Outline

We can use Earthquakes

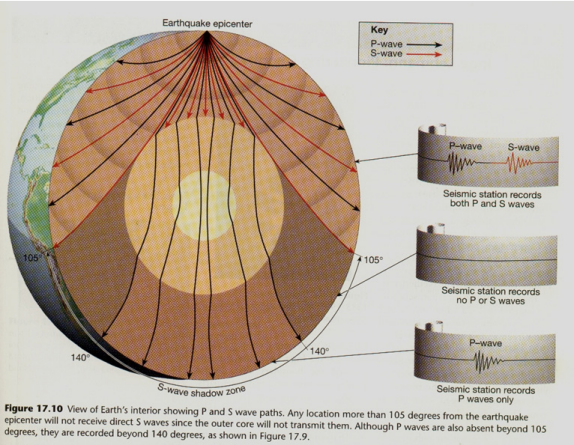
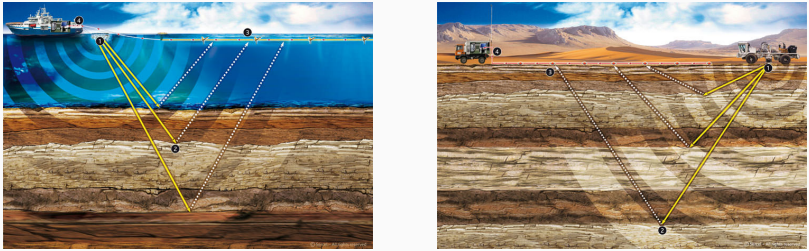


Figure 17.10 View of Earth's interior showing P and S wave paths. Any location more than 105 degrees from the earthquake epicenter will not receive direct S waves since the outer core will not transmit them. Although P waves are also absent beyond 105 degrees, they are recorded beyond 140 degrees, as shown in Figure 17.9.

Global tomography sketch: an earthquake acts as a source which propagates elastic waves which are recorded by seismic stations spread at different point of the surface

or controlled sources



Controlled source acquisition sketch, in a marine environment (left) or on land (right)

Notations for data

In terms of mathematics, the seismic data is thus a collection of time functions $d(t)$ associated with a source s and a receiver r. We will denote it as

$$d_{r,s}(t), \tag{2}$$

in the following, or equivalently

$$d(x_s, x_r, t), \tag{3}$$

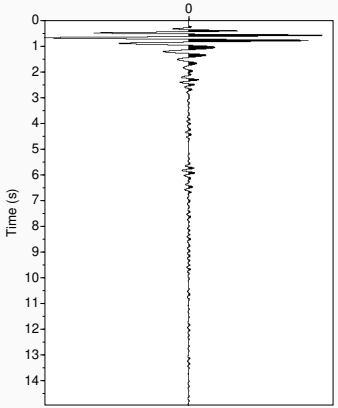
or

$$d_s(x_r, t), \tag{4}$$

depending on the context. In these notations x_r and x_s denote the spatial position of the receiver r and the source s respectively. A single function $d_{r,s}(t)$ will be referred to as a *seismic trace* in the following.

Seismic trace

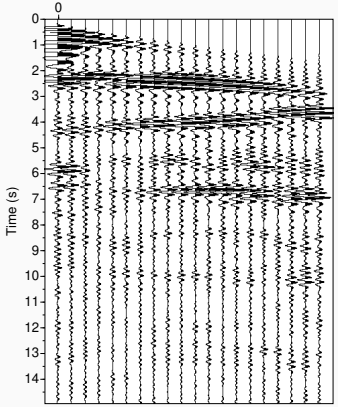
A typical example of a seismic trace is presented in Figure 20.



Typical seismic trace $d(t)$ as a function of time.

Seismogram

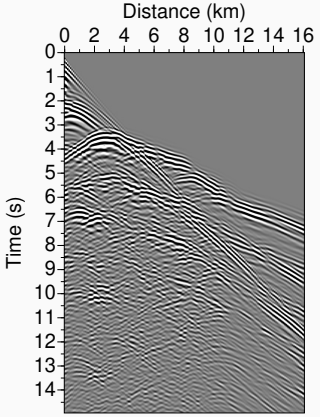
Instead of analyzing the data trace by trace: look simultaneously at several traces.



20 seismic traces $d_r(t)$ as a function of time, depending on the receiver/source distance, also referred to as *offset* in the following.

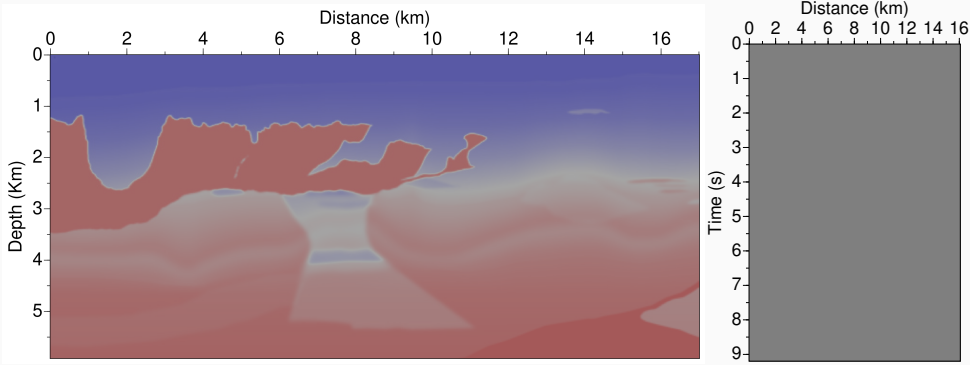
Seismogram

When the number of traces is even larger: use a 2D plot with a black & white chart



A typical seismogram in black and white representation. 161 traces spanning 16 km are used here. White correspond to negative values, black to positive values, while gray corresponds to 0. This yields the typical seismogram representation, widely used in exploration geophysics.

Where does this seismogram come from?



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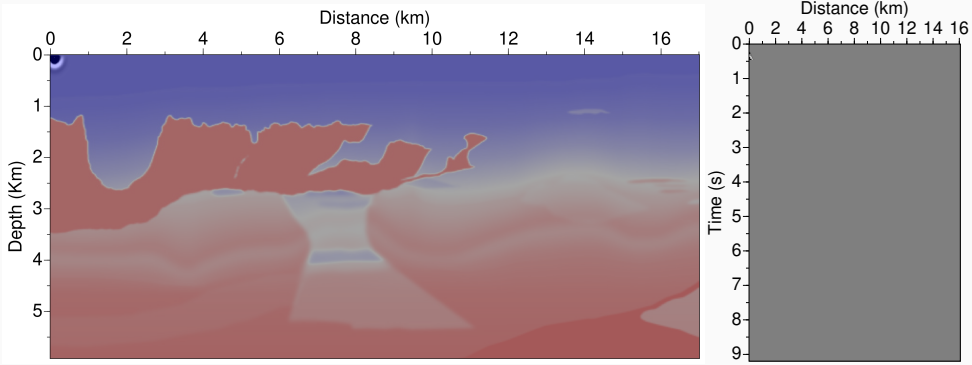

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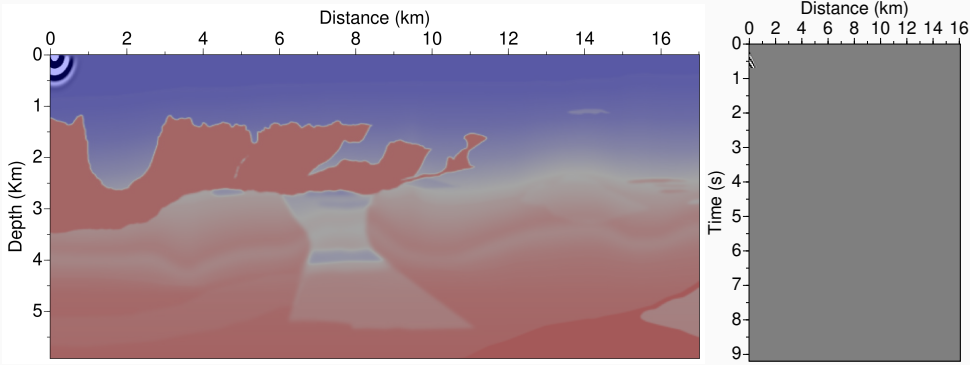

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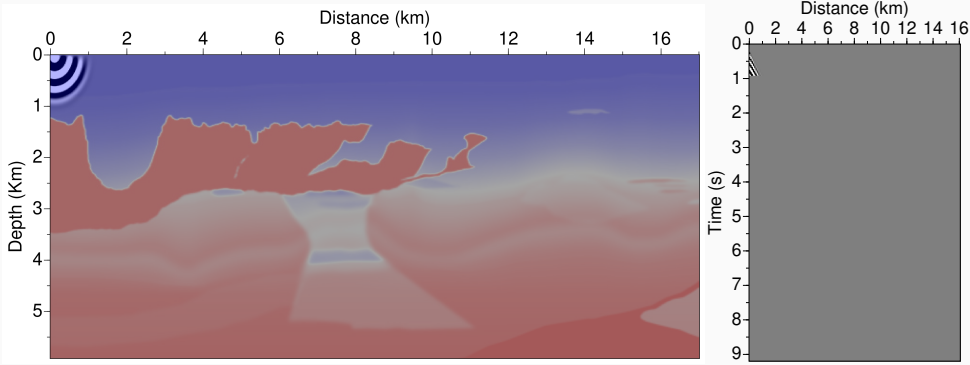

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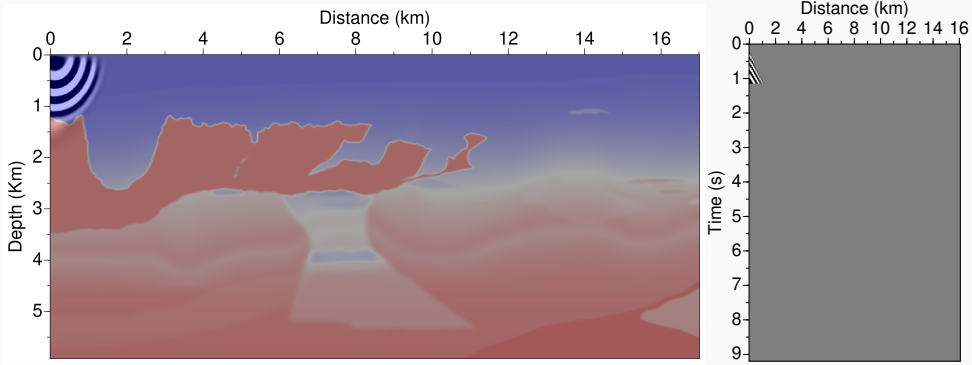

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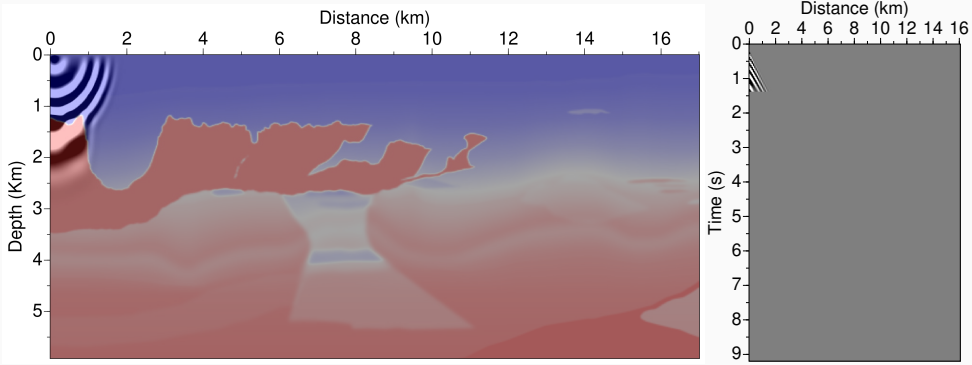

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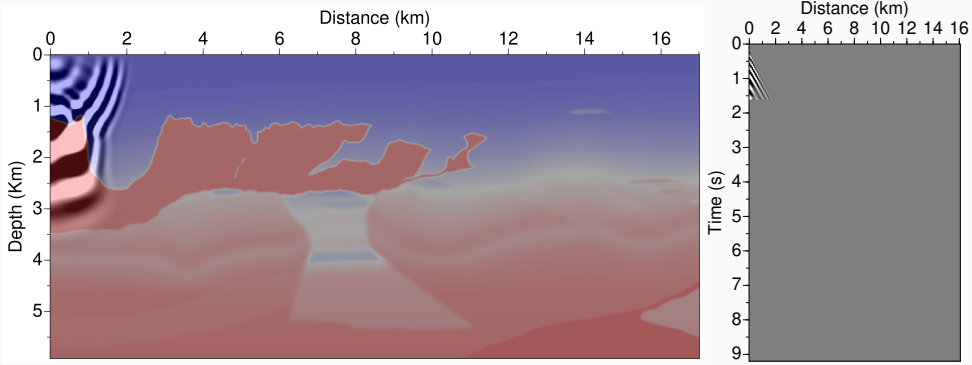

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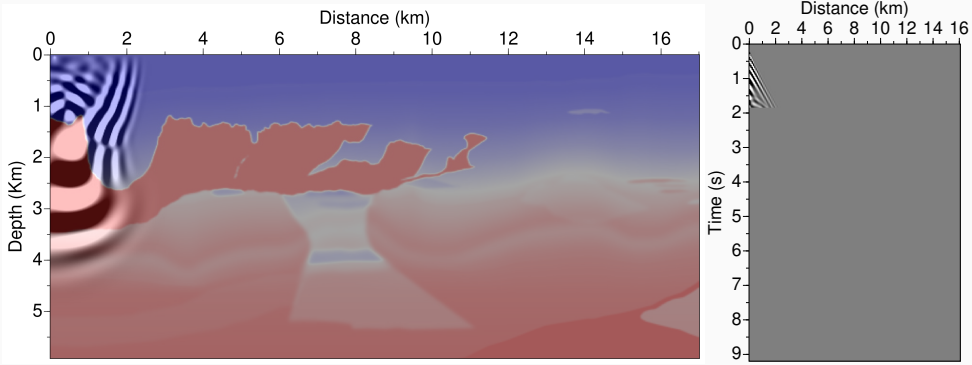

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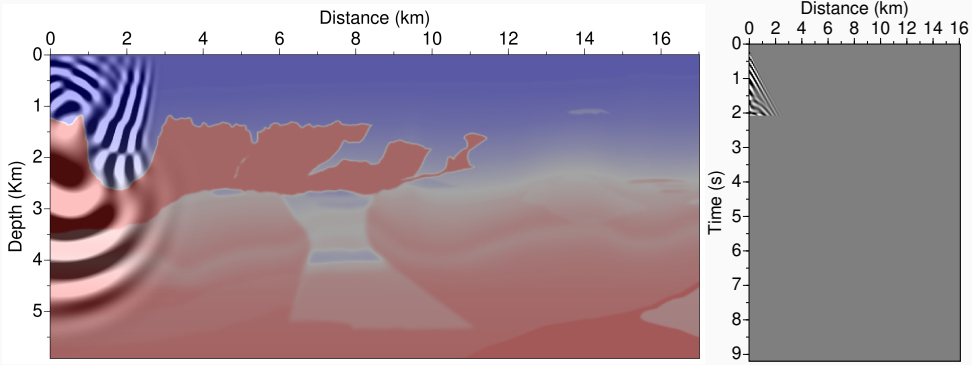

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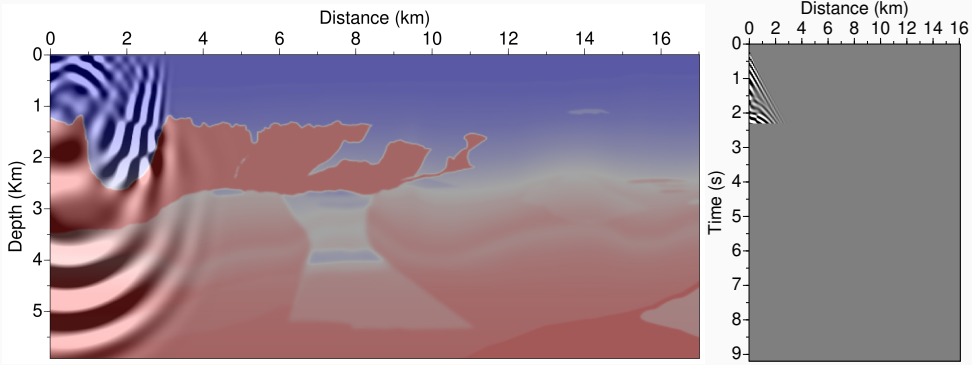

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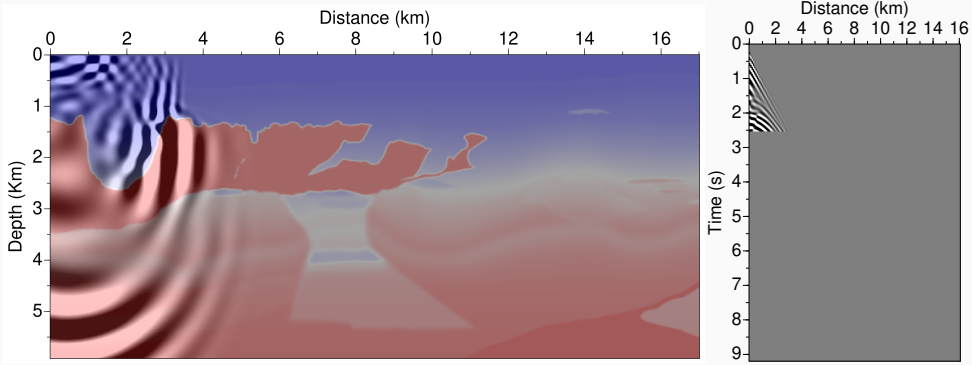

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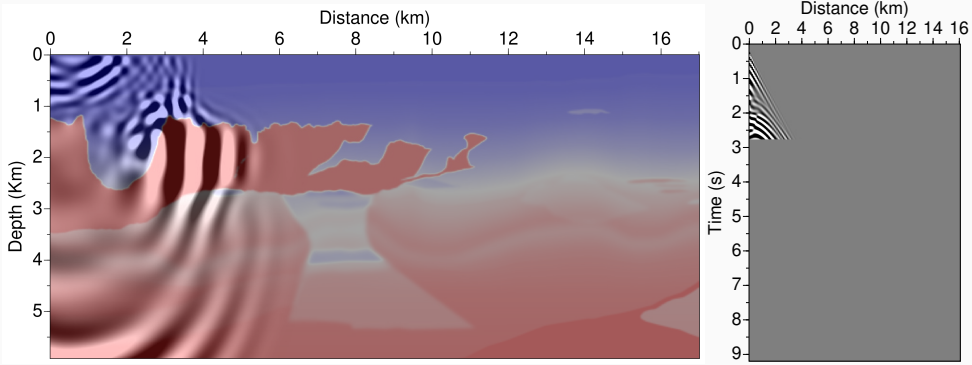

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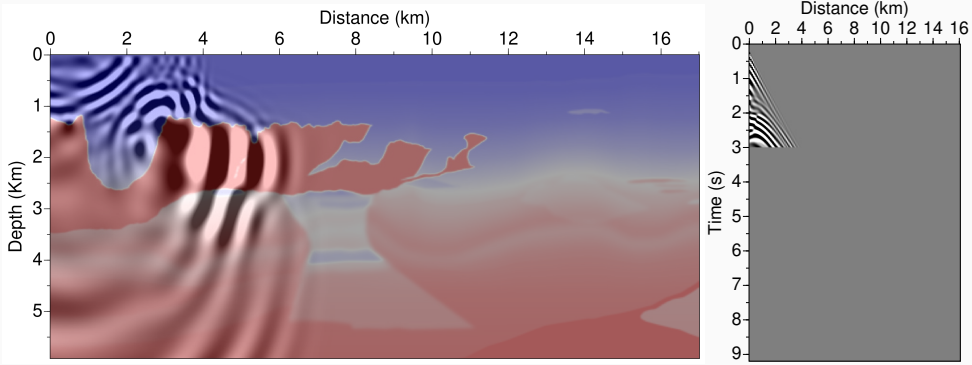

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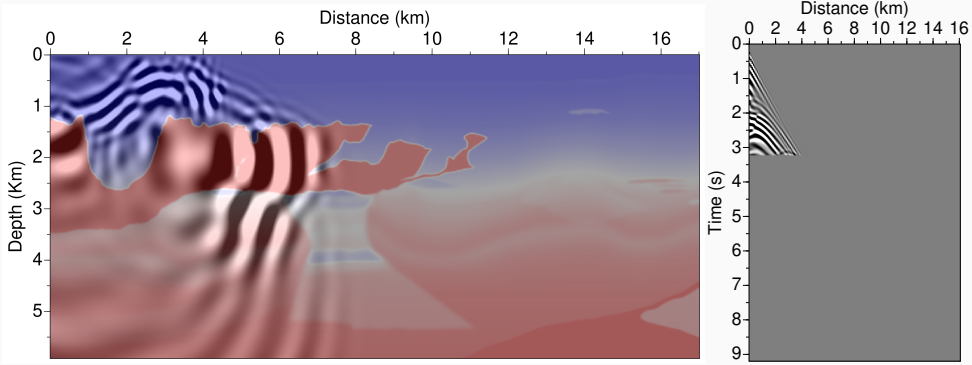

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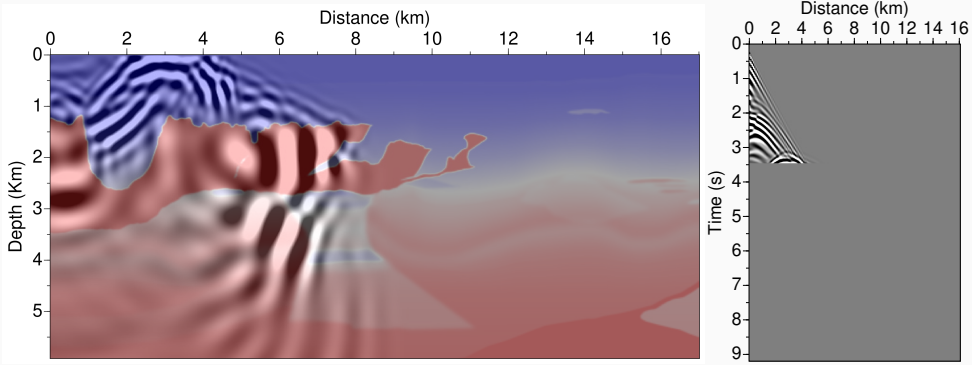

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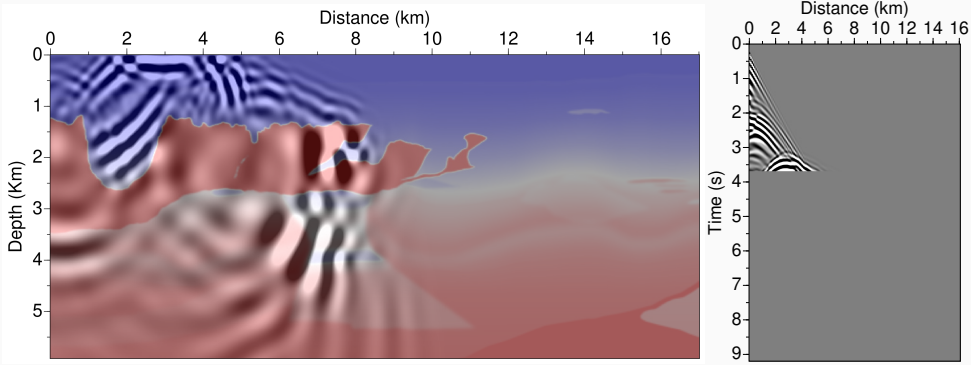

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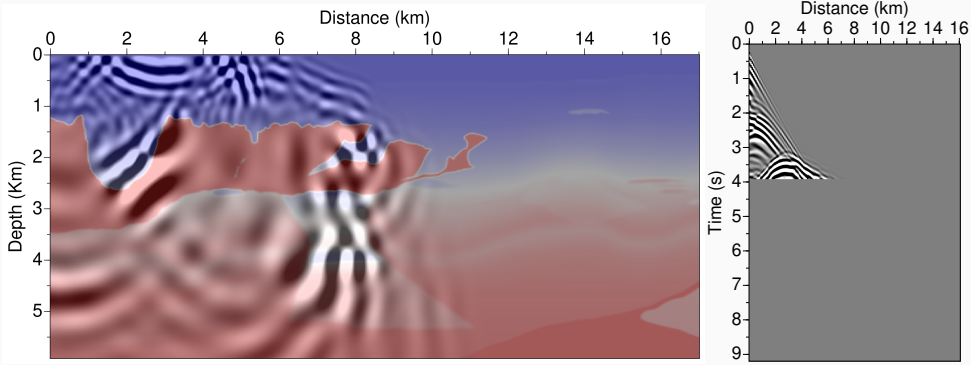

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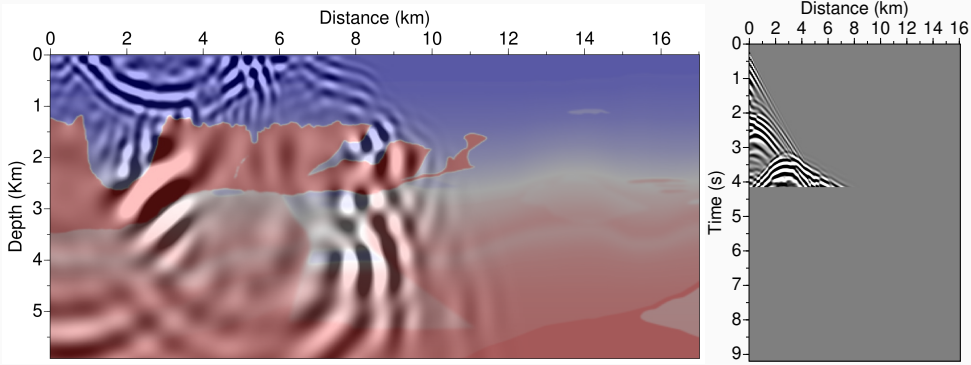

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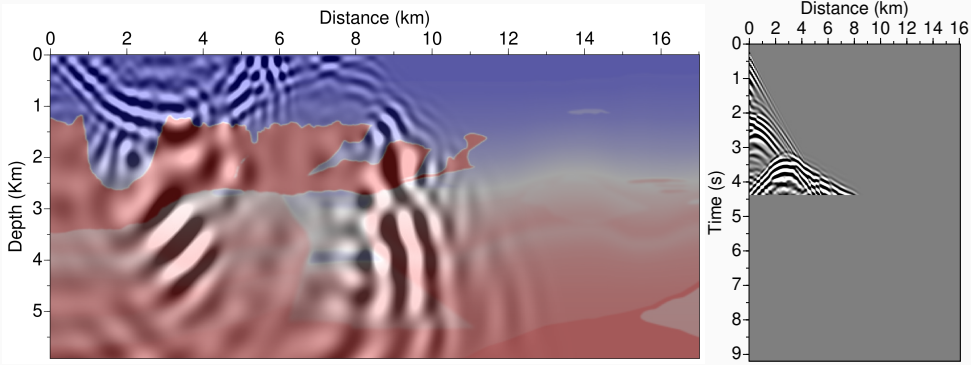

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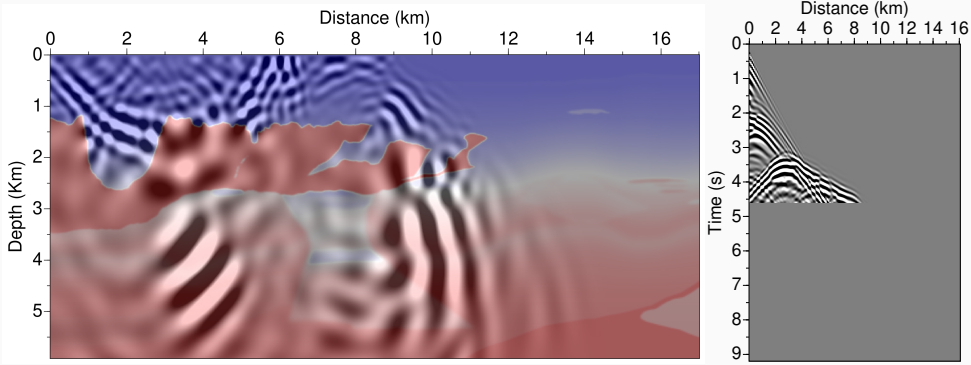

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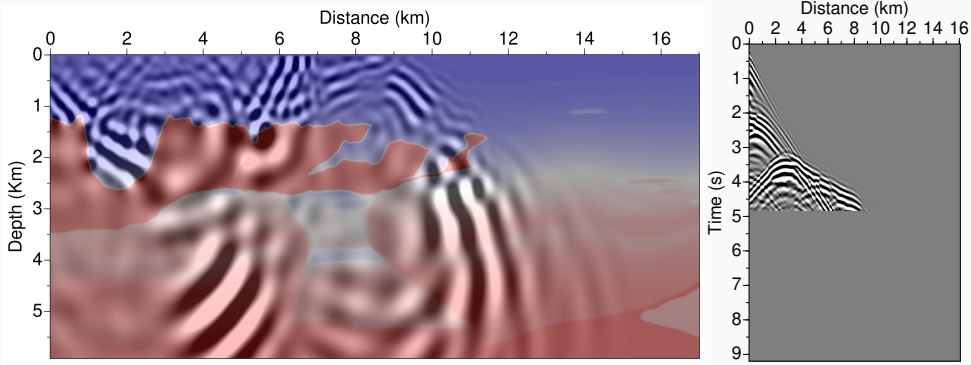

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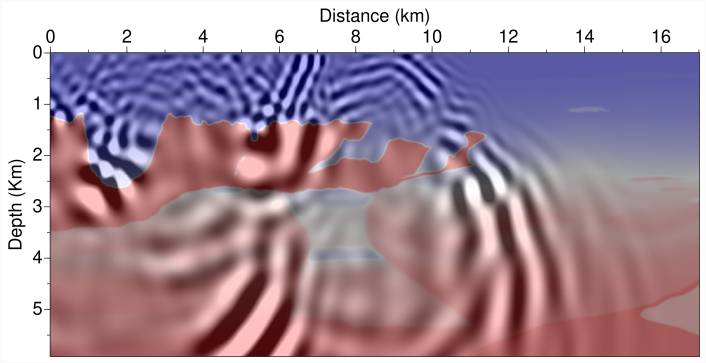

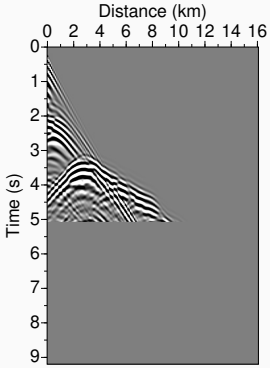

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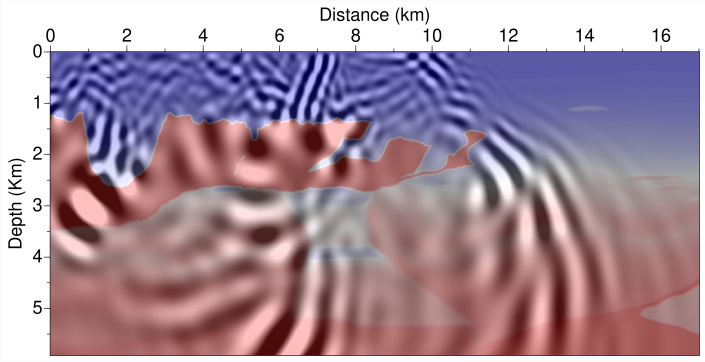

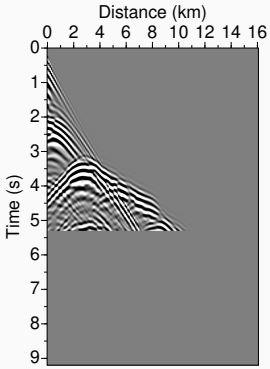

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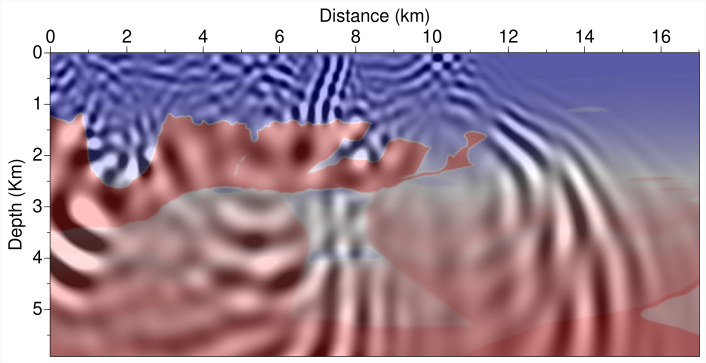

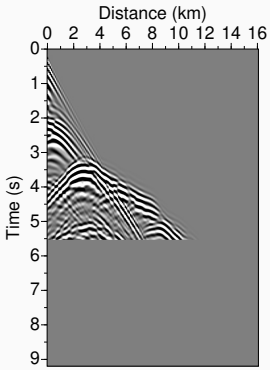

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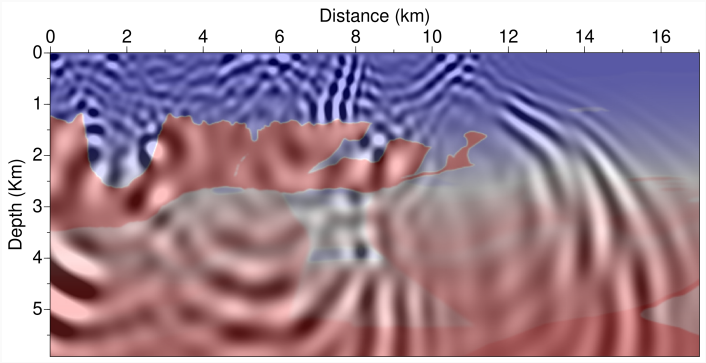

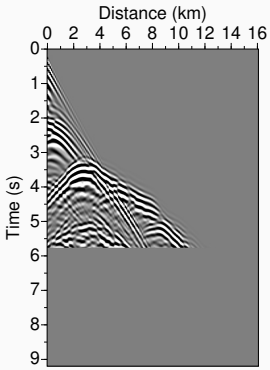

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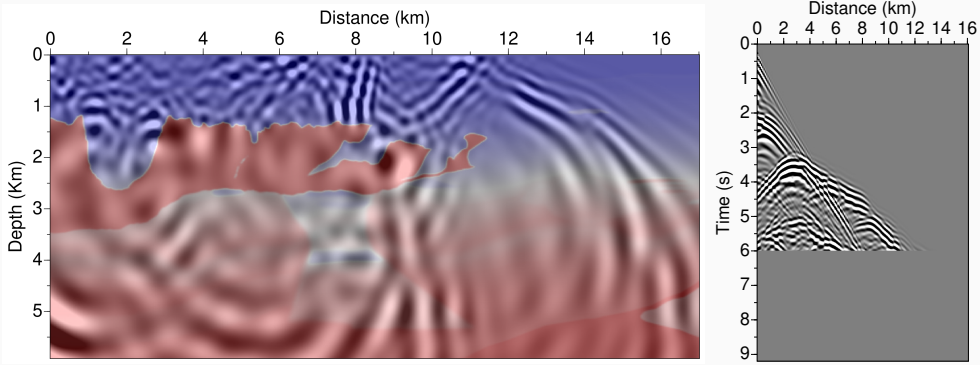

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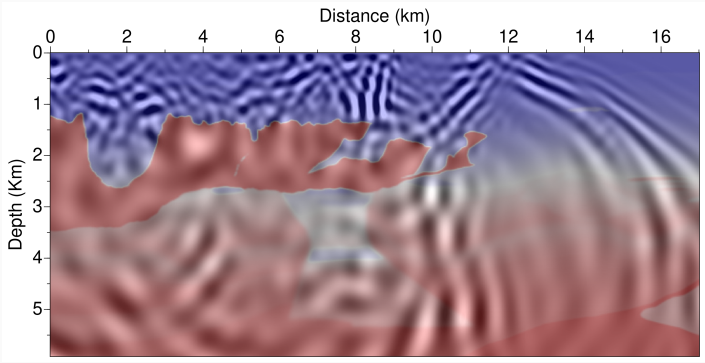

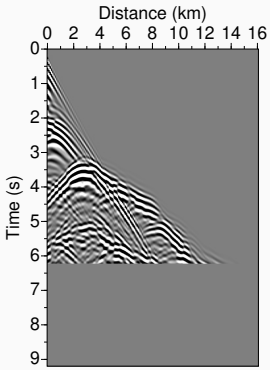

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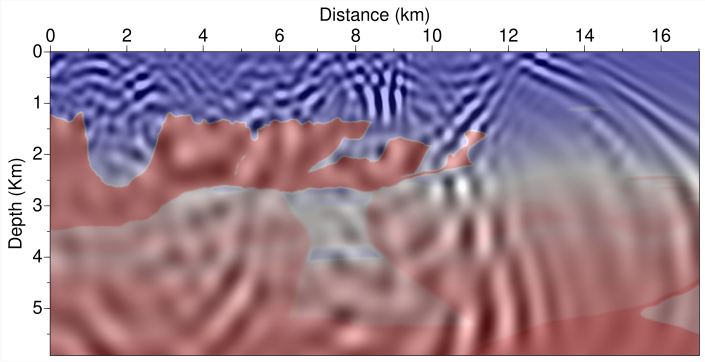

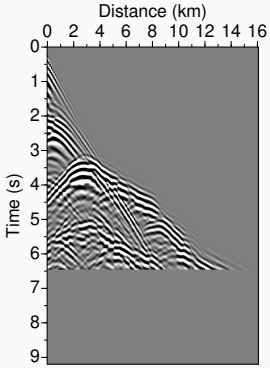

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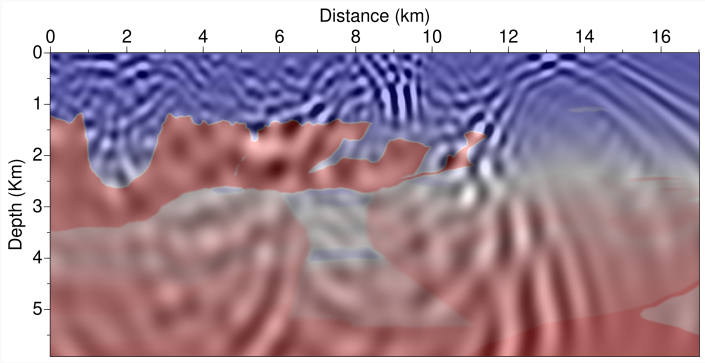

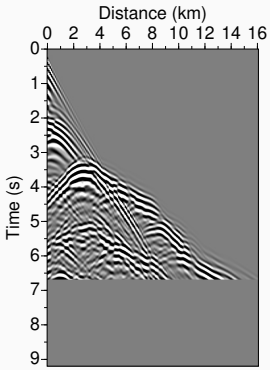

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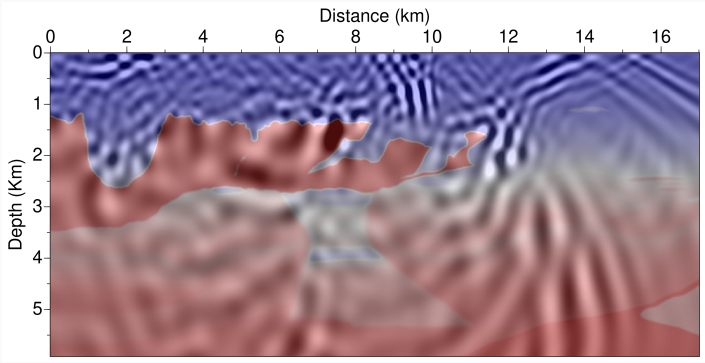

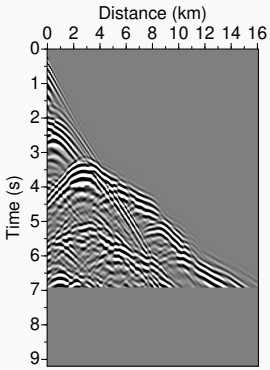

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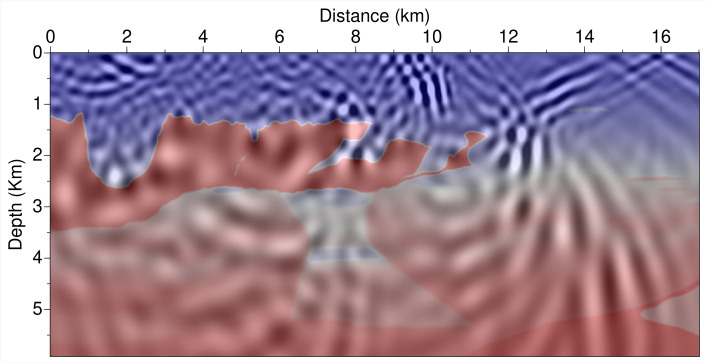

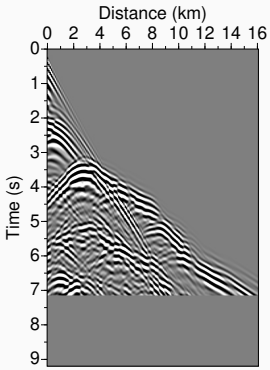

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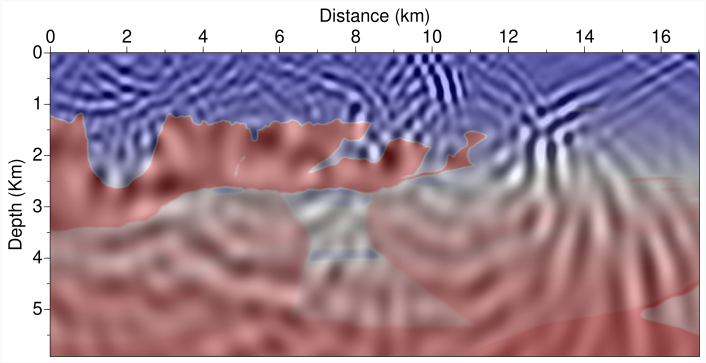

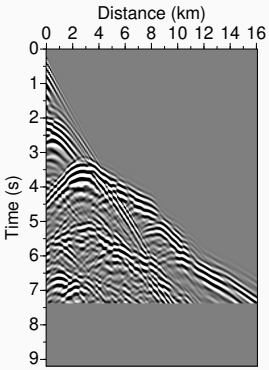

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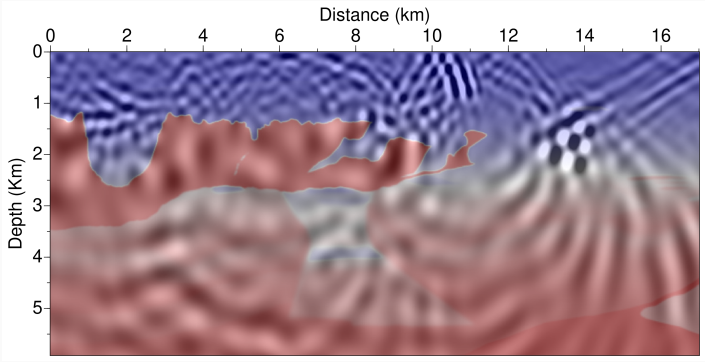

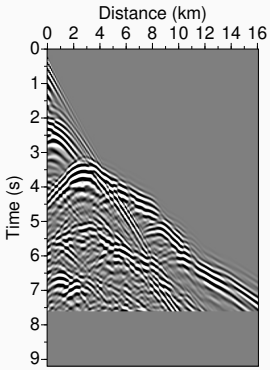

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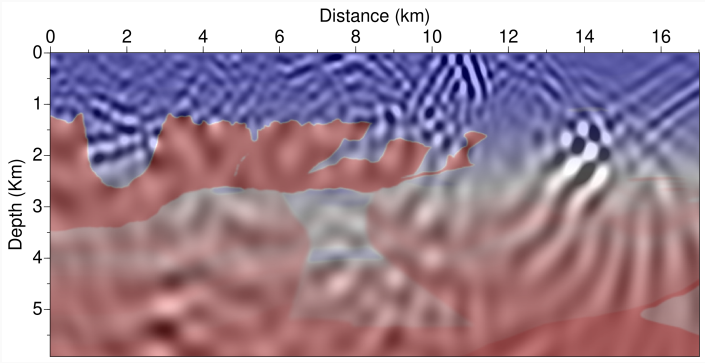

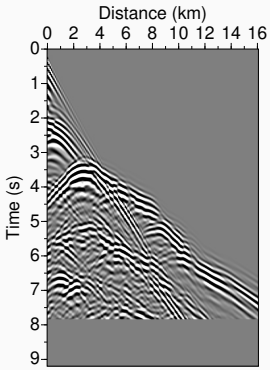

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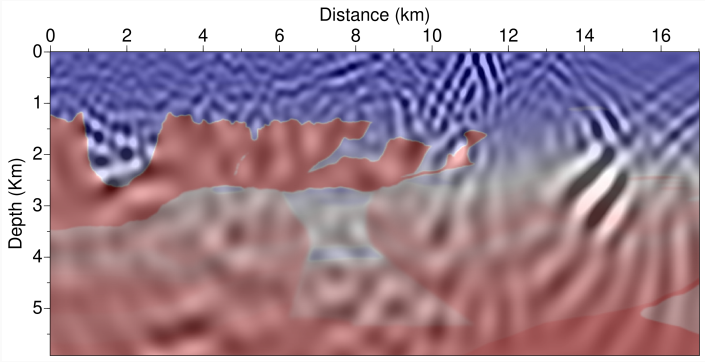

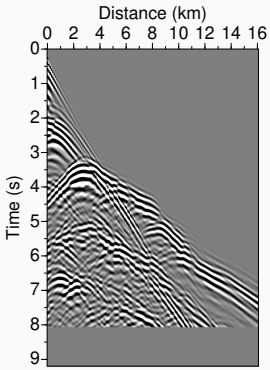

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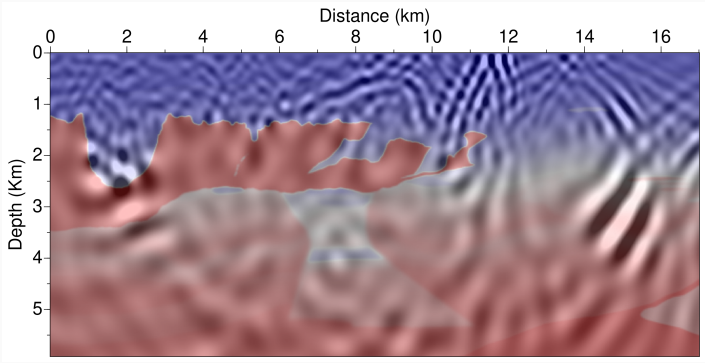
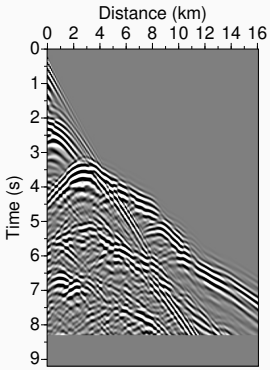
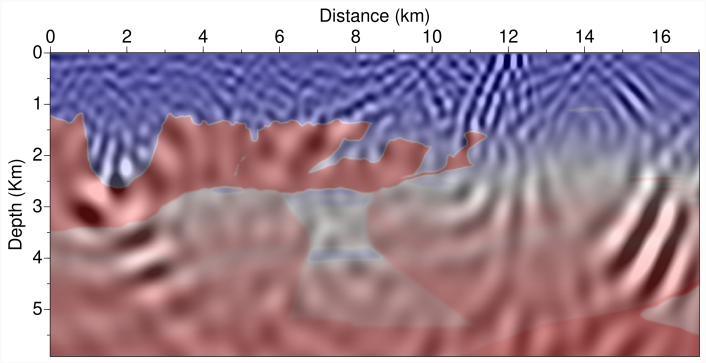
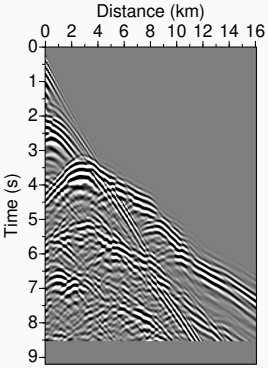


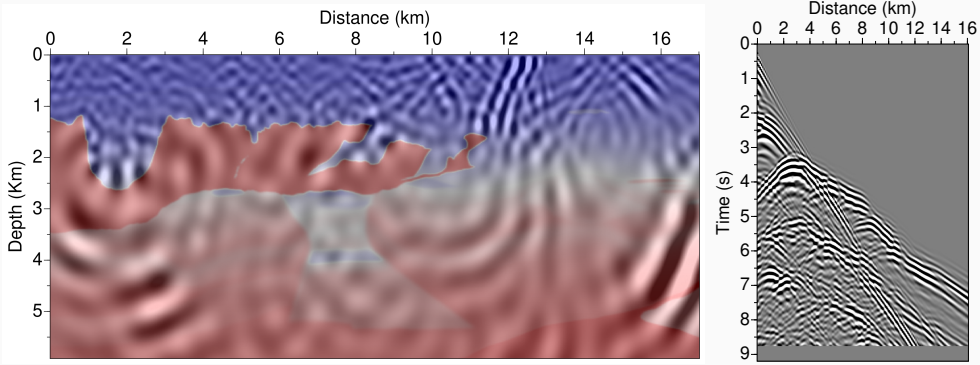


Where does this seismogram come from?

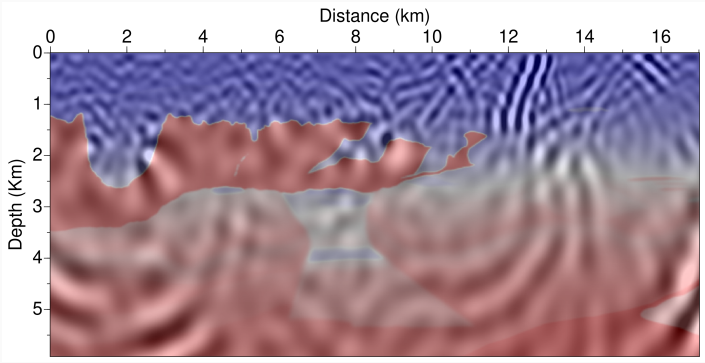


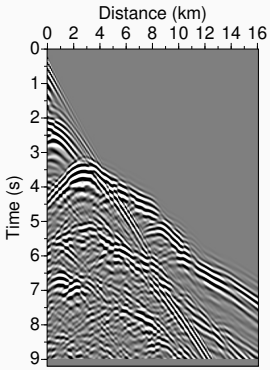


Where does this seismogram come from?

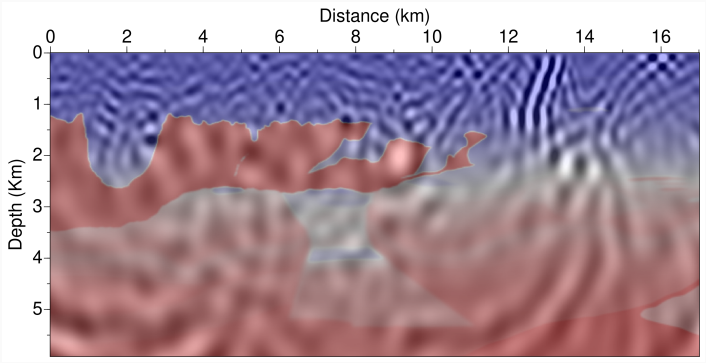


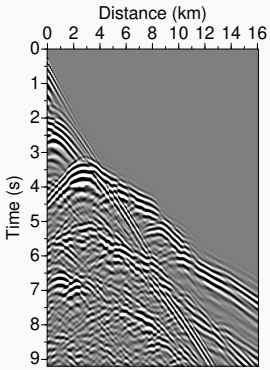
Where does this seismogram come from?



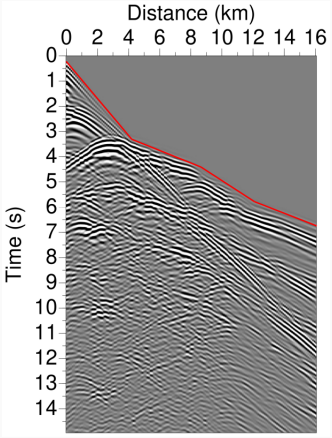


Where does this seismogram come from?





Outline



Same seismogram as in Figure 22 with first-arrival travel time denoted by the red line.

Tomography

Inverse tomography problem

$$d_{obs} = t_{obs}(x_s, x_r), \quad m = v_P \tag{5}$$

where $t_{obs}(x_s, x_r)$ denotes the picked travel times from source s to receiver r, and v_P is the pressure wave velocity.

Least-square first-arrival travel time tomography

$$\min_{v_P} \frac{1}{2}\|t_{cal} - t_{obs}\|^2 + \eta R(v_P), \quad t_{cal} = g(v_P). \tag{6}$$

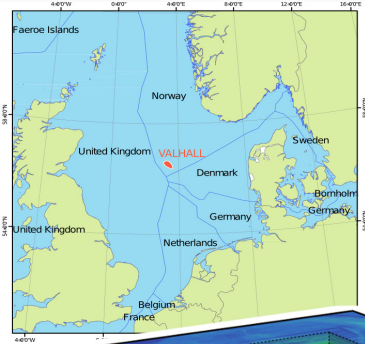
Full waveform inversion: exploiting all the data

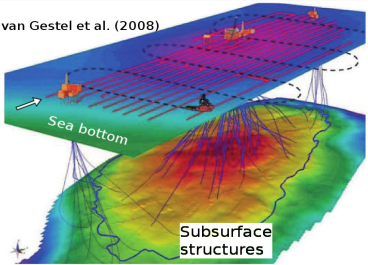
Idea: replace the forward modeling operator $g(m)$ by a full wave modeling solver, and to compare the resulting synthetic data to the full observed data $d_{obs}(x_s, x_r, t)$. The FWI problem is thus formulated as

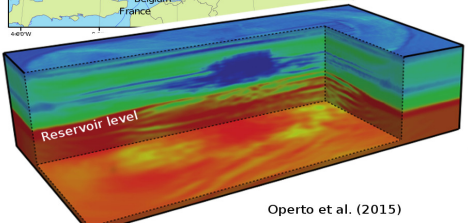
$$\min_m \frac{1}{2}\|d_{cal} - d_{obs}\|^2 + \eta R(m), \quad d_{cal} = g(m) \tag{7}$$

3D acoustic FWI of the Valhall data (Operto et al., 2015)

Valhall target





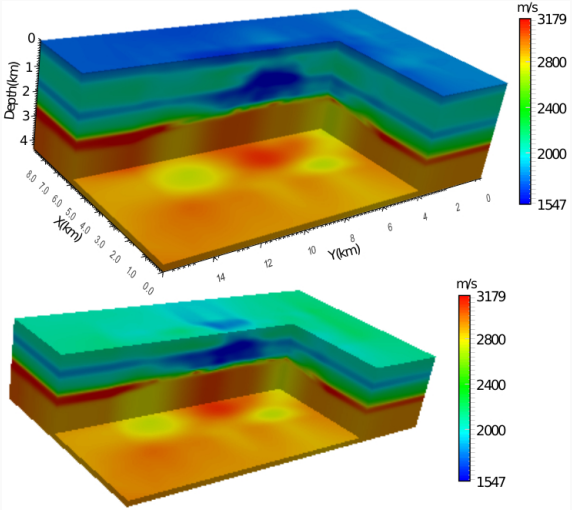


Operto et al. (2015)

- Area: $\sim$ 145 km^2
- $\sim$50,000 shots at 5 m depth
- $\sim$2,300 receivers (4C) at 75 m depth (12 OBCs)
- Reservoir level $\sim$2.5 km depth
- Frequency-domain strategy : time-harmonic

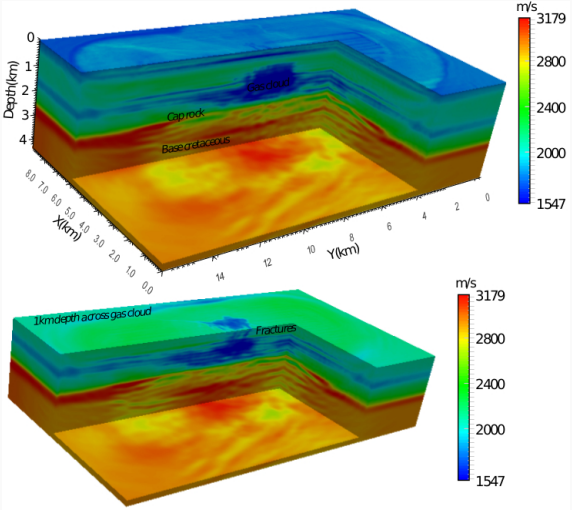
3D acoustic FWI of the Valhall data (Operto et al., 2015)

Initial model



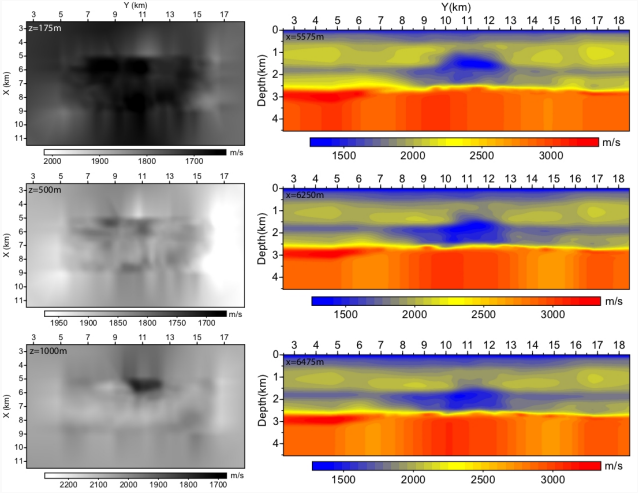
3D acoustic FWI of the Valhall data (Operto et al., 2015)

Final FWI model



3D acoustic FWI of the Valhall data (Operto et al., 2015)

Horizontal and vertical 2D slices: initial model



3D acoustic FWI of the Valhall data (Operto et al., 2015)

Horizontal and vertical 2D slices: final FWI model