Vertical Seismic Profiling using Distributed Acoustic Sensing

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VSP using DAS

- DAS and fibre-optics
- CaMI Field Research Station
- Examples
- Conclusions

DAS and Fibre-optics

In DAS, a laser pulse is sent along a fibre-optic cable and the intensity of the backscattered light is measured as a function of time.

Interferometry is a measurement technique based on the superposition of waves that uses the combination of the waves to infer something about their state.

To create optical interference within the fibre, a pulse of light is launched into the fibre and is reflected back and interferes with itself.

DAS and Fibre-optics

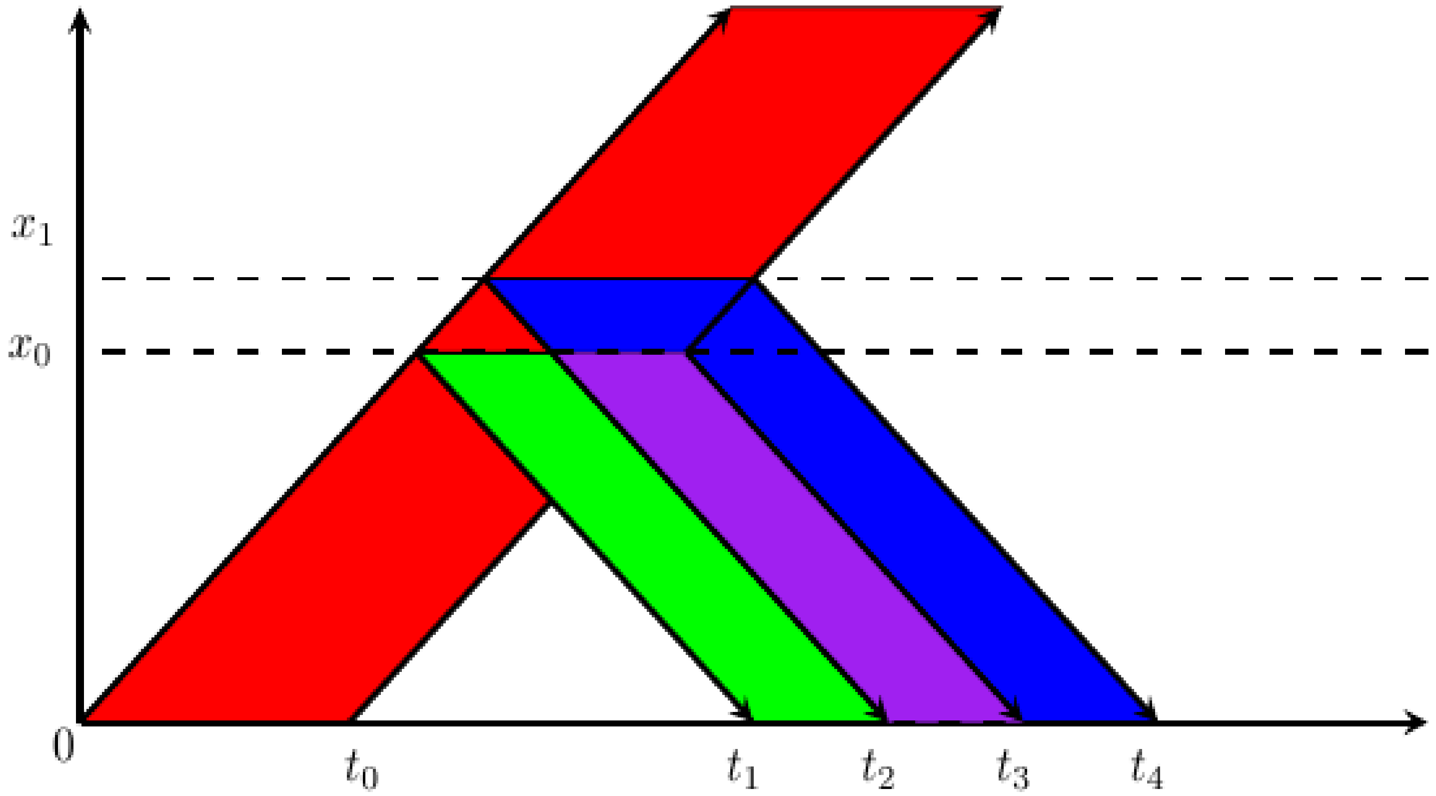


Figure 1: Interference from multiple scattering points.

DAS and Fibre-optics

Assume that light inside fibre optic cables obeys the basic wave equation

$$u_{tt} = c^2 u_{xx}.$$

Then, the general solution is any linear combination of complex exponentials of the form

$$u(x,t) = e^{i(kx+\omega t)}$$

where k is the angular wavelength and ω is the angular frequency.

If $\Delta x = x_1 - x_0$, then the light reflected at x_0 and x_1 accumulate a $2x_0/c$ and $2x_1/c = 2(x_0 + \Delta x)/c$ second phase delay, respectively.

DAS and Fibre-optics

Therefore, the returning waveform for the point x_0 can be written as

$$u_0(t) = r_0 e^{i\omega(2x_0/c+t)}$$

and

$$u_1(t) = r_1 e^{i\omega(2(x_0+\Delta x)/c+t)} = r_1 e^{i\omega 2\Delta x/c} u_0(t)$$

for the point x_1 where r_0 and r_1 are the reflection coefficients from x_0 and x_1.

Therefore the complete returned waveform is

$$u_r(t) = r_0 u_0(t) + r_1 u_1(t) = \left(\mathrm{r}_0 + \mathrm{r}_1 \mathrm{e}^{\mathrm{i}\omega 2\Delta x/\mathrm{c}}\right) u_0(t).$$

The output intensity is

$$I = u_r(t)u_r^*(t) = r_0^2 + r_1^2 + 2r_0r_1\cos(2k\Delta x).$$

Recall the intent is to measure Δx. For uniqueness, it is required that $2k\Delta x \in [0,\pi]$ or $\Delta x \le \pi/2k$.

The wavelength of the source must be very stable for the sensor to be reliable.

DAS and Fibre-optics

Pulse-repetition-frequency (PRF) is the fastest rate at which we may launch a pulse of light into the fibre if we would like all of the backscattered light to exit the fibre before we launch the next pulse. If T is the amount of time it takes to reach the end of the fibre and return, then $PRF = 1/T$.

CaMI Field Research Station

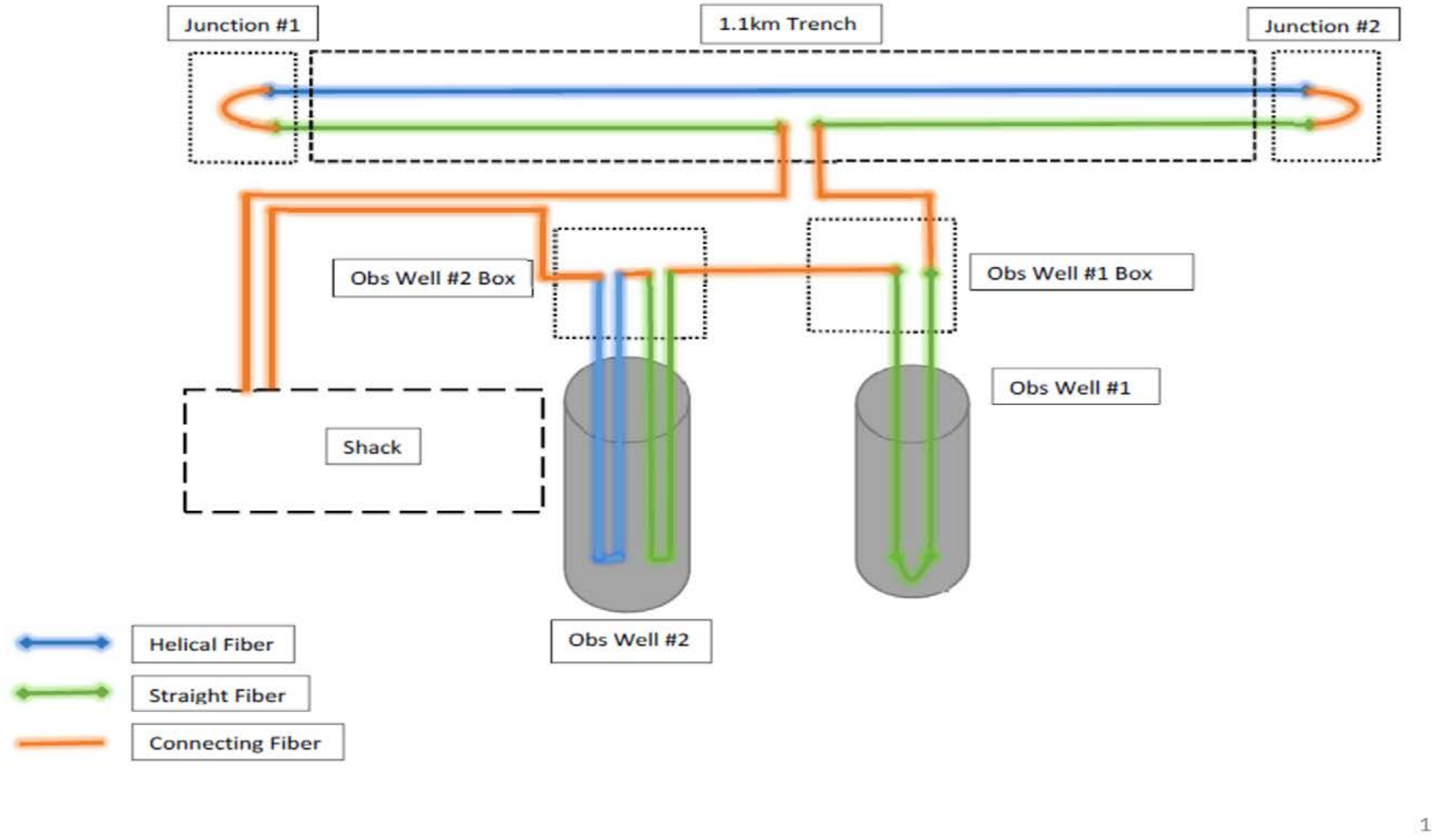


Figure 2: A schematic of the fibre at the site in Newell County, AB.

CaMI Field Research Station

- The experiment was conducted at the CaMI Field Research Station in Newell County, AB.
- The experiment consisted of 270 shots over 49 locations along 2 full lines.
- The source location 103 resided between wells 1 and 2 and was approximately 500m from source locations 101 and 105.
- The wells reach a depth of approximately 300m.
- Processing is applied to the raw backscatter data to obtain the optical phase, and then each shot is cross-correlated with the pilot sweep and then stacked.

Examples

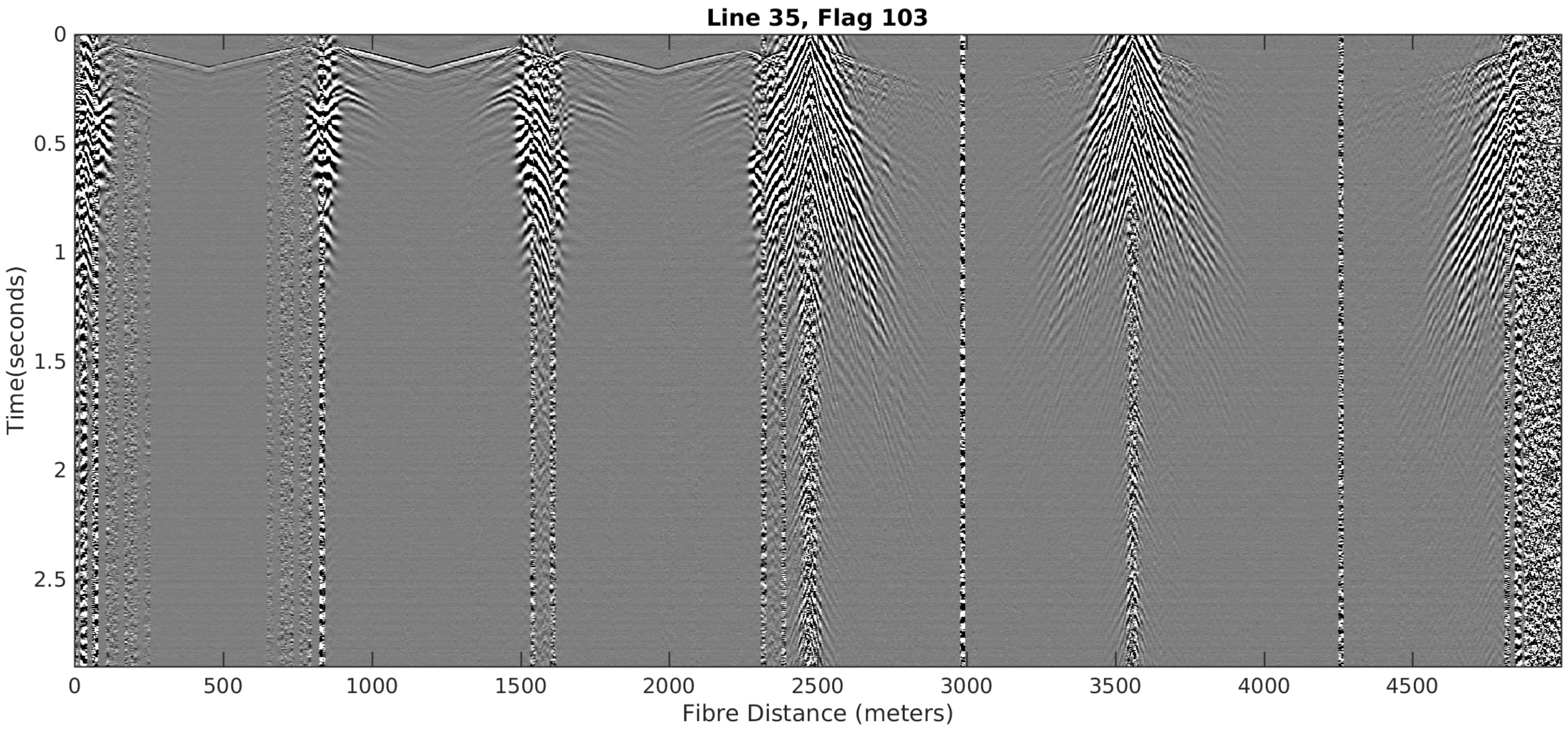


Figure 3: Full fibre data for line 35 flag 103

Examples

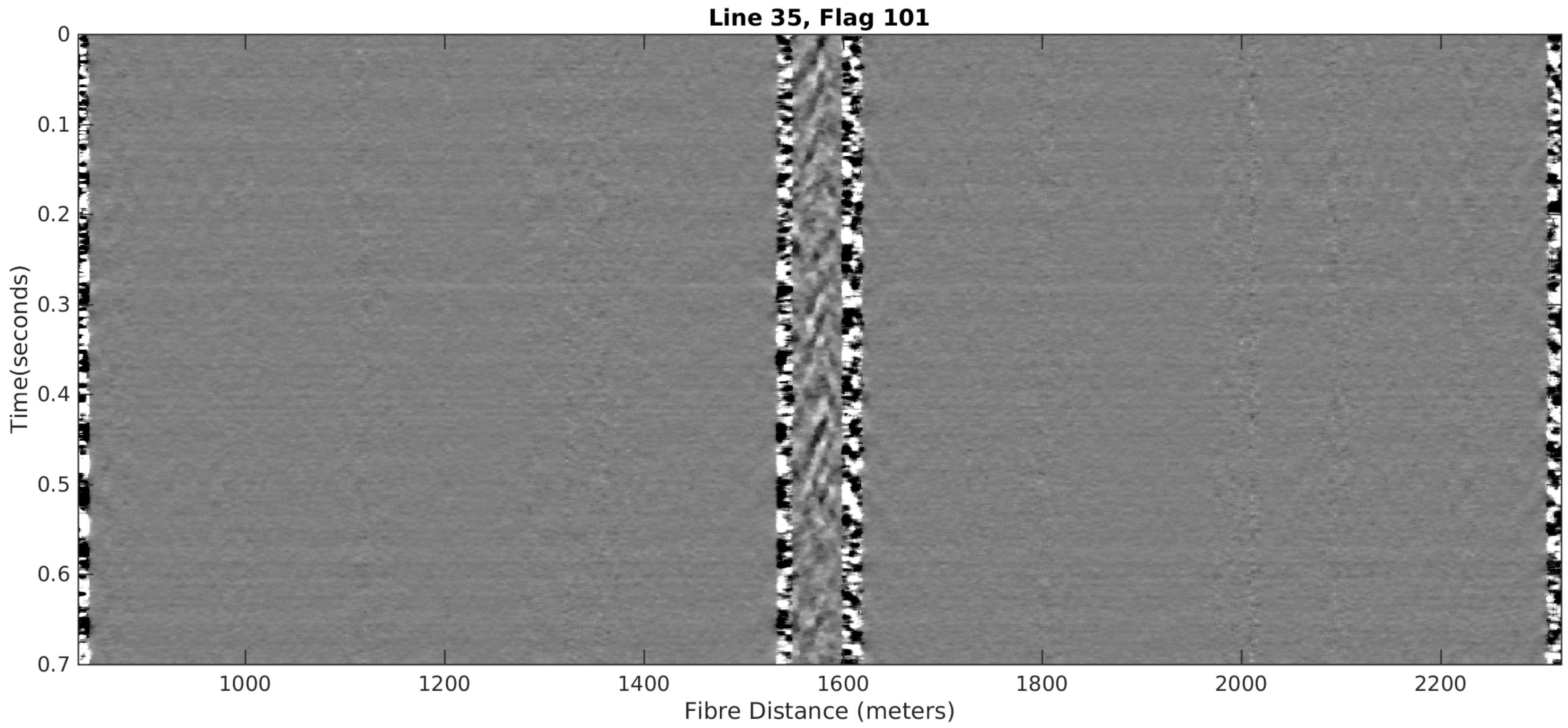


Figure 4: The straight-fibre from well 2 to the straight-fibre in well 1 acquired when the vibroseis truck was at source location 101.

Examples

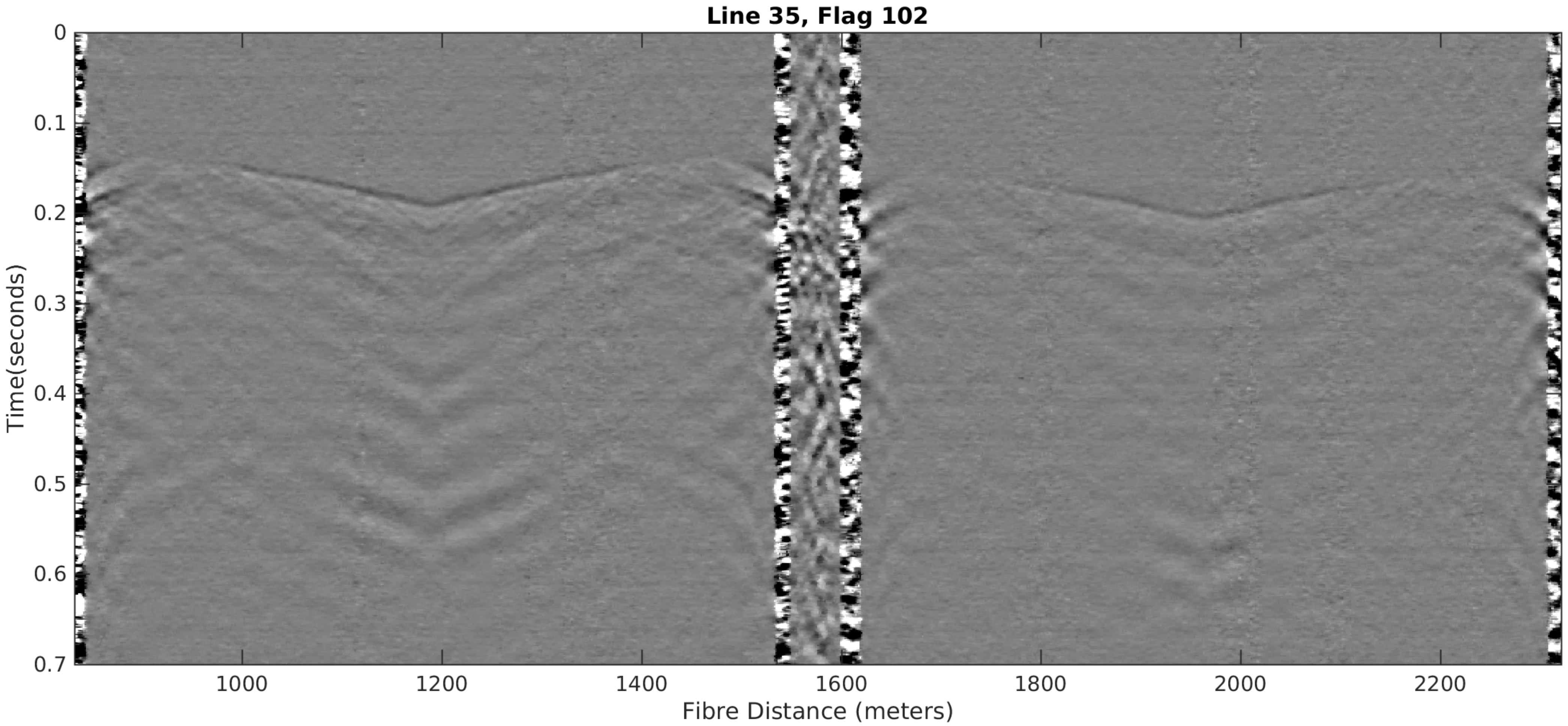


Figure 5: The straight-fibre from well 2 to the straight-fibre in well 1 acquired when the vibroseis truck was at source location 102.

Examples

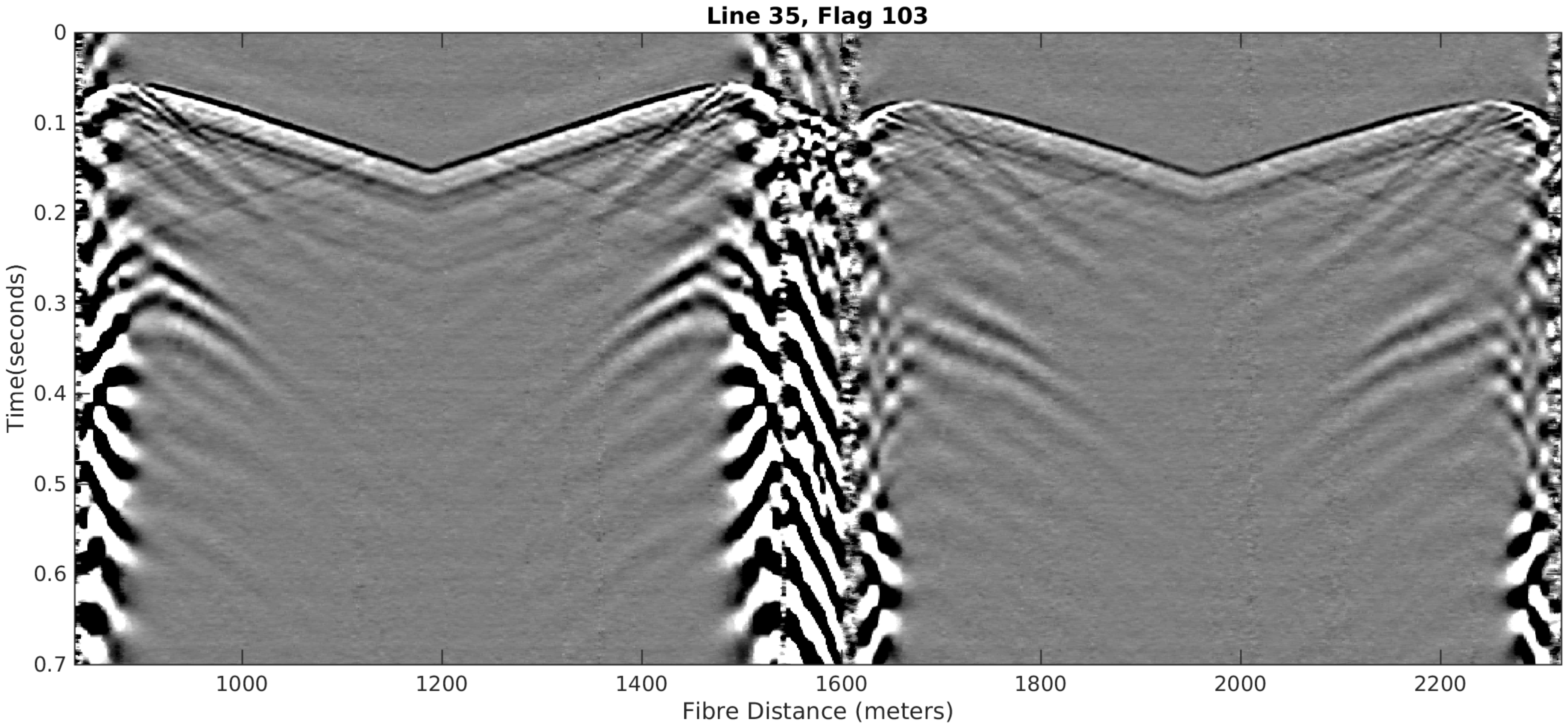


Figure 6: The straight-fibre from well 2 to the straight-fibre in well 1 acquired when the vibroseis truck was at source location 103.

Examples

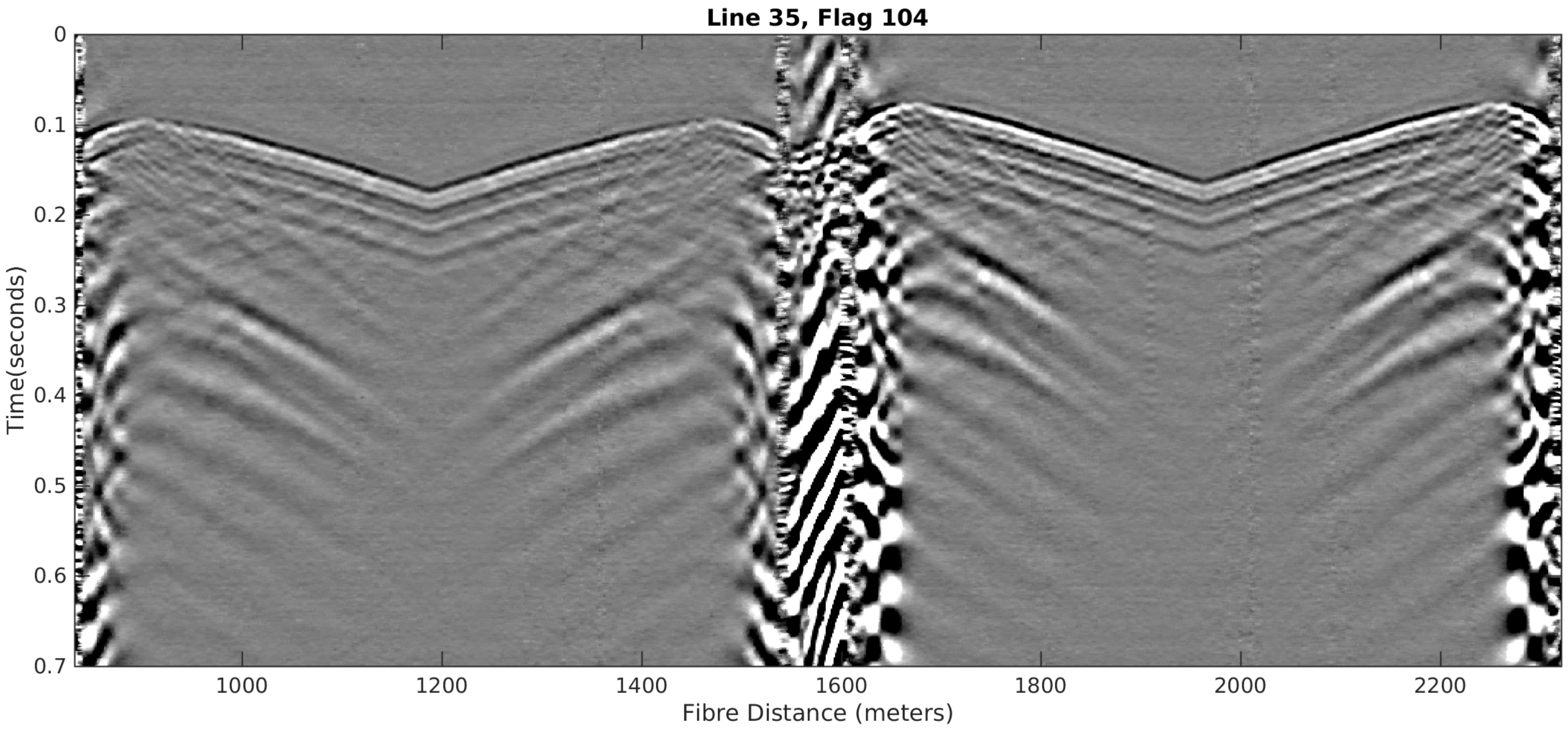


Figure 7: The straight-fibre from well 2 to the straight-fibre in well 1 acquired when the vibroseis truck was at source location 104.

Examples

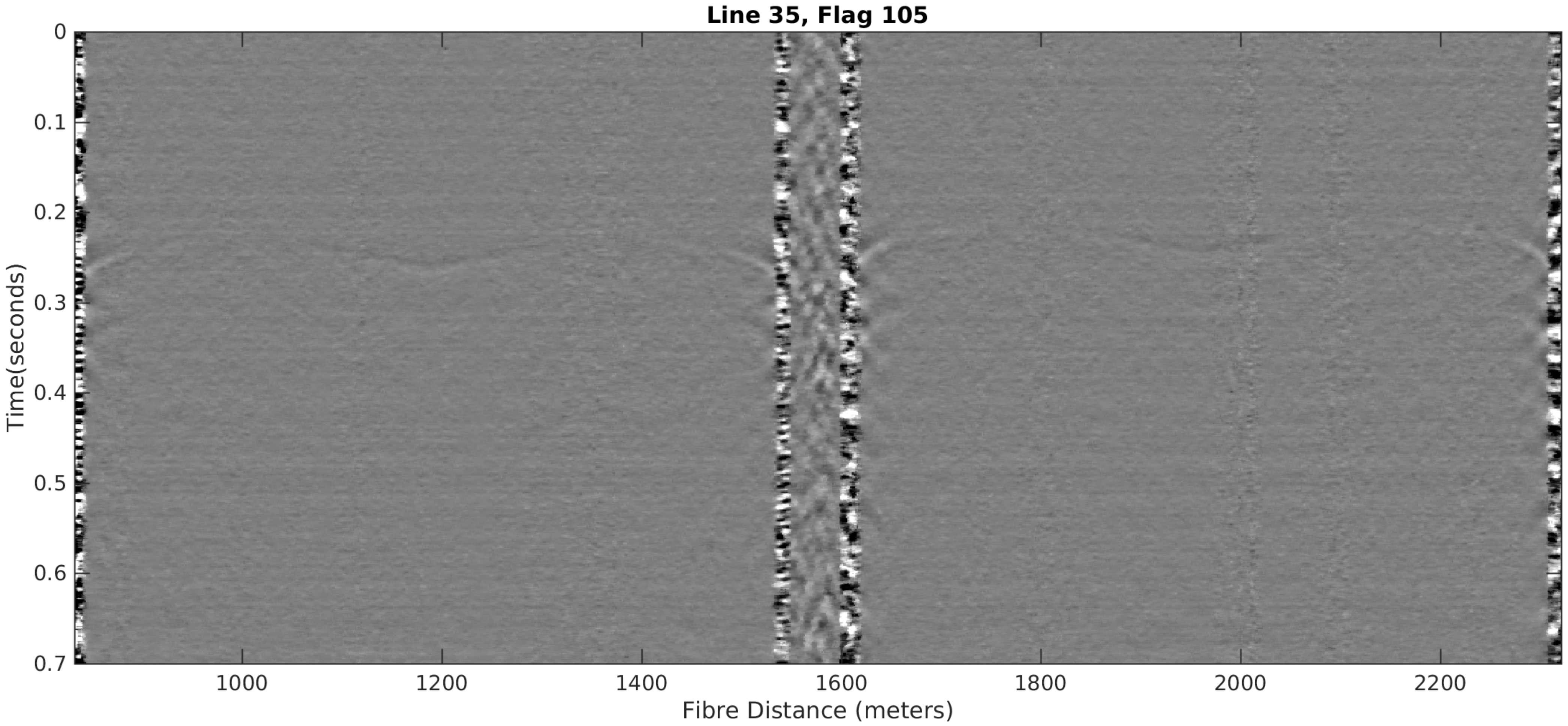


Figure 8: The straight-fibre from well 2 to the straight-fibre in well 1 acquired when the vibroseis truck was at source location 105.

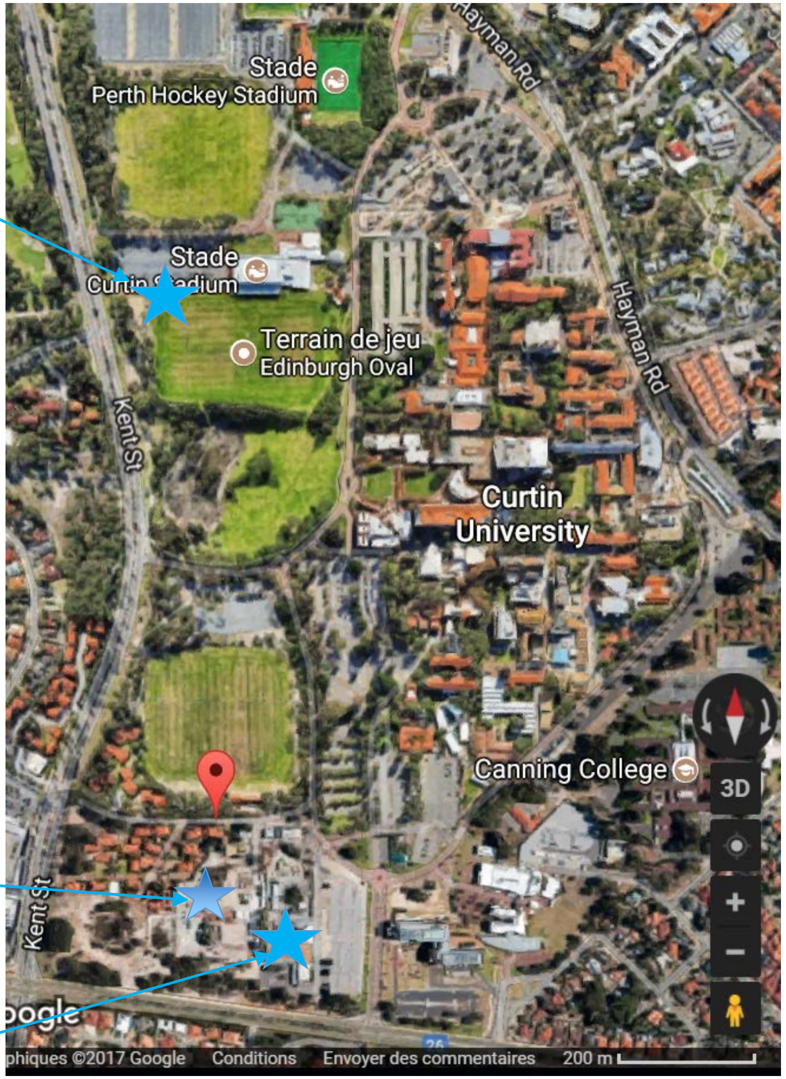
Source

- Inova UniVIB 26 000 lbs. 30% PF near offset; 70% PF far offset
- Sweep freq range: 8-150 Hz
  Length: 24s; Listening time: 4s;
  Front Taper: 500ms; End Taper: 500ms
- Near offset – 70 m, far offset -700 m

Far Offset Source Position

Well Location

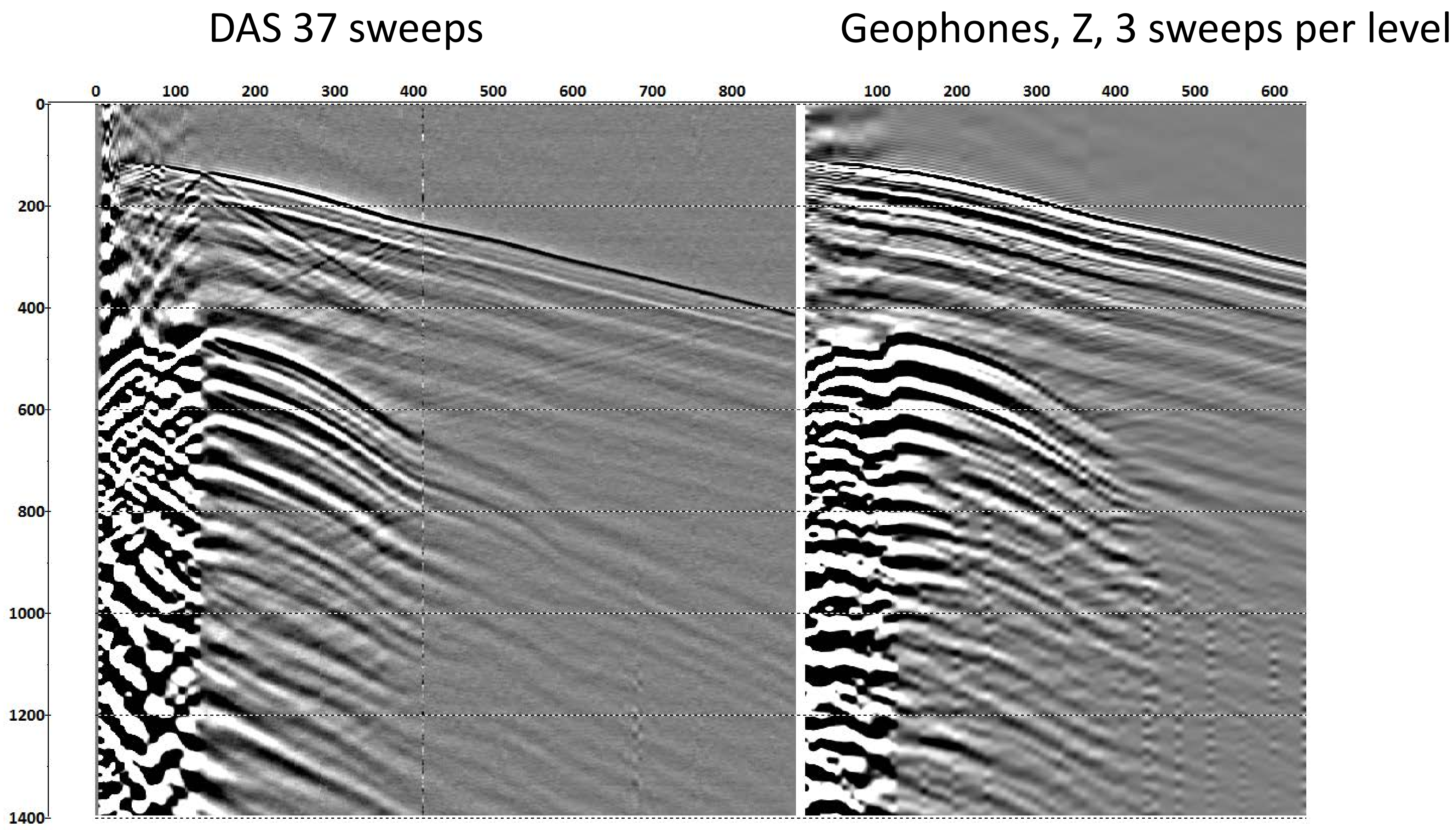
Near Offset Source Position



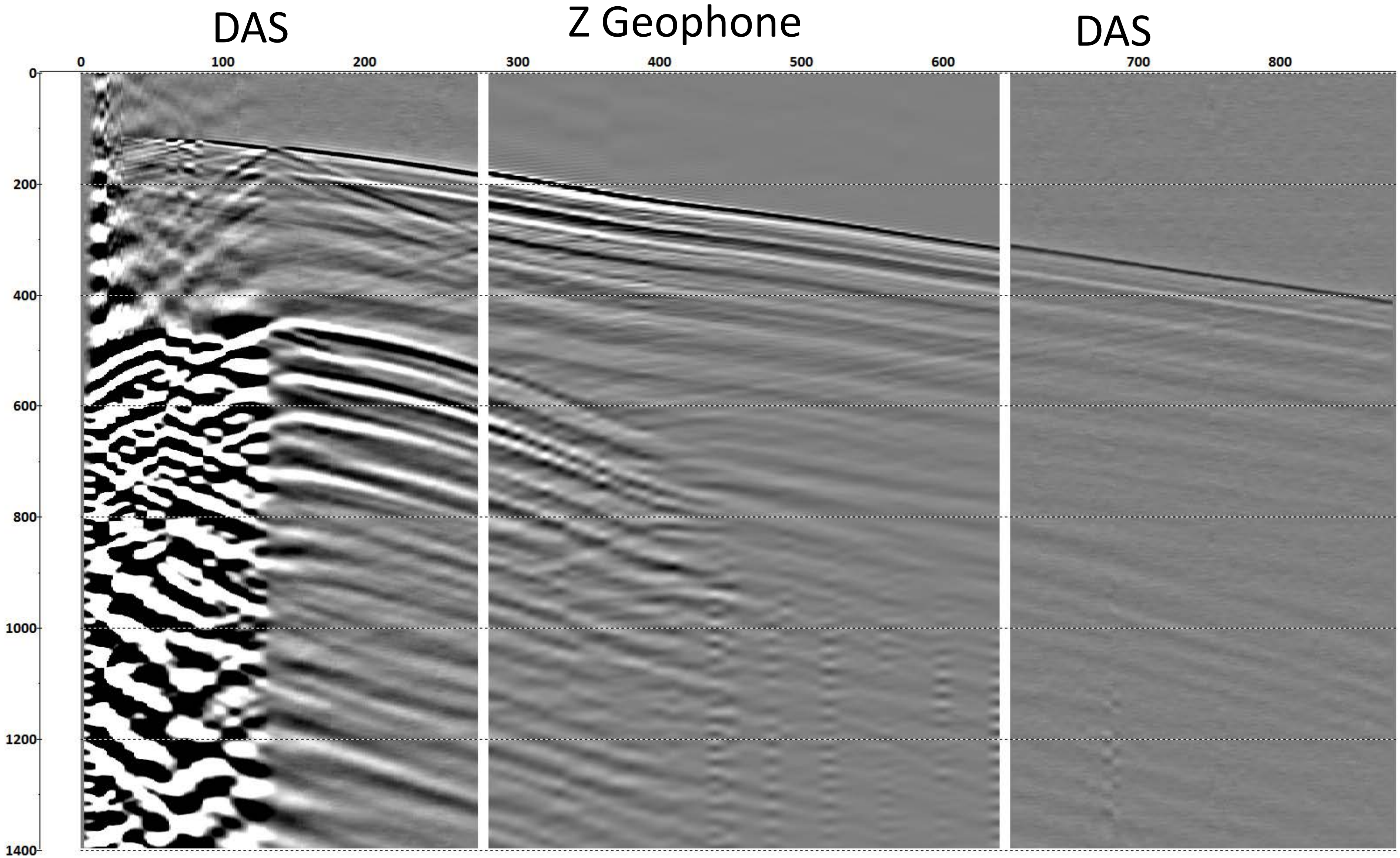
Ruggedized FO Cable inside wellbore

- ITU-G652D
- WW FIBRE-OPTIC CABLE 12FIBRE SINGLE-MODE PE/NY/PE ITU-G652D 2012 SM12CSMOFNY
- 740 metres deep

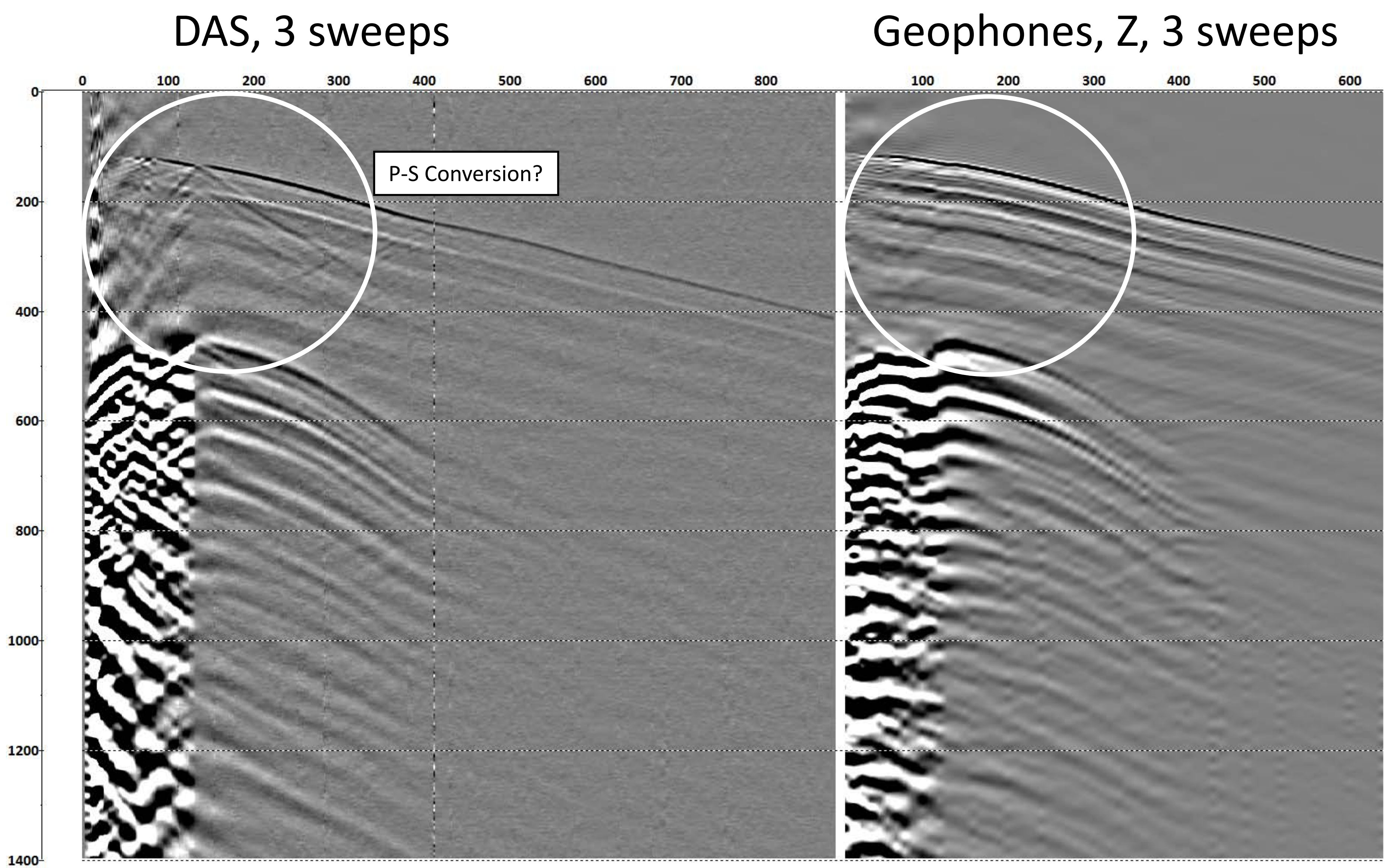
Zero Offset VSP



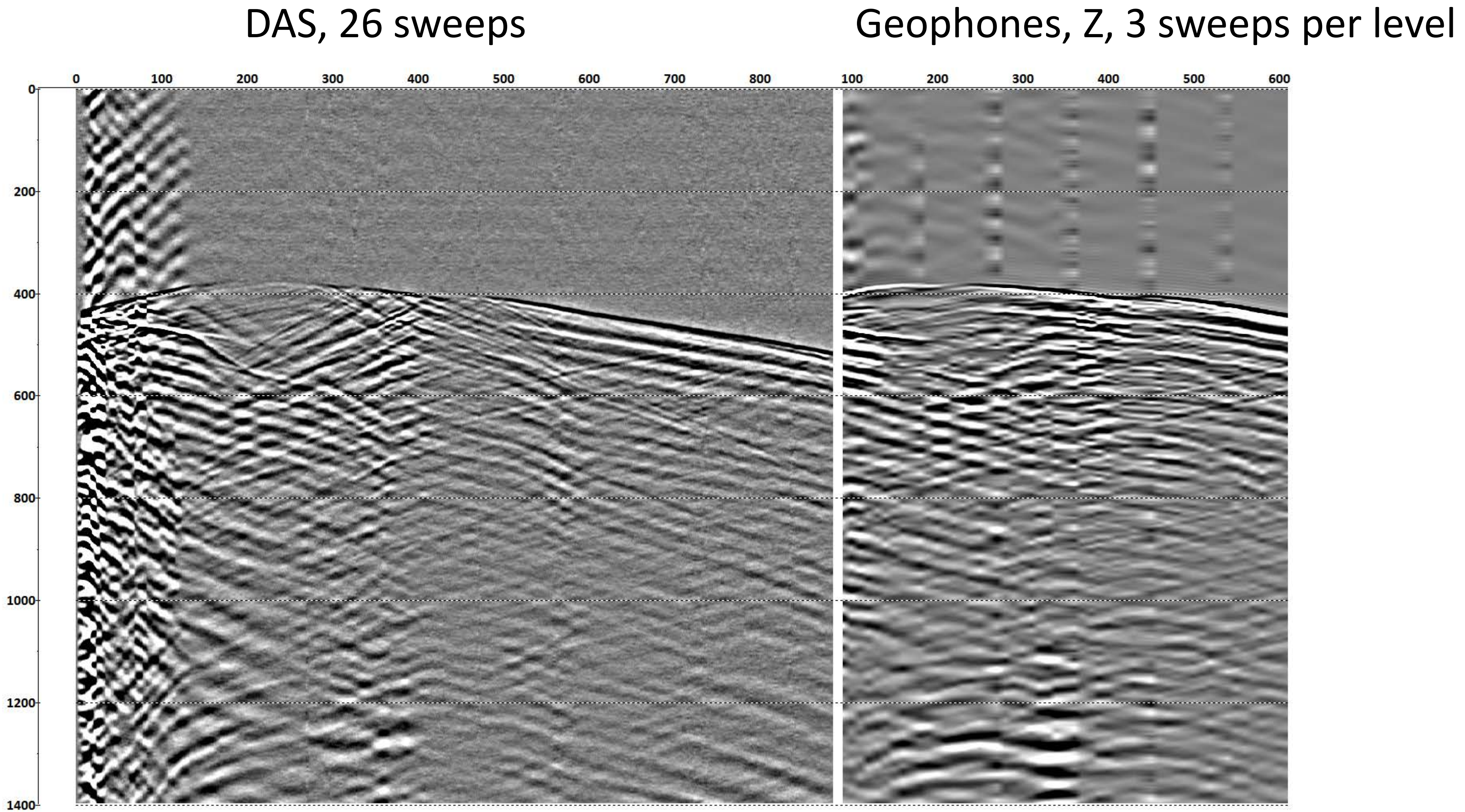
Zero Offset VSP



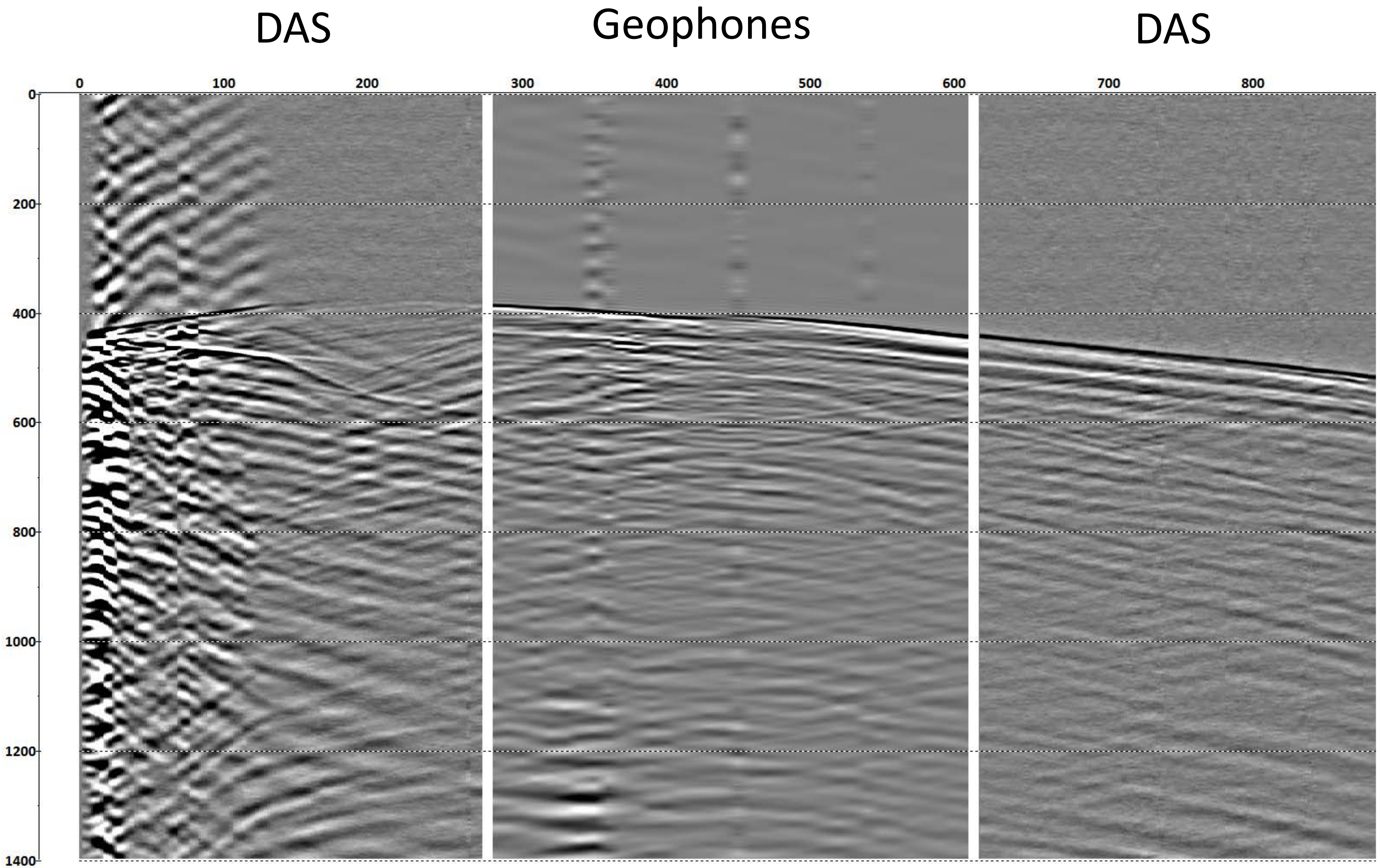
Zero Offset VSP



Far (~700m) Offset VSP



Far (~700m) Offset VSP



Conclusions

- We explained the process of acquiring DAS data using fibre-optics.
- We showed that it can be used to acquire seismic data.
- We then considered the data acquired from the CaMI site in Newell County, AB.
- The source location 103 provided the best results for the data from CaMI.
- We considered zero-offset and far-offset VSP data from a borehole in Australia.

Acknowledgements

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Thank you for listening! Any questions?

NSERC CRSNG
CMC Containment & Monitoring Institute
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
Department of Geoscience

Examples

- Acquired from a borehole located at a site in the southern United States
- The fibre-optic cable was cemented outside the casing between borehole and the formation

Examples

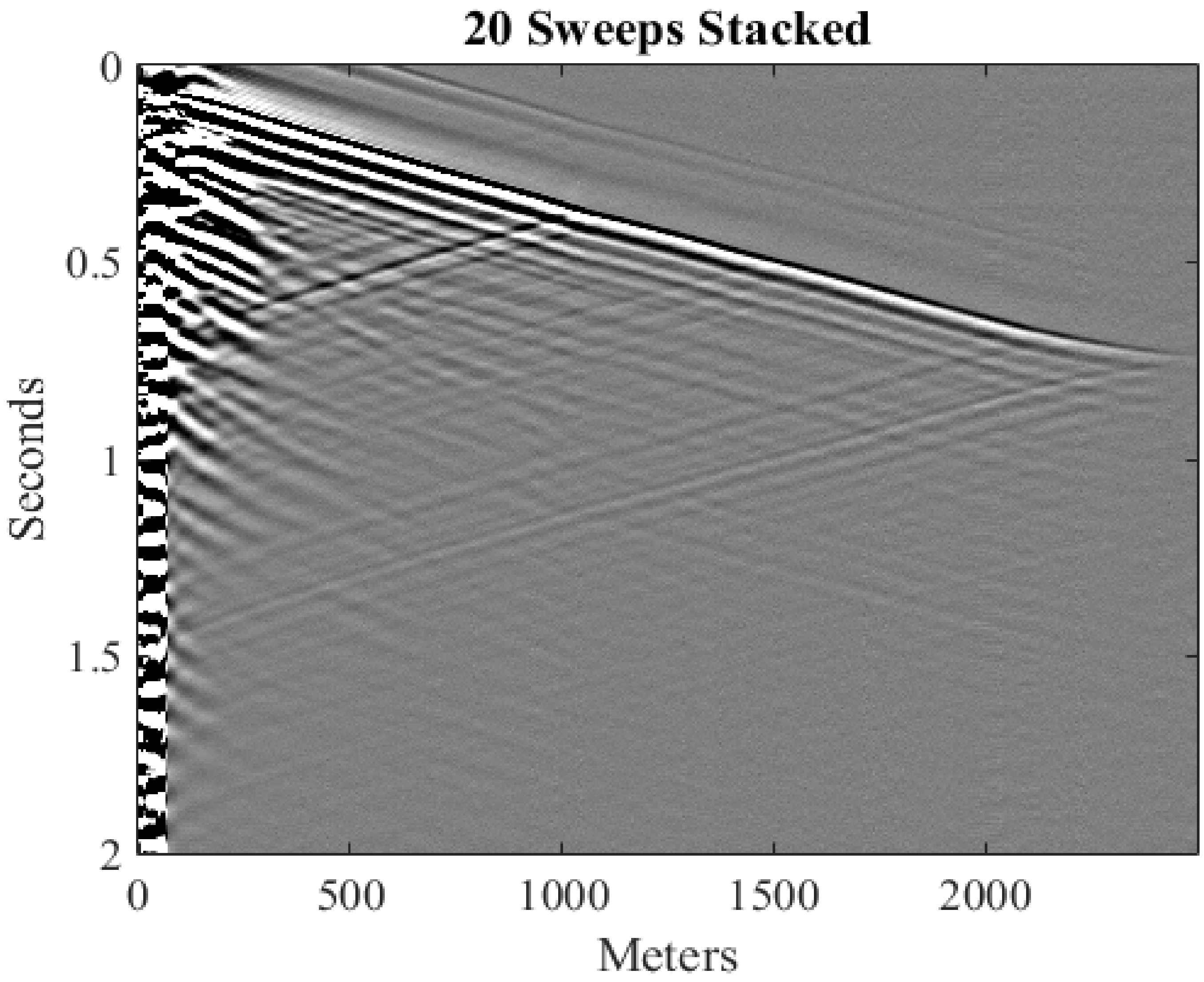

Figure 9: The stacked zero-offset VSP data set.

Examples

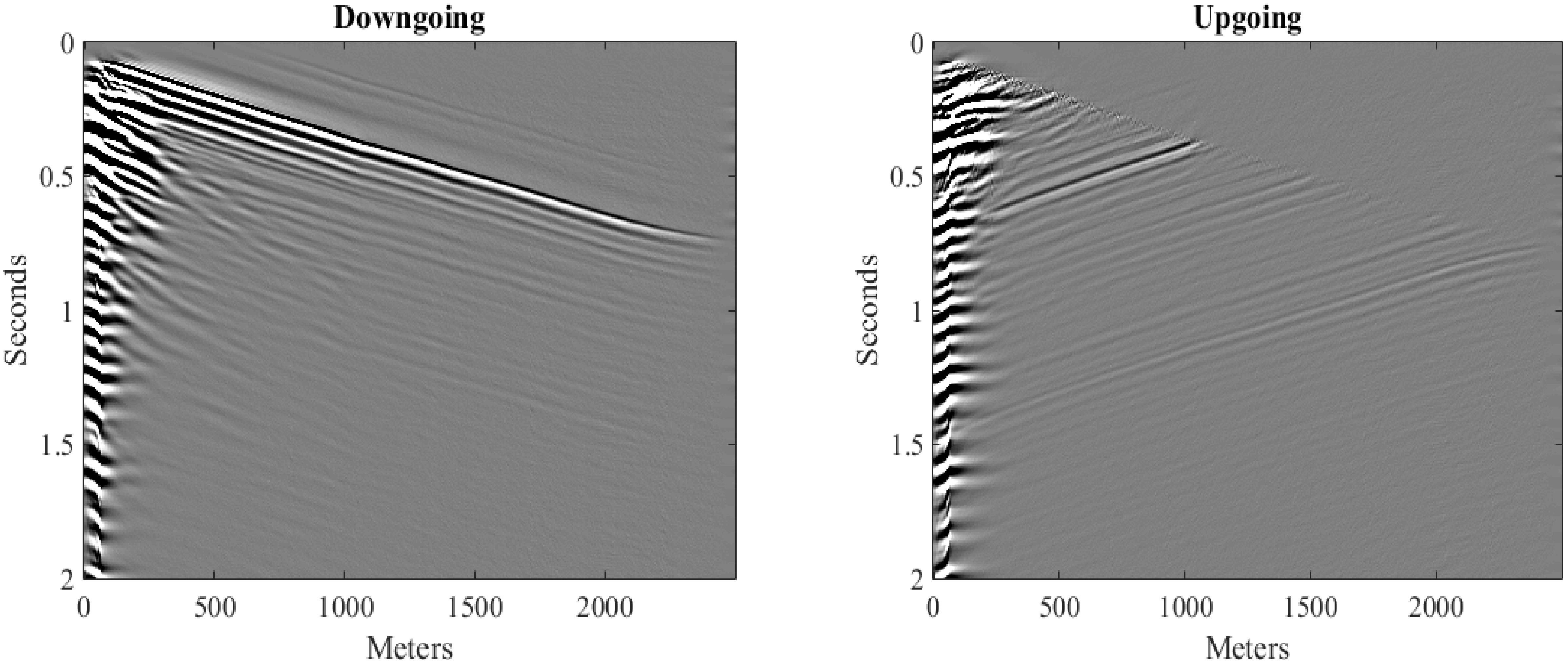

Figure 10: The downgoing (left) and upgoing (right) wavefields for the zero-offset VSP seen in Figure 9.

Examples

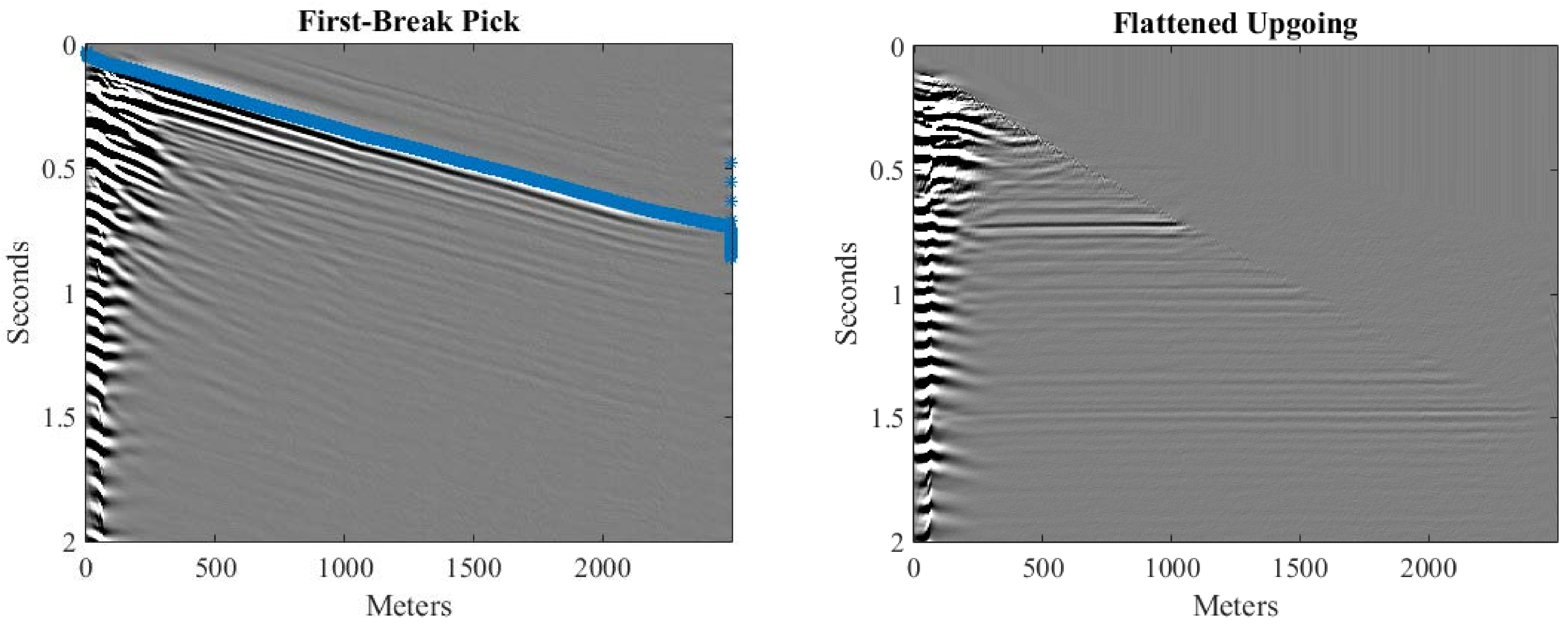

Figure 11: The first-break is highlighted in blue.

Examples

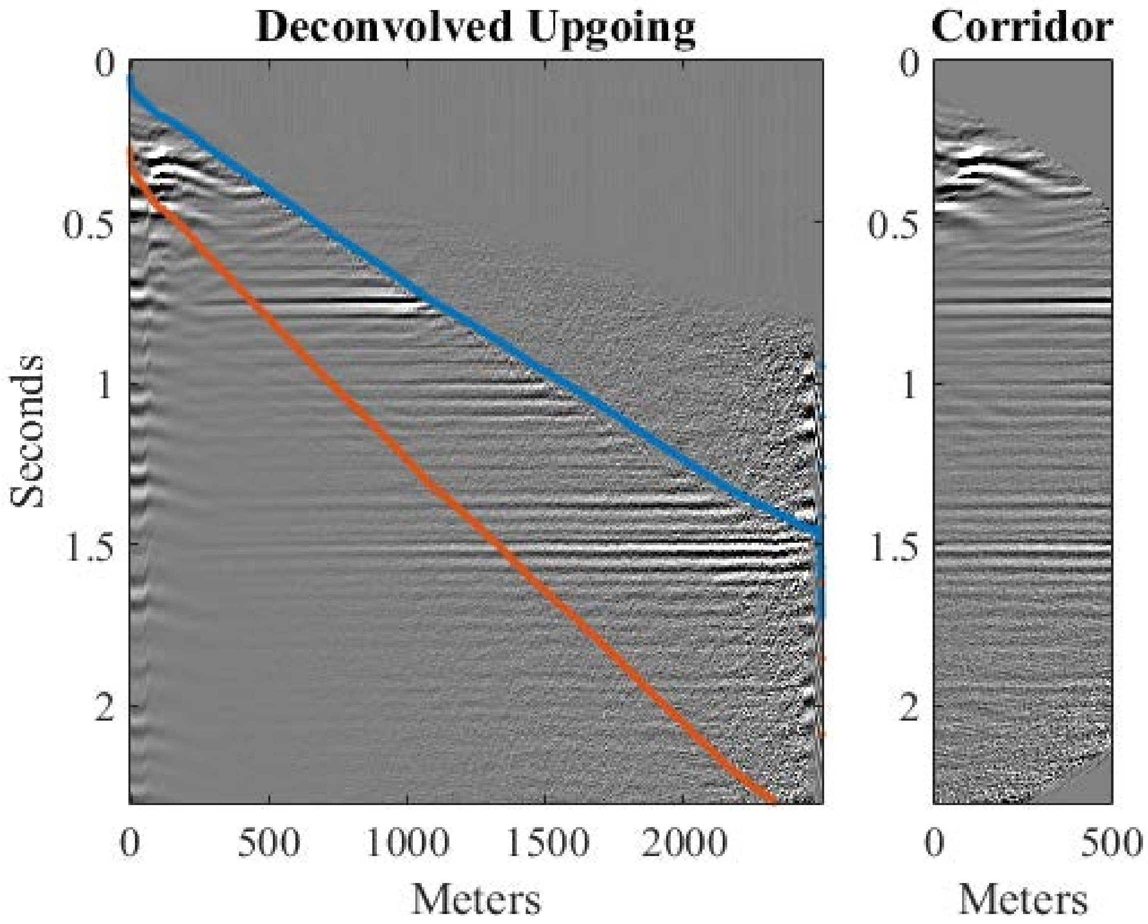

Figure 12: The deconvolved upgoing wavefield (left) and the outside corridor (right). The top (blue) line denotes the first break times and the red line depicts the end-times of the corridor. This outlines the outside corridor on the deconvolved upgoing wavefield.