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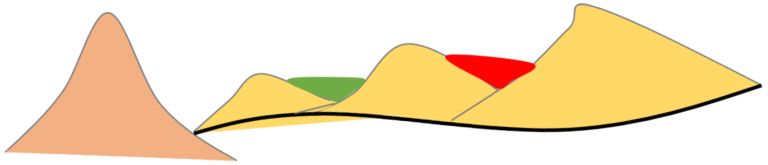

Imaging the Deep Galicia margin using three-dimensional full waveform inversion

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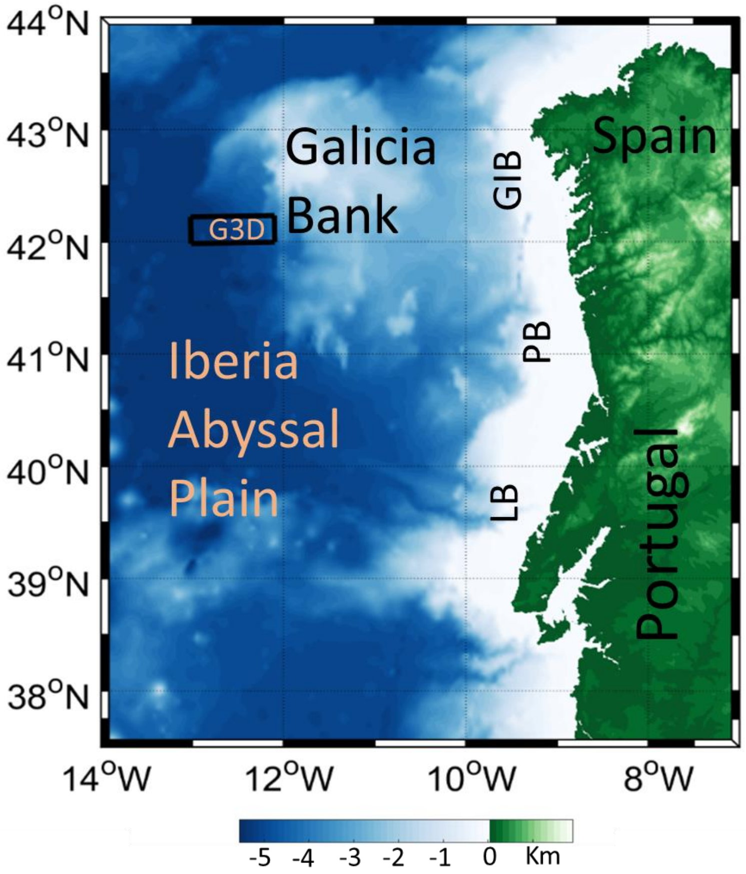
Outline

- Tectonic setting: The Deep Galicia margin (DGM)
- Data acquisition: Galicia 3D experiment
- Full waveform inversion (FWI) and QC
- Comparison between 2D and 3D FWI results
- Nature of the crystalline crust
- Serpentinization of the upper mantle rocks

Tectonic setting



- Magma-poor margin; No evaporates; thin sedimentary cover
- The rifting occurred in multiple phases over a span of 100Myr (2D multichannel seismic profiles and ODP drilling leg 103 results)
- Initial phases Late Triassic – Early Jurassic: formation of basins in the proximal margins. e.g. Porto Basin (PB), Lusitania Basin (LB)
- Intermediate phases Late Jurassic – Early Jurassic: development of Galicia Interior Basin (GIB)
- In the final stages (Early Cretaceous), extension happened in the Deep Galicia margin thinning the crust to less than 5 km.
- G3D represents Galicia3D experiment at the Deep Galicia margin

Deep Galicia Margin

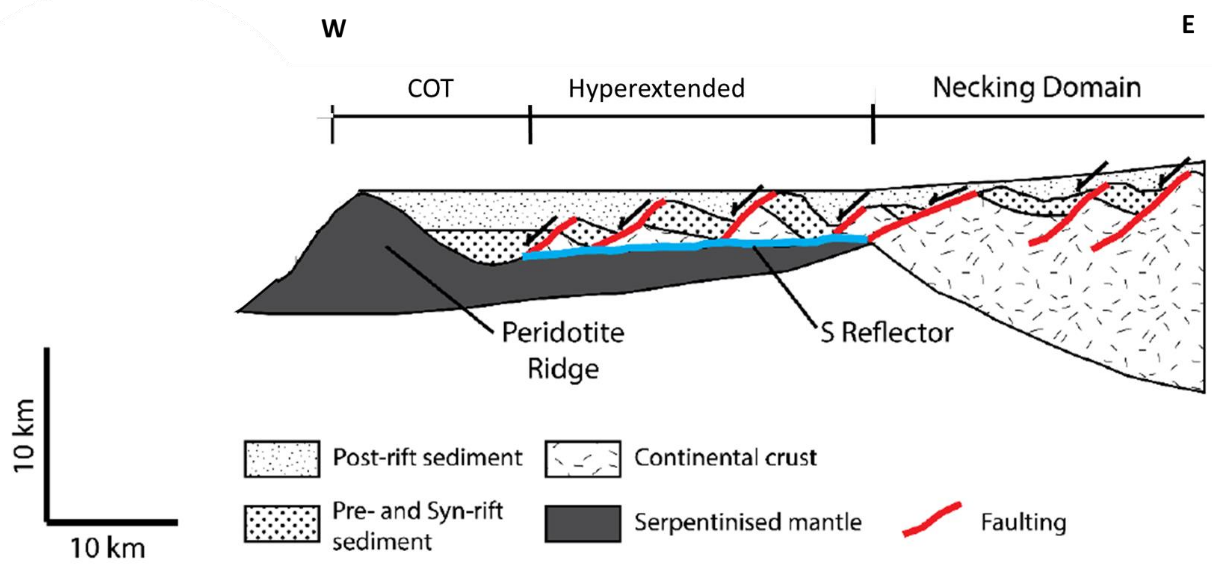
- Direction of rifting changed oceanward from E-W to ESE-WNW (Lymer et al., 2019)

- Crustal thinning and stretching over a distance 100km:

a) Depth-dependent stretching (Driscoll and Karner, 1998)
b) Polyphase faulting (McDermott and Reston, 2015)
c) Sequential faulting (Ranero and Perez-Gussinye, 2010)

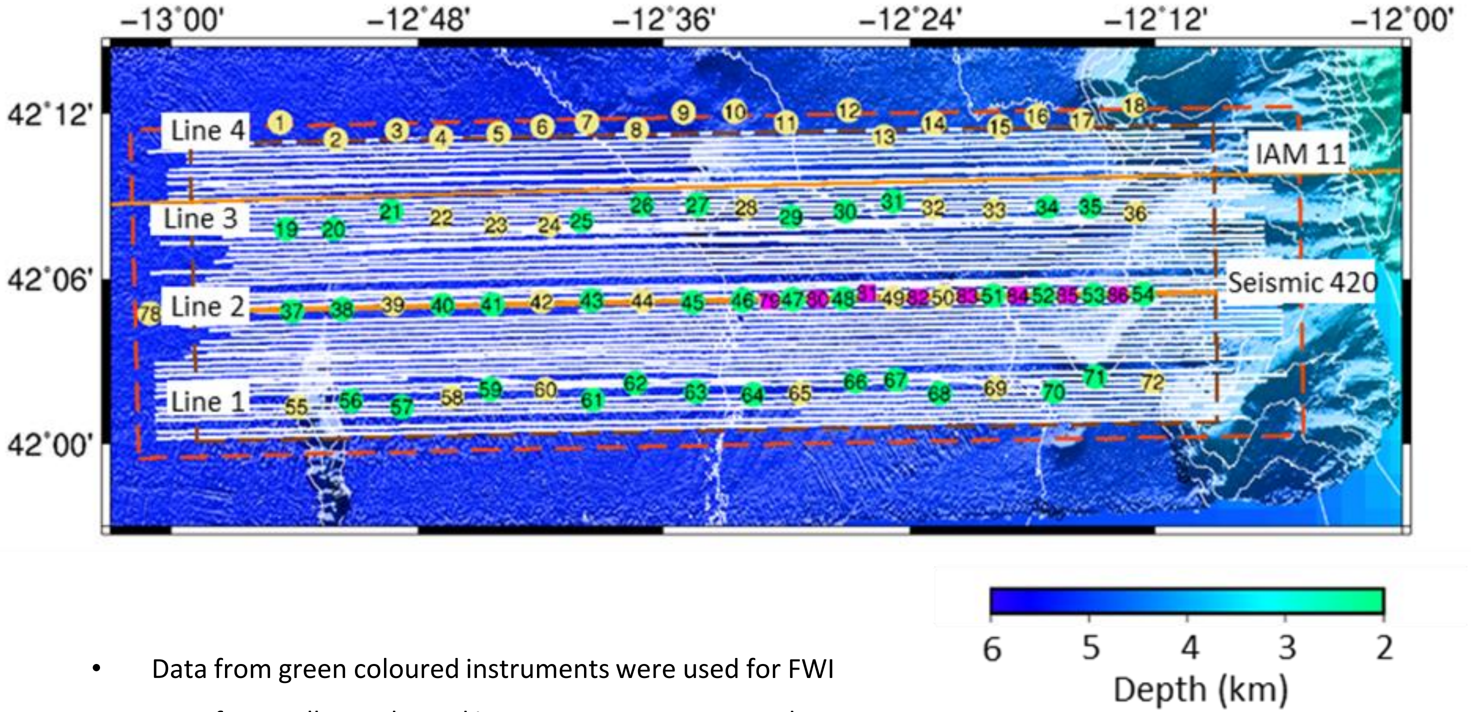
- Normal faults acting as fluid conduits sole into the S-reflector (Bayrakci et al., 2016)

- Serpentinised mantle exhumed to the seafloor : Peridotite Ridge



Modified from Davy (2017)

Data Acquisition



- 100 shooting profiles with a shot spacing of 37.5 m recorded by four 6 km long streamers and OBSs.
- Average spacing between the OBS along the profiles is 3.2 km and across the profiles is 6.5 km
- Air gun volume 3300 cu.in

- Data from green coloured instruments were used for FWI
- Data from yellow coloured instruments were not used
- Pink coloured instruments are instruments which recorded just two shooting lines directly above them.
- Dash red box is the grid used for FWI (78.5 (east-west) x 22 (north-south) km^2)
- Dashed brown grid is for multichannel seismic volume
- Seismic lines: Seismic 420 (3D volume) and IAM 11

- **Wavelet** developed using the near offset direct water arrivals by designing a weiner filter
- **Wide-angle** data refraction data recorded by hydrophones was used after filtering frequencies – 2-3-5-7 Hz

Starting frequency (3Hz)

- Frequency at which phase residuals of the first arrivals are minimum was selected as the starting frequency
- Also, results from test runs starting from different frequencies a using data subset were checked to choose the starting frequency

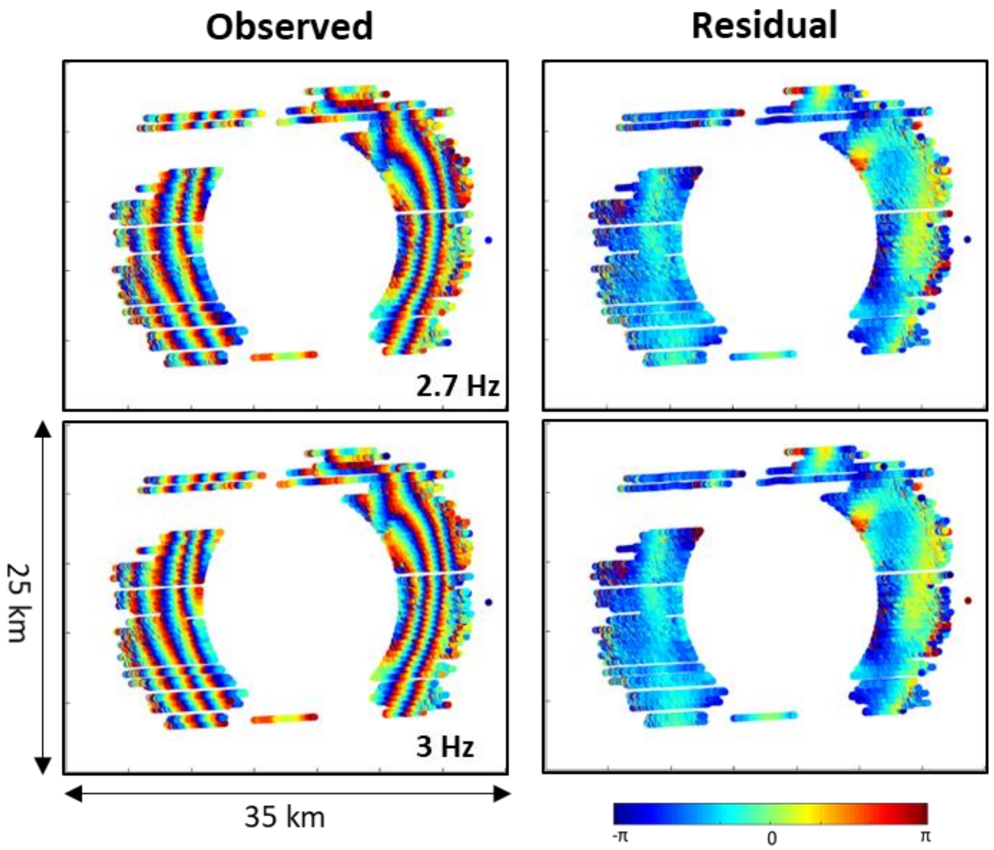
Full Waveform Inversion

Inversion strategy

- Acoustic FWI
- Frequencies: 3, 3.4, 3.9, 4.5, 5.2 Hz
- Model size: 78.5 km x 22 km; depth 12 km
- Grid size: 50 m
- Smoothing applied to suppress artefacts
- 30 iterations at each frequency

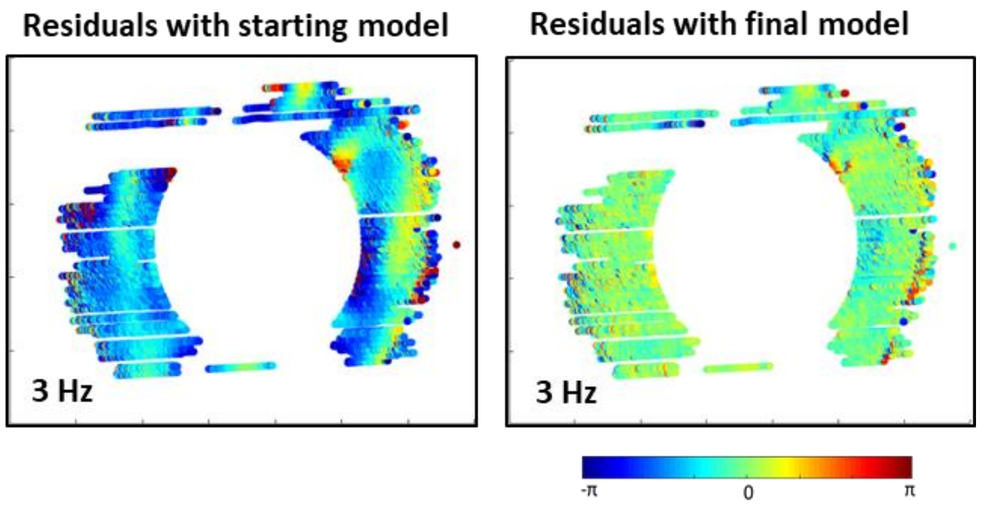
- **Starting model** was obtained from traveltime tomography of the first arrivals
- The model was tested for its ability to predict the refraction arrivals using the wavelet

Starting frequency

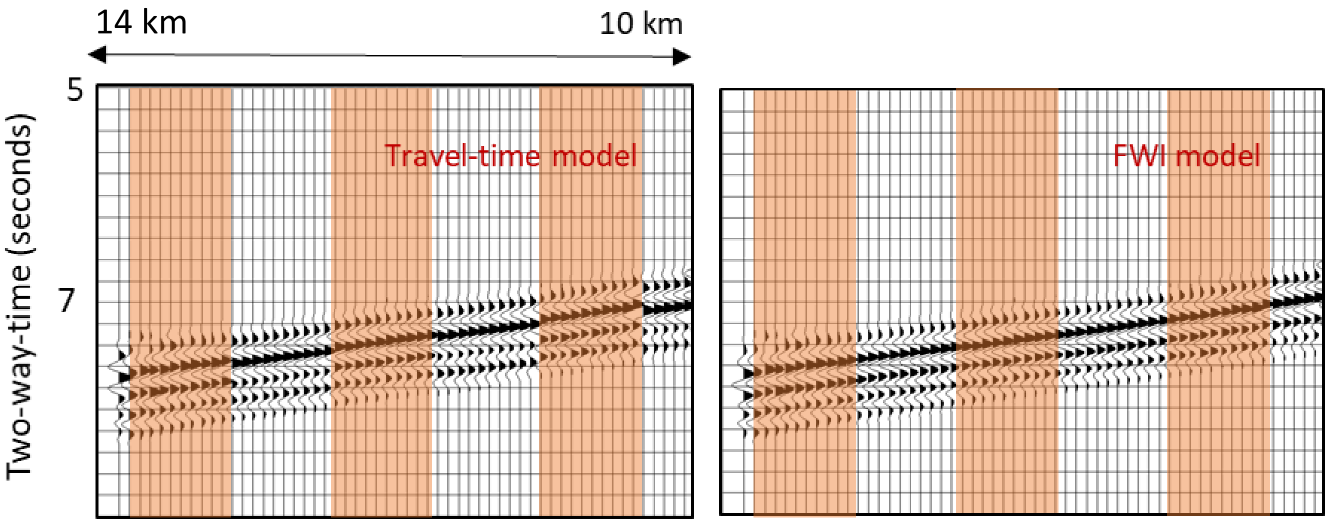


- Phase plots along with residual plots (observed – synthetic) for an OBS over 15km offsets at frequencies 2.7 and 3 Hz.
- Dots represent phase of the first arrivals at each shot location. Phase is computed by windowing the traces individually to extract the first arrivals using a Gaussian window. Fourier transform is applied to individual windowed trace and phase is extracted at a given frequency.
- Residual at 2.7 and 3 Hz show close residual patterns.
- No significant difference between the inversion results of the test runs starting from 2.7 and 3 Hz were observed. Hence, we selected 3 Hz as the starting frequency for the final run to gain computational time
- Phase plots were also used to check the progress of the inversion at intermediate stages.

Quality Control

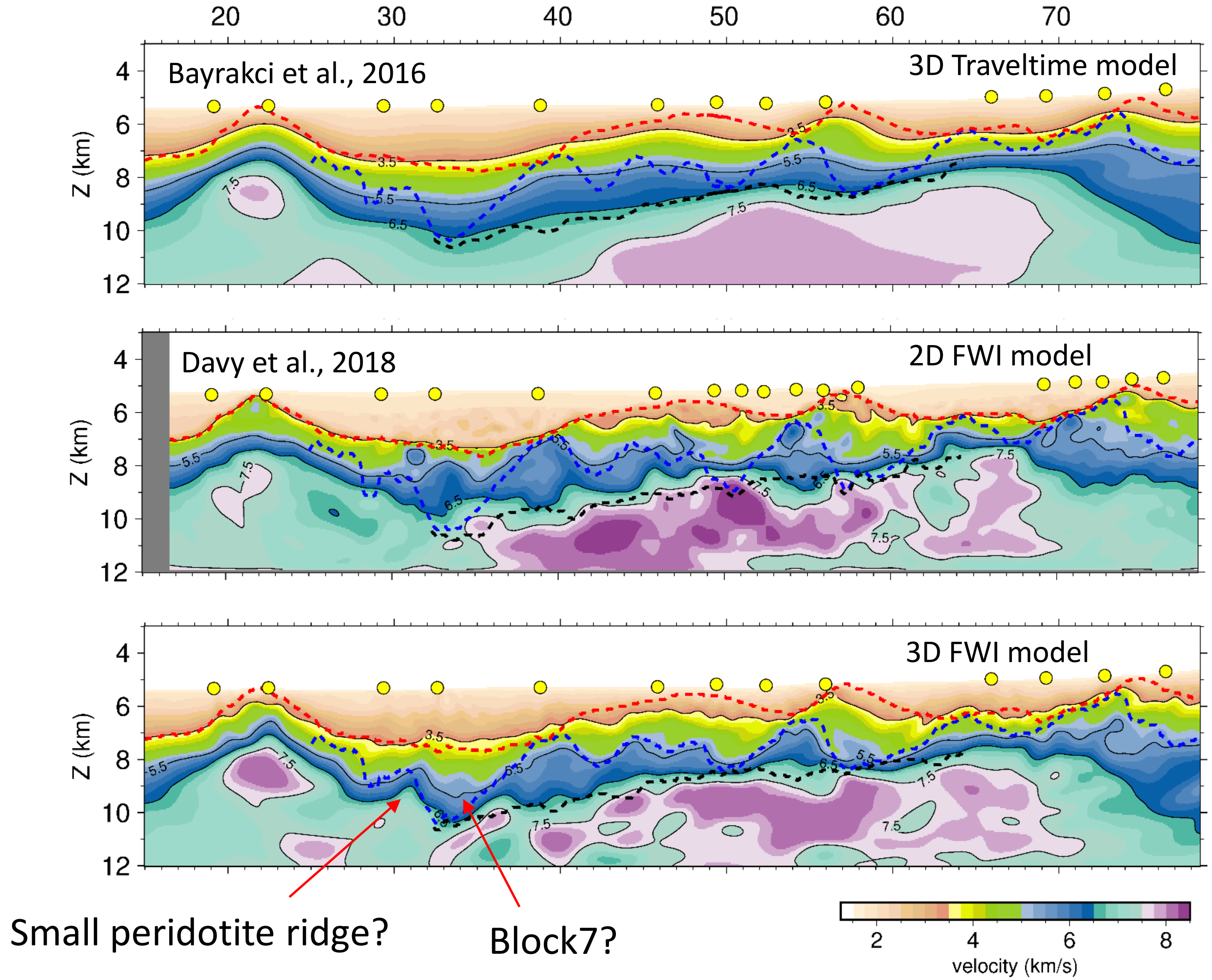


- Phase residuals with the starting and final models



- Fit between the observed and the predicted data along a profile from an OBS. Left-hand side profile is from traveltime model and right-hand side from FWI model. The observed data is highlighted in orange bands.

2D- vs 3D-FWI using a sparse OBS dataset

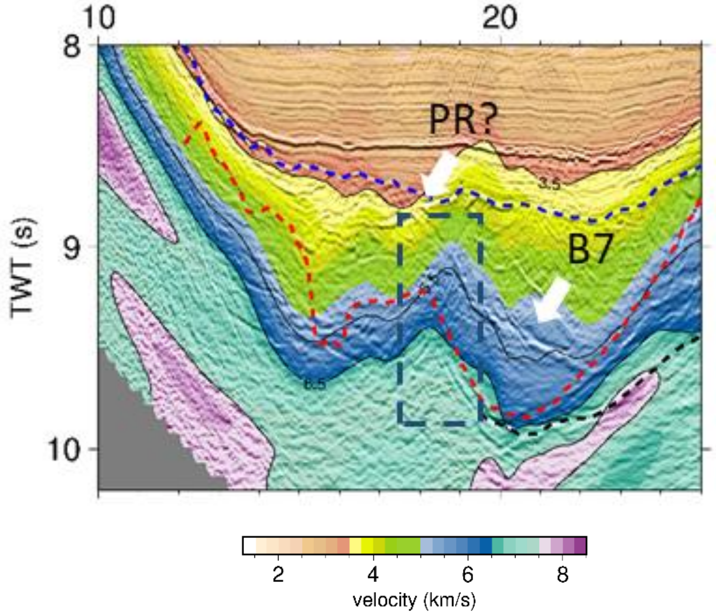


- Starting model, 2D FWI and 3D FWI result along profile 420. Interpretations from the MCS volume are overlaid on the velocity sections.
- Dashed red line: Base of the post-rift sediments
- Dashed blue line: Top of the crystalline crust
- Dashed black line: the S-reflector
- Yellow circles indicating OBS locations

Results

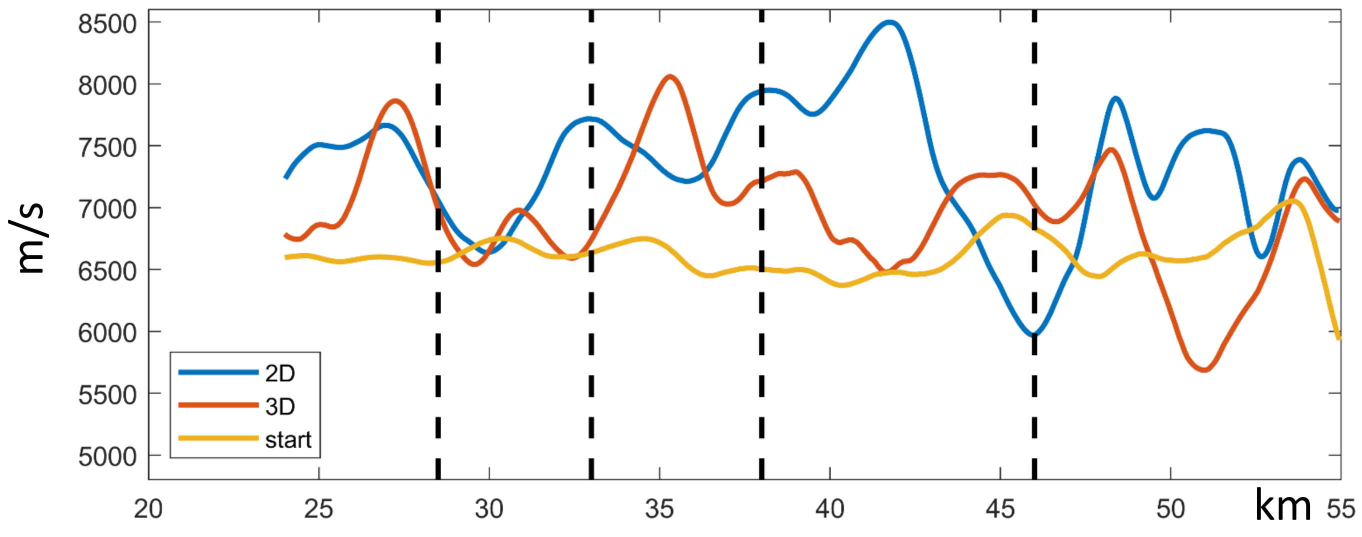
- 3D Imaging reduced the oscillations of the velocity contours and shows better fit with the multichannel interpretations compared to the 2D result
- Circular features within the crystalline crust in 2D – poorly constrained inverse problem – data sparsity
- A small peridotite ridge and crystalline crustal block identified
- Pre- and syn-rift sediments: ~3.25 km/s to ~5.25 km/s
- Crystalline crust: ~5.25 km/s to ~6.5 km/s

Crystalline crust or Peridotite ridge?



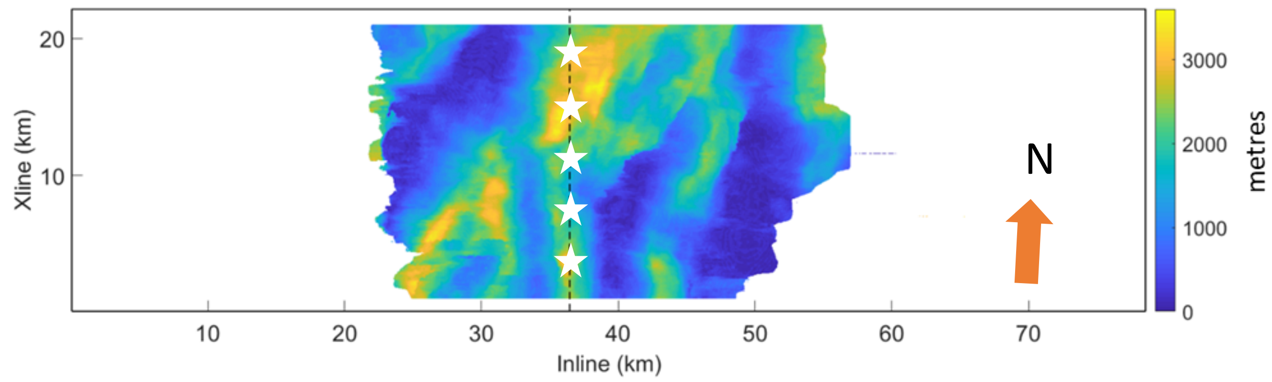
- 3D FWI velocities converted to time and overlaid on a multichannel seismic image
- Complex tectonic setting observed seawards between the crystalline crust and small peridotite ridge (PR)
- We identified block B7 (landward-dipping) terminating on the flank of a small peridotite ridge
- Exhumation of the PR caused the last fault-block to turn further from a sub-horizontal position, assuming the stretching of the continental crust occurred following sequential faulting mechanism (Ranero and Perez-Gussinye, 2010)

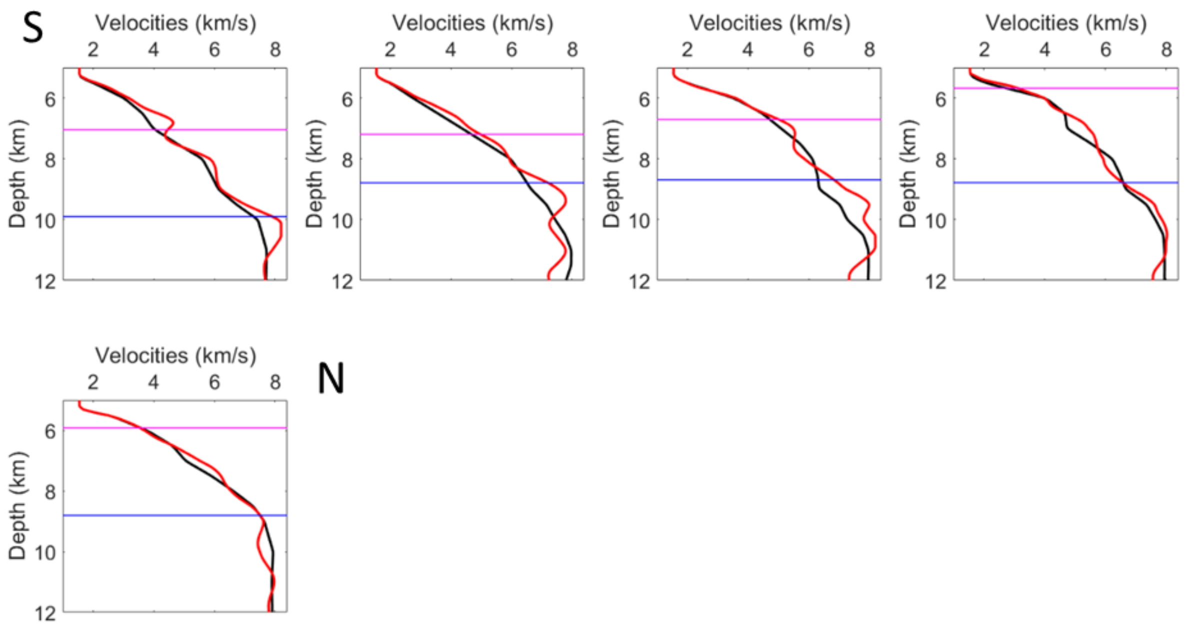
Serpentinization



- Velocities below the S-reflector at a depth of 100 milliseconds along the 2D profile.
- Compared to the starting model, 3D FWI model shows a enhanced pattern with low velocity zones correlating with the fault intersections at the S-reflector.
- 2D and 3D curves do not show a fit
- The maximum velocity in the 3D curve is ~8 km/s corresponding to unaltered peridotites
- 0 – 45% serpentinization is estimated for velocities ranging between 6.5 – 8 km/s.

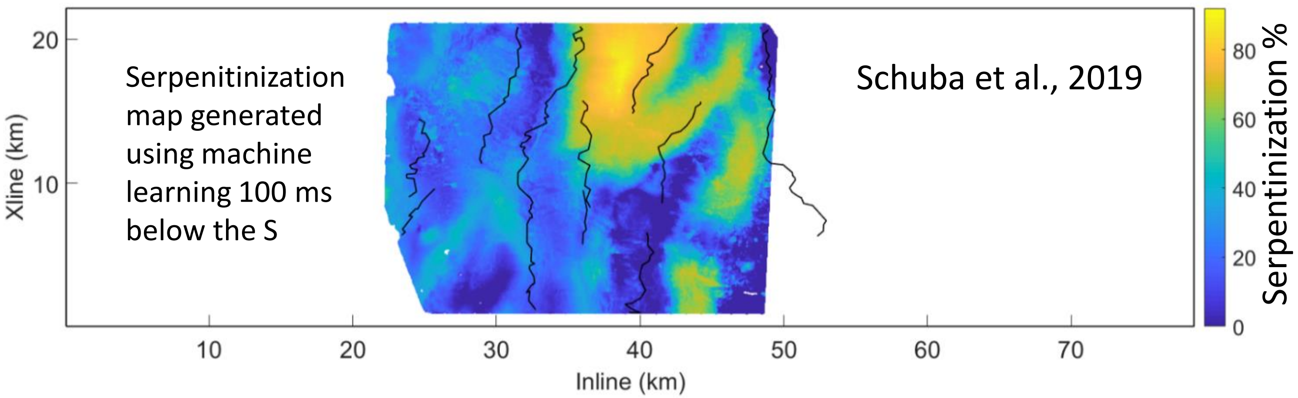
Upper or lower crust?

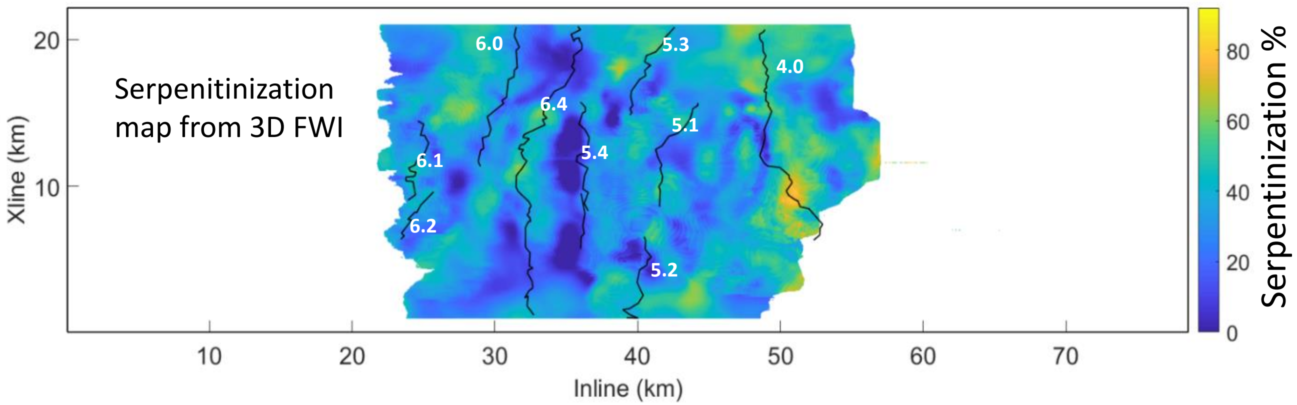




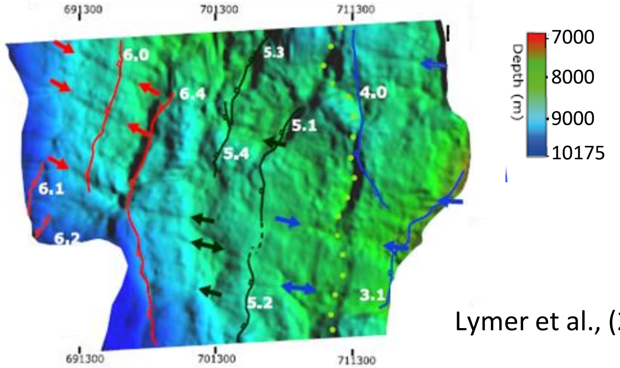
- Thickness of crystalline crust (0 – 3600 m)
- Velocity profiles from starting (black) and FWI (red) models at the star locations with top of the crystalline crust (magenta) and the S-reflector (blue)
- No consistent evidence for upper and lower crusts as separate layers within the crystalline crust – coupled brittle crust
- Velocity range for the crystalline crust span the velocity ranges of the upper and lower crust from Galicia Interior Basin (5.3 – 6.9 km/s) (Perez-Gussinye et al., 2003)

Serpentinization maps of the Deep Galicia margin





S-reflector Depth (km)



Lymer et al., (2019)

- Serpentinization of the upper mantle rocks at a depth of 100 ms below the S-reflector with fault intersections with the S-reflector overlaid
- Higher serpentinization values were predicted by the machine learning algorithm trained using the 2D FWI results
- 3D FWI results shows an excellent match with the topography of the S-reflector from the multichannel volume
- The pattern of the serpentinization between two maps is different
- 3D FWI model show a correlation with the fault intersections with the S-reflector.

Conclusions

- Spatial sampling is a crucial factor for performing FWI using OBS data. A 3D dataset can mitigate the problem of receiver sparsity to a certain degree.
- We identified a new crystalline crustal block and a small peridotite ridge toward seawards of the hyperextended zone.
- 3D FWI enhanced resolution of the pattern of serpentinization below the S-reflector compared to the starting model.
- We estimate 0 - 45 % serpentinization along the profile 420, with a good correlation between the associated low velocity zones and fault intersections with the S-reflector.
- There is no consistent evidence for the occurrence of upper and lower crust as different layers within the crystalline crust in the 3D FWI model. However, the velocity range of the crystalline crust spans the upper and lower crustal velocities from Galicia Interior Basin (5.3 – 6.9 km/s).
- We developed a serpentinization map based on the velocities from the 3D FWI at a depth of 100 ms below the S- reflector and compared our map with the map generated by training a machine learning algorithm based on 2D FWI results.

Thank you!

I am looking for a post-doc opportunity

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