Characteristics of seismicity induced by gas production in Northern Germany

Landesamt für Bergbau, Energie und Geologie

M. Bischoff[1], N. Gestermann[2], T. Plenefisch[2], S. Viola[1] und J. Fritz[1]

[1]Landesamt für Bergbau, Energie und Geologie (LBEG), Hannover (monika.bischoff@lbeg.niedersachsen.de)

[2] Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover

Bundesanstalt für Geowissenschaften und Rohstoffe

Seismicity & natural gas production

The North German Basin is a tectonic region of low natural seismicity. No damaging earthquake is known from historical archives. With instrumental recordings only few and relatively weak events were observed in the recent decades. The most seismically active part spans the region of gas production of about 400 km in east-west and about 70 km in north-south directions from the Dutch-German border to the Altmark region. The two strongest events had local magnitudes (M_L) of 4.5 and 4.0. They occurred near Rotenburg in 2004 and near Soltau in 1977, respectively. In total, 77 seismic events with local magnitudes (M_L) between 0.5 and 4.5 have been observed since 1977.

- epicentres cluster at productive gas fields
- no seismicity at larger distances from gas fields or before production
- focal depths at reservoir level at about 5 km

→ seismicity is induced by gas production

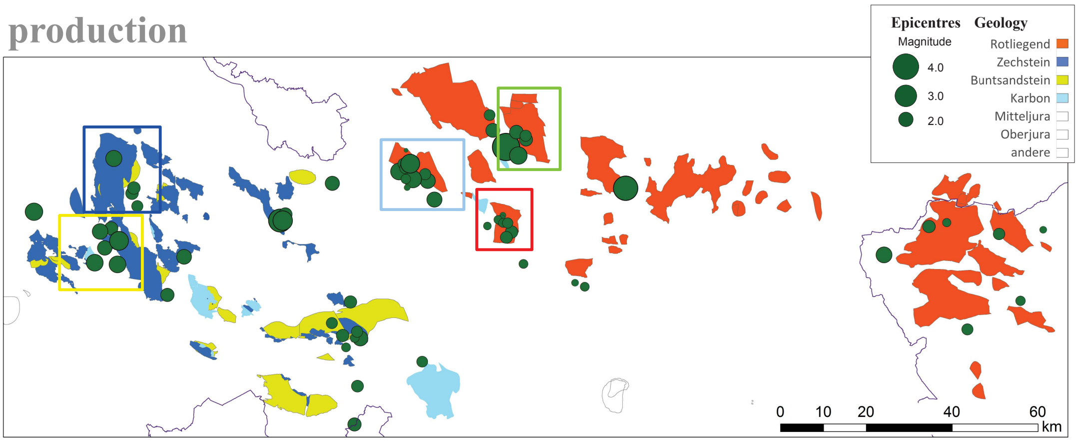


Fig. 1: Map of the gas production region between Cloppenburg in Lower Saxony and Salzwedel in Saxony-Anhalt. Productive gas fields are color-coded according to the stratigraphic units: Rotliegend (Lower Permian, red), Zechstein (Upper Permian, blue), Buntsandstein (Lower Triassic, yellow), Karbon (Carboniferous, light blue) and others (white). Epicentres of the 77 recorded seismic events in the magnitude range $0.5 \leq M_L \leq 4.5$ are plotted as dots. Seismicity is mainly related to Rotliegend fields and Zechstein carbonates at depths between 3.5 and 5 km. With a total of only 77 events statistical analysis is very poor. Still, the seismic characteristics of the individual gas fields seem to vary. Characteristics of the active fields and regions that are highlighted with color-coded frames are discussed below (Fig. 4).

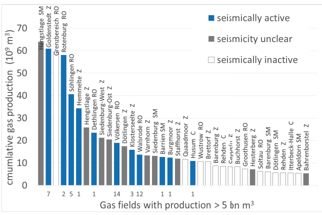


Fig. 2: Total production of the largest gas fields until 2013 (> 5 billion m^3) in Northern Germany. Colors denote their seismic (in)activity: not active – white, seismically active – blue, unknown – gray. The vast majority of the fields does not show seismicity at all.

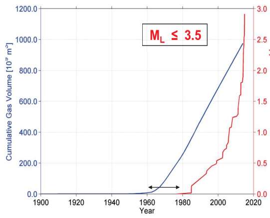


Fig. 3: Cumulative annual gas production in Northern Germany (blue) and cumulative seismic energy release (red) of events up to M_L 3.5. Seismicity is delayed compared to gas production by about 20 years.

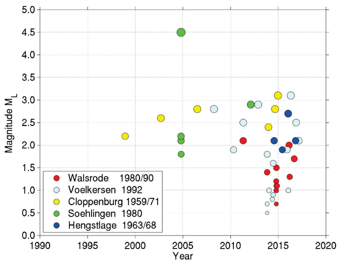


Fig. 4: Magnitude vs. time for events of selected gas fields (Fig. 1) showing different characteristics:

Walsrode: small and rather regular events ($M_L \leq 2.1$)
Völkersen: rather regularly events, most active field in recent years (17 events, $0.5 \leq M_L \leq 3.1$), delay of 14 years between the start of production and the first seismic event ($M_L > 2$)
Cloppenburg region: association with specific gas fields is ambigious, regular events above $2.0 \leq M_L \leq 3.1$
Söhlingen: single large events: M_L 4.5 and aftershocks, M_L 2.9; (similar observations at Klosterseelte near Syke: M_L 3.8 and aftershocks, M_L 3.2)
Hengstlage: first seismic event ($M_L > 2$) more than 40 years after begin of production

→ no simple relations exist between seismicity and cumulative extracted gas volume, extraction rate and the total size of the field

Mechanism: Pore pressure reduction and reactivation of tectonic faults

Natural gas production
↓
Pressure drop within reservoir
↓
Differential compaction
↓
Increased stresses
↓
Earthquake
Stress release by shear failure on reactivated faults

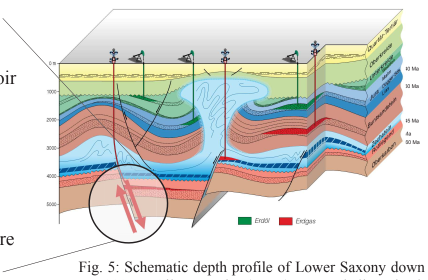
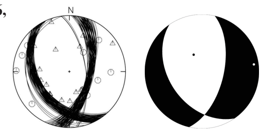


Fig. 5: Schematic depth profile of Lower Saxony down to 5000 m. Oil reservoirs (green) are at shallow depth down to about 2200 m while the most gas reservoirs (red) are at greater depth down to 5000 m. The thick tertiary sedimentary layers are highly disturbed by salt tectonics. The deeper layers below the Zechstein formation are characterized by movements at tectonic faults in geologic times.

The most probable reason for seismicity at the natural gas fields in Northern Germany is pore pressure depletion resulting in the compaction of sediments and hence the increase of stresses at tectonic faults and their release in seismic events.

Fig. 6: Fault plane solution for the recent Völkersen event, M_L 3.1, showing a normal faulting mechanism which is typical for events at the gas fields in Northern Germany. Faults below the Zechstein formation might be reactivated by increased stresses due to gas production.

22nd April 2016, Völkersen, M_L 3,1



Seismic network & Detection threshold

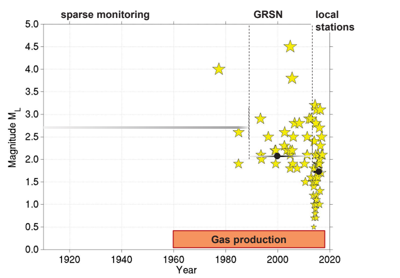


Fig. 7: Magnitudes of the recorded events (stars) with respect to time together with likely detection thresholds (lines) roughly guessed from the varying station coverage and experience with signals from the sedimentary basin. Gas production started in 1960. Till the early 1990s seismic events larger than magnitude 2.7 should have been reported in bulletins due to their perceptibility. With the German Regional Seismic Network in the 1990s detection capability increased and reached M_L 2.1 in 2000 (black dot). Recent improvements led to an overall detection threshold of about 1.7 in December 2014 (black dot). At sites with dense local networks or arrays it is considerably lower.

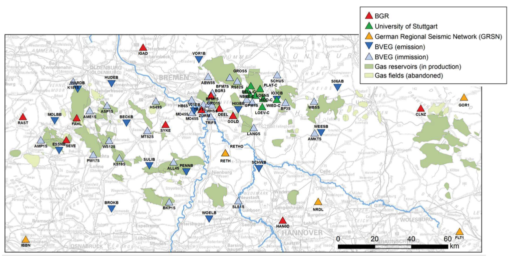


Fig. 8: Current seismic stations (triangles) in the area of the natural gas fields (green) in Northern Germany. Stations are color-coded according to their associated network: German Regional Seismic Network (GRSN, orange), Federal Institute of Geosciences and Natural Resources (BGR, red), Bundesverband Erdgas, Erdöl und Geoenergie e.V. (BVEG, light and dark blue) and University of Stuttgart (green).

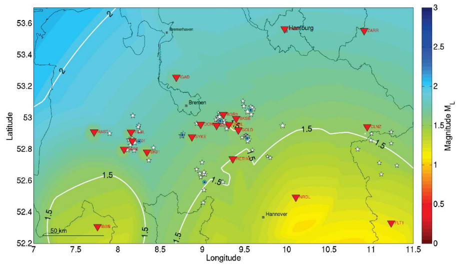


Fig. 9: Detection threshold for GRSN and BGR stations (red triangles) in the region of gas production in December 2014 estimated from the noise levels, a signal-to-noise ratio of 3 and minimum three stations for each detection. At daytimes a detection threshold of M_L 1.7 is achieved for the whole region. Relatively bad signal-to-noise conditions as a result of thick sedimentary layers impede the further enhancement of the detection capability for the whole region. Local stations have only minor effects on the detection capability. However, they are important to improve localisations.

Conclusions

1. The most probable reason for seismicity at the natural gas fields in Northern Germany is pore pressure depletion resulting in the compaction of sediments, the increase of stresses at tectonic faults and their reactivation in seismic events.

2. Comparisons between times and locations of hydraulic fracturing or waste water disposal and seismic events do not show any relation between them.

3. Seismic characteristics of the individual gas fields seem to vary. Comparisons with production parameters show that no simple relations exist between seismicity and cumulative extracted gas volume, extraction rate or the total size of the field.

4. With the current public network an overall detection threshold of local magnitude (M_L) 1.7 has been achieved for the region of gas production. Local stations have only minor effects on the detection capability of the network, however, they are important to improve the accuracy of the localisations.

5. Natural causes such as isostatic rebound effects or pure tectonic origin are being discussed for some events in Northern Germany. They might lead to further stress concentrations over long time spans. However, gas production led to huge pressure drop within the gas reservoirs in the recent decades. Thus, it is judged to be a dominant influence on enhancing stresses that might be released seismically. Differences in seismic energy release between gas fields might be explained by local structures, i.e. the existence of preferably oriented faults, different rheology or stress fields.

Acknowledgements

Permanent stations of the industry are operated by Bundesverband für Erdöl, Erdgas und Geoenergie e.V. (BVEG) and DMT Gmbh & Co. KG. Funded by a DGMK-project the gas field Söhlingen is monitored with mini-arrays by University of Stuttgart. We acknowledge the professional exchange of information.