CHAPTER 3

REGIONAL TECTONIC CONTEXT
Figure 1: Topography of the Central and Northern Atlantic and location (white polygon) of the study area. The Newfoundland Transform Zone and the Azores-Gibraltar transform zone separate the Northern Atlantic from the Central Atlantic.

Figure 2: Bathymetry map offshore Nova Scotia and Newfoundland Island. The study area covers the Laurentian Channel Slope and the steep talus linking the Sohm abyssal plain (more than 5,000 m deep) to the South Bank High consisting of a large platform at 100 m water depth. Available seismic lines of the Scotian and Grand Banks slope are shown as thin black lines.

Figure 3: Bouguer gravimetric anomaly map

Figure 4: Bouguer gravimetric anomaly map and main tectonic features. Mesozoic sedimentary basins of the Grand Banks (Whale basin, Horseshoe basin, Jeanne d’Arc basin) and of the Scotian Shelf (Orpheus graben) are clearly imaged by negative values of the Bouguer anomaly. The Appalachian thrust front is also shown by the Bouguer anomaly. Other tectonic features such as main faults and Continent Ocean Boundary (COB) are mainly deduced from the magnetic anomaly map, Laurentian sub-basin and South Whale sub-basin gravimetric signature is also characterized by low values.
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Magnetic anomaly map and major structural features

Figure 5: Magnetic anomaly map (Dehler, 2010) and main tectonic features. The Oceanic domain is characterized by a typical succession of normal and reverse linear magnetic anomalies. Georges banks and Scotian Shelf are separated from the oceanic domain by the strong positive regional anomaly of the East Coast Magnetic Anomaly (ECMA). Continent Ocean Boundary (COB) is deduced from previous PFA studies (Sibuet, 2011; Labails, 2010).

From potential data (gravimetry + magnetic anomaly maps) several major tectonic elements of the Nova Scotia - Newfoundland area can be traced:

1) The East Coast Magnetic Anomaly and the Continent Ocean Boundary (COB). This latter major limit is clear and easy to define in the Georges Bank and Scotian shelf area. It is more difficult to define in the Laurentian sub-basin where the ECMA and COB signals become poor and along the Grand Banks where ECMA no more exists.

2) The Newfoundland Transform Zone (NFTZ) is one of the most prominent fault system. It constitutes the main escarpment of the South Bank High and form a sharp limit just north of the J ridge and Newfoundland ridge anomaly. Its trace along the South Bank High is less well expressed on potential data and was constrained by seismic data. (see plate 3.7.)

3) The Chebucto Cobequst fault clearly imaged by gravimetric and magnetic data. Its trace is clear offshore, along the Orpheus Graben, and onshore, where it constitutes a major fault separating the Middle Paleozoic Terranes of the Meguma block from the Upper Paleozoic (mainly Carboniferous) units. East of the Orpheus graben, the main fault seems to split in various splay faults but does not seem to be connected directly to the Newfoundland Transform Zone (NFTZ).

4) The Appalachian front, mainly shown by the contrast between a) gravimetric "lows" of the Appalachian foreland corresponding to the Carboniferous flexural basin b) gravimetric "highs" of the deformed belt.

Figure 7: Enlargement of the magnetic anomaly map from Dehler, 2010. Study area is shown by the white polygon.
The Nova Scotia-Newfoundland margin results of a complex evolution since Proterozoic times. The present day passive margin stage appeared after a first complete Wilson cycle with the breakup of the Rodinia supercontinent, the formation of the Pangea supercontinent and the breakup of the Pangea. Breakup of Rodinia and formation of Pangea result of the following events.

**Grenville Orogeny (1 000 Ma)**
Grenvillian rocks are subdivided into a set of allochthonous terranes arranged in the form of a south-easterly dipping thrust stack emplaced over a continental margin of Archean age and intruded by numerous post orogenic plutons.

**Post-Grenville rifting (~ 500 My ago - Cambrian)**
Post-Grenville rifting (~ 500 My ago - Cambrian) induced the closure of the Rheic ocean and the formation of the Pangea result of the following events.

**Grenville Orogeny**
After the Grenville orogeny, resulting of two continental blocks collision, the newly formed Rodinia continent is broken during a rifting event in Cambrian times. This break-up leads to the formation of a new ocean (the Iapetus Ocean) separating two large continental blocks (Laurentia and Gondwana).

**Cambro-Ordovician passive margin (~ 500 Ma)**
During Ordovician times Island arc material is accreted to the Cambro-Ordovician passive margin inducing a first major orogeny.

**Taiacian orogeny (Ordovician 450 Ma)**
During Ordovician times, the collision of an isolated continental block (Avalonia block) induced the closure of the Iapetus ocean and the second major orogeny.

**Acadian orogeny (Devonian 400-380 Ma)**
During Devonian times the collision of a second isolated continental block (Avalonia block) induced the closure of the Iapetus ocean and the second major orogeny.

**Appalachian orogeny (Carboniferous 350 - 300 Ma)**
During Carboniferous times the collision of the future African continental block (Gondwana) with the north America continental plate (Laurentia) caused the closure of the Rheic ocean, the formation of the Appalachian orogen and the Pangea supercontinent.

The Foreland Anticosti basin preserved Cambrian to Carboniferous shelf and foreland basin rocks (figures 9 and 11). Cambrian and Ordovician rocks of the Anticosti Basin include sandstones and carbonates that once formed part of a broad continental shelf that bordered the ancient continent of Laurentia. Basins such as these in Quebec and Ontario have produced oil and gas from reservoirs in Ordovician carbonates. 

**Trassic rifting (250-200 My ago) Atlantic Ocean Passive margin history**
The next step of this evolution is the Trassic rifting, initiating a new Wilson Cycle.

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**Figure 8:** Geological map of Proterozoic and Paleozoic basement. Contours indicate:
1) Depth to pre-Mesozoic basement (brown and yellow colors)
2) Depth to pre-Carboniferous basement (grey-blue colors)
3) Depth to pre-Paleozoic basement (grey-green colors)

**Figure 9:** Nova Scotia-Newfoundland island main tectonic units. 1) Canadian Archean and Proterozoic Craton (white) 2) Proterozoic Grenville Orogen (Pinkish) 3) Paleozoic units including Appalachian foreland and Appalachian orogen (Greyish) 4) Mesozoic passive margin (yellow and brown contour map) 5) Jurassic oceanic domain (Violet) 6) Cretaceous oceanic domain (green)
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Appalachian orogeny (Carboniferous 350 -300 Ma) PANGEA SUPERCONTINENT
Laurentia

Gondwana

Triassic rifting (250-200 My ago) Future Africa

Present passive margin of the North American continental blocks Atlantic Ocean

modified from
https://mountainbeltway.wordpress.com/category/west-virginia/

Passive margin evolution PLATE 3.5

Rifting and drifting processes induced stretching of the lithosphere, exhumation of the lithospheric mantle with serpentinization and early subsidence at the onset of drifting during Late Jurassic- Early Cretaceous times.

The Opening of the Central and Northern Atlantic is diachronous and occurred in two distinct provinces separated by the NFTZ:

Nova Scotia:
Breakup between 200 and 190 Ma (accretion of oceanic crust or mantle denudation) High sedimentation rate since Jurassic times in the northern Nova Scotia margin (average up to 100 m/My)

Grand Banks:
Breakup between 145 and 140 Ma (accretion of oceanic crust or mantle denudation) Poor magmatic margin Starving basin (average sedimentation rate lower than 25 m/My)

Magmatic Provinces: From the Gulf of Mexico to Nova Scotia, the North Atlantic continental margin is considered as a magma rich continental margin. The end of the rifting phase at the Triassic-Jurassic transition, is associated to large aerial volcanic lava flows (Central Atlantic Magmatic Province CAMP) inducing Early Jurassic shallow marine conditions. North of the Newfoundland-Azores transform NFTZ, the North Atlantic margin behaved like a magma poor passive margin (Whitmarsh et al.,2001).
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Passive Margin Evolution and plate reconstruction (from PFA 2011)

PLATE 3.6

The Newfoundland Transform Fault Zone acted as a left lateral strike-slip between Grand Banks and Morocco continental blocks during Early Jurassic times.
The Nova Scotia margin is a classical passive margin with progressively stretched continental crust and progressive transition to oceanic domain. Average sediment thickness is less than 5 km. The southern Grand Banks is characterized by an abrupt transition between continental crust and oceanic domain. Average sediment thickness is less than 5 km. The stretched crust was loaded by a more than 10 km thick sedimentary wedge.

The Newfoundland Transform Zone is a major crustal transform zone separating Grand Banks continental block from oceanic domain of the Scotian passive margin. In seismic profiles it appears as a 30 km wide zone of highly faulted basement. The vertical offset of the base of the sediments is approximately 7 km. Seismic images suggest fault zone was mainly active during Early Jurassic times. As shown by kinematic reconstructions the NFTZ was a left lateral strike-slip fault during the Jurassic drift of the future African plate with respect of the North American plate. It seems to be sealed by Cretaceous strata as shown by onlaps on the paleo-fault escarpment. Neogene deposits drape the paleo-escarpment and are not cut by any reactivation of the fault zone suggesting the fault zone is presently inactive (?) Distribution of autochthonous salt basins and discontinuity of the ECMA suggest possible secondary faults "offseting" continental blocks of the Scotian margin. Those secondary faults are minor replicas of the main NFTZ and acted also as early transforms faults. It seems there is no direct connection of the NFTZ with the Cobequid-Chedabucto fault.

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The "Avalon unconformity" results of a major tectonic uplift which occurred in the Grand Banks area at the Jurassic–Cretaceous boundary (between 145 and 140 Ma).

This event is characterized by a sharp angular unconformity (Figures 23 and 24) resulting from deformation and subsequent uplift and erosion.

**Deformation** mainly consists in:
- Normal faulting and block tilting caused by the rifting event associated to the Grand Banks-Iberia separation
- Salt tectonic: salt dome and collapse structures (Carboniferous Winsor salt + Triassic Argo salt diapirs) also probably related to the rifting event

**Uplift and erosion** is the result of combined phenomena:
- Domning before rifting between Iberia and Grand Banks (lithospheric thinning)
- Rift shoulder uplift: "free" light lithospheric promontory bounded by dense oceanic domains
- Volcanic activity (uprising of hot manteletic material)

This uplift and erosional event is responsible of the large influx of elastic material (sandstone) of Early Cretaceous age (Mississauga Fm.) in the Laurentian and Scotian basins.

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Figure 21: Approximate depth to basement map in km showing the Avalon uplift zone and the location of (A) Figure 23 and (B) Figure 24.

Figure 22: Stratigraphic diagram showing the effect of the Avalon erosional event in the South Whale sub-basin, Whale basin and Jeanne d’Arc basin. Jeanne d’Arc basin was poorly affected while, in the South Whale and Whale basins, erosion took place at the Jurassic and Cretaceous boundary. Locally, in "ridge" areas, the Avalon erosional event could have removed the whole Jurassic and Carboniferous series. Ridge areas (Bear ridge and Treworgie ridge) remained emerged zones till the end of Lower Cretaceous.

Figure 23: Grand Banks NW-SE seismic section (see location in Figure 21) showing the Avalon angular unconformity. Carboniferous and Trias-Jurassic tilted strata (Salt tectonics + tilted faulted block) have been deeply eroded.

Figure 24: Grand Banks NW-SE seismic section (see location in Figure 21) showing the Avalon angular unconformity.


Sibuet, J. C., Rouzo, S., & Srivastava, S. (2012), Plate tectonic reconstructions and paleogeographic maps of the central and North Atlantic oceans 1, 2 1 This article is one of a series of papers published in this CIES Special Issue on the theme of Mesozoic–Cenozoic geology of the Scotian Basin. 2 Earth Sciences Sector Contribution 20120172. Canadian Journal of Earth Sciences, 49(12), 1395-1415.


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