Orphan Basin crustal structure from tomographic inversion with dense receivers

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Orphan Basin is located offshore north-eastern Newfoundland, between the Bonnavista Platform and Flemish Cap. This basin is characterized by a zone of ultra-stretched continental crust as determined by an earlier refraction study using 15 instruments on a 550 km long line (Chian et al., 2001). A hypothesis for its formation is a clockwise rotation of Flemish Cap from the north-eastern Newfoundland shelf between the late Triassic and early Cretaceous (Sibuet et al., 2007). Gravity modelling shows that the extended crust might be as thin as 5 km in the thinnest areas of the basin (Welford & Hall, 2007).

The OBWAVE (Orphan Basin Wide-Angle Velocity Experiment) project has acquired a much higher resolution refraction seismic data, than common surveys, using ~100 OBSs (Ocean-Bottom Seismometers) along a 500 km long profile across the Orphan Basin (Sept.-Oct. 2010). The spacing of the instruments varies from 3 km in the highest resolution part of the profile, where the crust was predicted to be the thinnest, to 6 km on Flemish Cap and in the western part of the basin.

After relocation of each instrument, we picked first arrivals (~67,000 picks) and PmP reflection arrivals from the Moho discontinuity (~23,000 picks) to obtain a joint tomographic inversion of both sets of arrivals using Tomo2D (Korenaga et al., 2000). The refraction arrival times constrain the velocities in the model, while the PmP arrival times control both the velocities in the crust and also the depth of the Moho interface. The final model was computed following a detailed parametric study to determine the optimal parameters controlling the ray-tracing and the inversion processes. Its normalized χ^2 is 0.86, which means that the model satisfies the picked arrival times within their uncertainties.

The final model was used as a basis for a checkerboard analysis, allowing us to define its spatial resolution. The finer structures (5 km horizontally and 2.5 km vertically) are well defined where a sufficient number of rays cross at depths of 5 to 10 km in the model. The coarser structures (e.g., 25 km horizontally and 5 km vertically or 50 km horizontally and 25 km vertically) are well defined at depths from 10 to 25 km. An additional tomography test using the picks of one OBS out of 5 – which simulates spacing used in conventional OBS surveys (e.g. the previous survey in the basin from Chian et al., 2001) – does not give as many details as the final model using all the OBSs (i.e. finer structures and crustal thinning are not recovered).

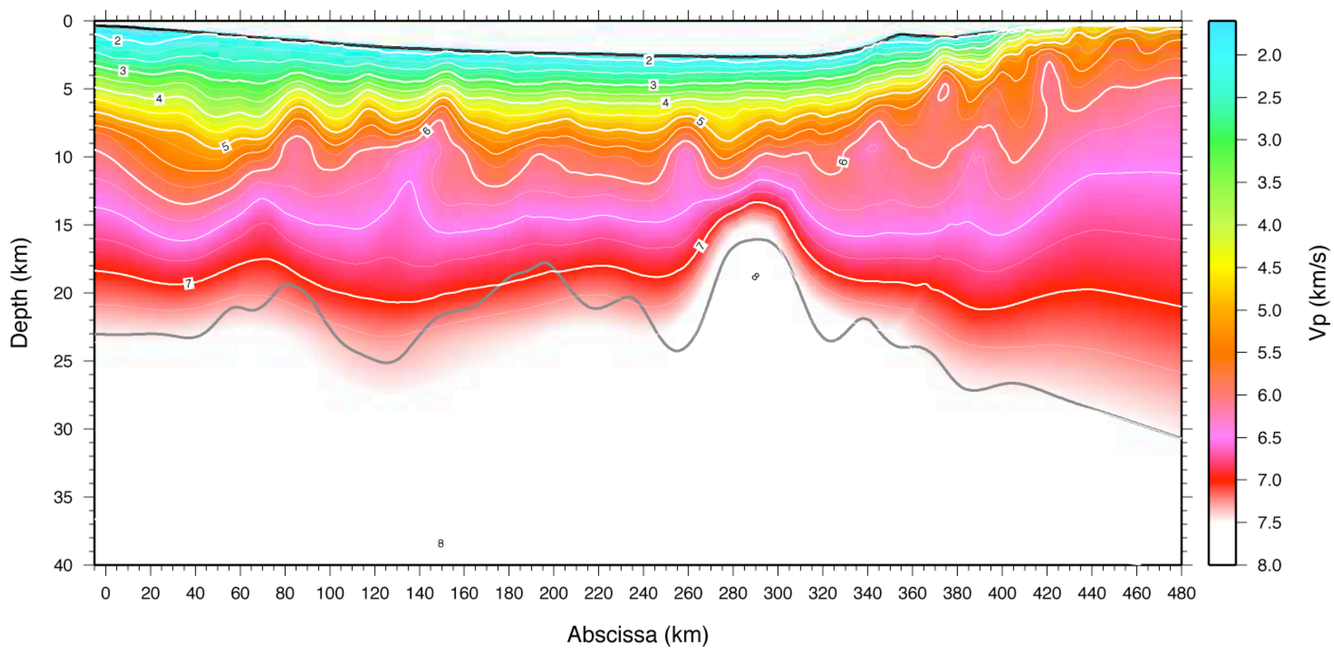
The final model (Figure 1) shows clear basement highs in the western part (85, 115 and 155 km), in the eastern part (between 310 and 440 km), and a major basin (280 km) consistent with a strong crustal thinning (high velocities and shallow Moho between 260 and 320 km). Two aspects of the model are of particular interest:

1. At 290 km, where the crust is the thinnest, the Moho discontinuity occurs at 16 km depth and the iso-velocity contours show 7.5 km/s at 15 km depth and 8 km/s at approximately 19 km depth. This means that the velocity at the top of the mantle is about 7.6 km/s. Such a velocity gradient at the top of the mantle might indicate the presence of partially (< 10 %) serpentinized mantle. However, tomographic modelling inherently results in a smoothed version of the crustal

structure. In contrast, the strong PmP reflections that we observe in this region suggest that the Moho is a sharp velocity discontinuity, with higher velocities (and thus little or no serpentinization) in the underlying mantle. Additional layer modelling will be required to better define such velocity discontinuities.

2. The shallowing of the Moho from 160 to 240 km crosses the 7 km/s iso-velocity contour, which is more characteristic of the lower crust. Therefore, it is possible that the PmP picks in this region correspond to lower crust reflectivity (e.g. a lower crustal mafic intrusion) that might prevent us from identifying the true Moho reflection.

This study shows that dense regional OBS deployments at extensional basins have the potential to image the crustal structures with details that cannot be observed with coarser OBS deployments that have been used routinely for regional crustal investigations of rifting. For the Orphan Basin study, increased image resolution was particularly useful to delineate the tilted blocks and capture the extreme thinning of the continental crust.



<u>Figure 1</u>: Final velocity model. Colours correspond to the modelled P-wave velocities; colour scale is presented on the right. White lines are iso-velocity contours every 0.5 km/s; the thick iso-contours are shown every 1 km/s. The thick black line represents the seafloor and the thick grey line corresponds to the modelled Mohorovičić discontinuity.

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