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Active tectonics in Northwest Germany: glacial isostatic adjustment and/or a consequence of hydrocarbon production?

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The aim of the DGMK (German Society for Petroleum and Coal Science and Technology) project 773 was to analyse trigger mechanisms for the recent earthquakes in NW Germany in order to better differentiate between potential anthropogenic and natural tectonic drivers. Possible trigger mechanisms are stress changes related to either the extraction of natural gas and/or processes of the ongoing glacial isostatic adjustment. The project was divided into three major parts; (i) seismological analyses; (ii) geological 3-D subsurface modeling and (iii) numerical simulations of glacial isostatic adjustment. In a novel approach, two differently scaled 3-D P-wave-velocity models were used in NonLinLoc to relocate seismic events in NW Germany. Focal mechanisms were determined and synthetic seismograms were calculated to constrain hypocenter depths and focal mechanisms. The geological 3-D subsurface models were created with GOCAD and used to visualize subsurface structures. Relocated hypocenters were linked with these subsurface structures to identify seismogenic active faults. Subsequently, numerical simulations with six different rheology models were carried out by Holger Steffen (Landmäteriet, Gävle, Sweden) to test the probability for GIA-induced earthquakes in NW Germany.

Most of the seismic events in NW Germany, which are ranging in depths between 5 and 9 km are concentrated along the Rotliegend rift normal faults in close proximity to the natural gas fields. Due to their spatio-temporal occurrence, their normal fault focal mechanism and their small magnitude they are most likely induced earthquakes caused by the natural gas extraction. Driving forces for slightly stronger earthquakes (ML $\geq$ 4.0) of greater depth seem to be more complex.

Controlling factors for the few deep earthquakes in northern Germany are difficult to derive. However, our results clearly indicate that also GIA-induced stress changes as a result of the melting of the Late Pleistocene ice sheet may play a role in case of fault reactivation in the study area.