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New approach to link depletion and induced seismicity in Lower Saxony gas fields

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Introduction

Seismic activity increased in Lower Saxony since the beginning of gas extraction in the 1950s. It is noticeable that these earthquakes occur nearby gas fields. The German mining law requires the seismological surveys to assign the earthquakes to the gas fields. However, this assignment is mostly based on the distance of the epicenter to the next gas field. The aim of this study is to provide an approach to include the activities (production rates, cumulative production and pore pressure reduction) within individual gas fields in addition to the geometrical distance to the epicenter. All data used is based on publicly available databases.

Objectives

1. Digitalization of gas extraction data and spatial extent of gas fields in Lower Saxony.
2. Compilation of earthquake information in the study area.
3. Development of MATLAB tools to process and visualize the compiled data.
4. Creation of a new approach to link gas extraction and nearby earthquakes.

1) Compilation of required data for further analyses

- Digitalization of gas extraction data and reservoir parameters (e.g. porosity) as excel spreadsheet (based on gas extraction data are published by LBEG, Hannover)
- Digitalization of the spatial extent of gas fields in the study area using ArcGIS (Fig. 1)
- Seismic events in proximity to gas fields in Lower Saxony
- Calculation of distance between gas fields and earthquakes using ArcGIS (compiled as an additional excel spreadsheet)

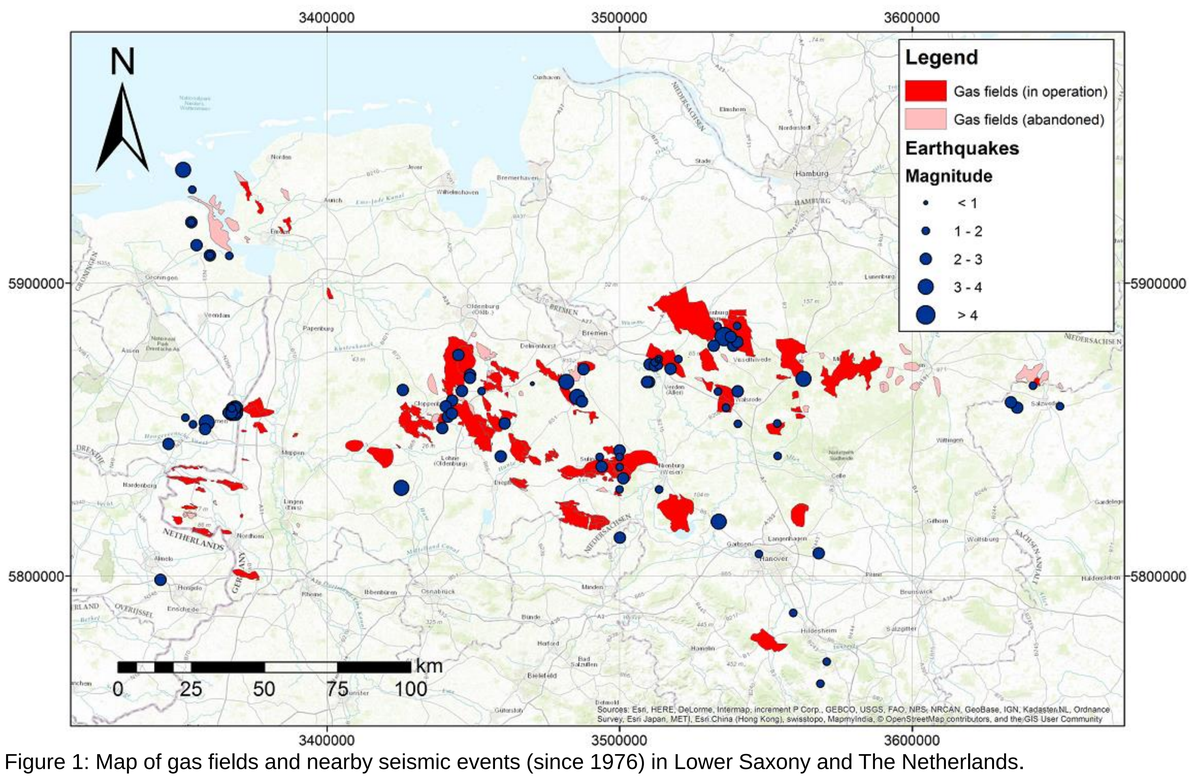

Figure 1: Map of gas fields and nearby seismic events (since 1976) in Lower Saxony and The Netherlands.

2) Calculation of average pressure reduction in the gas reservoirs

The basis for our calculations is described by the ideal gas equation:

$$pV = nRT \quad (1)$$

We used two approaches for the computation of the pressure reduction:

Closed system approach:

- Flux of formation water into the reservoir is neglected
- Calculation of temperature using a geothermal gradient of 30 $^{K}/_{km}$
- Reservoir pressure equals the hydrostatic pressure plus overpressure due to gas occurrence
- Computation of reservoir volume as product of spatial extent of gas fields, thickness of reservoir and porosity
- Correlation of extracted gas volume and amount of substance using eq. (1)
- Back calculation of reservoir pressure reduction with following equation:

$$p(t) = \frac{n_{res(t)} * RT}{V} \quad (2)$$

($n_{res(t)}$ equals the amount of substance [mol] in the reservoir at time t)

Open system approach:

- Flux of formation water into the reservoir causes pressure compensation
- Reformulation of ideal gas equation considering constant temperature, pore volume and ideal gas constant as well as pressure compensation:

$$p_2' = p_2(p_1 - p_2)x \qquad (p_2 = p_1\frac{n_2}{n_1}) \quad (3)$$

(x equals the amount of pressure compensation ($0 \leq x \leq 1$))

3) Functionalities of our MATLAB tools

- Visualization of annual and cumulative gas extraction as well as pressure reduction of gas fields in Lower Saxony (Fig. 2)
- Sensitivity analysis (*Monte-Carlo simulation*) of calculated reservoir pore pressure by variation of reservoir parameters
- Correlation of pressure reduction of reservoirs with seismic events (earthquakes within 10 km distance to gas field boundaries; Fig. 3)
- Comparison of cumulative gas extraction and by earthquakes released cumulative energy

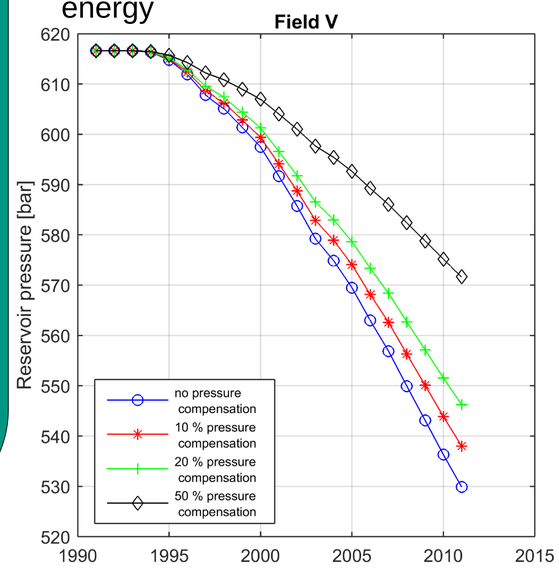

Figure 2: Calculation of pressure reduction of gas field V with time by using our MATLAB tool

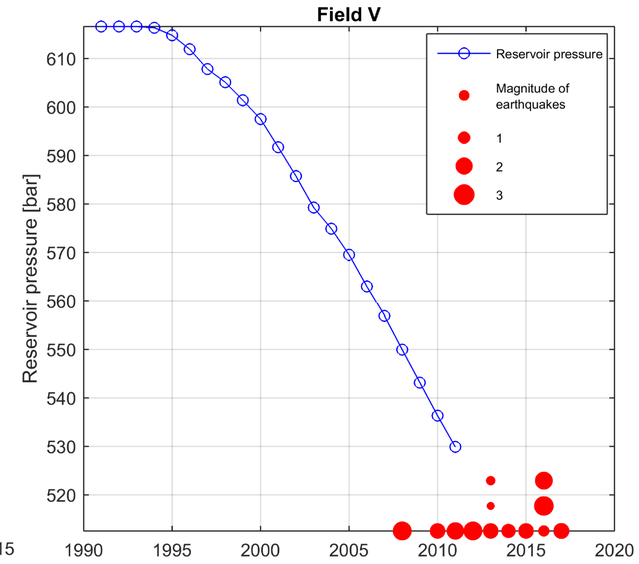

Figure 3: Correlation of reservoir pressure reduction with nearby seismic events

4) New approach to link gas extraction and seismicity

In addition to the work of Bischoff et al. (2017), we utilize the following parameters to assign earthquakes to gas reservoirs:

- Squared weighting of distance between gas field boundary and epicentres (due to decreasing probability of causing earthquakes with distance)
- Ratio between current and initial reservoir pressure (in contrast to the quantity of gas extraction used by Bischoff et al. (2017))

From this information we derive an assignment parameter AP – if AP has high values, the probability that the earthquake is caused by the gas field is low.

In addition, we consider if gas field has been producing at the time of earthquake occurrence.

5) Exemplary application of our new approach

- Earthquake south of Oldenburg (02.09.2014)

Gas field	Distance [m]	Period of production	Pressure ratio	Assignment parameter (AP)
Goldenstedt/Visbek	1837	1971 - today	0,83	2,79
Cappeln	6380	1970 – today	0,86	34,83
Hengstlage	976	1968 – today	0,90	0,86
Ahlhorn	696	1972 – 1998	0,96	0,47

- If only the distance is considered, one would assign the earthquake to Ahlhorn
- This is unlikely because the earthquake was triggered 16 years after the end of production of Ahlhorn
- Based on our assignment parameter, we assign the earthquake to Hengstlage

6) Suggestion for further development

Since pressure reduction is localized around production wells depending on the permeability, we expect an improvement of our approach if production rates of individual wells are provided (Fig. 4). The figure shows that even if the average pressure reduction after 20 years of production is around 10 Mpa, there are local variations within the field where some wells exhibit close to 15 Mpa pressure reduction.

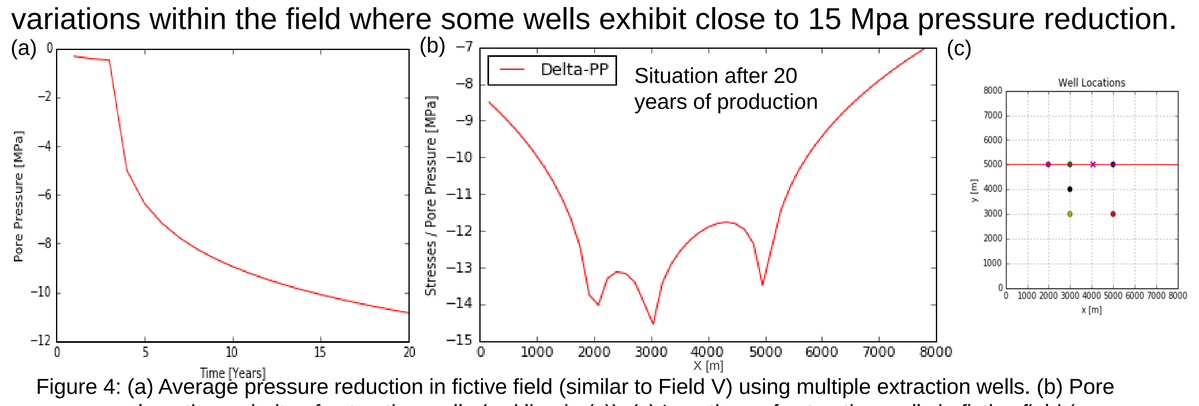

Figure 4: (a) Average pressure reduction in fictive field (similar to Field V) using multiple extraction wells. (b) Pore pressure along the majority of extraction wells (red line in (c)). (c) Locations of extraction wells in fictive field (x: Observation well)

Conclusion

- We successfully developed a toolbox containing two excel spreadsheets (one with gas reservoir data and the other with earthquake data) and our MATLAB program
- We further developed a new approach to assign earthquakes to gas fields

This can help to explain the time offset between beginning of gas production and first nearby seismic events (in many cases 16 – 18 years; also observed by Bischoff et al. (2017)) as well as the increase of magnitude and frequency of earthquakes close to several gas fields.

References:

State Authority for Mining, Energy and Geology (LBEG) (2012): Die Erdgasförderung in Deutschland von 1951 bis 2011, Hannover.

Bischoff et al. (2017): Zeitliche Entwicklung der Erdgasfelder und Seismizität. Presentation at LBEG on 16.01.2017.