New wide-angle seismic constraints across a magma-starved, hyper-extended North Atlantic rift basin – Orphan Basin

K.W. Helen Lau[1,3], Louise Watremez[1], Keith E. Louden[1] , Mladen R. Nedimović[2] & J. Kim Welford[3]

1. *Deparment. of Oceanography, Dalhousie University, Halifax, NS, Canada.*
2. *Department of Earth Sciences, Dalhousie University, Halifax, NS, Canada.*
3. *Earth Sciences Department, Memorial University of Newfoundland, St. John's, NF, Canada*
4. *kwhlau@dal.ca*

Introduction

The Orphan Basin is a large, deep water basin located north of the Grand Banks and northwest of Flemish Cap (Fig.1). It is one of the largest rift basins to have undergone hyper-extension without continental breakup and seafloor spreading. Such a setting allows detailed imaging of a cross section of a complete continental crustal extension system along a single profile. Several industry boreholes exist within the deep-water basin and the extensional structures also connect to wells within Flemish Pass and the petroleum prolific Jeanne d'Arc Basin to the south.

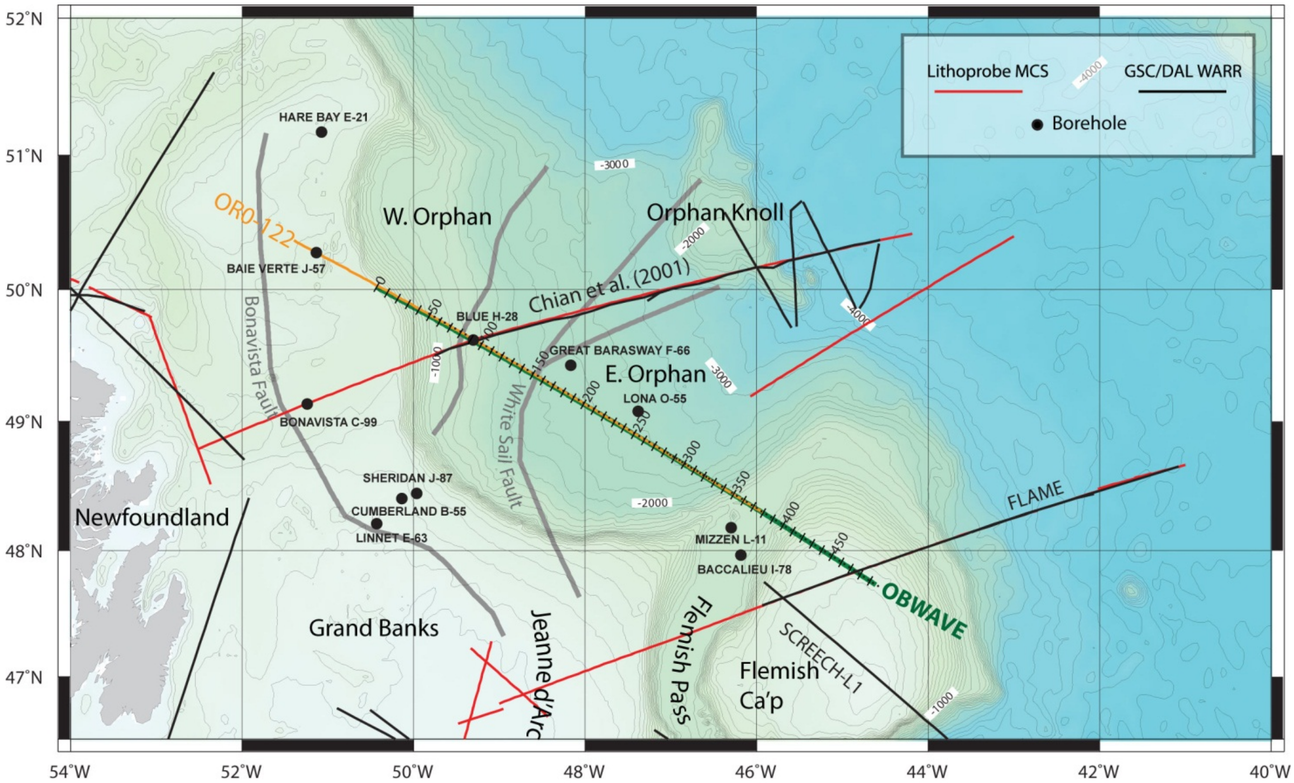

Fig. 1. Location map of selected reflection and refraction profiles across Orphan Basin and major wells. Tick marks are for velocity model distance in kilometers. Gray lines are major faults (Enachescu *et al.*, 2005).

Previous studies show that Orphan Basin is divided into eastern and western sub-basins by a series of faults and high relief basement ridges (Fig. 1). Within each sub-basin, there are series of smaller ridges and troughs trending N-S in the west to NE-SW in the east, which formed during Mesozoic rifting between N. America and Africa/Europe and the rotation of Flemish Cap (FC) to the southeast (Enachescu *et al.*, 2005). An older Lithoprobe MCS profile and a more recent grid of extensive industrial MCS profiles have provided detailed images of these structures. However, the link between basement structures with underlying crustal layers and Moho depths remains uncertain. The only basin-wide, wide-angle seismic profile (Fig. 1; Chian *et al.*, 2001), used to constrain deeper crustal structure, crossed the basement structures at an oblique angle and had wide spacing (~10-50 km) between the ocean bottom seismometers (OBS) that limited the resolution of the velocity model.

Method
In order to improve imaging of crustal structures, high resolution wide-angle data were acquired in 2010 during the OBWAVE (Orphan Basin Wide Angle Velocity Experiment) project. The refraction line (Fig. 1) stretches along a NW-SE profile from Flemish Cap across the eastern sub-basin and into the western sub-basin. The profile is coincident with MCS profile OR0-122, previously acquired by GSI. Usable 4-component OBS data were collected at 89 receiver stations with 3-5 km spacing along a 500-km-long profile. An airgun array, consisting of 3 clusters of 3 G-guns (total volume of 4680 in^3), was fired every 60 s for an average shot spacing of 140 m. The western half of the profile was double-shot to increase fold. First arrivals and wide-angle Moho reflections (PmP) were picked from common receiver gathers. Tomographic inversion for the first arrival picks and PmP arrivals used the Tomo2D algorithm (Korenaga *et al.*, 2000) with optimization of parameters (e.g. smoothness).

Results
In this paper, we present our final Tomo2D P-wave velocity model with the Moho depths and their comparison with the coincident MCS profile. Although velocity variations in this grid-based model are smooth, we can divide the crust into upper, middle and lower zones with average velocities of 6.0 km/s, 6.5 km/s and 7.0 km/s, respectively. The whole crust thins gradually from ~30-32 km under FC to ~14-km-thick at model distance 320 km beneath a series of tilted fault blocks. Immediately westward, the crust thins abruptly to ~5-km-thick over a 67-km-wide zone, with partition of thinning mainly within both upper and lower zones. However, the maximum thinning in the upper crust located 13 km to the west of that of the lower crust, showing asymmetry. Also, the shallow Moho correlates well with a system of strong reflections topping a region of fuzziness in the MCS data. This indicates that mantle has not been significantly serpentinized beneath the thinned crust.

The crust thickens to 15-km-thick at the western end (255 km distance) of the abrupt thinning. Farther north-westward, the crust thins again to ~9-km-thick near the edge of the west basin (180 km distance). The connection of Moho variation with the deep crustal continuation of the White Sail Fault suggests that the thinning may be fault controlled. A velocity of 7-7.3 km/s is observed beneath the Moho in a region of strong reflectivity, suggesting a complex crust-mantle boundary.

Three major basement fault blocks are observed between 70-160 km distance, where the crust thickens to 17 km. Major faults that flank both sides of the blocks extend into the deep crust; while faults within the blocks sole within the middle crust, suggesting a complex brittle-ductile transition. Within the west basin (<70 km distance), the crust thins to 12-km-thick. In conclusion, our model shows detailed crustal deformation that could not with confidence be interpreted based solely on MCS data. The multiple zones of thinning imply complexity in subsidence history, which would impact the deposition of syn-rift sediment and its petroleum potential.

References

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