East Orphan Basin, offshore Newfoundland and Labrador: Structural Setting and Evolution with Seismic and Potential Fields Arguments

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East Orphan Basin is a highly attenuated Mesozoic-Tertiary sedimentary area situated north and northeast of the Grand Banks of Newfoundland in water depths ranging between 1500 and 3500m. The Western Orphan Basin that lies westerly on the same NE Newfoundland continental margin is a younger rift basin that contains seven dry holes drilled between 1974 and 1985 (Smee et al, 2003). While good reservoirs and very large structural traps were tested, neither significant hydrocarbon flows were obtained nor did Kimmeridgian source rocks were encounter *(Figure 1).*

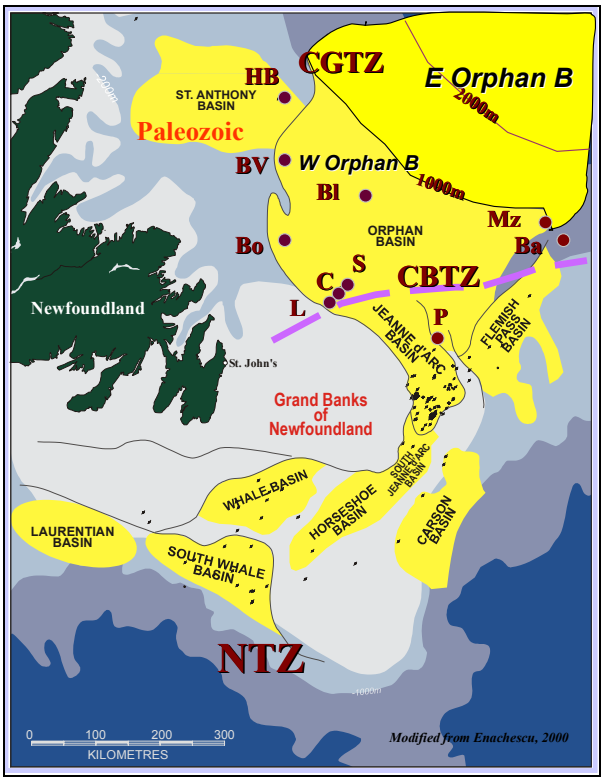

Figure 1. Location of **East Orphan Basin** (E Orphan B) on Newfoundland continental margin (modified from Enachescu, 2000). Old exploration wells, all dry, in Western Orphan Basin and St. Anthony basins are: L = Linnet E-63, C = Cumberland B-55, S = Sheridan J-87, Bo= Bonavista C-99, Bl = Blue H-28, BV = Baie Verte J-57 and HB= Hare Bay M-21. Significant wells for petroleum potential of the basin are P = Panther P-52, Ba = Baccalieu I-78 and Mz = Mizzen L-11. CBTZ = Cumberland Belt Transform Zone (Enachescu, 1987) and CGTZ = Charlie Gibbs Transfer Zone. To the east, the basin extends to Orphan Knoll and beyond, all the way to the Continent Ocean Boundary.

Over 20,000km of 2D and 3D seismic data recently recorded (2000-2003) and some older data (1975-1982) were donated by Geophysical Service Incorporated (GSI) to the Memorial University of Newfoundland to be used for basin definition and petroleum system research over the area previously known as the Northeast Newfoundland Basin or the Orphan Basin. Interpretation of these high quality modern seismic data, integration with existing potential field maps and an extensive basin evaluation performed during the past year indicate that the area can be divided into shallower water West Orphan Basin and deeper water **East Orphan Basin** which had dissimilar structural and tectonic evolution and distinct paleogeographic position on the Atlantic margin. West Orphan Basin is not discussed here.

Situated close to 1) a major late Paleozoic Transform fault (Bay of Biscay); 2) a major Mesozoic triple junction located just north of Orphan Knoll and 3) the Charlie Gibbs Transform Zone from Cretaceous to Tertiary, the **East Orphan Basin** suffered the most prolonged extensional and thermal subsidence history of all the basins on the Canadian margin and as a result it is now exceedingly stretched and buried into deepwater. Based on seismic mapping, regional correlations and literature review, a viable petroleum system can be postulated for this basin.

The Orphan Basin was initially a Paleozoic sedimentary platform area that was affected by Permo-Trassic rifting only in its eastern part. The initial narrow rift expended during Late Triassic-Early Jurassic within the Thethys rift system that spread from Gulf of Mexico to Barents Shelf and Southern Europe. After a long thermal subsidence stage, the newly formed rift basin was reactivated, enlarged and matured during the Late Jurassic-Early Cretaceous Atlantic rifting phase. At that time, the East Orphan Basin was connected with other North Atlantic areas of source rock and reservoir deposition: the petroliferous Jeanne d'Arc Basin to south, the source rock host Flemish Basin to southeast and the petroliferous Porcupine Basin to northwest (examples *Figure 2 and 3)*.

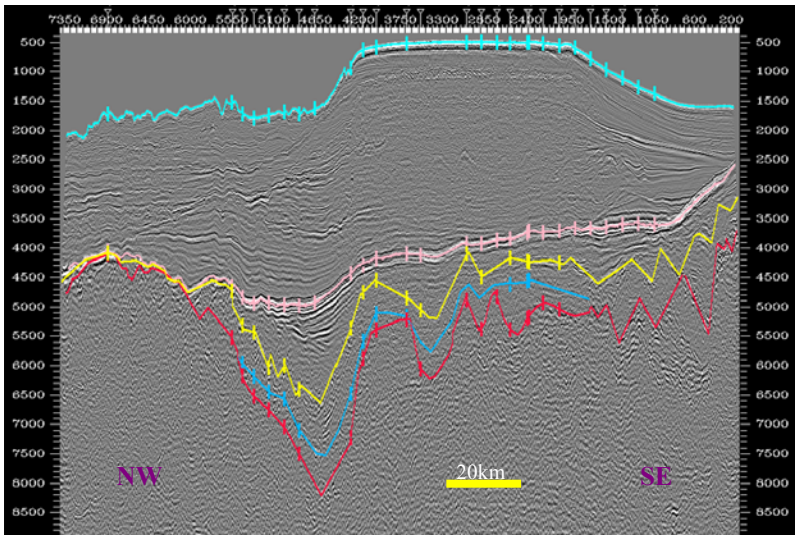

Figure 2. This is a seismic line (Courtesy of GSI) riding over the Grand Banks' Central Ridge and plunging into the **East Orphan Basin**. The syncline in the middle contains a complete rift sequence including Kimmeridgian source rock below the Top of Jurassic yellow marker. The sequence projects toward the northeast (away from eyesight) into the East Orphan Basin.

Paleozoic and Precambrian terrene such as Bonavista Platform to the west, Orphan Knoll, Porcupine Bight, Rockall Bank and Flemish Land to the east were emergent and provided coarse sediment sources for the elongated half-grabens. Continental, lacustrine and shallow marine deposits, including early red beds and stratified evaporites are associated to the Thethys and Atlantic rift phases which are the dominant phases in

the East Orphan Basin formation and establishment of its petroleum system. After additional thermal subsidence in the Early Cretaceous, block rotation and graben-ridge structural build up continued, first during the Mid-Cretaceous and then in the Late Cretaceous rifting phases associated with opening of the Labrador and Greenland seas. Simultaneously, rifting processes propagated westward, stretching and fragmenting successive areas of the Bonavista Platform and setting increasingly younger Cretaceous sub-basins. The basement time structure map shows these successive half-grabens with their axis parallel and oriented in a NE-SW direction which is almost perpendicular on the Appalachian magnetic field trends from Bonavista Platform. A major unconformity especially visible in the deeper half-grabens separates the Early Cretaceous from the Late Cretaceous sedimentary successions. This angular unconformity may be equivalent to the Avalon Unconformity on the Grand Banks *(Figures 2 and 3).*

Due to the successive counter-clockwise rotation of the extensional vector, several episodes of readjustment of basement blocks and transtensional movements have occurred. These are revealed by offsets in the direction of the main structural elements of the basin, sudden differences in their elevation, the en-echelon aspect of the basin bounding fault and small amounts of inversion observed in the Late Cretaceous beds. Hard to believe, transfer faults within this intra-continental extensional area are not spectacular zones of deformation, but have rather small lateral slip displacement and clearly more vertical displacement. As on the Grand Banks, the Base Tertiary Unconformity is a widespread, sub-aerial on places, angular unconformity. Also similar, the Base Tertiary Unconformity is marked by latest Cretaceous chalks and early Tertiary sandstone members that translate by strong reflectivity horizons *(Figure 2 and 3).* Most major basement and Cretaceous horsts and anticlines are eroded during the Paleocene, with the derived sediments deposited as marginal or basin floor fans within the adjacent elongated half-grabens. During the Tertiary the East Orphan Basin and its outer ridge - the Orphan Knoll - suffered rapid subsidence and were submerged under the Atlantic deep water. Tertiary sedimentation is dominated by mud-rich highly sculptured submarine fans and turbidite deposits. Sand prone intervals are without doubt present in the Tertiary succession as they are indicated by large seismic amplitude variations *(Figure 3).*

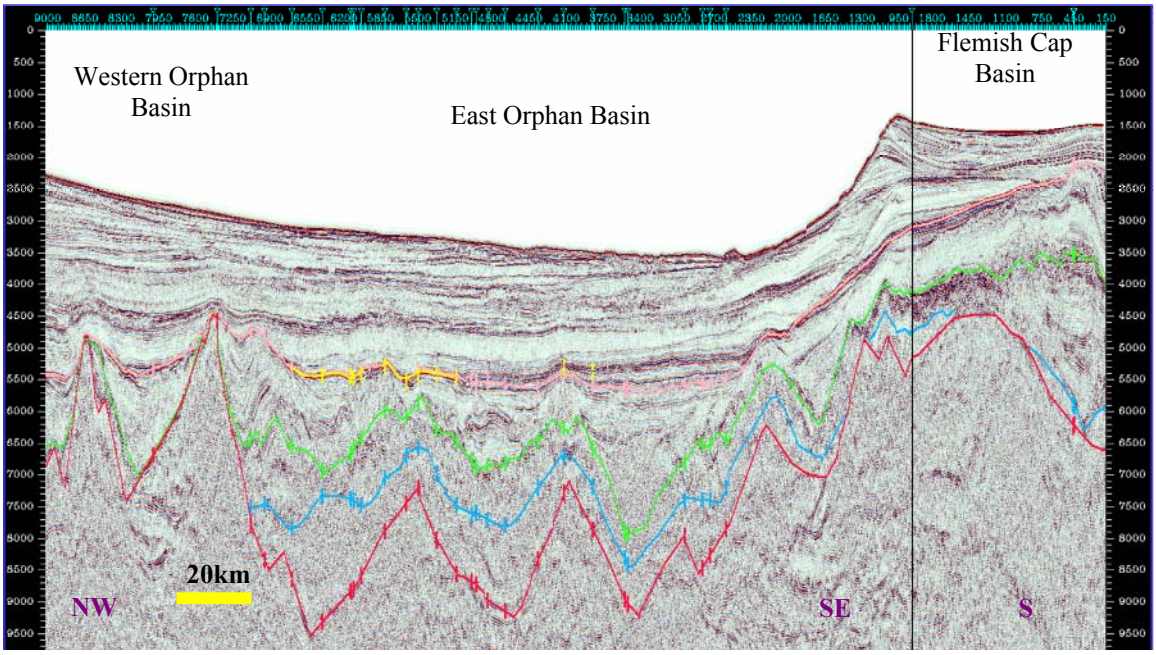

Figure 3. Seismic line (Courtesy of GSI) showing bathymetric profile and correlation of basement, synrift and postrift sequences from Flemish Cap Basin into **East Orphan Basin** and West Orphan Basin.

Repeated synrift block tilting accompanied and followed by drastic crestal erosion creates complications in restoring the original geology/topography, retrieving the direction of bounding fault plane and balancing the regional cross-sections. A peculiar basement high that is located in the northern part of the basin, reaches very close to the water bottom and deforms Holocene sediments, indicate that some kind of vertical movements continued very late in this basin. This is an unusual occurrence for the Canadian Atlantic Margin and suggests late rifting or recent transtension in the basin *(Figure 4)*.

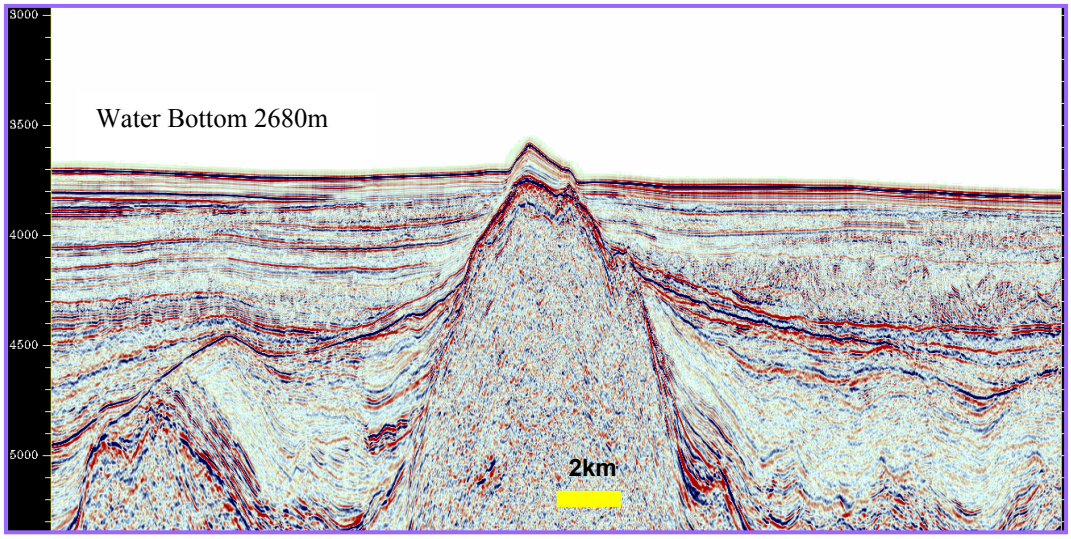

Figure 4. Seismic line showing young movements of a basement block (no, is not salt!). This implies that rifting or trastensional movements have continued into Tertiary in the East Orphan Basin. Tertiary and Avalon unconformities are clearly expressed. Seismic line courtesy of GSI.

With a long intra-continental rift evolution, shallow marine interludes of possible source rock deposition and numerous synrift structural and stratigraphic trapping possibilities, the East Orphan Basin has recently attracted the highest land bid (Can $672.7MM) and the highest singular block bid (Can $251.6MM) in the Canadian oil exploration history, from an exploration consortium led by Chevron Canada, that includes ExxonMobil and Imperial Oil. Situated on trend with other oil prolific basins, the East Orphan Basin's petroleum potential remains to be validated by future deepwater drilling.

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