

1 **Seismic evidence for deep hydrothermal circulation and faulting at slow**
2 **spreading Mid-Atlantic Ridge**

3 **Venkata A. Vaddineni¹, Hanchao Jian^{2,*}, Satish C. Singh¹**

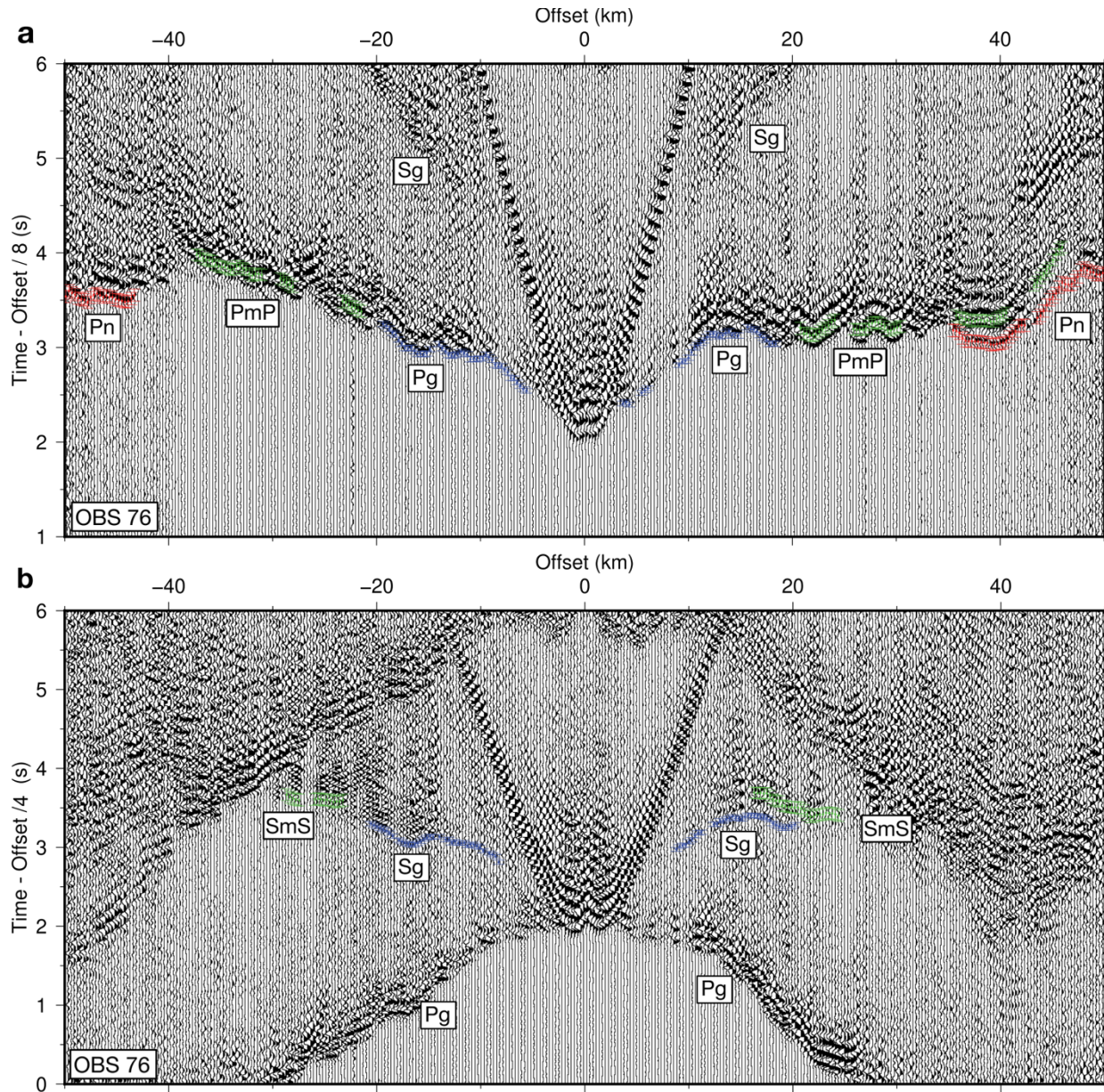
4 1. Université Paris Cité, Institut de Physique du Globe de Paris, CNRS, 1 rue Jussieu, Paris
5 75238, France

6 2. Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods
7 Hole, MA 02543, United States

8 *Corresponding author: hjian@whoi.edu

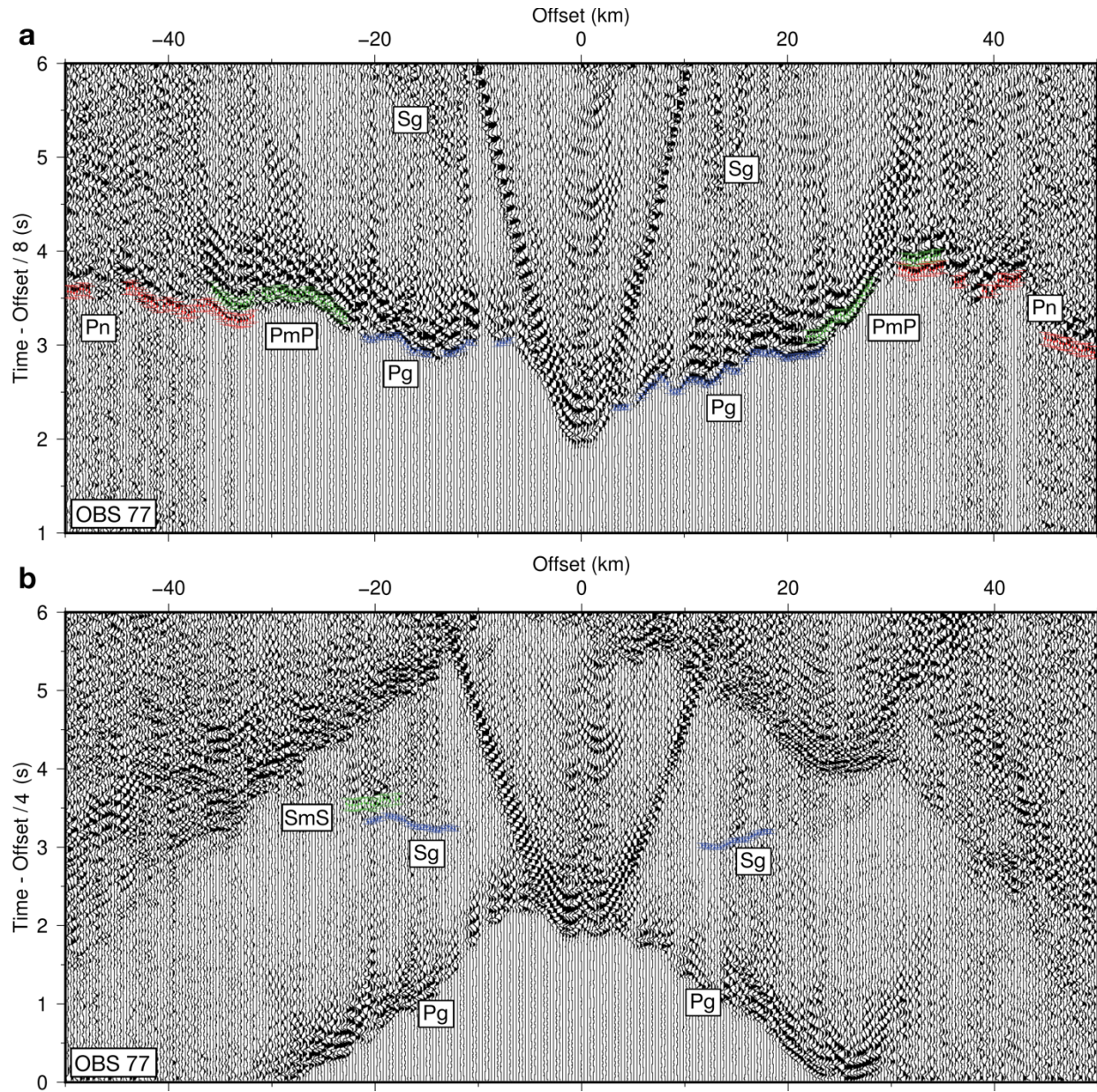
9 **SUPPLEMENTARY INFORMATION**

10 **SUPPLEMENTARY FIGURES 1-23**



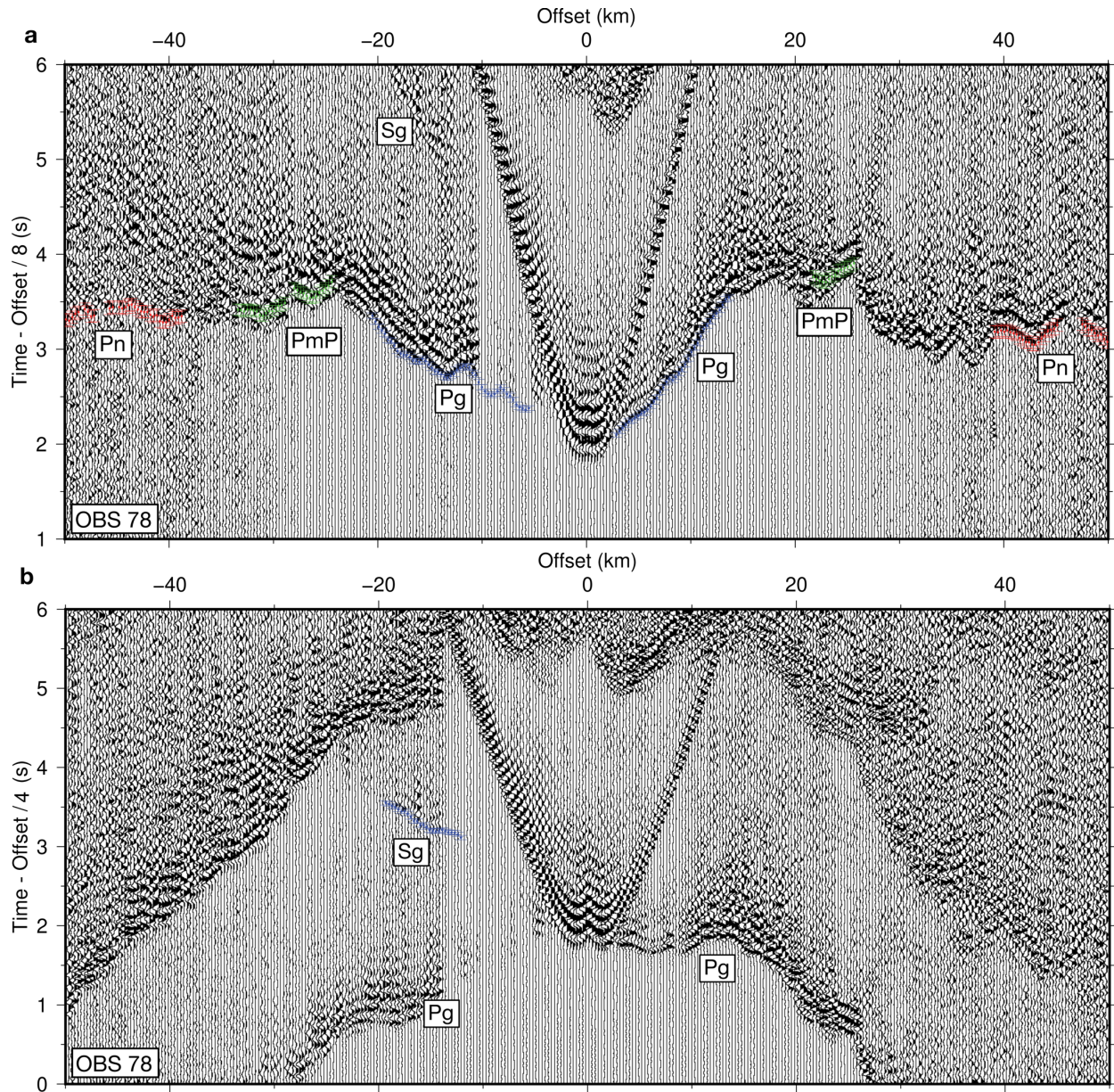
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12 **Supplementary Fig. 1 | OBS 76 Seismic data with traveltimes picks.** **a**, Seismic record for the
 13 hydrophone component of OBS 76 showing traveltimes for Pg (crustal turning rays) in blue,
 14 PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the
 15 picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter
 16 between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone
 17 component of OBS 76 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho
 18 reflections) in green. The data is reduced with a velocity of 4 km/s.

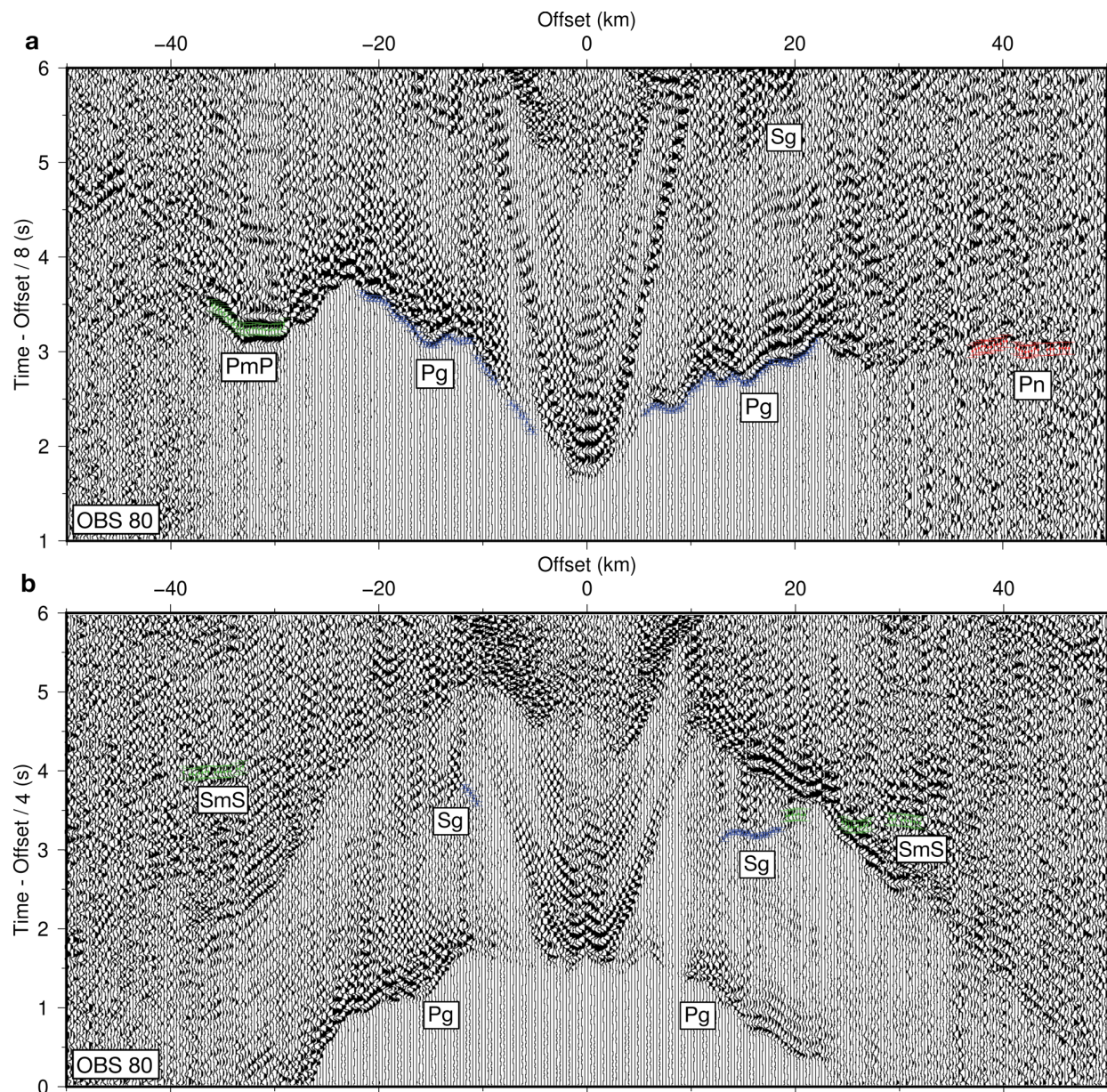


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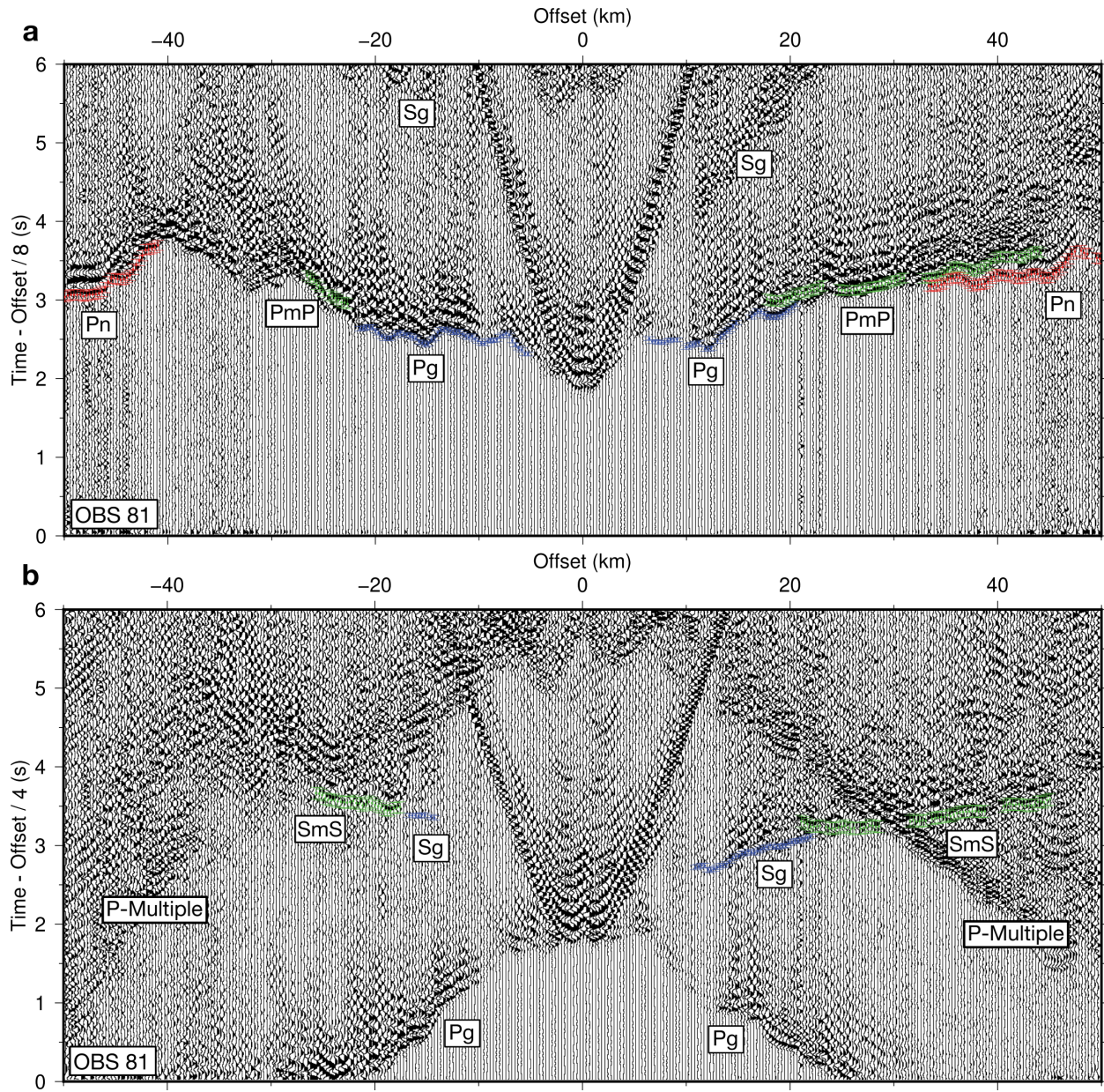
20 **Supplementary Fig. 2 | OBS 77 Seismic data with traveltimes picks.** **a**, Seismic record for the
 21 hydrophone component of OBS 77 showing traveltimes for Pg (crustal turning rays) in blue,
 22 PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the
 23 picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter
 24 between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone
 25 component of OBS 77 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho
 26 reflections) in green. The data is reduced with a velocity of 4 km/s.



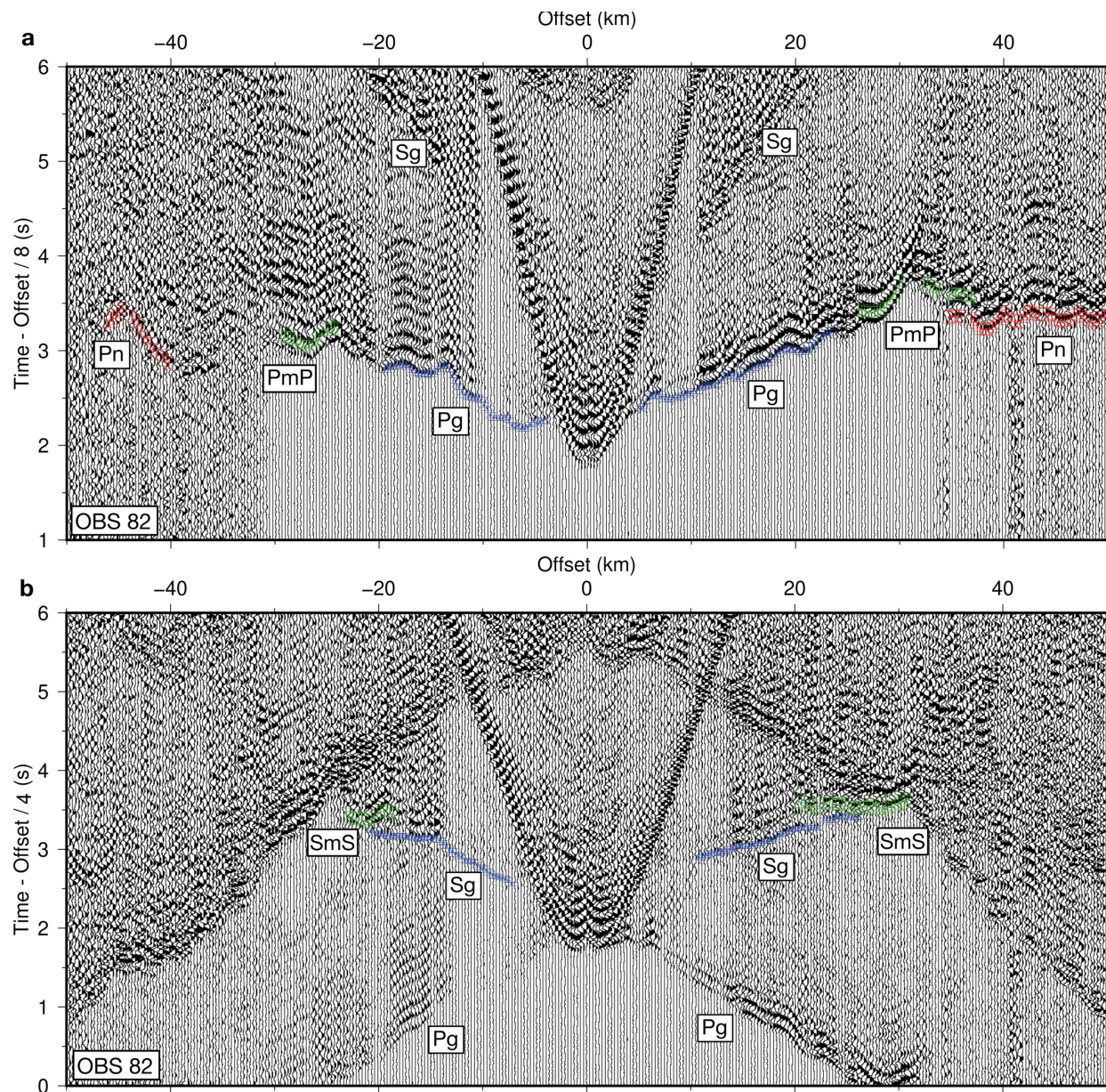
Supplementary Fig. 3 | OBS 78 Seismic data with traveltimes picks. **a**, Seismic record for the hydrophone component of OBS 78 showing traveltimes for Pg (crustal turning rays) in blue, PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone component of OBS 78 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The data is reduced with a velocity of 4 km/s.



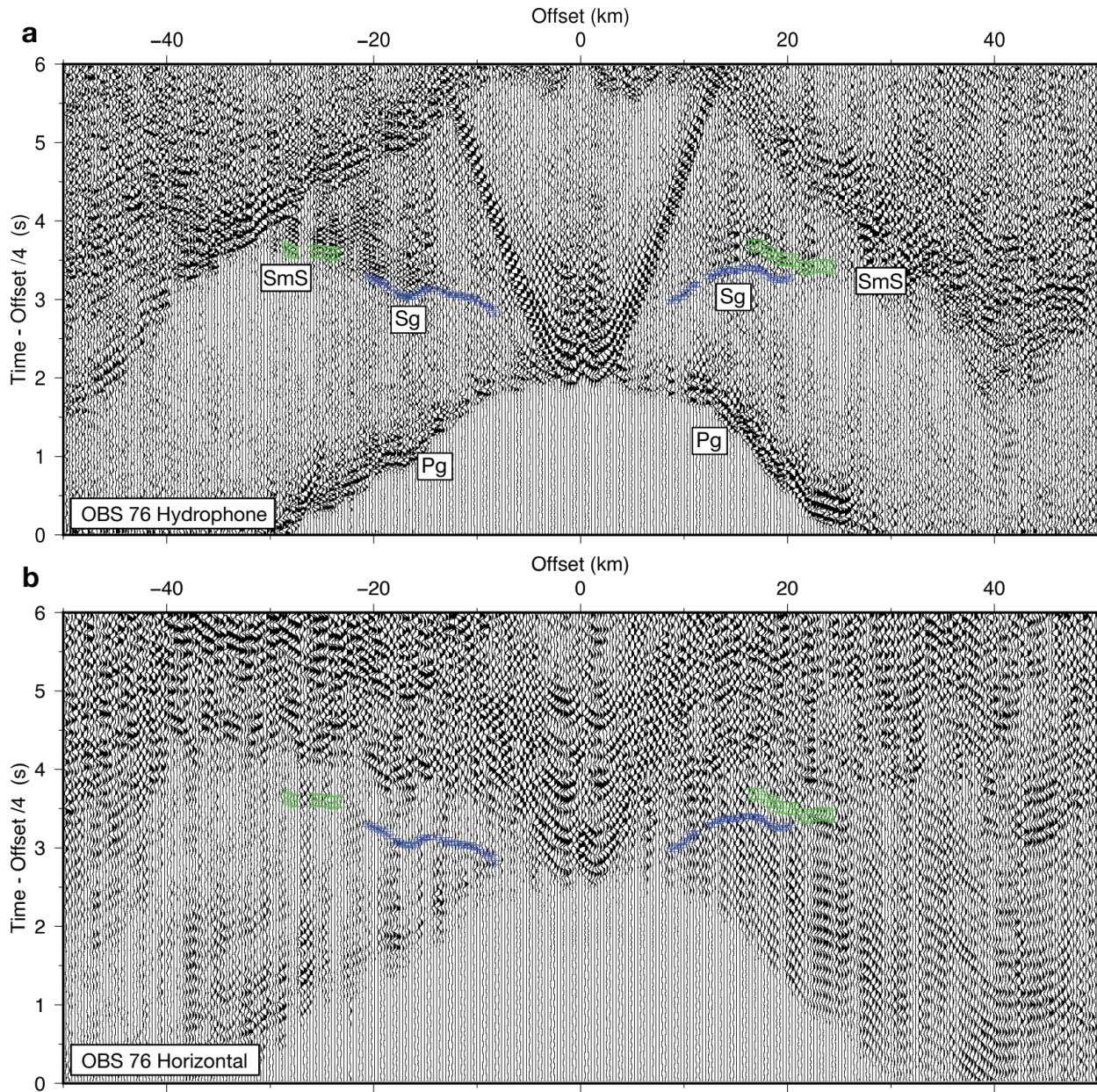
Supplementary Fig. 4 | OBS 80 Seismic data with traveltime picks. **a**, Seismic record for the hydrophone component of OBS 80 showing traveltimes for Pg (crustal turning rays) in blue, PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone component of OBS 80 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The data is reduced with a velocity of 4 km/s.



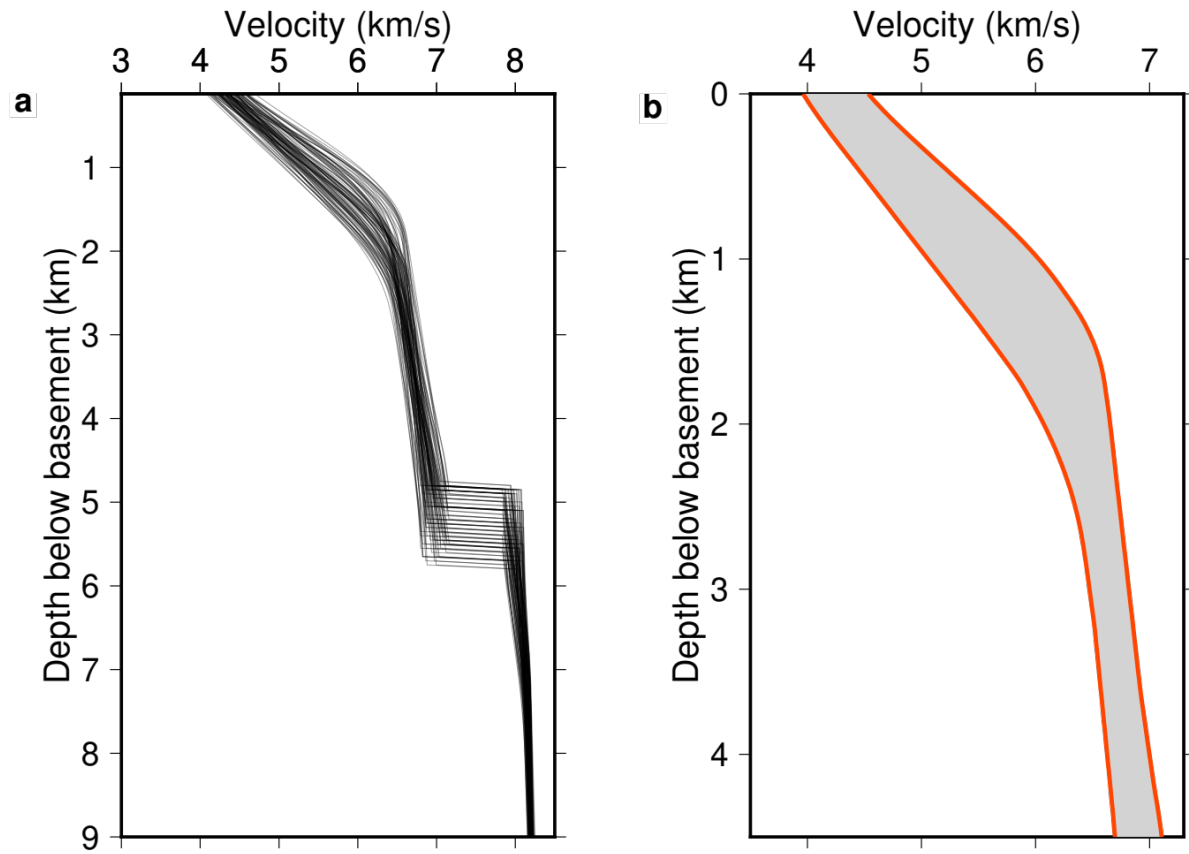
Supplementary Fig. 5 | OBS 81 Seismic data with traveltimes picks. **a**, Seismic record for the hydrophone component of OBS 81 showing traveltimes for Pg (crustal turning rays) in blue, PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone component of OBS 81 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The data is reduced with a velocity of 4 km/s.



Supplementary Fig. 6 | OBS 82 Seismic data with traveltimes picks. **a**, Seismic record for the hydrophone component of OBS 82 showing traveltimes for Pg (crustal turning rays) in blue, PmP (Moho reflections) in green and Pn (mantle turning rays) in red. The error bars represent the picking uncertainty. The data is reduced with a velocity of 8 km/s. A zero-phase band-pass filter between 3 and 20 Hz is applied to suppress noise. **b**, Seismic record for the hydrophone component of OBS 82 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The data is reduced with a velocity of 4 km/s.

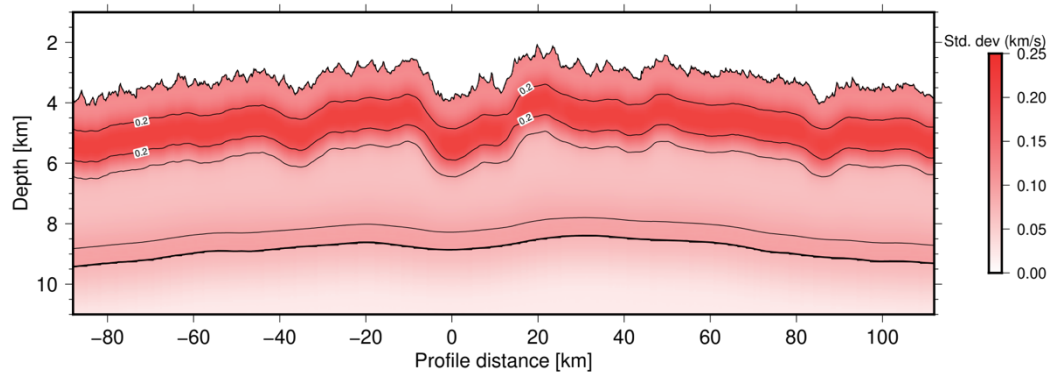


Supplementary Fig. 7 | OBS 76 Seismic data with traveltimes picks for S-waves. **a**, Seismic record for the hydrophone component of OBS 76 showing traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The data is reduced with a velocity of 4 km/s. **b**, Seismic record for the horizontal component of OBS 76 overlain with picked traveltimes for Sg (crustal turning rays) in blue, SmS (Moho reflections) in green. The horizontal component records phases traveling through sediments as S-waves, but the hydrophone records phases traveling through sediments as P-waves. Note the delay in the arrivals in the horizontal component with respect to the picked arrivals on the hydrophone due to the sediments.



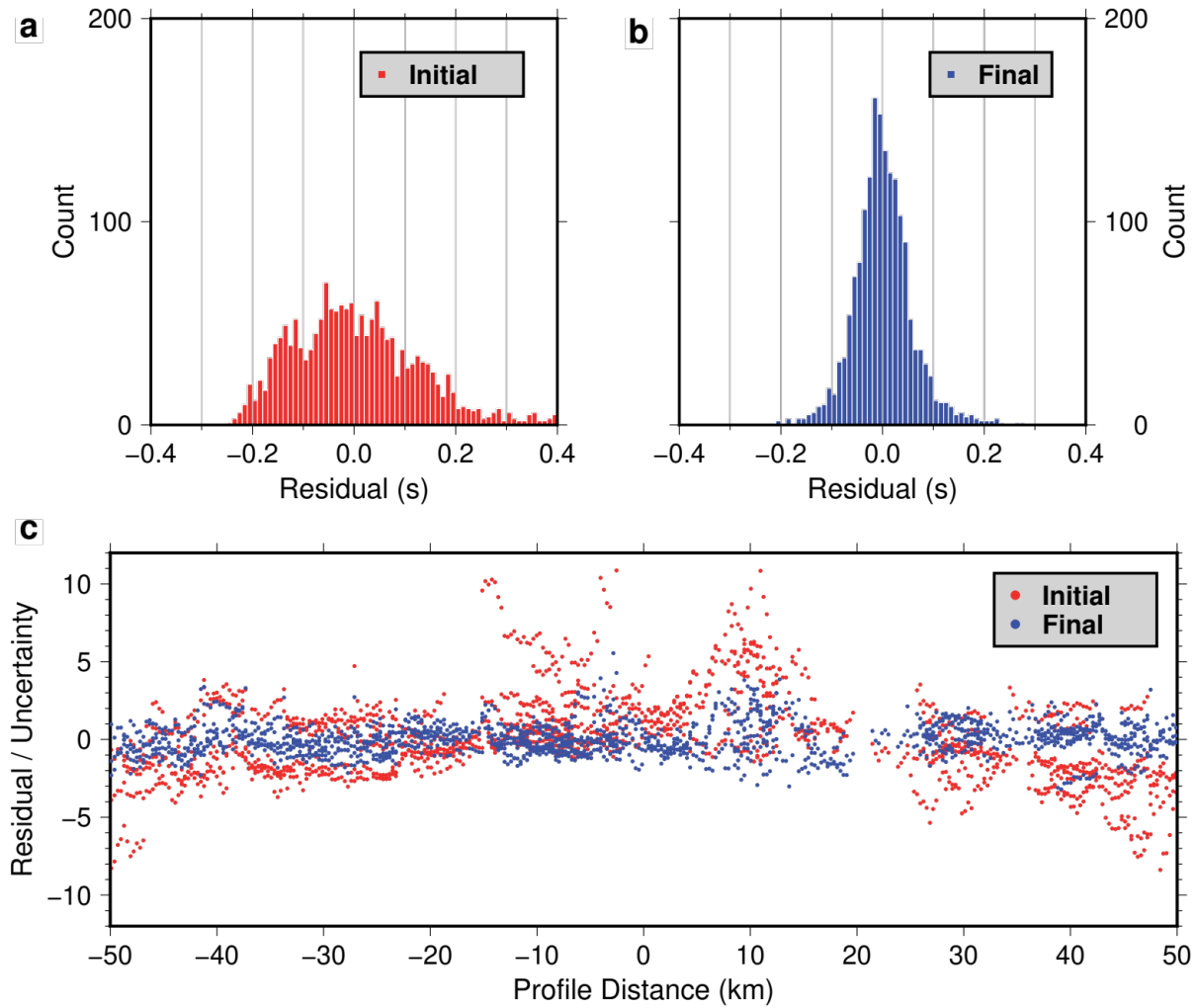
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70 **Supplementary Fig. 8 | 1D velocity for the Monte-Carlo analysis.** **a**, 1D velocity profiles of
 71 the 100 random starting models used to estimate the dependence of the inversion on the starting
 72 model. **b**, The maximum and minimum crustal velocity bounds in red.

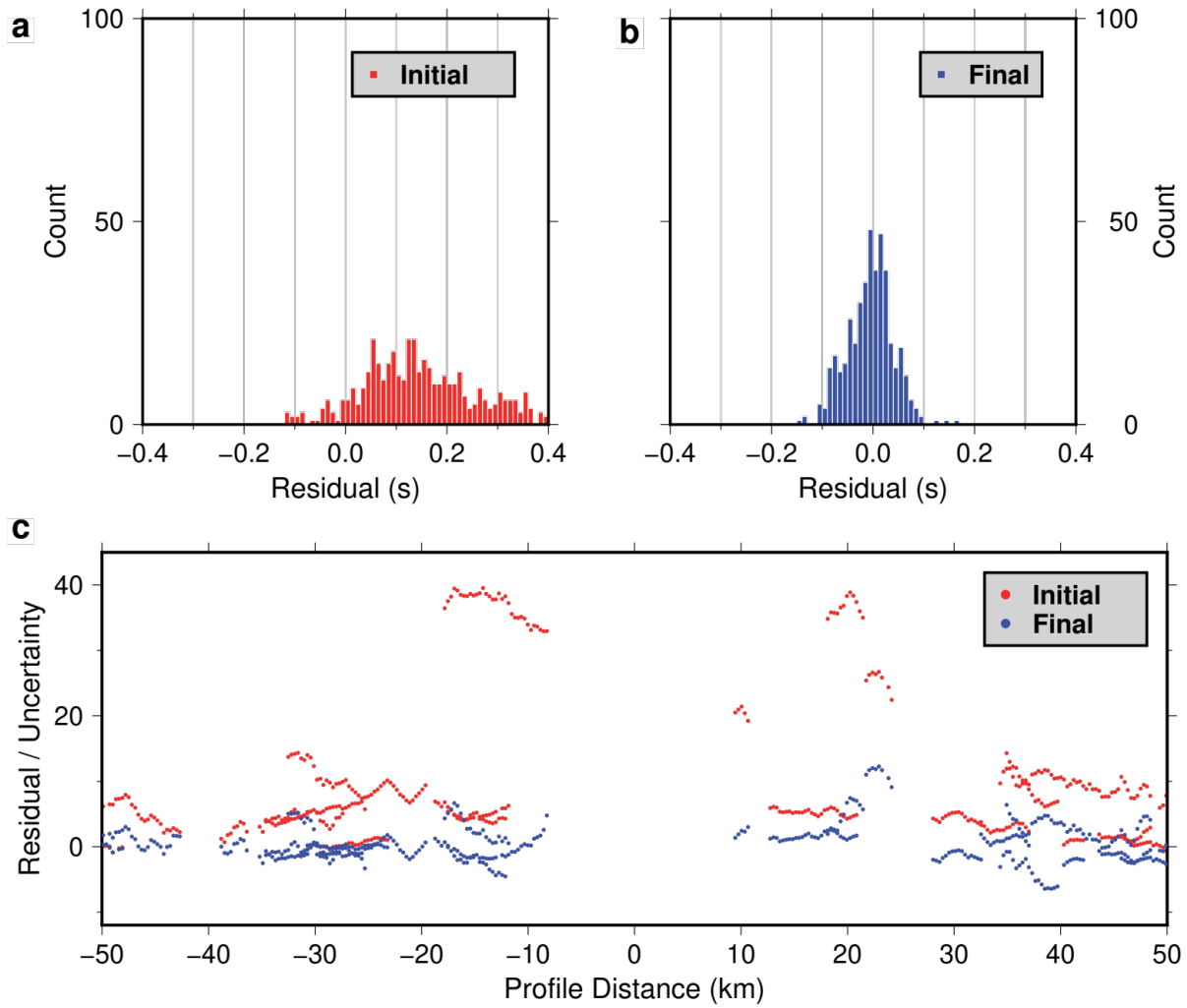


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74 **Supplementary Fig. 9 | 2D velocity for the Monte-Carlo analysis.** Standard deviation of 100
 75 random starting models with respect to the mean starting model. There is a large variation (up to
 76 $1\sigma=250$ m/s) in the velocities of the upper crust as more heterogeneity is expected in this part of
 77 the crust, whereas the lower crust is more homogeneous with $1\sigma=100$ m/s.

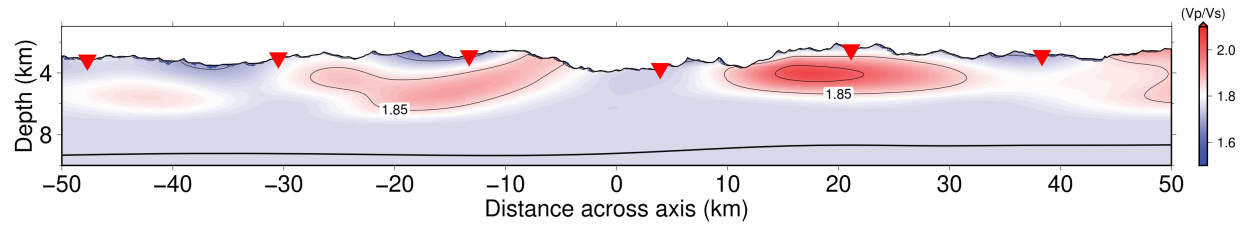


Supplementary Fig. 10 | P-wave traveltime residuals. **a**, Histogram of the initial residual values ($t_{\text{pick}} - t_{\text{synthetic}}$) for all Pg, PmP and Pn traveltime picks. **b**, Histogram of the final residual values for all traveltime picks. **c**, Normalized residuals versus profile distance in the starting model (red) and the final inverted model (blue).



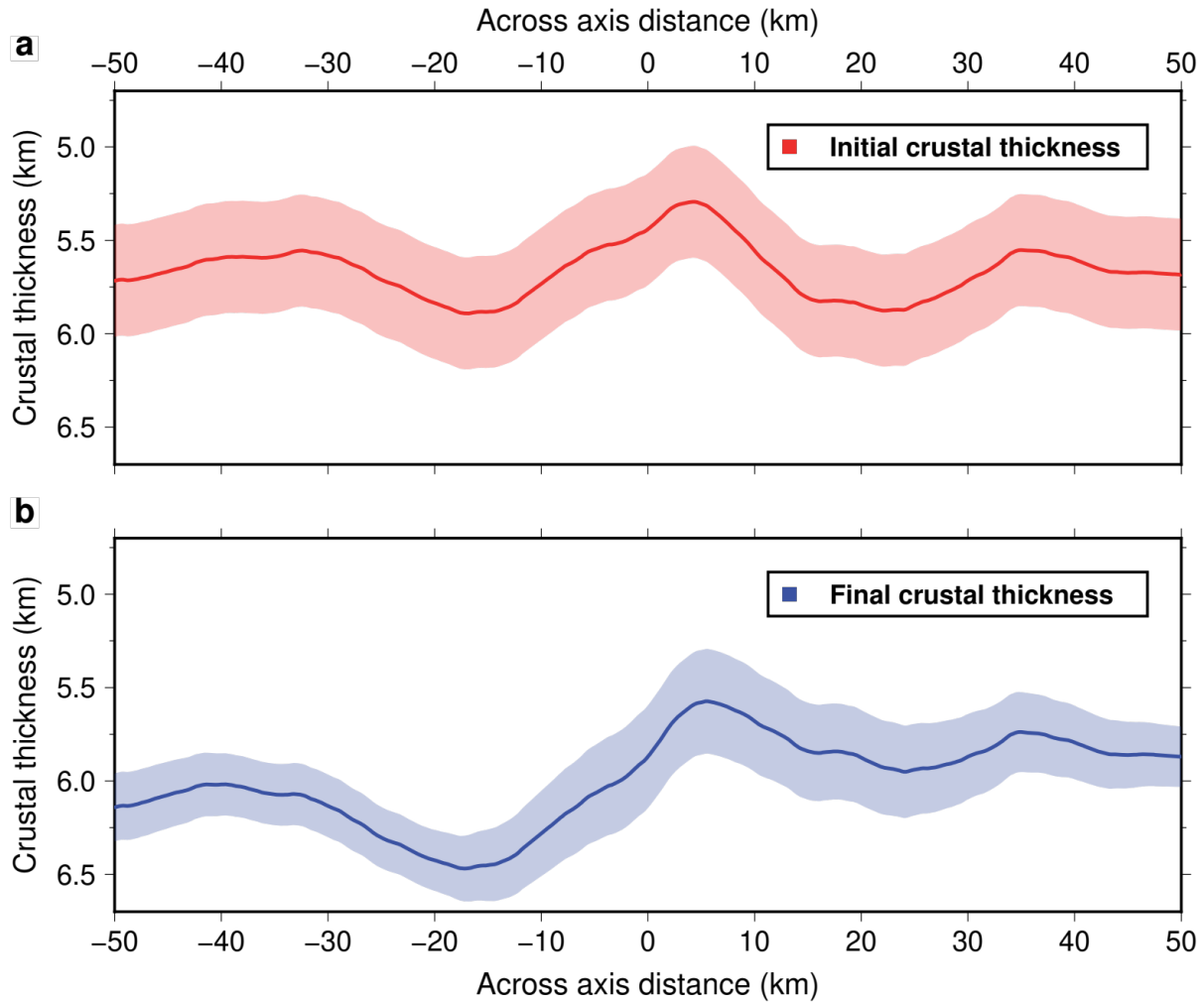
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84 **Supplementary Fig. 11 | S-wave traveltime residuals.** **a**, Histogram of the initial residual
85 values ($t_{\text{pick}} - t_{\text{synthetic}}$) for all Sg and SmS traveltime picks. **a**, Histogram of the final residual
86 values for all traveltime picks. **c**, Normalized residuals versus profile distance in the starting
87 model (red) and the final inverted model (blue). Note large initial residuals near the ridge axis at
88 distances ± 20 km.



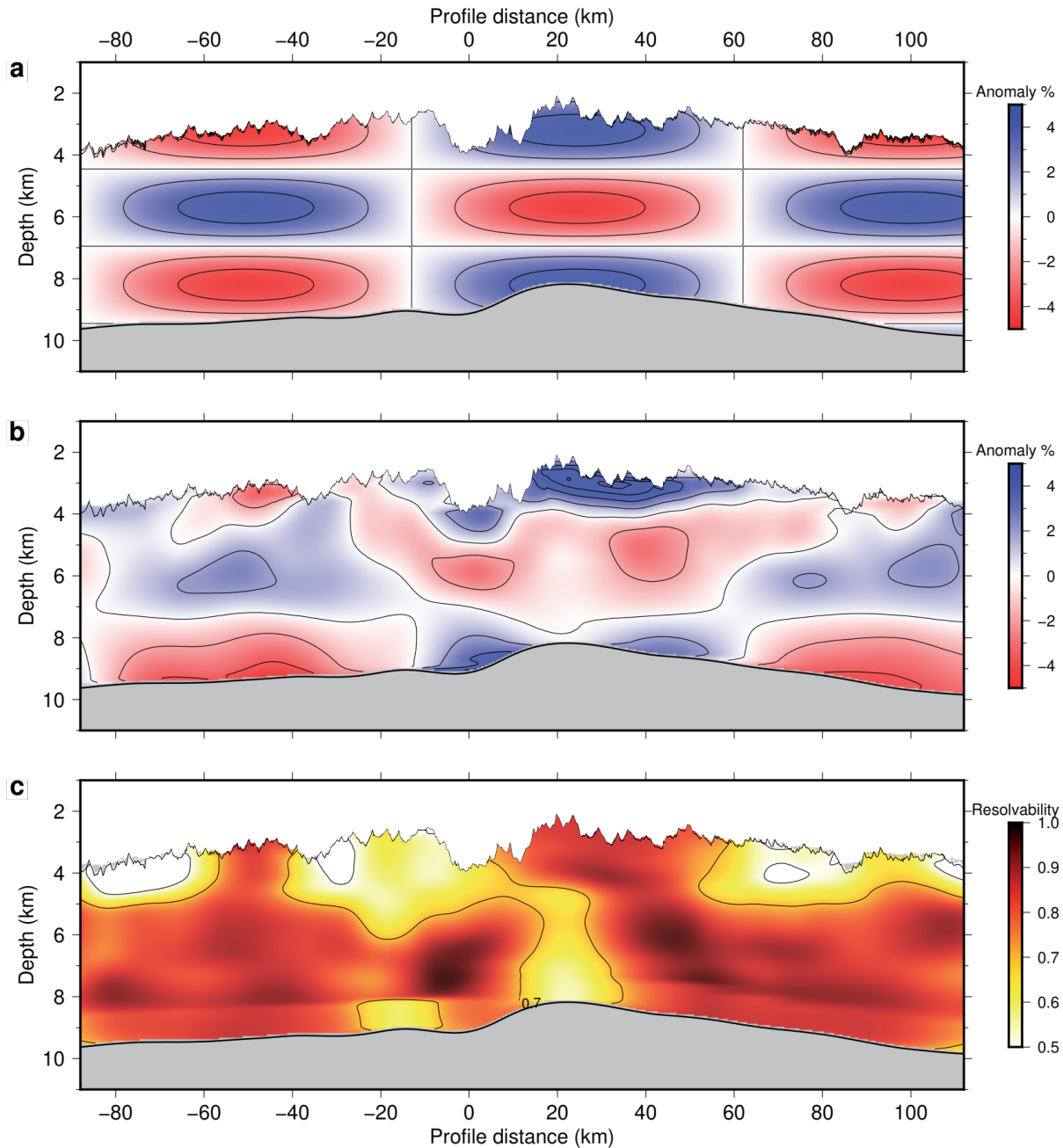
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90 **Supplementary Fig. 12 | V_P/V_S ratio test.** V_P/V_S ratio obtained without using the data of OBS
 91 79 located in the axial valley plotted with a horizontal to vertical exaggeration of 1:1. This plot
 92 clearly shows that high V_P/V_S ratio of >1.85 is also constrained by two other OBSs adjacent to
 93 the axial valley further confirming that the high V_P/V_S ratio is a true feature that can be
 94 interpreted reliably.



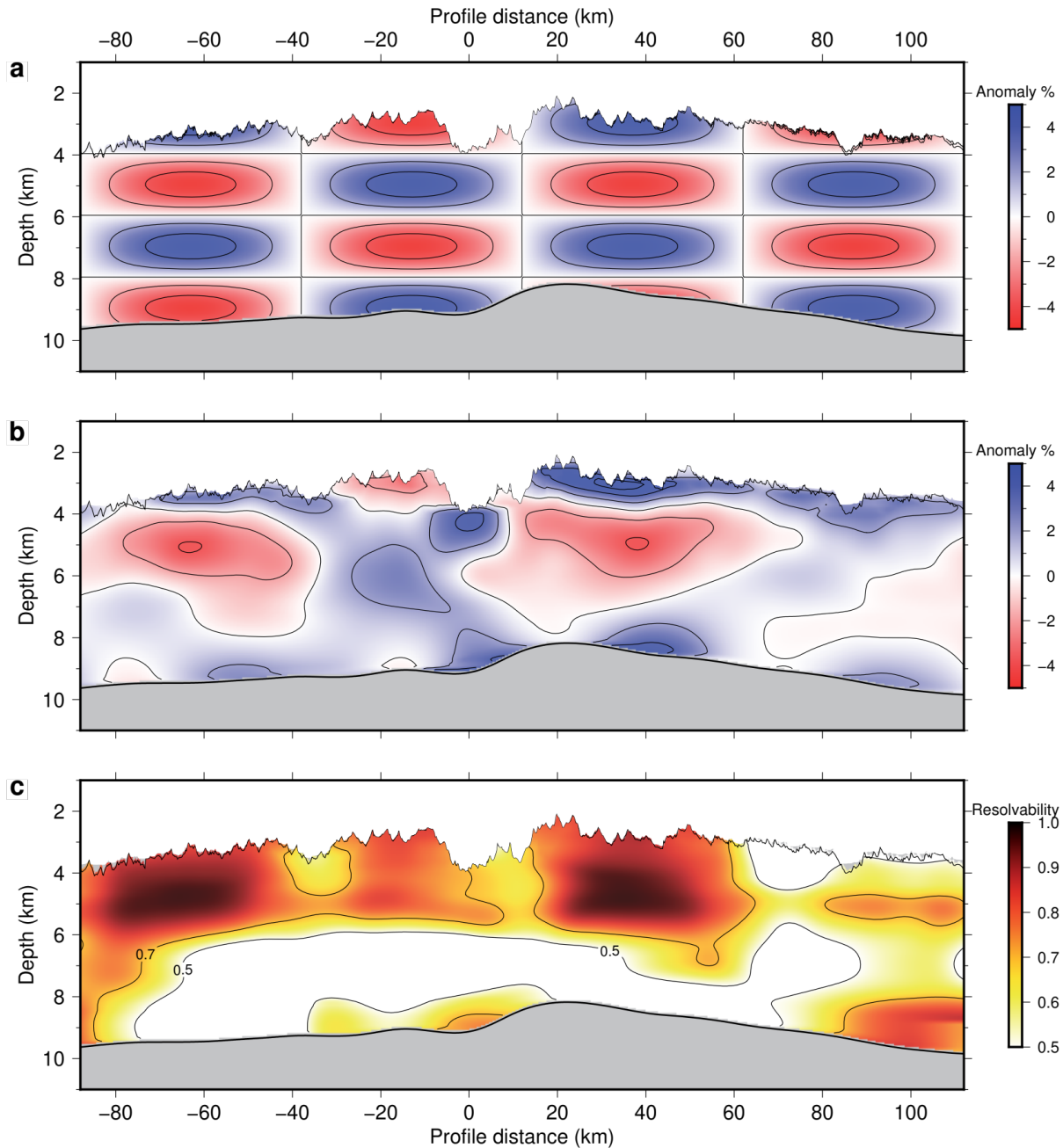
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96 **Supplementary Fig. 13 | Crustal thickness. a,** Crustal thickness variation along profile shown
 97 with the uncertainty bounds for the 100 random starting models in the Monte-Carlo analysis. **b,**
 98 Final crustal thickness variation shown with the uncertainty bounds.



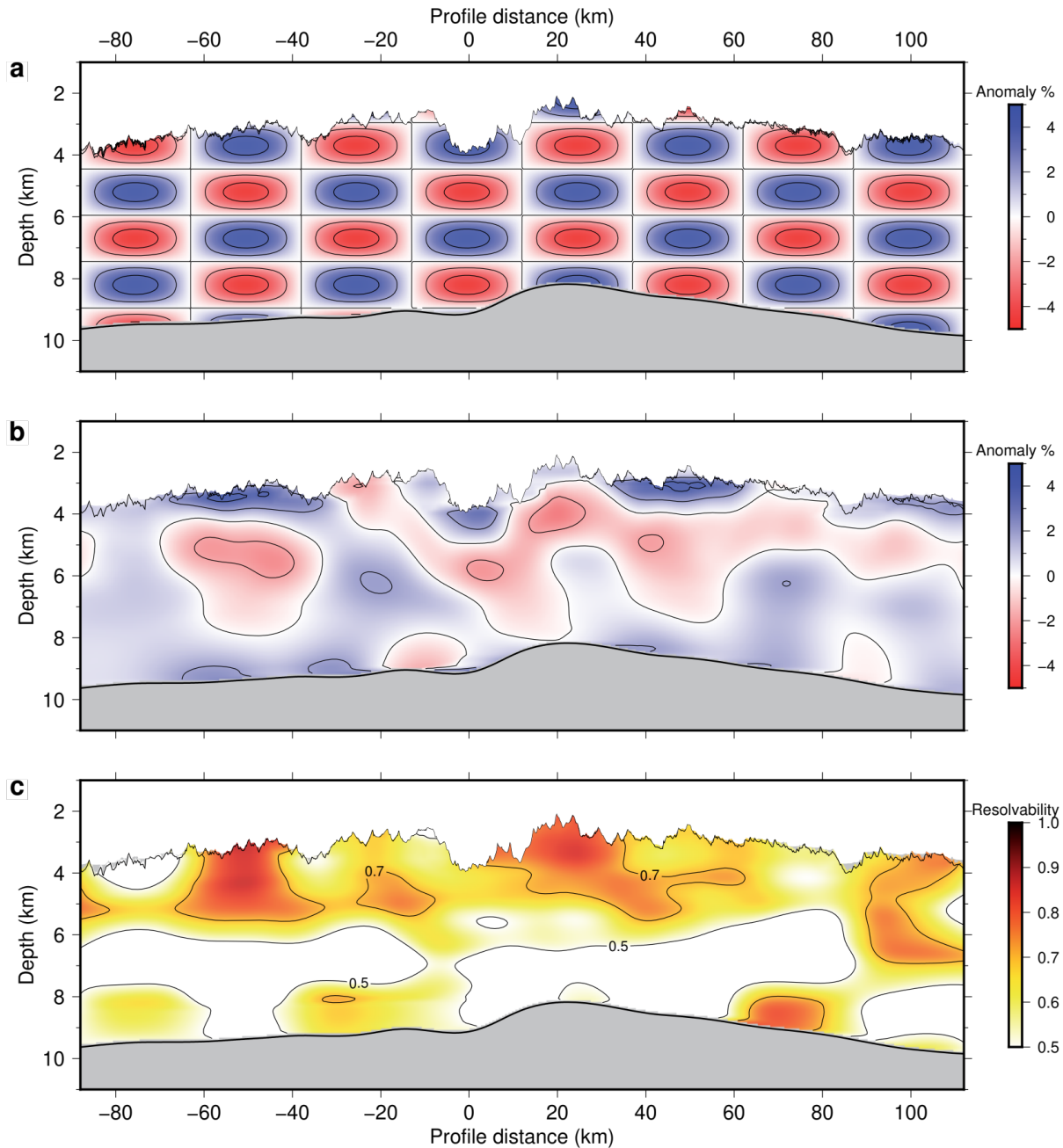
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100 **Supplementary Fig. 14 | Checkerboard test 1.** **a**, Sinusoidal anomaly pattern with a size of 75
 101 km x 2.5 km is added to the standard model plotted with a vertical exaggeration of 1:10. **b**,
 102 Recovered pattern after performing the inversion using the same regularization constraints as in
 103 the standard model. **c**, Semblance plot for the recovered anomalies.



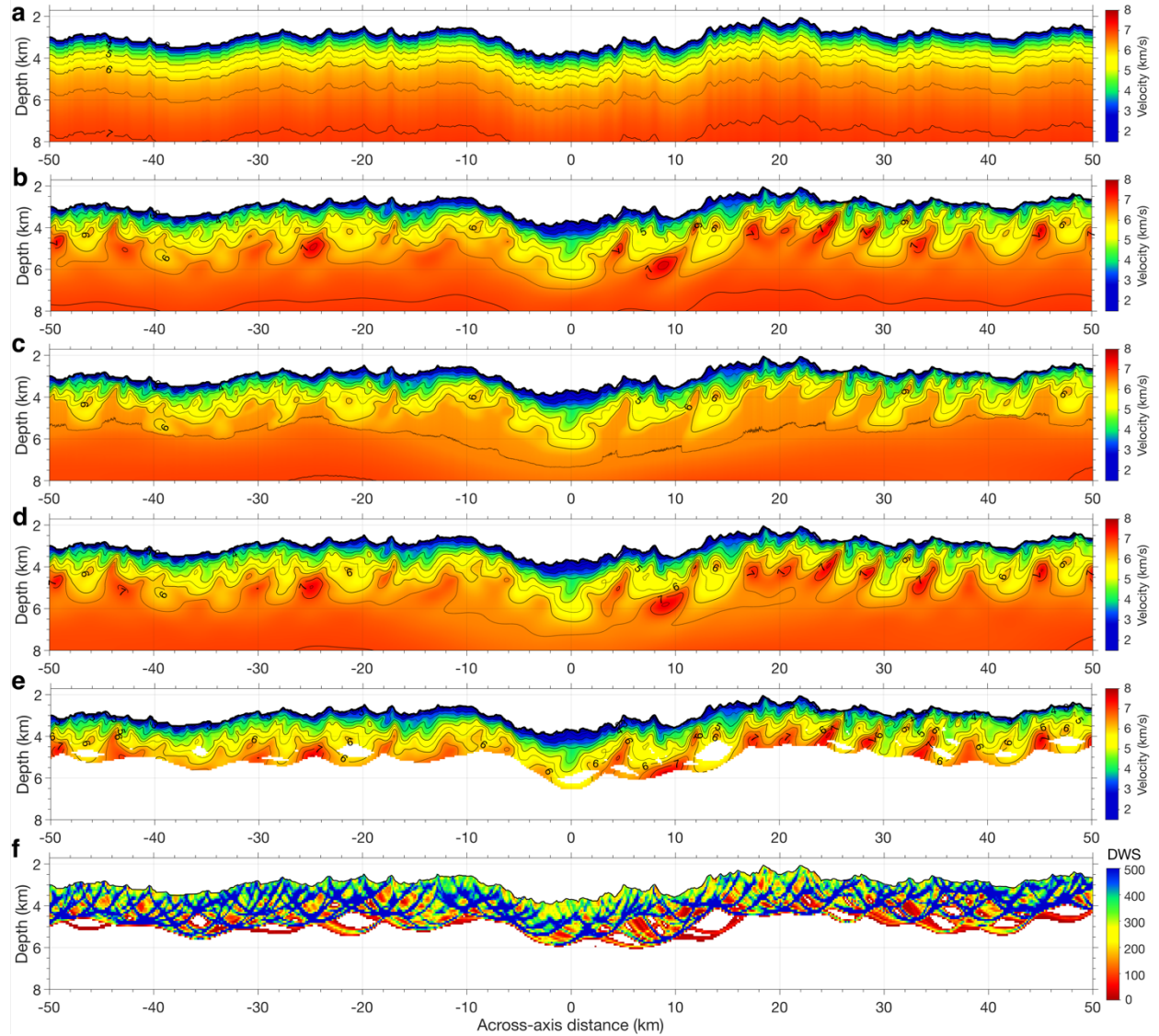
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105 **Supplementary Fig. 15 | Checkerboard test 2. a,** Sinusoidal anomaly pattern with a size of 50
 106 km x 2 km is added to the standard model plotted with a vertical exaggeration of 1:10. **b,**
 107 Recovered pattern after performing the inversion using the same regularization constraints as in
 108 the standard model. **c,** Semblance plot for the recovered anomalies.



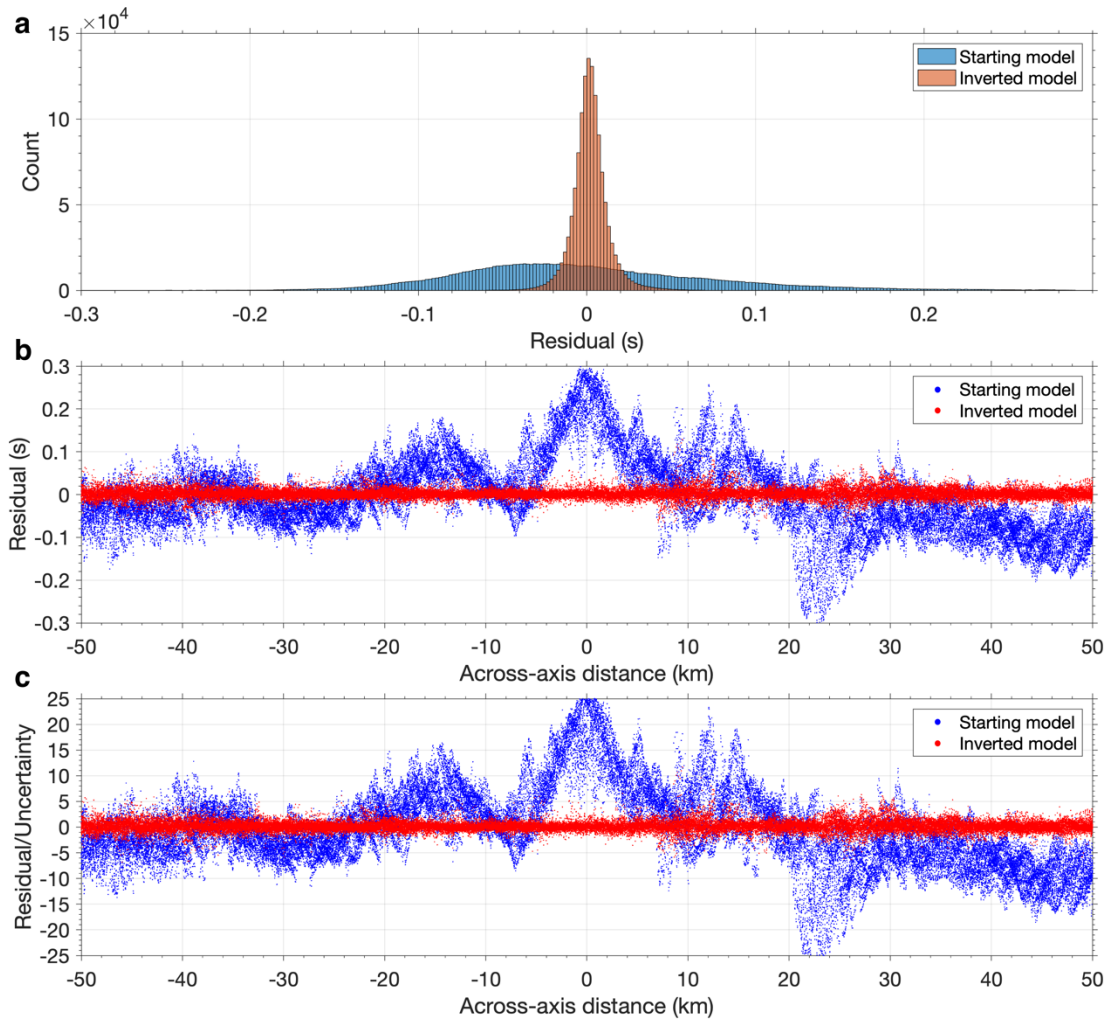
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110 **Supplementary Fig. 16 | Checkerboard test 3. a,** Sinusoidal anomaly pattern with a size of 25
 111 km x 1.5 km is added to the standard model plotted with a vertical exaggeration of 1:10. **b,**
 112 Recovered pattern after performing the inversion using the same regularization constraints as in
 113 the standard model. **c,** Semblance plot for the recovered anomalies.



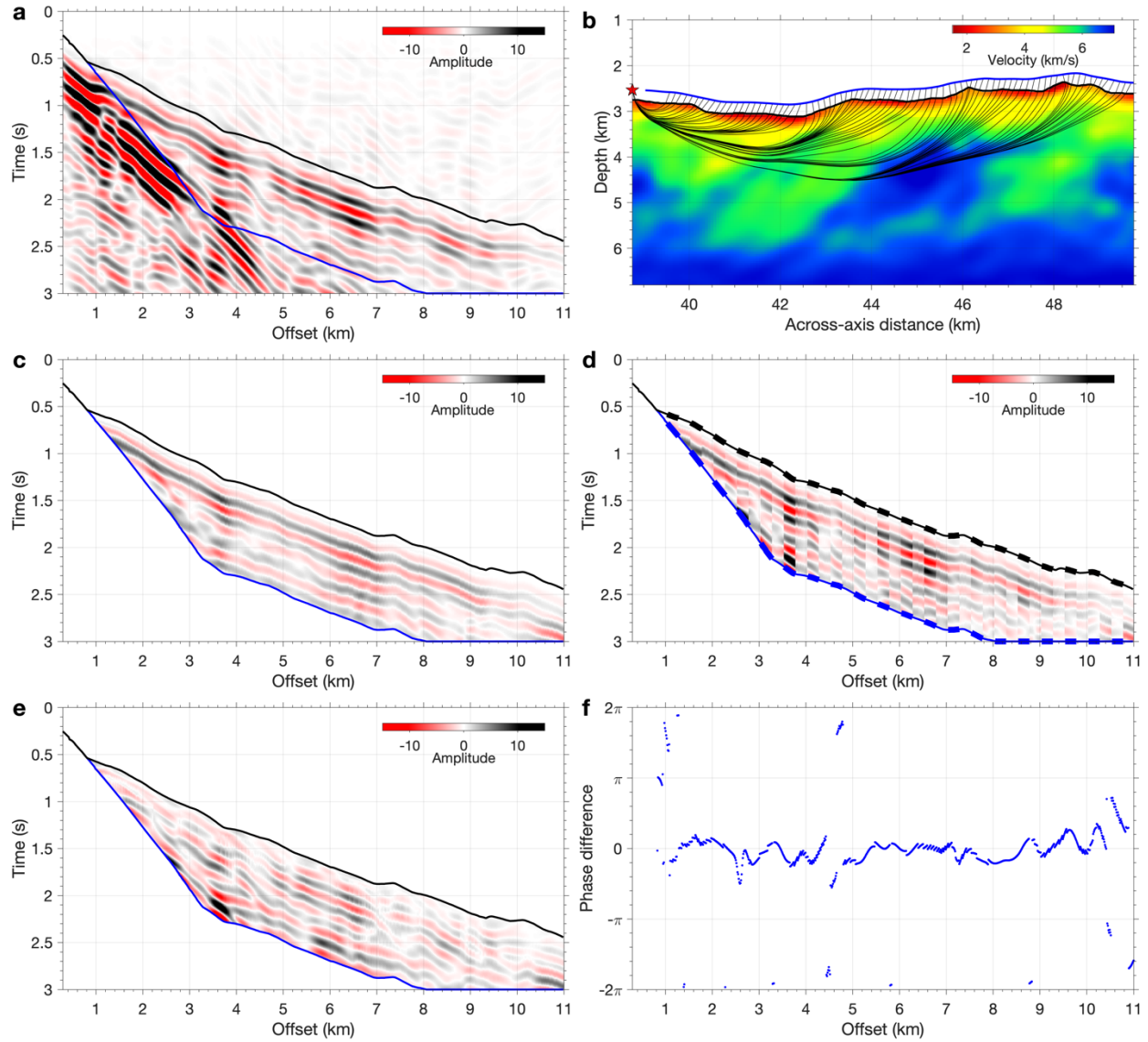
114

115 **Supplementary Fig. 17 | MCS tomography models. a,** The 2-D starting model derived by
 116 hanging the best-fitting 1-D model below the seafloor. **b,** The inverted 2-D model by starting
 117 from the model in (a). **c,** The combined model by replacing lower crust in model **b** with the OBS
 118 tomography P-wave velocity model (Fig. 3a). **d,** The inverted model by starting from the model
 119 in (c). **e,** Same as (d), except the model nodes without ray coverage are masked. **f,** The derivative
 120 weight sum (DWS) corresponding to the final model (d) and (e). All panels are plotted with a
 121 vertical exaggeration of 1:2.



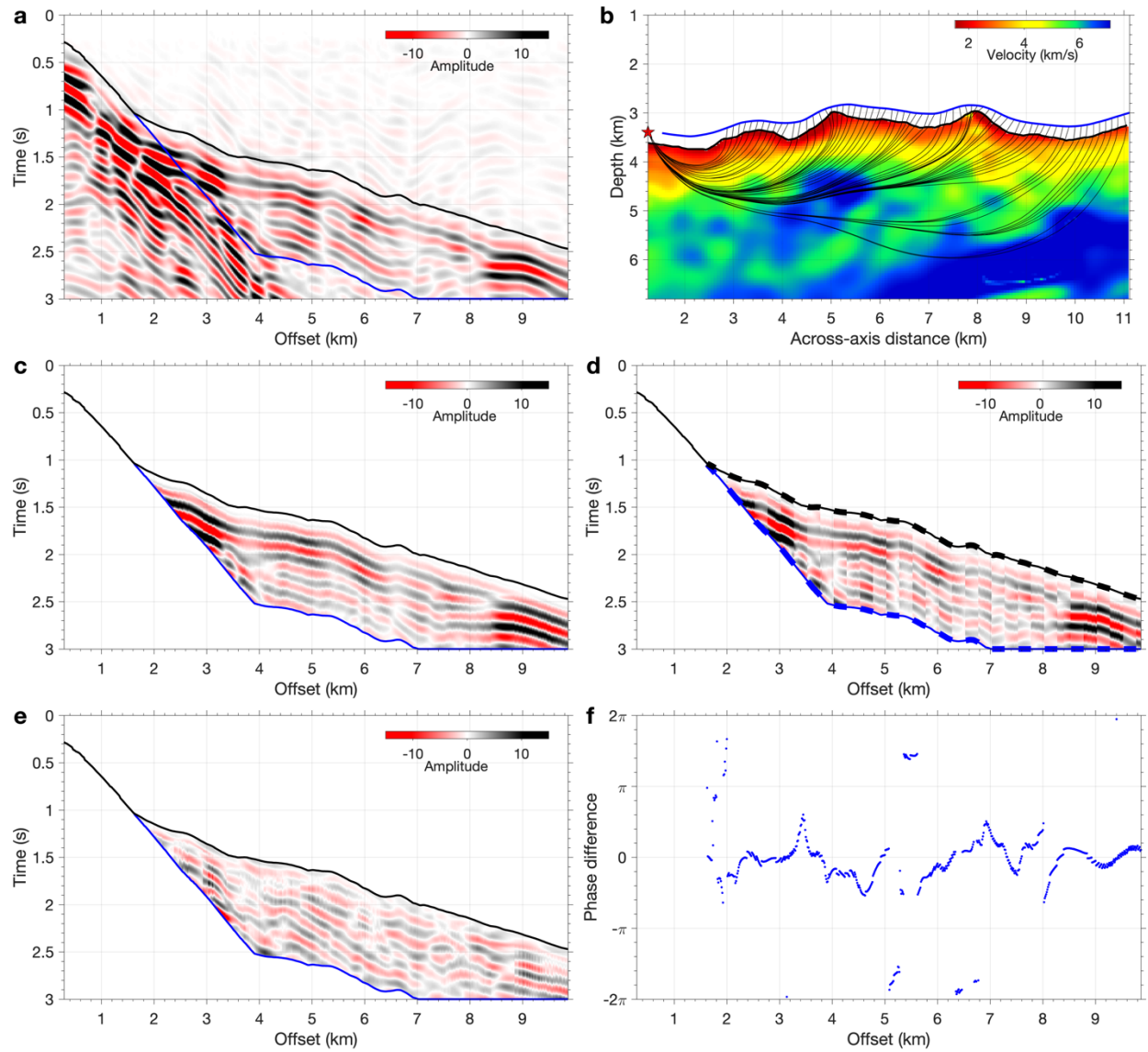
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123 **Supplementary Fig. 18 | MCS tomography data residuals.** **a**, Histogram of traveltime
 124 residuals (picked traveltime minus modelled ones) for the initial (Supplementary Fig. 17a) and
 125 inverted (Supplementary Fig. 17d) models. **b**, Residuals and **c**, residuals normalized with picking
 126 uncertainties, plotted as functions of source-receiver midpoint locations. Data in **(b)** and **(c)** are
 127 decimated by 20 for displaying purpose.



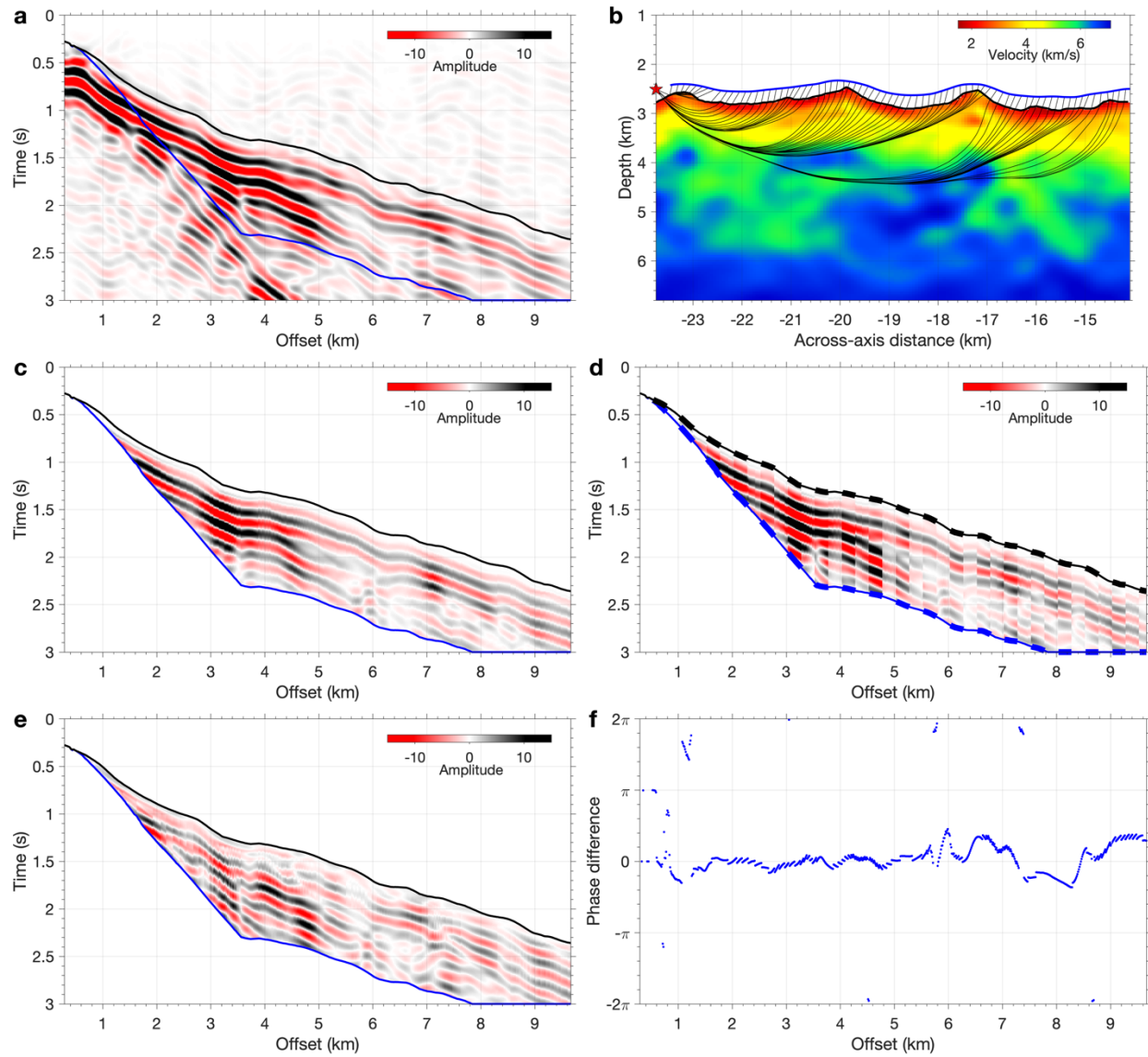
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129 **Supplementary Fig. 19 | MCS FWI data fitting example.** **a**, The pre-processed MCS shot
 130 gather for the shot located at 38.75 km distance. The black curve marks the beginning of the time
 131 window used in the FWI, which is calculated based on the predicted first-arrival traveltimes. The
 132 blue curve is the end of the time window, which is before the arrivals of seafloor reflections and
 133 no more than 1 second after the beginning of the window. **b**, First-arrival ray paths from the
 134 MCS tomography overlying the MCS FWI model. **c**, The final modelled data. **d**, Interleaved plot
 135 of the observation and final modelled data, where the observation data segments are marked with
 136 bold time window outlines. **e**, Residual between the observation and final modelled data. **f**, Phase
 137 difference between the observation data and the final modelled data at 4.0 Hz. Most values are
 138 within $\pm\pi$, indicating the inversion result is not affected by cycle skipping.



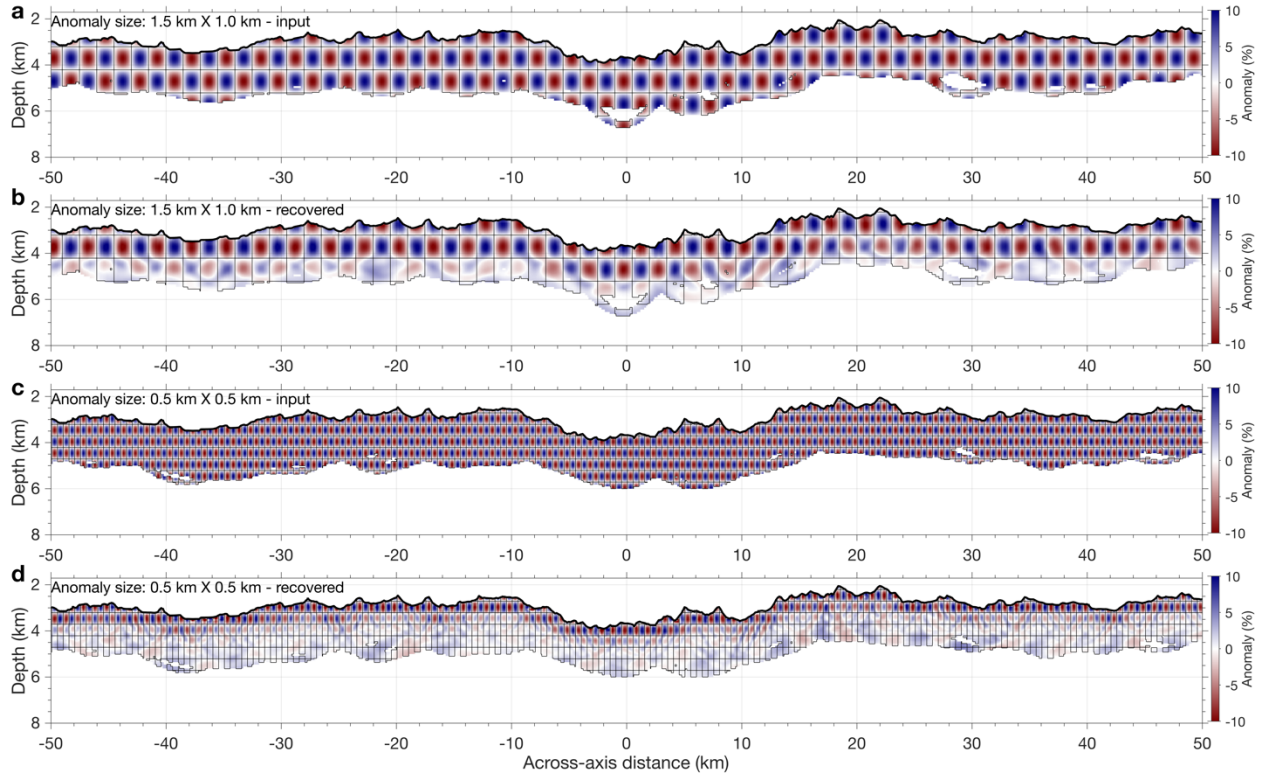
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140 **Supplementary Fig. 20 | MCS FWI data fitting example.** Same as Supplementary Fig. 19,
 141 except for the shot located at 1.25 km distance.

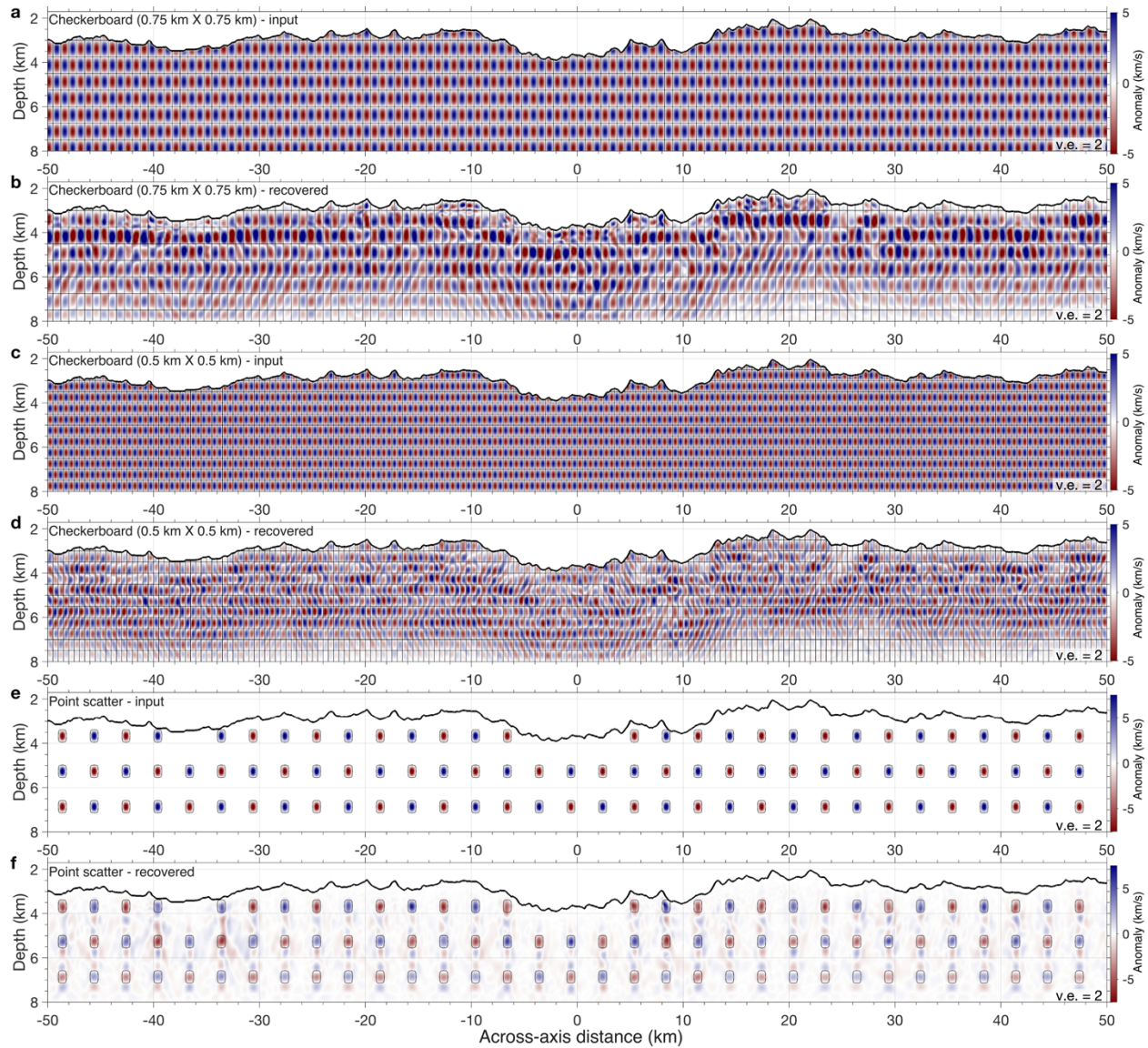


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143 **Supplementary Fig. 21 | MCS FWI data fitting example.** Same as Supplementary Fig. 19,
 144 except for the shot located at -23.75 km distance.



Supplementary Fig. 22 | Checkerboard tests for the MCS tomography. **a**, Input checkerboard pattern with anomaly amplitude of 10% and size of 1.5 km X 1.0 km (horizontally X vertically). **b**, Recovered anomaly pattern using the synthetic traveltime data generated from the input pattern in (**a**). Thin black curves are contours of zero from the input anomalies. Model nodes without ray coverage are masked. **c** and **d**, Same as (**a**) and (**b**), except for an input pattern with anomaly size of 0.5 km X 0.5 km.



153

154 **Supplementary Fig. 23 | Checkerboard and point scatter tests for the MCS FWI.** **a**, Input
 155 checkerboard pattern with amplitude of 5% and anomaly size of 0.75 km X 0.75 km
 156 (horizontally X vertically). **b**, Recovered anomaly pattern with the synthetic waveform data
 157 generated from the input pattern in (**a**). Thin black curves are contours of zero from the input
 158 anomalies. **c** and **d**, Same as (**a**) and (**b**), except for an input pattern with anomaly size of 0.5 km
 159 X 0.5 km. **e**, Input point scatter anomalies with amplitude of 10%, size of 0.8 km X 0.6 km and
 160 spacing of 3 km X 1.6 km. Black squares outline the positive and negative Gaussian shaped
 161 anomalies. **f**, Recovered anomalies. Black squares are the same as in **e** to compare the locations
 162 and size of anomalies.