What can we learn from the pattern of subsidence above the Groningen gas field?

A study of the sensitivity of the subsidence to the subsurface structure and deformation processes

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DeepNL 'Subsidence' project

Since the start of gas production in the early 1960s in the Groningen area, considerable surface subsidence has occurred above the gas field (**Figure 1a**). This subsidence has mostly been caused by pressure depletion and compaction of the reservoir. However, the exact mechanism and distribution of compaction is not known (Van Thienen-Visser & Fokker, 2017). Subsurface structures and other deformation processes can alter the subsidence signal from compaction and generate additional subsidence signals (**Figure 1**). The DeepNL 'Subsidence' project aims to identify the drivers of subsidence and forecast future subsidence. The team plans to use data assimilation to combine geodetic time series (InSAR, GNSS) of surface displacement with geomechanical models.

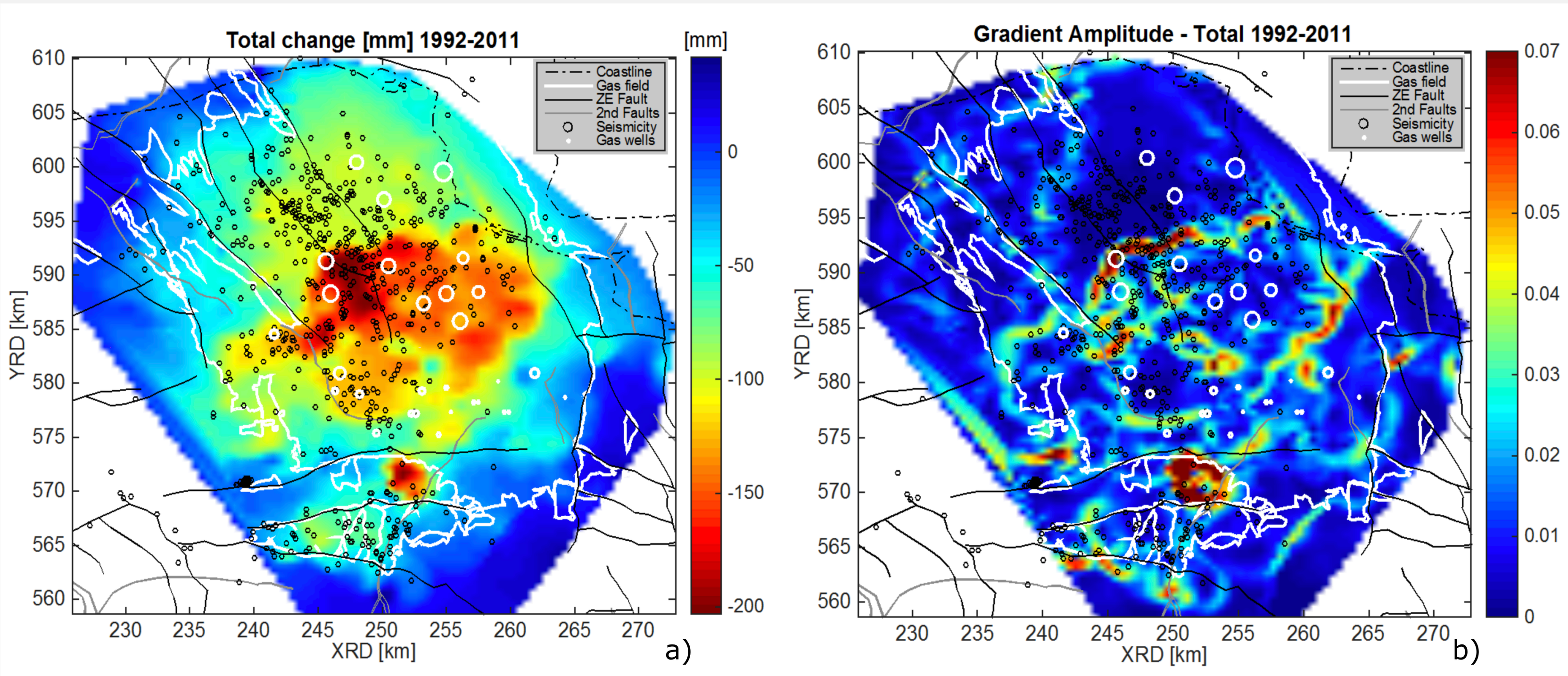

Figure 1: Surface displacement estimates for 1992-2011 based on satellite (InSAR) measurements (a) and the amplitude of their spatial gradient (b), showing the spatial variability (compartmentalisation) of deformation (Hanssen et al., 2015).

Satellite observations

The satellite observations contain signals of:

- Noise (atmospheric, thermal etc.)
- Deep subsurface
  - Reservoir compaction (**Figure 2**)
  - Salt flow (**Figure 3**)
  - Transmission through the overburden
- Shallow subsurface ("soils")
  - Peat oxidation
  - Groundwater level fluctuations and aquifer pumping (**Figure 2**)

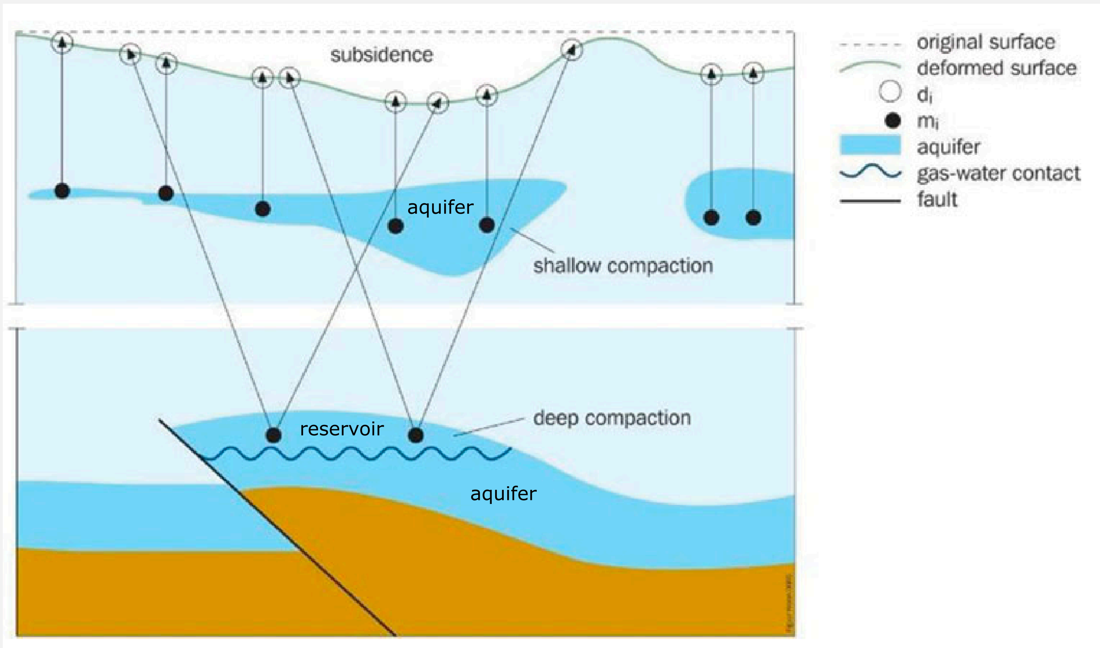

Figure 2: Schematic illustration of the cumulative contribution of subsidence sources in both the shallow and deep subsurface (after Fokker et al, 2018).

Geomechanical models

- The pattern of **Figure 1b** suggests compartmentalisation.
- To constrain the origin of this pattern, the team will develop models of both deep and shallow subsurface.

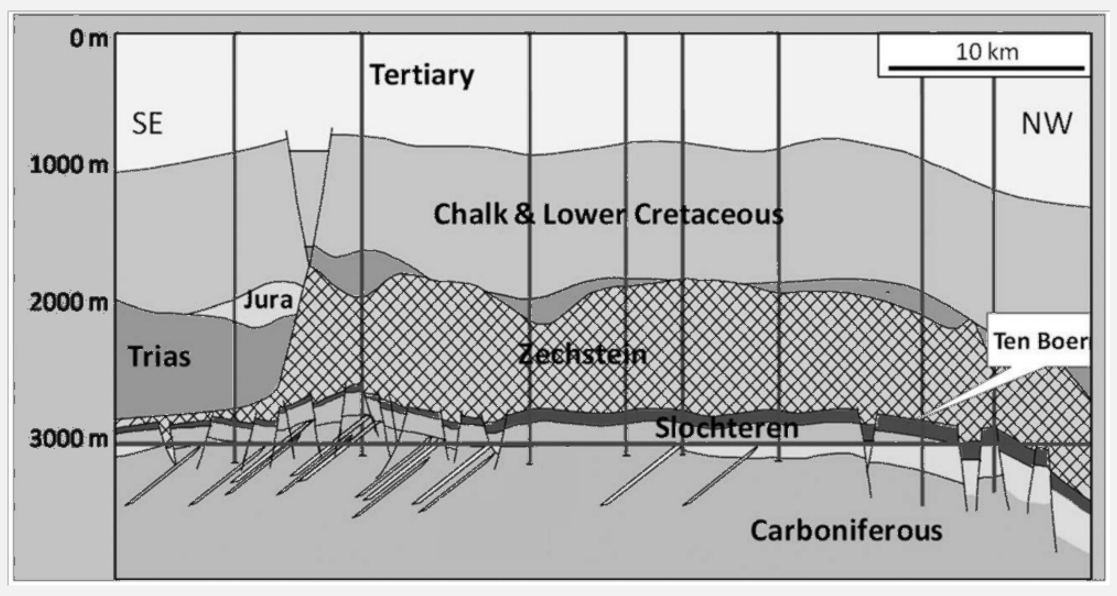

Figure 3: Schematic cross section trough the Groningen field. The Slochteren sandstone is the reservoir rock. Note the strong spatial variability in thickness of the strata, especially for the Zechstein salt caprock. (after Bourne et al, 2014).

Data assimilation

- Using data assimilation we will determine which model setups best match subsidence observations.
- The goal is to keep model complexity low, because
  - Complexity leads to computational load
  - Complexity could lead to overfitting (Occam's razor)

Sensitivity study

In order to determine which structures and deformation processes could contribute to detectable subsidence expression, we will perform a sensitivity study. We plan to create synthetic forward (finite element) models of the multiple complexities. The method is similar to the more limited study on the Ameland gas field by Marketos et al. (2015), where the influence of salt flow on the subsidence evolution was tested (**Figure 4**).

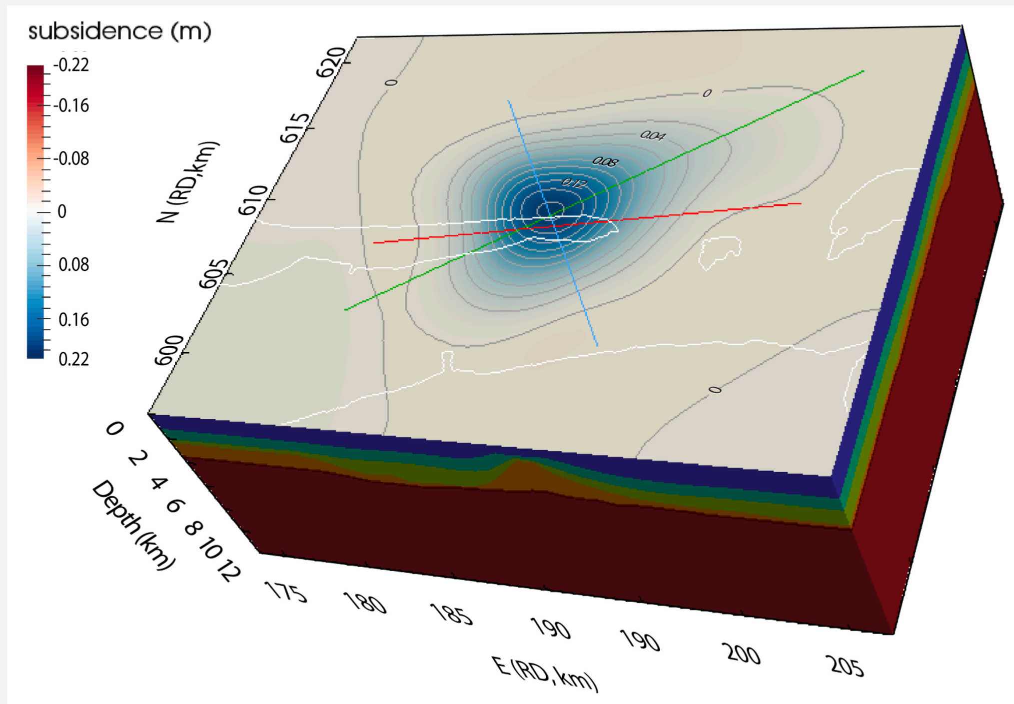

Figure 4: Subsidence modelled above the Ameland gas field using a finite element model of the subsurface (Marketos et al., 2015).

To test

- Geometry of reservoir and overburden, especially variation in rocksalt thickness (**Figure 3**)
- Faulting in the reservoir (**Figure 5a**)
- Material properties
  - Distribution of porosity (**Figure 5b**)
  - Elastic properties
  - Rheologies: both for reservoir (Pijnenburg et al., 2019) and rocksalt flow (Marketos et al., 2015)
- Aquifer response to pressure drop in connected gas reservoir (**Figure 2**)
- Transmission of subsidence through the soils

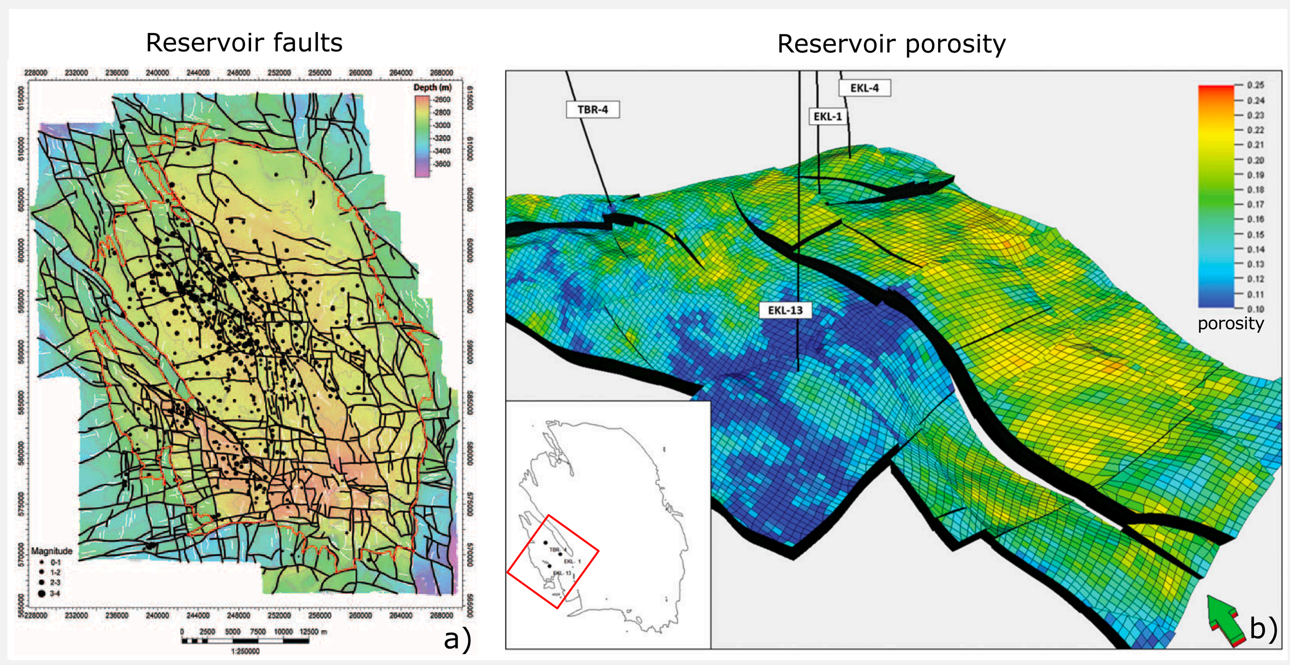

Figure 5: Faults in the reservoir as imaged from seismics by the NAM, with colours showing the depth of the top of the reservoir (a) (Van Thienen-Visser & Breunese, 2015) and a perspective view of porosity distribution as modelled by the NAM for the southwestern part of the Groningen field (b) (after Visser & Solano Viota, 2017).

References

Bourne, S. J., Oates, S. J., van Elk, J., & Doornhof, D. (2014). A seismological model for earthquakes induced by fluid extraction from a subsurface reservoir. *Journal of Geophysical Research: Solid Earth*, *119*(12), 8991-9015.
Fokker, P. A., van Leijen, F. J., Orlic, B., van der Marel, H., & Hanssen, R. F. (2018). Subsidence in the Dutch Wadden Sea. *Netherlands Journal of Geosciences*, 97(3), 129-181.
Hanssen, R. F., Arikan, M., Samiei, S. & van Leijen, F. J. (2015) Bodemdalingsvariabiliteit uit InSAR data, Een studie naar haalbaarheid van het gebruik van 'secundair' bodemdalingssignaal en haar relatie tot aardbevingen in Groningen. *Report for SodM.* (in Dutch)
Marketos, G., Broerse, T., Spiers, C. J., & Govers, R. M. A. (2015). Long-term subsidence study of the Ameland gas field: time-dependence induced by rocksalt flow.
Pijnenburg, R. P. J., Verberne, B. A., Hangx, S. J. T., & Spiers, C. J. (2019). Inelastic deformation of the Slochteren sandstone: Stress-strain relations and implications for induced seismicity in the Groningen gas field. *Journal of Geophysical Research: Solid Earth*, 124(5), 5254-528
van Thienen-Visser, K., & Breunese, J. N. (2015). Induced seismicity of the Groningen gas field: History and recent developments. *The Leading Edge*, 34(6), 664-671.
van Thienen-Visser, K., & Fokker, P. A. (2017). The future of subsidence modelling: compaction and subsidence due to gas depletion of the Groningen gas field in the Netherlands. *Netherlands Journal of Geosciences*, *96*(5), s105-s116.
Visser, C. A., & Viota, J. L. S. (2017). Introduction to the Groningen static reservoir model. *Netherlands Journal of Geosciences*, 96(5), s39-s46.