CHAPTER 4

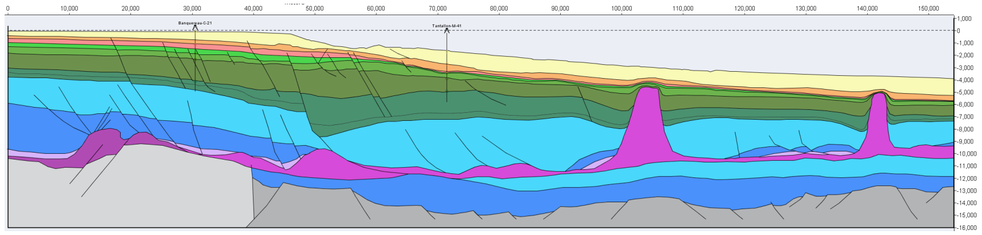
STRUCTURAL RESTORATION

STRUCTURAL RESTORATION

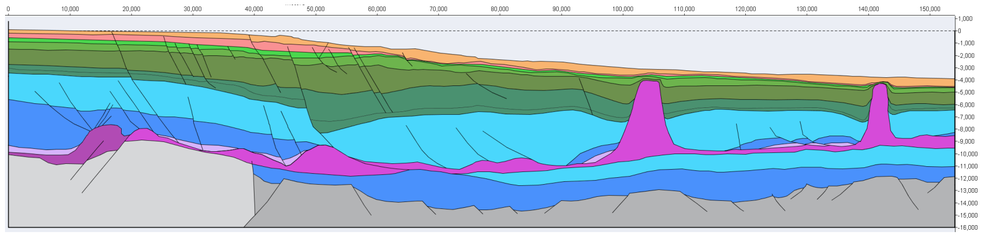
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

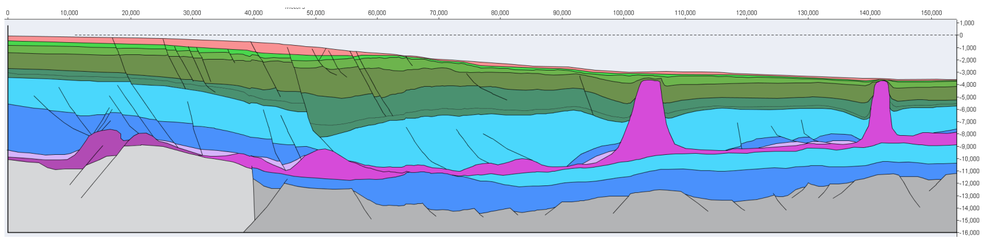
NW SE



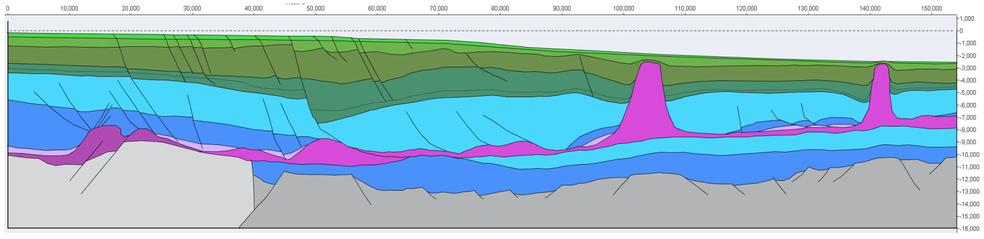
~4516 km



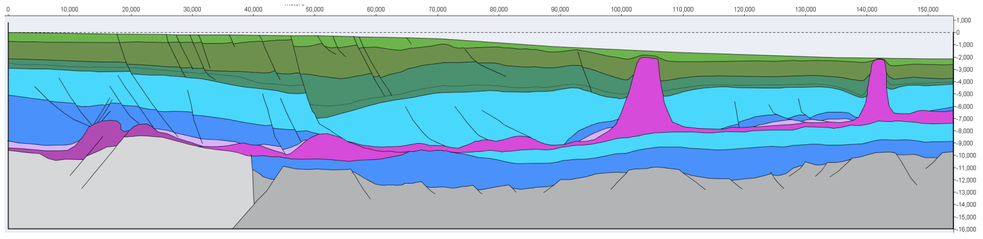
~3958 km



~3310 km



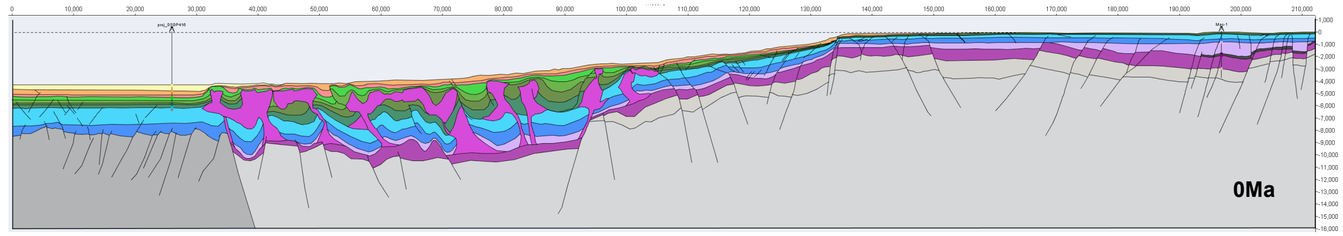
~2942 km

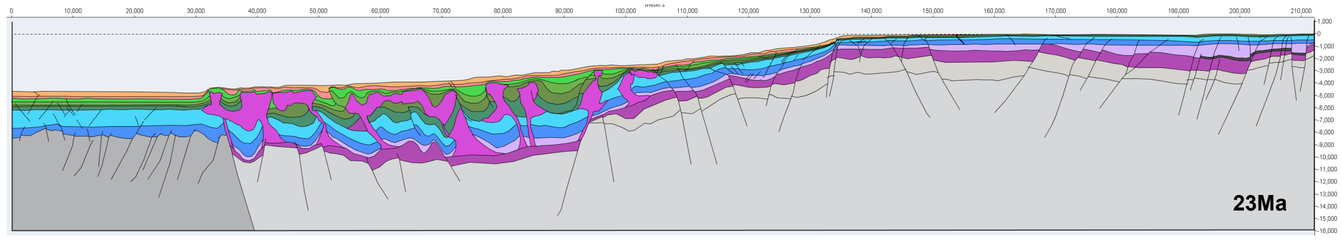


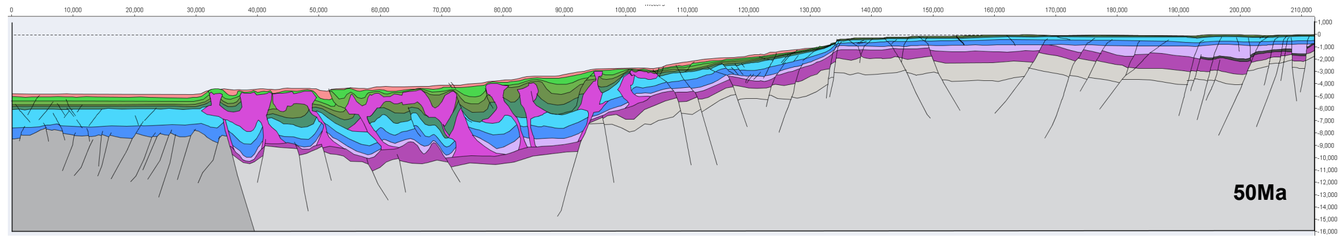
~2298 km

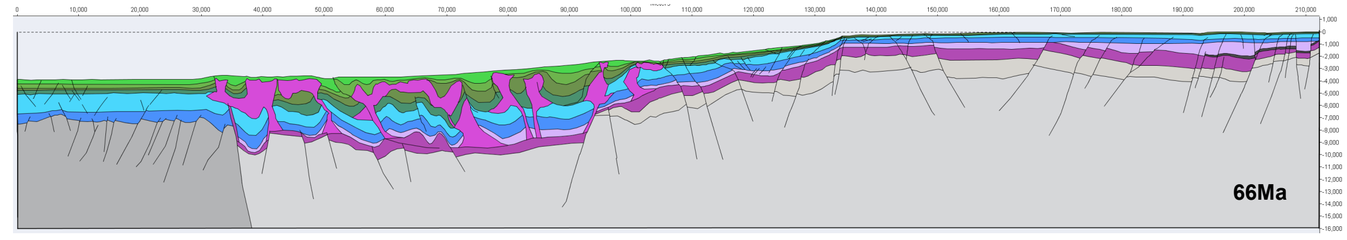
NORTHERN MOROCCO

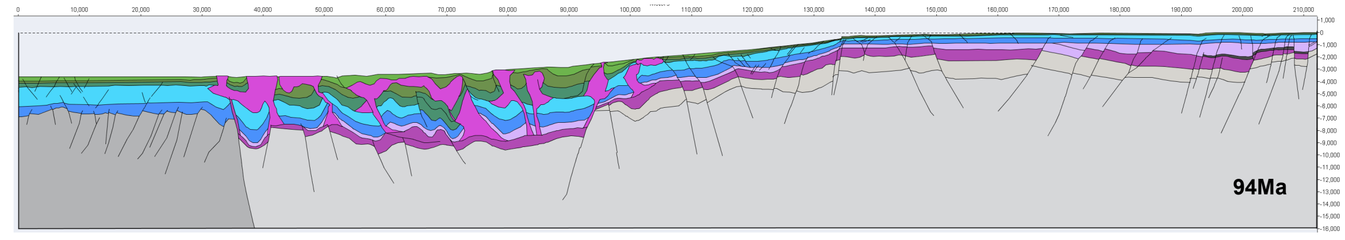
NW SE











Displayed distances are between “COB”

Vert. Ex. *2

50 km

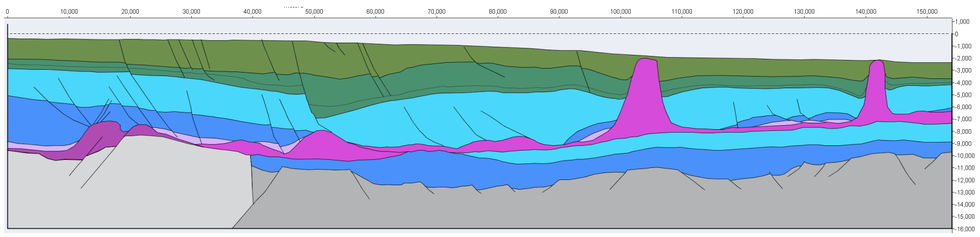
Sequential restoration of the T1 conjugate transect **PL. 4.1.A**

STRUCTURAL RESTORATION

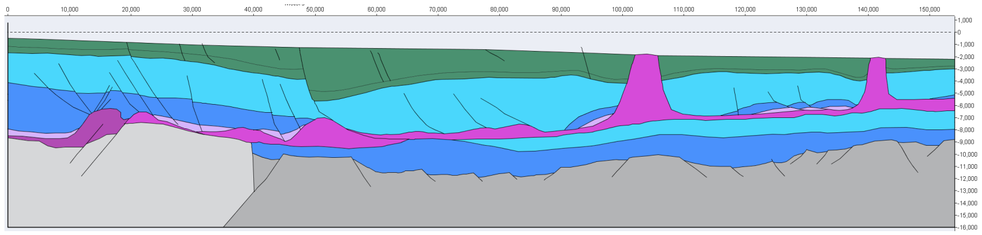
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

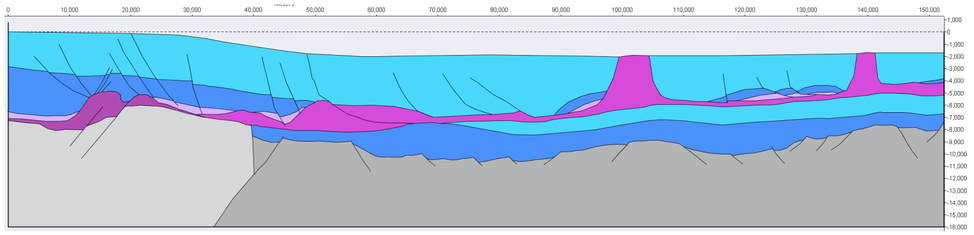
NW SE



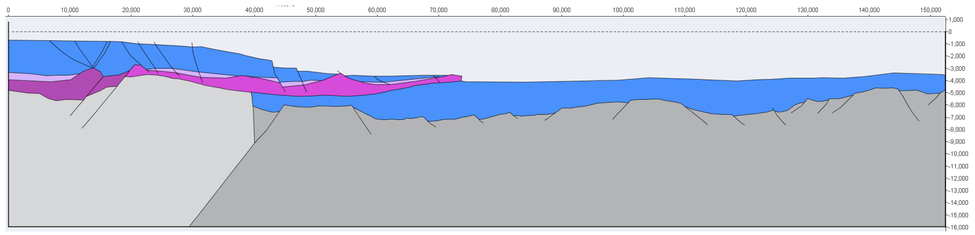
~2137 km



~1470 km



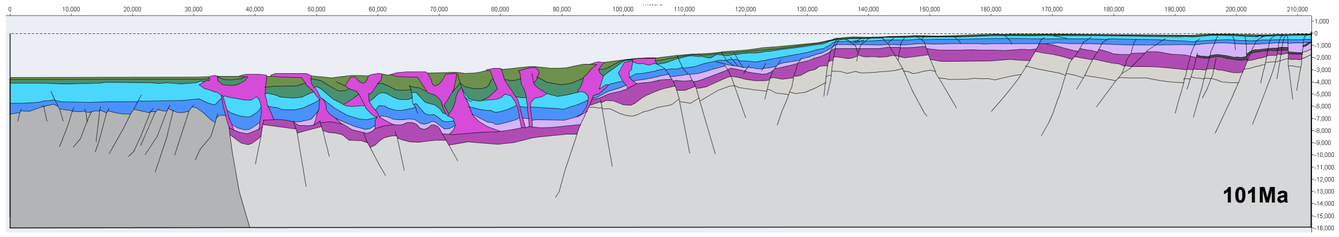
~1080 km

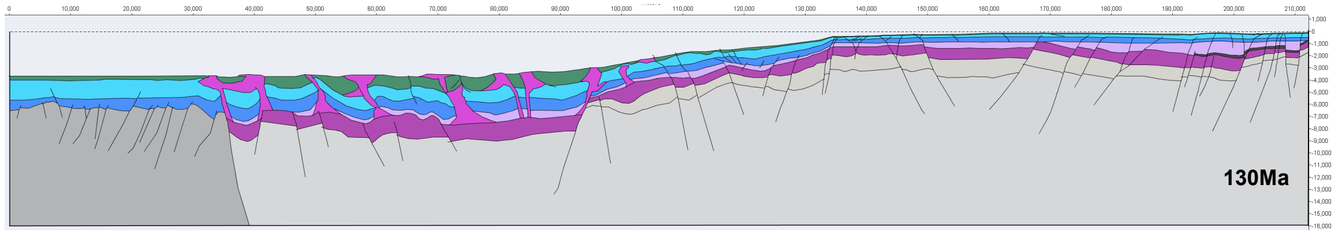


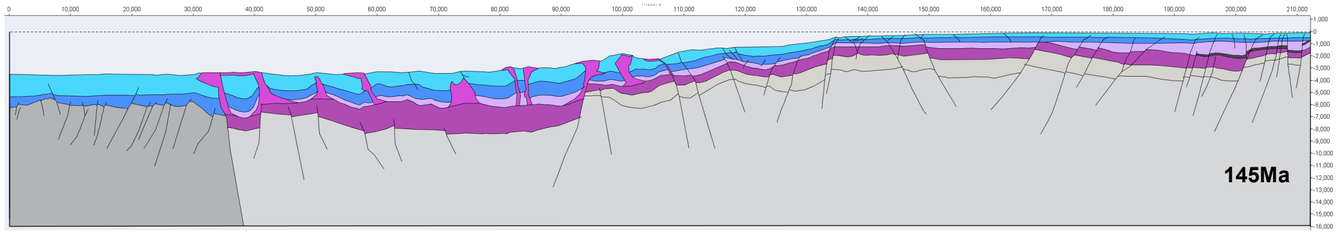
~320 km

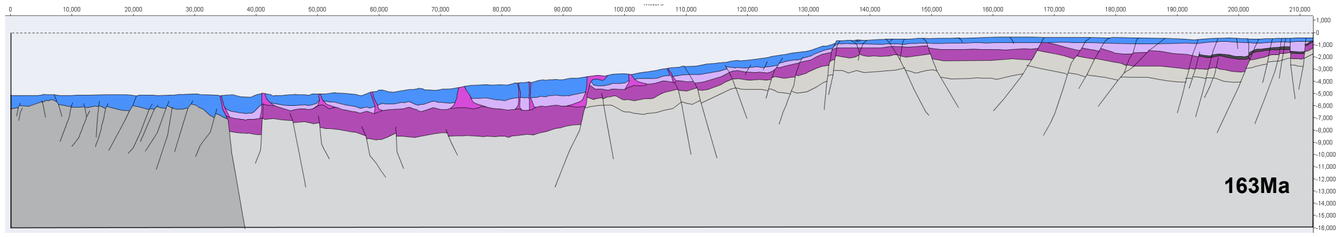
NORTHERN MOROCCO

NW SE









NOVA SCOTIA

Thickest deposits (up to 10 km) due to Laurentian River supply from Jurassic to Present

Banquereau syn-kinematic wedge (BSW) starting from Early Jurassic on top of allochthonous Triassic salt (expelled from Huron Sub-basin, out of the section)

Raft of Early Jurassic with potential source rocks

MOROCCO

Thinner deposits (max 6 km)

Very thin Cretaceous and Tertiary sediment thickness on the shelf and slope domains (thicker within the salt basin)

Effect of Atlassic orogeny (uplift of the Morocco margin). Local compressional structures (reverse faults)

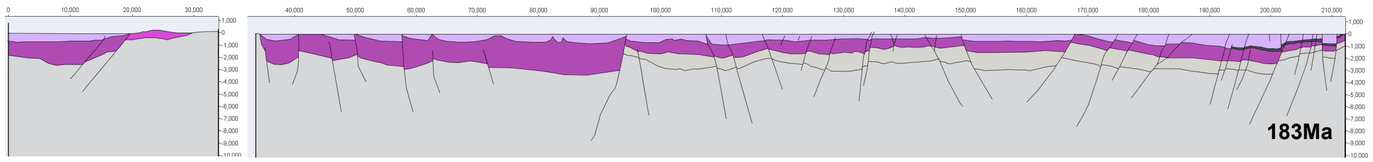
Complex allochthonous salt structures (salt tongues, canopies…)

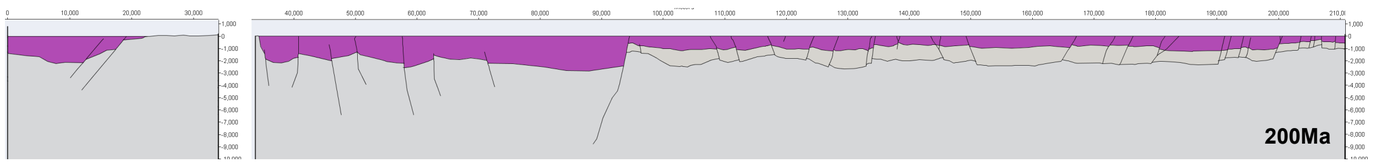
More than 100 km wide salt basin

BOTH MARGINS

Salt movements cease by the Upper Cretaceous

Late Jurassic gravitational toe-thrusts





Age (Ma)
0
T23
T50
K66 (BTU)
K94
K101
K130
J145
J163
J183 (BKU)
Allochthonous Salt
Autochthonous Salt
Oceanic crust
Trias (?)
Basement

Displayed distances are between "COB"

Vert. Ex. *2

50 km

PL. 4.1.B

Sequential restoration of the T1 conjugate transect

STRUCTURAL RESTORATION

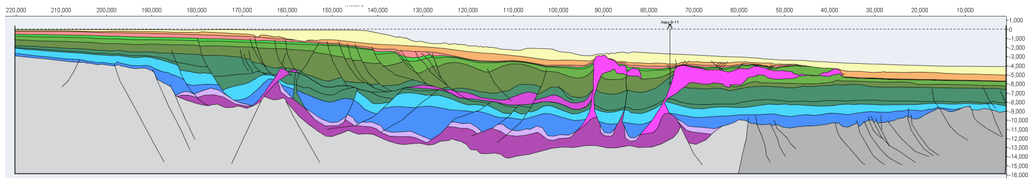
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

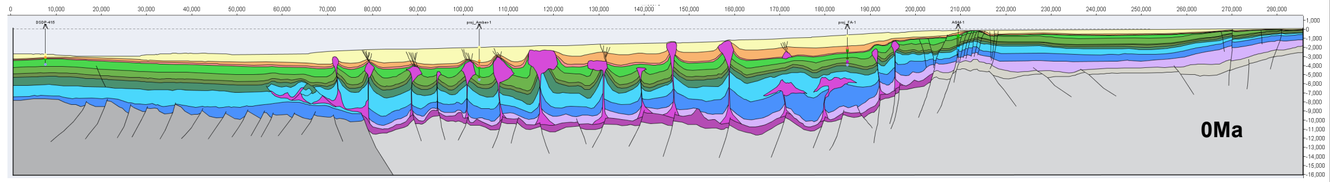
NW SE

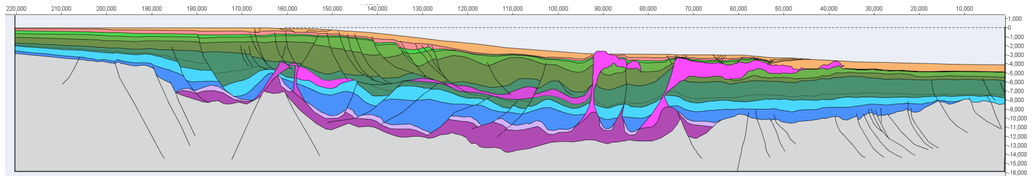
NORTHERN MOROCCO

NW SE

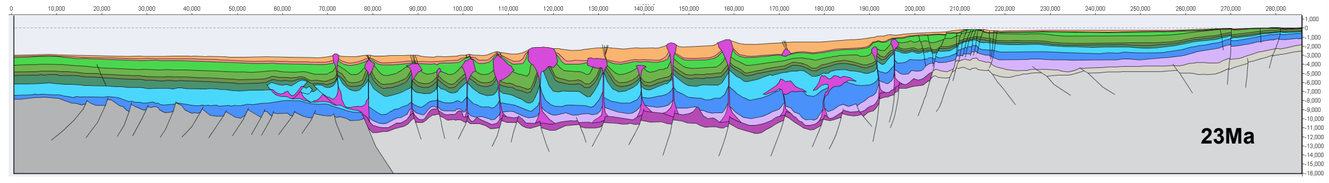


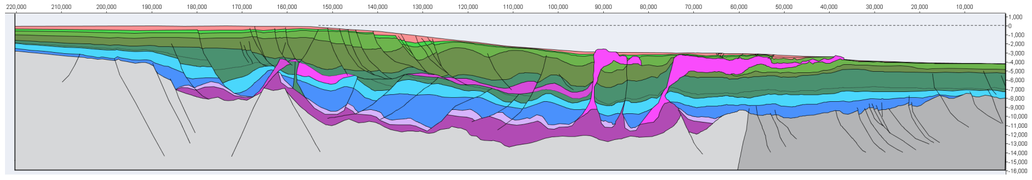
~4516 km



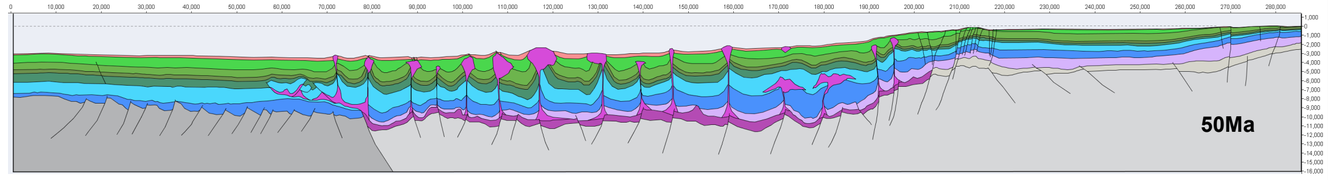


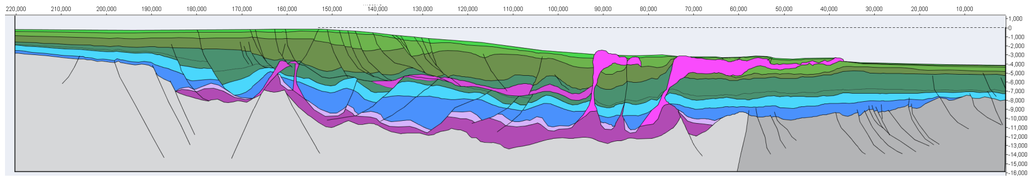
~3958 km



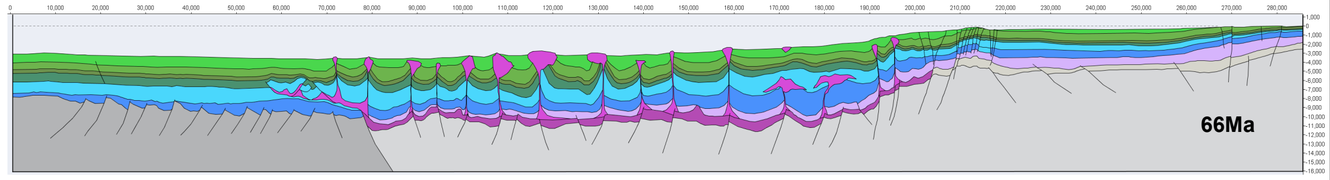


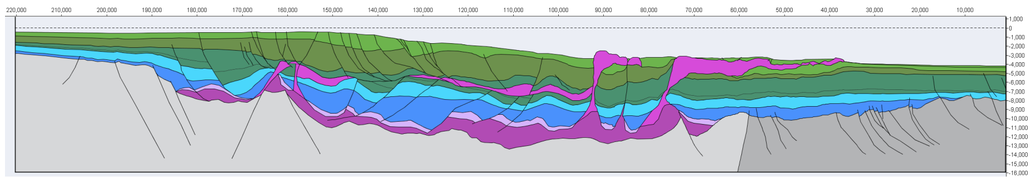
~3310 km



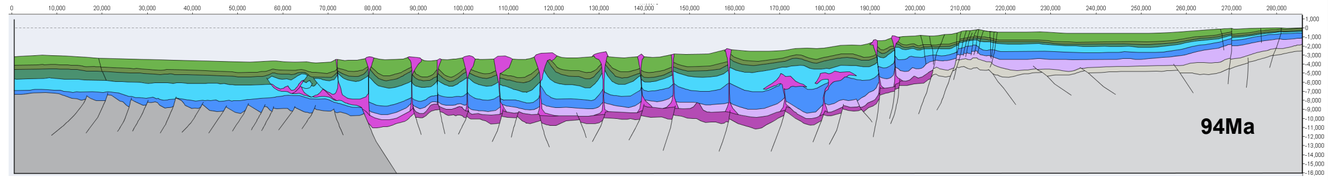


~2942 km





~2298 km



Displayed distances are between "COB"

Vertical exaggeration ***x2***

50 km

Sequential restoration of the T2 conjugate transect

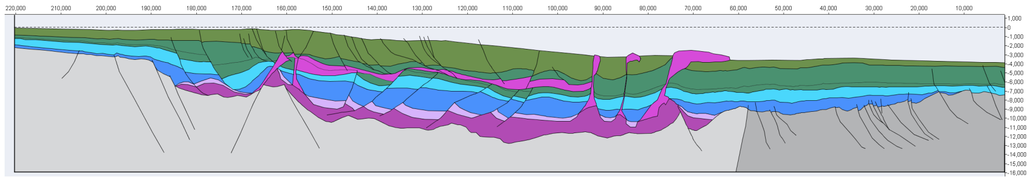
PL. 4.2.A

STRUCTURAL RESTORATION

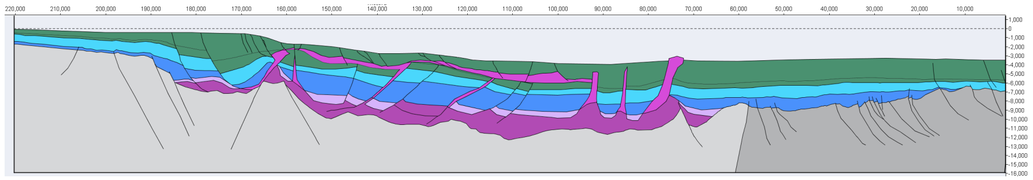
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

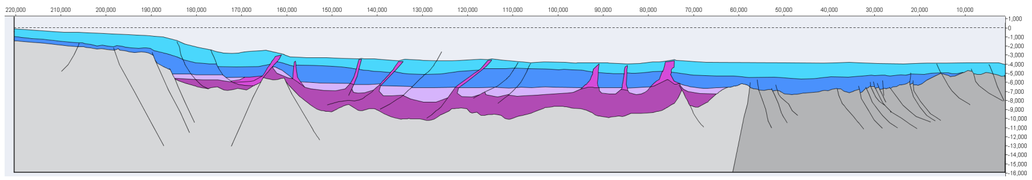
NW SE



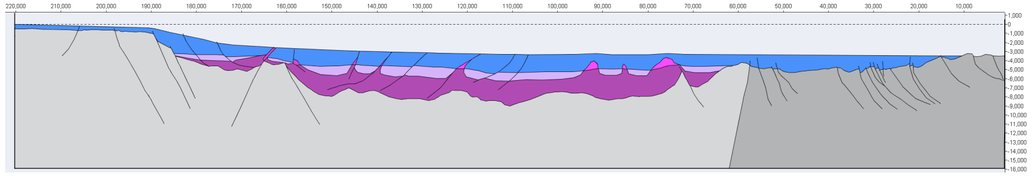
~2137 km



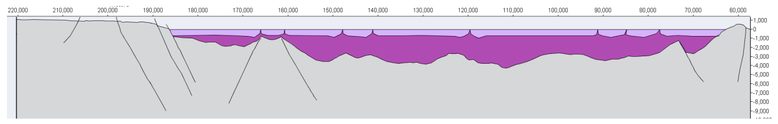
~1470 km

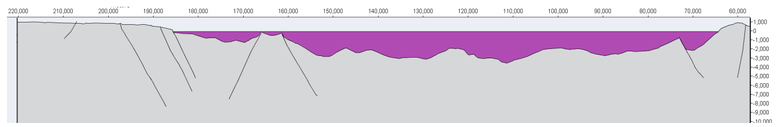


~1080 km



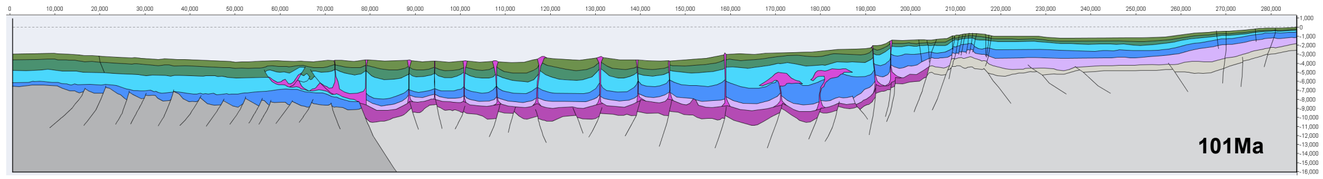
~320 km

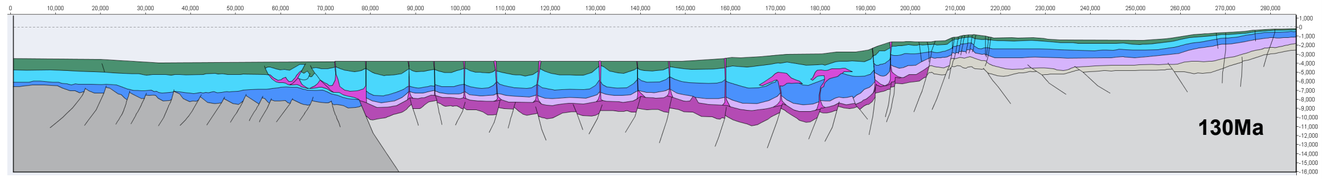


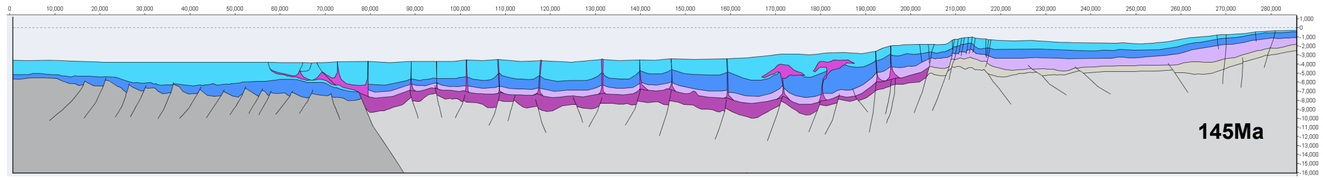


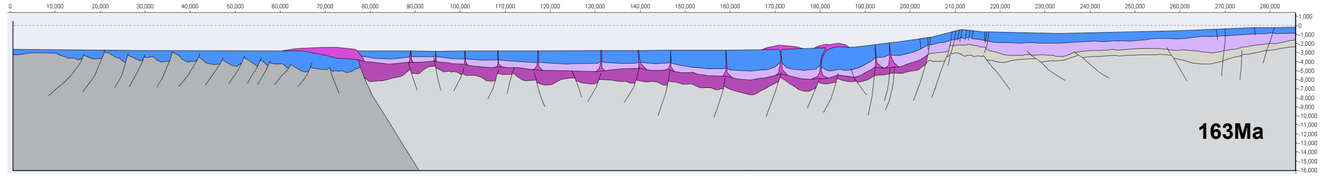
NORTHERN MOROCCO

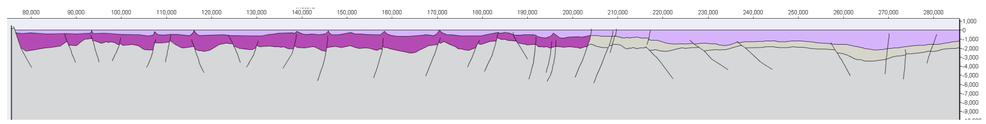
NW SE

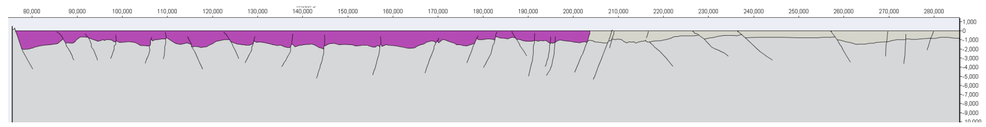












Age (Ma)
- 0
- T23
- T50
- K66 (BTU)
- K94
- K101
- K130
- J145
- J163
- J183 (BKU)
- Allochthonous Salt
- Autochthonous Salt
- Oceanic crust
- Trias (?)
- Basement

NOVA SCOTIA
Thicker Lower Cretaceous series
"Roho system" starting during the Lower Cretaceous. Gravitational faulting of Jurassic and Cretaceous series
Approximately 110 km wide salt basin

MOROCCO
Middle Jurassic frontal salt tongue and slope salt movements
Very clear Base Tertiary unconformity (BTU)
Vertical diapirs since Early Jurassic creating isolated mini-basins (poorly faulted)
Approximately 120 km wide salt basin

*Vertical exaggeration **x2***

50 km

Displayed distances are between "COB"

BOTH MARGINS
Comparable evolution of the two margins during the Jurassic
Lower sedimentary rate in the deep-water domain allows for large frontal canopy (NS) or bubble-shape diapirs (MOR) that develop around 100 Ma
Minor salt movements during Tertiary time

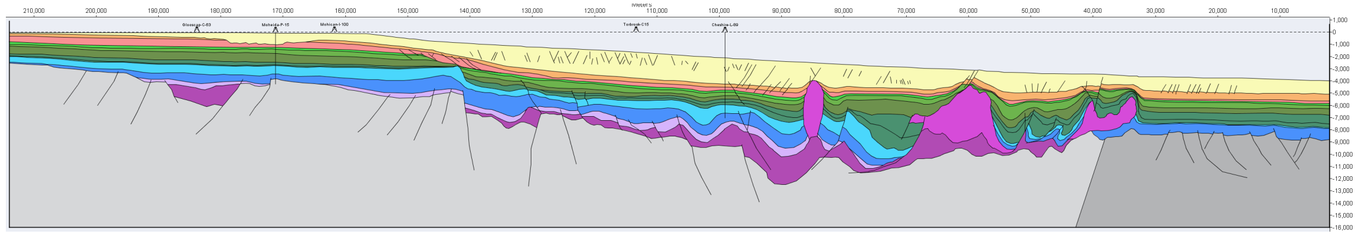
PL. 4.2.B **Sequential restoration of the T2 conjugate transect**

STRUCTURAL RESTORATION

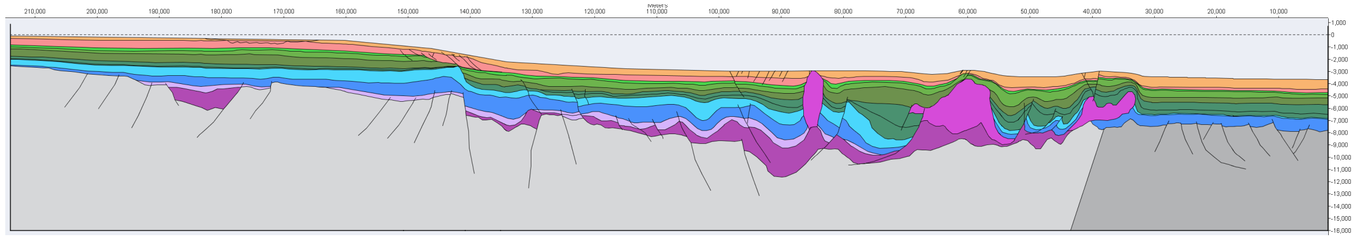
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

NW SE



~4516 km



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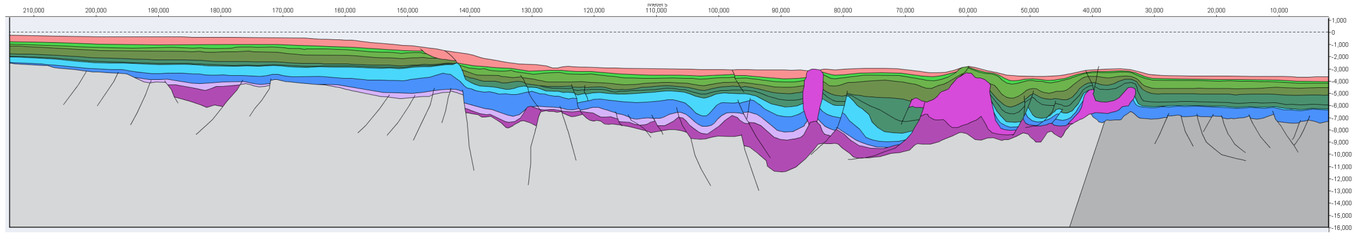
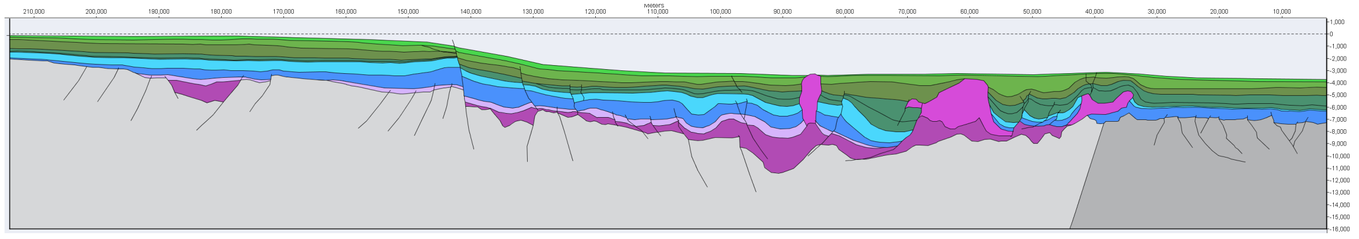
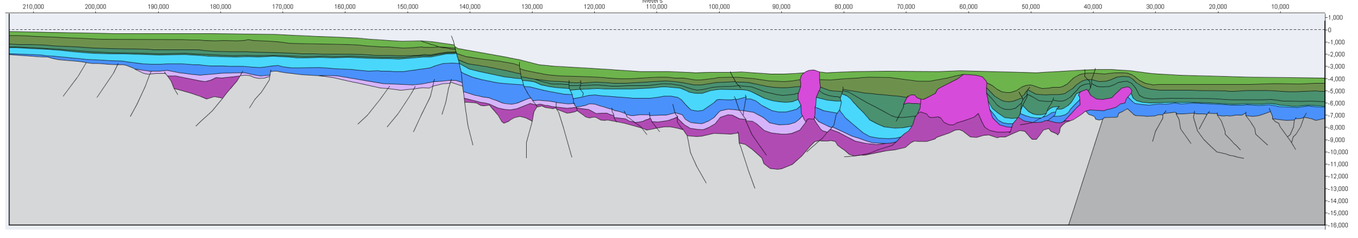


~3310 km



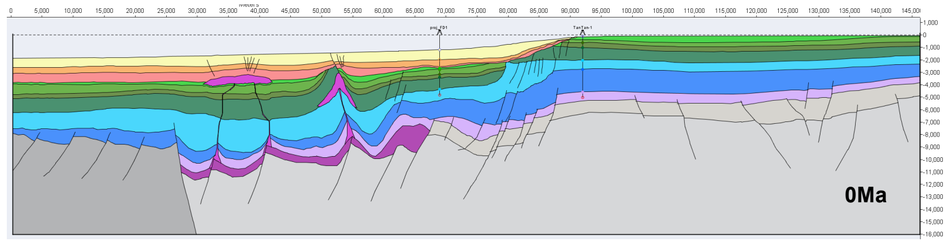
~2942 km

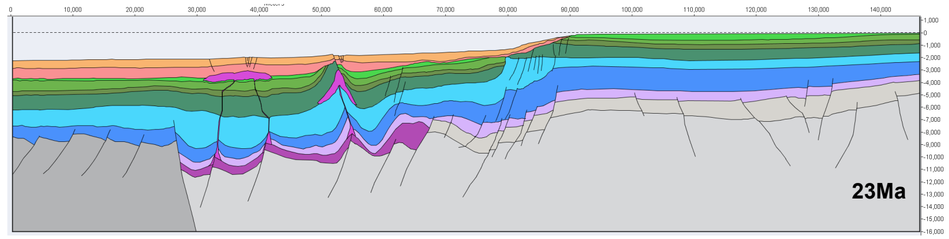


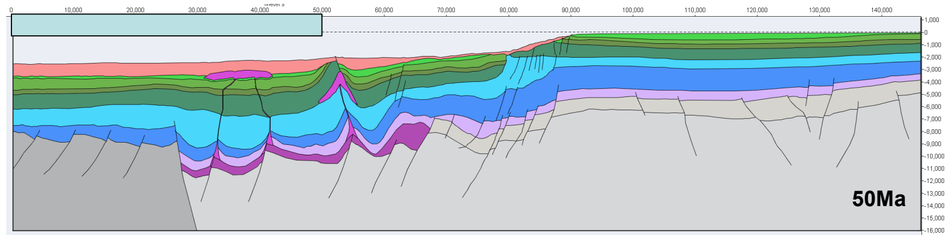
~2298 km

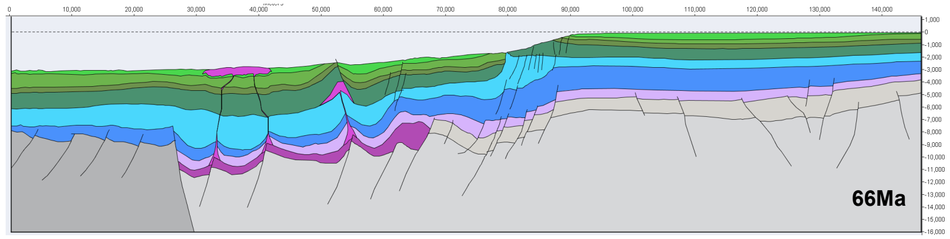
NORTHERN MOROCCO

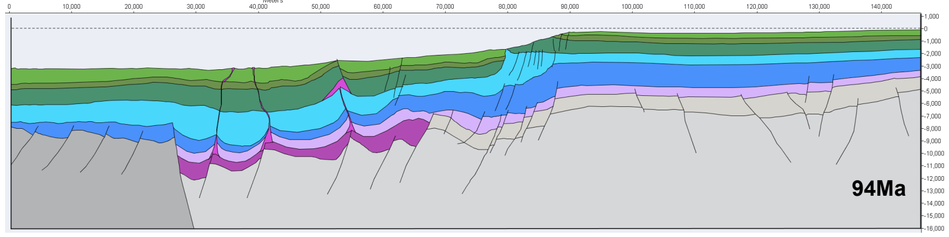
NW SE











Displayed distances are between “COB”

*Vertical exaggeration **x2***

50 km

Sequential restoration of the T3 conjugate transect

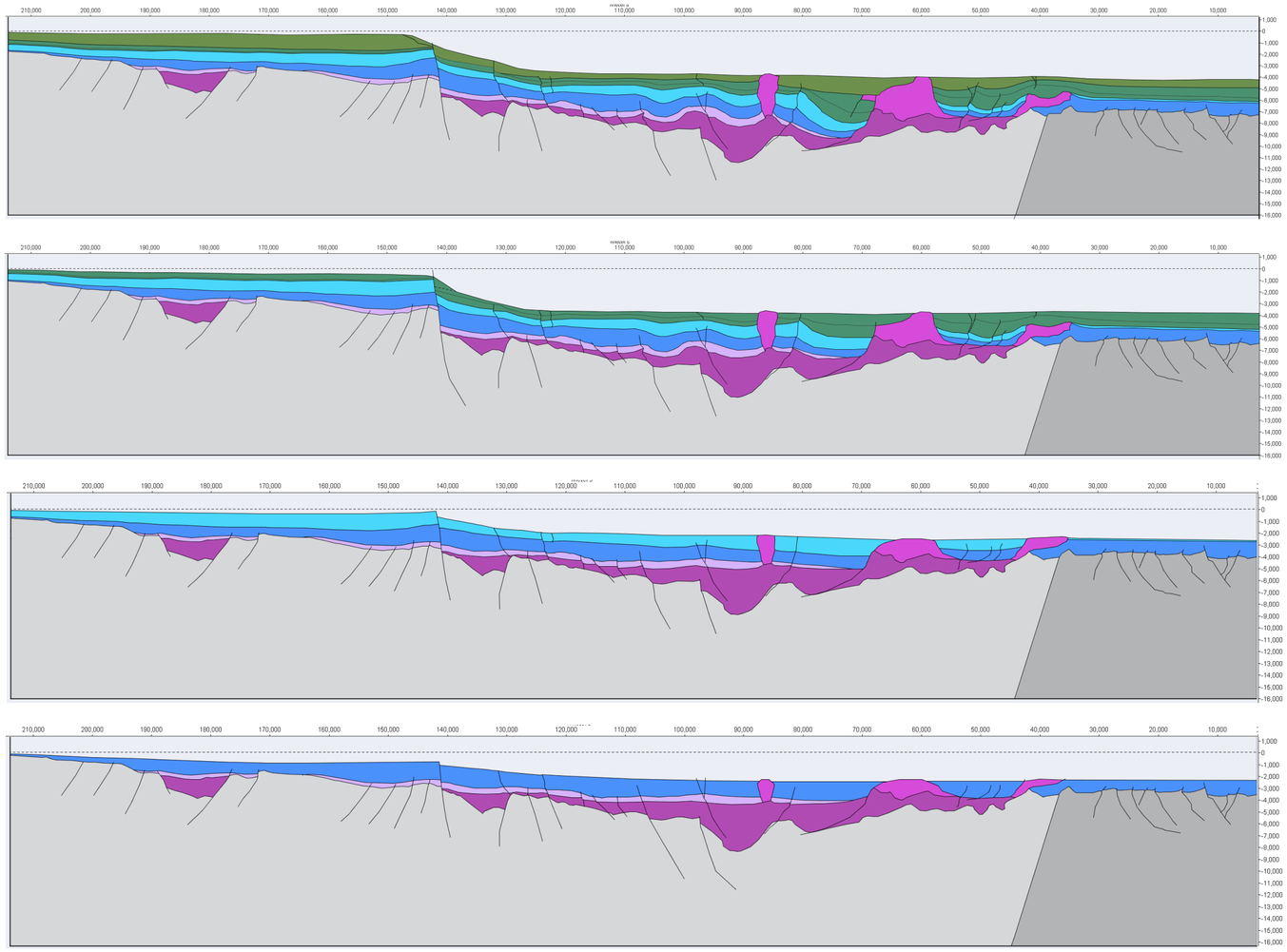
PL. 4.3.A

STRUCTURAL RESTORATION

Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NW — NOVA SCOTIA — SE

NW — NORTHERN MOROCCO — SE



Age (Ma)
0
T23
T50
K66 (BTU)
K94
K101
K130
J145
J163
J183 (BKU)
Allochthonous Salt
Autochthonous Salt
Oceanic crust
Trias (?)
Basement

NOVA SCOTIA

Starved margin during Jurassic and Cretaceous times. Higher sedimentation rates during Tertiary

Early Jurassic frontal salt tongue and mini-basin development

Approximately 100 km wide salt basin

MOROCCO

Greater thickness of Jurassic and Cretaceous series

Very clear base Tertiary unconformity (BTU)

Local salt movements: limited feeding due to reduced salt stock

Approximately 50 km wide salt basin

BOTH MARGINS

Upper Jurassic carbonate platforms

Mostly vertical diapirism stopping end of Cretaceous (probably different causes)

*Vertical exaggeration **x2***

50 km

PL. 4.3.B

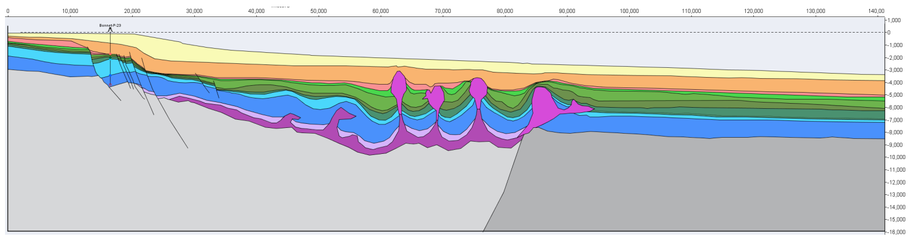
Sequential restoration of the T3 conjugate transect

STRUCTURAL RESTORATION

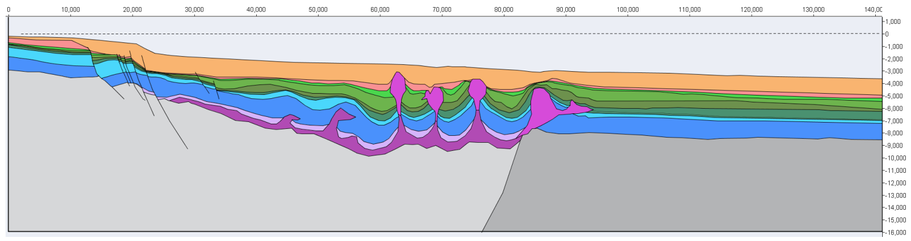
Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

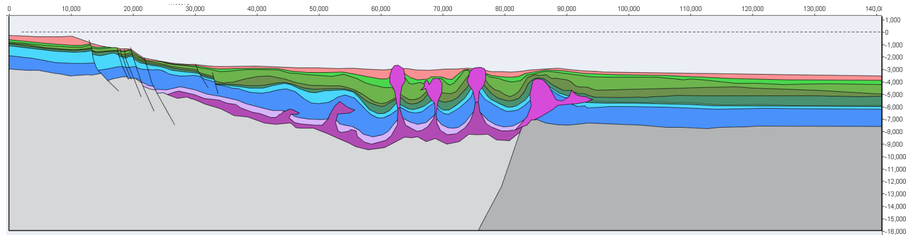
NW SE



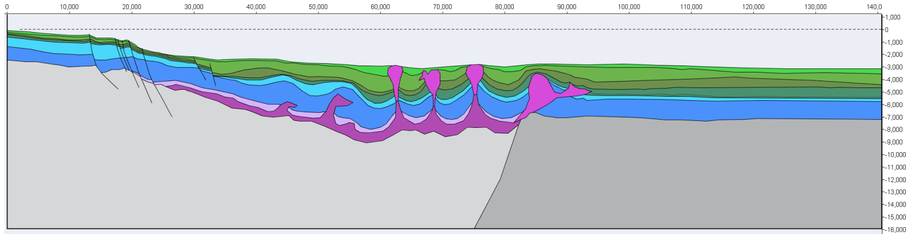
~4516 km



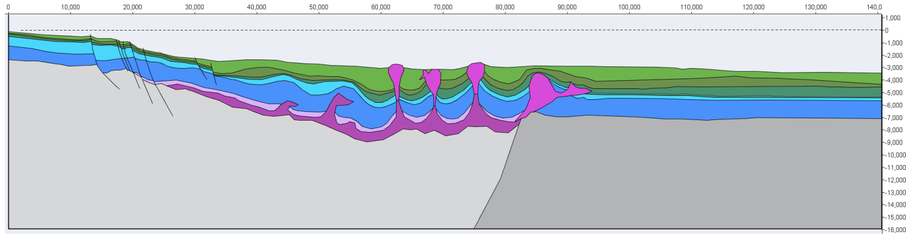
~3958 km



~3310 km



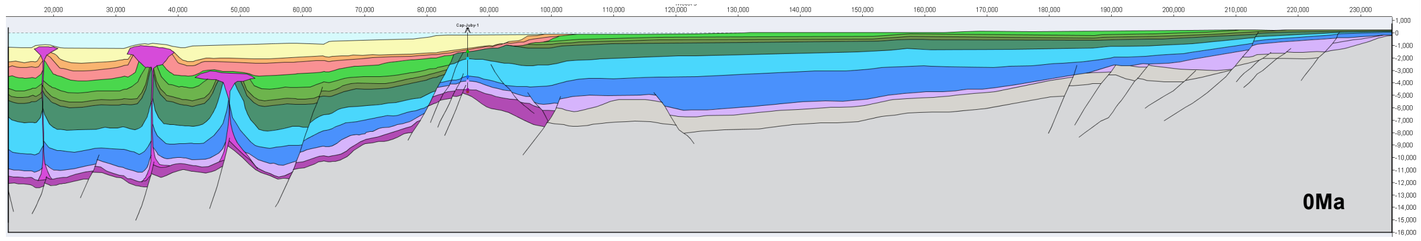
~2942 km

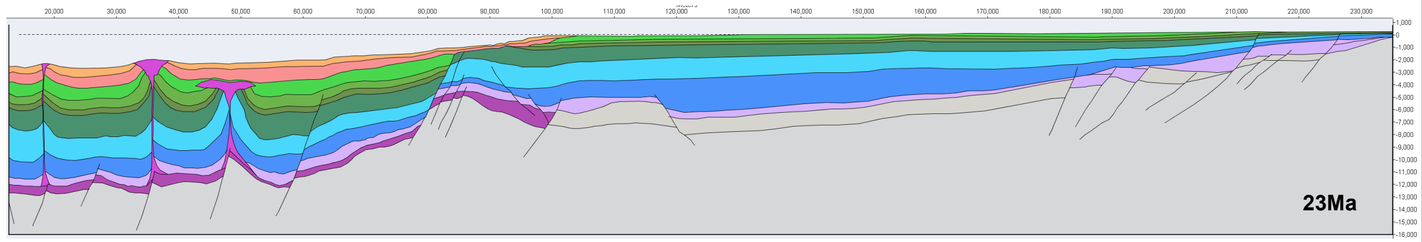


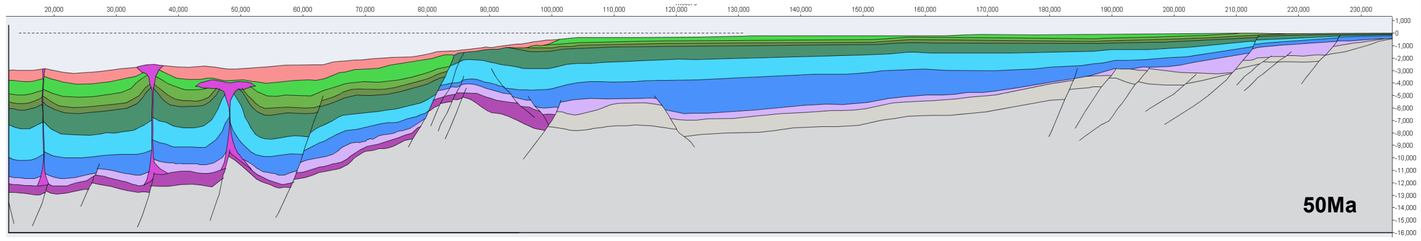
~2298 km

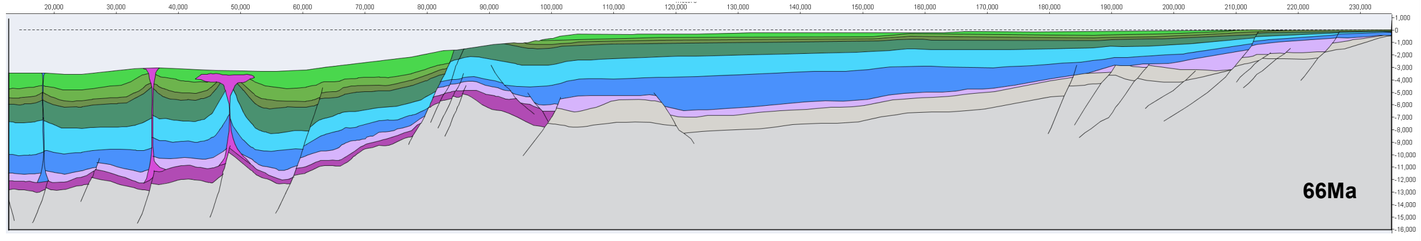
NORTHERN MOROCCO

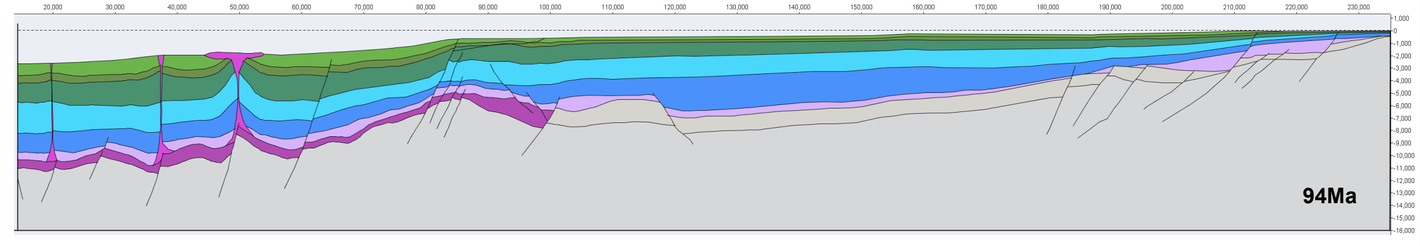
NW SE











Displayed distances are between “COB”

*Vertical exaggeration **x2***

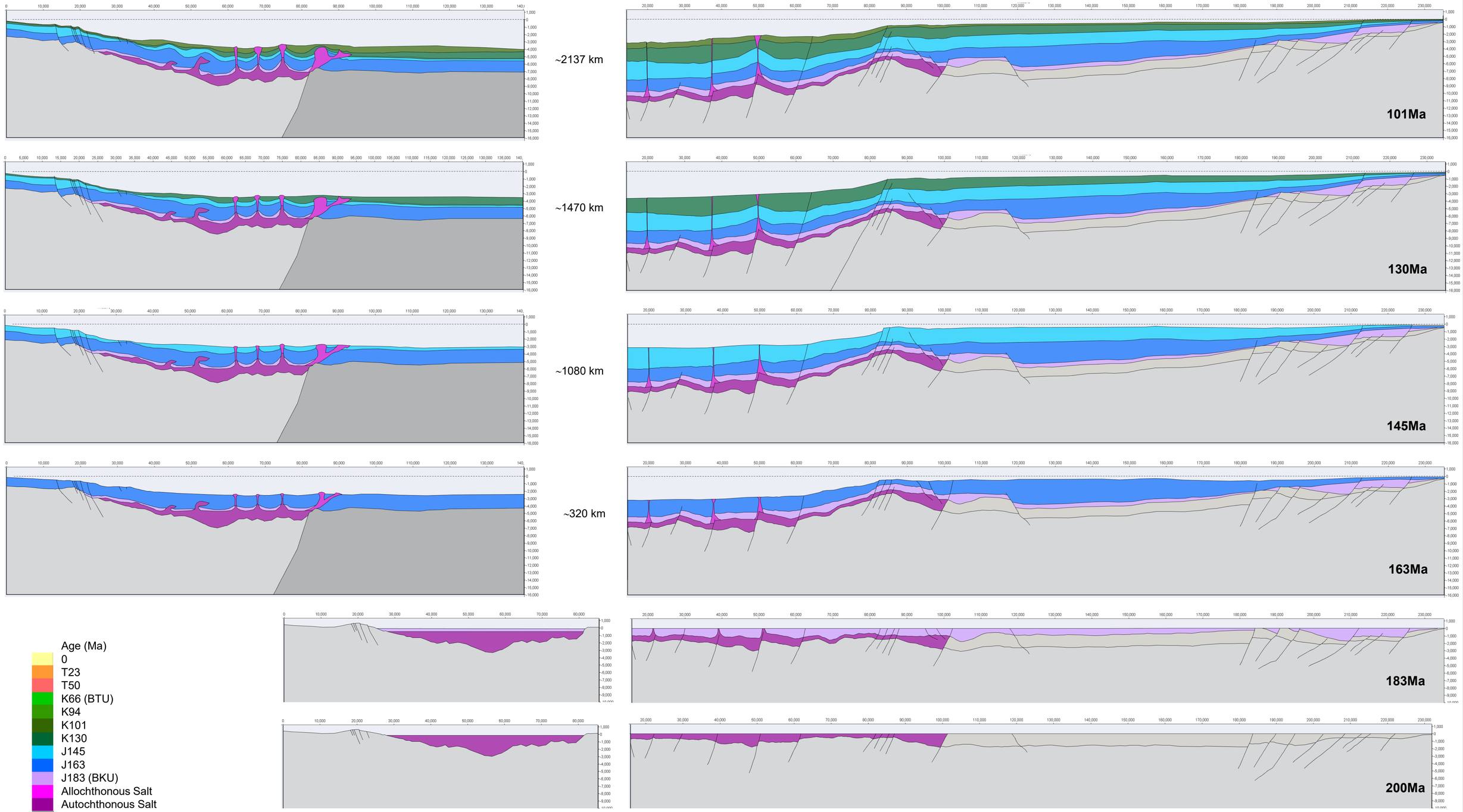
50 km

Sequential restoration of the T4 conjugate transect

PL. 4.4.A

STRUCTURAL RESTORATION

Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019



NOVA SCOTIA
Starved margin during the Jurassic and Cretaceous
Higher sedimentation rates during the Tertiary
Early Jurassic frontal salt tongue and mini-basin development
Approximately 60 km wide salt basin

MOROCCO
Comparatively greater thicknesses of Jurassic and Cretaceous sediments
Very clear base Tertiary unconformity (BTU): strong erosion of the shelf break. The fault bordering the shelf to the west (Cap Juby structural high) is active during Late K times
Canary Island volcanism starting from Paleocene-Eocene time
Approximately 80 km wide salt basin

BOTH MARGINS
Upper Jurassic carbonate platforms
Mostly vertical diapirism
Lower sedimentation rate allows for salt bubble-shape diapirs during end of Cretaceous – Early Tertiary times

*Vertical exaggeration **x2***

50 km

PL. 4.4.B

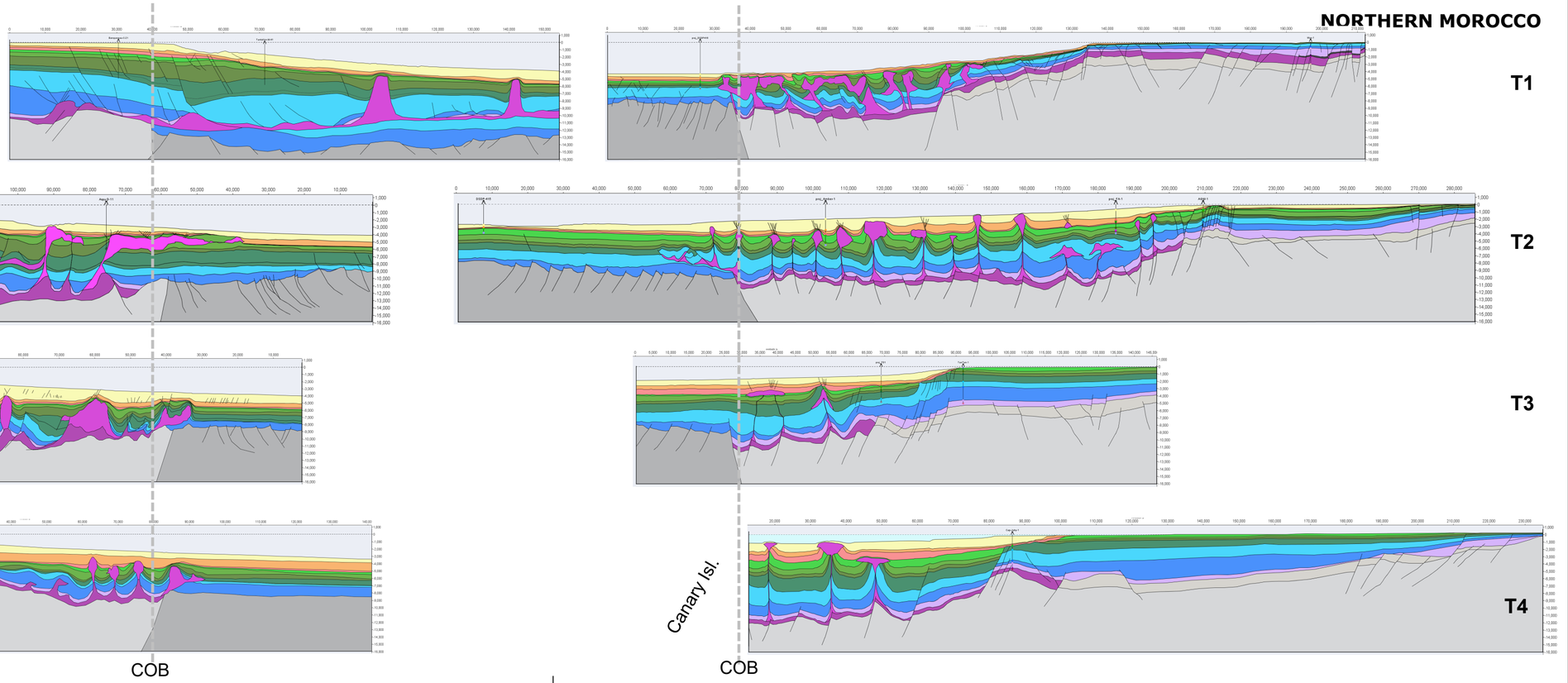
Sequential restoration of the T4 conjugate transect

STRUCTURAL RESTORATION

Seismic Reconstruction, Thermal and Maturity Modeling of the Nova Scotia – Morocco Conjugate Margins - 2019

NOVA SCOTIA

NORTHERN MOROCCO



Nova Scotia margin

Following the sub-division proposed by Shimeld, 2004; Albertz et al., 2010; and PFA, 2011 the four cross-sections restored in the present study are located in various sub-provinces and show examples of the different structural styles and salt geometries characterizing the slope domain of the Nova Scotia margin.

Transect 1 is located in the Banquerau Syn-kinematic Wedge province described in detail by Ings and Shimeld, 2006. It is characterized by a major gravity gliding allochthonous wedge active mainly during the Jurassic to Early Cretaceous. This wedge is detached on top of a large early-created salt tongue. Late vertical diapirs define the southwest boundaries of this major wedge.

Transect 2 goes through the Canopy province described in detail by Deptuck et al; 2009; Deptuck, 2010; Deptuck et al., 2015. It is characterized by large allochthonous salt tongues (canopies) fed by one or several deep salt stems that may be of allochthonous or autochthonous origin. These canopies can be completely disconnected from their feeding zone, the stems corresponding to steeply dipping weld zones.

Transect 3 lies between the Canopy and Diapir provinces (PFA, 2011). Transect 4 is located in the Diapir province characterized by mainly vertically raised diapirs on top of the autochthonous salt basin with local salt tongues of relatively reduced extent (compared to structures in the Canopy province) at the southwestern limit of the salt basin (Deptuck et al. 2010).

General observations

There is a significant variation of sediment thicknesses from the NE to the SW (i.e. from the T1 to the T4). This variation is not the same in the two margins: overall sediment thickness increases from the NE to the SW on the Morocco side whereas it decreases on the Nova Scotia side. This difference should be related to different geological causes, for example the strong sediment supply from the Laurentian River at the north of the Nova Scotia margin, and the presence of the Canary Island Arc capturing sediments starting in the Early Paleogene in the south of the Morocco margin.

Different structural style and salt geometries are noted in the two margins (for example the presence of the Banquereau Syn-kinematic Wedge and the “roho” system in the Canadian margin), which are likely to be mainly related to the initial salt thickness and the sediment supply through time.

In both margins, the salt basin termination to the south has been sampled at level of Transect 4 as described in literature. Both margins are characterized in their conjugate southern parts (Transects 3 and 4) by the presence of Upper Jurassic carbonate platforms.

Northern Morocco margin

Based on the Morocco salt basin sub-division proposed by Tari et al., 2003; Tari and Molnar, 2005; Tari and Jabour, 2013, the four cross-sections restored in the present study are located in various sub-provinces and show examples of the different structural styles and salt geometries characterizing the slope domain of the northern Morocco margin.

Transect 1 is located in the Safi Sub-basin (Essaouira Basin). It shows the characteristic halokinetic elements of a passive margin such as extensional salt structures beneath the shelf and the upper slope, and compressional features downdip on the lower slope (Tari and Jabour, 2013).

Transect 2 is located in the Agadir Basin characterized by simple, mostly vertical diapirism driven dominantly by the load of supra-salt, mostly Cenozoic age sediments (Tari et al. 2003). Gravity-driven compressional features, such as toe-thrust, are present at the western boundary of the salt basin.

Transect 3 and Transect 4 are located in the Tarfaya Basin and Cap Juby area, respectively, where there are only a few salt pillows and diapiric salt walls outboard of the prominent Jurassic shelf margin (Hafid et al., 2008). The Cap Juby area is bounded to the west by Canary Island volcanism starting in the Paleocene-Eocene.

Implications for petroleum systems

Relative distribution of the gas and oil provinces related to burial over time should not be comparable between the two margins and even reversed in a N-S direction, as the sediment thicknesses show significant variations.

The Early Jurassic series deposition (including a possible Early Jurassic source rock) is related to mini-basin development controlled by early salt movements. Therefore mini-basin evolution can locally control the distribution and characteristics of the Liassic source rocks.

Clastic reservoir presence and distribution can be related to sediment supply and therefore are reversed in the Nova Scotia and northern Morocco margins.

On the other hand, potential Jurassic carbonate reservoirs appear to be similar in the southern part of both margins (T3-T4 areas).