Ambient noise tomography: North Sea

E. Crowder[1,*], N. Rawlinson[2], D. Cornwell[1], C. Sammarco[1], E. Galleti[3], A. Curtis[3]

1. School of Geosciences, University of Aberdeen
2. Department of Earth Sciences, University of Cambridge
3. School of Geosciences, University of Edinburgh

NERC SCIENCE OF THE ENVIRONMENT

Centre for Doctoral Training (CDT) in Oil and Gas

Ambient noise tomography: North Sea

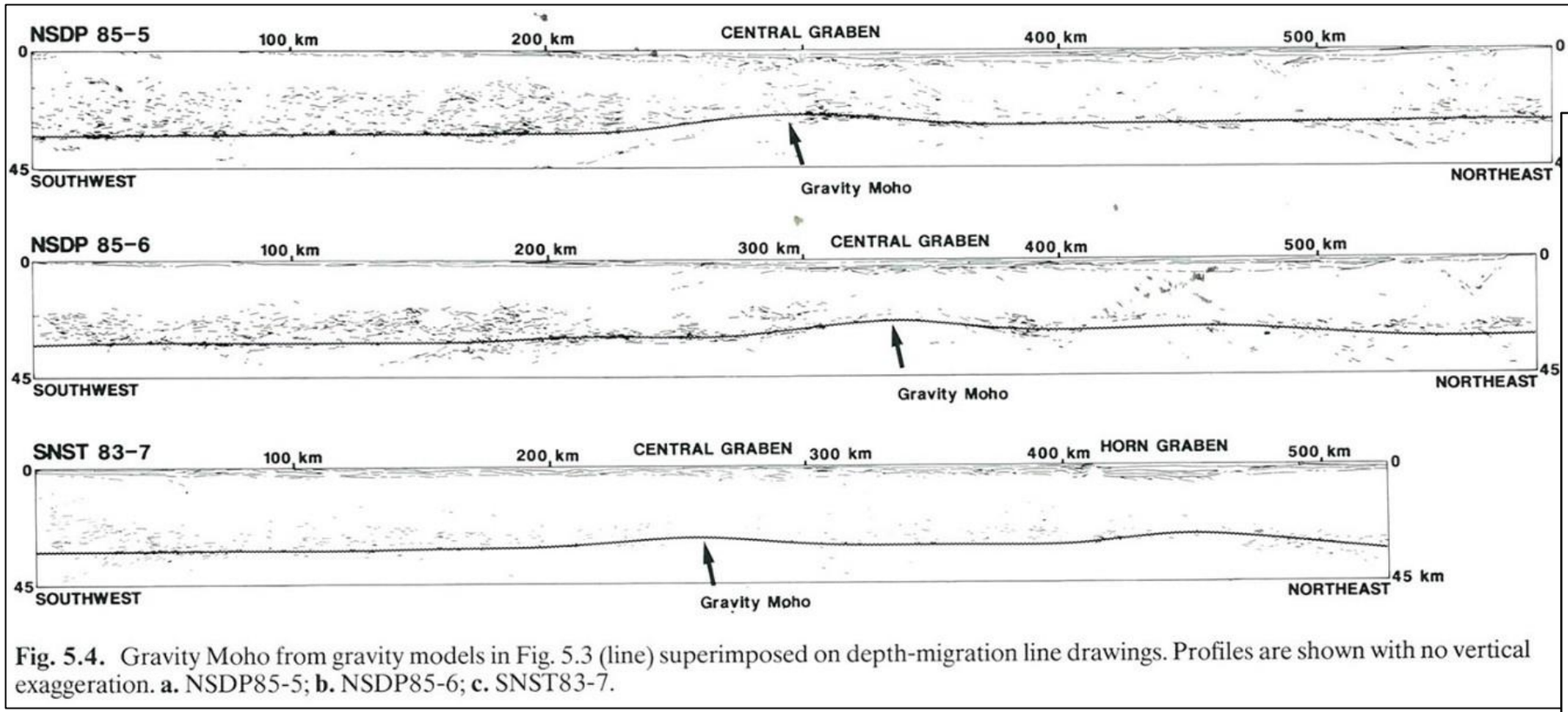


Fig. 5.4. Gravity Moho from gravity models in Fig. 5.3 (line) superimposed on depth-migration line drawings. Profiles are shown with no vertical exaggeration. **a.** NSDP85-5; **b.** NSDP85-6; **c.** SNST83-7.

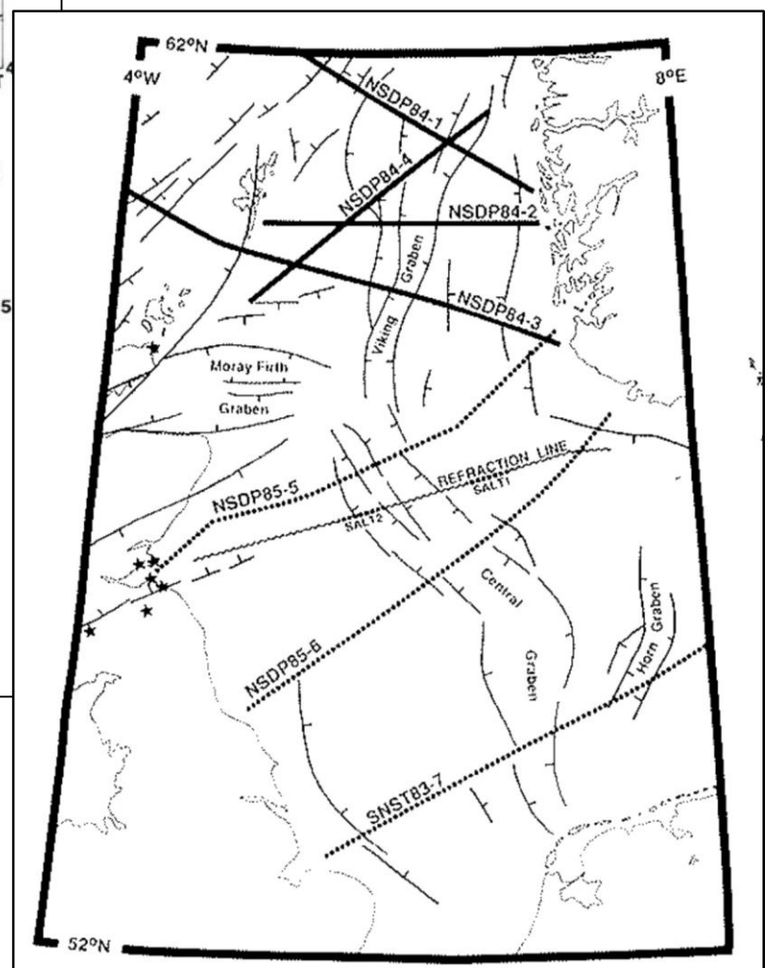
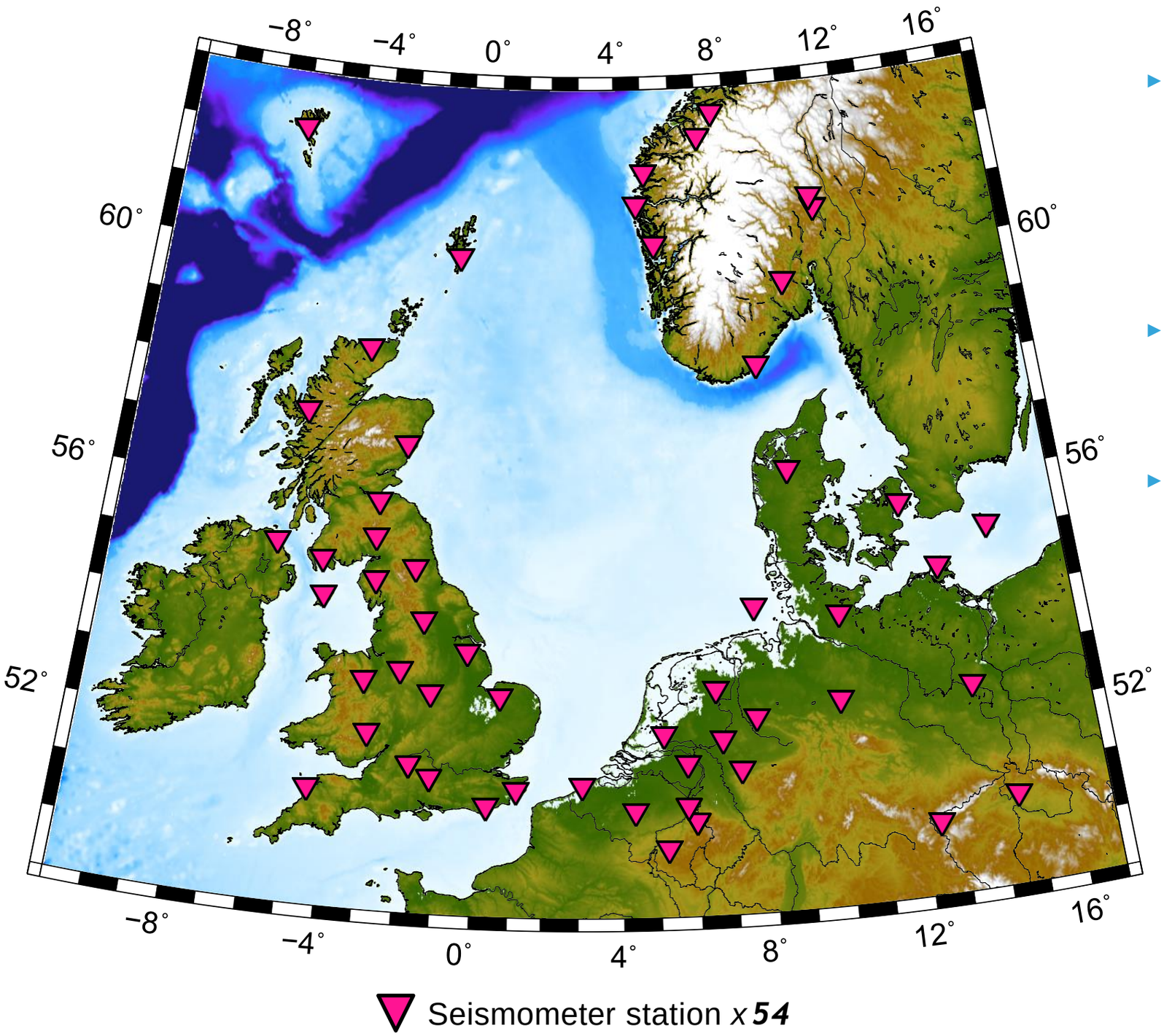


Fig. 5.1. Map of the North Sea area showing the location of the seismic profiles discussed in the text. Thin solid lines are principal fault structures. Stars indicate crustal-xenolith localities reported by Upton *et al.* (1983) and Hunter *et al.* (1984).

- Directly constrained by only a few *1980*'s deep seismic lines
- Crustal thickness and composition are critical *a priori* information for quantitative basin analysis
- Inaccessibility of outcrop, large areas blanketed in thick sediments and volcanics, obscuring deeper basement

Ambient noise tomography: North Sea



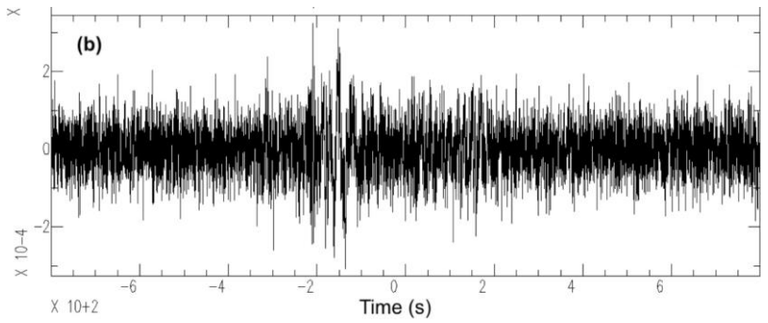
Continuously-recording 3-component broadband seismometer stations

- Dataset access - stations from different national networks that have different instruments, responses and sample rates
- Previously thought to be too noisy (highly attenuative crust)
- Recent advances in processing method (phase weighted stacking, ts-PWS, Ventosa et al., 2017)

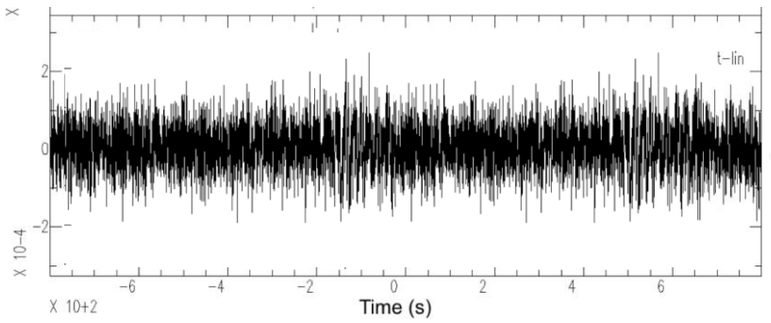
Ventosa, S., Schimmel, M. and Stutzmann, E., 2017. Extracting surface waves, hum and normal modes: time-scale phase-weighted stack and beyond. Geophysical Journal International, 211(1), pp.30-44.

Method: cross-correlation

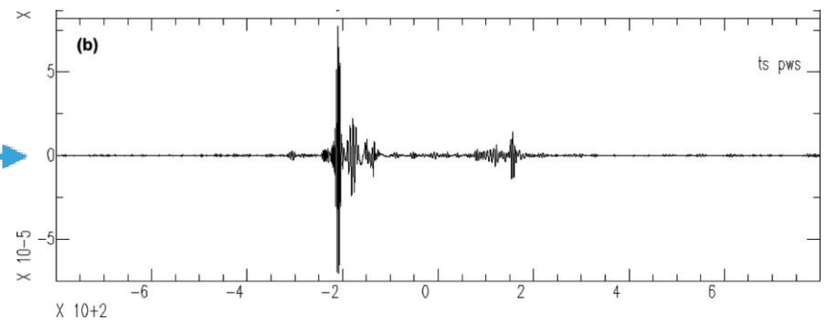
*Continuous noise from station **X***



*Continuous noise from station **Y***

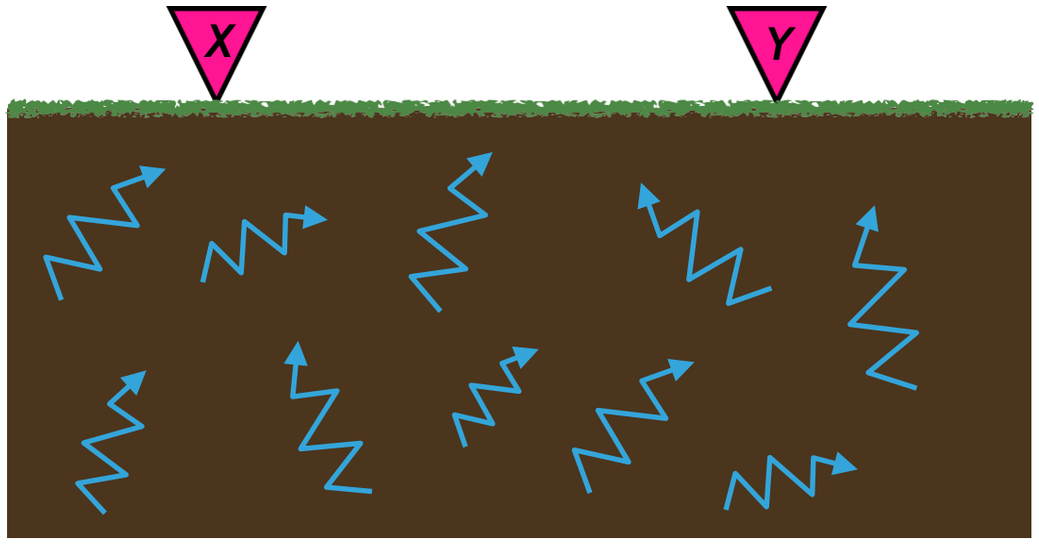


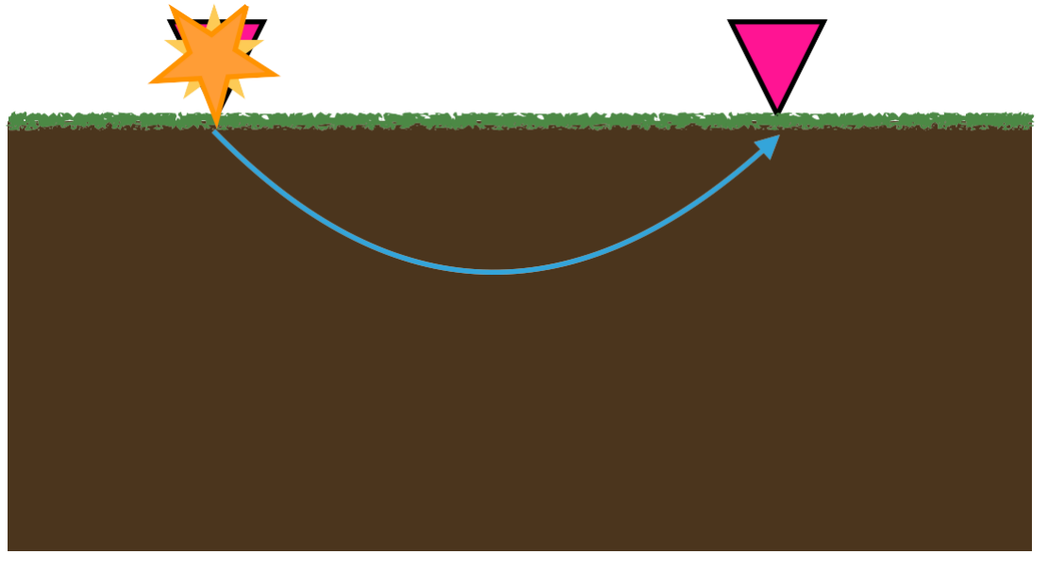
Cross-correlated output



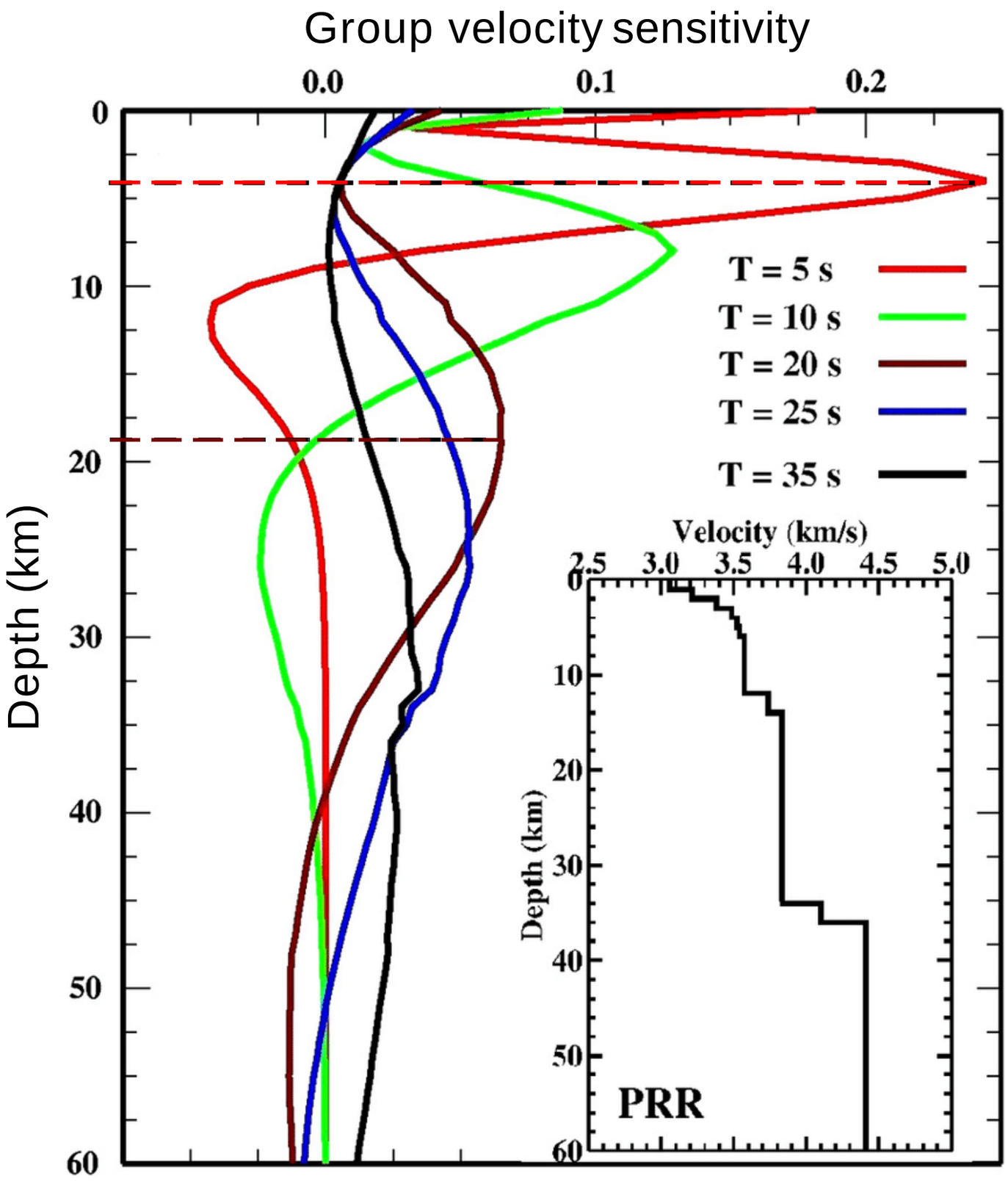
- If this noise is random, the only common "signal" is a function of the impulse response between the two stations

- Each receiver can be turned into a virtual seismic source
- Surface waves are created and S-wave velocities derived from them



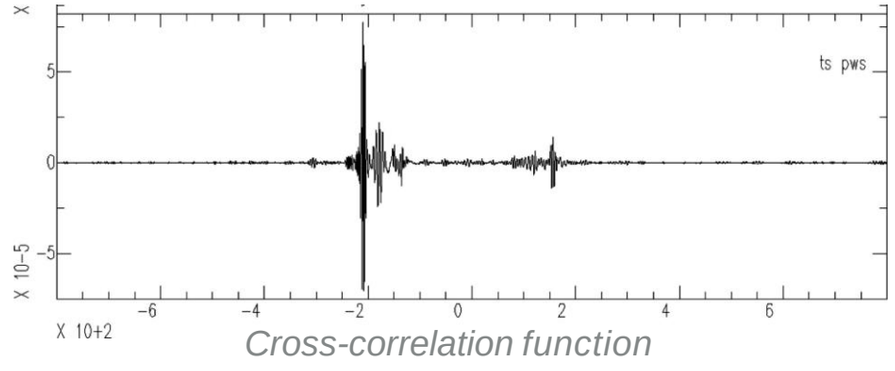


Method: surface wave dispersion analysis



Shorter periods *(higher frequencies)* are most sensitive to **shallow** crustal structures

Longer periods *(lower frequencies)* are most sensitive to **deeper** crustal structures

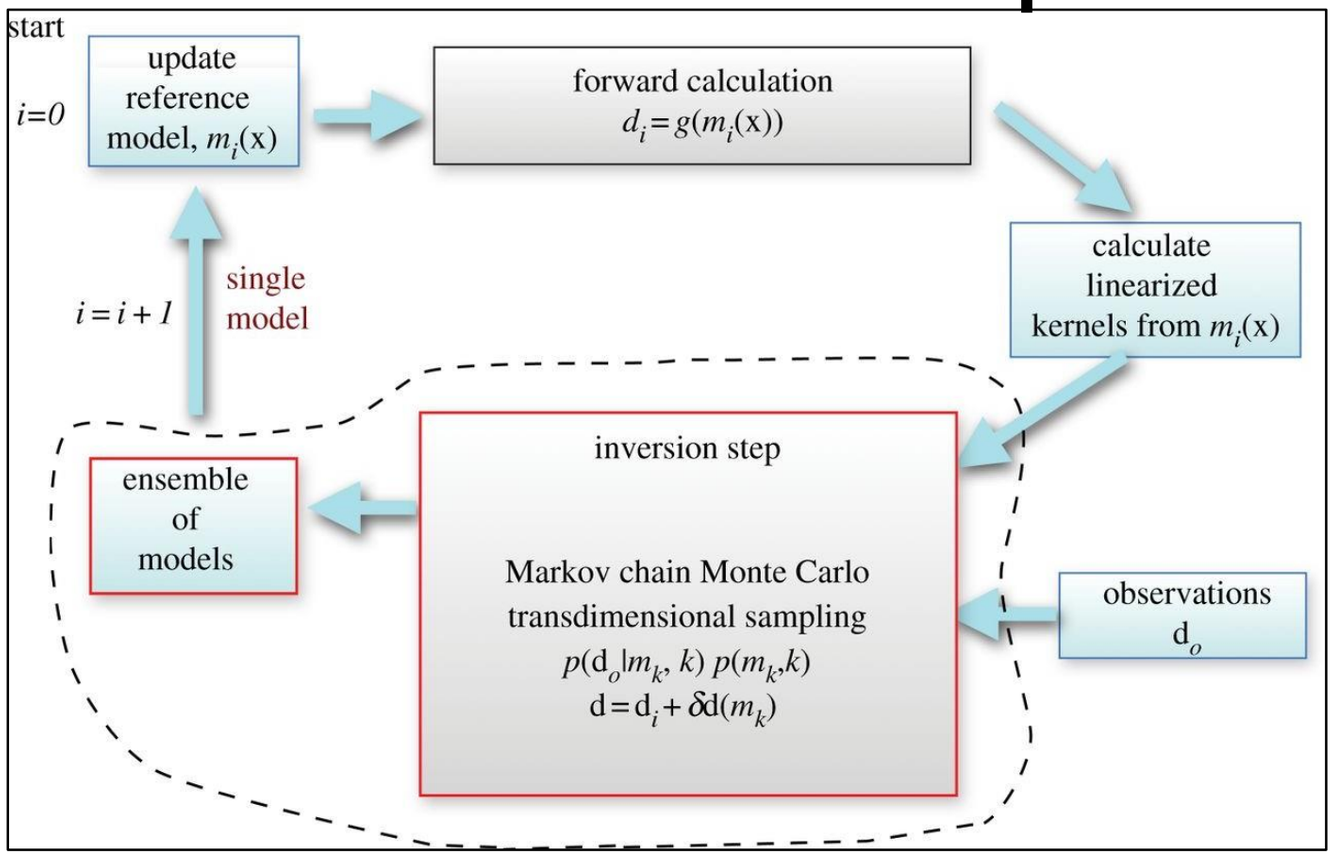


Cross-correlation function

Method: inversion for velocity model

- Inter-station surface wave travel-times inverted for V_S
- Two stage transdimensional, hierarchical, Bayesian inversion *(Bodin & Sambridge, 2009)*

Inversion process



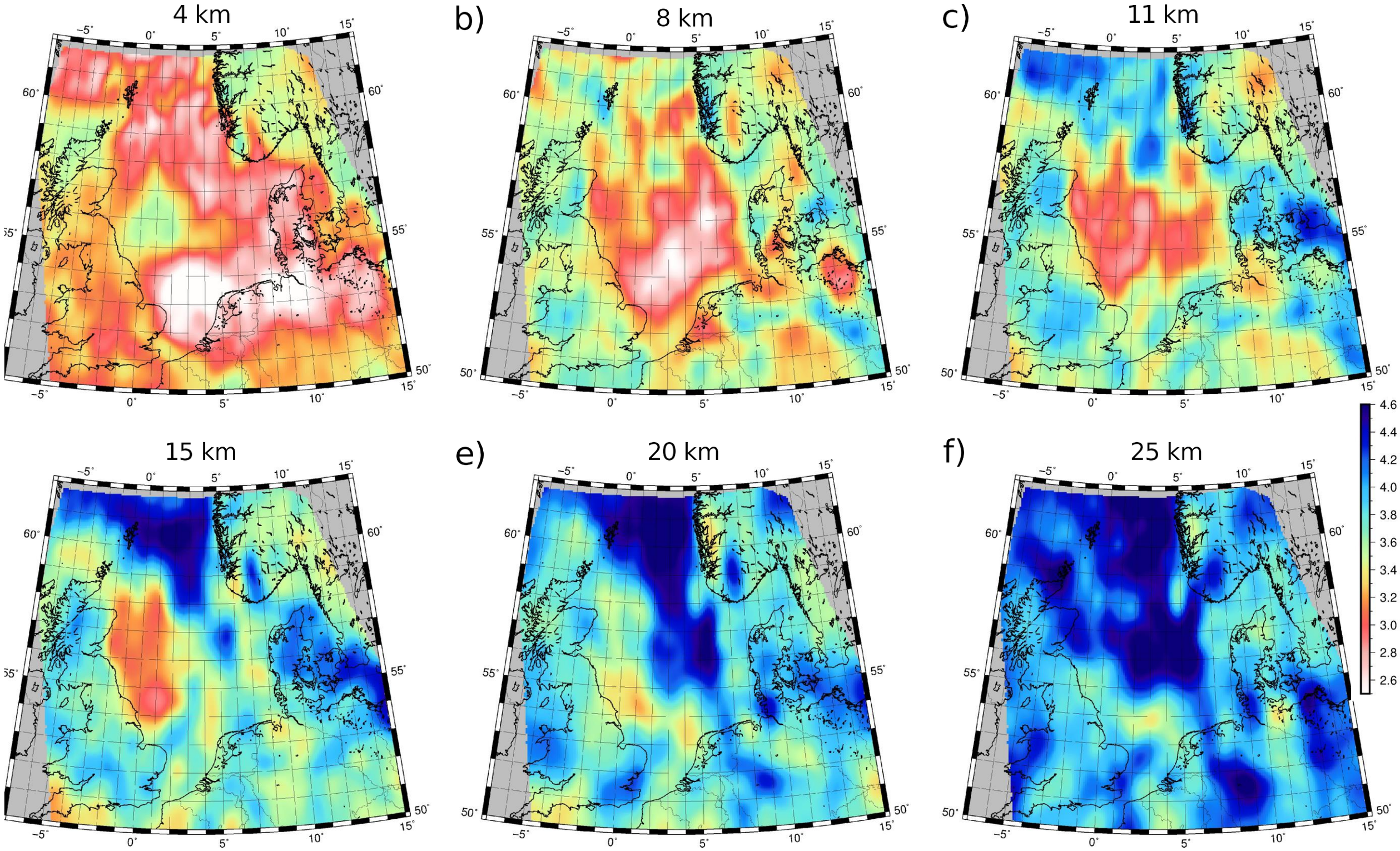
- Data driven parameterisation that allows the number and distribution of velocity unknowns to vary, and the data noise to also be treated as an unknown in the inversion

Bodin, T., Sambridge, M., Tkalčić, H., Arroucau, P., Gallagher, K. and Rawlinson, N., 2012. Transdimensional inversion of receiver functions and surface wave dispersion. Journal of Geophysical Research: Solid Earth, 117(B2).

Red: *slower velocity*

Blue: *faster velocity*

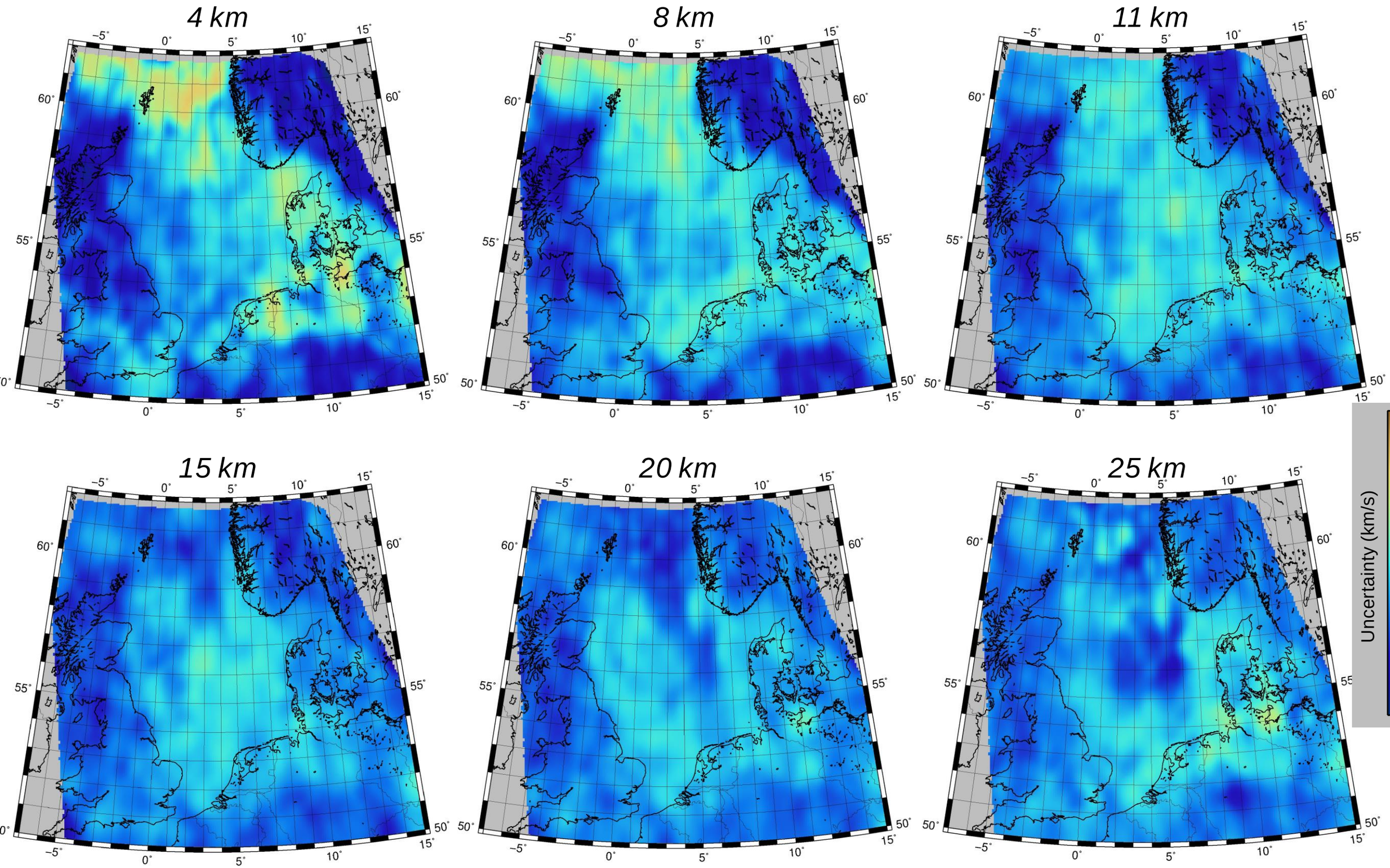
Results: shear velocity (V_s) model



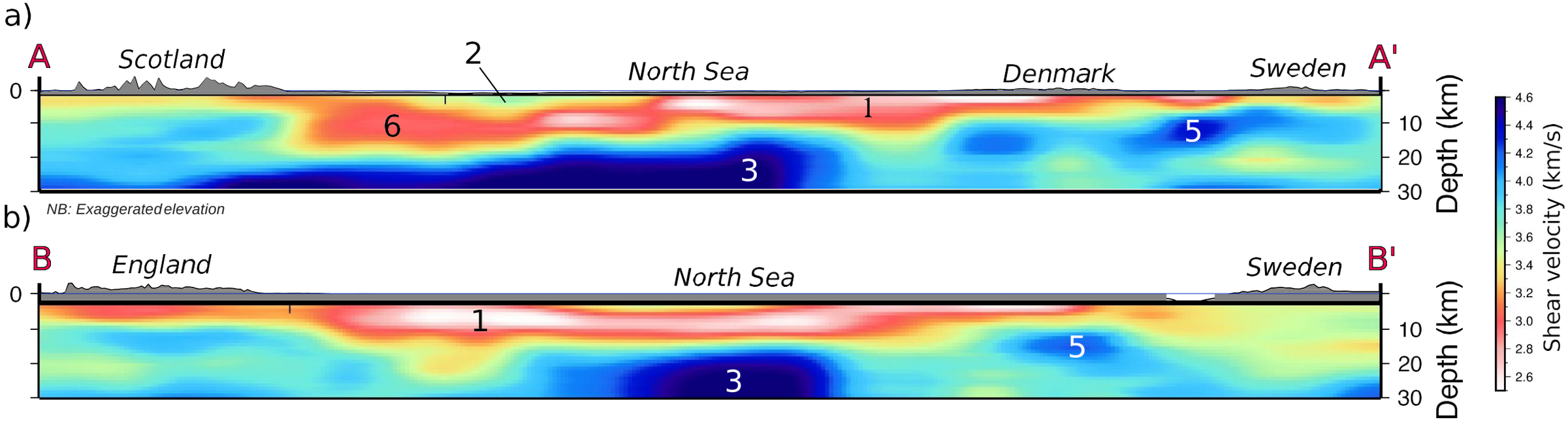
Blue: *low uncertainty*

Brown: *higher uncertainty*

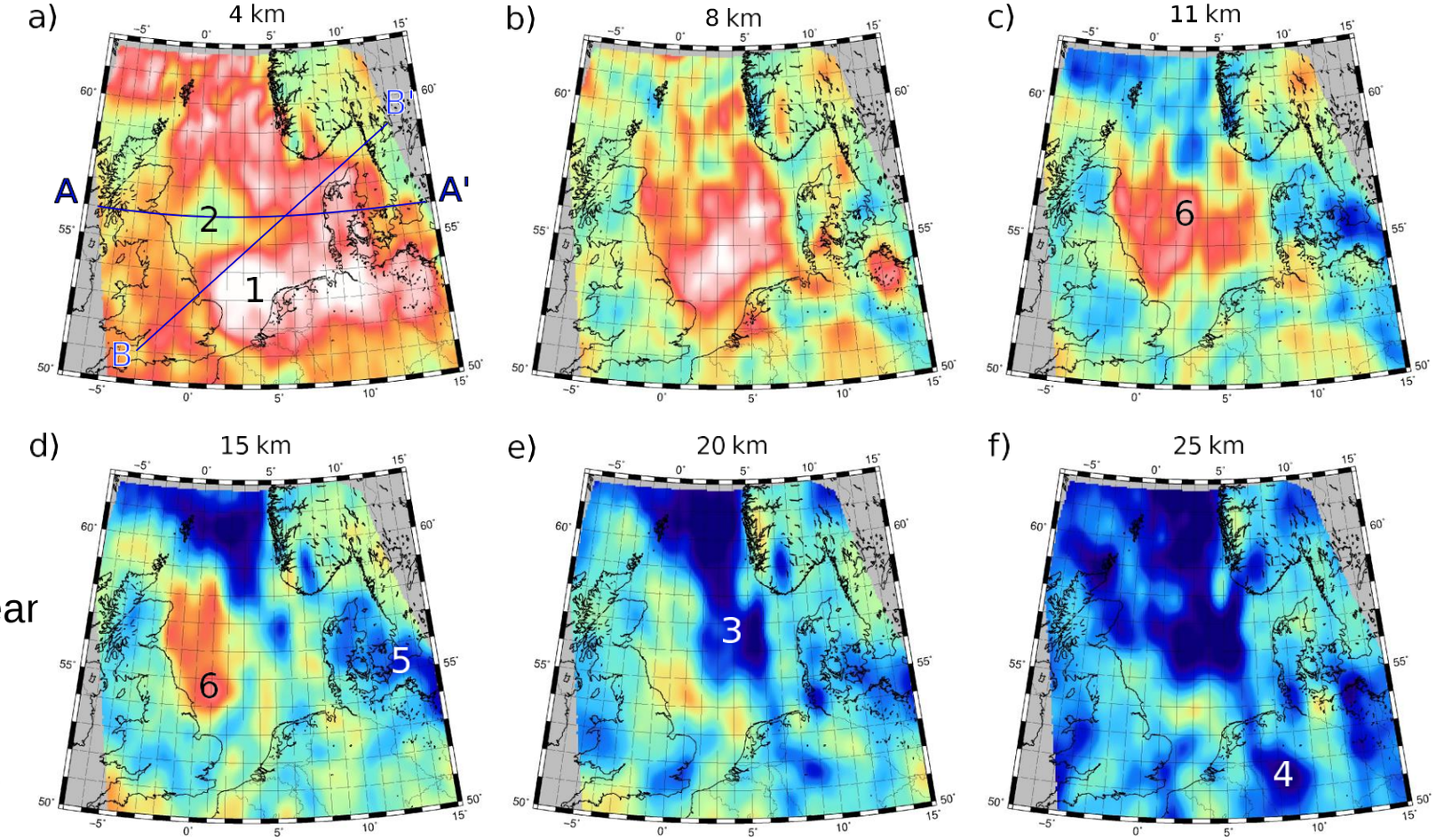
Results: shear velocity (V_s) model



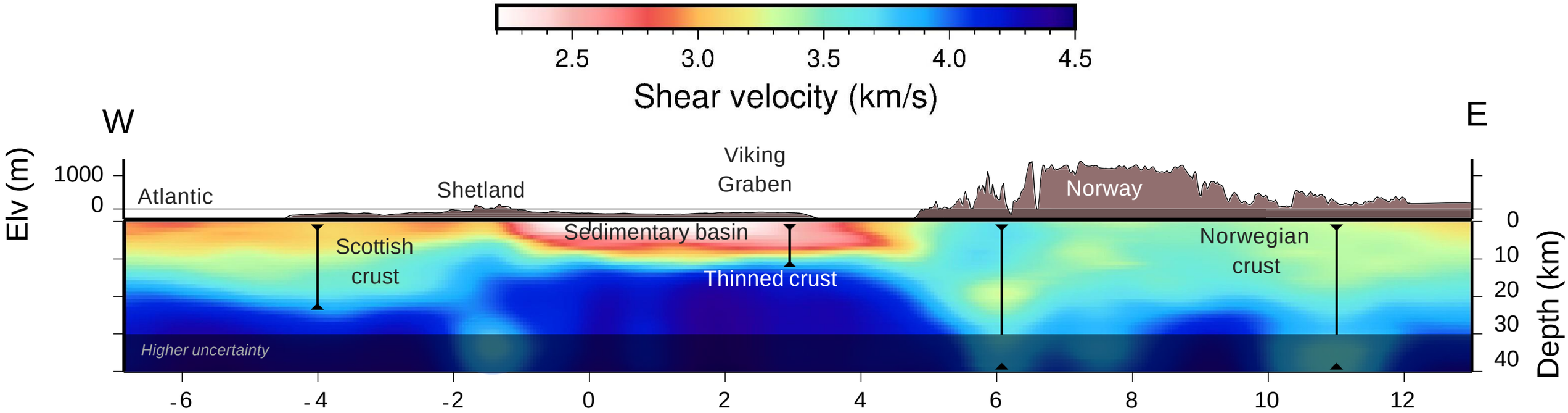
Interpretation: shear velocity (V_s) model



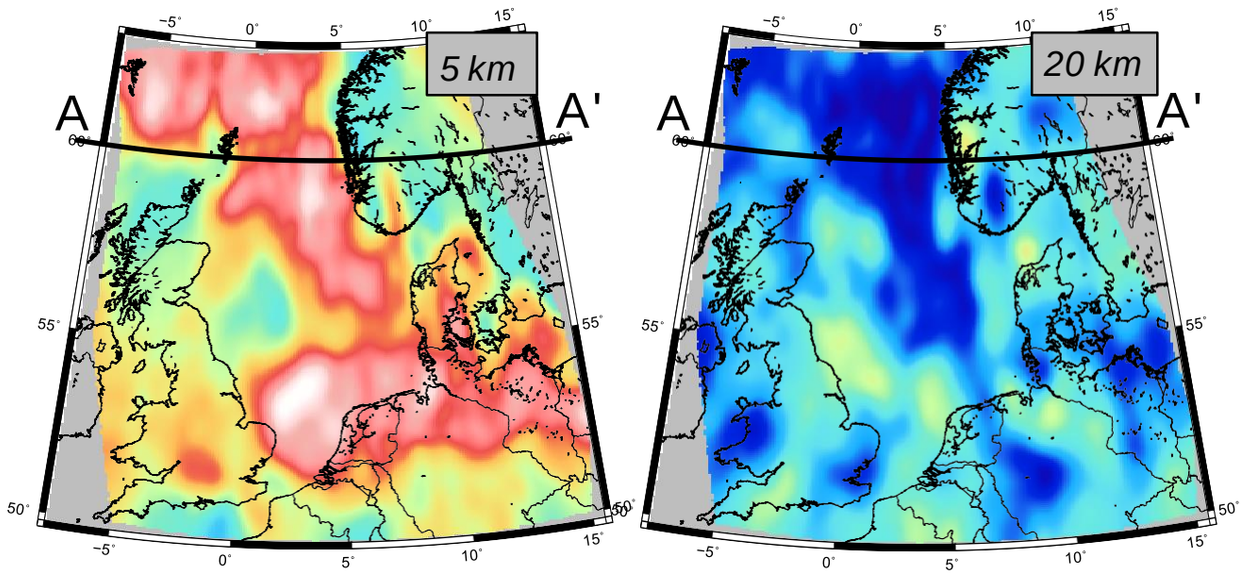
1. Slow velocities of sedimentary rocks
2. Relatively faster velocities of Mid North Sea High
3. Significantly elevated velocities - mantle influence, thin crust
4. Fast velocity (thinned crust) below Germany - connection to NS?
5. Relatively faster velocities - Trans European Suture Zone
6. Anomalously slow velocities in mid-crust



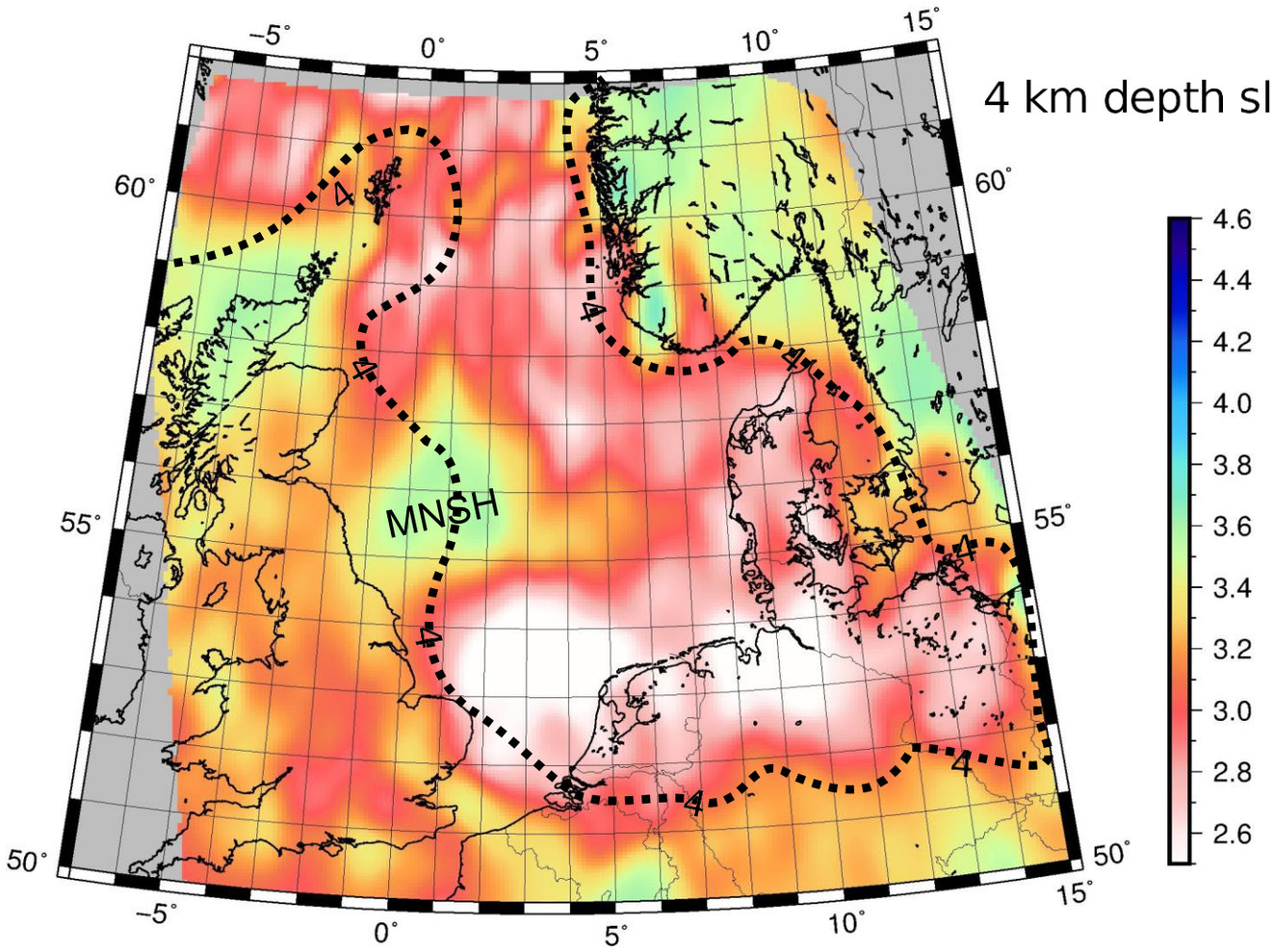
Interpretation: shear velocity (V_s) model



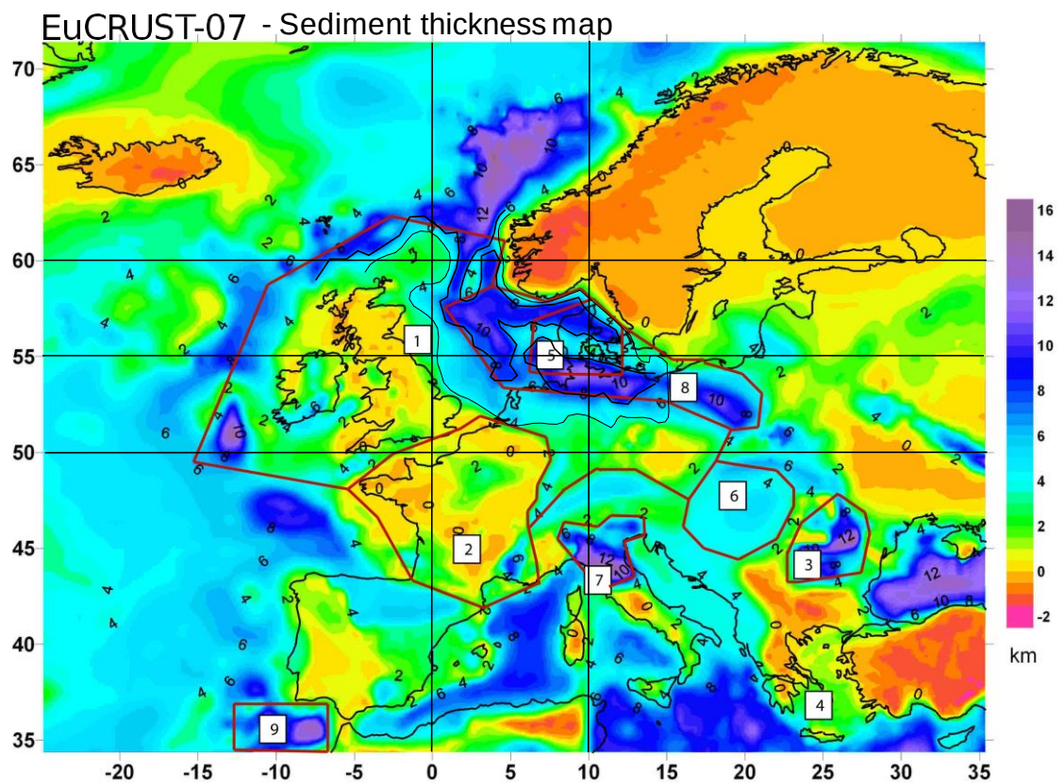
- Significantly thinned crust below Viking Graben (*~14 km*)
- Thicker crust below Norway (*40+ km*) then Shetland Plateau (*~23 km*)
- Different shear velocity character in Scottish vs. Norwegian crust



Sediment thickness map comparison

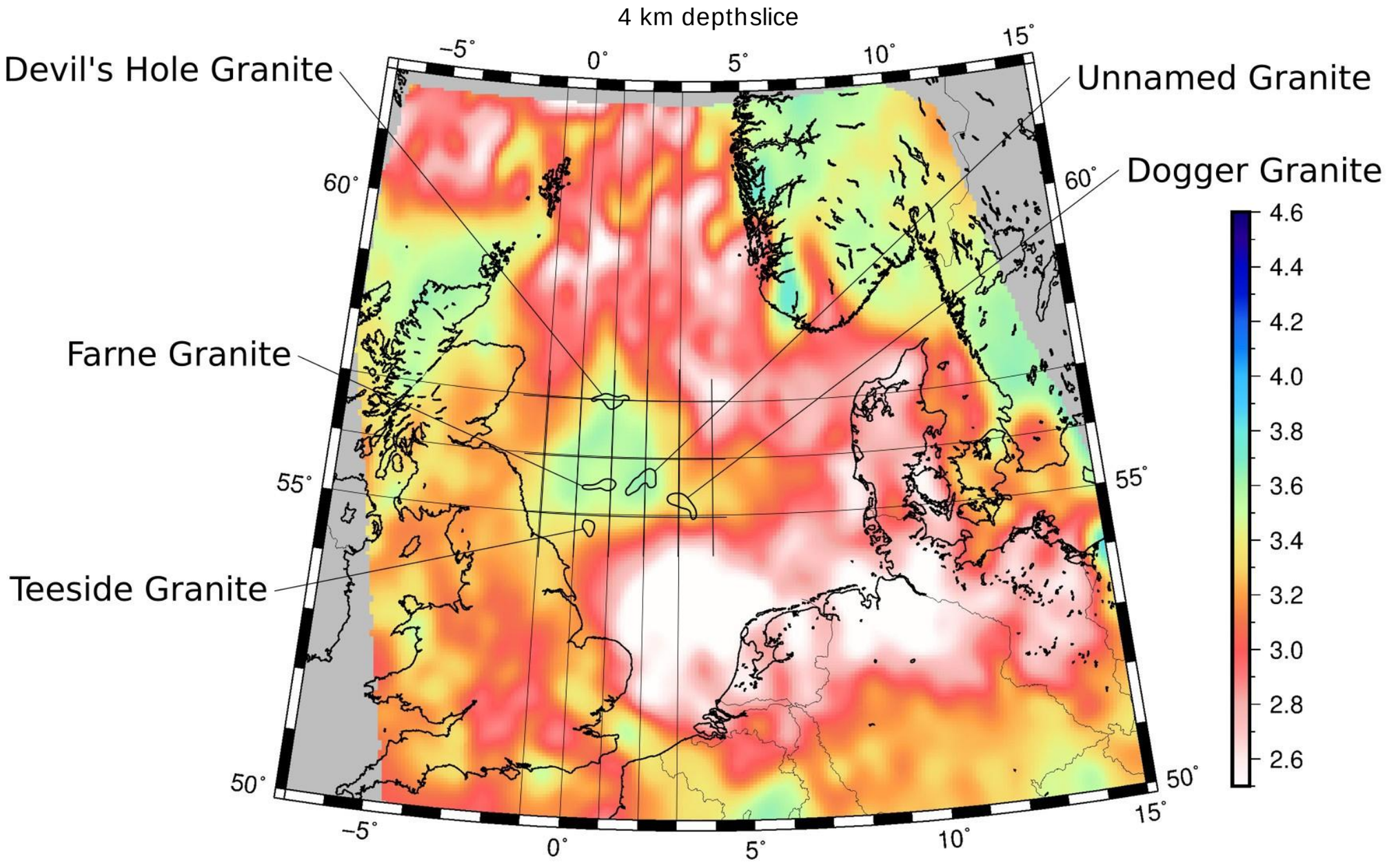


- Comparison to EuCRUST-07: a compilation based on ~15 previous regional compilations for crustal parameters *(Tesauro et al., 2008)*
- Generally good fit to existing sediment thickness map, some discrepancy across Mid North Sea High

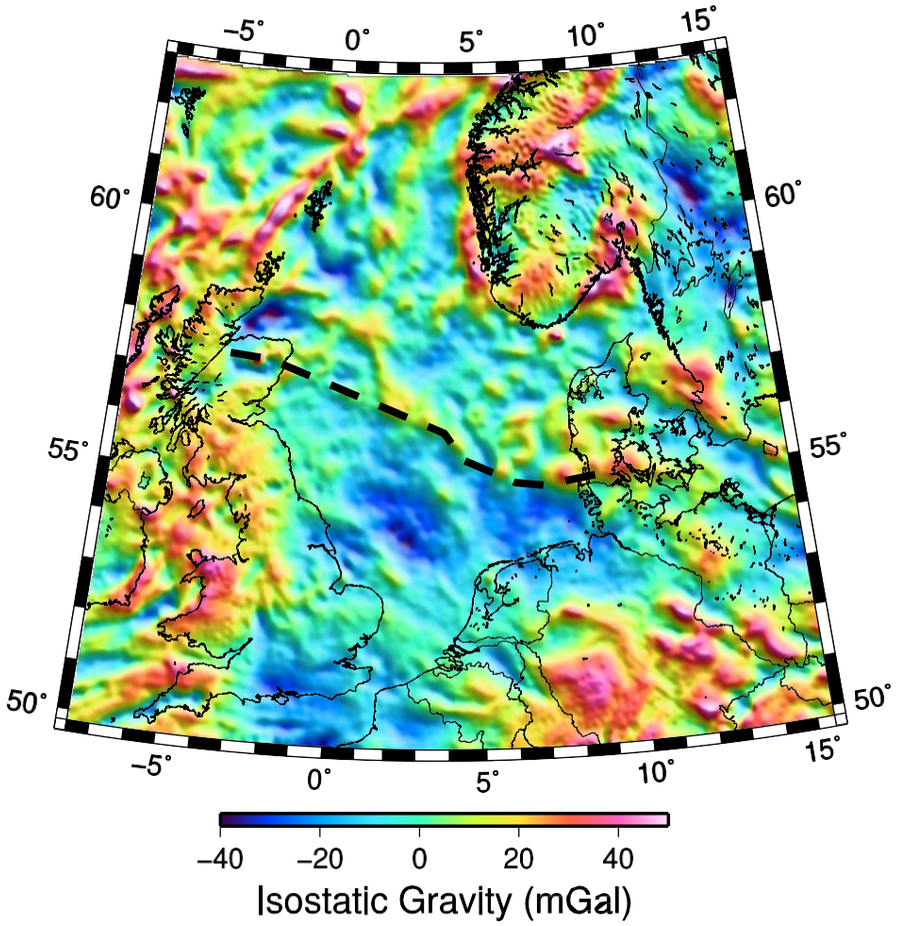


Tesauro, M., Kaban, M.K. and Cloetingh, S.A., 2008. EuCRUST-07: A new reference model for the European crust. Geophysical Research Letters, 35(5).

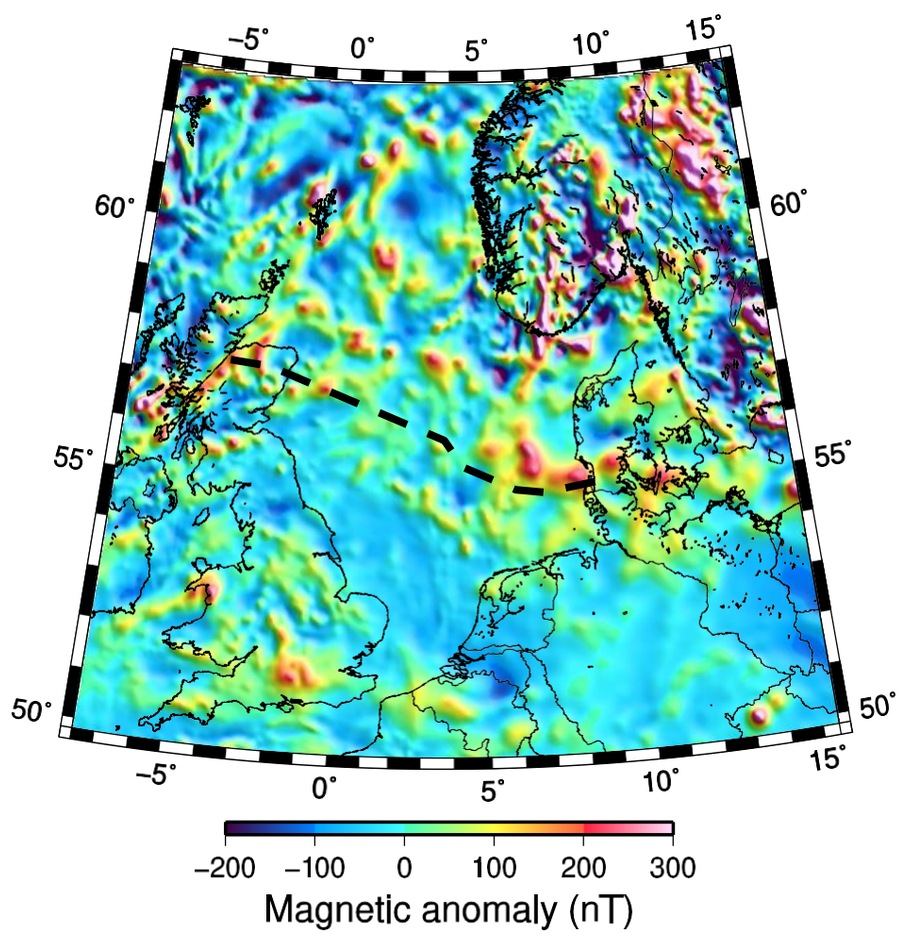
Mid North Sea High: granite-cored basement

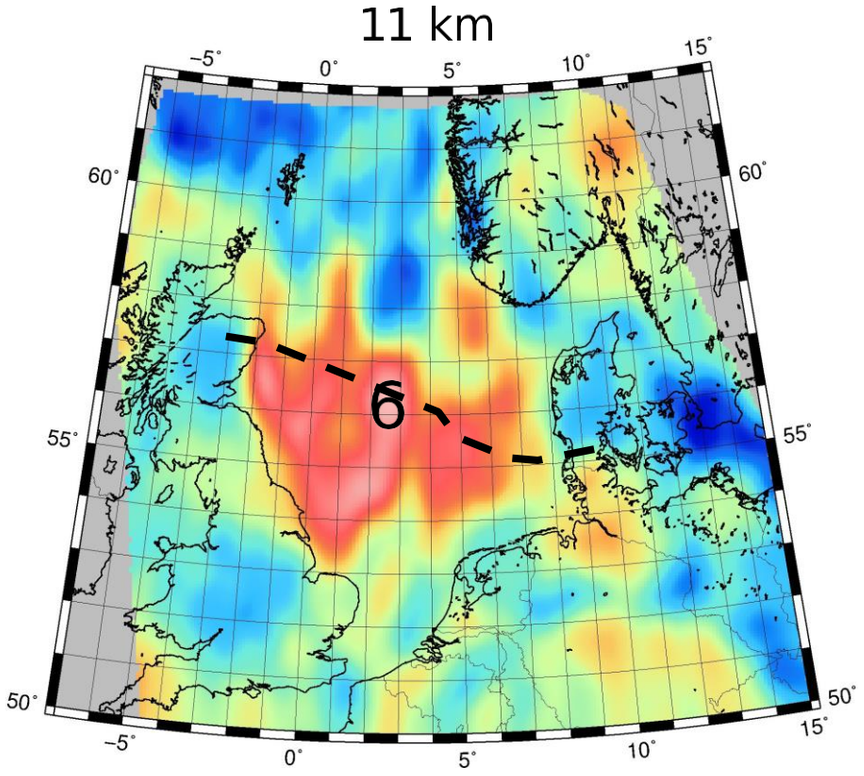


Gravity & magnetic data



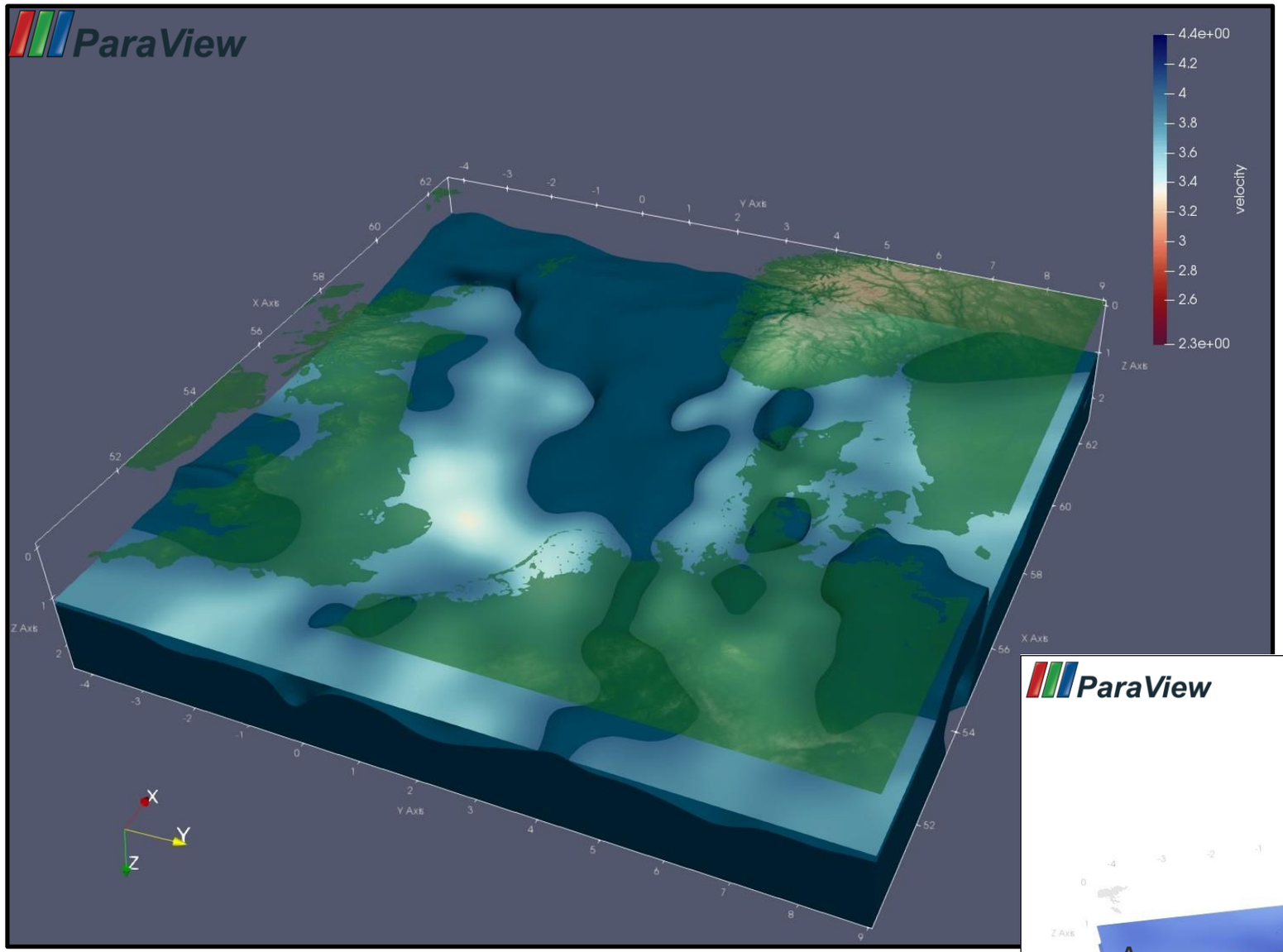
- Regional change of potential field character across dashed line
  - Corresponding shear velocity change in mid-crust



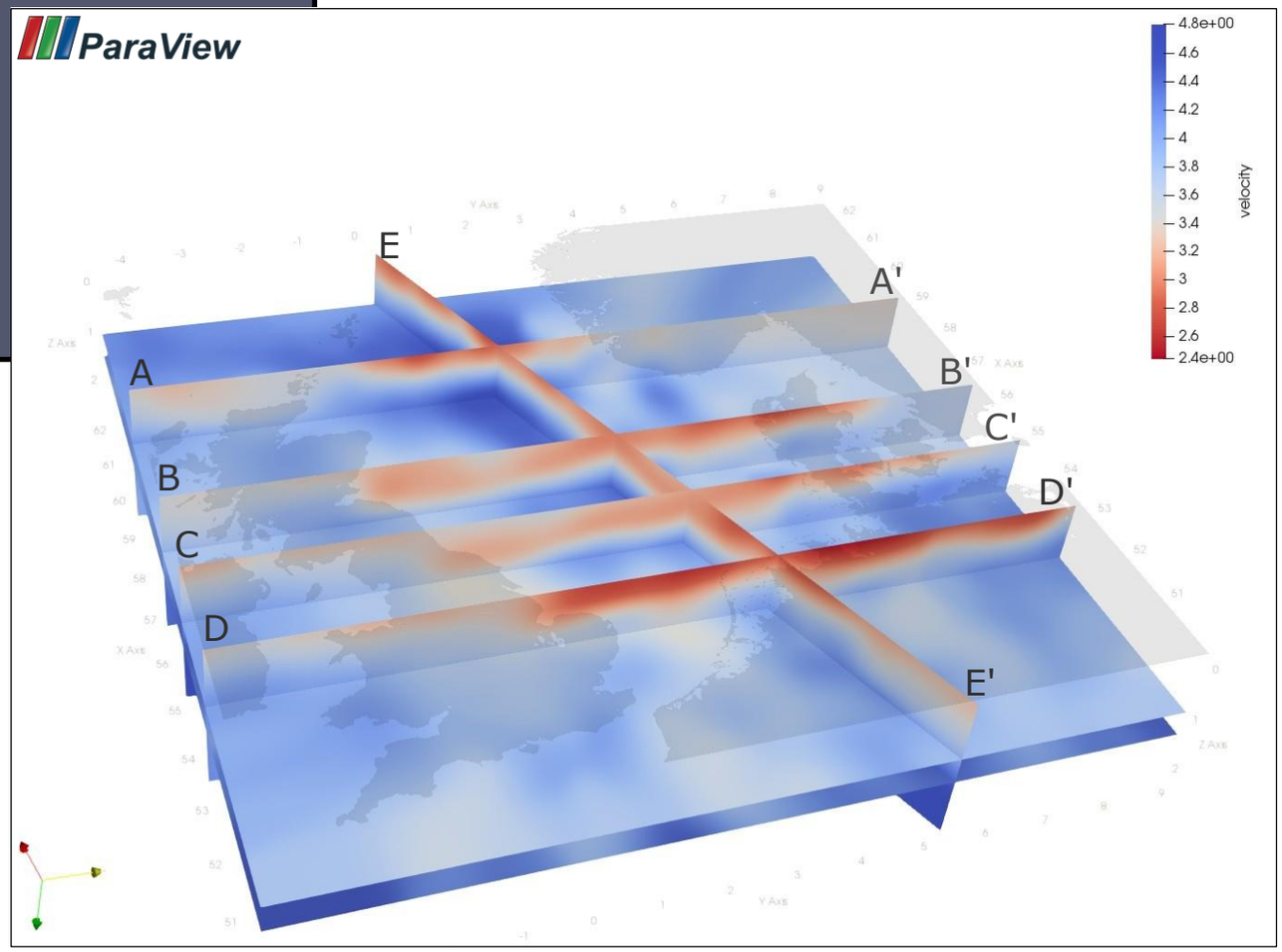


6. Anomalously low velocities in mid-crust

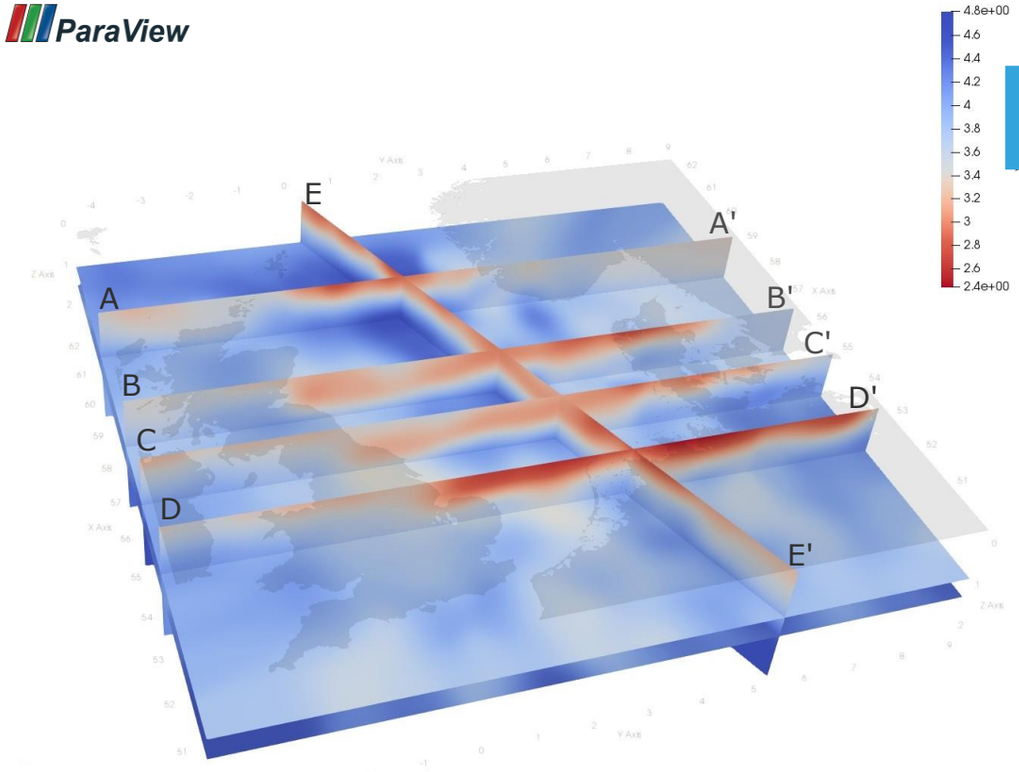
3D visualisation of results

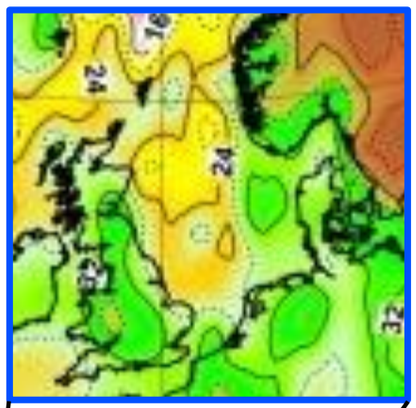


- ParaView: open-source data analysis and visualisation software
- Depth slices, rift parallel and perpendicular cross-sections
- Surface of Moho (base of crust) based on equal velocity surface



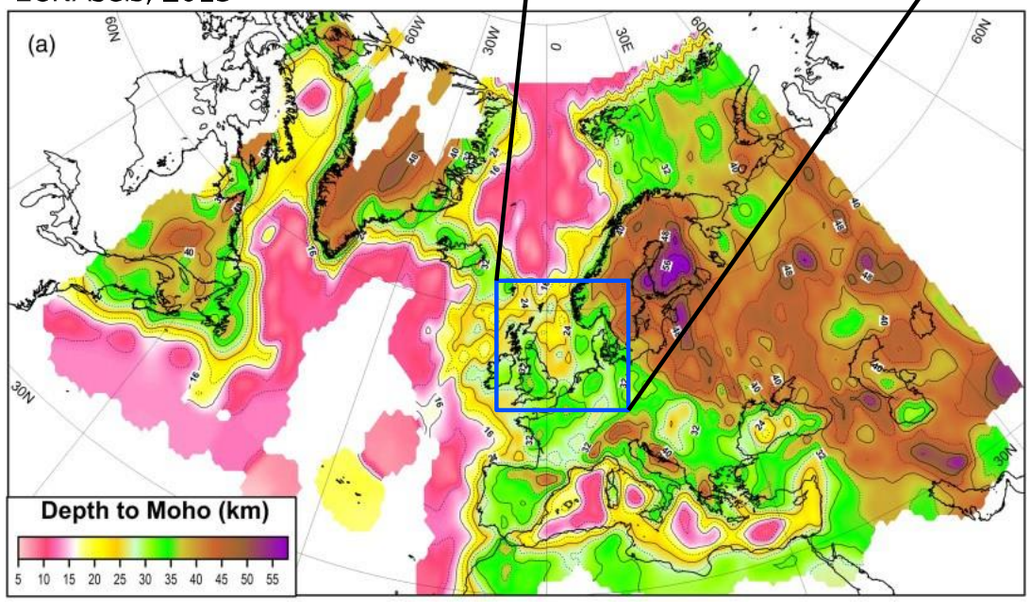
Model cross-sections

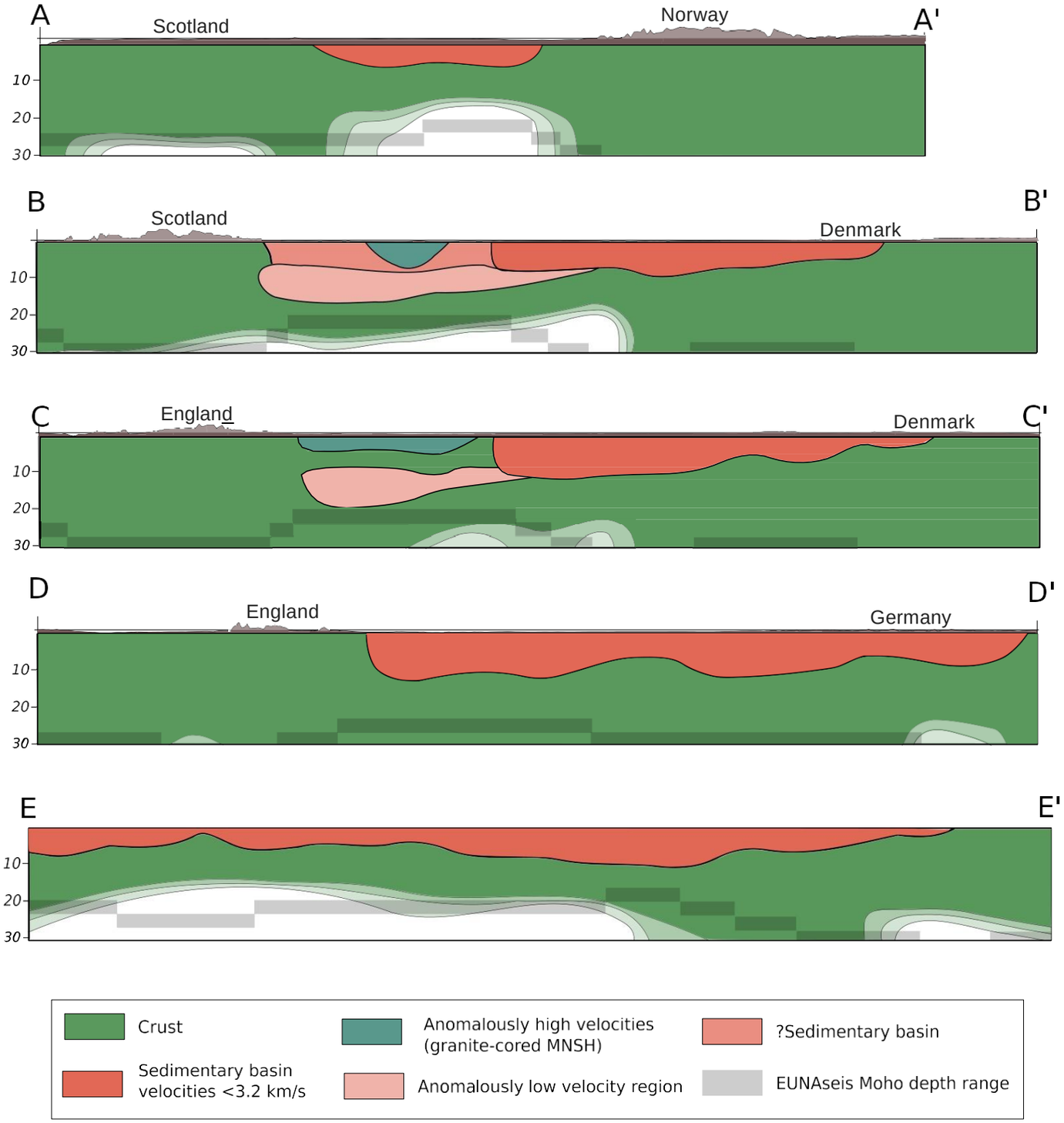




Crustal thickness map

EUNAseis, 2013

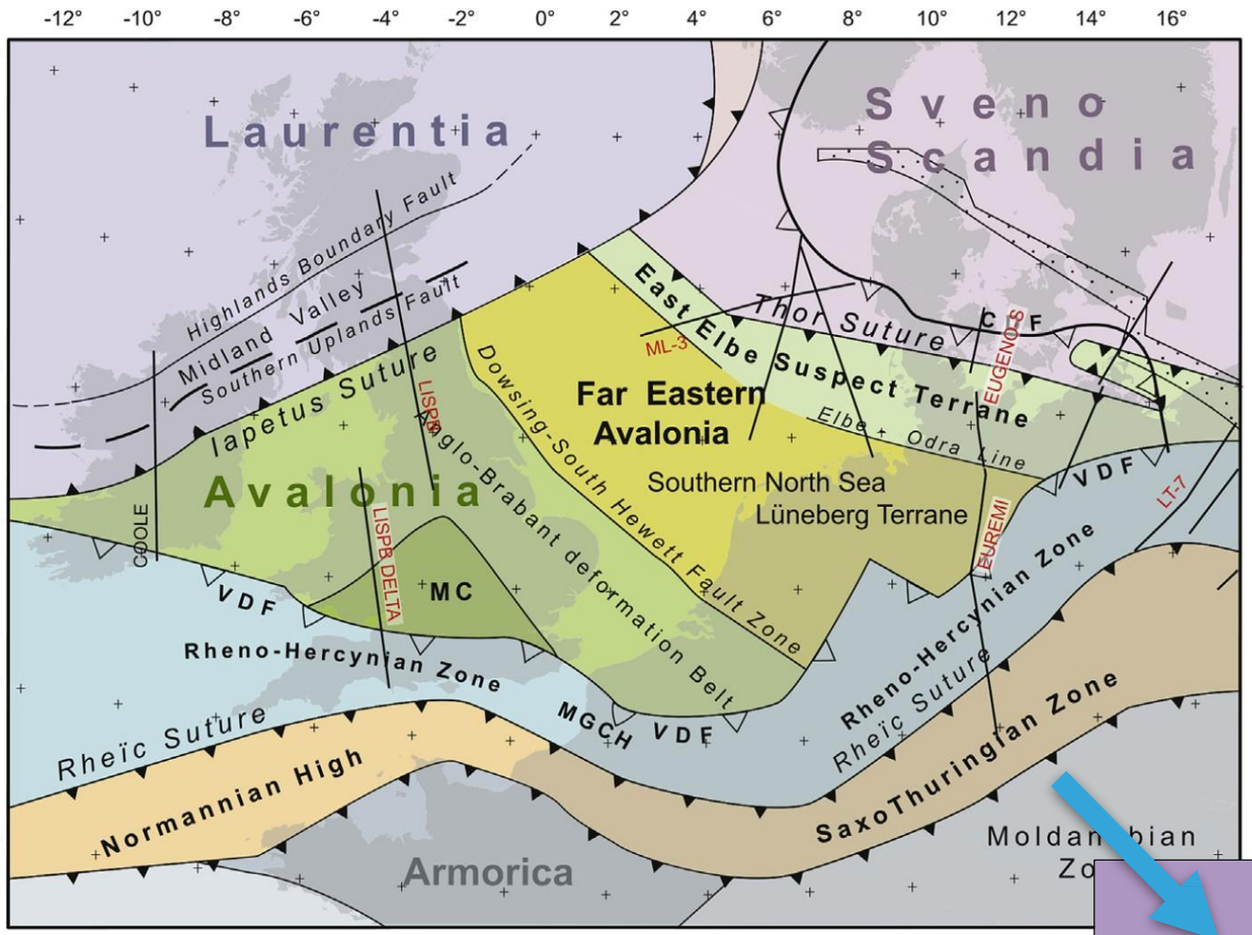




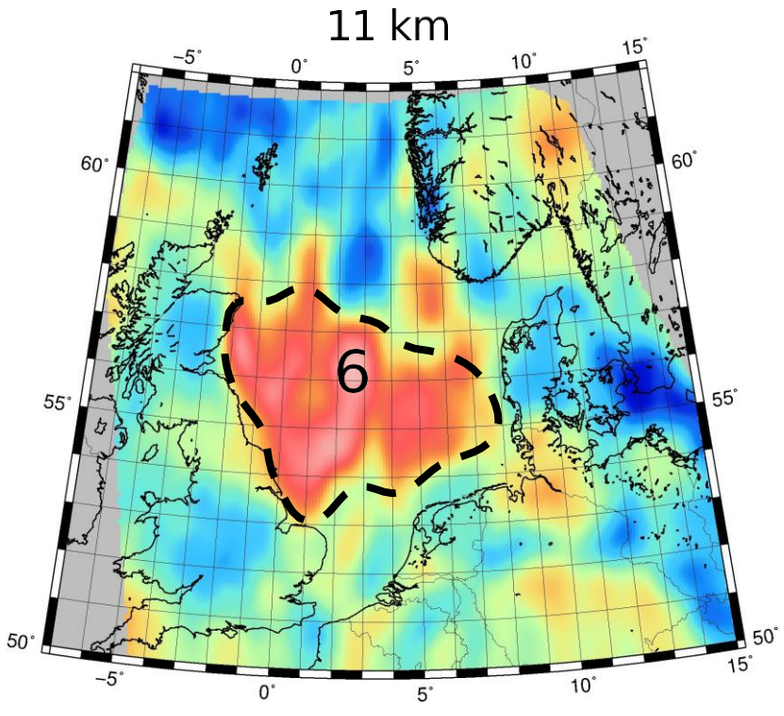
Artemieva, I.M. and Thybo, H., 2013. EUNAseis: a seismic model for Moho and crustal structure in Europe, Greenland, and the North Atlantic region. Tectonophysics, 609, pp.97-153.

Caledonian orogeny

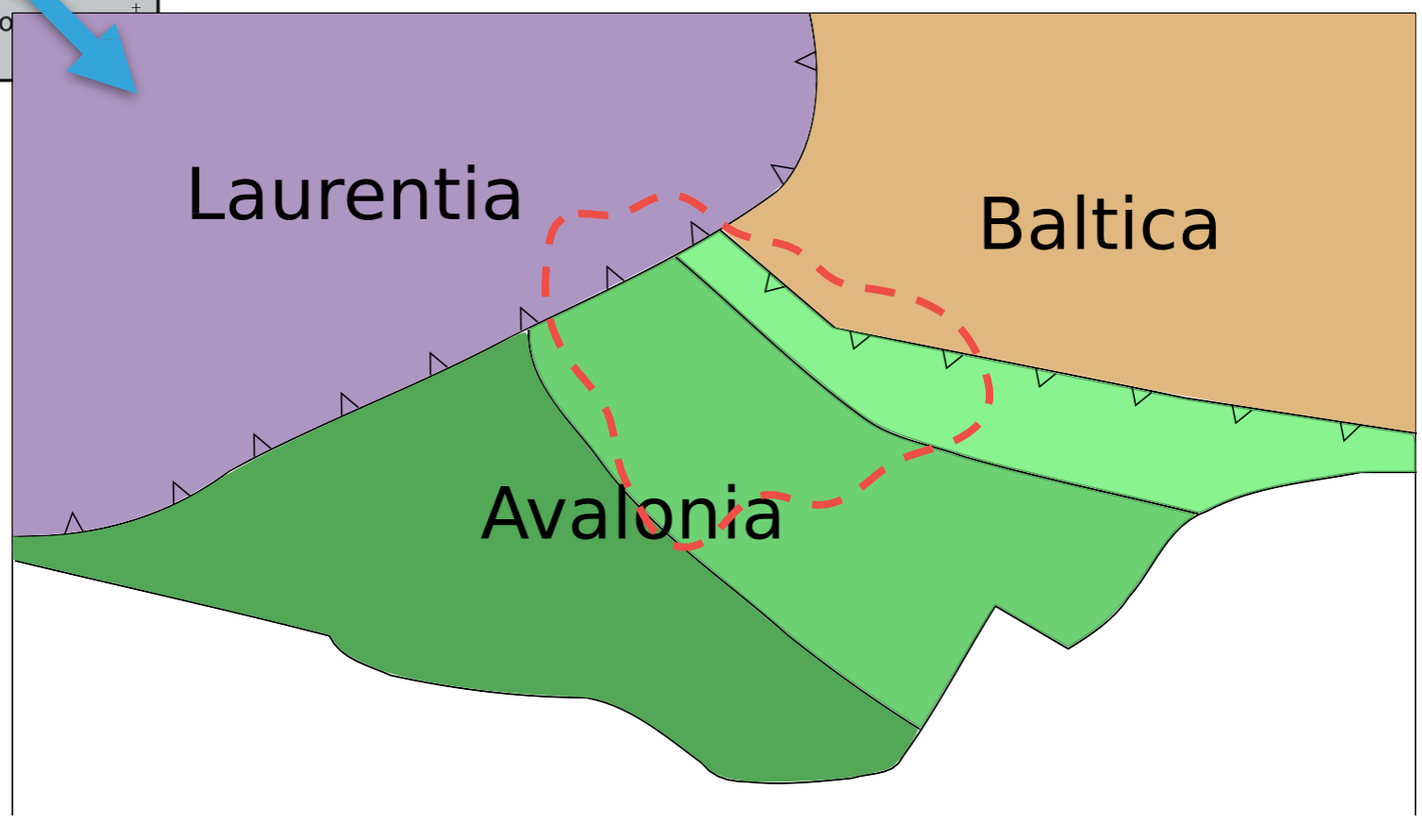
- Triple plate collision zone in the Silurian - Devonian times
- Subduction of *Baltica* under *Avalonia* took place before the closure of the Iapetus Ocean and collision with *Laurentia*



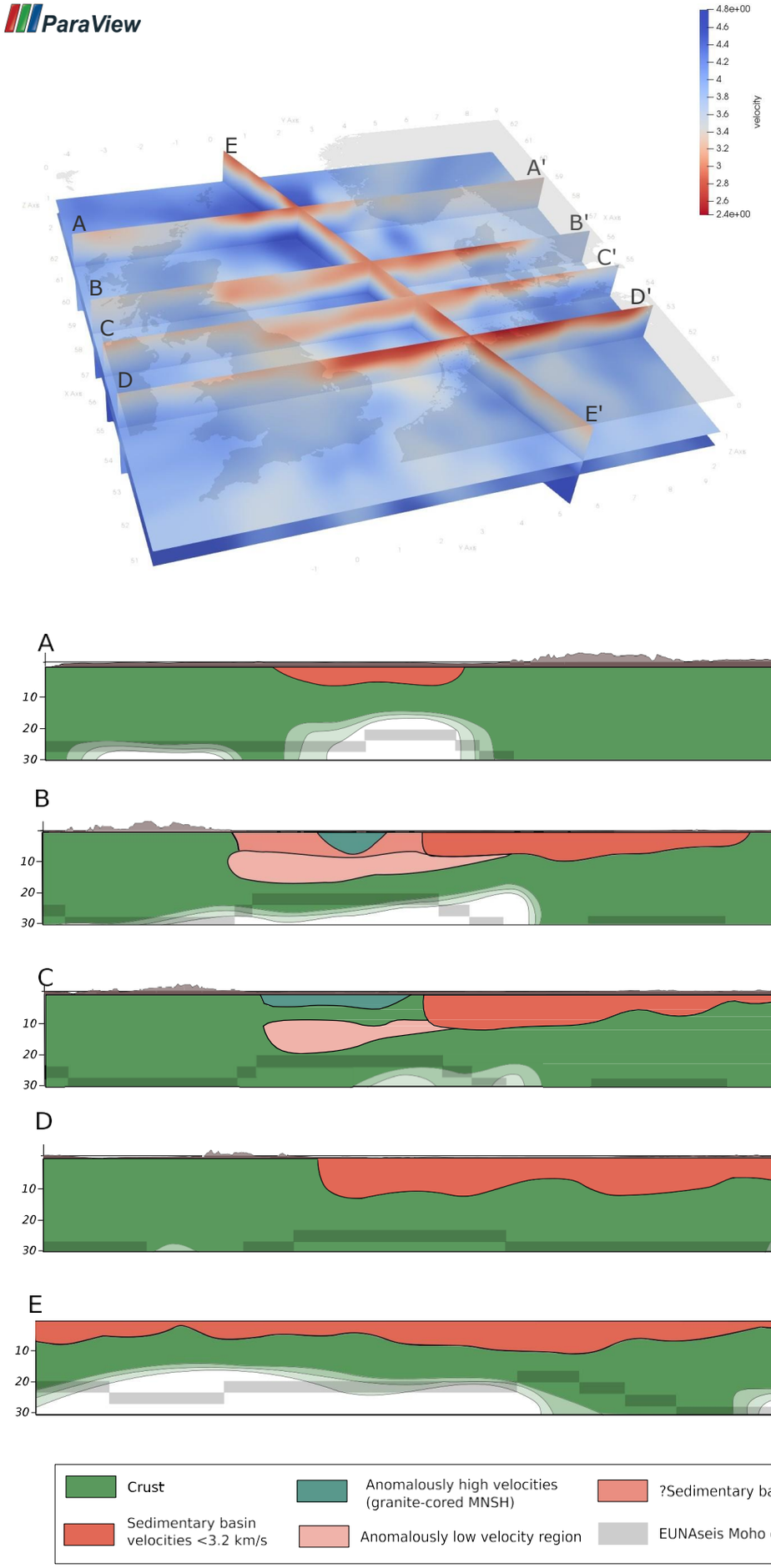
Pharaoh, T.C., 1999. Palaeozoic terranes and their lithospheric boundaries within the Trans-European Suture Zone (TESZ): a review. Tectonophysics, 314(1-3),pp.17-41.

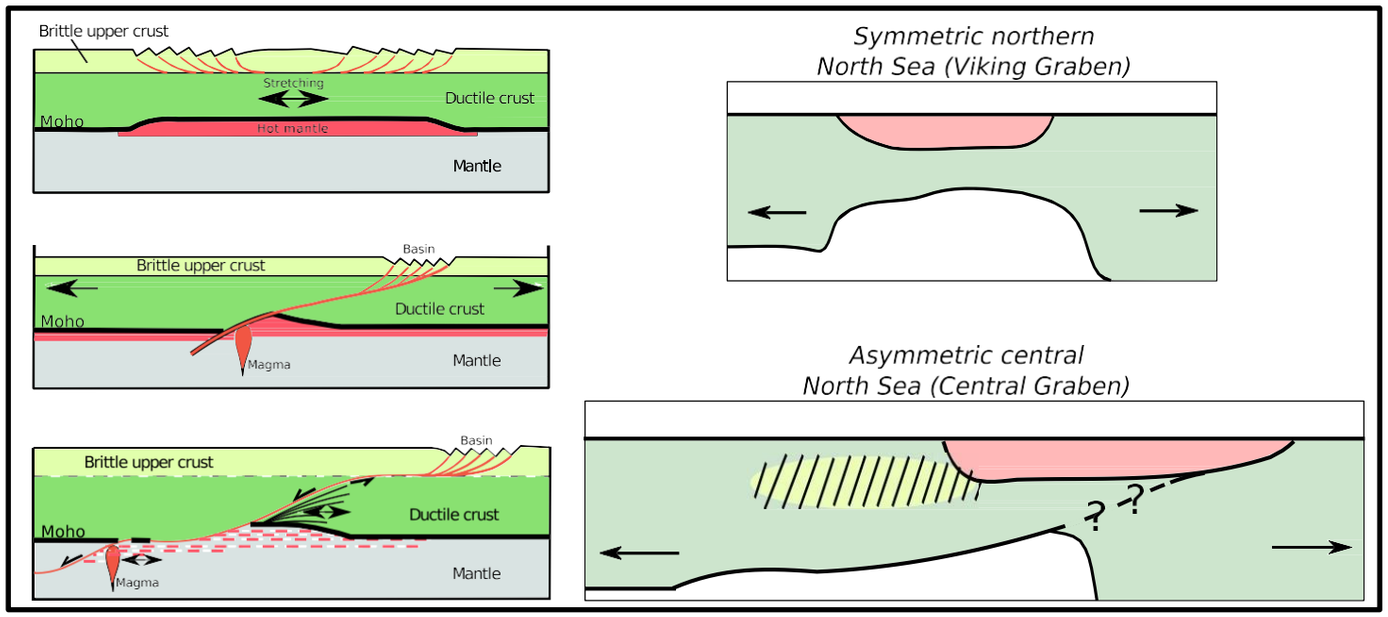


6. Anomalously slow velocities in mid-crust

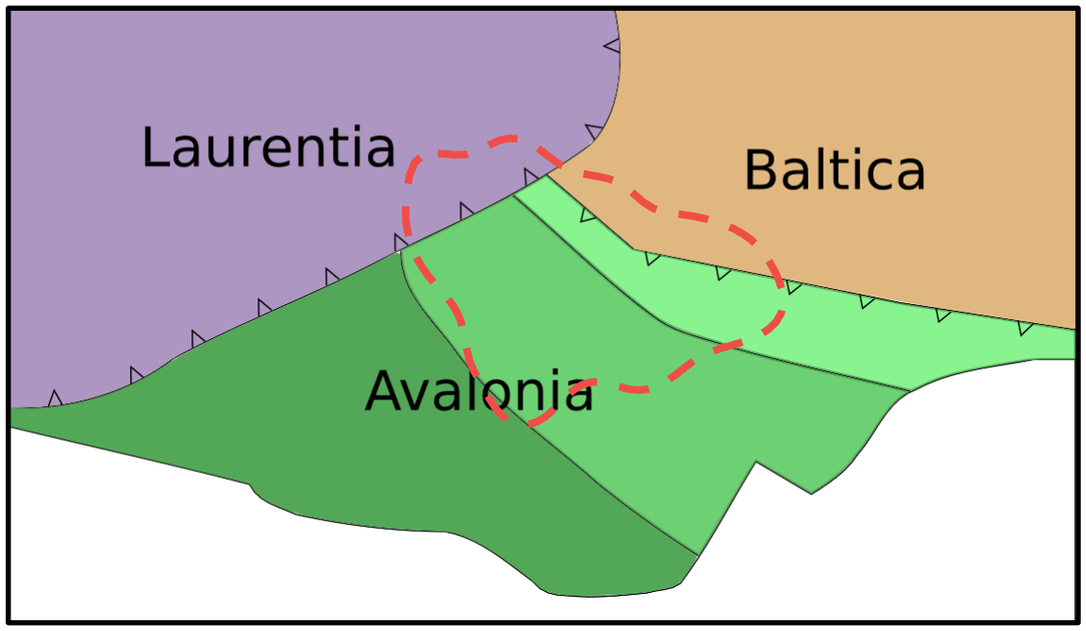


Interpretations - end members



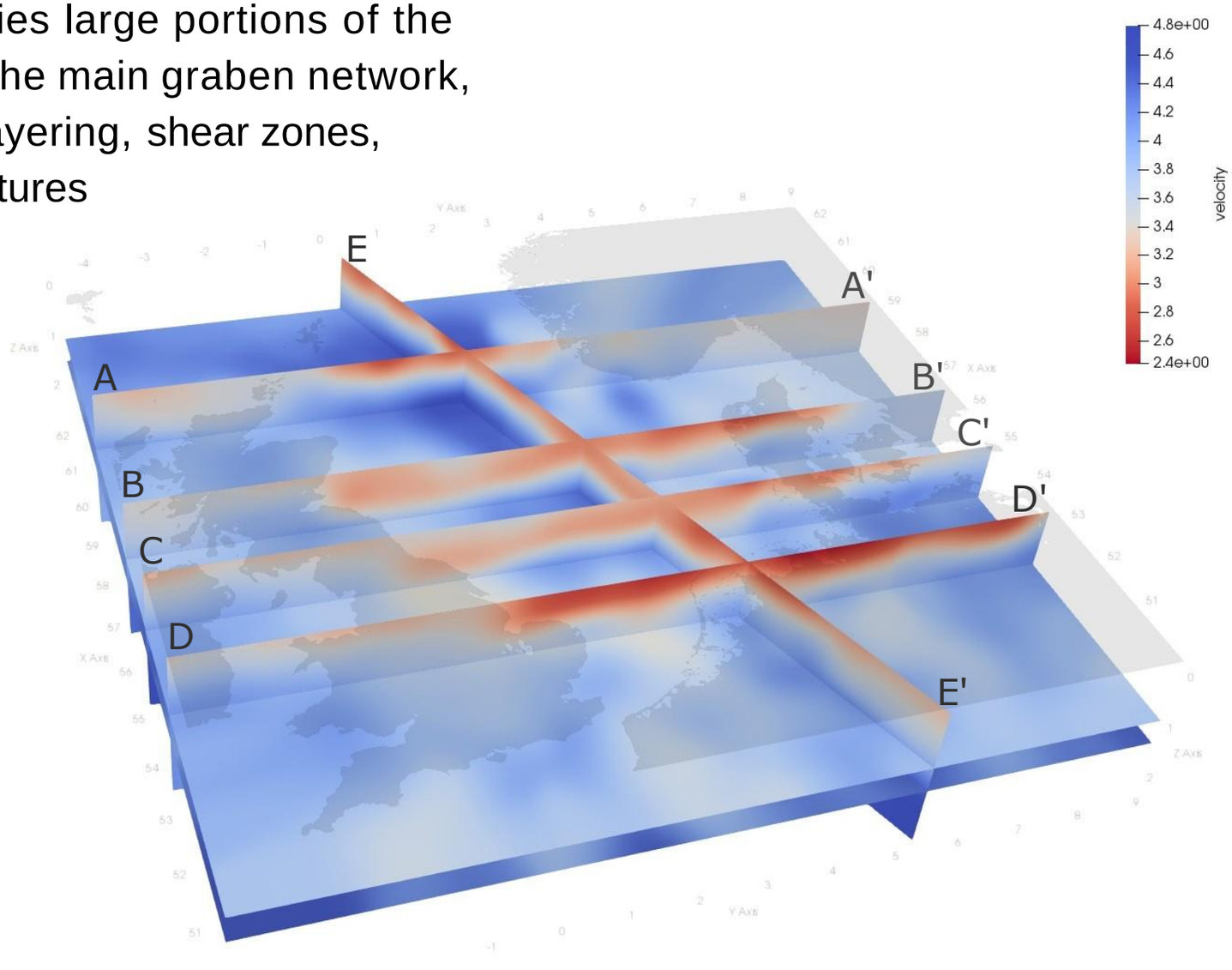


- All model structures related to most recent NS Jurassic rifting OR
- Slow velocity anomaly related to Caledonian tectonics, +additional structures more recent



Conclusions

- We successfully applied new and advanced processing methods to ambient seismic noise data from around the North Sea region
- The primary result of our analysis is the most detailed 3D shear-wave velocity model ever created of the North Sea and surrounding landmasses down to a depth of 30 km
- A number of coherent velocity structures can be observed within the crust, including features related to the failed Jurassic rift system
- An anomalously slow velocity region underlies large portions of the central and southern North Sea adjacent to the main graben network, and may be a signature of compositional layering, shear zones, anisotropy and/or fluid-filled faults and fractures



Ambient noise tomography: North Sea

E. Crowder[1,*], N. Rawlinson[2], D. Cornwell[1], C. Sammarco[1], E. Galleti[3], A. Curtis[3]

1. School of Geosciences, University of Aberdeen
2. Department of Earth Sciences, University of Cambridge
3. School of Geosciences, University of Edinburgh

NERC SCIENCE OF THE ENVIRONMENT

Centre for Doctoral Training (CDT) in Oil and Gas