Sound imaging of variable water layer structure in Rockall Trough, NE Atlantic

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1. Introduction

- Variation in sound speed within ocean water can cause serious problems in subsurface seismic reflection imaging. Water layer sound speed variations arise from natural variations in temperature and salinity associated with oceanic currents.
- In 3D seismic surveying, water layer sound speed variations cause TWT offsets and amplitude variations between sail lines. Vertical sound speed gradients cause ray bending and lead to migration problems.
- 4D seismic surveying compounds these problems.
- Even in a 2D survey, water layer sound speed variation can adversely affect line ties and merging of re-shot sections of a single line.
- Important questions for the hydrocarbon industry include:
  1) How might water layer sound speed vary during acquisition of a single sail line?
  2) How might sound speed vary between acquisition of adjacent sail lines?
  3) How might sound speed vary between repeated 3D survey acquisitions in a 4D imaging program?
  4) What acquisition and processing strategies are required to cope with the expected variability?
- The deep water basins offshore west of the UK and Ireland provide a natural laboratory to study the effect of water layer variability in seismic reflection images, and to compare the signatures of water layer variability in legacy oceanographic and seismic reflection data sets (Fig. 1).

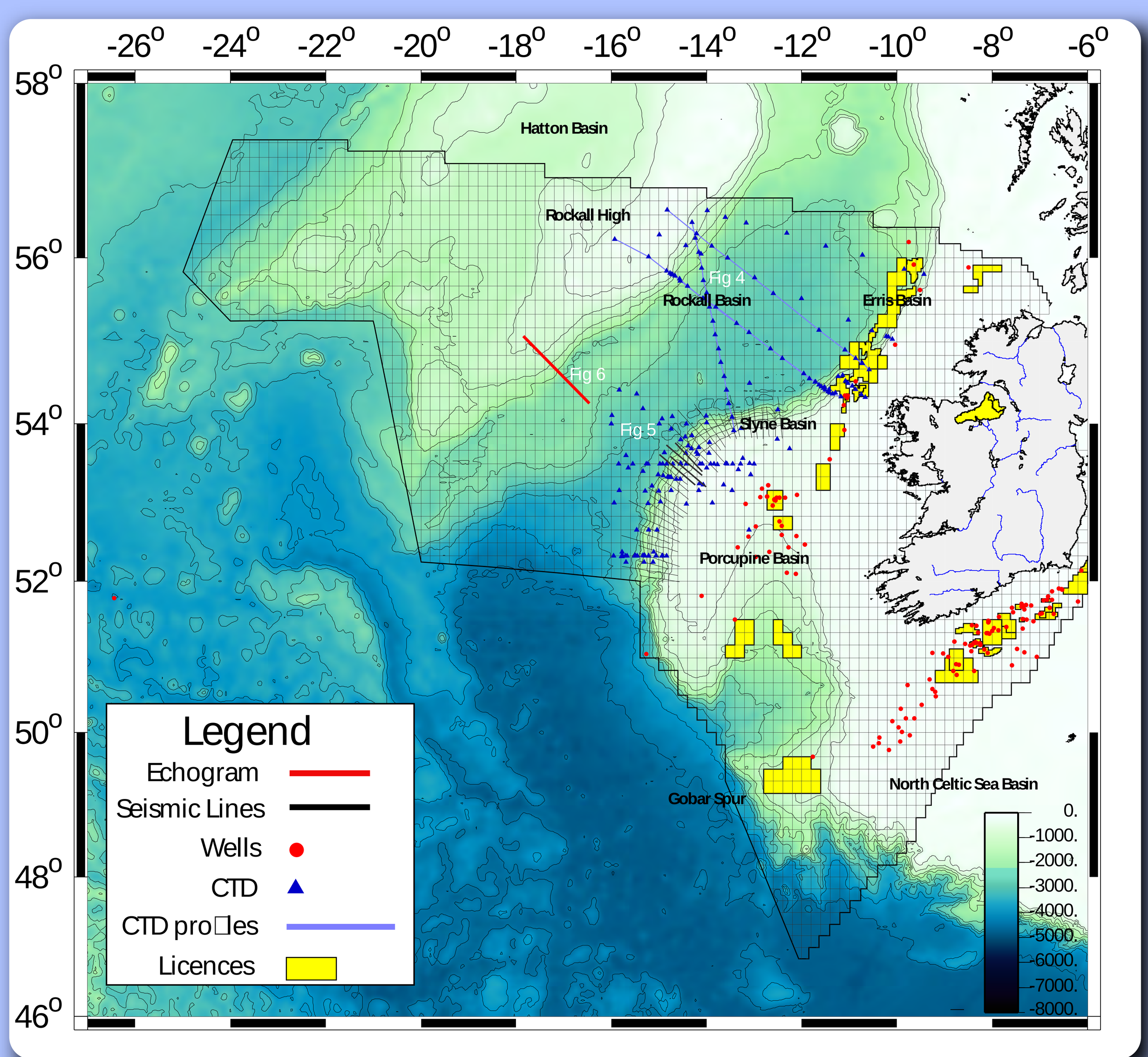

Figure 1. Location map of the research area West of Ireland. Heavy black lines represent the seismic lines shown.

2. Oceanographic Data

- Legacy oceanographic data from Rockall Trough, NE Atlantic, illustrate both pronounced vertical layering and significant space-time variation.

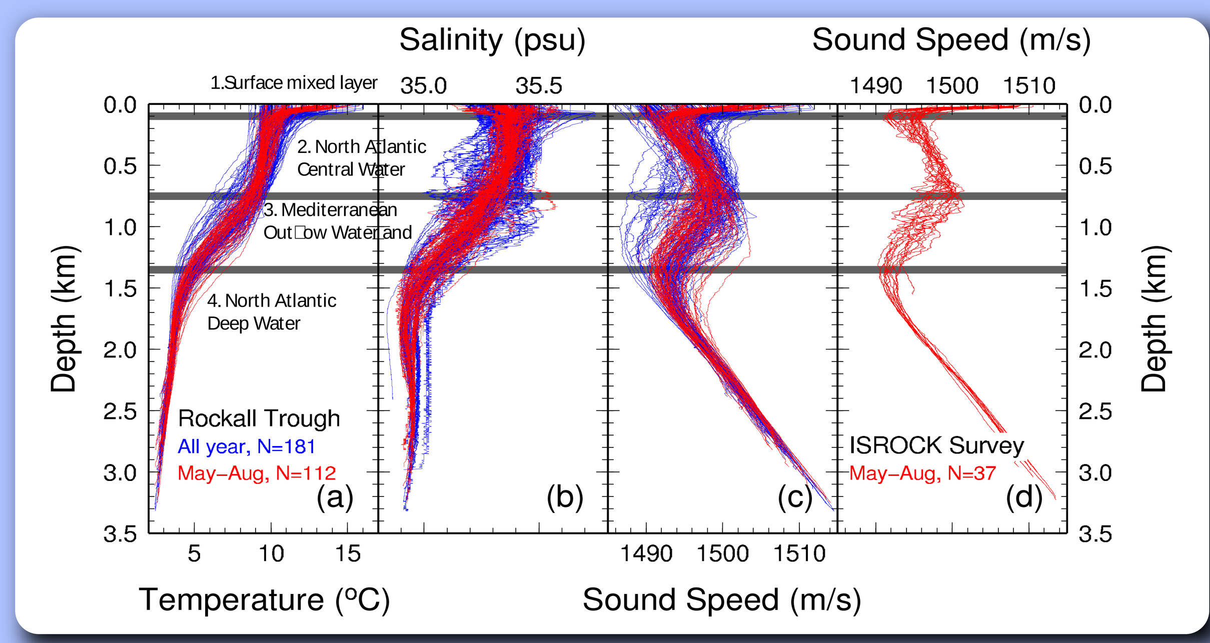

Figure 2. Oceanic structure of Rockall Trough. At depths shallower than 1.5km temperature and salinity vary strongly and generate significant sound speed differences

- Mean water layer sound speed in Rockall Trough mostly varies between 1490 and 1500 m/s (Fig. 3a). Variability is greater in winter and less, though still significant, in summer. Strong variability in mean sound speed occurs above 2 km and variability decreases somewhat in deeper water (Fig. 3b).

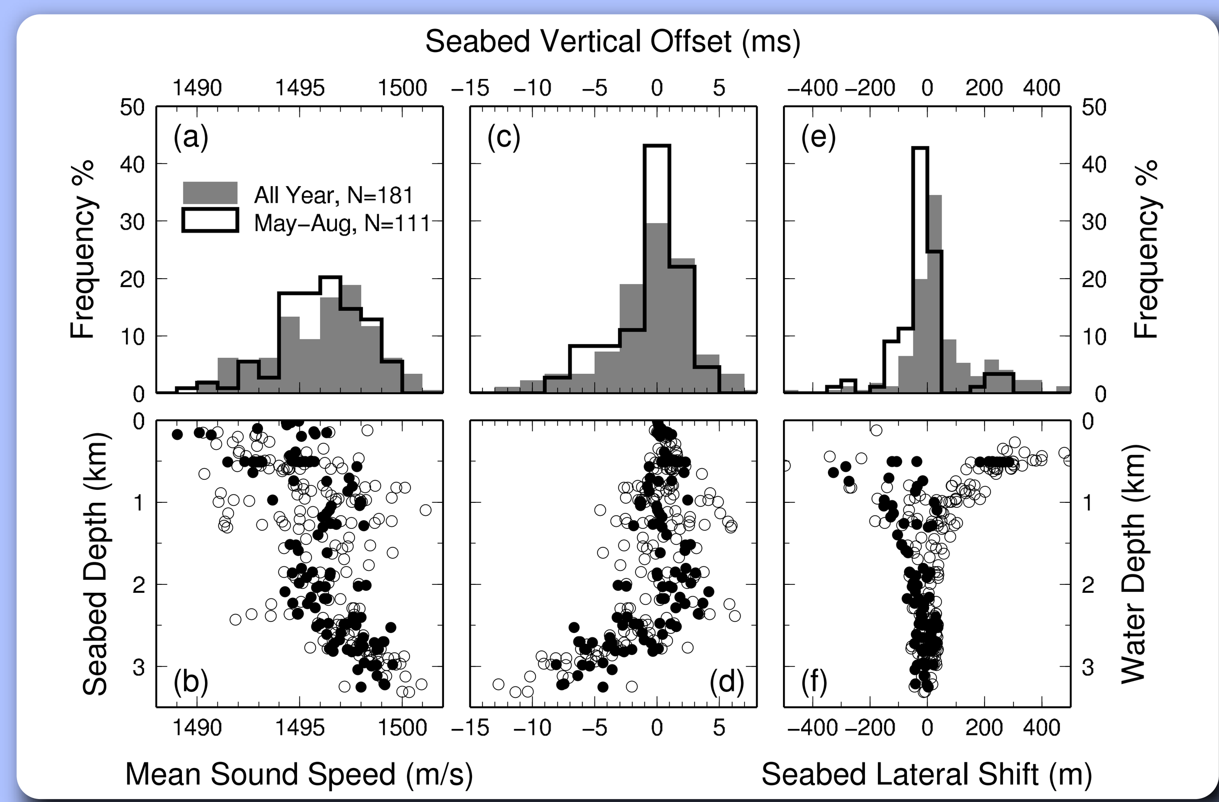

Figure 3. a)+b) Mean water layer sound speed, c)+d) Seabed vertical offsets, e)+f) Seabed lateral shift

- Seabed TWT vertical offsets of over 15 ms are expected if the water layer is assigned a constant sound speed. Misties shown in Fig. 3c & d result when the water layer is assigned the modal mean sound speed of 1496.5 m/s. Poor choices for mean water layer sound speed will lead to larger mis-ties. Large mis-ties are more likely in deeper water.
- Ray bending can cause many hundred metres of lateral shift in water with vertical sound speed gradients (Fig. 3e & f). If migration is done using a constant water layer sound speed, mis-positioning of rays can significantly impair subsurface images. In Rockall Trough, the largest lateral shifts occur in water depths shallower than 1 km, and this problem is equally severe in summer and winter. The mis-positioning problem is less severe in deeper water because of opposing sound speed gradients at different levels in the water column.

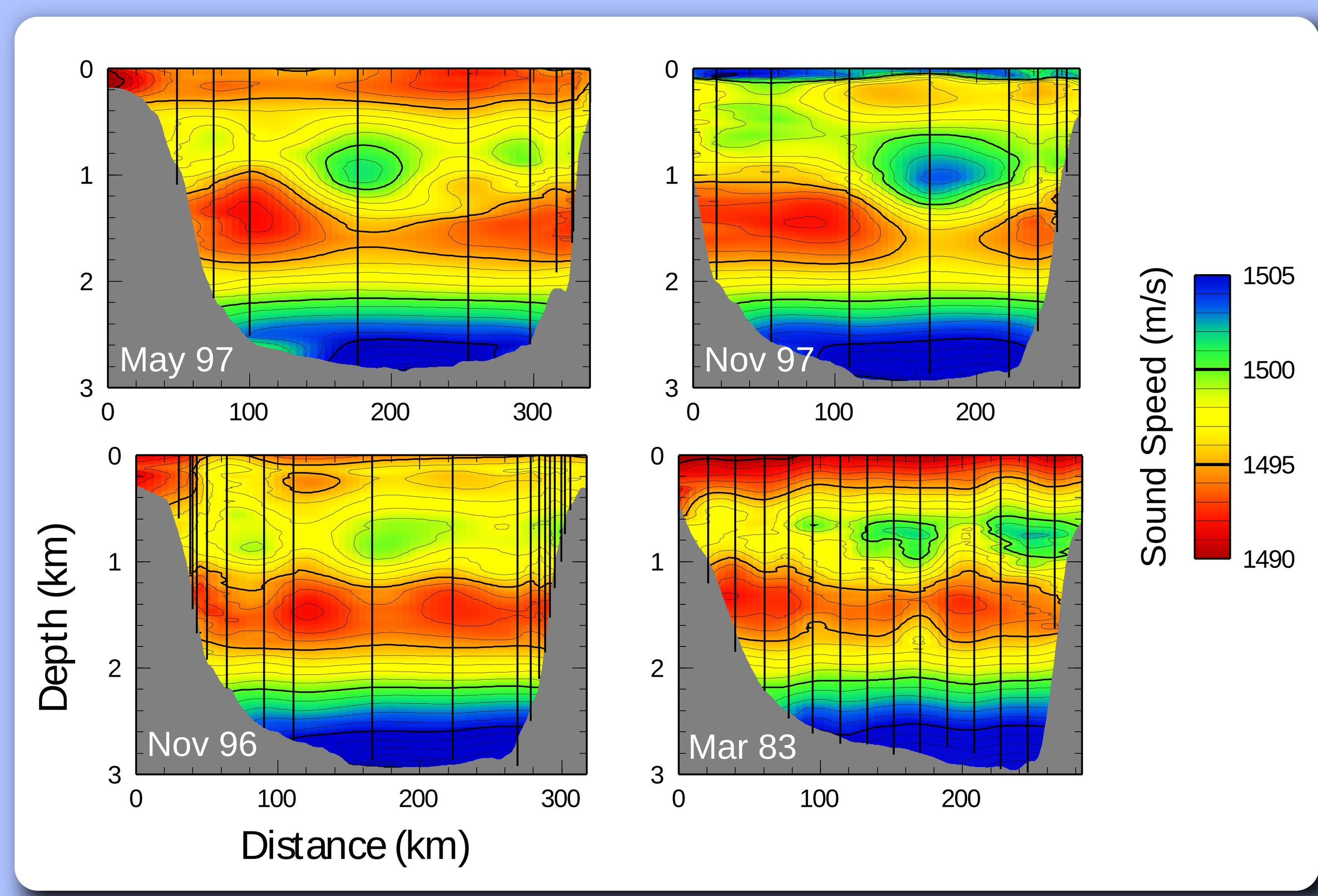

Figure 4. Four CTD profiles (near Westline Fig. 8) highlighting that sound speed lateral variability within layer 2+3 (Fig. 2) occurs at both a monthly and yearly scale, equivalent to the variation in reflections seen in seismic profiles (Section 3).

Acknowledgements

All seismic processing was performed using the Seismic Unix system.

We thank the Irish petroleum Infrastructure Project for supporting our seismic processing facility and the Irish Marine Institute for access to oceanographic data sets. The MOST project currently involves Trinity College Dublin, University of Durham, Memorial University of Newfoundland, GX Technology, Spectrum, Statoil Ireland Exxon-Mobil & BG Group.

We thank the Irish Petroleum Affairs Division for highlighting this project to participating oil companies.

5. Conclusion

- Risk assessment for water layer variation is essential in 3D and 4D seismic acquisition and processing. Risk also affects line ties and re-shot segment ties in 2D surveys.
- Use legacy oceanographic data for initial assessment of water layer risk. This may be complimented with echosounder data. Use legacy seismic data to refine the risk assessment by showing how rapidly and by how much the water layer sound speed is likely to vary at a given location.
- In areas of vigorous oceanic mixing, such as offshore west of the UK and Ireland, expect strong water layer variability along individual sail lines. Pick average water layer speeds at a fine horizontal scale (< 1km).
- In areas of strong vertical sound speed gradients, it is necessary to account for ray bending when migrating data.
- Make the water layer of seismic data available for academic research into oceanic mixing. Improved understanding of mixing will feed through into improved models of global oceanic circulation and global climate change.

3. Seismic data

- Ocean data indicate strong oceanic variability on a basin scale. What is the variability on the space-time scale of a seismic survey?
- In Rockall Trough, the oceanic variability is clearly visible as a strongly reflective layer at depths between 500 m and 1.5 km. Related to strongly developed temperature and salinity fine structure observed over this depth range in the oceanographic data.
- Strong lateral variations of reflectivity are visible. Some features can be interpreted as eddies originating in Mediterranean outflow water and carried into Rockall by the along-slope current. The corresponding thermo-haline variations are expected to be associated with strong sound speed variations.
- Some reflective packages have steep and sharp edges. Such edges will generate abrupt changes in average sound speed along individual seismic sail lines..

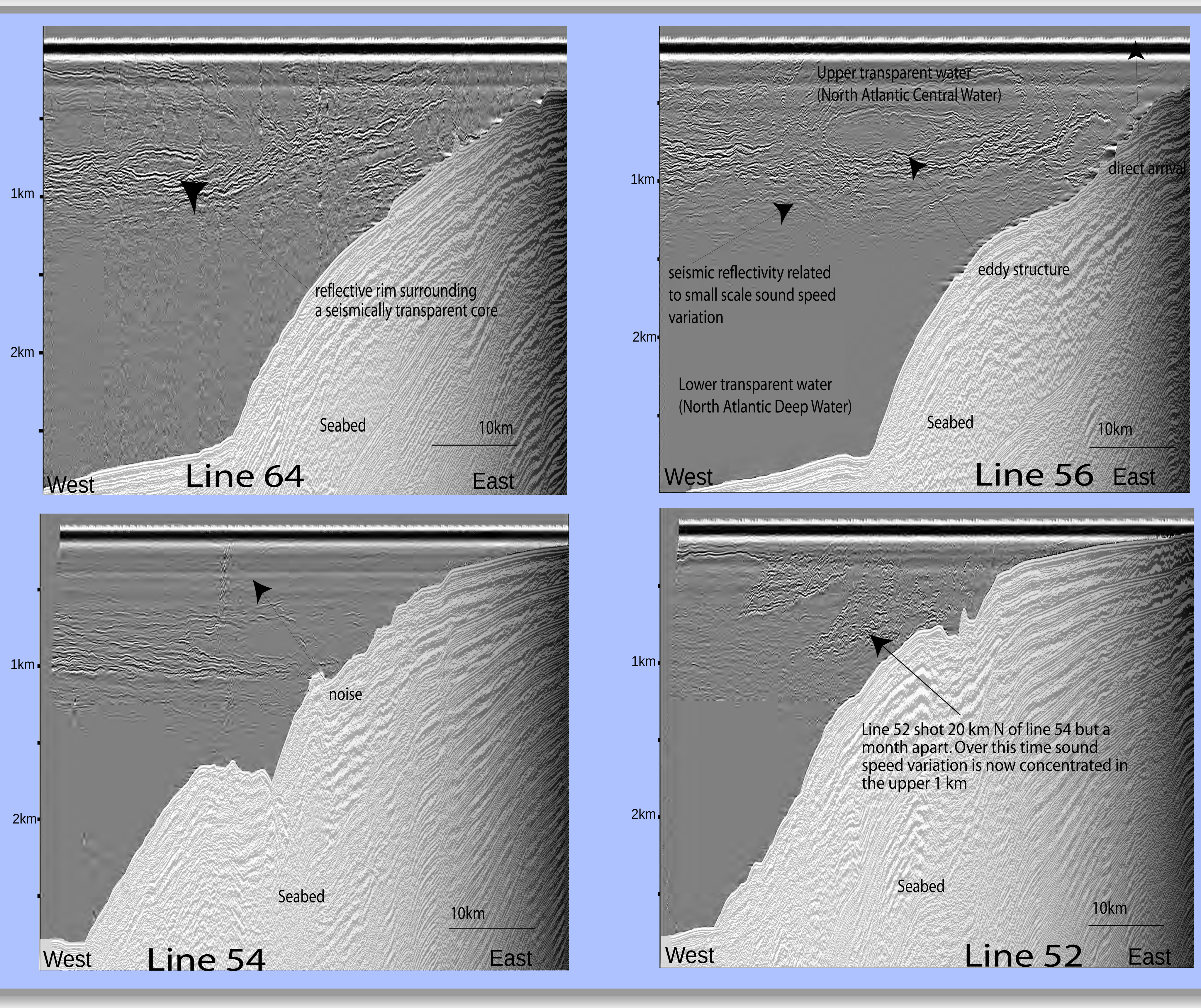

Figure 5. Line 64, 56, 54, 52 from the ISROCK96 survey NE Rockall, showing reflections in the water column that correspond to changes in sound speed

4. Echo sounder data

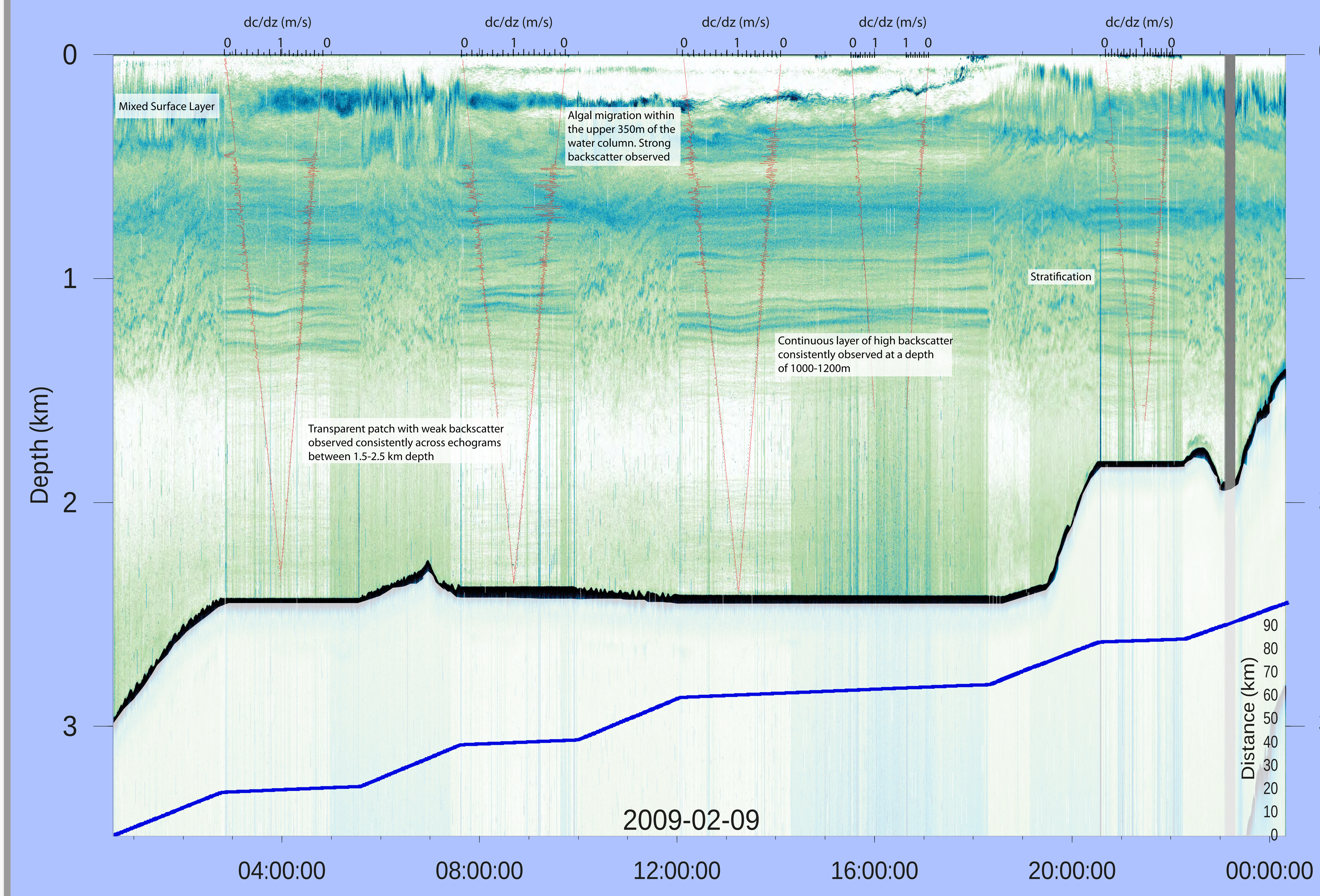

Figure 6. An 18 kHz echogram taken on February 2nd 2009. Superimposed on the echogram are 5 CTD (conductivity-temperature-depth) casts which have been manipulated to show change in sound speed with depth (dc/dz). The thick blue line at the bottom indicates the ship speed, being completely flat when the ship is stationary.

- Oceanic variability can also be imaged using echo sounder techniques. The advantage of using this technique over seismic is:
  1) can be used when ship is stationary
  2) financially & computationally inexpensive
  3) potential to show oceanographic features at a higher resolution
- The dark wave like reflections in the 18 KHz echogram in Figure 7 relate to a series of internal waves passing under the ship while it is stationary. Concurrent CTD casts are used to show dc/dz -> difference in sound speed with respect to depth (in red). Inflections in the dc/dz plots correlate well with the stronger reflections.
- Measurable wave parameters include period, displacement and vertical wavelength. With this data it is possible to calculate the frequency, phase speed and horizontal wavelength of the internal waves which have previously only been measured using seismic techniques.

5. Temporal variations

- Re-shot sections (owing to gun failure) show that there can be significant variability in water layer reflectivity at a single location over a matter of hours.
- These reflections are the result of variations in temperature and salinity. Over time these water properties change and therefore different reflections are observed over the 3-5 hours reshoot gap. These reflections can be quantified in terms of average seismic energy.

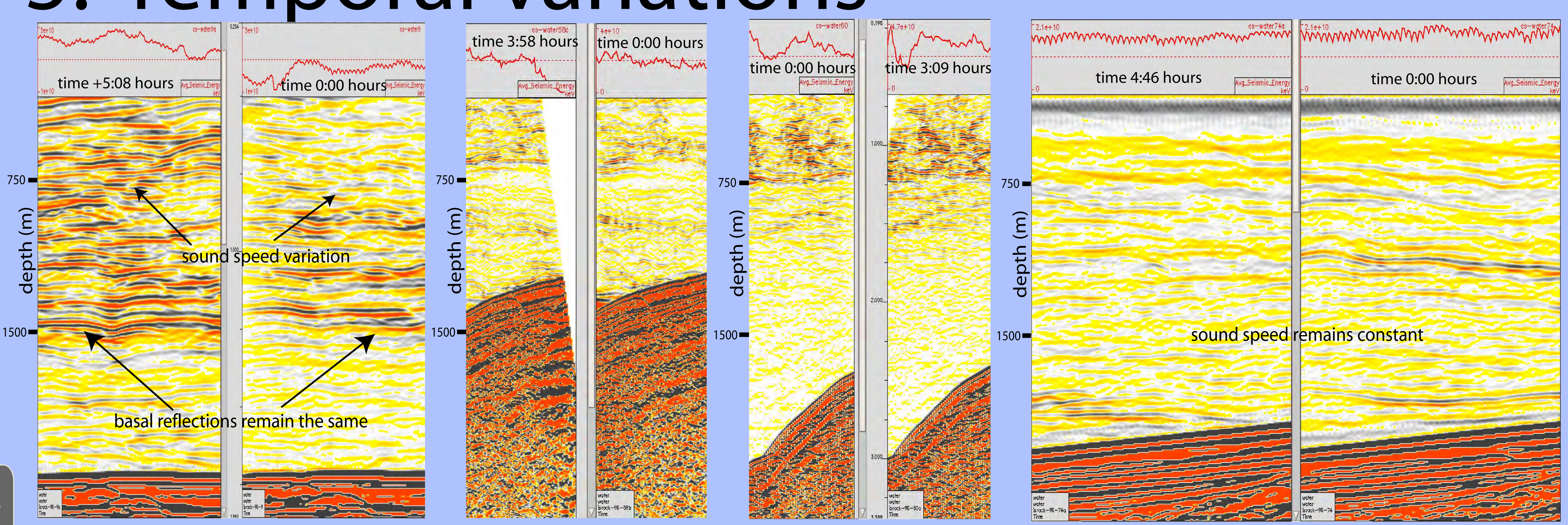

Figure 7. a) Line9 b) Line58 c) Line60 d) Line74 and corresponding reshoot. Plotted on top is the average seismic energy for the water column