Tectonics

Supporting Information for

Tectonic Evolution of a Sedimented Oceanic Transform Fault: the Owen Transform Fault, Indian Ocean

Alexandre Janin[1], Nicolas Chamot-Rooke[1], Matthias Delescluse[1], Marc Fournier[2], Jean-Arthur Olive[1], Alain Rabaute[2], Philippe Huchon[2], Jérôme Dyment[3], Christophe Vigny[1] and Mathieu Rodriguez[1]

[1] Laboratoire de Géologie - CNRS UMR 8538, École normale supérieure - PSL University, 75005 Paris, France
[2] Sorbonne Université, CNRS-INSU, Institut des Sciences de la Terre de Paris, ISTeP UMR 7193, 75005 Paris, France
[3] Université de Paris, Institut de physique du globe de Paris, CNRS, 75005, Paris, France

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Figures S1 to S13 and technical details from Text S1 to S5

Introduction

This Supplementary Information file contains additional figures and texts related to technical details regarding the calibration of seismic reflection lines (Text S1-S3 and Figures S1-S4), their interpretation (Raw profiles in Figures S5-S13) and the depth of the basement within the Owen transform fault valley (Text S4-S5).

Text S1 Seismic Calibration method at ODP sites

We apply the following calibration scheme for all high-amplitude seismic reflectors identified regionally:

- Estimate a first-order reflector depth in mbsf (meter below the seafloor) using Nafe & Drake empirical laws (Nafe and Drake 1957, 1961) calibrated regionally on the Indus turbiditic sediments at site DSDP23-222 (location on the Figure 1). We choose this site for the Nafe & Drake calibration for the dense measurements (on average every 23 m) of porosity and grain density.
- Check the presence of a discontinuity in seismic wave velocities and/or lithostratigraphic log near the estimated depth, and assign the drilling depth if found.
- Compute a synthetic seismogram where sampling rates of density and compressional wave-speed measurements are dense enough. A comparison of depths estimates using Nafe & Drake laws and a synthetic seismogram is given in Figure S1.
- Finally, an age is assigned to the reflector using the nearest dated core sample at the estimated depth.

Text S2 Calibration at ODP Abyssal Plain Site 720

Site 720 (ODP leg 117) is the only drilling site located over the middle/distal Indus turbiditic system (Figures 3 and S2a). The sedimentary cover is typically composed of turbidites/pelagites alternations, at least in the upper part since drilling stopped in the upper Pleistocene at 414-m-depth (Shipboard Scientific Party 1989a). The first 17 m of sediments are dominated by pelagites, while the rest of the core is dominated by interbedded turbidites and clays. Within the sequences dominated by pelagites, nannofossils are abundant, fairly diversified and well preserved, allowing precise age assessment. The calibration of the pre-site survey seismic lines at site 720 is shown in Figure 3d (faunal identification is detailed in the Figure S2d). Four reflectors were calibrated, labelled R1 (the youngest one) to R4 (the oldest one), ranging in age from 0.82 Ma to 1.57-1.66 Ma. The pelagites cap covering the Indus turbiditic sediments at this site is younger than 0.49 Ma. The first dated reflector (R1) is below this pelagites cap, in the Indus turbidites near ~180 m depth. The estimated basement age at this site is Paleocene (~60 Ma, Shipboard Scientific Party 1989a), so that the calibration covers less than 3% of the seafloor history.

Text S3 Calibration at ODP Sites on Top of the Owen Ridge

Four drilling sites are located on the top of the Owen Ridge: sites 721, 722, 731 of ODP expedition 117 (Shipboard Scientific Party 1989b,c,d) and site 224 of DSDP expedition 23 (Figures 3a and S2a, Whitmarsh et al., 1974a). Turbidites of unknown source have been recovered from their base switching progressively to pelagites upward with the uplift of the Owen Ridge above the level of turbidite deposition in the Late Miocene (Shipboard Scientific Party 1989b,c,d, Rodriguez et al. 2014).

ODP sites 722 and 731 reached the stratigraphic basement with a high recovering ratio (>80% of the total core length). The bio-stratigraphic and magneto-stratigraphic analysis conducted on the cores of these two sites give a fine time calibration of the entire sediment cover topping the ridge. At site 722, nannofossils are identified and dated down to ~400 m depth covering a time window from the present to 14.5 Ma. Cores drilled at site 731 contained poorly recognizable nannofossils beneath ~560-meters depth, but the paleofaunal and magnetic reversals analysis returned sediments ages spanning from the present to 23-25 Ma.

Calibration at these two sites is shown in Figures 3b (S2b) and 3c (S2c) based on pre-site survey seismic lines. Ten reflectors have been recognized and dated. They span ~21 Myrs from 2.4-2.5 Ma to 23-25 Ma and are labelled R5 (the youngest one) to R16 (the oldest one). Our calibrations at sites located on the top of the Owen Ridge are in agreement with both ODP preliminary results (Shipboard Scientific Party 1989c,d) and more recent works on Arabia-India tectonic (Rodriguez et al. 2018) and on Miocene paleoceanography of the Northwestern Indian Ocean (Bialik et al. 2020) that both estimate the sediments ages distribution at site 722. Reflector R10 (8.6 Ma) was identified by Rodriguez et al. (2014) as marking the onset of the Owen Ridge uplift. At site 731, only reflectors beneath R11 were dated due to two sedimentation hiatuses affecting shallower horizons (Shipboard Scientific Party 1989d).

Text S4 Unloaded basement depth

In the last section of the paper (section 6.5), we discuss the depth of the unloaded basement in the transform fault valley (Figure 18c). This depth has been computed assuming local isostasy. As a result, h', the unloaded basement depth can be expressed as follows:

$$h' = h + \left(\frac{\rho_m - \rho_s}{\rho_m - \rho_w}\right) h_s$$

where h is the bathymetry before the unloading and h_s the sediment thickness. ρ_m, ρ_s and $\rho_w$are densities for the mantle, the sediments and the water, respectively. We choose $\rho_m = 3300\ kg.m^{-3}$, $\rho_s = 2500\ kg.m^{-3}$ and $\rho_w = 1025\ kg.m^{-3}$ to unload the basement of the Figure 18.

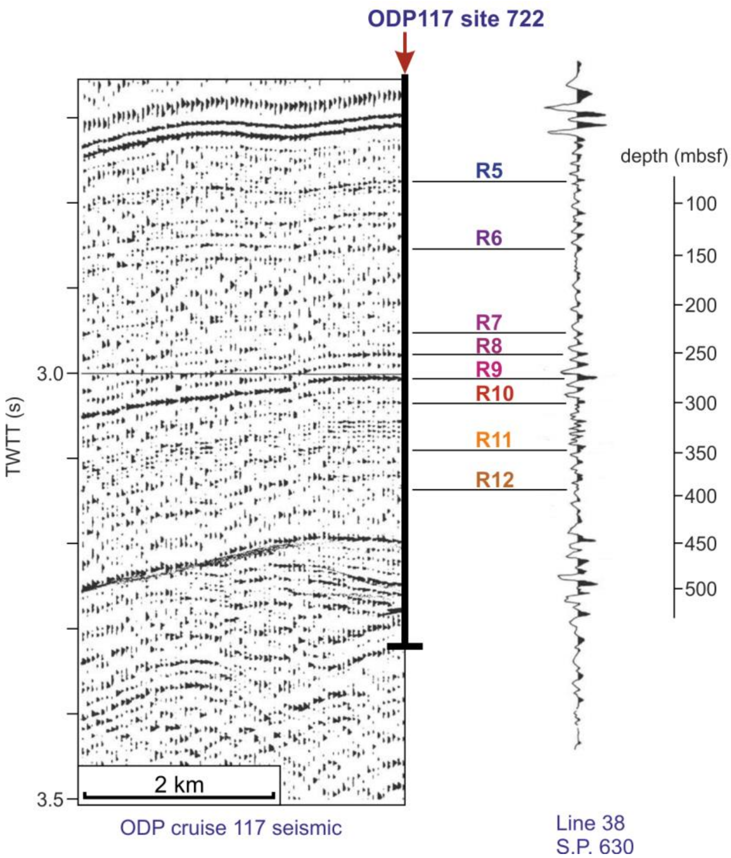
Text S5 Thermal subsidence models

The two half-space cooling models represented as orange lines in the Figures 18 (a-c) follow the formulation of Stein and Stein (1992):

- Model for the Carlsberg Ridge (Figure 18a, 18c): $d = 2600 + 365\sqrt{age}$
- Model for the Sheba Ridge (Figure 18b): $d = 2400 + 365\sqrt{age}$

where age is given in Myr.

Supporting Figures



Reflectors	Depths from synthetic (m)	Depths from Nafe-Drake (m)	Core level
R5	70	66	8H-5, 115-117
R6	140	132	12X-CC and 15X-5, 115-117
R7	225	218	24X-4, 85-87
R8	247	240	25X-CC
R9	275	268	28X-CC
R10	290	292	31X-2, 65-67
R11	345	340	36X-CC
R12	395	392	41X-CC

Figure S1. A comparison of depths estimates using Nafe and Drake laws and synthetic seismograms. From left to right: seismic line crossing the site 722 (Shipboard Scientific Party 1989c); seismic trace close to the hole on which we indicate 8 reflectors that we calibrate at this site; a table with the names of the 8 reflectors drawn on the left and two independent depth estimates of these reflectors: one using the synthetic seismogram and the second using the Nafe and Drake method. The last (right) column corresponds to the core level associated to these depths as descried in Shipboard Scientific Party (1989c). You can notice on this figure the very good agreement between the two methods illustrating the robustness of our depth estimates using the Nafe and Drake method. The dating of each reflector is then obtained by the analysis of all information contained on the corresponding core section (nanno fossils etc).

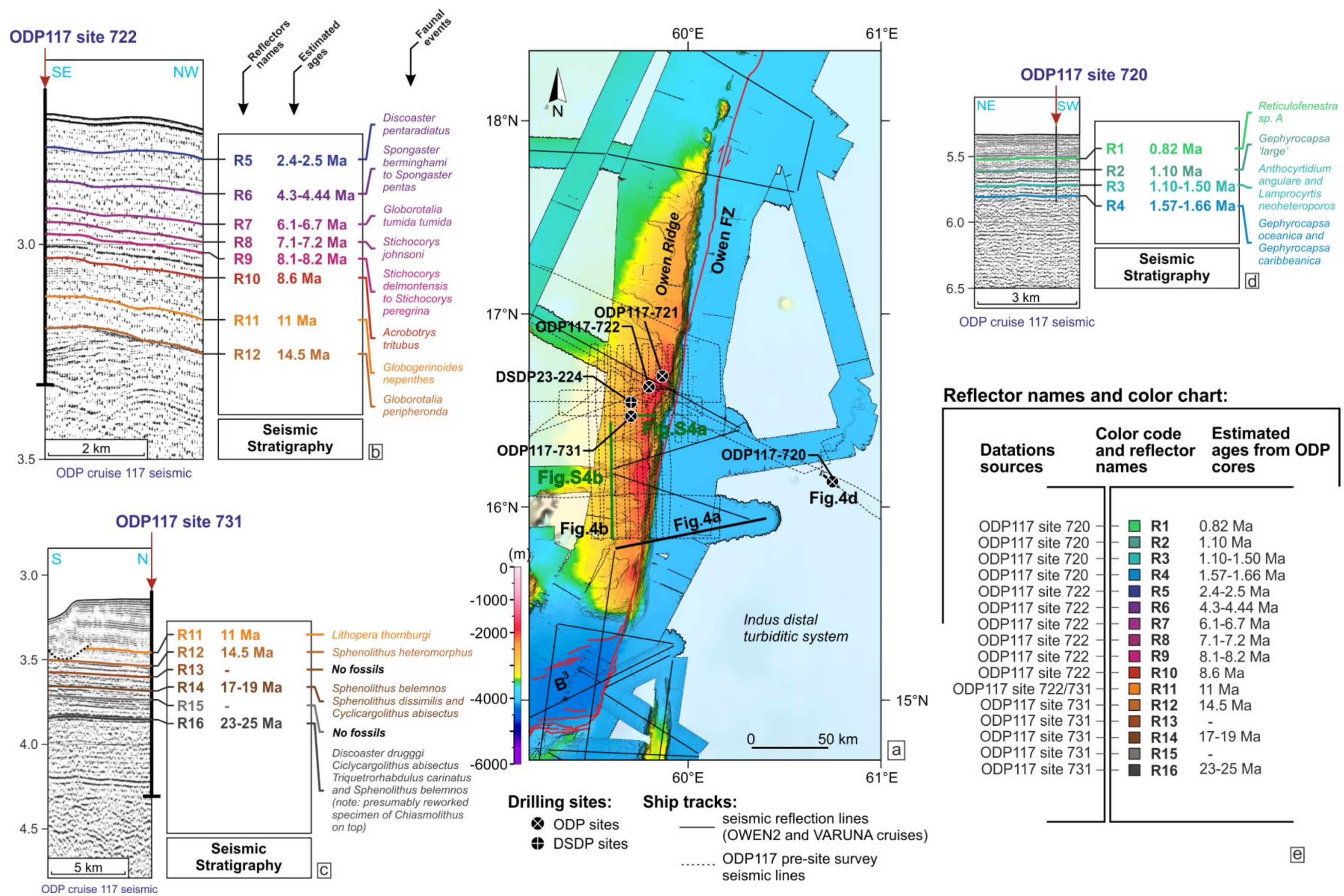


Figure S2. Supporting information for the Figure **3** including faunal event. Seismic Stratigraphy and time-calibration of reflectors on ODP seismic profiles. (a) Location map of drilling sites. (b-d) Time-calibration summaries at sites 731, 720 and 722 of ODP Leg 117, respectively. (e) Summary table of all dated reflectors. B3 Beautemps-Beaupré Basin; FZ, Fracture Zone.

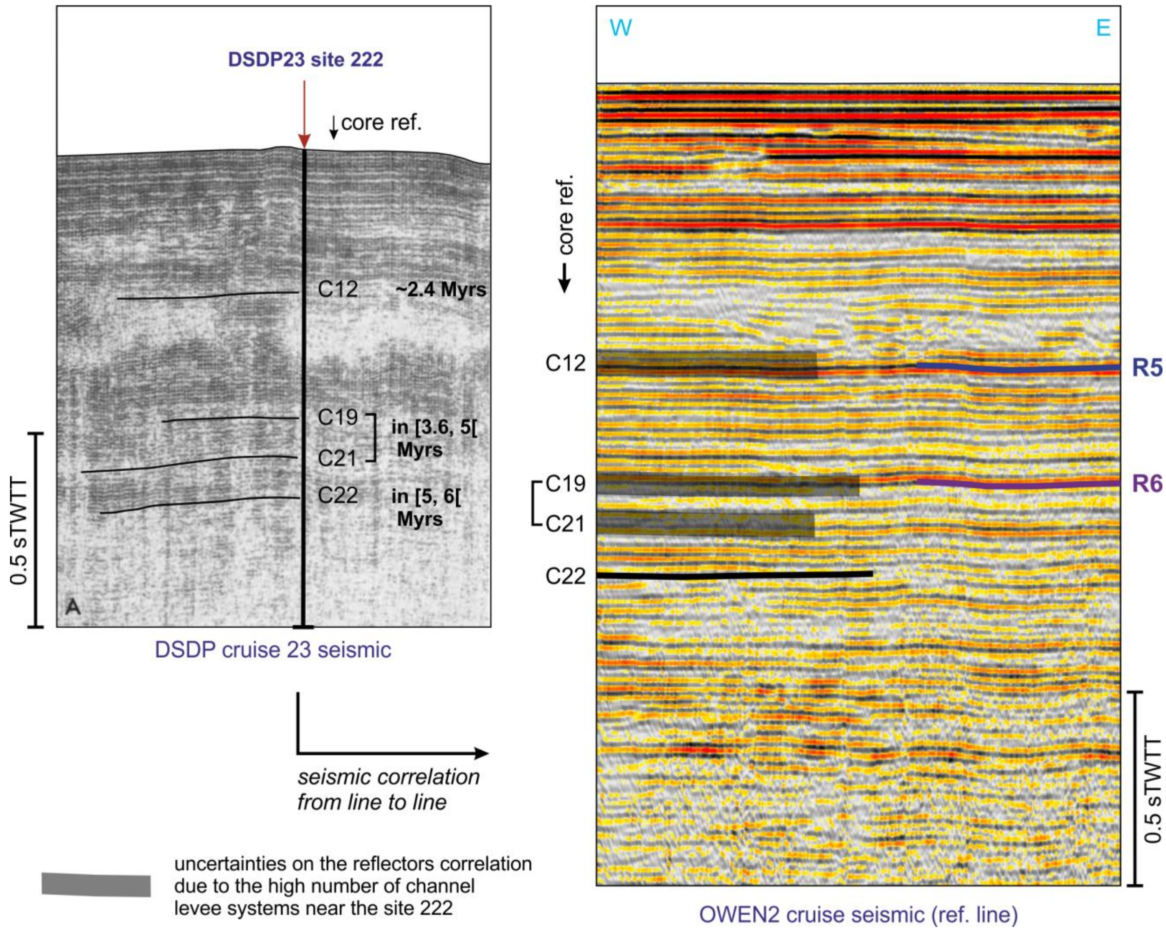


Figure S3. Additional calibration at the site 222 of the DSDP leg 23 (Whitmarsh et al., 1974b). This additional far correlation is less robust than the others (ODP117) because of (1) its remoteness from the Owen Ridge sites, (2) the poor diversity of the fauna recovered on the core and (3) the high number of channel-levee systems making the correlation difficult. However, this calibration allows us to frame the age of the dark blue reflector around 2.4 Ma and the purple reflector between 3.6 Ma and 5 Ma and thus identify them as R5 and R6, respectively. Furthermore, this calibration is in agreement with similar correlation done in the Beautemps-Beaupré Basin (Rodriguez et al. 2018).

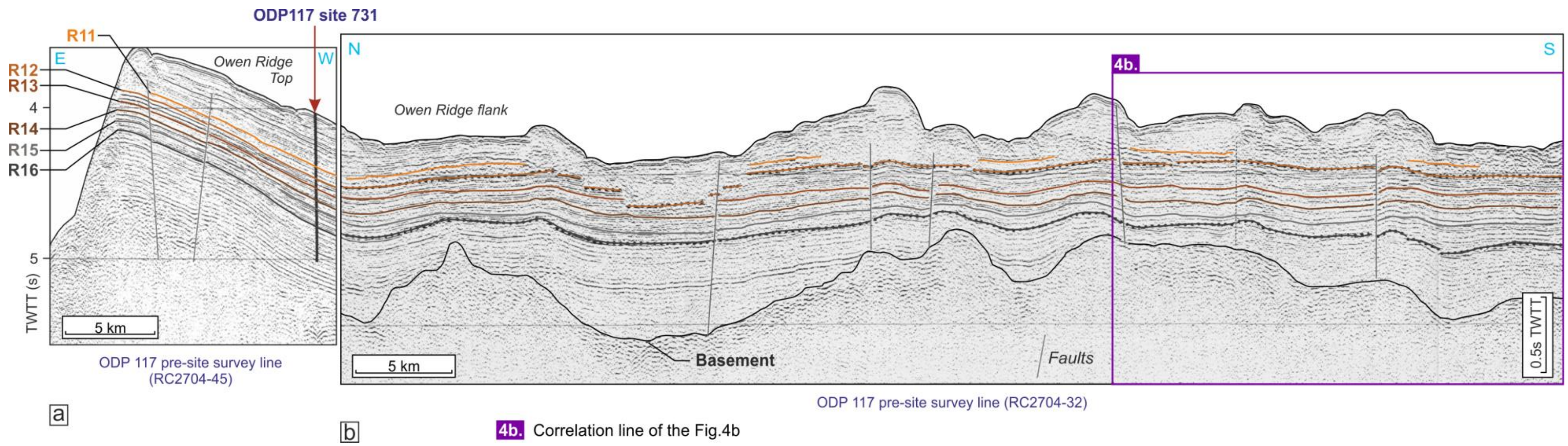


Figure S4. Correlation of the pre-site survey lines along the flank of the Owen ridge from the ODP117 site 731. The location of these two lines is shown on Figure S2.a (green tracks). (a) Line crossing the ODP117 site 731. (b) Correlation of the 6 recognized reflectors along the flank of the Owen Ridge, from the north (left) to the south (right).

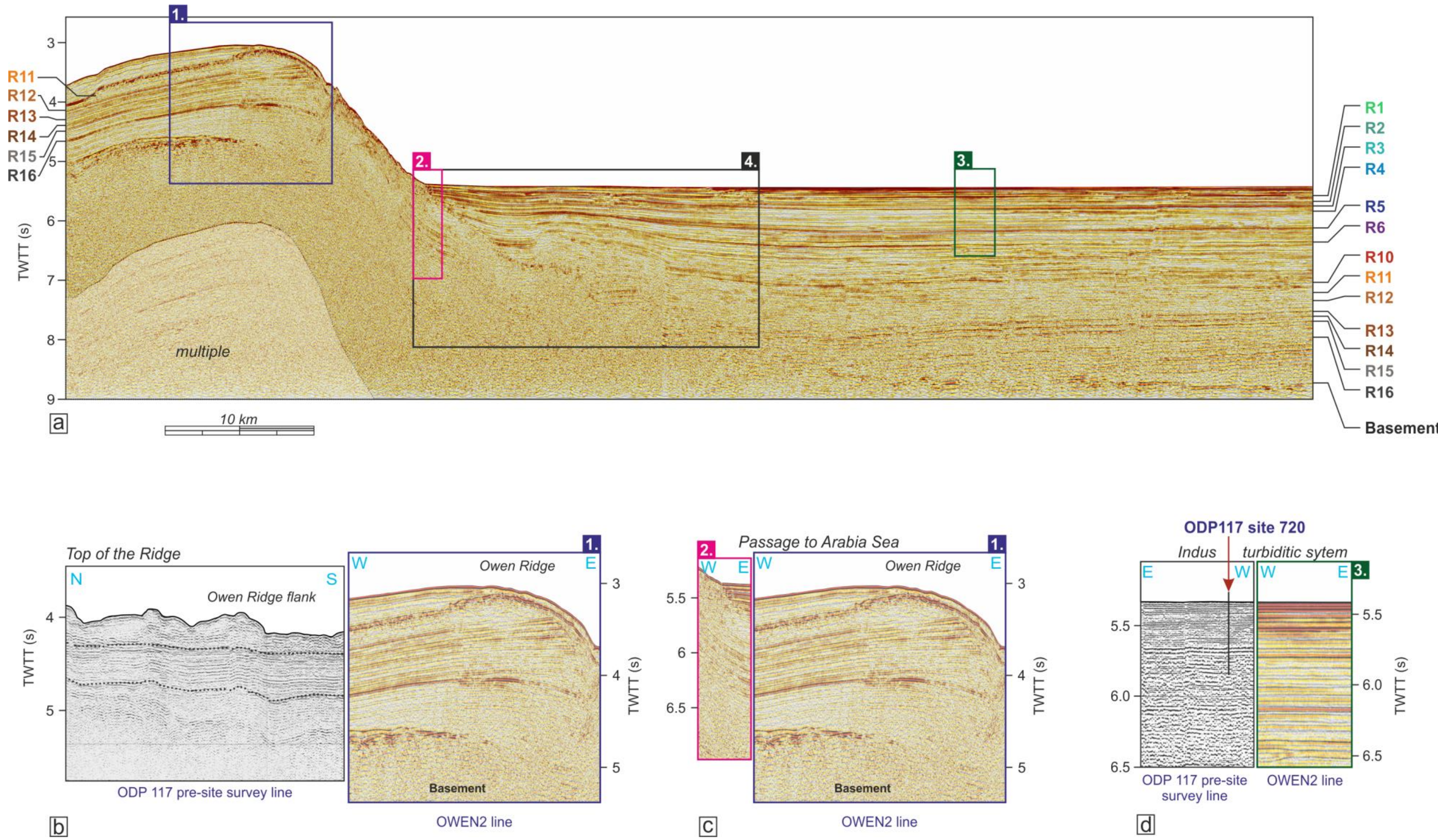


Figure S5. Raw profiles of the Figure 4.

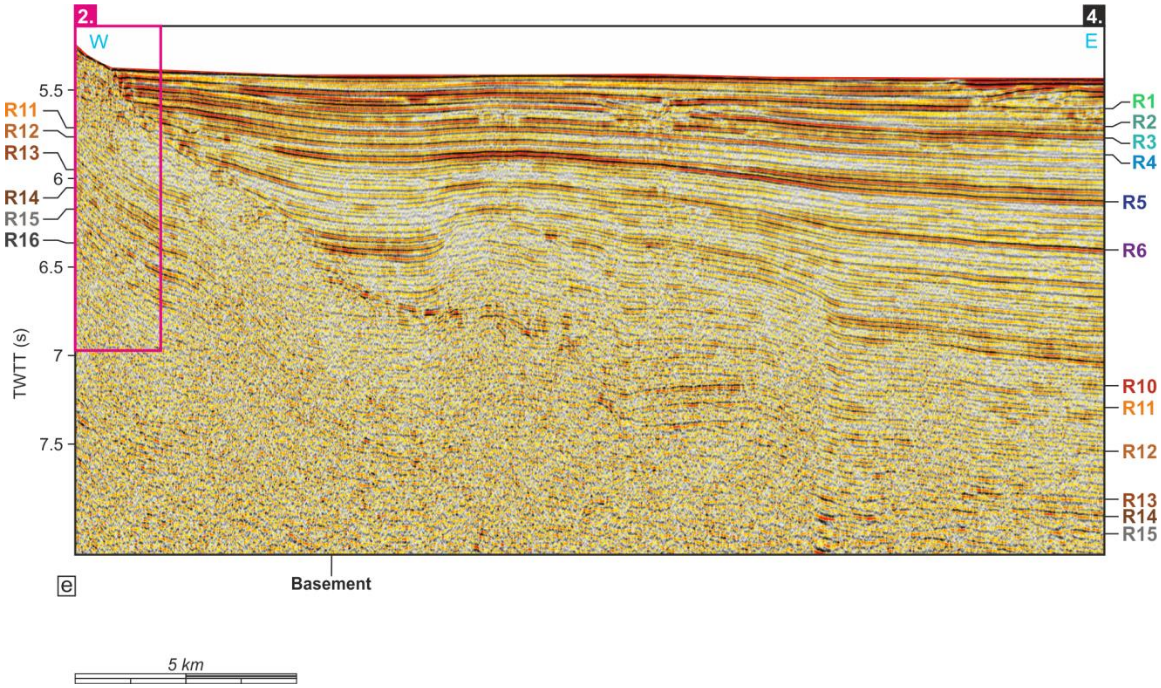


Figure S6. Raw profile of the Figure 4.

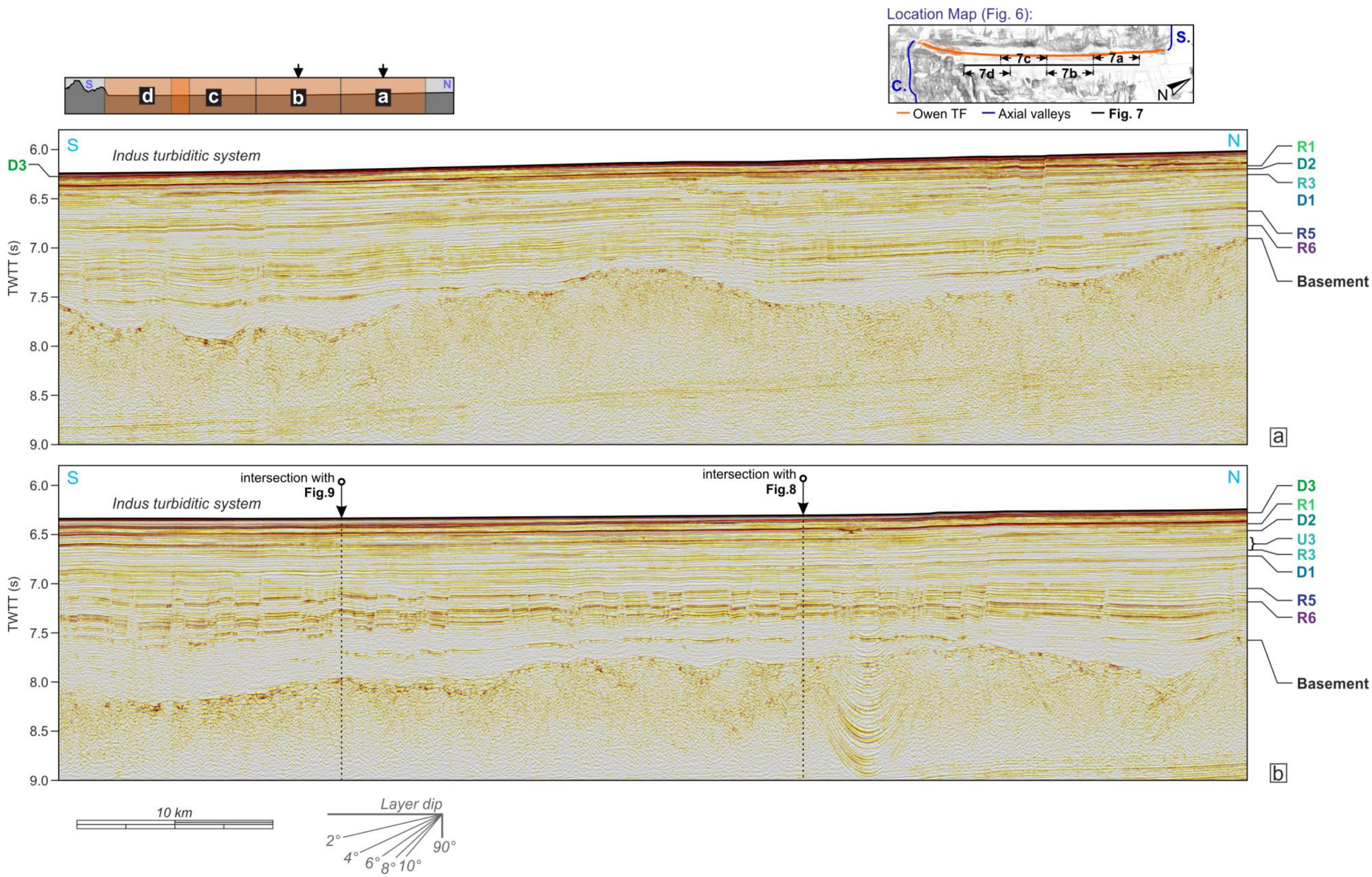


Figure S7. Raw profiles of the Figure 7.

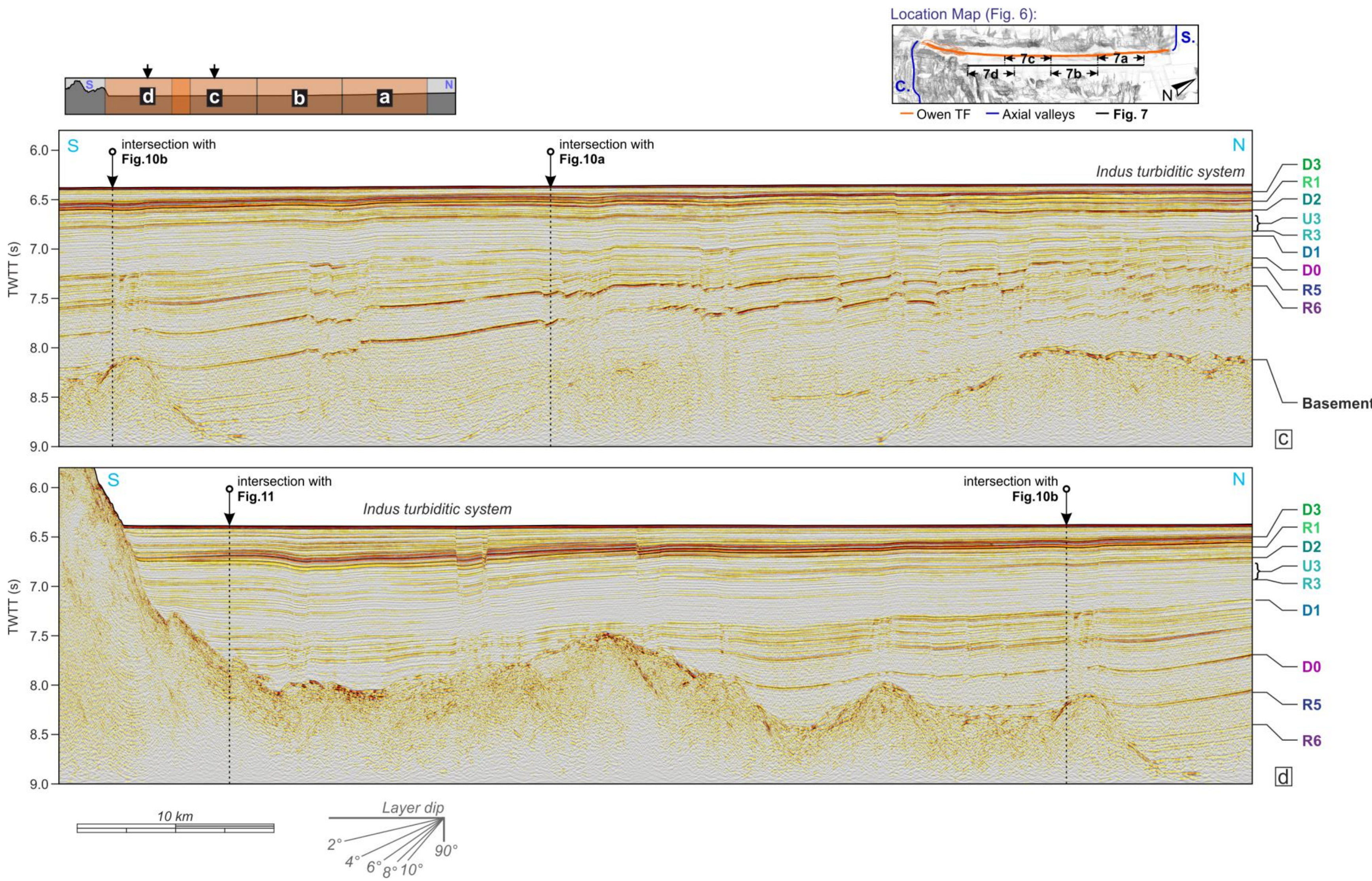


Figure S8. Raw profiles of the Figure 7.

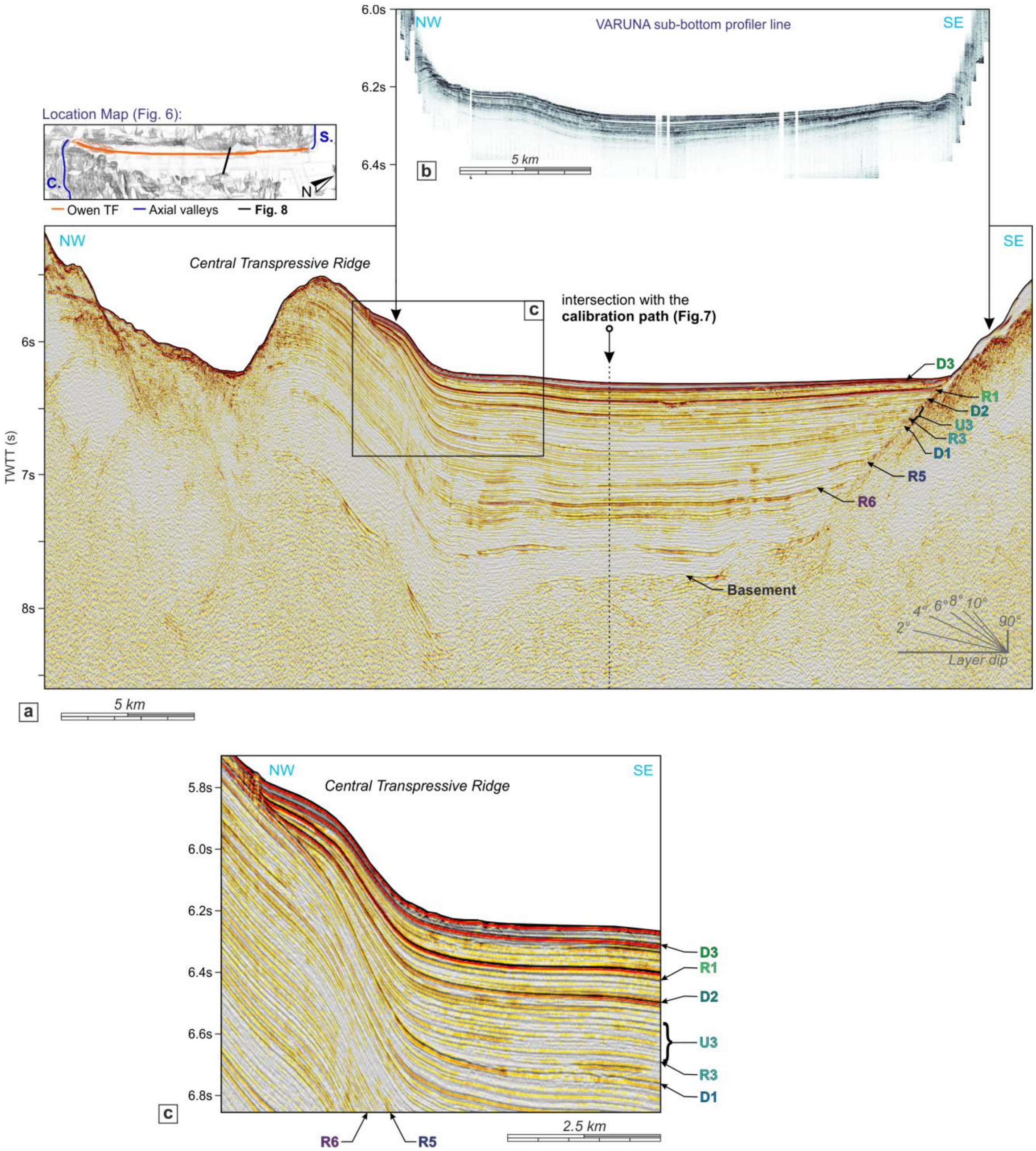


Figure S9. Raw profiles of the Figure 8.

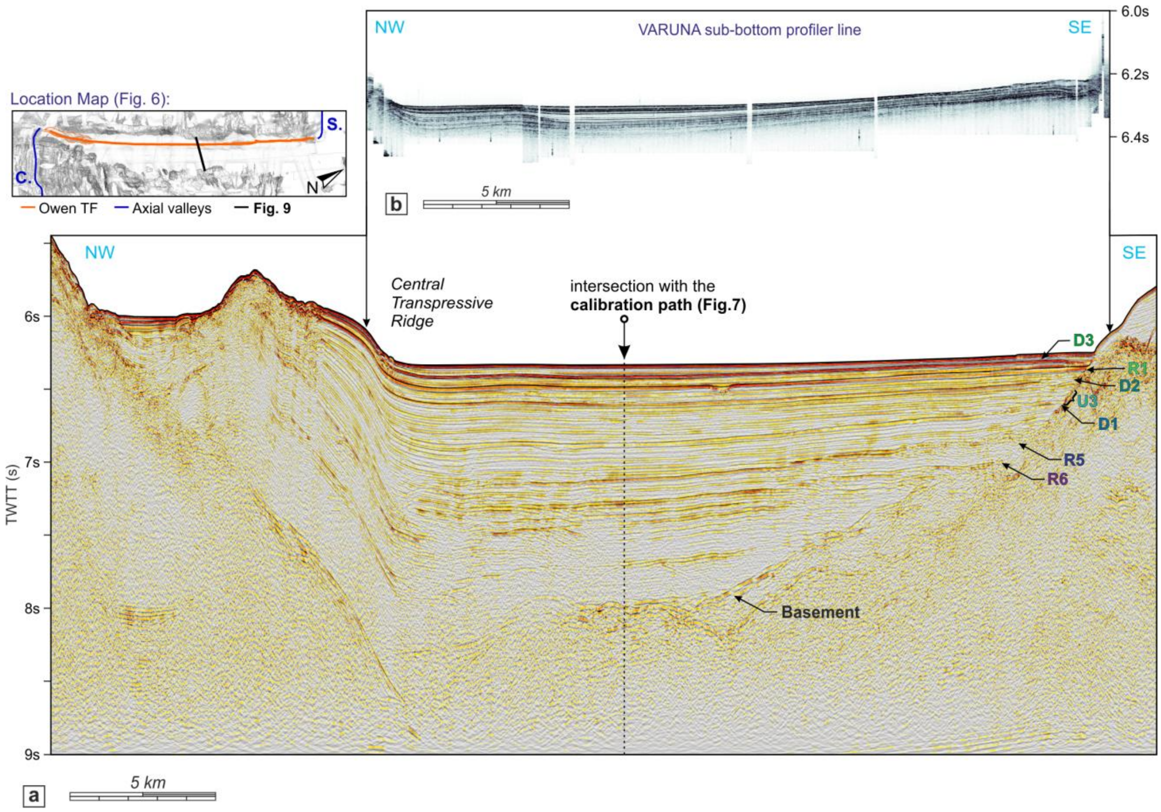


Figure S10. Raw profiles of the Figure 9.

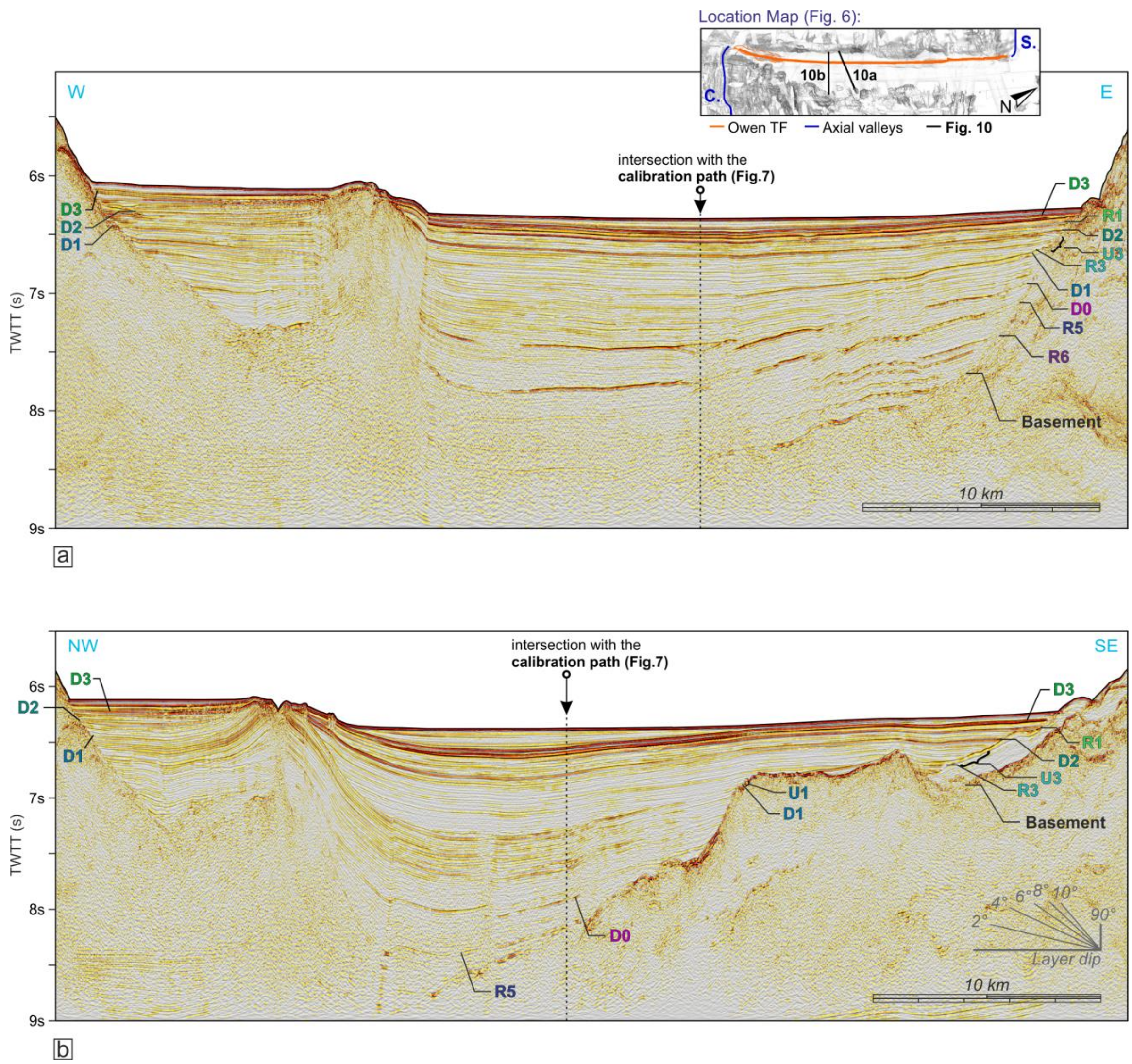


Figure S11. Raw profiles of the Figure 10.

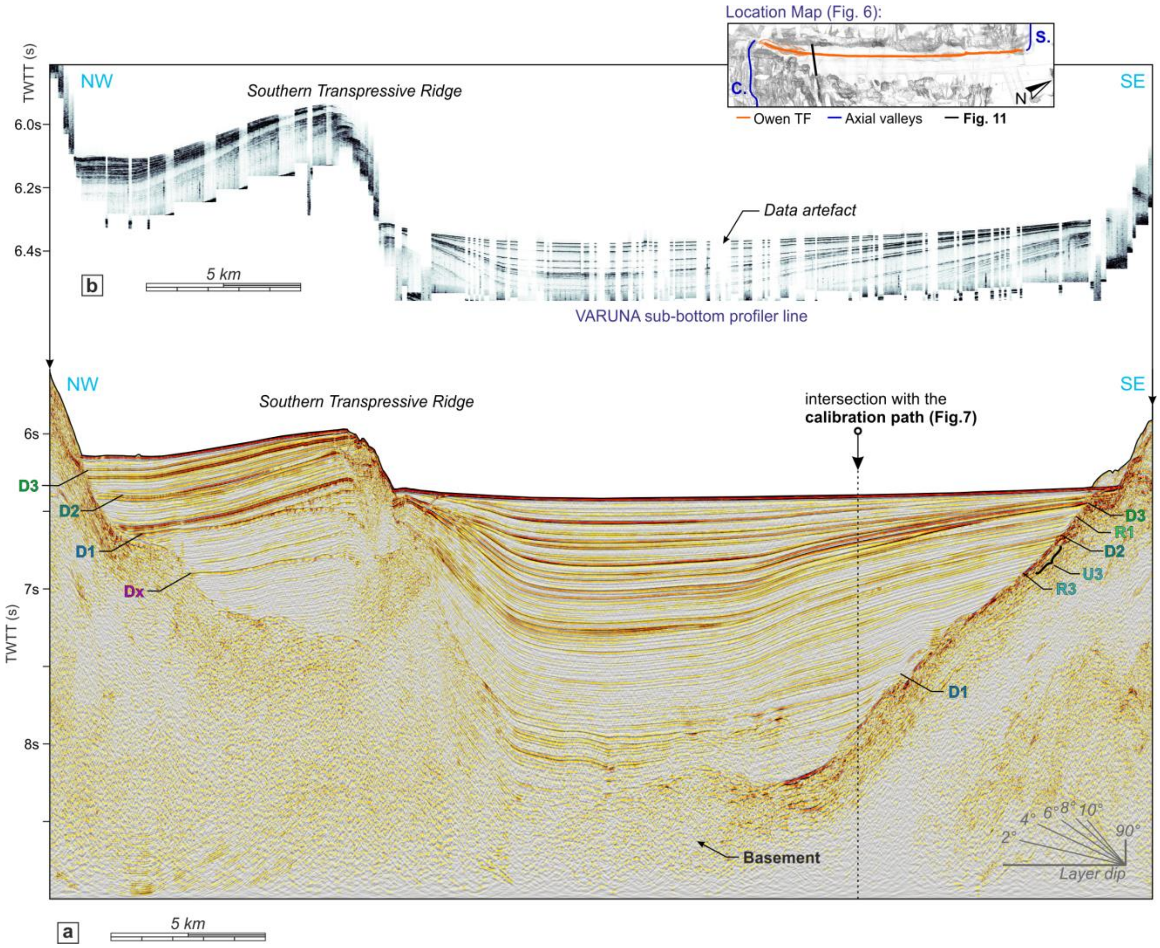


Figure S12. Raw profiles of the Figure 11.

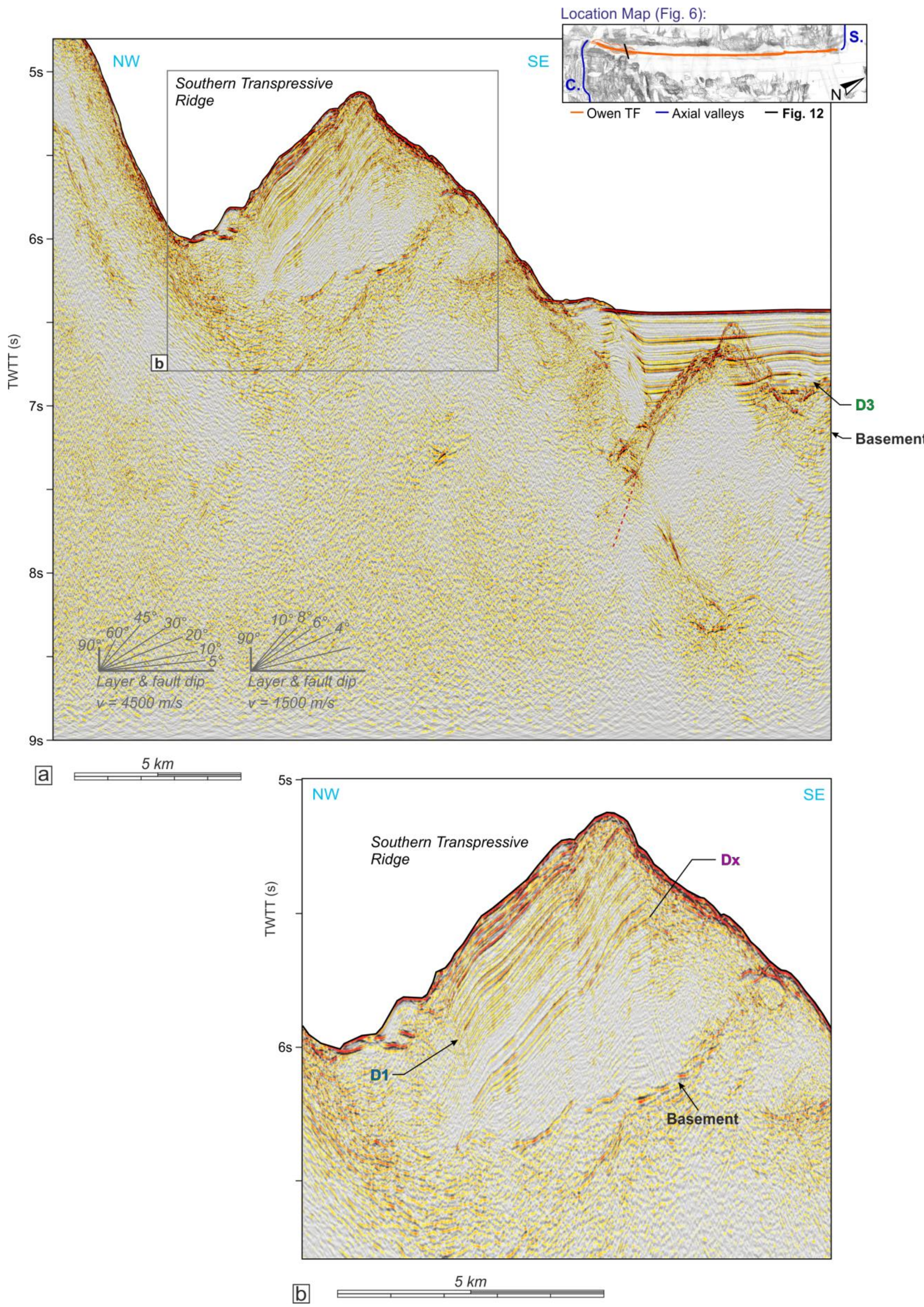


Figure S13. Raw profiles of the Figure 12.

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