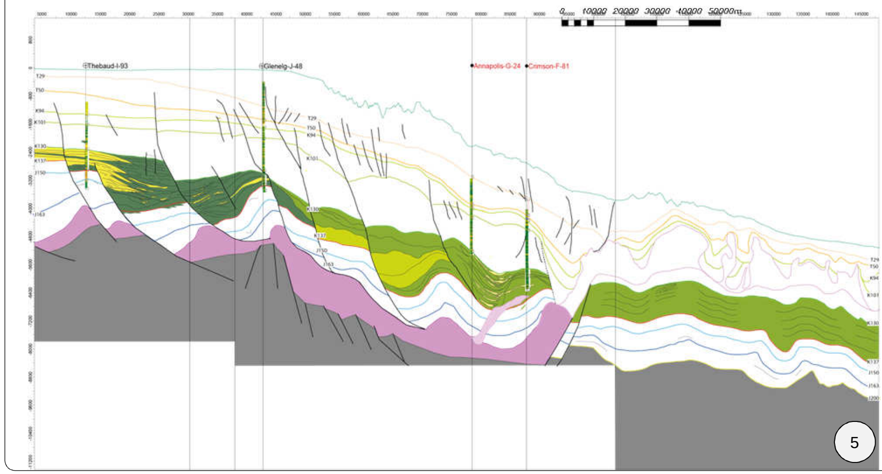
**Middle MISSISAUGA Fm GDE map** PL. 6.3.11



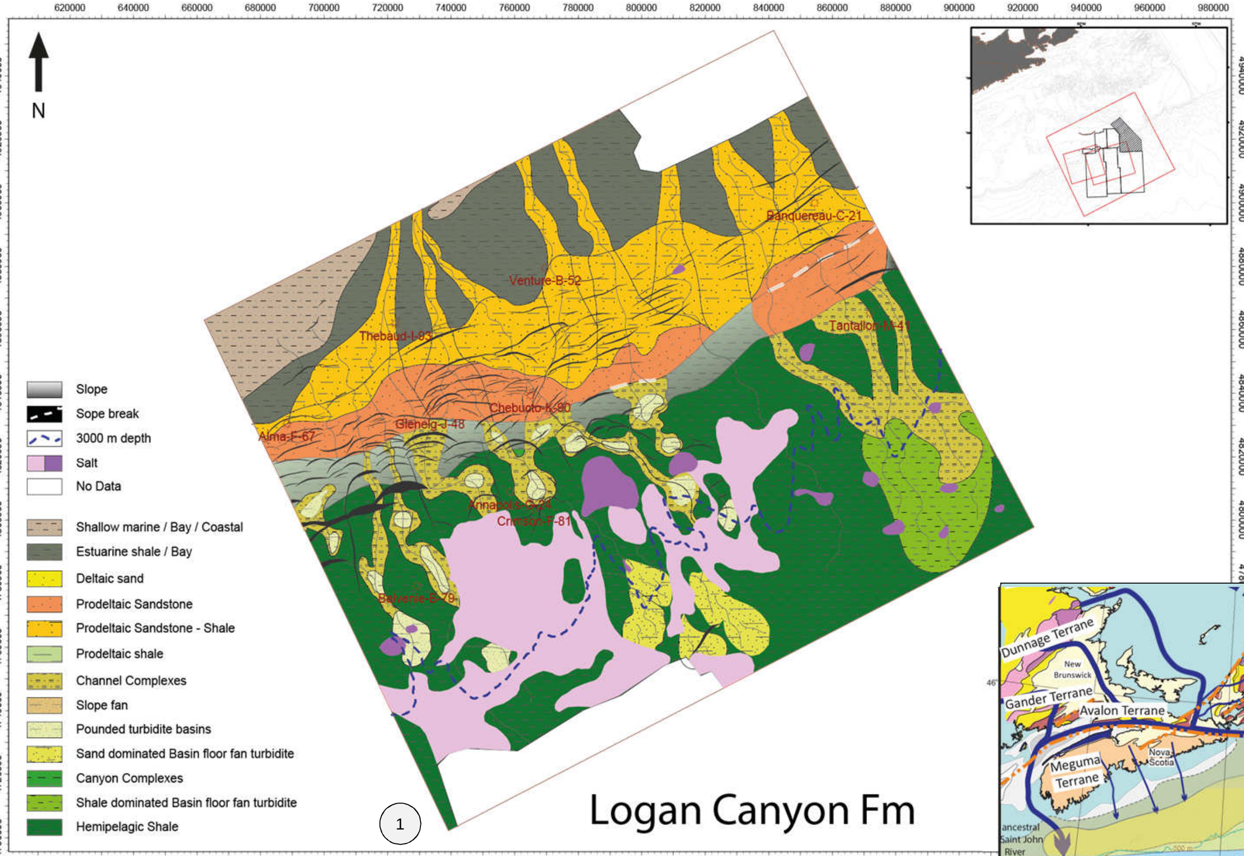

1- Gross Depositional Environment Map at K130

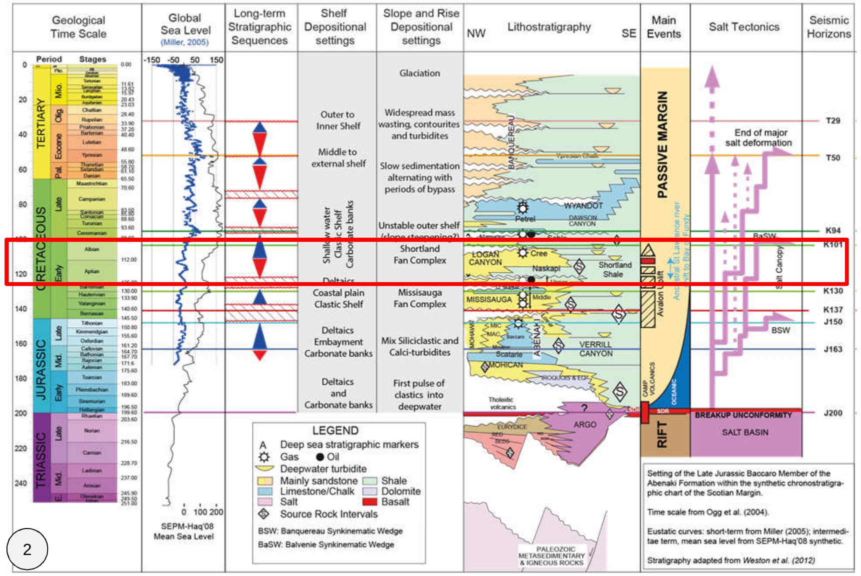
2-Stratigraphic Chart of the Scotian Margin Eastern Canada

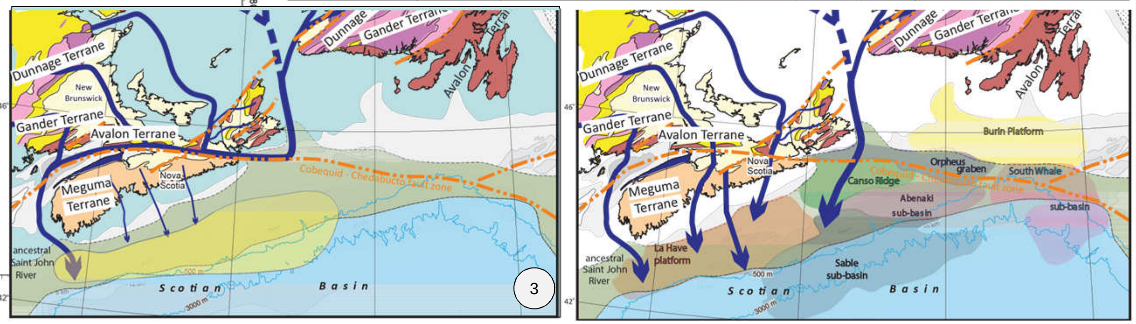
3- Sediment source distribution along the Scotian and South Newfoundland Margins during the Early Cretaceous

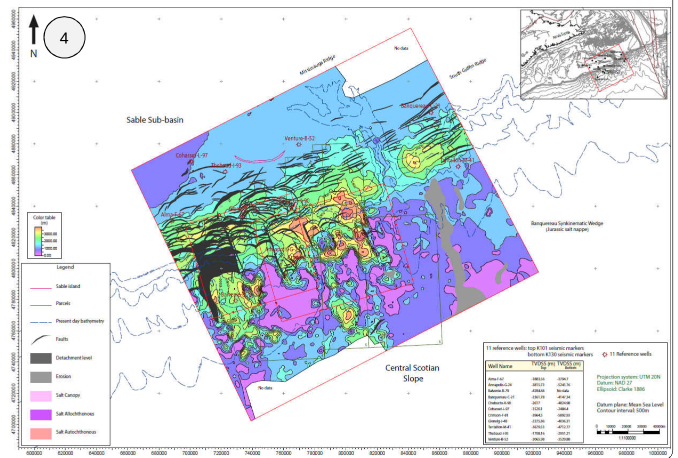
4- K 130 Structure Map

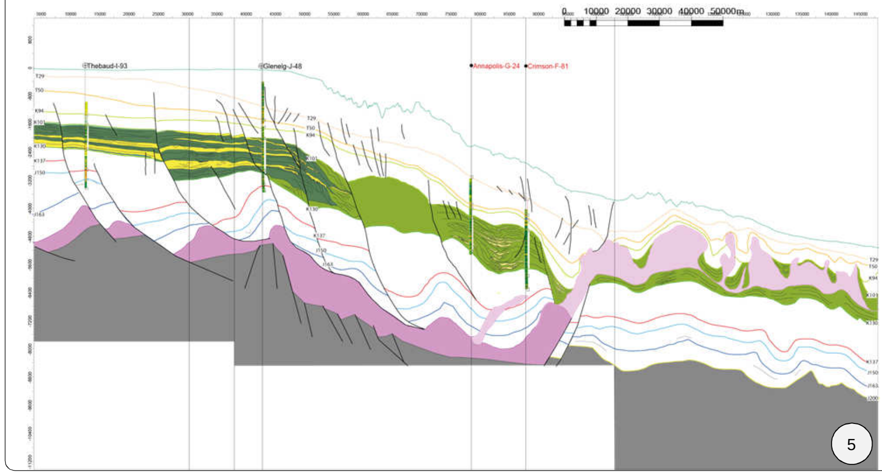
5- K130 - K137 Interval in Annapolis Cross-section




1- Gross Depositional Environment Map for the Logan Canyon interval

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

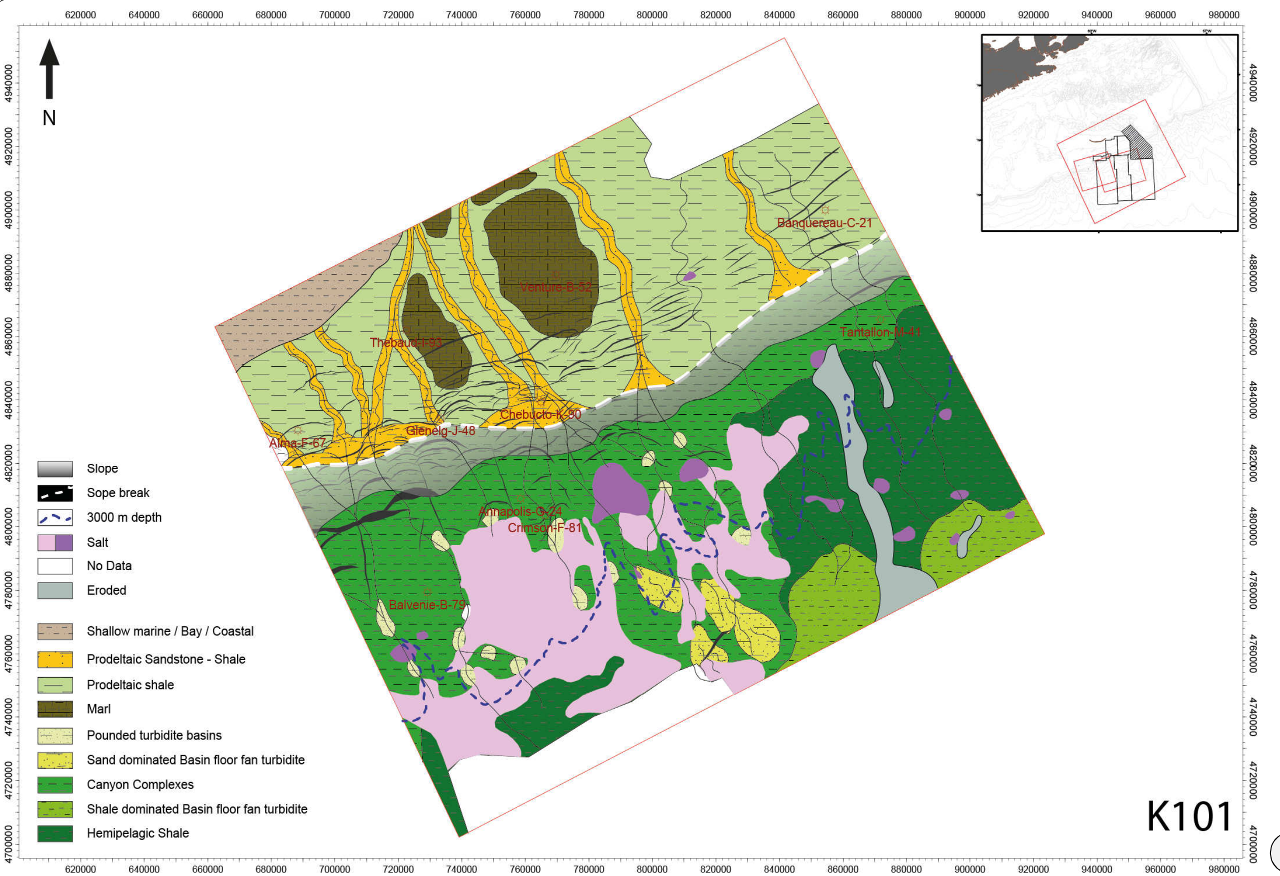
3- Sediment source distribution along the Scotian and South Newfoundland Margins during Aptian (left) and Albian (right)

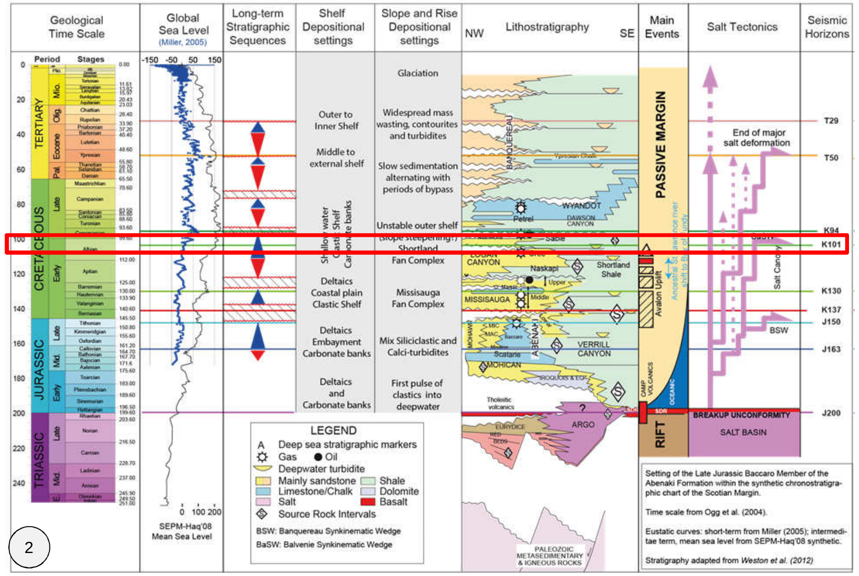
4- K 101 – K130 Thickness Map

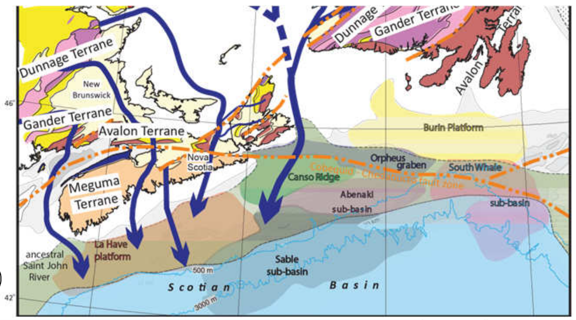
5- K101 - K130 Interval in Annapolis Cross-section

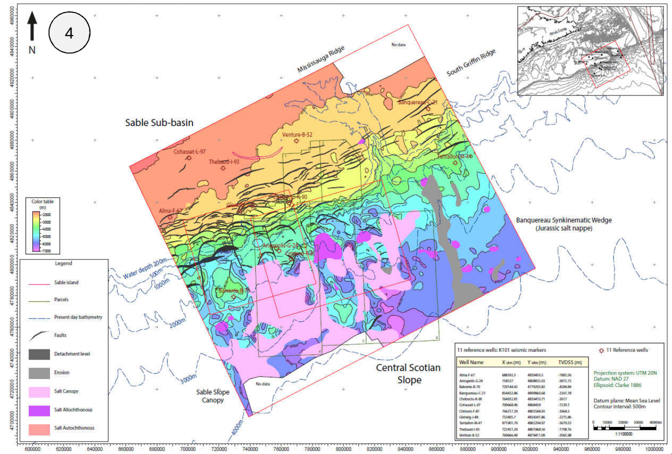
# GDE MAPPING

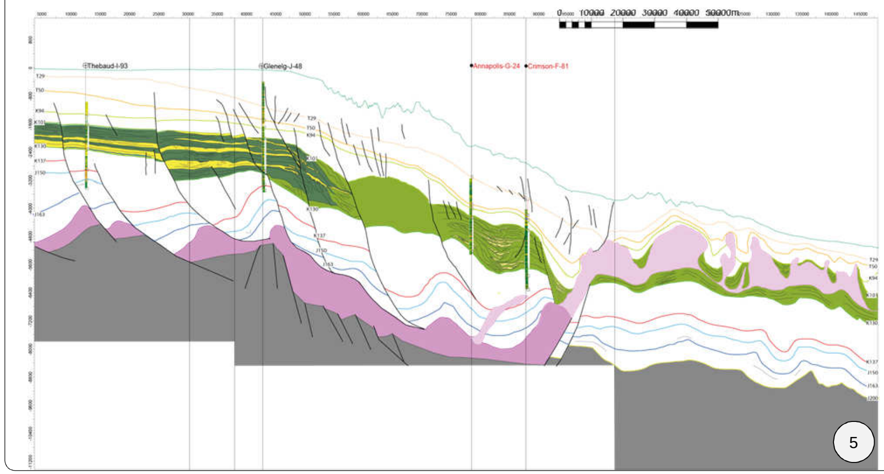
Central Scotian Slope Study– CANADA – July 2016



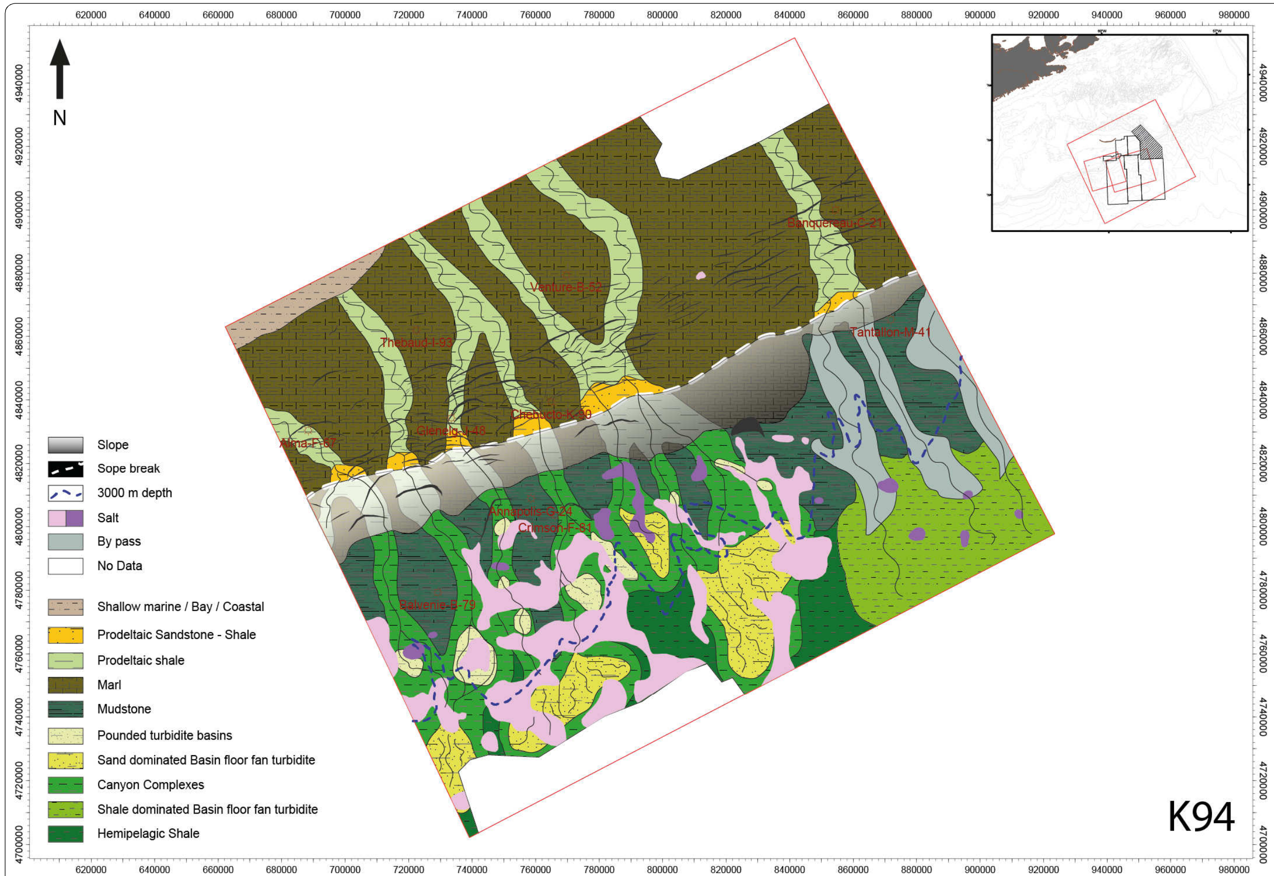

1- Gross Depositional Environment Map at K101

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

3- Sediment source distribution along the Scotian and South Newfoundland Margins during the Late Cretaceous

4- K 101 Structure Map

5- K101 - K130 Interval in Annapolis Cross-section

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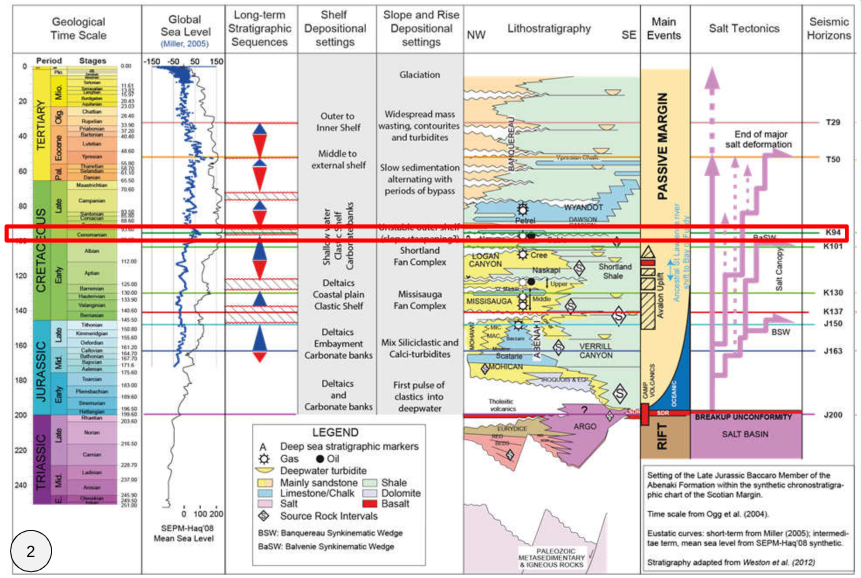


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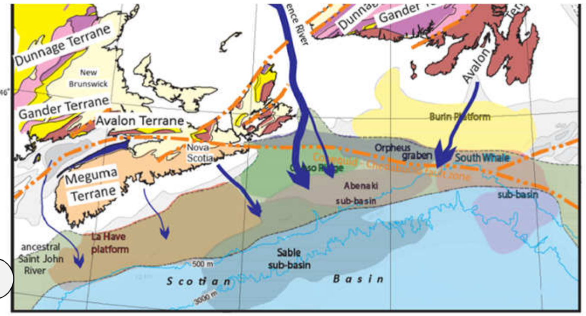


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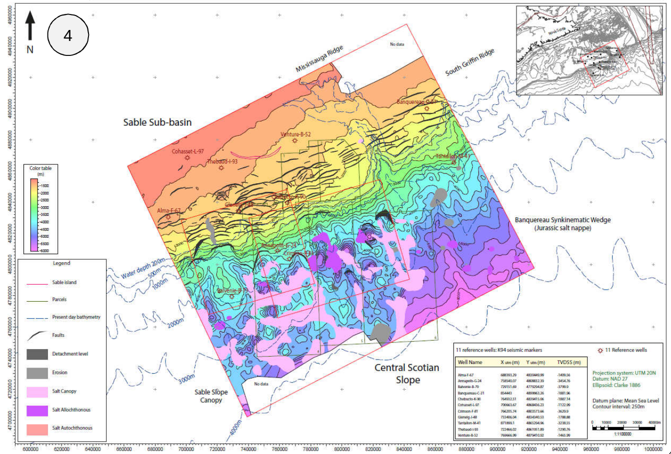


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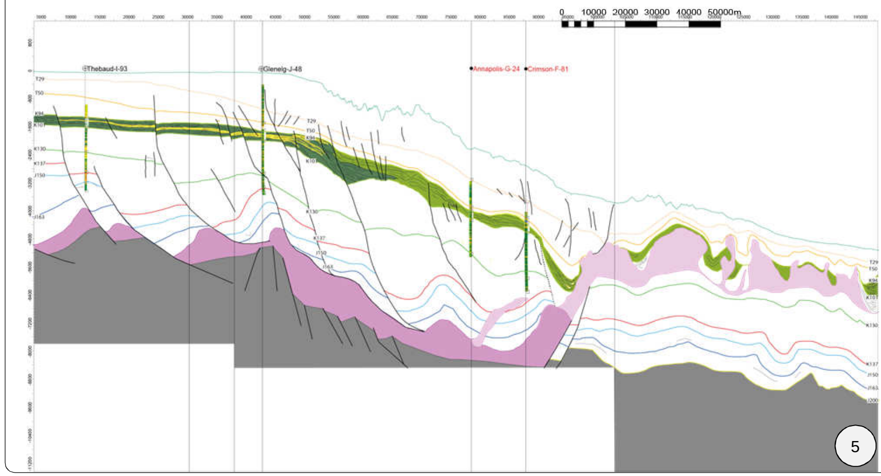


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1- Gross Depositional Environment Map at K94

2-Stratigraphic Chart of the Scotian Margin Eastern Canada

3- Sediment source distribution along the Scotian and South Newfoundland Margin during the Late Cretaceous

4- K 94 Structure Map

5- K94 - K101 Interval in Annapolis Cross-section