geoconvention
Calgary • Canada • June 20-22 2022

Structural analysis and numerical tectonic modeling of the Scotia Basin

Eren, D, Berberoglu, Elena Konstantinovskaya, Nicholas B. Harris, Lucia, I, Vivanco
University of Alberta, Faculty of Science, Department of Earth and Atmospheric Sciences

Summary

The Nova Scotia passive continental margin is characterized by longitudinal variation in crustal structure and amount of extension from the volcanic U.S. Atlantic Margin in the southwest to a non-volcanic Newfoundland Margin in the northeast. The thickness of Mesozoic sedimentary cover reaches up to 19 km along the central and northeastern segments of the Nova Scotia passive margin that experienced higher degree of crustal thinning, compared to the southwestern segment of the margin, where the thickness of the Mesozoic sedimentary cover is up to 10-12 km (Dehler, 2012). Tectonic and eustatic effects, compaction, and sediment loading are recognized as principal components contributing in the subsidence within the Scotia Basin (Watts and Steckler, 1979). This study aims to describe tectonic structure of the Scotia Basin and carry out structural reconstructions to quantify sediment loading and tectonic extension during the Atlantic opening, assess the impact of salt kinematics and evaluate onshore uplift and erosion and offshore subsidence across the Nova Scotia passive margin.

Method and Workflow

Methods applied in this study include interpretation of 10 000 km of 2D seismic lines and 87 km² of 3D seismic cube (Figure 1) acquired and processed during forty years of exploration history, integration with published topographic, gravity and aeromagnetic surveys, application of published apatite fission track data, and modeling of tectonic and isostatic uplift and subsidence. The well-to-seismic tie was performed using a total of 86 wells with checkshot or velocity surveys, well logs, well tops, well reports spreading over both the Scotia shelf and slope. The published plate kinematic models are applied to reconstruct principal phases of tectonic evolution of the margin, while the published Apatite Fission Track (AFT) datasets and GPS data are analyzed to determine the amount of crustal uplift and subsidence rates. The amount of extension and decompaction is quantified by carrying out 2D structural reconstruction. Iterative analyses of lithospheric flexure are conducted taking into account isostatic effects of lithospheric bulging, sediment loading and tectonic extension.

The main steps in conducting this research project include: (1) preparing time and depth structural maps of each seismic markers, (2) identifying major structural elements of the basin and constructing balanced sections and structural reconstructions, (3) estimating of uplift and subsidence across the margin, (4) contributing into tectonic history of the study area, by analyzing phases of sedimentary loading, subsidence and isostatic uplift on the Nova Scotia margin with a comparison to the conjugate Moroccan continental margin.

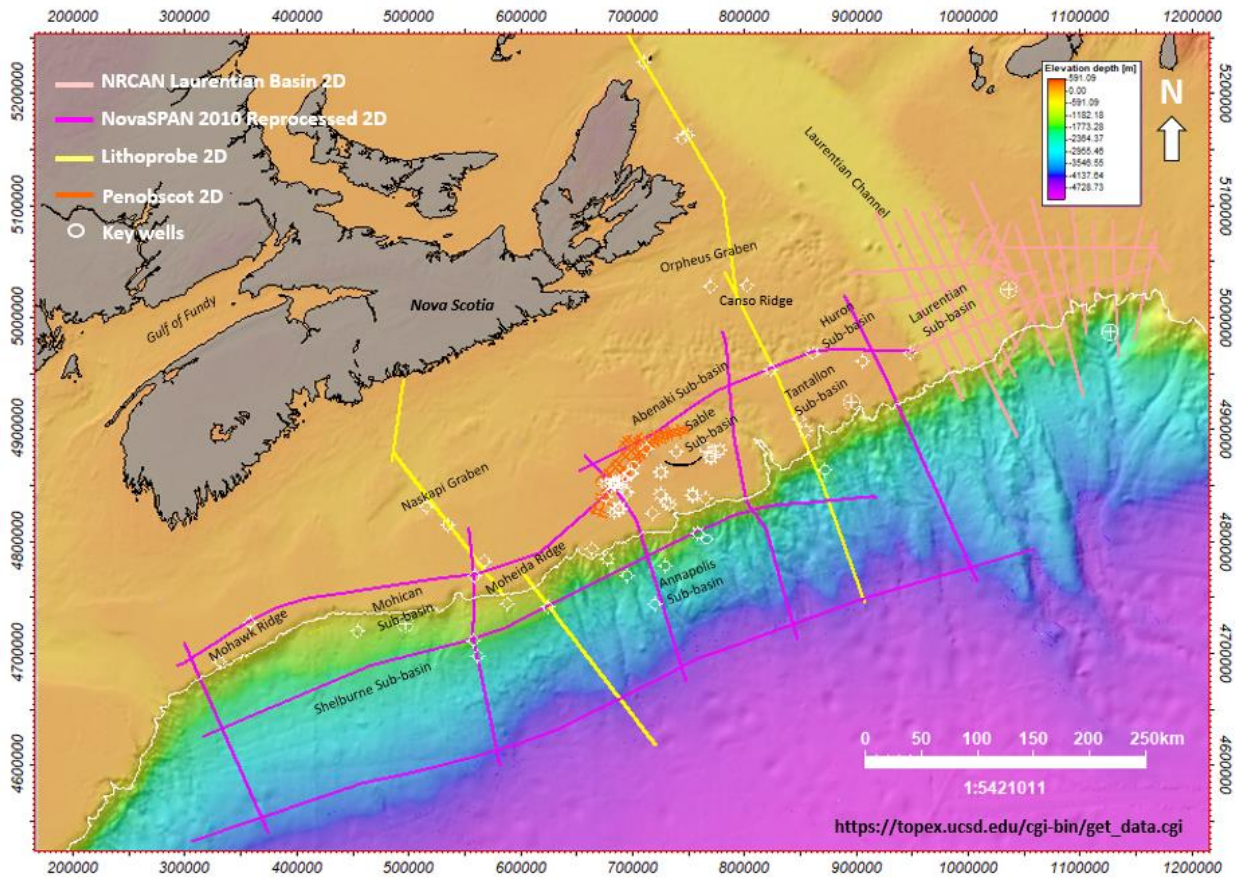

Figure 1. Well data and seismic data coverage shown against the background of the present-day topography of the Scotia Basin

Results

Several sets of faults delineate the tectonic structure of the Scotia Basin (Figs. 2-3), including faults: (1) below the top J200 in the Triassic – Lower Jurassic strata, (2) above the autochthonous salt in Middle-Upper Jurassic beds, and (3) above the allochthonous salt in the Cretaceous and Tertiary deposits. The amount of extension and associated faulting and salt kinematics vary across the Nova Scotia margin. The southwestern segment of the margin (Fig. 2) is less faulted than the northeastern one (Fig. 3). Three main structural domains are recognized along the margin from the Salt Diapir Province in the southwest to the Salt Canopy Province in the central segment (Fig. 2) to the Banquereau detachment wedge zone (Fig. 3) in the northeast (Deptuck, and Kendell, 2017).

The deep-seated NE-SW-striking syn-rift faults are interpreted below the top of the J200 post-rift base horizon and generally cannot be traced into the overlying autochthonous salt deposits or Middle (183-163) and Late Jurassic J163 horizons (Figs. 2-3). The geometry of the syn-rift faults varies across the Nova Scotia margin. The faults are planar below the shelf and continental slope, within the zone of continental crust. SE-dipping listric faults that flatten into a detachment at about 12,000 ms TWT (~15,000 m TVDSS) occur at the southeastern edges of seismic lines, to the SE of the continent-ocean boundary. The East Coast Magmatic Anomaly (ECMA) (PFA, 2011) marks the transition from planar to listric growth syn-rift faults in Triassic-Lower Jurassic beds (Fig. 2). The syn-rift faults were emplaced during the onset of continental breakup during the Triassic and Early Jurassic.

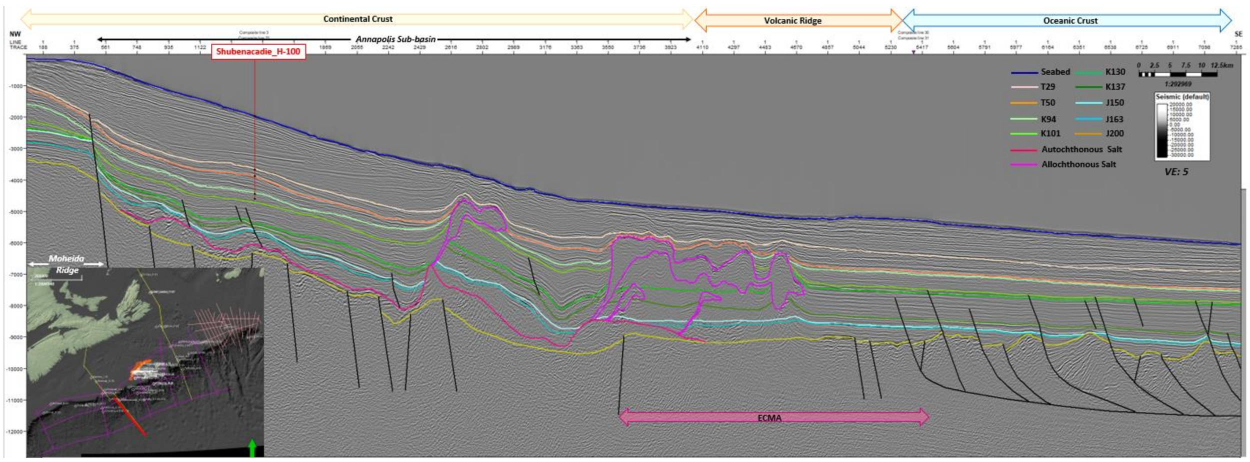

Figure 2. Interpreted Lithoprobe 881a seismic line; vertical axis in TWT, ms; the Salt Canopy Province, central segment of the Nova Scotia margin.

The Middle-Upper Jurassic and Early Cretaceous strata are affected by the NW-dipping and SE-dipping listric faults. The NW-dipping faults are interpreted below the continental slope and form as a result of low-scale movements in the autochthonous salt above the syn-rift horst- and graben-structures. The SE-dipping listric faults and roll-over anticlines develop in the Upper Jurassic strata in a distal part of the basin, above thin allochthonous salt detachment propagated to the southeast (Fig. 3). Fault geometry depends on salt kinematics and dip angle of the detachment. The faults above the allochthonous salt are associated with salt remobilisation and gravitational sediment loading in slope settings. The sediment oversupply in the northeastern part of the Scotia Basin during the Early Cretaceous (Missasuga Formation) resulted from the onset of the Avalon Uplift and erosion at the Late Jurassic-Cretaceous boundary (Grist et al., 1992).

The youngest faults are a set of small-scale conjugated normal faults associated with crestal deformation in Tertiary deposits above salt diapirs in the Salt Diapir Province of the southwestern segment of the Nova Scotia margin. Similar sets of faults are interpreted in Tertiary deposits above the salt canopies in the Salt Canopy Province and associated with remobilization of pre-existing salt tongue (Fig. 3).

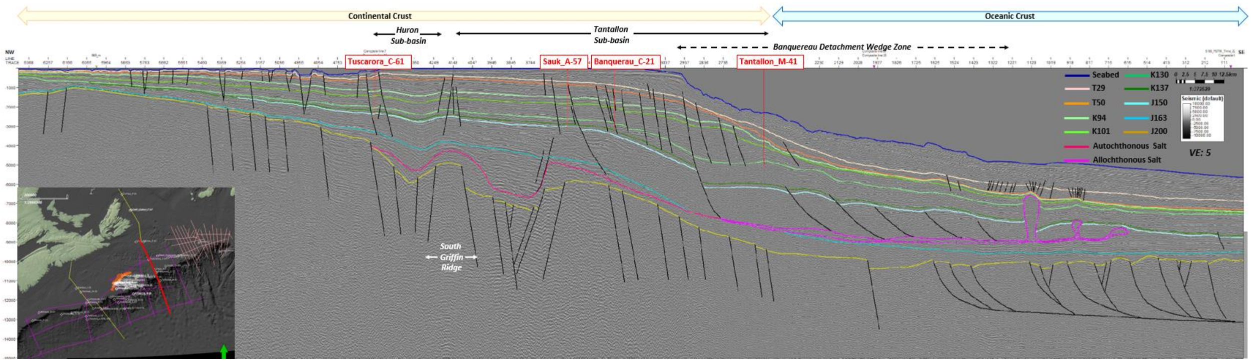

Figure 3. Interpreted Lithoprobe 891 seismic line; vertical axis in TWT, ms; the Banquereau Detachment Wedge Zone, northeastern segment of the Nova Scotia margin.

Conclusions

The interim results of our study summarize the observations of structural interpretation of 2D seismic data. Several sets of the NE-SW striking faults were interpreted at three main structural levels within tectonic structure of the Scotia Basin. Fault geometry varies along the margin and it is likely controlled by presence and dip of ductile basal detachment and mechanical stratigraphy of the Mesozoic sedimentary succession. The southwestern segment of the volcanic passive margin is less faulted than the northeastern segment of the non-volcanic margin.

The emplacement of interpreted sets of faults can be correlated with main deformation phases in tectonic history of the Scotia margin. The initiation of deep-seated syn-rift normal faults corresponds to the onset of continental breakup during the Triassic and Early Jurassic. The faults in the Upper Jurassic and Cretaceous beds are associated with salt remobilization and/or gravitational sediment loading under the settings of continental slope.

Acknowledgements

Authors thank Mark Cooper and Marian J. Warren for support and help in structural interpretation; Russell Dmytriw, Duncan Keppie and Natasha Morrison and OERA (Offshore Energy Research Association) for financial and technical support of the project; Schlumberger for providing an academic license of Petrel software to University of Alberta; Petroleum Experts for Move academic non-commercial license and very helpful technical support.

References

Dehler, S.A. (2012). Initial rifting and breakup between Noca Scotia and Morocco: insight from new magnetic models. Canadian Journal of Earth Science, 49, 1385-1394.

Deptuck, M.E., and Kendell K.L., 2017. A Review of Mesozoic-Cenozoic Salt Tectonics Along the Scotian Margin, Eastern Canada. In: Soto, J.I., Flinch, J.F., Tari, G., (Eds), Permo-Triassic Salt Provinces of Europe, North Africa and the Atlantic Margins. pp. 287-312. http://dx.doi.org/10.1016/B978-0-12-809417-4.00014-8

Grist, A.M, Reynolds, P.H., Zentilli, M., Beaumont, C., 1992. The Scotian Basin, offshore Nova Scotia: thermal history and provenance of sandstones from apatite fission track and 40Ar/39Ar data. Can. J. Earth Sci., 29, 909-924.

Nova Scotia Energy Department (2011). Play Fairway Analysis (PFA) offshore Nova Scotia Canada.

Watts, A.B., and Steckler, M.S., 1979. Subsidence and eustasy at the continental margin of Eastern North America. Maurice Ewing Symposium, Series 3, AGU, 218-234.