Time lapse seismic analysis of the Tohoku-Oki earthquake

by

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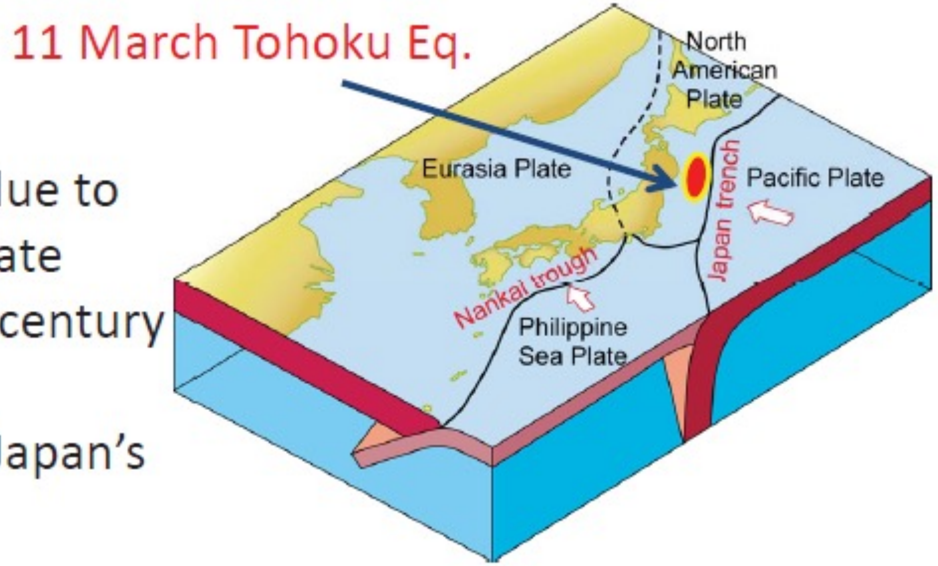
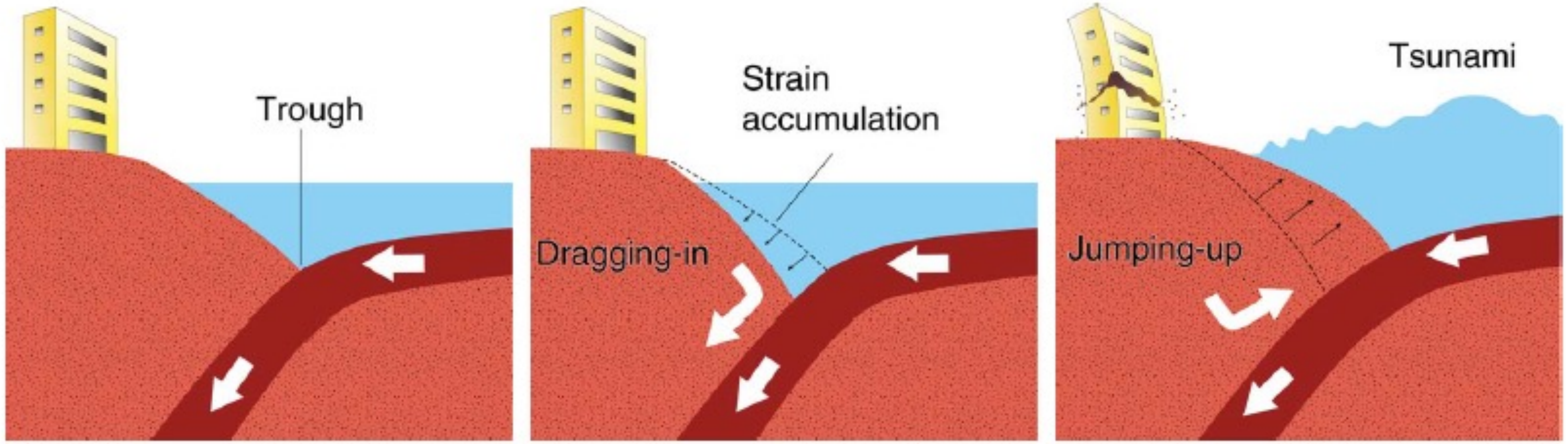
ROSE meeting 2016

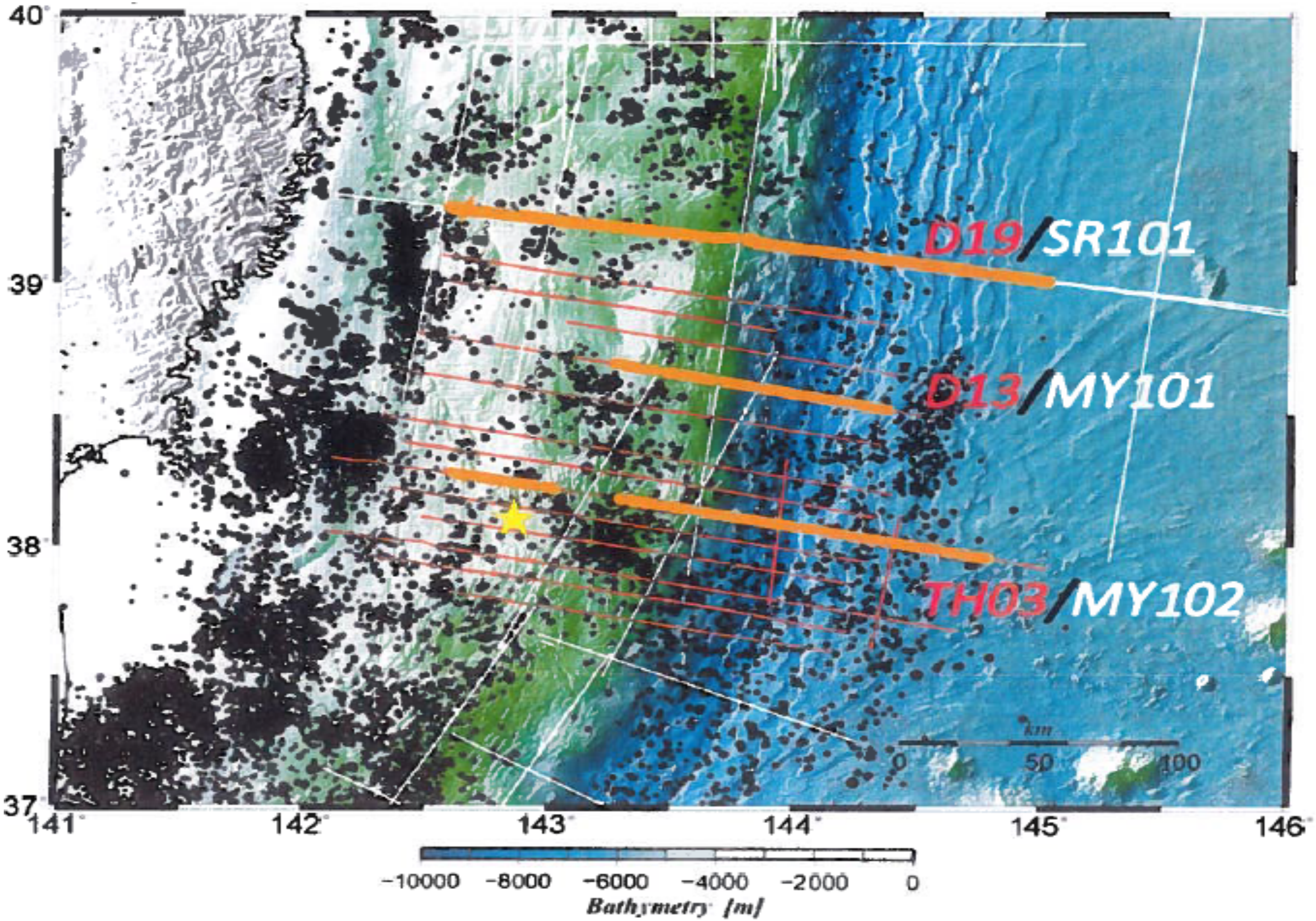
The 2011 Tohoku Earthquake



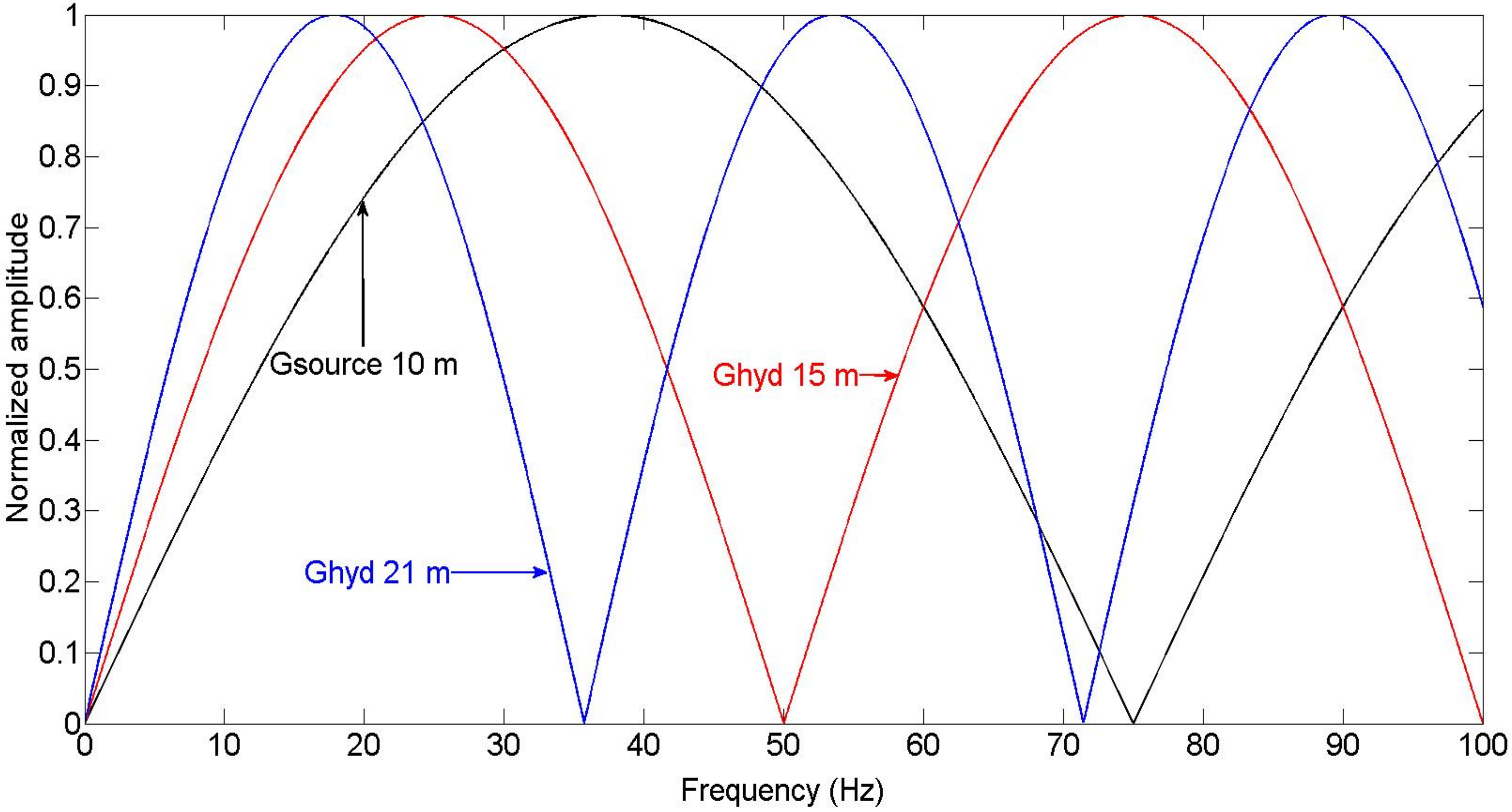
- Interplate earthquake due to subduction of Pacific plate at 8 cm /year or 8 m / century
- Largest size (M=9.0) in Japan's history



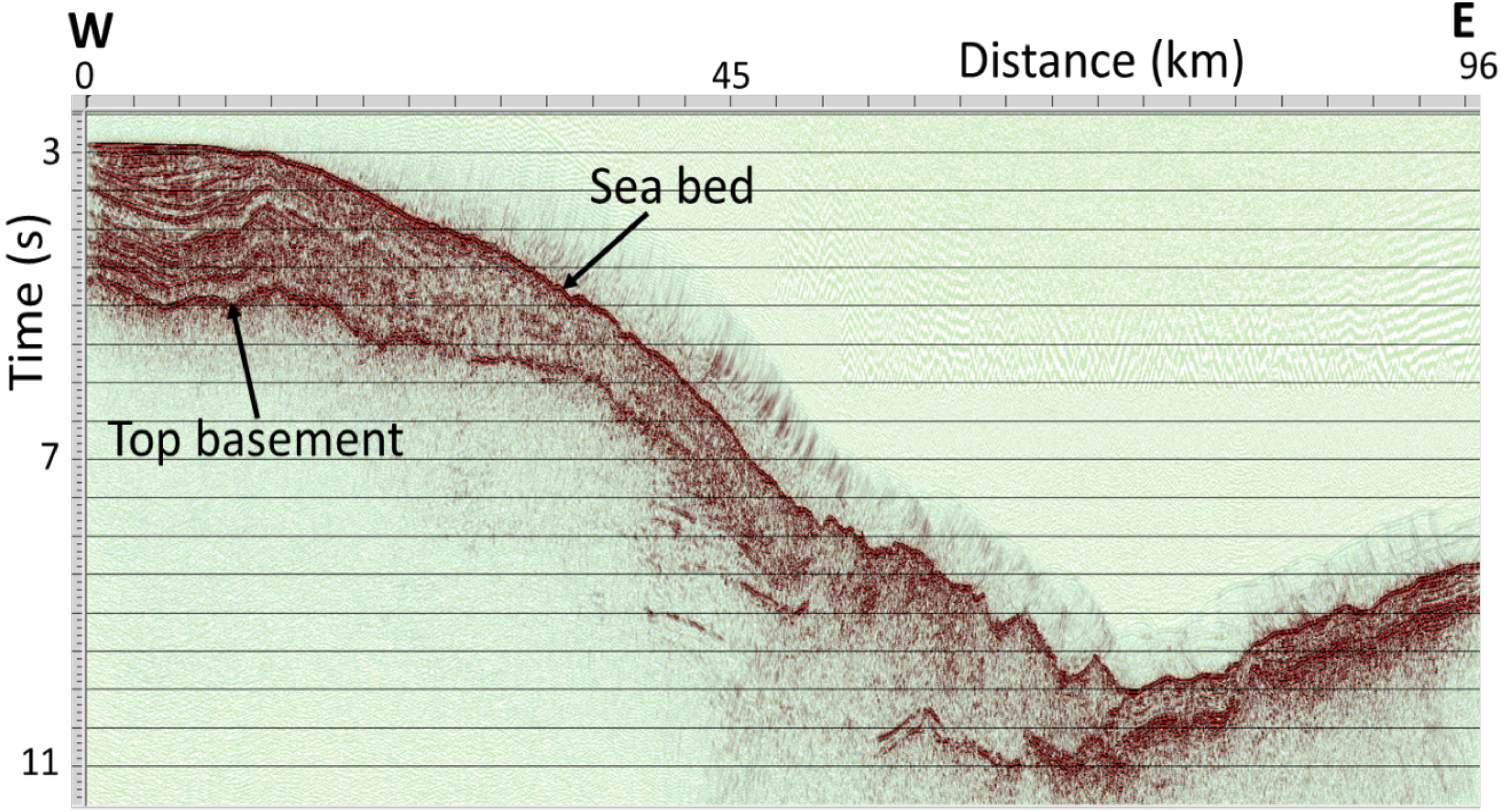
100 km 2D line crossing the Japan Trench axis



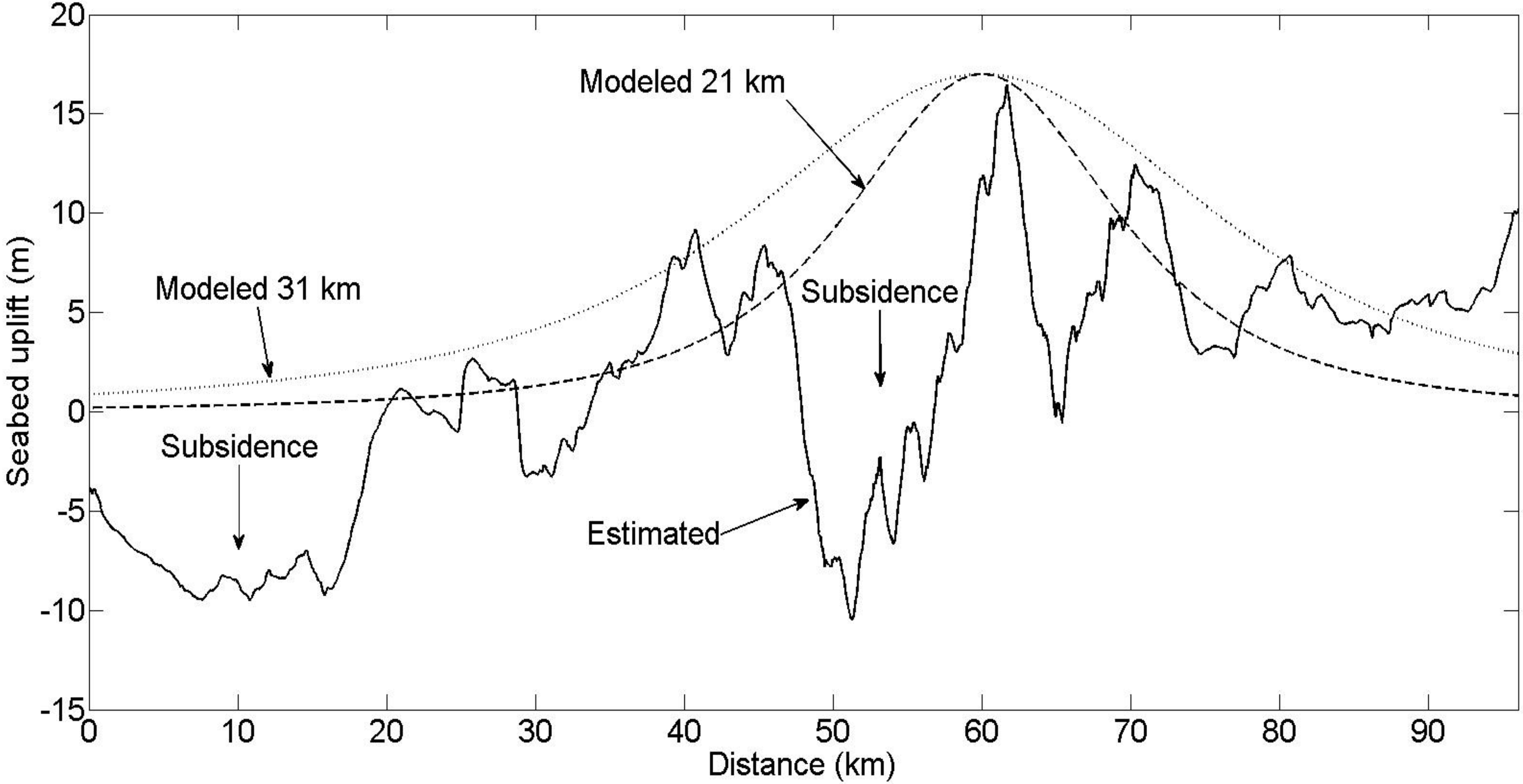
Differences in acuqisition… not ideal for 4D..



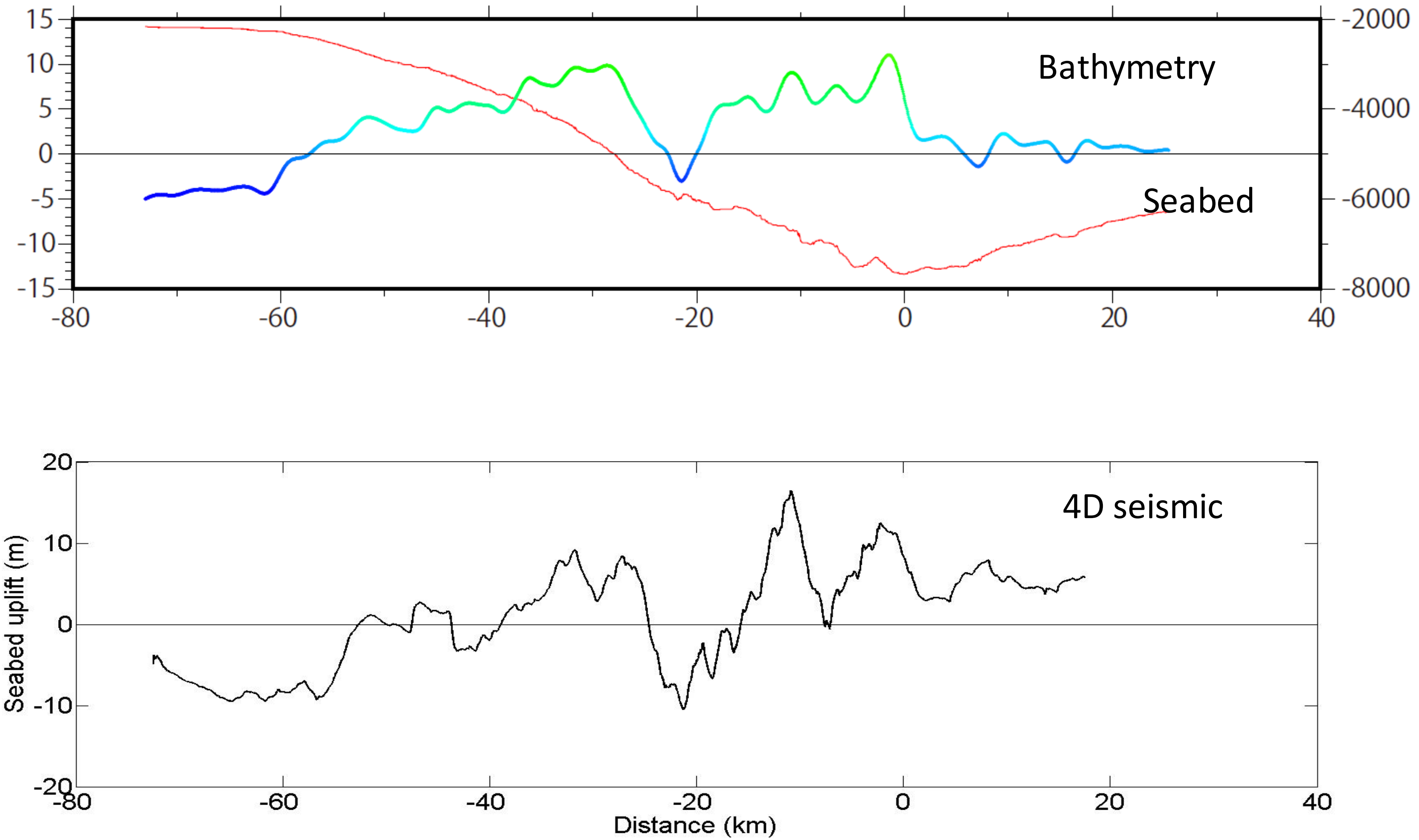
1999: Zs = 10 m; Zh = 15 m
2011: Zs = 10 m; Zh = 21 m


W
E
Distance (km)
0
45
96
Time (s)
3
7
11
Sea bed
Top basement

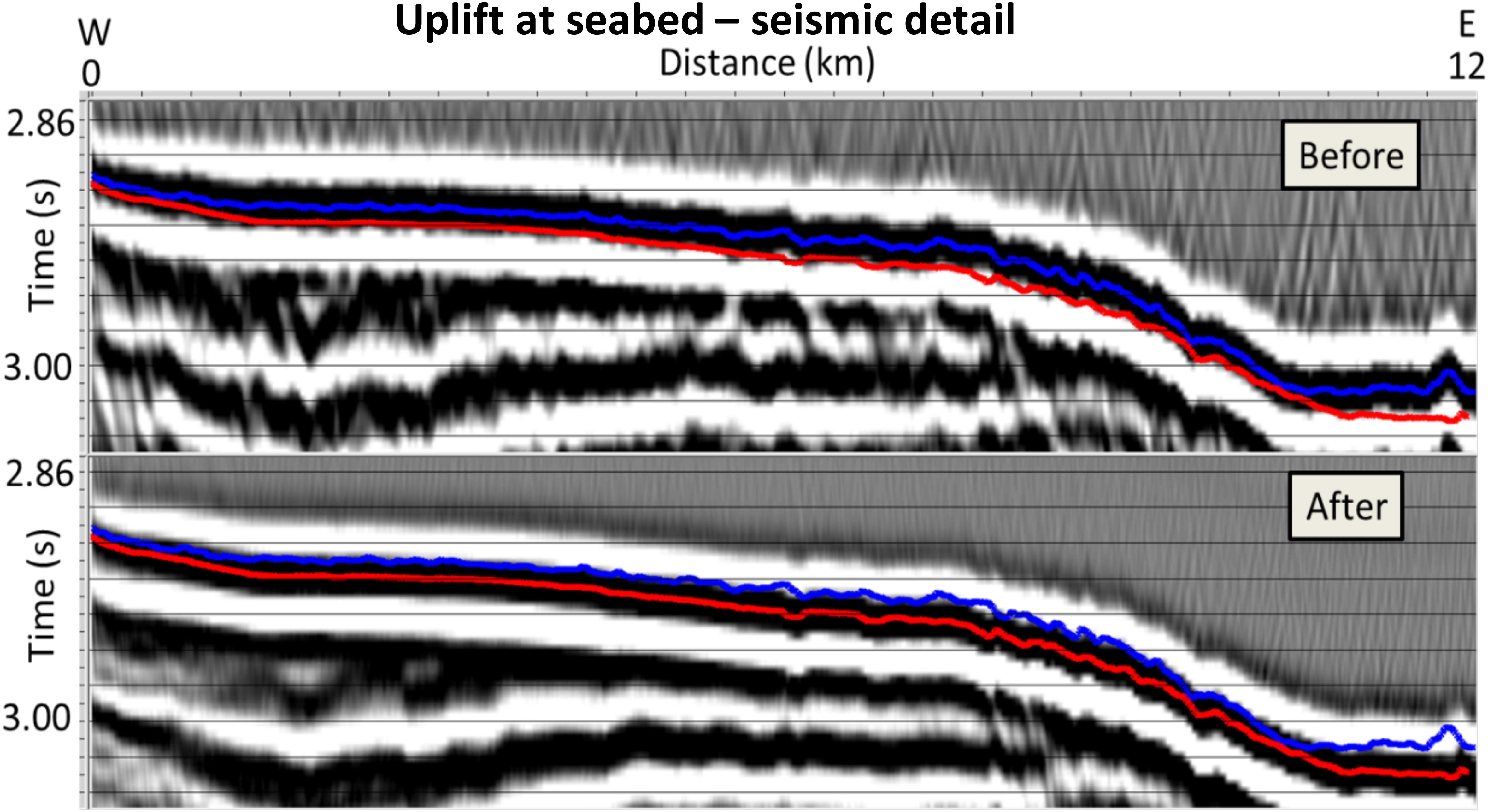
Estimated 4D uplift at seabed – modeled uplift from a point source at 21 km



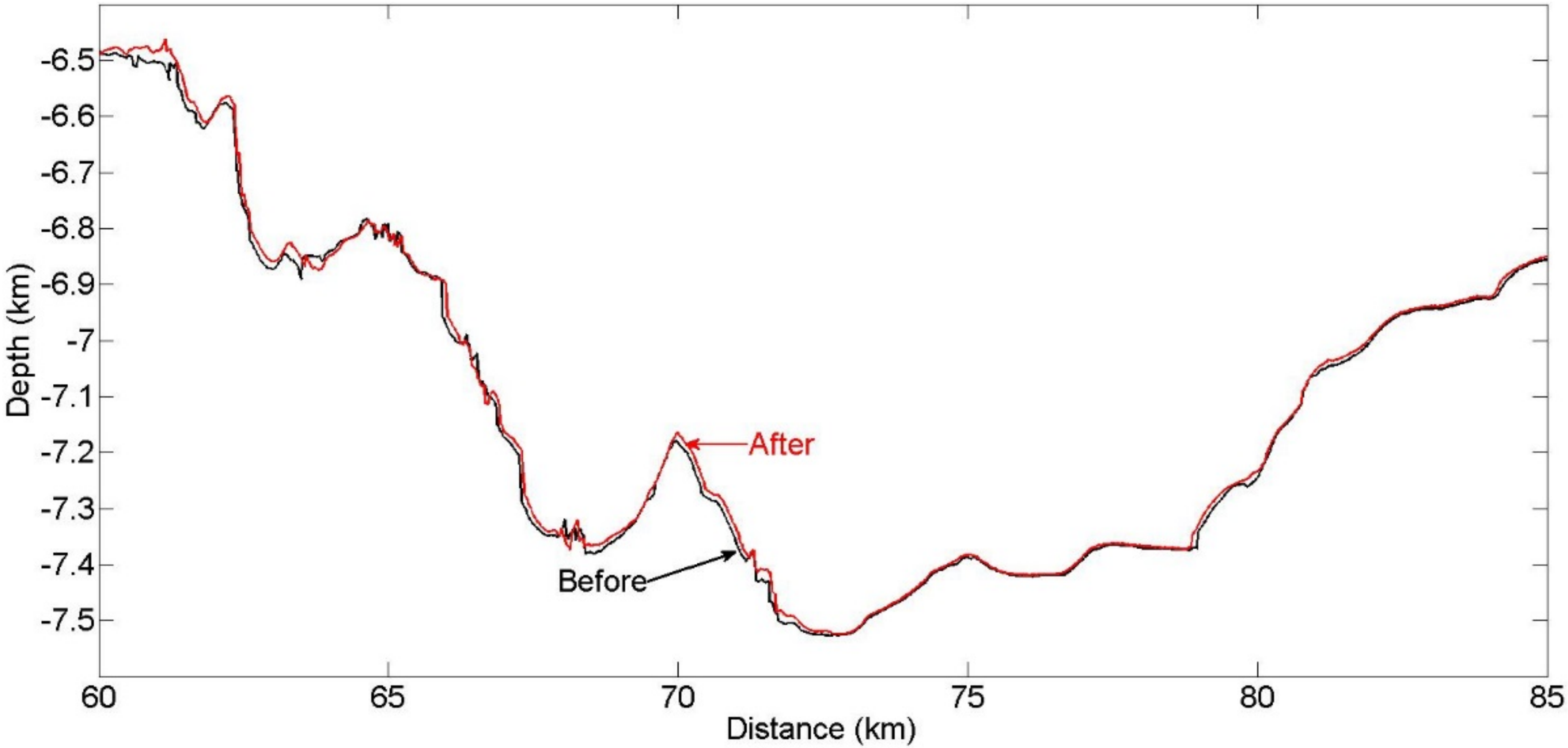
Comparison with bathymetry data



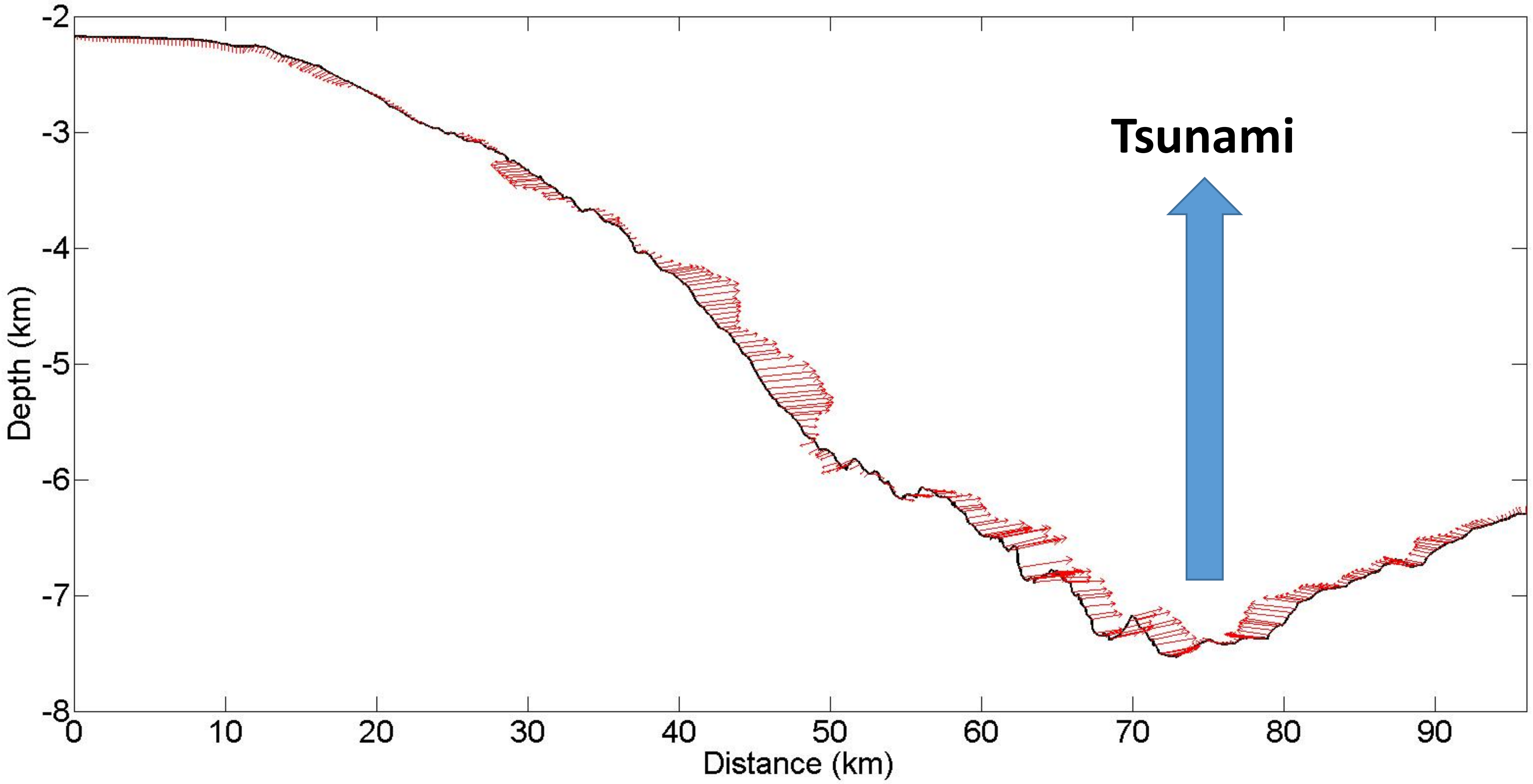
Uplift at seabed – seismic detail



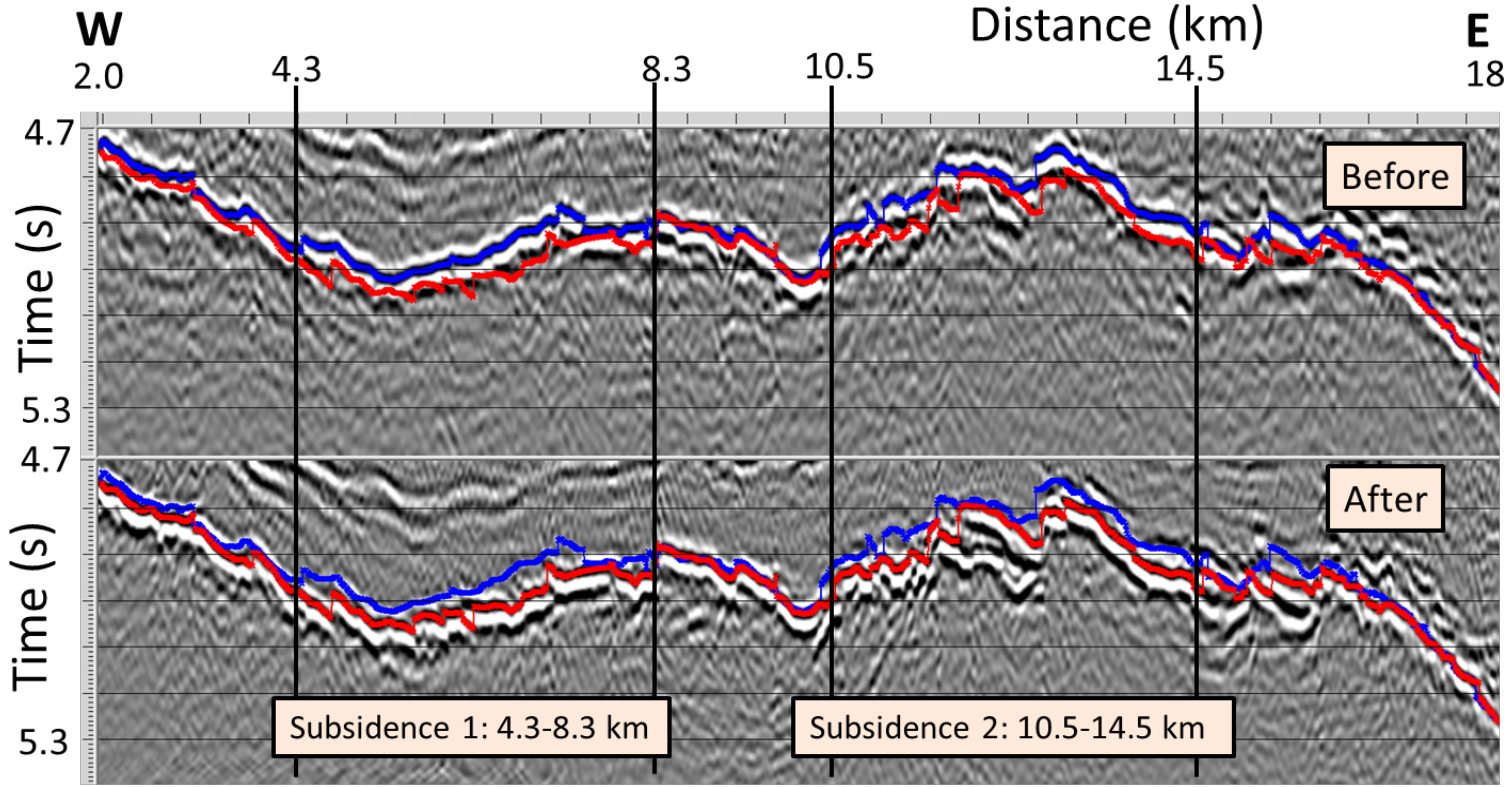
Seabed position before and after earthquake – close to the trench axis



Estimated displacement vectors at the seabed

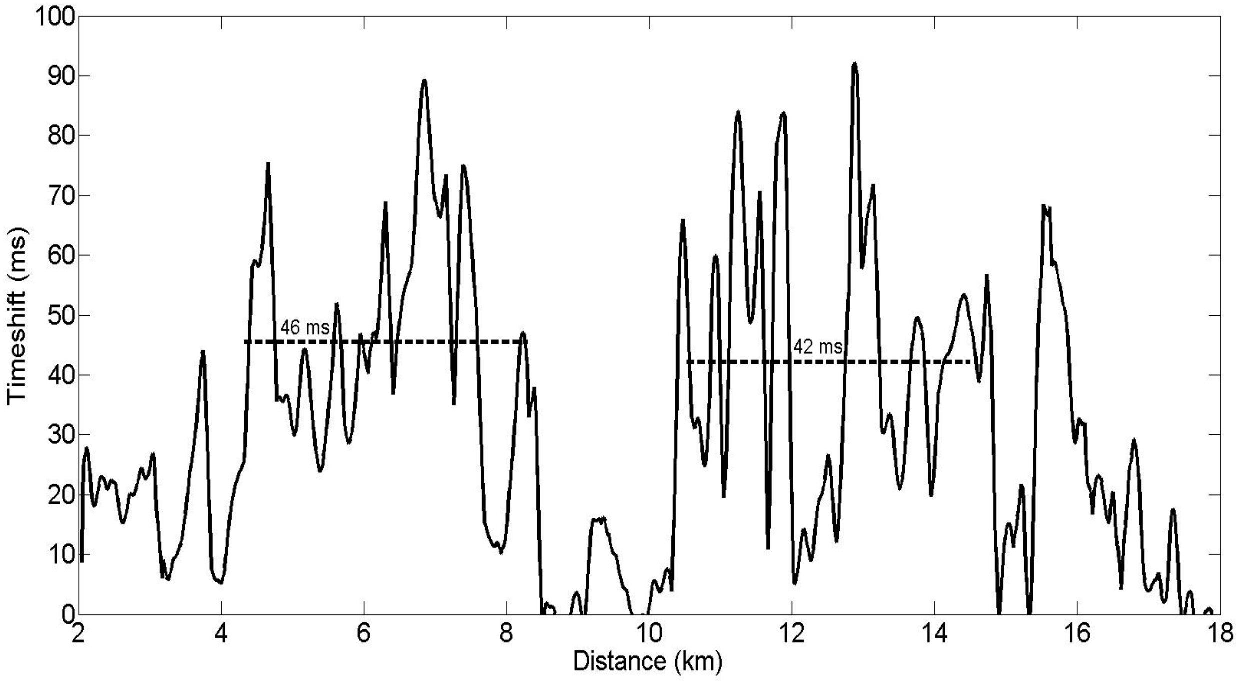


Seismic detail: Vertical subsidence at top basement

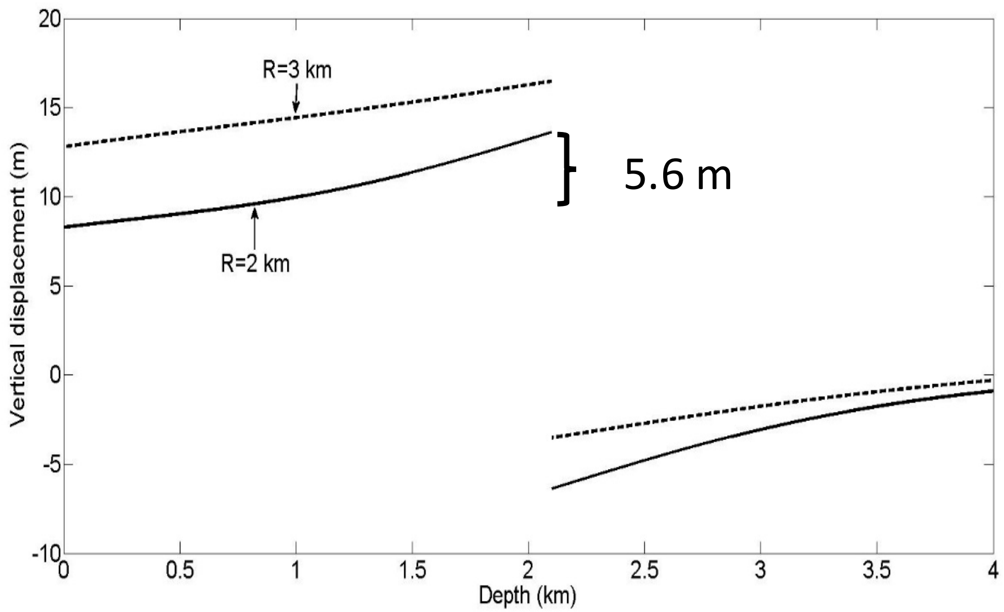


Estimating the dilation factor

Estimated 4D timeshifts at top basement



Geomechanical modeling cylinder of radius R



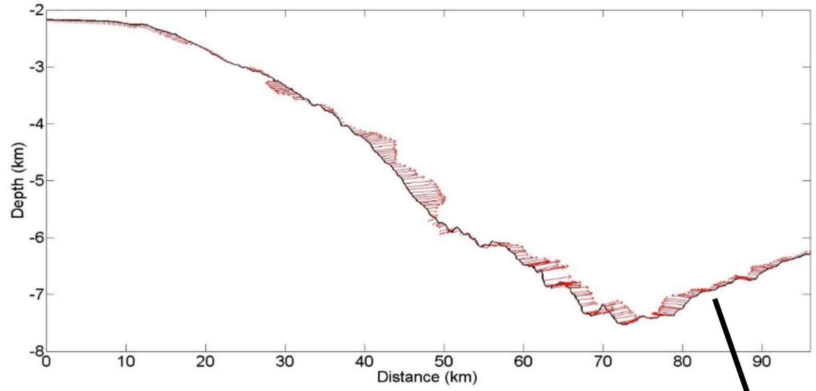
Time shift at seabed: 11 ms; T = 2.1 s => dT/T = 0.017

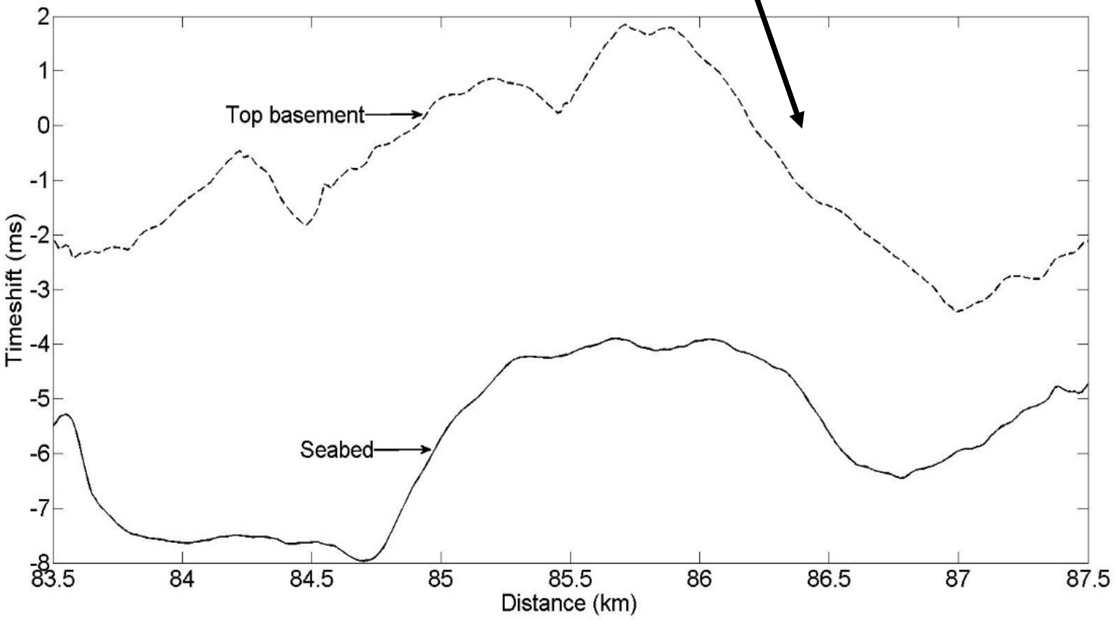
dz = 5.6 m z = 2.1 km => dz/z = 0.0027

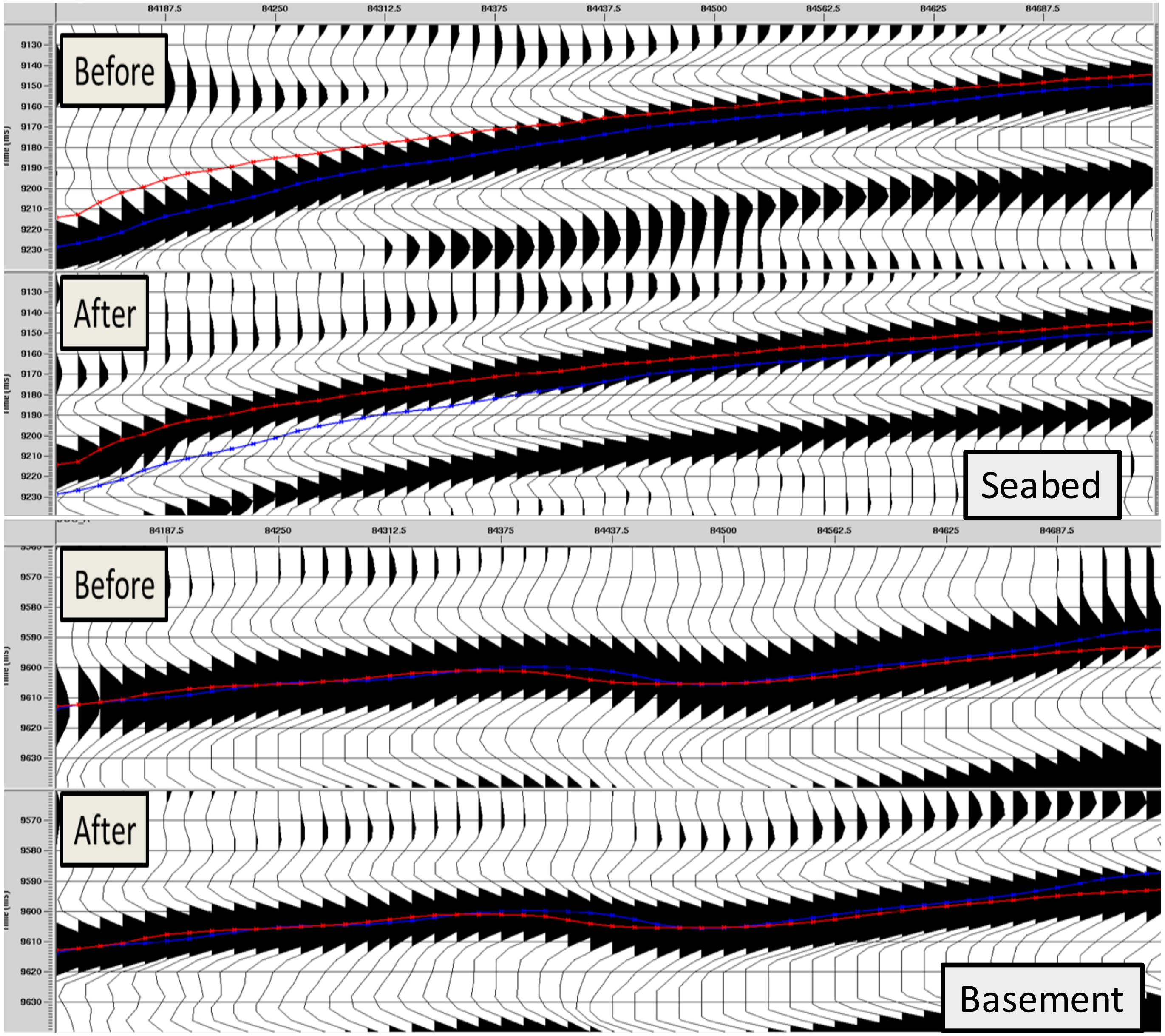
$$\frac{dT}{T} = -\frac{dv}{v} + \frac{dz}{z} \Rightarrow R = -\frac{dv/v}{dz/z} \Rightarrow \frac{dT}{T} = (1+R)\frac{dz}{z} \Rightarrow$$

R ~ 5.3

Negative R-factor West of the trench axis



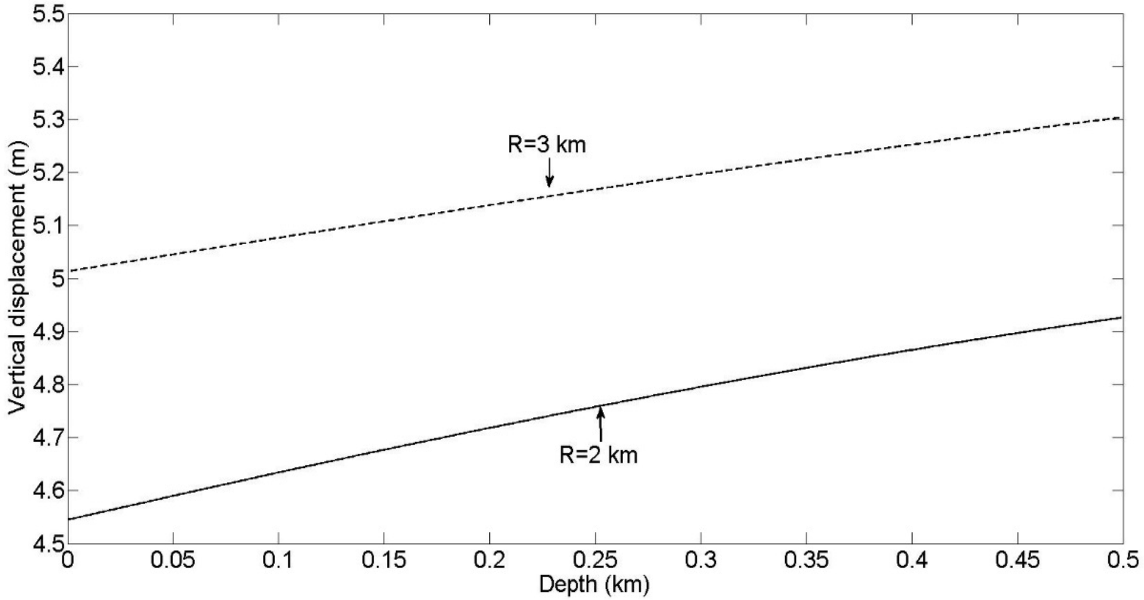




Less timeshifts at top basement compared to seabed + horizontal stretching in this area

Estimating dilation factor for a vertically compacted and horizontally stretched rock

Vertical compaction ~ 0.3 m assuming R = 3 km



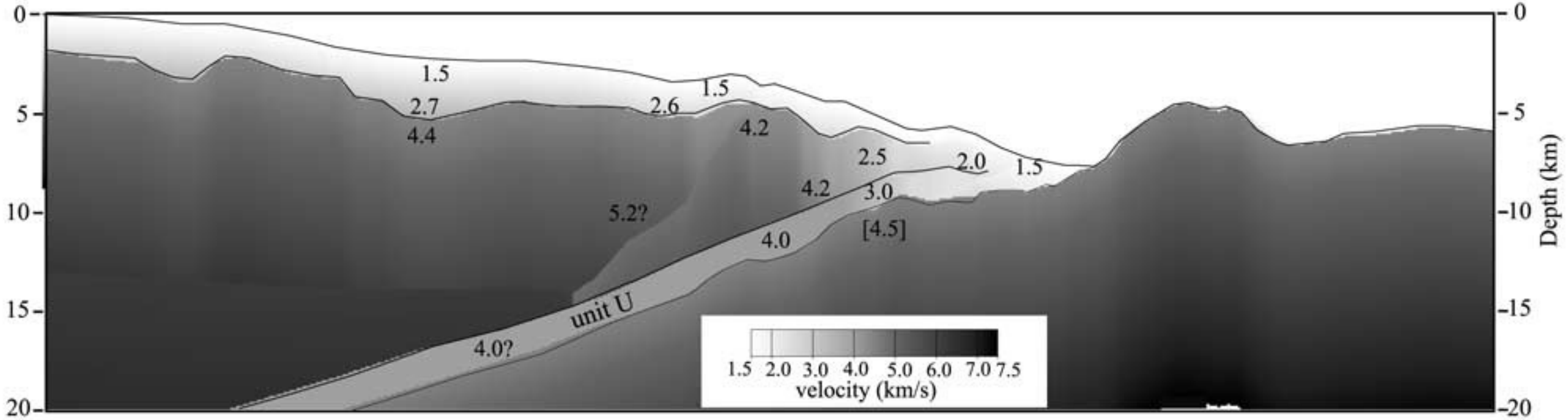
Time shift for the 500 m thick section: dT/T = 0.0088

dz = 0.3 m z = 0.5 km => dz/z = -0.0006

$$\boxed{\frac{dT}{T} = (1+R)\frac{dz}{z}}$$

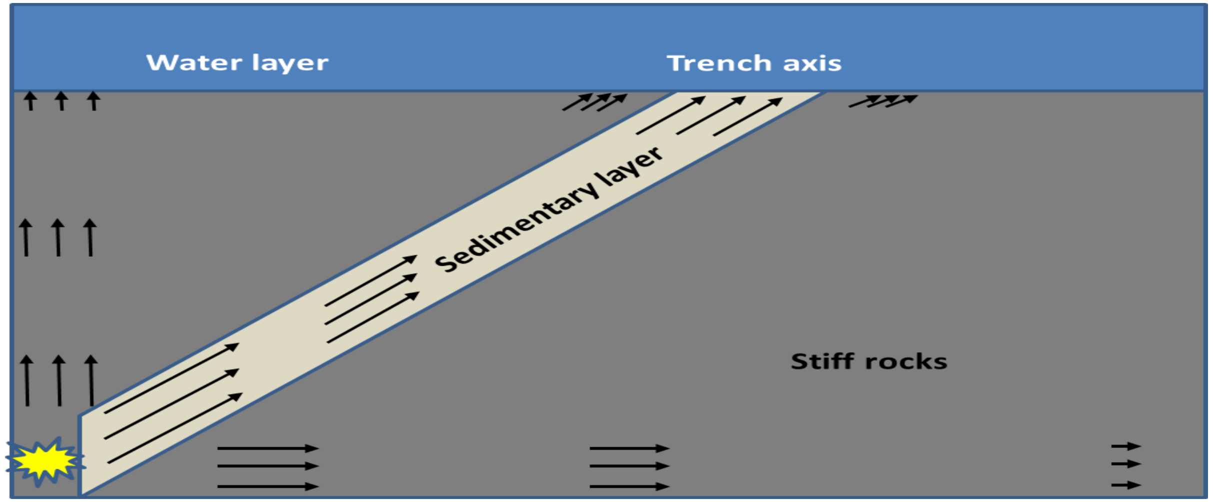
R ~ -15.7

The role of the sedmentary layer between the two plates.

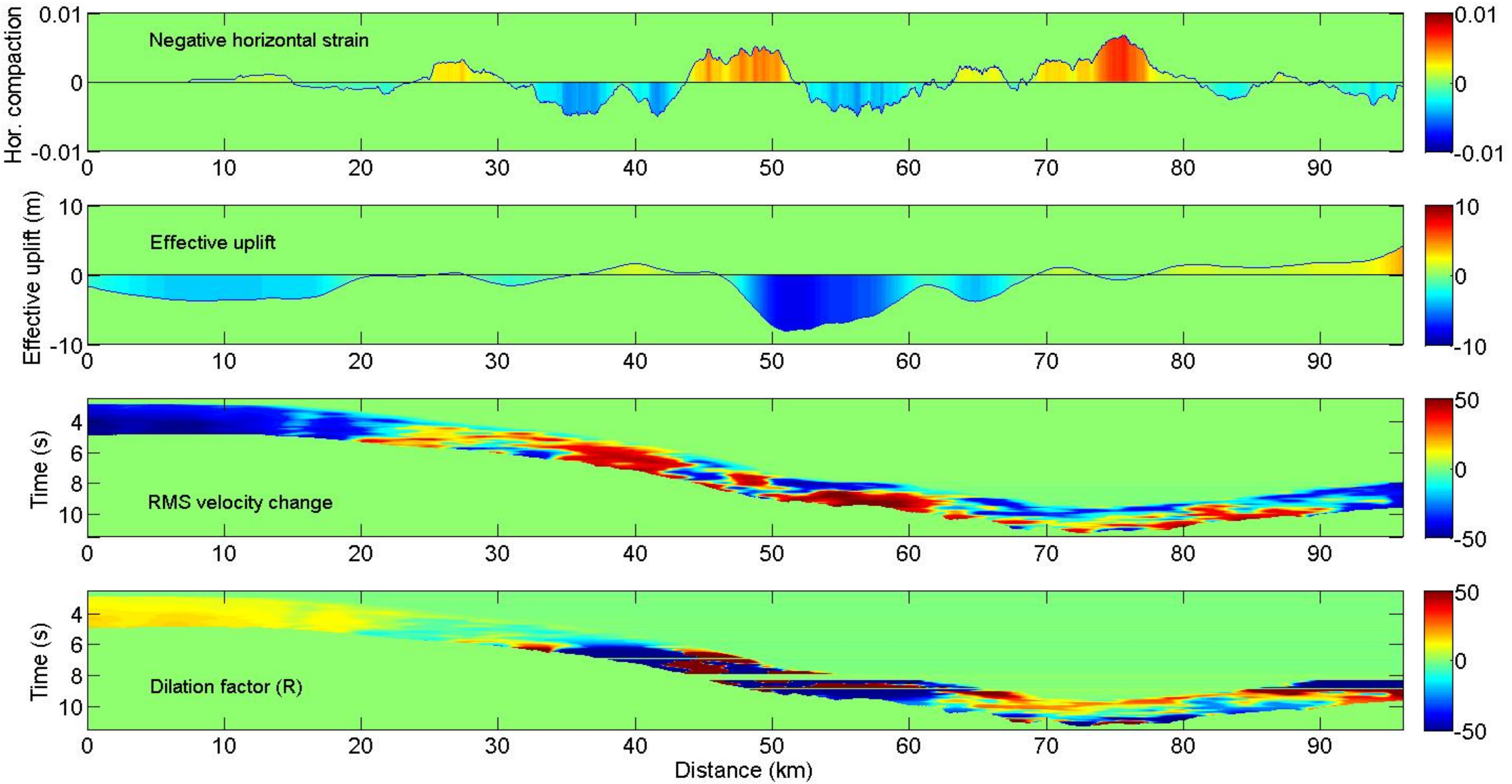


(b) Velocity model of Line 11.

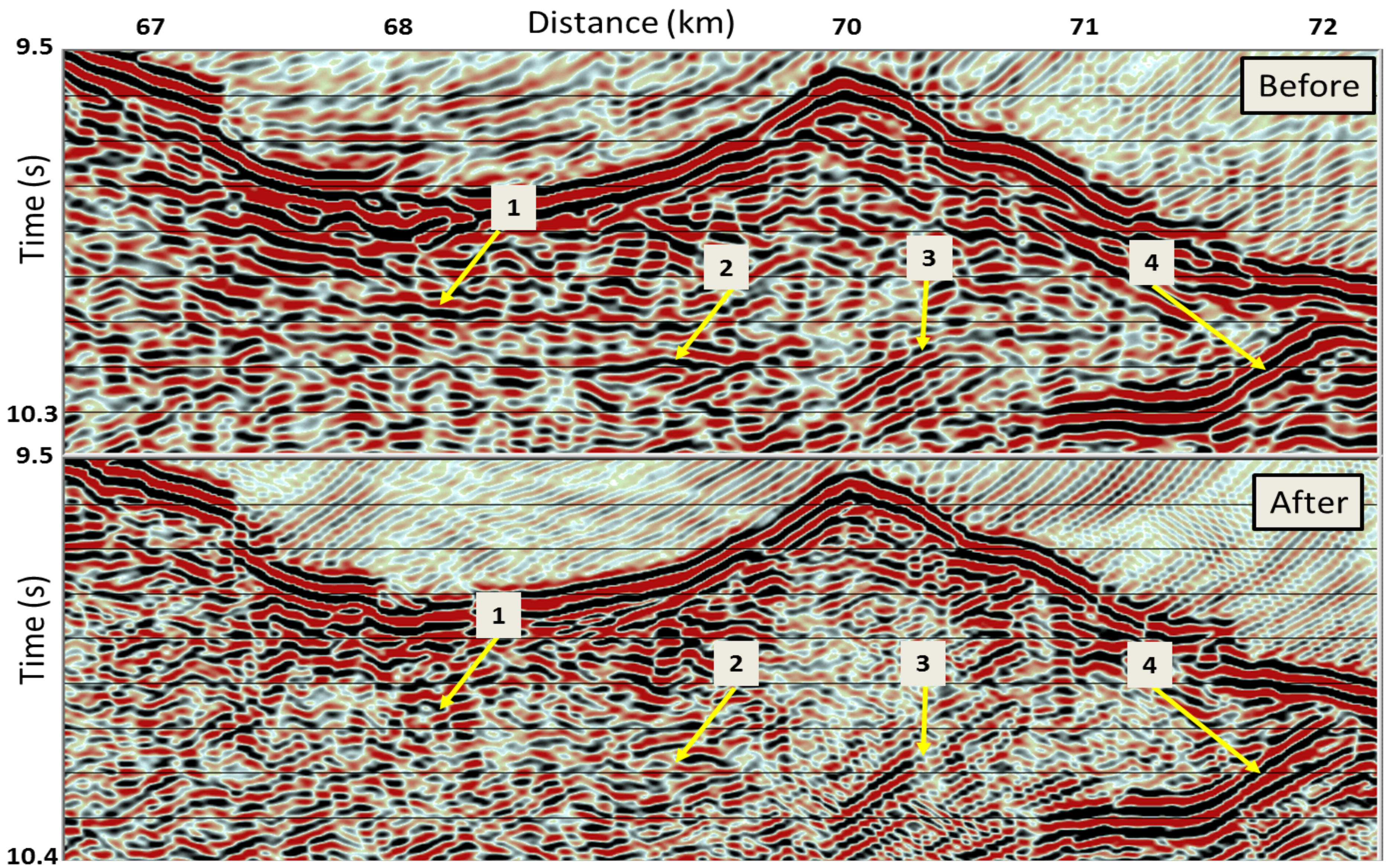
Tsuru et al., 2002



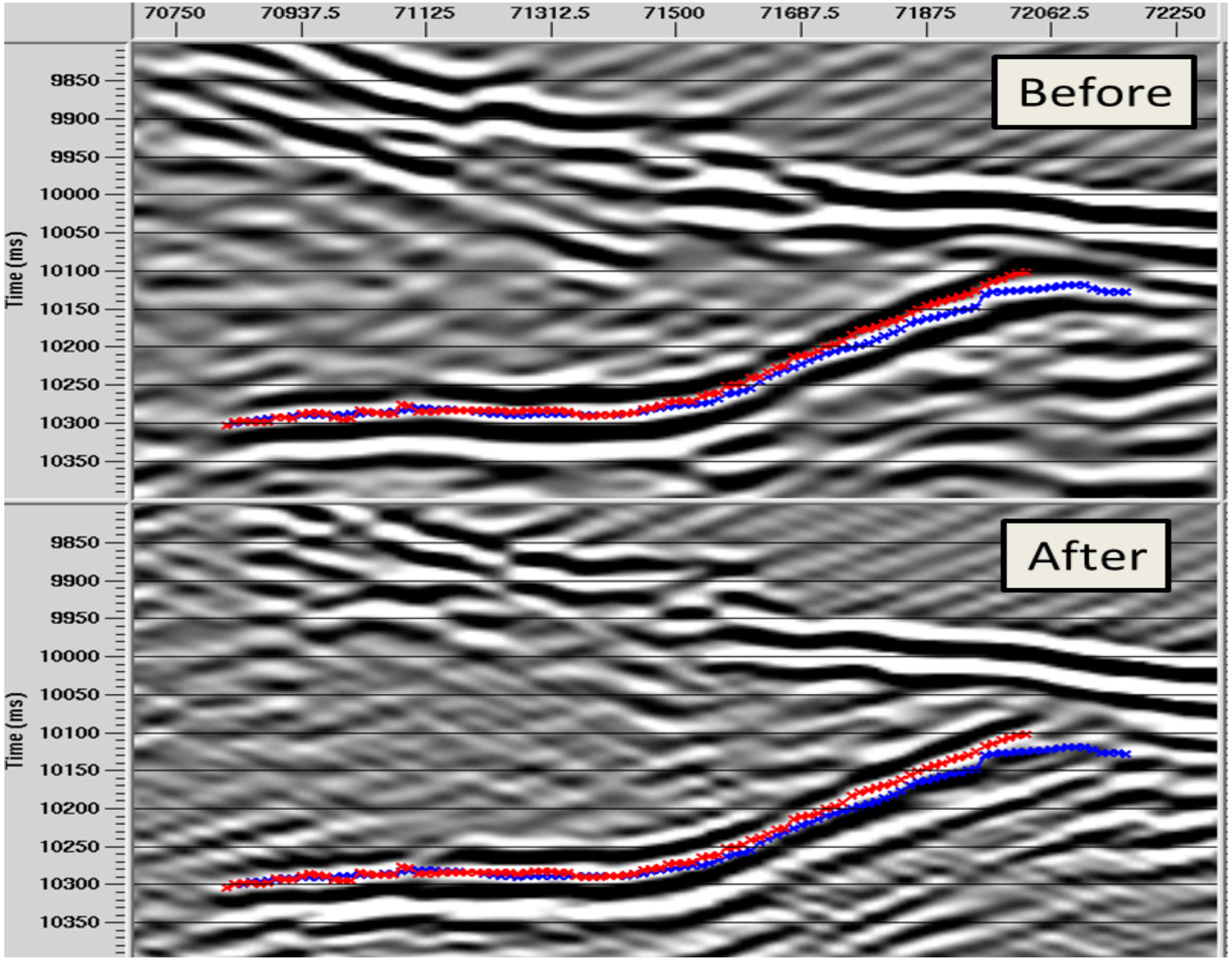
Horizontal and vertical displacements at seabed verus RMS velocity changes



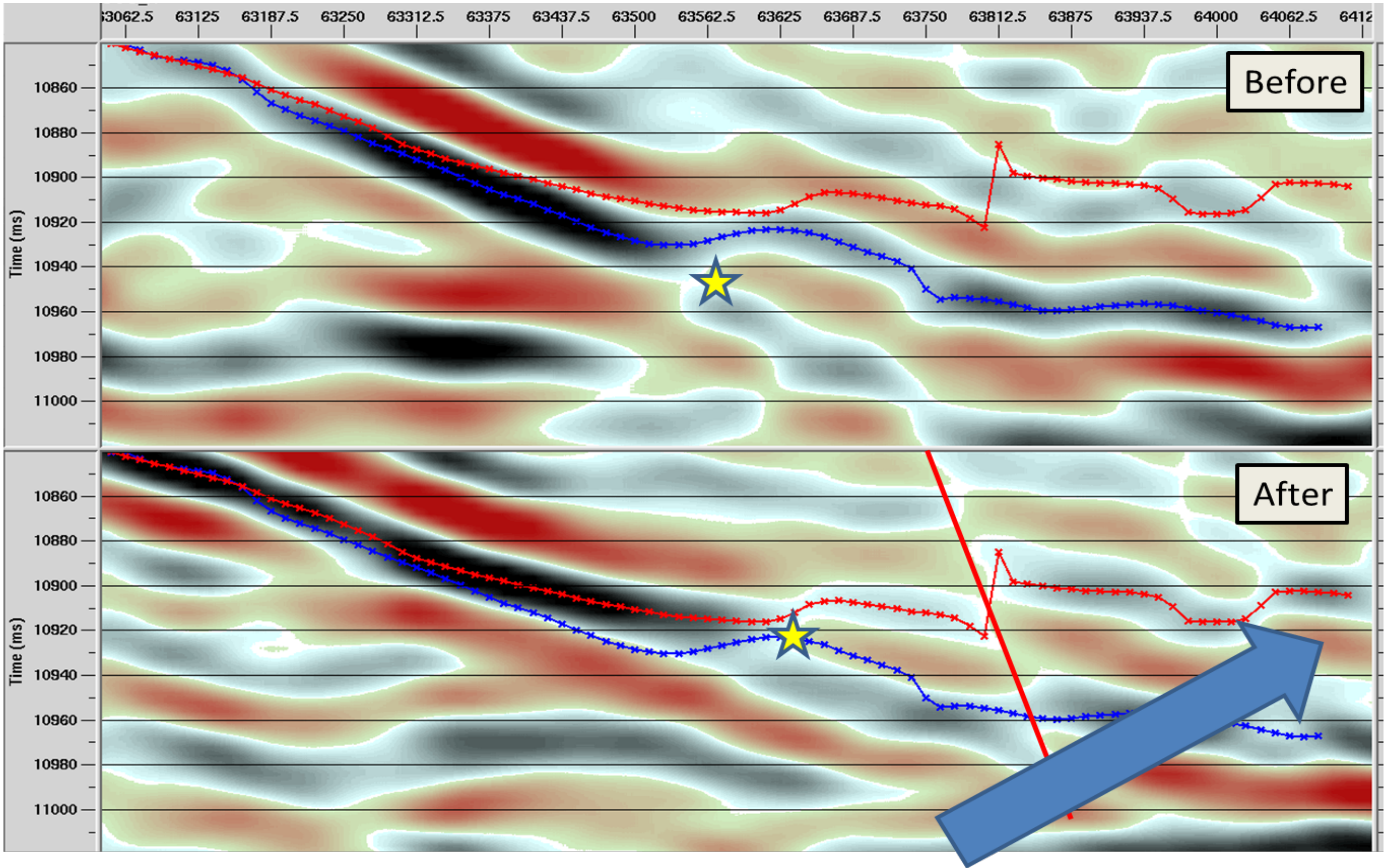
Other 4D features



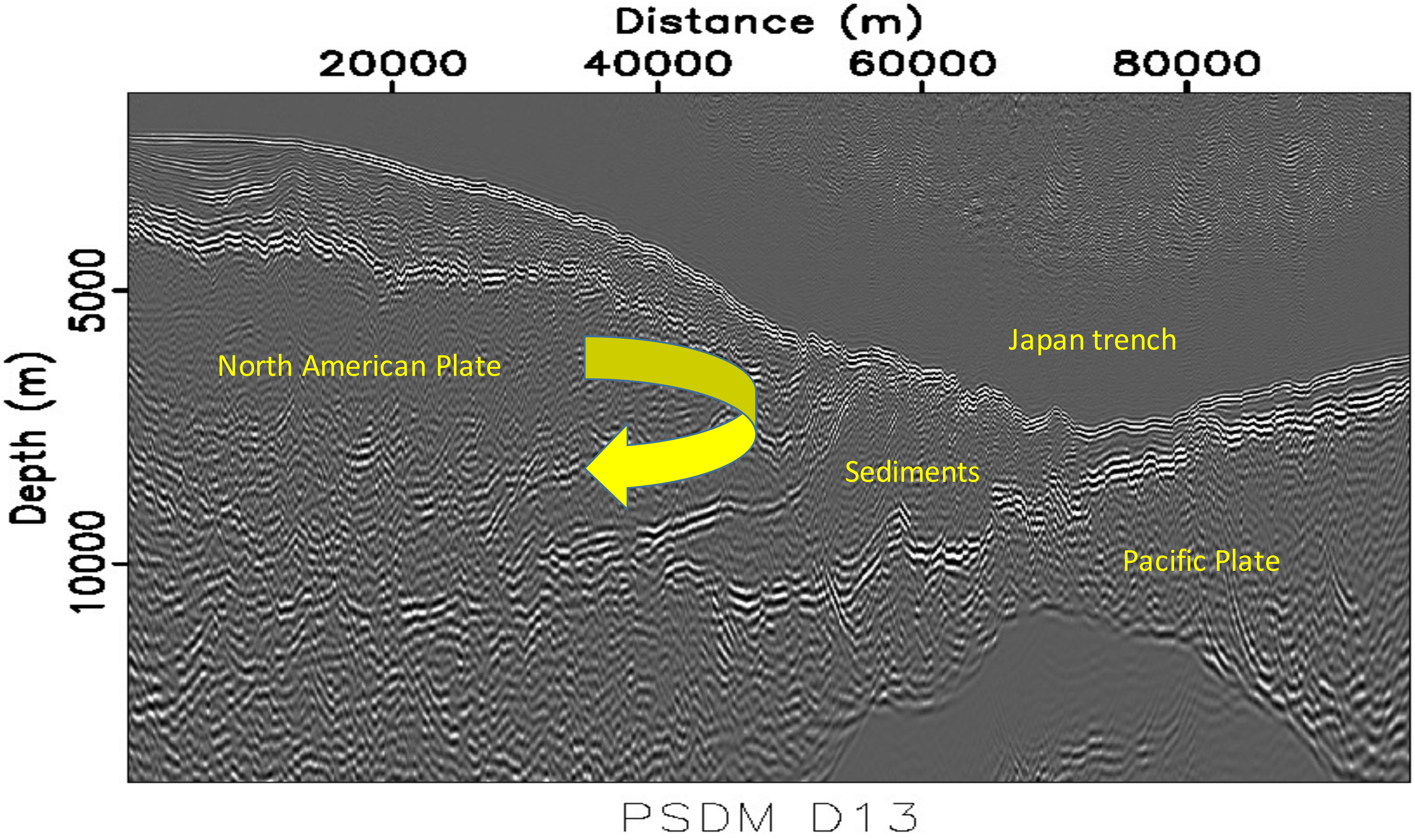
Steepening of dipping reflector

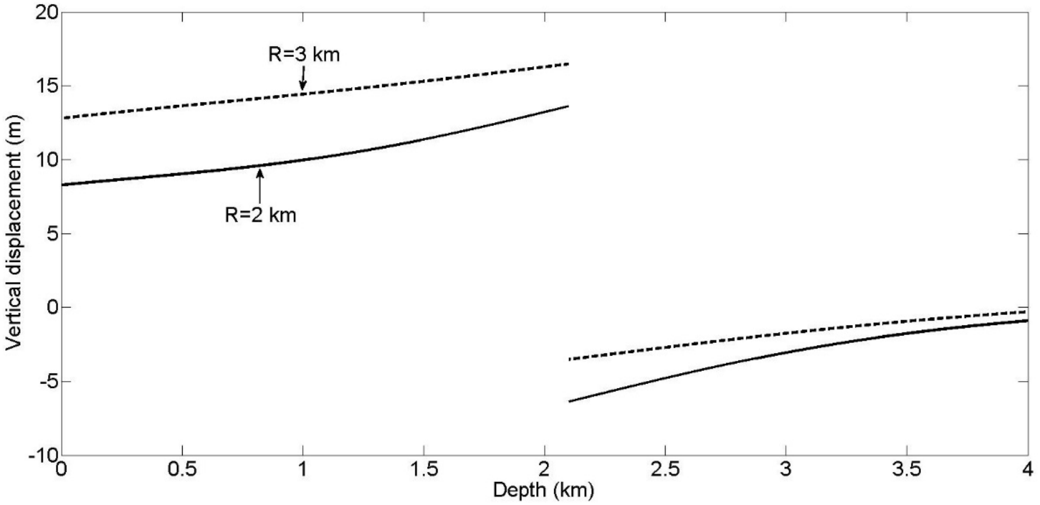


Horizontal movement and new fault

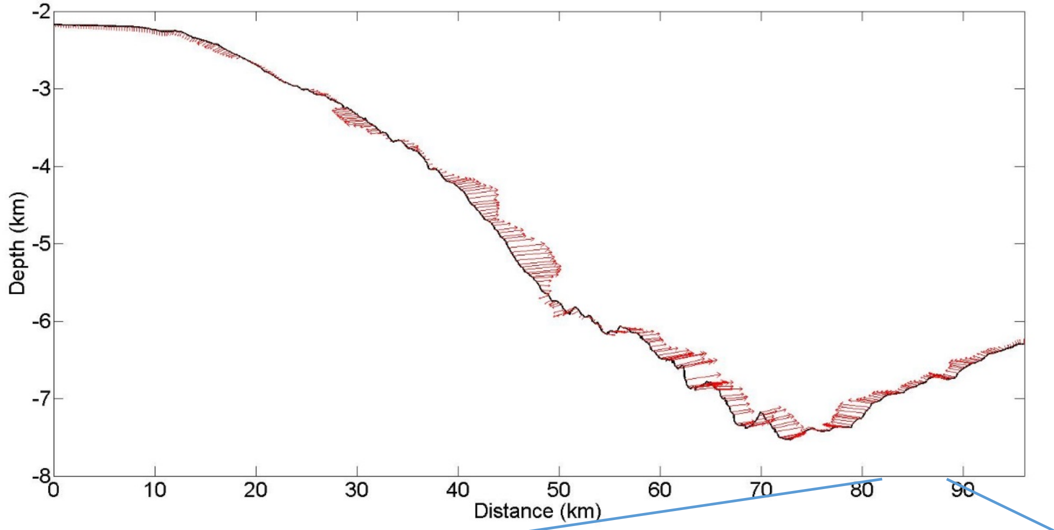


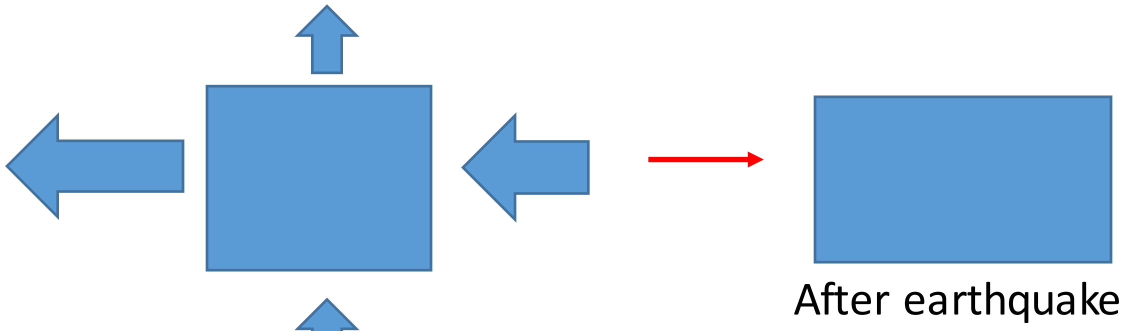
PSDM images using frequencies 10-15 Hz

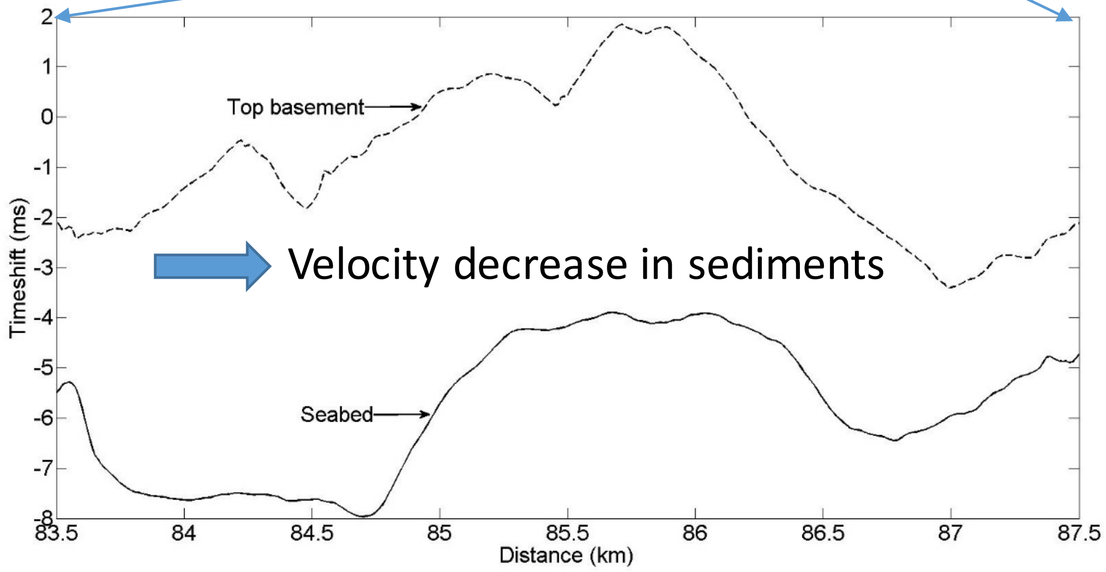



R=3 km
R=2 km
Vertical displacement (m)
Depth (km)
20
15
10
5
0
-5
-10
0
0.5
1
1.5
2
2.5
3
3.5
4

Horizontal stretching stronger than the vertical compaction:

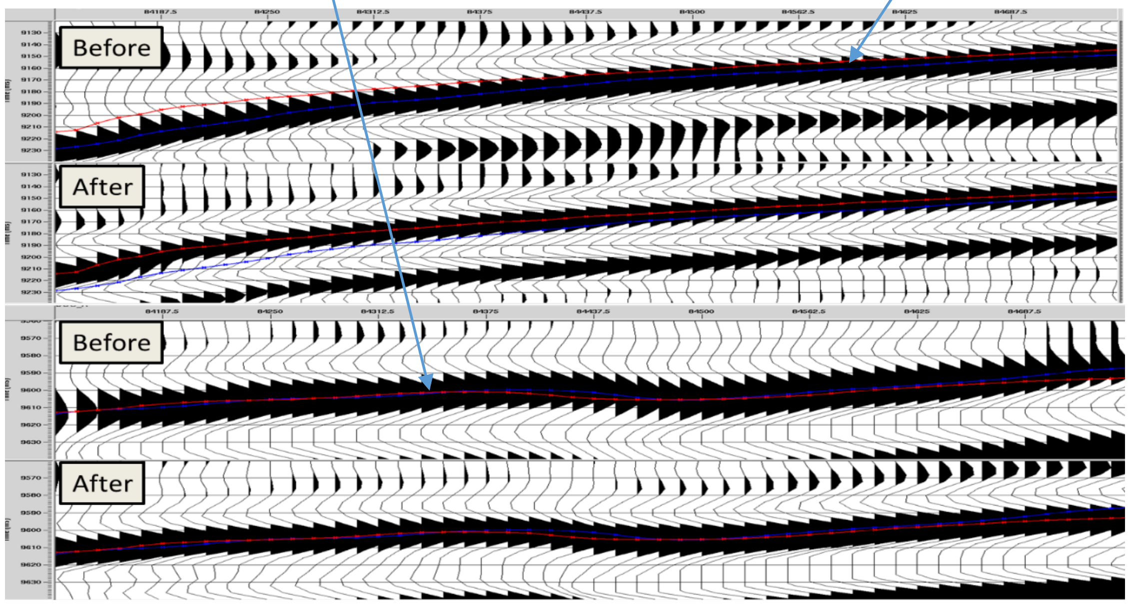






Top basement: No uplift

Seabed uplift



$$\boxed{\frac{dT}{T} = -\frac{dv}{v} + \frac{dz}{z}}$$

$$R = -\frac{dv/v}{dz/z}$$

$$\boxed{\frac{dT}{T} = (1+R)\frac{dz}{z}}$$