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Impact of fluid extraction on the creep behaviour of clay-rich formations enveloping Rotliegend sandstone reservoirs

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Introduction

Extraction of fluids from the subsurface can result in surface subsidence and induced seismicity. In the Netherlands, prolonged gas production from Rotliegend gas fields has resulted in these phenomena, with the Groningen gas field being the most extensively impacted. Most of the compaction in these fields occurs in the porous sandstone reservoir rock, which in case of the Groningen field is the Slochteren sandstone. However, the overlying Ten Boer claystone and the underlying Carboniferous shales, directly bounding the reservoir, are affected as well.

Slow pore pressure equilibration between the reservoir and these low-permeability, clay-rich formations results in time-dependent deformation, as observed from in-situ strain measurements. This time-dependent deformation will result in additional compaction on top of the compaction of the reservoir rock itself. The microscale deformation mechanisms active in the clay-rich formations are most likely different from the deformation mechanisms in the reservoir. Furthermore, the time-dependent deformation near existing faults may impact the state of stress acting on those faults, affecting the possibility of seismicity. Understanding the role of these clay-rich formations on subsidence and induced seismicity is key to make accurate predictions for the evolution of the Groningen gas field.

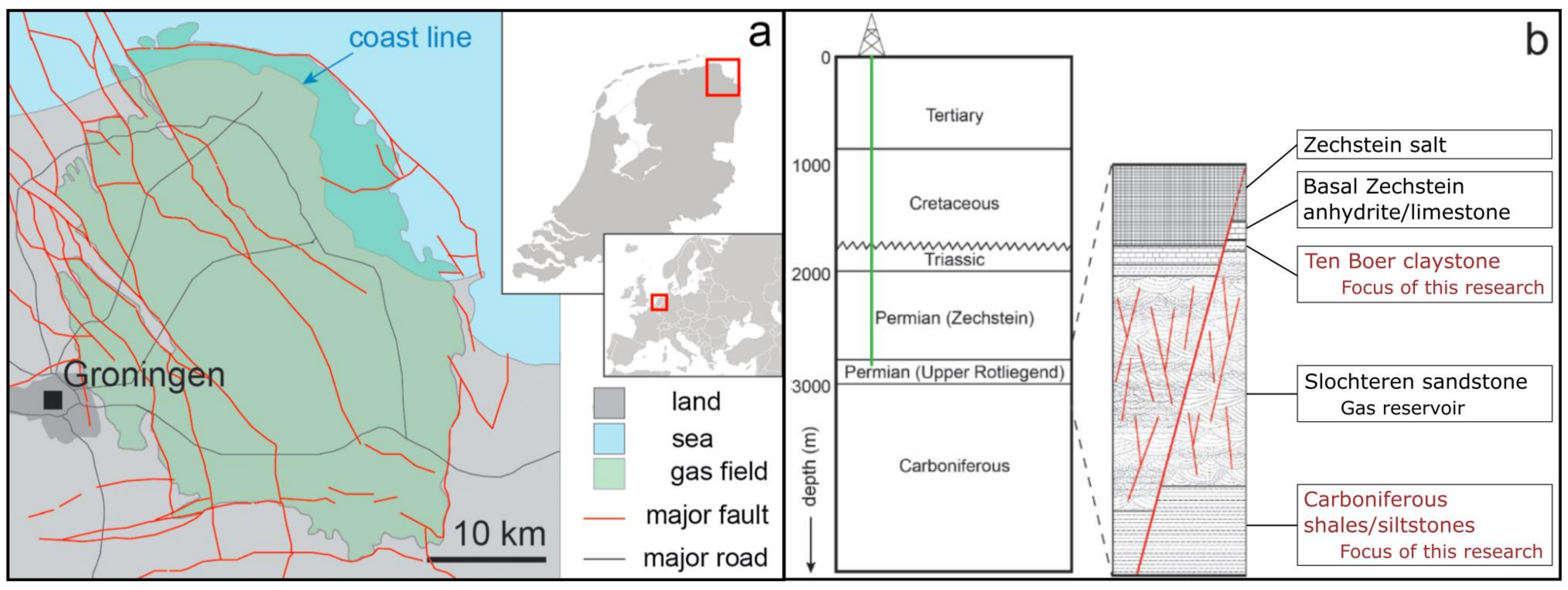


Figure 1: a) Location of the Groningen gas field. Major faults (vertical throw > 150 m) cutting the sandstone reservoir are indicated in red (figure after Pijnenburg et al. [2018]). b) Schematic stratigraphy of the Groningen gas field (figure after Spiers et al. [2017]). The formations which are the focus of this research are indicated in red.

Methodology

We perform triaxial experiments under in-situ conditions relevant to the Groningen gas field to investigate the time-dependent deformation of the clay-rich formations. The main challenge is to control the pore fluid pressure, which poses difficulties due to the low permeability of the samples (i.e., < 0.01 mD). Microstructural analyses are used to improve the understanding of the deformation processes on a microscale.

In-situ conditions

Temperature	100 – 125°C
Vertical stress	60 – 80 MPa
Horizontal stress	30 – 60 MPa
Pore fluid pressure	10 – 35 MPa

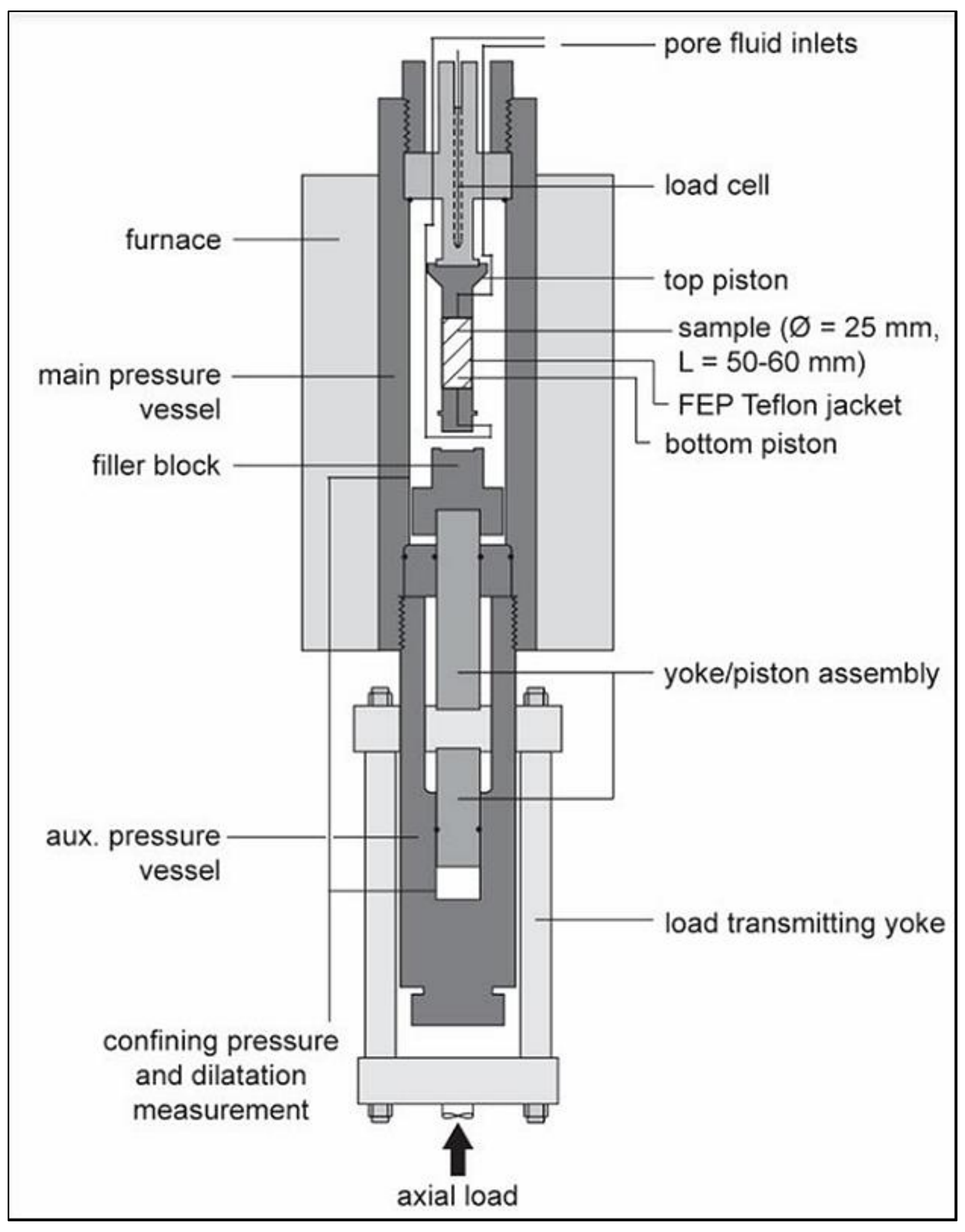
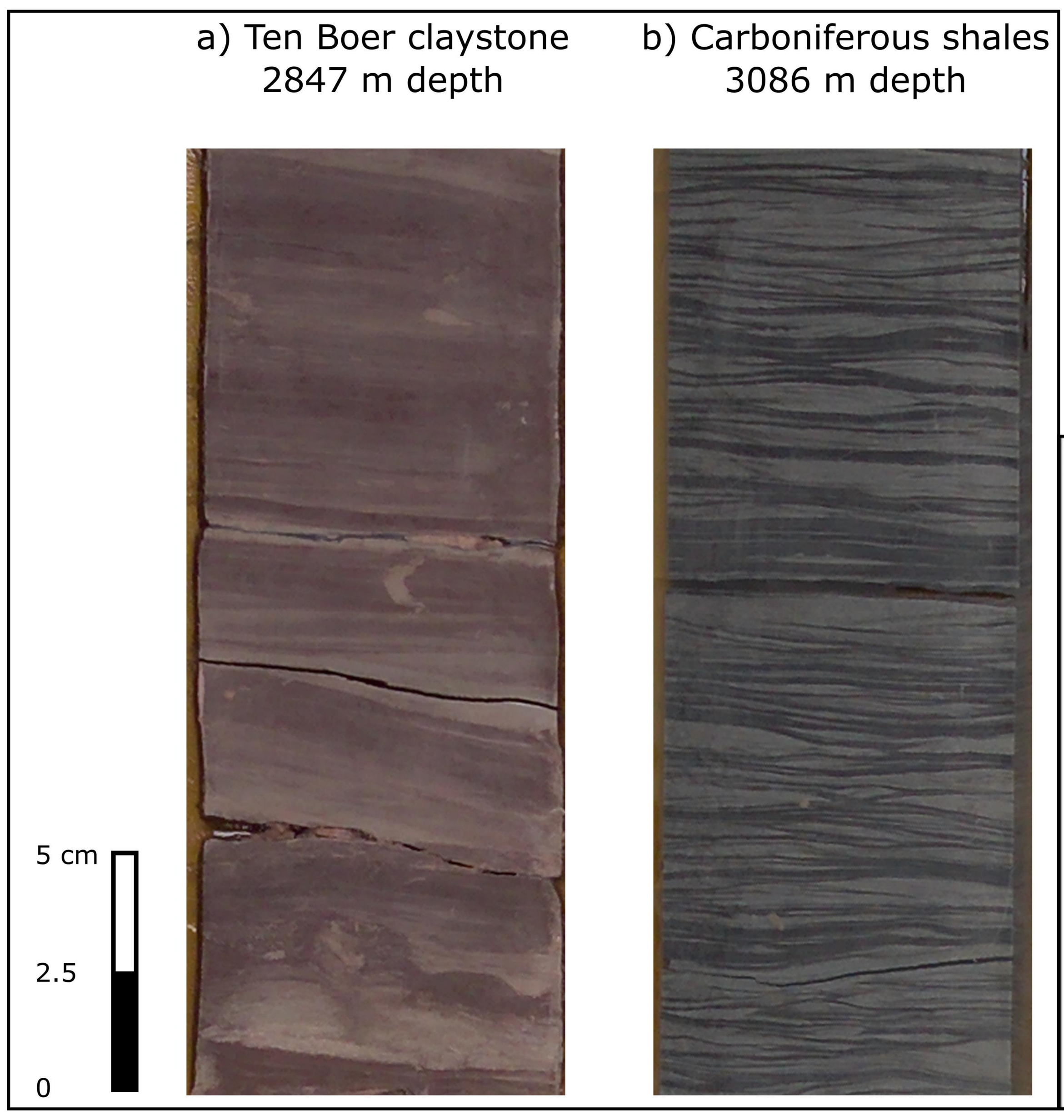


Figure 2: Schematic drawing of the setup for conventional triaxial experiments (Hangx et al. [2015]). Note that the setup has two pore fluid inlets, connected to separate pressure pumps. This means that the pore fluid pressure can be controlled from both ends of the sample.



Sample characteristics

To help understand the processes that occur in these clay-rich rocks, we will perform detailed, quantitative XRD-analyses on multiple Ten Boer and Carboniferous samples to find the mineralogical heterogeneities. Besides that, we will determine the porosity and permeability of the formations.

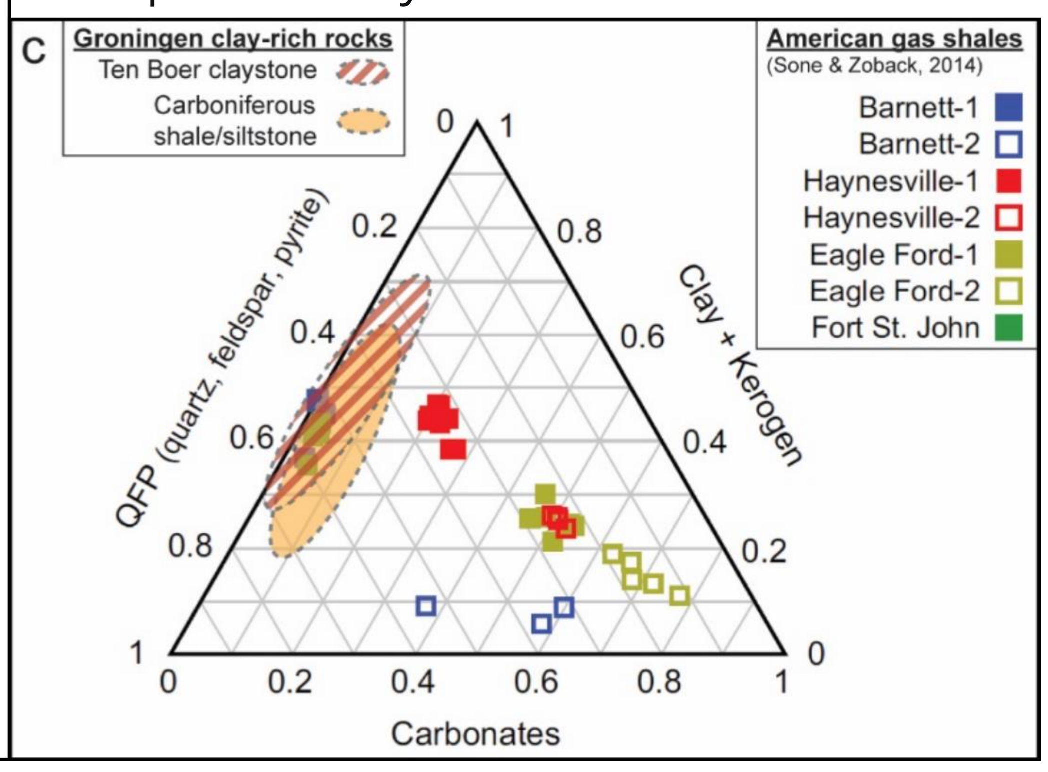


Figure 3: Photographs of core slabs of the Stedum-1 well showing representative sections of a) Ten Boer claystone and b) Carboniferous shale (provided by NAM through EPOS-NL). c) Ternary diagram showing an indication of the mineralogical composition of the Ten Boer claystone and the Carboniferous shales (based on Hunfeld et al. [2017]). For reference, some well studied American gas shales are shown as well (Sone & Zoback [2014]).

Applications

The results of this research will be presented in the form of flow laws describing the time-dependent deformation in the Ten Boer claystone and the Carboniferous shales. These flow laws can directly be incorporated in geomechanical models of the Groningen gas field.

The results of this research are relevant beyond the lifetime of the Groningen gas field as well, as many other Dutch and German Rotliegend reservoirs are considered for sustainable use of the subsurface. For both extraction and injection of fluids, the mechanical response of all formations involved is key to minimize the risk of leakage and induced seismicity.

References

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