**P wave travel time changes in the Groningen reservoir**

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**Introduction**

The Groningen gas field in The Netherlands (Fig. 1) is one of the largest onshore gas fields in the world. Production started in 1963, causing induced seismicity and damage to houses especially in the last two decades, leading to a production decrease and a production stop planned for 2030. It is suggested that the triggering of earthquakes in Groningen is related to reservoir compaction as a result of gas depletion (Bourne et al., 2014). Thus, in situ monitoring of reservoir compaction is essential to assess its impact with seismic activity. Temporal variations of a reservoir can be inferred from 4D reflectivity seismics (e.g., MacBeth et al., 2019). Here we show that it is also possible to measure travel time variations with downhole passive data using noise interferometry. In 2013, two former production wells (SDM-1 & ZRP-1; Fig. 1.3) were equipped with geophone strings at 3 km depth to monitor the seismicity in the reservoir. Using ambient noise interferometry by cross-correlation for borehole SDM-1, Zhou & Paulssen (2017) showed that the P and S velocity structure of the reservoir could be accurately retrieved. Now we find that deconvolution of isolated train signals gives very accurate travel time measurements that can be used to monitor temporal variations in the reservoir.

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**Noise interferometry**

![Fig. 3. (a) Seismic section with monitoring wells. (b) Lithology of borehole SDM-1 and geophone locations (black triangles, geophone 9 was out of order).](image)

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**P wave travel time changes**

Data were analysed for two separate deployments in 2015: 23 Jan - 28 June, and 03 Jul - 1 Dec. Although barely significant, the travel time along the reservoir (from geophone 2 to 8) decreased 0.05 - 0.07 ms over 10 months (Fig. 8). This cannot be explained by vertical shortening only. A velocity increase with a fractional change in velocity $V$ of 25 is required for a travel time decrease of 0.05 ms and 7 mm of vertical shortening ($\nabla v = -R e^{0.25}$, Hatchell & Bourne, 2005).

Travel times from geophone 1 to 2, across the Anhydrite-ten Boer claystone interface, show no change in the first half year, but a decrease of ~1% in the second half year of 2015 (Fig. 9). The cause of this travel time decrease is still unclear, and can only partly be explained by downward movement of the interface. Note that the pattern over 2015 resembles that of surface subsidence (Fig. 7). (The geophones were not exactly placed back at their original locations, causing the shift in travel time between geophone 1 and 2 for the two deployments.)

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**Conclusions**

This study shows that it is possible to measure temporal travel time variations in a borehole from noise interferometry using repetitive noise sources such as train signals. The estimated travel time decrease along the reservoir requires a medium velocity increase associated with compaction. The drilling of another deep well at 5 km distance has affected the travel times to the bottom geophone below the gas-water contact. The Z drilling report mentions “downhole losses” at the Ten Boer claystone on 18/07, and drilling stopped on 28/08.

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**References**


