Subsidence above the Groningen gas field: using InSAR to detect potential aseismic fault slip

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Introduction

This study is part of the DeepNL-Subsidence project, a collaboration between TU Delft and Utrecht University. Its aim is to determine the subsurface drivers of subsidence in the Groningen gas field area, by assimilating geodetic time series (like InSAR satellite data, **Figure 1**) into geophysical models. In order to build an efficient model of the reservoir and overburden, we model only those features that produce detectable surface signals. Thus, we investigate:

- What reservoir fault slip occurs in the Groningen field?
- Does this fault slip produce surface signals that are detectable in the geodetic time series?

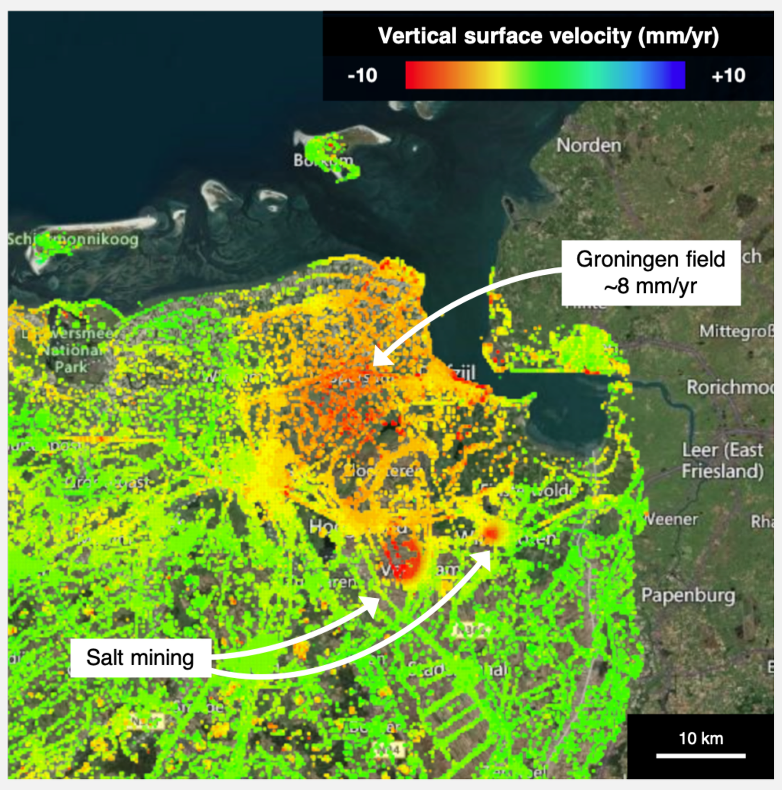

Figure 1: **PS-InSAR derived subsidence rates above the NE of the Netherlands (after bodemdalingkaart.nl).**

Co-seismic slip (earthquakes)

Data collection by the InSAR satellite occurs every six days at best. As a result, InSAR is completely insensitive to the seismic waves. However, the fault slip occurring during an earthquake (co-seismic slip) also leads to permanent deformation of the subsurface. At the surface this deformation is expressed by a region of subsidence and a region of uplift (see **Figure 2**).

We have applied estimated slip parameters (Dost & Kraaijpoel, 2013) of the largest earthquake to date, the 2012 M_W 3.6 Huizinge earthquake, to the Okada (1992) model. This results in a surface signal with an amplitude of 0.3-0.6 mm and a spatial wavelength of 5-10 km (**Figure 2**).

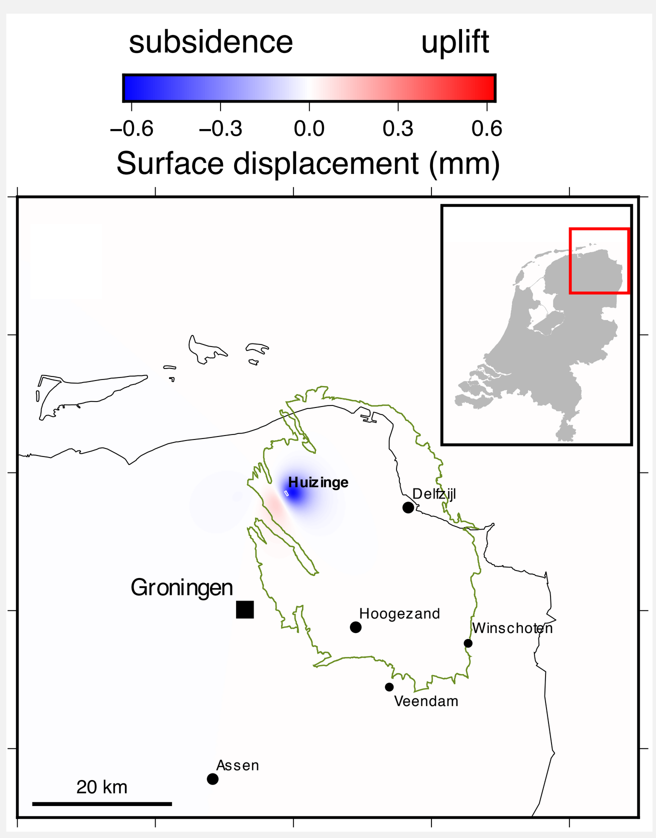

Figure 2: **Modelled surface subsidence resulting from the 2012 M_W 3.6 Huizinge earthquake.**

The small amplitude and large wavelength of the signal leads to very small spatial gradients. This, combined with the signal being instantaneous and uncertainties in the InSAR time series (e.g. atmospheric noise and shallow soil deformation), makes it very unlikely that co-seismic signals are detectable, even for the largest earthquake.

Aseismic slip

Fault slip can also occur without producing earthquakes, when faults slip aseismically. The three main drivers for slip on a fault in a depleting reservoir are summarised in **Figure 3**. Reservoir fault slip can be induced either by differential compaction, or, in the case of a non-vertical fault, by the horizontal tensional effective stresses arising from the reservoir depletion.

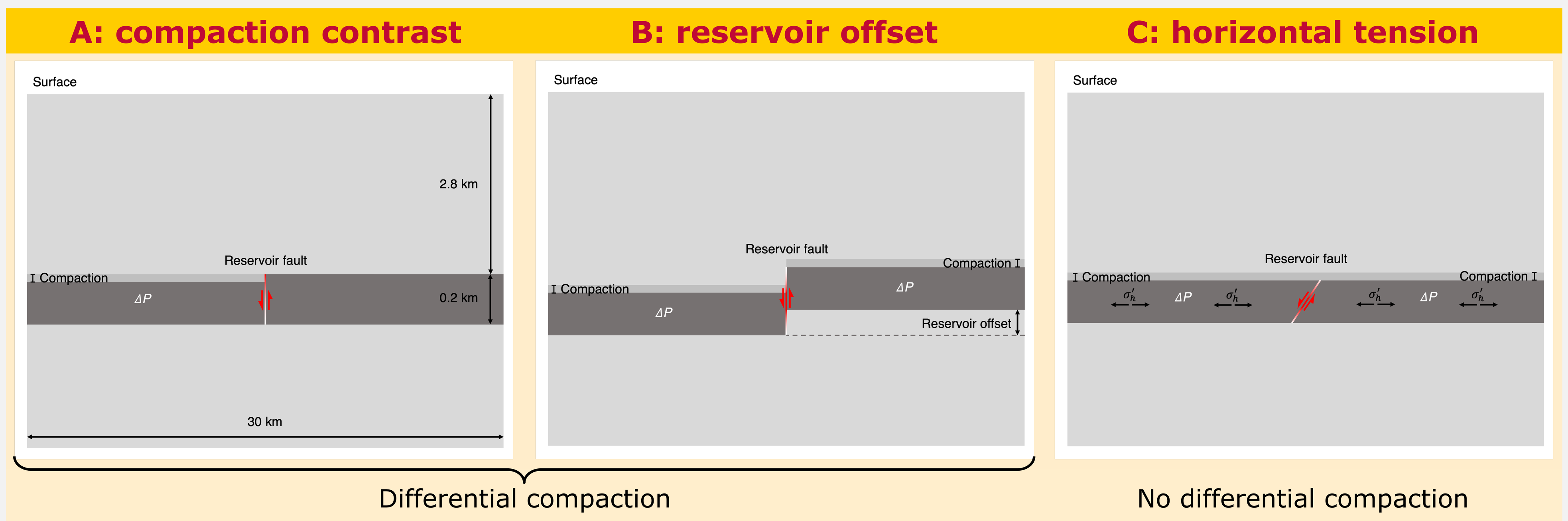

Figure 3: **Conceptual cross-sectional diagrams of the different formation mechanisms of slip on a reservoir fault. Regions subject to pressure reduction are indicated by ΔP, with σ_h' showing the horizontal tensional effective stresses.**

Fault creep

Faults with a low frictional strength can exhibit more or less continuous aseismic slip, called fault creep. To investigate the possible impact of fault creep in Groningen we use 2D plane strain finite element models (GTECTON; Govers & Meijer, 2001) of the geometries in **Figure 3**. The reservoir fault is modelled as a frictionless fault. We compare models with and without fault slip, to find the influence of the creeping fault.

Creeping faults in the A, B and C geometries of Figure 3 lead to subsidence rate signals with maximum amplitudes of approximately 0.06, 0.18 and 0.15 mm/yr, respectively. A creeping fault in a model combining geometries B and C (**Figure 4a**) can induce a subsidence pattern with an amplitude up to 0.4 mm/yr (**Figure 4b**), depending on the exact geometry. This signal is small compared to the ~8 mm/yr overall subsidence signal above the field (**Figure 1**).

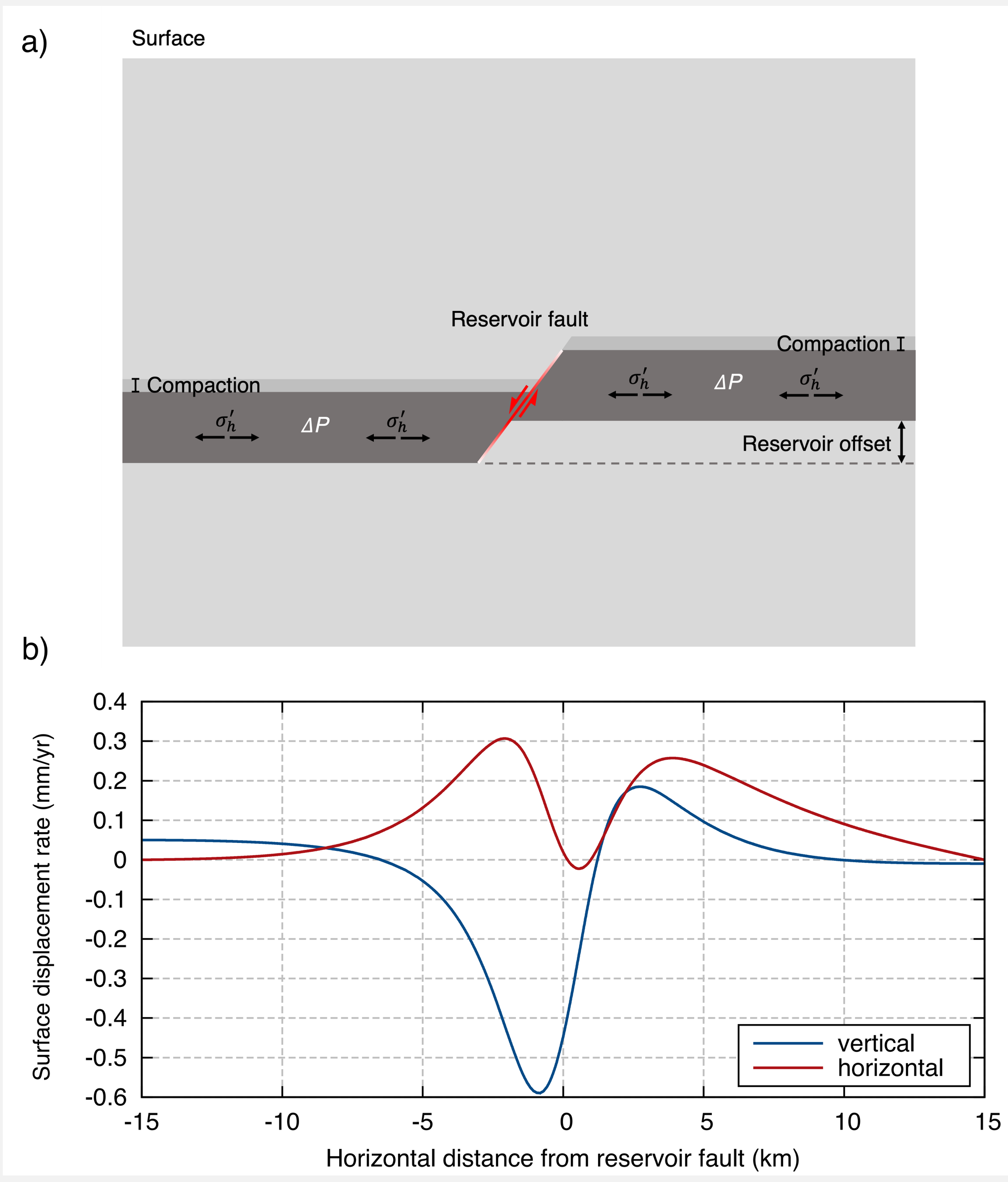

Figure 4: **(a) Conceptual diagram of for the model combining the B and C geometries of Figure 3 and (b) the impact of the creeping fault on the surface displacement rate.**

Because of small amplitude and long spatial wavelength (small spatial gradients) of the signal, and because of uncertainties in the InSAR time series, we see detecting the tiny potential aseismic slip signal within the overall signal as impossible.

Slow slip events

Faults that are not continuously creeping accumulate stresses across the fault plane. These stresses can be relaxed during earthquakes, which generally last only a few seconds. Alternatively, stresses can be relaxed during aseismic slow slip events, with durations of days to months. Slow slip events have been shown to occur in settings relatively similar to Groningen (e.g. Eyre et al., 2022).

Because of the finite duration of the event the deformation rates can be significantly higher than in the case of continuously creeping faults (**Figure 4b**), especially if the event is short-lived and the magnitude is large. We are currently investigating if we can detect such transient events with patterns similar to that of **Figure 2** within the geodetic time series over Groningen.

References

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