Sensitivity Kernels for Receiver Functions – Deep Borehole Data in the Groningen Gas Field

J.H.E. de Jong*, H. Paulssen & J.A. Trampert

1. Receiver Functions in a Groningen Borehole

The receiver function technique (Vinnik 1977, Langston 1979) was developed to analyse seismic discontinuities near the receiver by highlighting waves that convert at these interfaces. We apply this global method to borehole data from the Stedum well in the Groningen Gas reservoir to investigate whether receiver functions are sensitive to interfaces in the overburden. Figure 1 shows synthetic borehole receiver functions in Groningen.

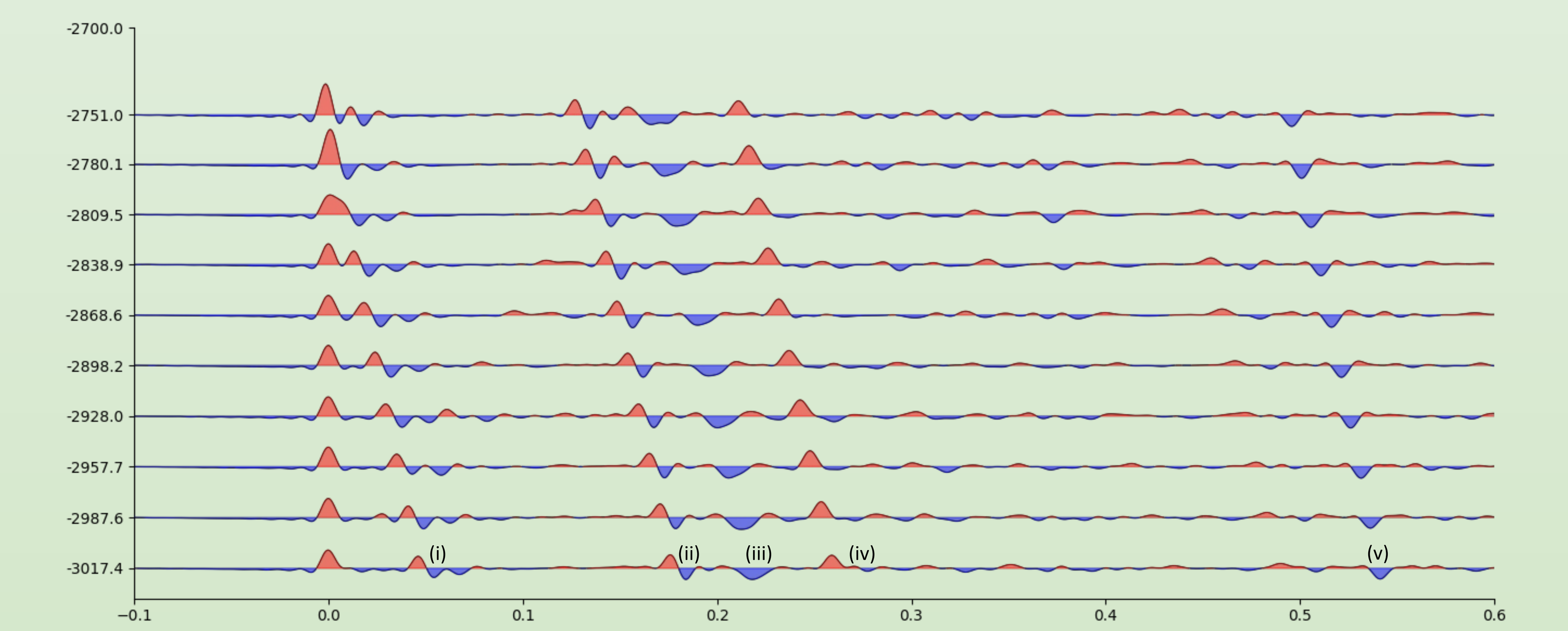

Figure 1: Synthetic receiver functions for 10 Stedum - borehole geophones. Five arrivals are clearly observed in the synthetic receiver functions.

2. Sensitivity of Borehole Receiver functions

To assess a receiver function's ability to observe the shifts in discontinuities in a regional setting such as the Groningen gas-field, we calculate their sensitivity to the model parameters using a Full Waveform Inversion technique, the adjoint method (Tarantola 1984, Tromp et al. 2005). We apply this first to a purely synthetic test case, where in our objective model all layers above reservoir are shifted downwards by 50cm. The senstivity kernels are shown in figure 2.

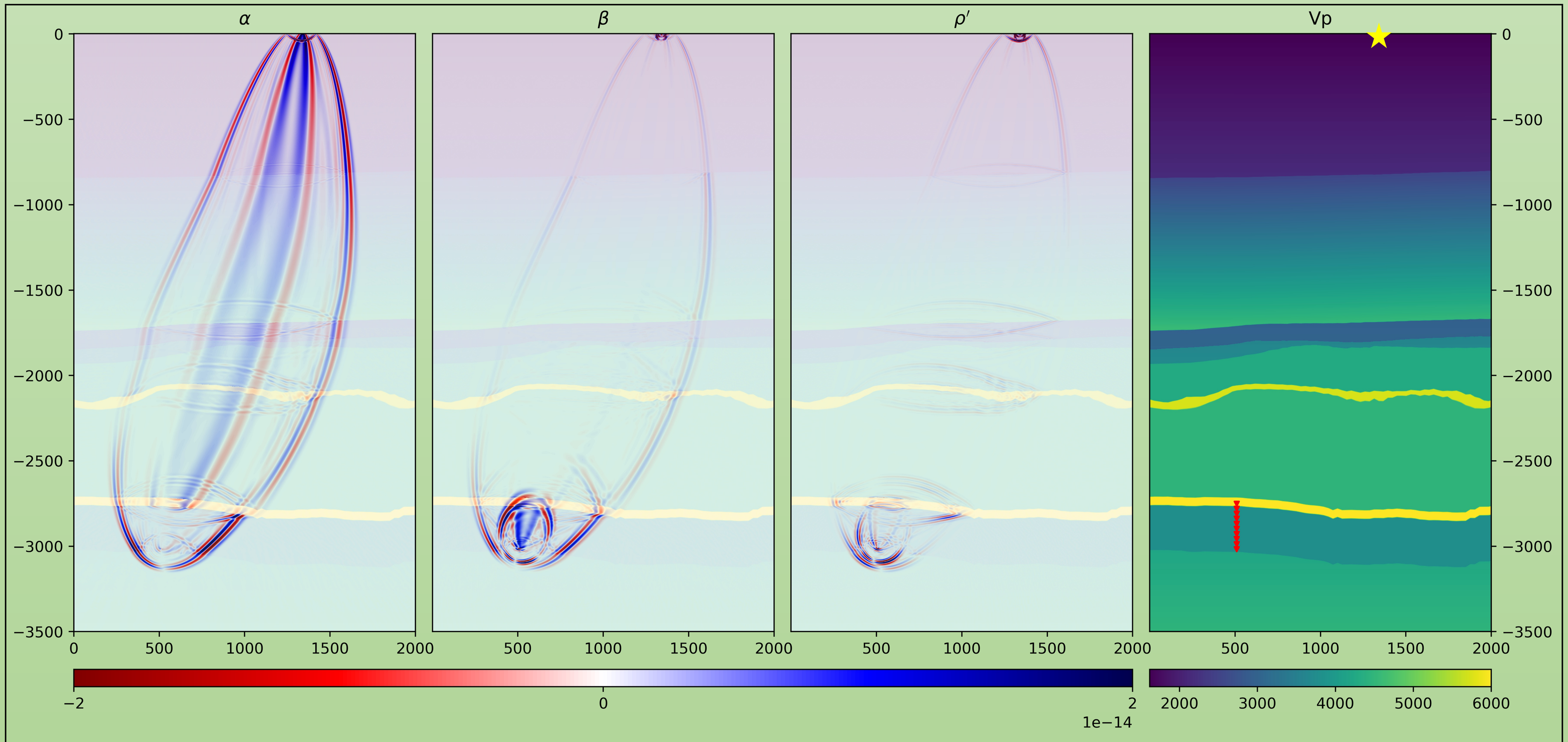

Figure 2: Sensitivity to Vp (α), Vs (β), and impedance (ρ'), of the first arrival on the bottom geophone for a purely synthetic case, with the Vp-model (right). Geophones (red triangles), source (yellow star).

3. Synthetic Observations

The most important observations in figure 2 are: (i) Strong sensitivity to converted S-wave in the β-kernel, (ii) Sensitivity to reflected phases in the impedance (ρ')-kernel, (iii) Sensitivity to P-wave in the α-kernel.

4. Real Borehole Receiver Functions

We compare the synthetic receiver functions of figure 1 to borehole receiver function calculated from a test shot recording (figure 3). We observe a strong similarity between the synthetic and real data, especially for the first arrival. Later arrivals show less similarity, although some clearly do correspond to arrivals seen in the synthetic receiver functions.

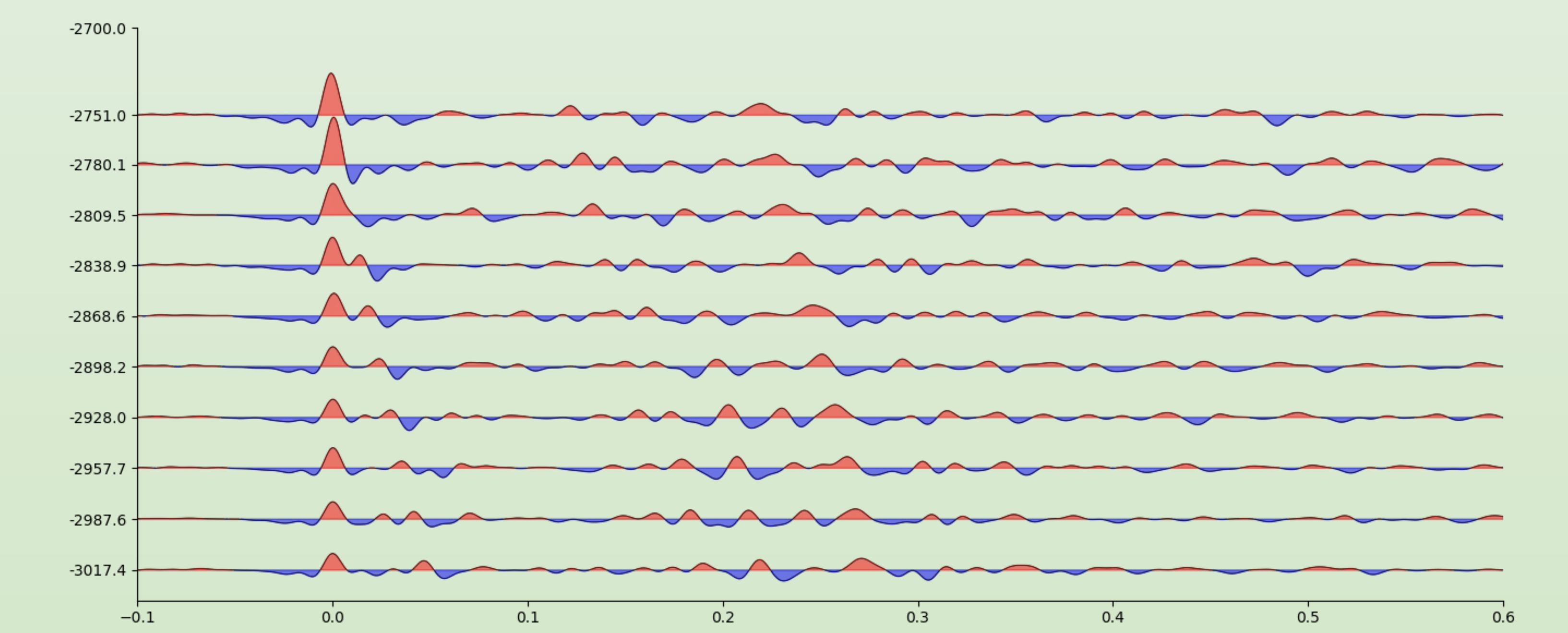

Figure 3: Real receiver functions for 10 Stedum - borehole geophones. Most arrivals seen in fig. 1 can be indentified here as well.

5. Real Senstivity Kernels and Observations

We also calculated sensitivity kernels of real receiver functions, shown in figure 4. We note similar sensitivity as in the kernels of figure 2. The first arrival sensitivity shown in figures 2 and 4 indicates that receiver functions are sensitive to the phase-conversion at the cap rock.

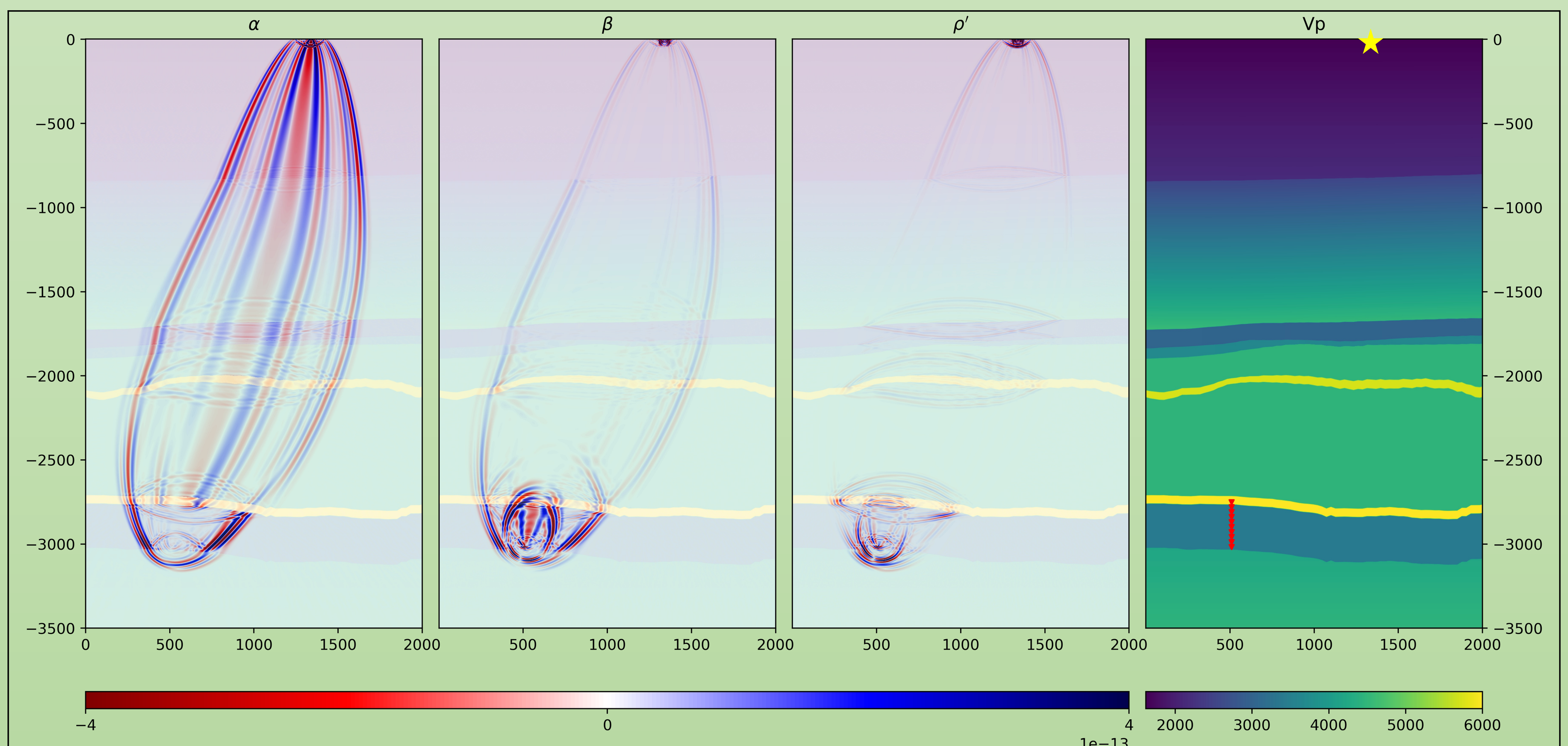

Figure 4: Sensitivity to Vp (α), Vs (β), and impedance (ρ'), for real data of the first arrival on the bottom geophone in a 2D-reference model.

6. Conclusions

Our results show that borehole receiver functions highlight the phases converted at the discontinuities of the overburden. The kernels indicate that the borehole receiver functions recorded in the Stedum well are sensitive to shifts of overburden discontinuities. Borehole receiver functions might therefore be used to identify arrivals from the interfaces and time-variations in the interface's depth.

References:

Langston, C. A. Structure under Mount Rainier, Washington, inferred from teleseismic body waves. J. geophys. Res. Solid Earth, 120:537–543, 1979.

Tarantola, A. Inversion of seismic reflection data in the acoustic approximation. Geophysics, 49(8):1259–1266, 1984a.

Tromp, J., C. Tape, and Q. Liu. Seismic tomography, adjoint methods, time reversal and banana-doughnut kernels. Geophys. J. Int., 160:195–216, 2005.

L. Vinnik. Detection of waves converted from P to SV in the mantle. Phys. Earth Planet. Inter., 15:39–45, 1977.

*j.h.e.dejong@uu.nl