Reply to the reviewer comments
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Dear Andrew,

Thank you for your positive assessment of our work and for your constructive comments. Also we are thankful for your thorough copy-editing of the manuscript. Please find hereafter our answers to your comments.

Best regards,
The authors

Reviewer comments

1. *It would be helpful to comment on which velocity models are in the "migrated" an "unmigrated" domains; for example, when lateral heterogeneity is present, velocities derived by standard stacking velocity analysis are not associated with the surface locations suitable for depth migration. Was this problem addressed when the stereotomography (ST) was applied? In contrast, the interval velocity model from FWI is in the depth domain suitable for migration.*

   We agree that more clarification is required regarding this issue.
   In principles we start our PSDM with two models derived from VA and FWI respectively. The model obtained with the classical time-domain VA is not only more inaccurate with increasing depth, but also (as you have mentioned) cannot handle properly the lateral velocity heterogeneities. Therefore the aim of application of ST in this case was to improve the limited accuracy of the velocity model built by VA for prestack depth imaging. ST does not rely on any assumption concerning the nature of the heterogeneities of the medium and therefore can handle properly the lateral velocity variations (e.g. the true medium can also generate diffractions, that will be exploited by ST if they can be picked).
   On the other hand, the FWI model is built in the depth-domain since the beginning and therefore it might be better suitable for PSDM. However, the velocities in FWI model are derived from the different seismic data, which due to the wide-angle propagation regime may not have the same meaning than those found by MCS data (and required for PSDM) in particular in presence of anisotropy. Therefore, in this second case, we might see ST as a tool to optimize the PSDM results by correcting sub-horizontal velocities (as potentially found from OBS) into NMO velocities and to assess the influence of the inaccuracies generated by the different propagation regime or anisotropy. Indeed, this correction is heuristic (without implementing explicitly anisotropy) and may add unrealistic velocities in the model in the presence of migration artefacts or insufficient sampling by the scattering points (Manuscript-Figure 7).
   To summarize, were are aware that VA and FWI models could be not accurate for PSDM of MCS data at such a geological scale (in the first case because of the lateral homogeneous assumption of classical time-domain VA; and in the second case because the OBS seismic data have been used to build the velocity model for PSDM of MCS data). Therefore, application of ST is yet another way to assess the accuracy of these velocity models for PSDM (if they are weakly modified, it means that they are accurate) and to optimize the migrated images.
   We modify the manuscript accordingly in the *Introduction* section as well as section *2.2.4 MCS data - slope tomography*

2. *Some discussion on the accuracy of the velocity model is also warranted. With raybased tomography it is common practice to evaluate spatial resolution using checkerboard tests, or something equivalent, and this method can also be used with wide-angle FWI, though this might prove more challenging when stereo-tomography is included. The FWI+ST model has velocities of 8000 m/s, i.e. mantle, 1-2 km below the top of the oceanic crust, which is unrealistic. Given the reduced constraint at depth documented in Fig. 7c, I doubt the accuracy of the velocities, and their variation, within the igneous oceanic crust. Could this be due to fitting out-of-plane arrivals? These velocity anomalies are less pronounced in the FWI model (Fig. 8c versus 8d). Note that the purple color in Fig. 11 a does not appear on the colorbar. So is the colour scaling in Fig. 11 correct?*

   We understand the importance of QC of the velocity models, and therefore we have spent significant efforts dedicated to validation of the FAT and FWI models in Górszczyk et al. (2017). The QC was based on: (i) qualitative and quantitative assessment of the real-vs-synthetic data fitting using Dynamic Image Warping (DIW, Hale, 2013); (ii) geophone response estimation (i.e. source wavelet estimation within the framework of source-receiver reciprocity); (iii) phase interpretation via ray-tracing; (iv) chequerboard tests of different scales.
   To recall some of the results of our QC (exhaustive discussion is provided in Górszczyk et al. (2017)) in Figure 1 we present the accuracy of data-fitting between the observed and synthetic data, generated in FAT and FWI models. From the zoom-insets in Figure 1(ab) it is clear that FWI drives the interleaved wiggles, which are not aligned in case of data generated in the initial model (Figure 1(a)), into their correct position (Figure 1(b)). The same consistency is also visible for the amplitude trends (Figure 1(d).
   To quantitatively express this accuracy we utilize DIW. In Figure 2(ab) we present the estimated local time-shift panels for the single OBS as well as for the whole dataset. Histogram of shifts presented in the inset and Figure 2(c) shows that vast majority of the time-shifts fall between ±30 ms which gives us an idea about the reconstruction accuracy.
   Moreover, in the presented manuscript we further extensively validate both models against the separate dataset and the different velocity model-building (namely Slope Tomography) and depth imaging (namely Kirchhoff PSDM) techniques. In the section *2.2.1 OBS data* we encourage the reader to see the full validation of both models in Górszczyk et al. (2017).
   For the ST+FWI model, indeed the local high velocities in the oceanic crust may not be relevant, and therefore we refer to them in the single paragraph we add to the section *2.2.4 MCS data - slope tomography.* The perturbations appear in the area which is partially covered the migration smiles - suggesting that the events were not migrated precisely. Since the depth is already significant the precision of PSDM is reduced. There are more geological investigations which suggest existence of the widely distributed faults in the subducting oceanic crust in the Nankai region (i.e. Tsuji et al., 2013). Since they are definitely the 3D structures, they might cause some problems for two-dimensional PSDM and ST. Therefore, the migration artefacts and the corresponding areas of over-saturated velocities can be associated with out-of-the-plane propagation.
   Thank you also for your sharp-eye spotting the wrong colorbar which is now corrected.

3. *Can you mask out the unconstrained parts of the velocity models, e.g. the region of zero ray coverage in Fig. 3a.*

   Thank you for this suggestions. We add the masks corresponding to the first-arrival ray-coverage in Manuscript-Figure 3.

4. *It is impressive that the velocity gradient increases in the igneous oceanic crust can be extracted from the velocity model. The increases at the top of the oceanic crust and the Moho seem reasonable. Is the thickness of oceanic crust implied here consistent with the known thickness of the*

incoming plate in this area?

Studies of (Kodaira et al., 2003) or Lallemand (2014) based on the FAT models suggests more exaggerated thickening of the crust (e.g. ranging from ∼ 7 km to ∼ 12 km in the areas considered as a subducted volcanic ridges; see Fig. 4 for details). In our case, we observe similar undulations of the crust. However, the thickening regions are not that much pronounced. One reason for that might be the fact our FWI model provides better focusing of the structure compared to the FAT model in Figure 4.

5. *It is suggested that the stepping within the Layer 2 gradient zone might be due to thrust faulting, but are these offsets more consistent with normal faulting with blocks dropped to the west; perhaps faulting created as the plate bends into the subduction zone?*

   Thank you for this comment. Perhaps we were too much focussed on the results of Tsuji et al. (2009) and Tsuji et al. (2013) referring to the thrusting within oceanic crust. Indeed, the stress environment below the decollement surface generally could be under extension and normal faulting is commonly dominant. While the thrust faults are also possible, but may be more common in the earthquake zones where friction would be higher.
   We correct the manuscript in the section *3.2.1 Structure of the subducting oceanic crust* accordingly.

6. *Page 12, line 6: I doubt that this velocity variation within the igneous crust is real. Even if it were I doubt that it could be simply attributed to volcanic ridges on the oceanic crust. Fracturing of the oceanic crust can reduced velocities where the incoming plate bends, but would likely be a more systematic, long-wavelength anomaly than shown here.*

   As we have mentioned before, some over-estimation of velocity value intruded by ST can occur in the areas where PSDM encounters problems related to the out-off-the-plane wavefield propagation. However, less pronounced (but still noticeable) velocity variations in the oceanic crust are observed also in FWI model itself as well as the FAT model, suggesting the structural heterogeneity and/or deformation of the crust.
   In Tokai area we can also expect the influence of the Izu Arc colliding with the central Japan as well as the initial thrusting stage around the Zenisu Ridge. Nevertheless, there have been previous studies which were tackling the subject of geometry of the subducting plate and they suggested existence of horst-like structures (volcanic ridges) underneath the accretionary prism. Therefore it can be accepted to assume the existence of such ridges in this region. Moreover, fluid migration can occur along the ridge-bounding faults causing alternation of the deep rocks (e.g. serpentinization) which may actually affect the crustal velocity structure. Such fluid rock interaction and velocity alteration have been reported at the outer ridge of the Tohoku margin (Korenaga, 2017).
   We change the manuscript text in the section *3.2.1 Structure of the subducting oceanic crust* accordingly to underline this informations. We also change the background velocity model in Manuscript-Figure 11(a) for the FWI model, to avoid the confusions related to the overestimated velocities introduced by ST.

7. *Pager 13, line 7: It is probable that the igneous oceanic crust would have some deep water, hemipelagic sediment cover before it receives any sedimentary input from the land.*

   To the best of our knowledge, the reality of the Tokai region is that the young Phillippine Sea Plate is subducting without hemipelagic sediment (but some volcanic rocks including volcanic ash) on top of it, without forming deep trench but shallow trough instead.

References

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Figures

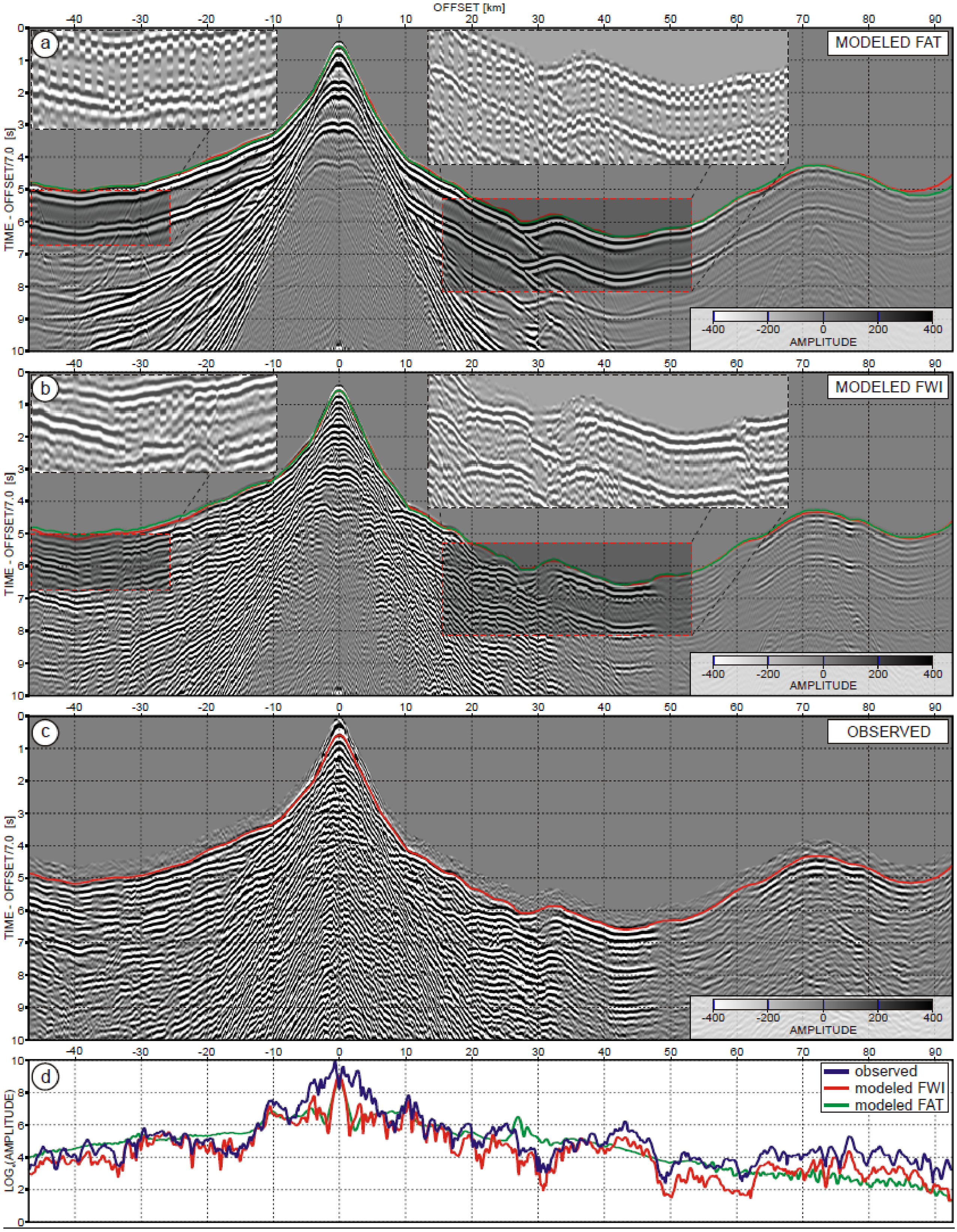

Figure 1: Comparison between the observed and modeled seismograms. (a-b) Synthetic data computed using the (a) FAT and (b) FWI models. (c) Observed data. Zoom-panels show 5 interleaved traces from modeled and observed OBS gathers. The red/green curves (a-c) represent the picked/calculated first-arrival traveltimes respectively using the (a) FAT and (b) FWI models. The true-amplitude seismograms in (a-c) are plotted using the same amplitude scale. (d) Comparison of the amplitude-versus-offset curves extracted from the seismograms shown in (a-c). The amplitudes are extracted from a 400 ms window after the first arrivals. From Górszczyk et al. (2017)

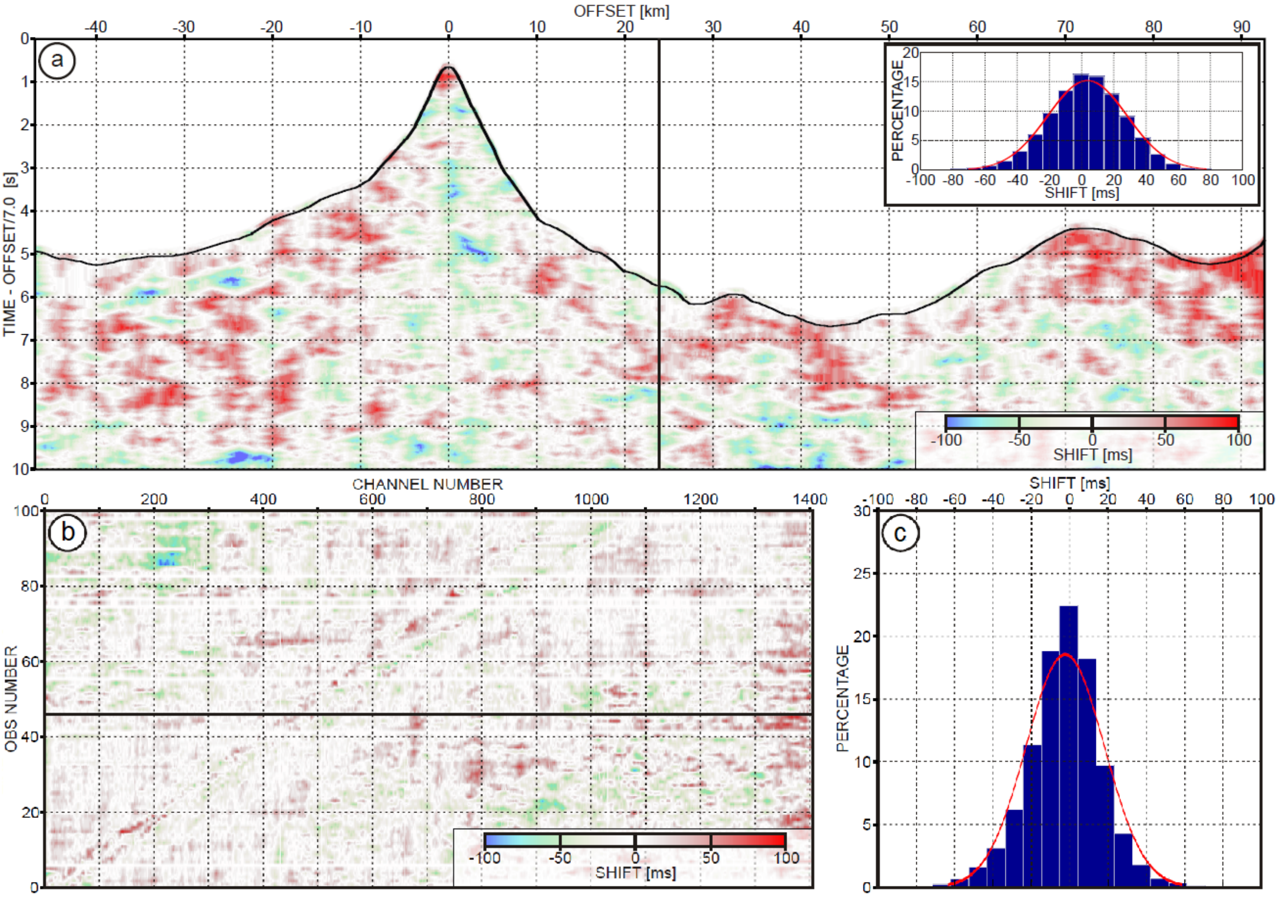

Figure 2: Illustration of DIW results. TOP: Map of the local shifts for all data samples in single OBS gather, with their histogram and fitted distribution shown in the inset. The black curve represents the samples collected 100 ms after the first arrivals. BOTTOM LEFT: Map of the local shifts for data samples located 100 ms after first arrival extracted from all OBS gathers. BOTTOM RIGHT: Histogram and fitted distribution of the shifts presented in BOTTOM LEFT panel. From Górszczyk et al. (2017)

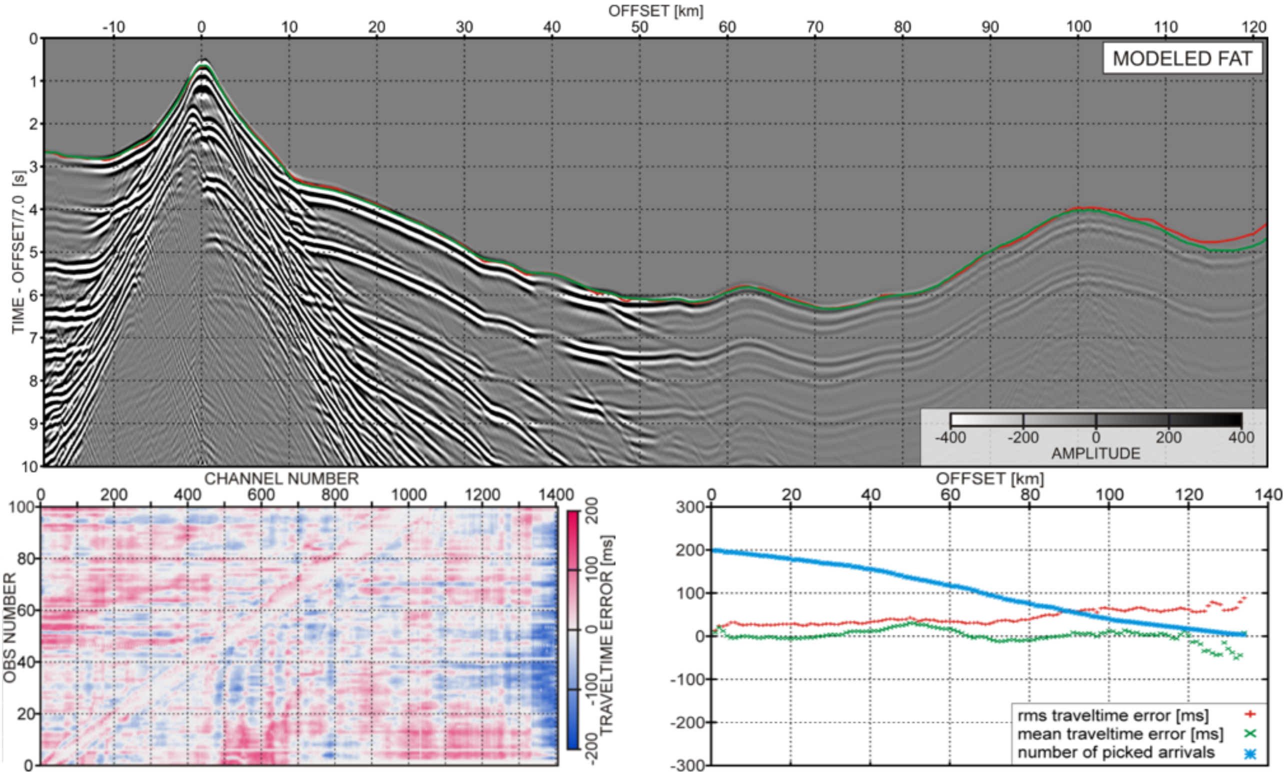

Figure 3: Assessment of the FAT model. TOP: Synthetic seismogram computed in the FAT model with superimposed picked (red line) and calculated (green line) traveltimes. BOTTOM LEFT: Traveltime difference map for all picked traces arranged in the source-vs-receiver coordinates. BOTTOM RIGHT: Mean traveltime difference and RMS (red + and green × respectively) calculated within 1-km offset intervals plotted against increasing offset. Cyan $*$ represent number of picked traces at given offset. From Górszczyk et al. (2017)

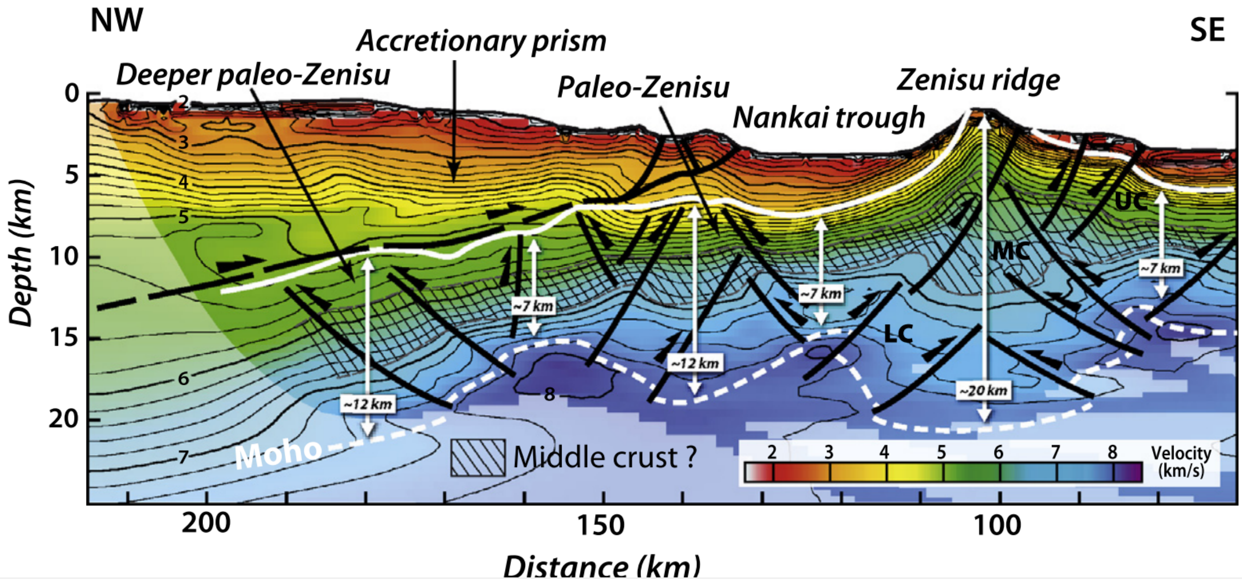

Figure 4: Figure 3 from Lallemand (2014) showing the structural interpretation of the nearby OBS profile in the Tokai area.