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P wave travel time variations in Groningen gas field caused by reservoir compaction

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Introduction

The **Groningen gas field in The Netherlands** is one of the largest onshore gas field in the world.

(1) In 2013 two former production wells were equipped with **geophone strings at 3 km depth** to monitor the seismicity in the reservoir.

(2) Using **noise interferometry** by cross-correlation, Zhou & Paulssen (2017) accurately retrieved the P and S velocity structure of the reservoir for borehole SDM-1.

(3) In the present study we show that **signals from nearby passing trains** can be used to infer **time-lapse variations in the reservoir.**

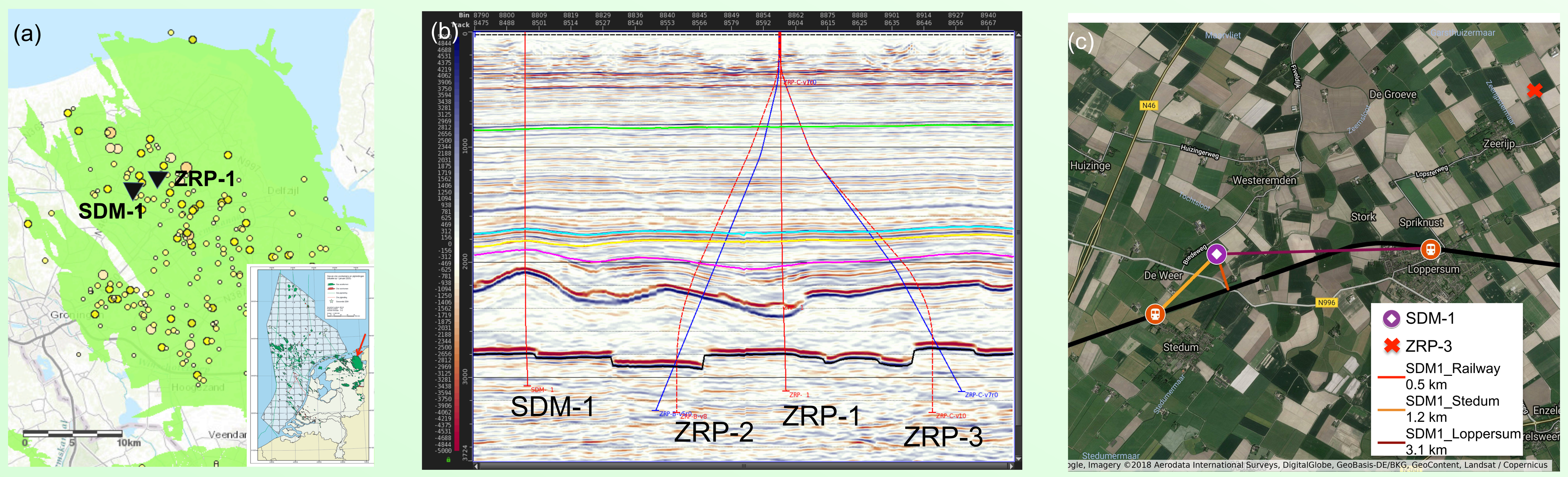

Fig.1. *(a), Location of the Groningen gas field, seismicity and location of borehole SDM-1 and ZRP-1. (b), Cross-section with borehole locations. (c) Location of SDM-1 within surface setting.*

Train noise interferometry by deconvolution

Train signals are identified from noise spectrograms. They are identified every 30 minutes from 5:00 to 20:00 for both directions, and every 1 hour from 20:00 to 1:00. **Deconvolutions** were calculated for 20 seconds of train noise with the highest amplitude. Data were analysed for two separate deployments: 23 Jan - 28 Jun 2015, and 03 Jul - 1 Dec 2015.

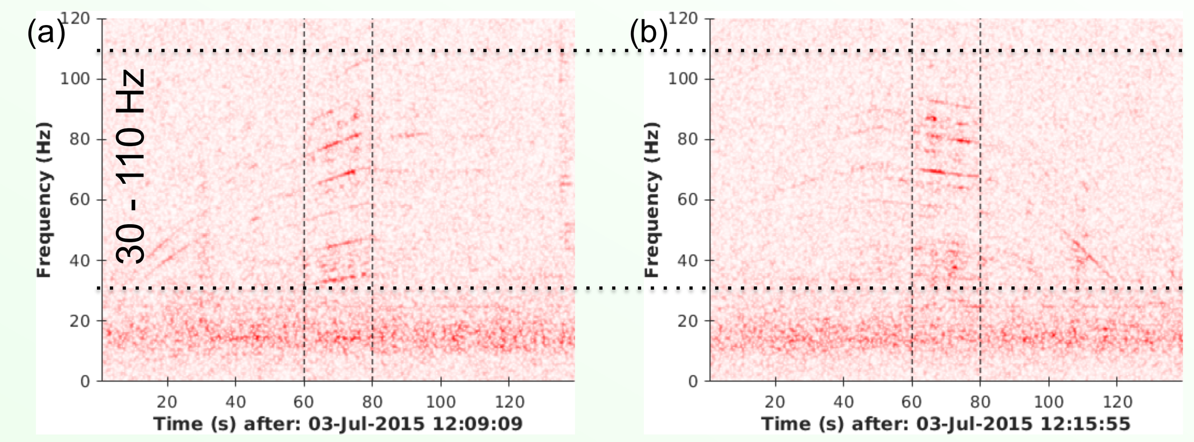

Fig.2. *Vertical component spectrograms from the bottom geophone. (a) Noise from a train leaving Stedum station at 12:09, reaching its highest amplitude 1 minute later. (b) Noise from a train from Loppersum arriving at Stedum station at 12:18, with highest amplitude 1 minute before. Vertical dashed lines indicate the time intervals used for interferometry by deconvolution.*

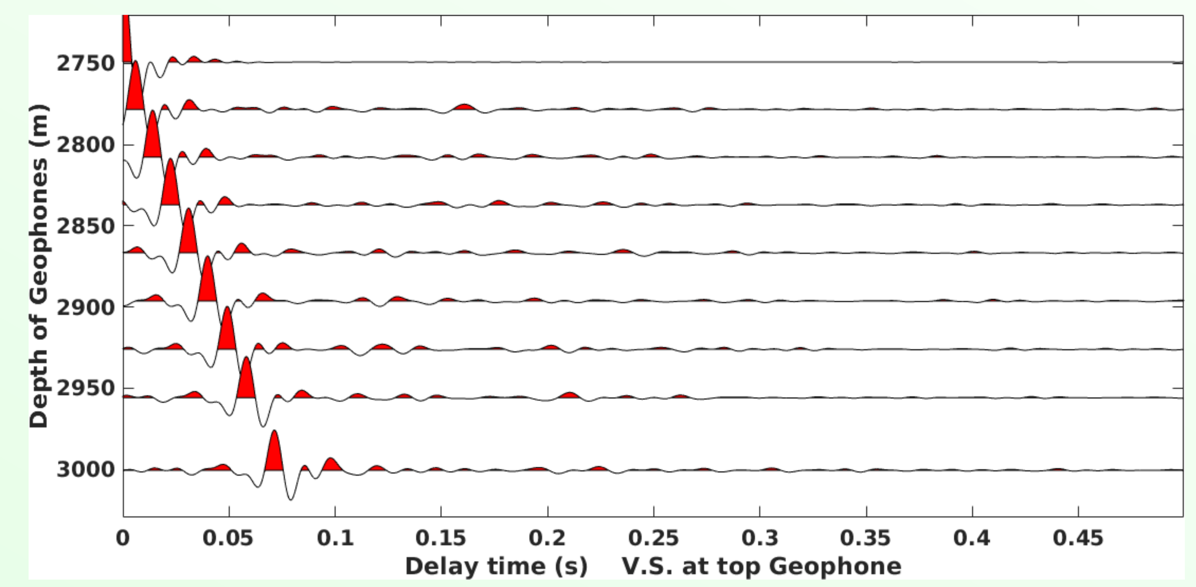

Fig.3. *Vertical component train noise deconvolutions using the signal of the top geophone (stacked over Jul to Dec 2015).*

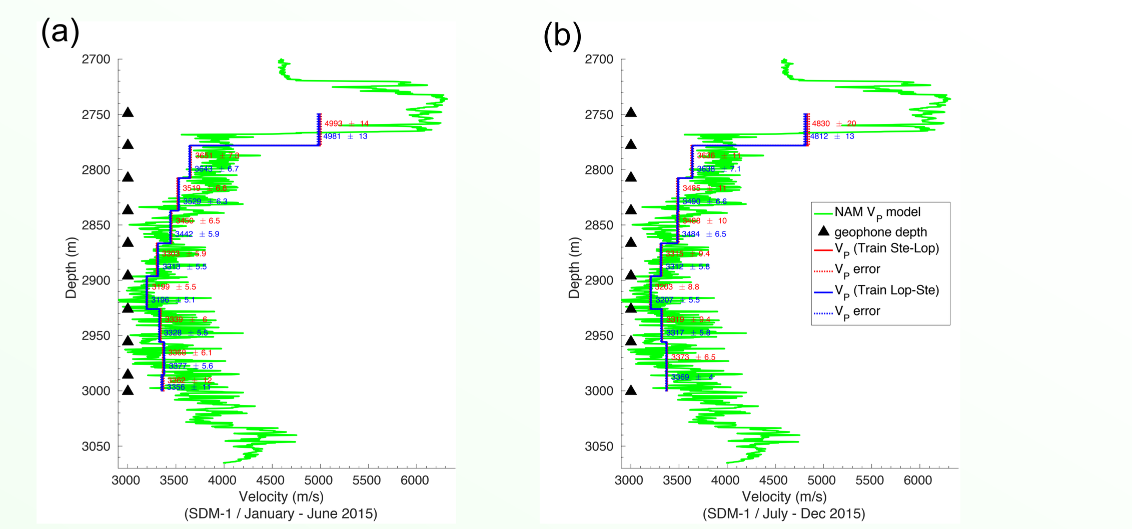

Fig.4. *P velocity profile inferred from the travel times of the deconvolutions: (a) from Jan to Jun 2015, and (b) from Jul to Dec 2015. The profiles are slightly different because the geophones were not perfectly repositioned at their original locations. P velocity profile from well-log data is shown in green. (Note that geophone 9 did not work during the second deployment.)*

P wave travel time changes

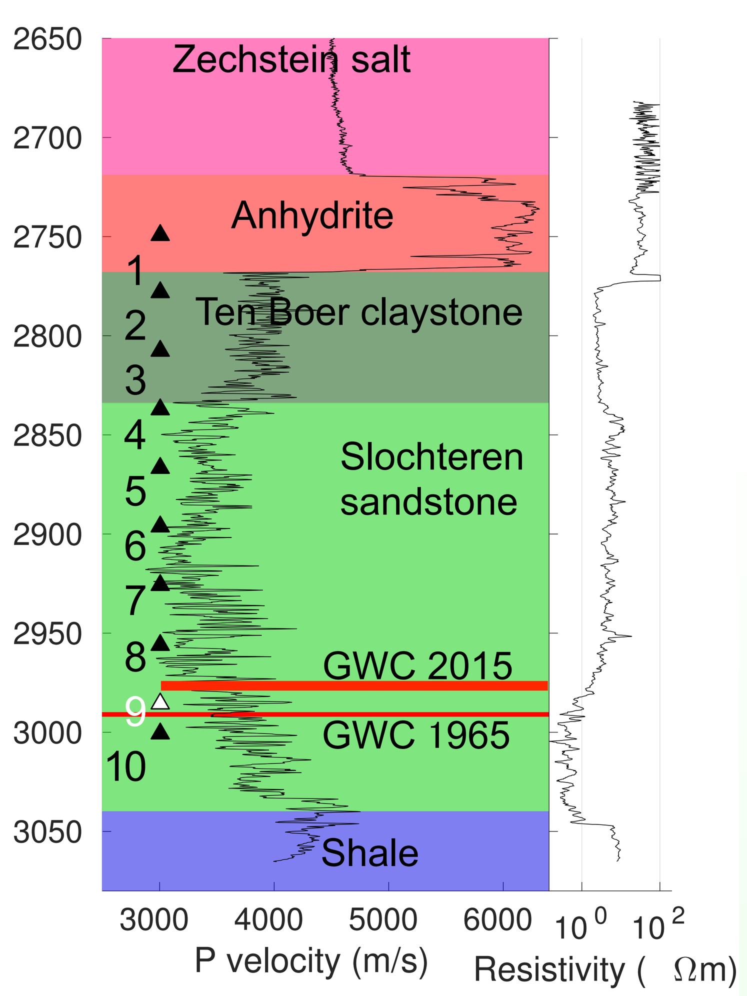

Fig.5. *Geophone locations, lithology and well-log data of SDM-1. The gas-water contact (GWC) from 1965 is indicated by the red line. The current GWC is ~12 m higher as measured from nearby well ZRP-3.*

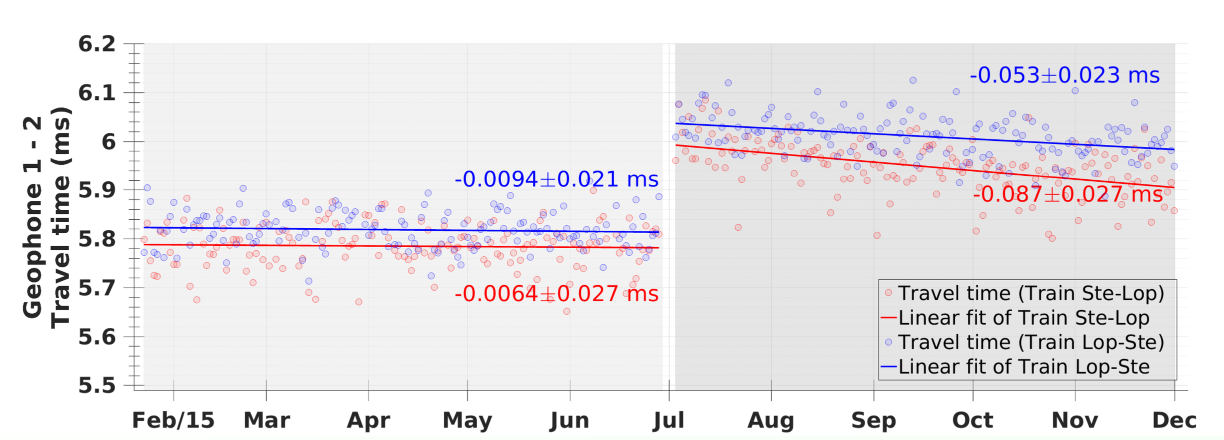

Fig.6. *Travel times from Geophone 1 in the anhydrite layer to Geophone 2 in the claystone. Red dots show the travel times from daily stacks for trains from Stedum to Loppersum, blue dots for trains in the other direction. Period 1 (Jan-Jun) shows a negligible travel time decrease, period 2 (Jul-Dec) a travel time decrease of ~1%. The shift in travel time between period 1 and 2 is caused by a difference in the geophone locations.*

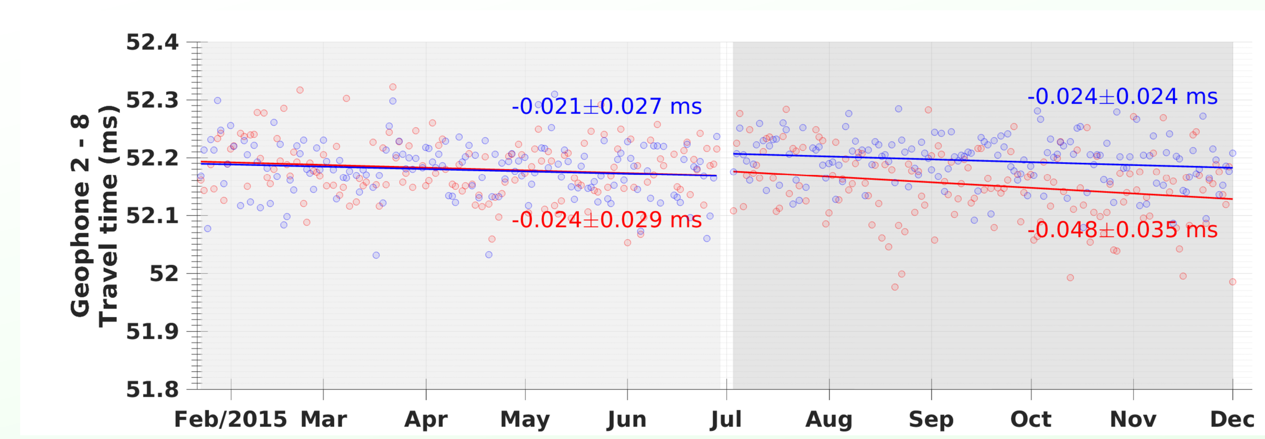

Fig.7. *Travel times (from daily stacks) between Geophone 2 in the claystone to Geophone 8 in the sandstone above the GWC. Linear fits to the data show a slight travel time decrease of ~0.022±0.028 ms for period 1. The travel time decrease during period 2 is 0.024±0.024 ms as measured from trains from Stedum to Loppersum (blue) and 0.048±0.035 ms for trains in the opposite direction (red). Although just barely significant, these travel time decreases of 0.05% - 0.1% cannot be explained by vertical shortening only, which would give ~0.003% for 7 mm per year. An additional P velocity increase due to compaction (Hatchell & Bourne, 2005) seems needed to explain the data.*

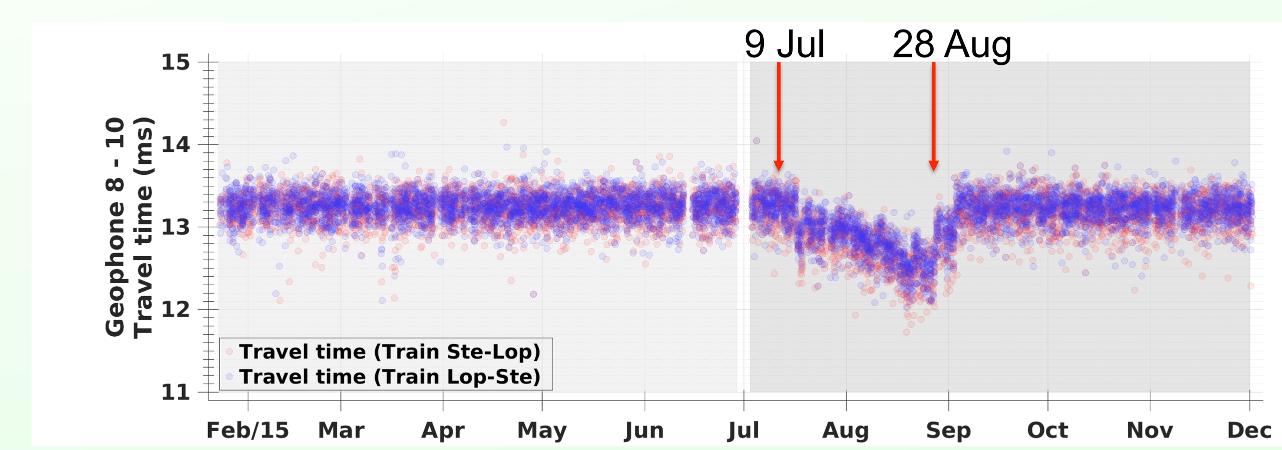

Fig.8. *Individual travel time measurements from Geophone 8 (above GWC) to Geophone 10 (below GWC). Period 1 does not show clear variations, but during period 2, from 17 July to 2 September, there is a strong travel time decrease of up to 0.8 ms (6%). This anomaly seems related to the drilling of borehole ZRP-3A at 5 km distance. Red arrows indicate the starting and ending day of the drilling.*

Conclusions

Train noise interferometry by deconvolution using deep borehole data allows the detection of small time lapse P wave travel time variations with a ~0.03 ms uncertainty over half a year. The travel times appear to consistently decrease with time which is likely due to compaction of the gas reservoir. A large travel time anomaly of up to 6% seems related to the drilling of a borehole at 5 km distance.

References

Hatchell, P. and Bourne, S. (2005). "Rocks under strain: Strain-induced time-lapse time shifts are observed for depleting reservoirs." The Leading Edge, 24(12), 1222-1225

Zhou, W., Paulssen, H. (2017). P and S velocity structure in the Groningen gas reservoir from noise interferometry. Geophysical Research Letters, 44(23)

Acknowledgements

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