Recent seismicity in the northern German gas fields - induced and tectonic?

Gregor Mokelke[1], Żaneta Heinrich[1], Benjamin Sick[1], Rolf Häfner[1], Marco Walter[1,2], Patrick Blascheck[1], Manfred Joswig[1,]

1 Institute of Geophysics, University of Stuttgart, Germany, gregor.mokelke@geophys.uni-stuttgart.de ; **2** Seismic Solutions, Tübingen, Germany

Institut für Geophysik

Universität Stuttgart

Overview: Seismicity in northern Germany and existing seismological networks

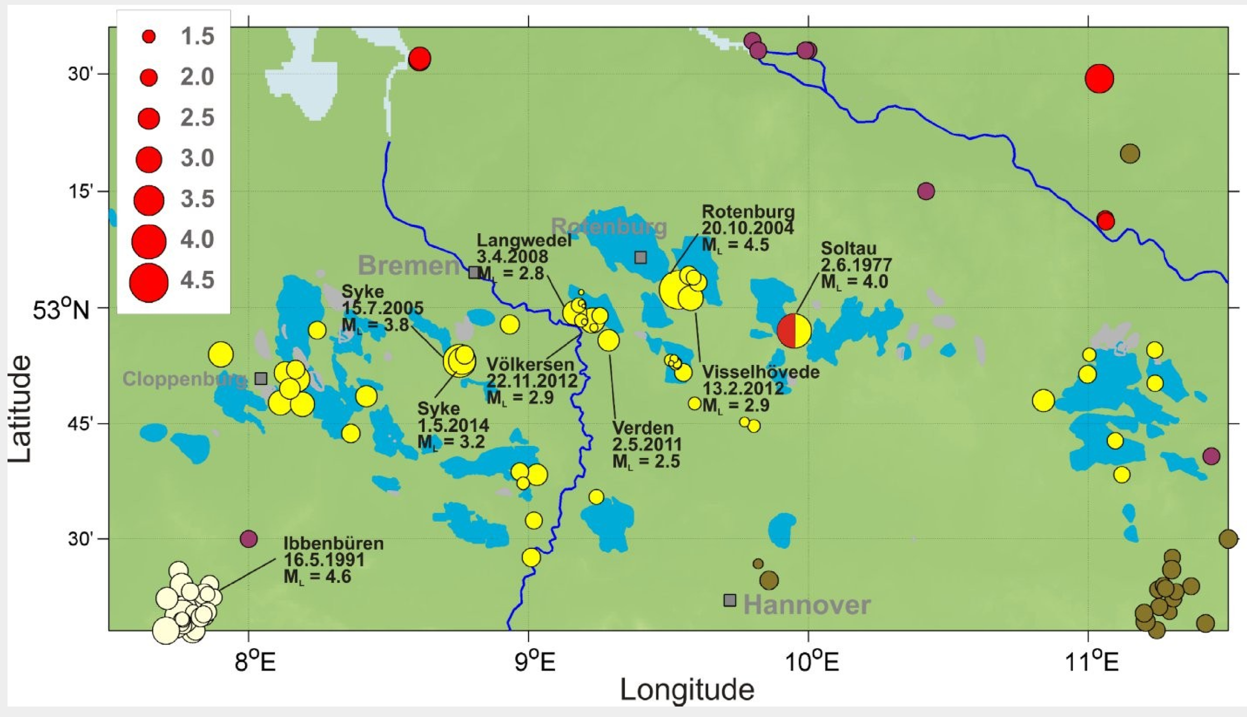


Fig.1: Seismicity in northern Germany. Gestermann, BGR 2015.

During the last decades seismic events consistently occurred in the vicinity of the natural gas fields and currently there are over 50 documented earthquakes with magnitude range M_L 0.5 – 4.5 (Fig.1). Due to their spatial vicinity, many of them are interpreted as the consequence of hydrocarbon recovery and ranked as induced events.

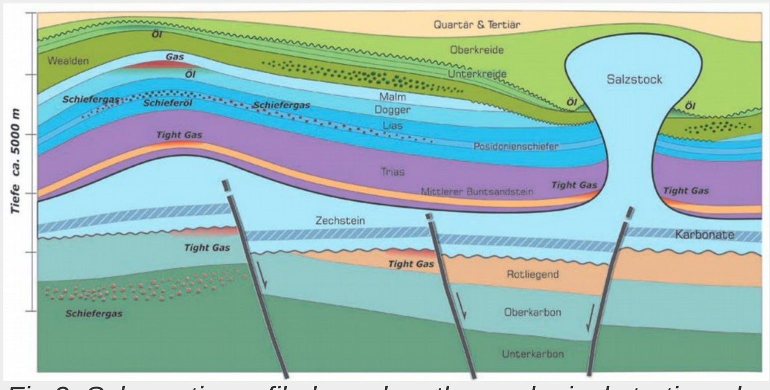


Fig.2: Schematic profile based on the geological stratigraphy in northern Germany [8].

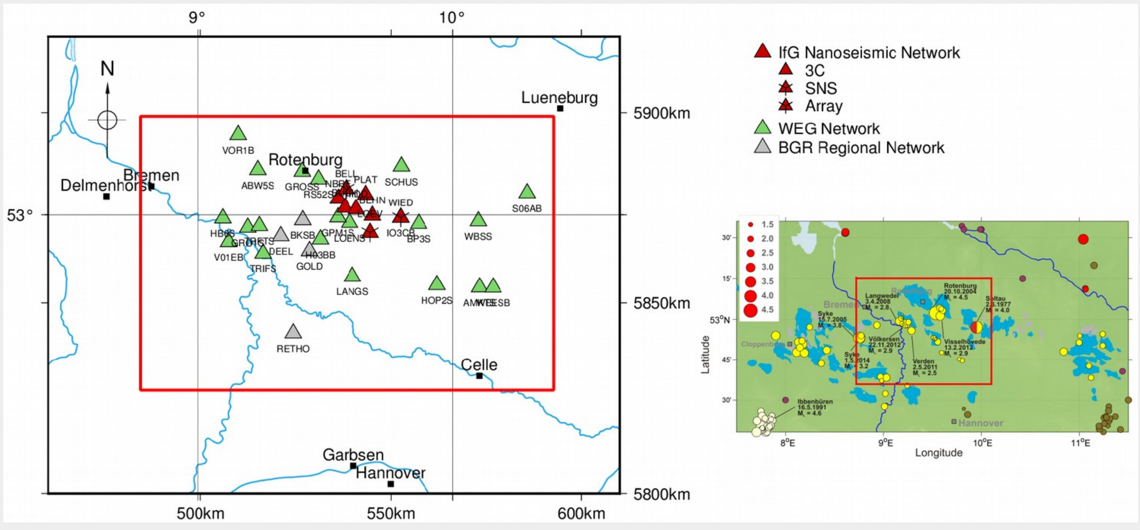


Fig.3: Left side: Distribution of seismic stations in northern Germany. Red triangles represent Nanoseismic Network of University of Stuttgart, light green – seismic stations of WEG. Gray colour indicates BGR seismic network (status from Feb. 2016).

Since northern Germany recently experienced several moderate earthquakes (which is proved by events like Soltau earthquake in 1977 with M_L 4.0, Rotenburg 2004 with M_L 4.5 or Syke 2014 - M_L 3.2), the need for seismic networks grew rapidly. Within the last few years new stations from BGR and DMT were established in the region of gas fields. The Institut of Geophysics (University of Stuttgart) has established a small-scaled but dense network since 2014. Fig.3 displays the arrangement of the various network stations.

Seismicity related and not related to gas-production

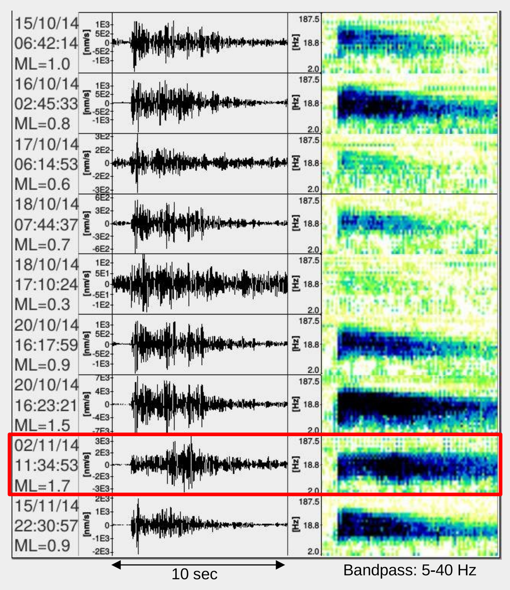


Fig.8: Walsrode cluster event overview, event window length is 10 s. The cluster consists of 9 timely clustered events with local magnitudes between 0.3 and 1.7. All events apart from the one of 02/11/14 are also clustered closely in space. The epicenter of the outlier event is around 5 km to the south of the main cluster and its depth is around 26 km instead of less than 5 km from the other events.

Walsrode cluster
10-11/2014

M_L 0.3 – 2.0
- several shallow (~ 5 km)
- one deep (26 km)

23.01.2016 04:57:27 53.214 09.437 27 km M_L 0.6

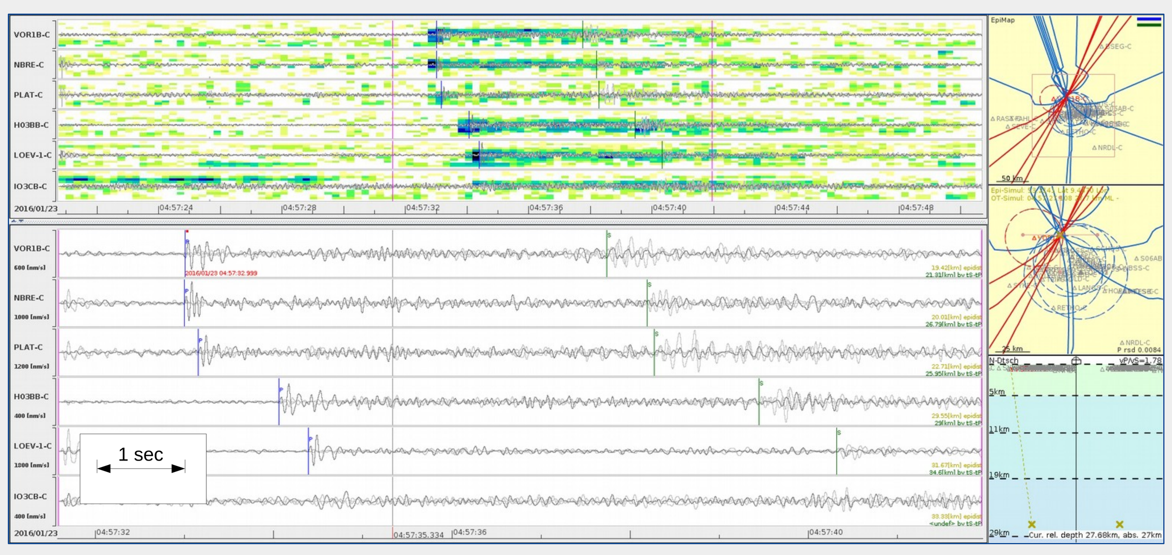


Fig.9: HypoLine screenshot of deep seismic event in northern Germany (23.01.2016, 04:57, M_L 0.6). From the selection of clearly visible P and S arrivals (left windows) the time difference ts-tp has been received and displayed here as circles (right middle window). Hyperbolas represent Equal Differential Time derived for each pair of tp-tp onset times. Only the coincidence of ts-tp circles with hyperbolas can give us a depth estimation. In this example a good converge has been received for a depth of 27 km (right lower window).

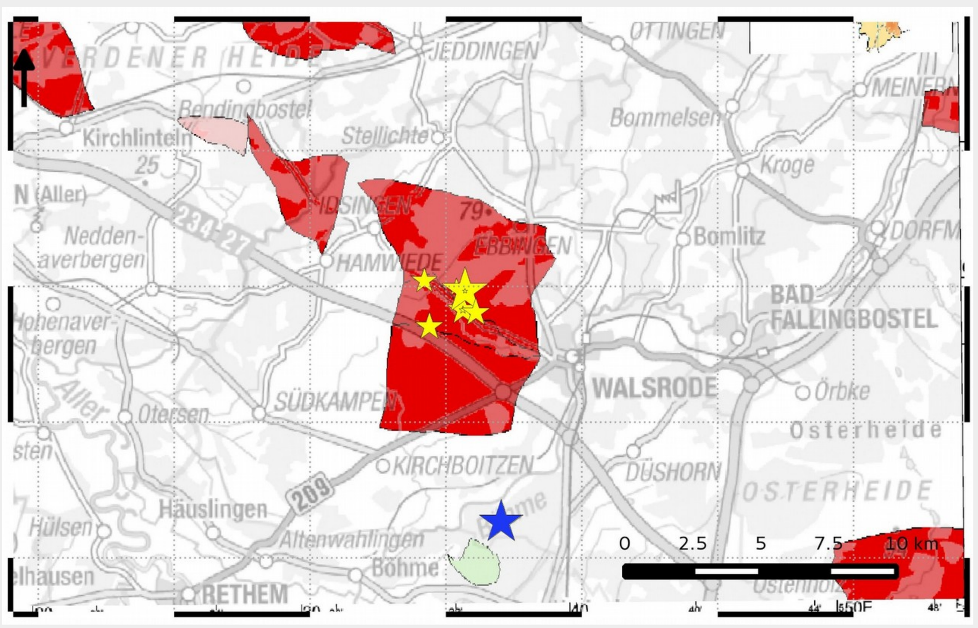


Fig.10: Localisation of events in the region of Walsrode gas field. Yellow stars indicate shallow earthquakes detected and localized during DGMK project 761. The blue star represents deep event on 02.11.2014, 11:34, M_L 1.7 [background map: NIBIS Kartenserver http://nibis.lbeg.de]

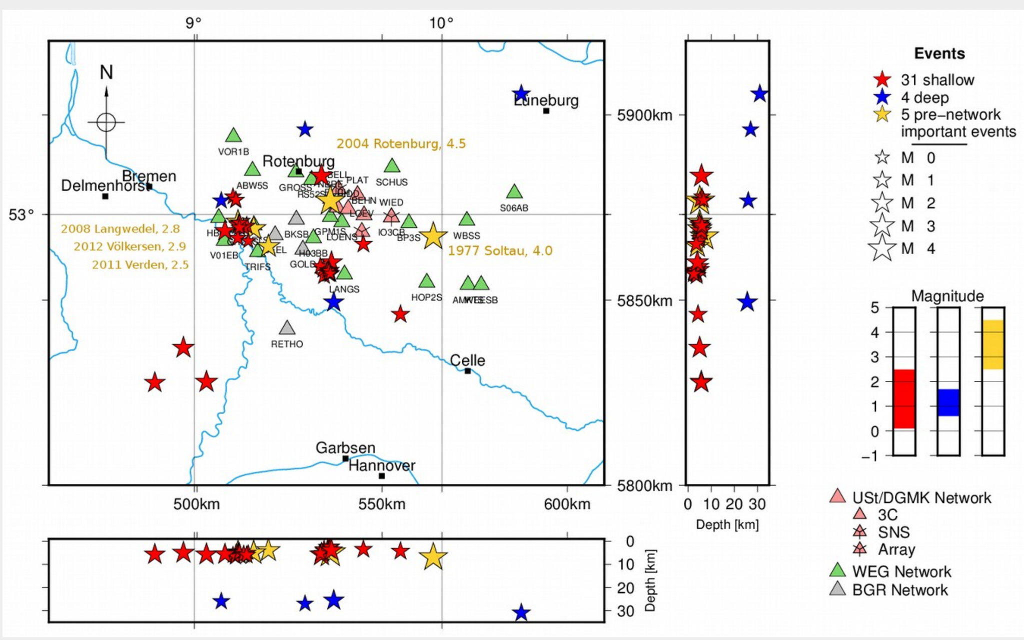
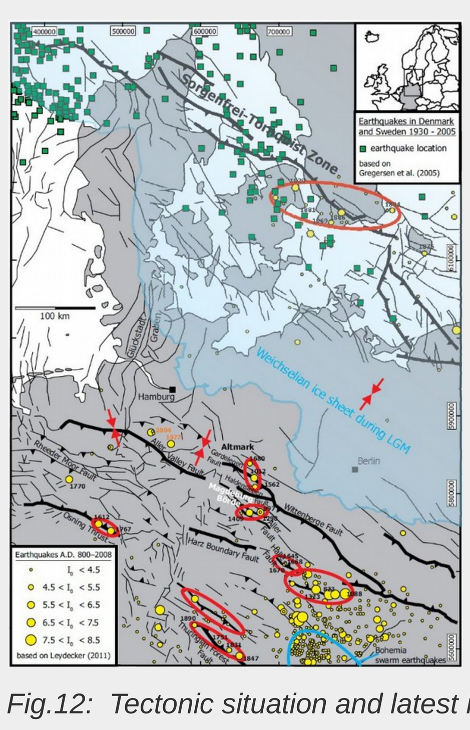


Fig.11: Localisation of all seismic events from DGMK project 761 in wider region. Red and blue stars indicate shallow and deep earthquakes (respectively) detected and localized by USt. Yellow stars represent older events like Soltau event (1977, M_L 4.0), Rotenburg (2004, M_L 4.5) and Visselhövede earthquake (2012, M_L 2.9).

Conclusions:

Northern Germany is regarded as a typical low strain intraplate area with generally low seismic activity. However, historic sources show that the region has been affected by some significant tectonic events during the last 500 years (see fig. 12). Our investigations have revealed several very deep crustal earthquakes situated between and around the existing gas-fields (see figs. 8-11). At least one of these deep earthquakes has been wrongly located at the edge of one of the gas-fields, in reservoir-depth; a fact that is of great importance for the gas-producing companies. The reasons for the deep-crustal seismicity is probably found in the post-glacial isostatic adjustments in northern Germany (see fig. 12). The ice-shields reached - during the last Weichselian Period - the North German Basin and may have now, 10.000 years later, larger effects on the seismicity in a regional and local scale than assumed before.



Elbe Fault System
(Central European Basin System [CEBS])

Ongoing field stress:
- Continent collisions in the Alps,
- The ridge push in the North Atlantic Ocean,
- Post-glacial isostatic adjustment process.

Faults of northern Central Europe and epicenters of historic earthquakes
potential earthquake clusters
major Late Cretaceous reverse faults
recent stress field orientation
LGM—Last Glacial Maximum
historic earthquakes from A.D. 800 to 2008
Soltau and Rotenburg events
earthquakes from 1930 to 2005
swarm earthquakes in Bohemia

Brandes et al. (2015)
Map based on Kley and Voigt (2008)

Fig.12: Tectonic situation and latest ice-shield extension in northern Germany.

Increase of Network performance

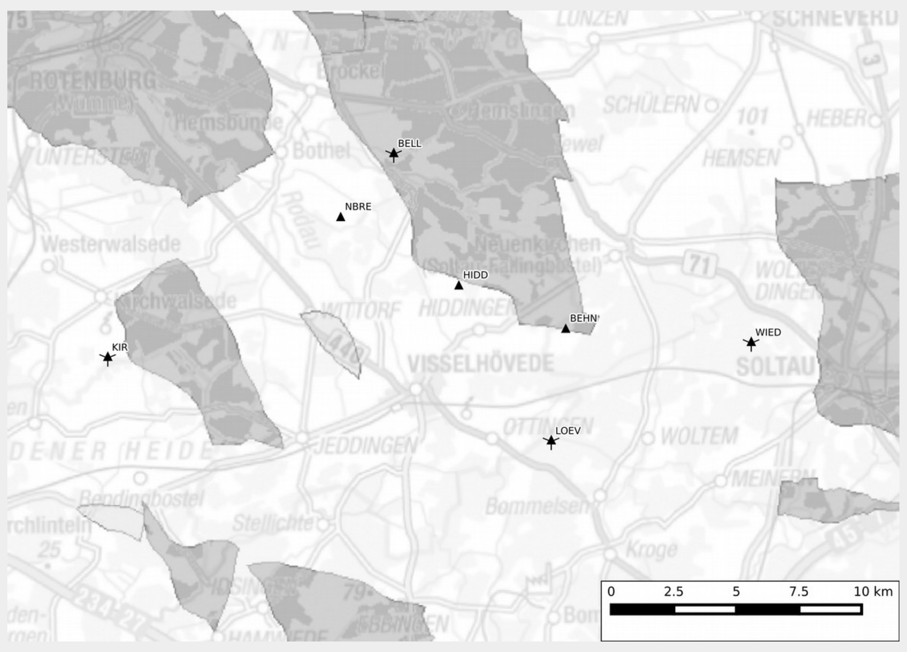


Fig.4: Overview of the current network arrangement in the region surrounding Visselhövede. The super-arrays KIR and LOEV are set up at former military sites in remote low-noise areas. The former BGR-station BKSB had its place at KIR, but was abandoned in the beginning of 2016. (Map data provided by NIBIS-Server (LBEG). Edited with QGIS.)

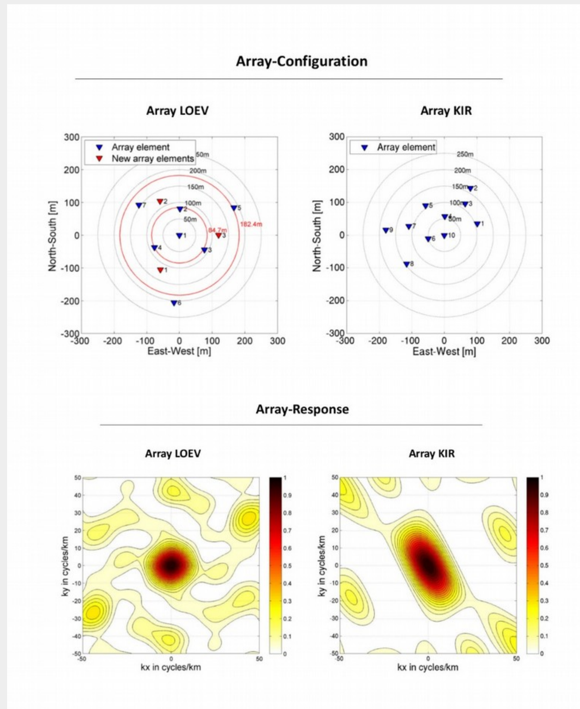


Fig.5: Array configuration (top) and array response (bottom) of the new super-array KIR in comparison to the well-established LOEV-super--Array. The stretched SW-NE orientation of KIR-seismometers leads to a perpendicular orientated, elongated behaviour of the Array-Response values distribution.

Seismic network build-ups of five or more stations is well known in literature and belongs to classical seismic technics. Evaluation of single array, like LOEV and KIR (see fig.4 for an overview), with F-K analysis is also familiar in seismology. However the concept of several mini-arrays and also two super-arrays (with 10 components; see fig. 5) as sensitive detection method for seismic monitoring of gas fields is new. This technic (Nanoseismic Monitoring) takes advantages of mini-arrays and advanced signal processing tools to optimize seismic event detection and location down to the noise threshold (equivalent to S/N-ratio of 1).

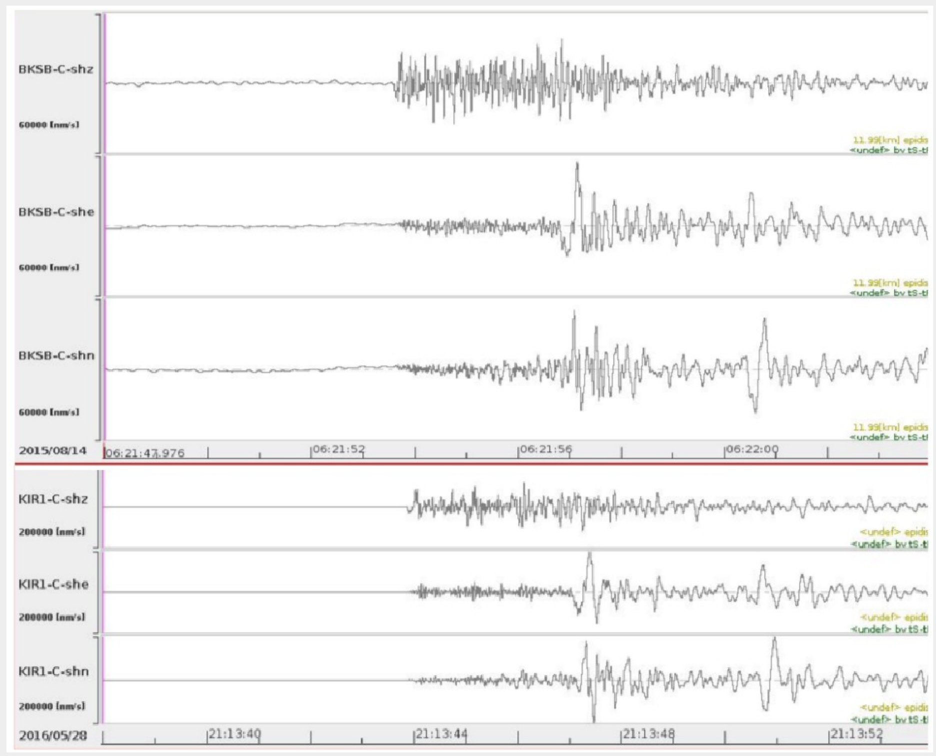


Fig.6: Raw data example from KIR: comparison of unfiltered waveform data of an event at Bothel/Helmsbünde in the year 2015 recorded at BKSB (a BGR-Station) and from May 28th in the year 2016 as recorded by the KIR-array (University of Stuttgart). The similarity of the onsets and of the behaviour of the horizontal traces is obvious and leads to the conclusion that the focal mechanism is comparable.

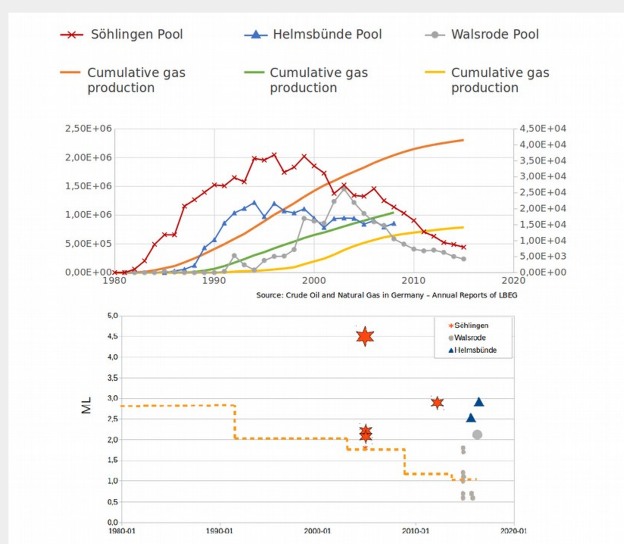


Fig. 7: Seismicity-time-plot for a part of the northern german gas-fields. The changes in detection threshold led to a increasing number of observations during the last decade and especially during the last years (due to the installation of the WEG/DMT-network and the network of the University of Stuttgart).

Although the DGMK Nanoseismic Monitoring network is scattered on a small area and all stations contain the same seismic sensors, there are a slight differences in noise level between them. The quality of data depends not only on local traffic but also on the type and thickness of substrate.Development and adaptation of automatic detection methods to the specific network configuration has significantly improved monitoring and detection of seismic events in the project (see fig. 7). Surprisingly, almost no events in close ambit of the network have been observed as it had been expected from the major local earthquakes 2004 M_L 4.5 Rotenburg and 2012 M_L 2.9 Visselhövede.

Literature:

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