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Editorial

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This special issue of the *Netherlands Journal of Geosciences / Geologie en Mijnbouw* contains research papers offering important new insights into aspects of the occurrence of gas-production-induced seismicity in Groningen, the Netherlands. The issue is a 'work in progress' and provides a snapshot of our knowledge at the end of 2016, which is when most of the contributions were written.

Since the early 1990s, relatively small earthquakes have occurred in the vicinity of the Groningen gas field. The earthquake in Huizinge, Groningen, in 2012 was the strongest event recorded to date, with a magnitude of 3.6, and caused damage to buildings. Following this event the Dutch Minister of Economic Affairs called for an extensive study programme involving various institutions, universities and research centres to increase the understanding of occurrences and magnitudes of earthquakes induced by gas production and to assess the hazard they pose. In 2013, 53.9×10^9 m^3 of natural gas was extracted from the Groningen field. Based on, among other things, newly obtained research results (some of which are presented in this issue), the government scaled down production from 42.5×10^9 m^3 in early 2014 to 27×10^9 m^3 for the year 2015/2016 and further to the current 21.6×10^9 m^3 for the 2017/2018 gas year. (A gas year starts in October and lasts until the end of September the next year.)

The Groningen gas field is operated by the Nederlandse Aardolie Maatschappij BV (NAM), a joint venture between Royal Dutch Shell and ExxonMobil, with each company owning a 50% share. After the Huizinge event, NAM set up an extensive accelerated research programme to provide a detailed seismic hazard and risk assessment and submitted a new production plan ('winningsplan' in Dutch) for the Groningen field in 2016. As part of the approval procedure, all technical reports became public (namplatform.nl). These studies mainly cover the relationship between production and subsidence, and the effect of earthquakes on buildings. A Scientific Advisory Committee, installed by the Ministry of Economic Affairs, provided independent external oversight of the NAM studies supporting the hazard and risk assessment in the production plan 2016. At the same time, parallel studies by, amongst others, TNO (Geological Survey of the Netherlands), KNMI (Royal Dutch Meteorological Institute), CBS (Statistics Netherlands) and SodM (Dutch State Supervision of Mines) are published on a regular basis and can be accessed through various sources (e.g. nlog.nl, knmi.nl and sodm.nl). The studies are considered a unique undertaking with a strong multidisciplinary character. Several of the reports present statistical proof that lowering gas production in the centre of the field since January 2014 has reduced seismicity.

The research resulted in a better understanding of induced seismicity, but these types of study are continuously evolving. We have only just started to learn lessons from the recent history in Groningen, and certainly these are not only technical, but also societal in nature. Scientists therefore have a role to play in communicating their work to the public; results should be able to support policymaking and strengthen programmes and decisions. Communication with our scientific colleagues normally takes place via research papers in peer-reviewed journals. These are, however, sometimes difficult to find and topics are spread out over a large number of such journals. Our wish was to combine all the, mostly subsurface, subjects related to gas-production-induced seismicity in Groningen in one scientific journal for communication to the broader scientific community and interested members of the public. In 2016, we therefore started to invite researchers to participate in a special issue of the *Netherlands Journal of Geosciences / Geologie en Mijnbouw*.

Papers in this special issue are grouped by a number of themes: 'Setting the scene', 'Statistical analysis', 'Geomodelling', 'Hazard assessment', 'Risk assessment' and 'Further studies'. In 'Setting the scene' a review paper on the geology of the Groningen field is followed by a paper on the challenges faced by the Dutch Regulatory Authority (SodM) for all mining activities in the Netherlands. The latter paper, 'From checking deterministic probabilities, scenarios and control loops for regulatory supervision', describes and analyses the tasks when translating incomplete and sparse datasets on earthquakes and variations in gas production into rules and regulations. The paper under the theme 'Statistical analysis' investigates the statistical

relationship between changes in production and the frequency and severity of earthquakes.

The 'Geo-modelling' theme comprises a set of eight papers covering various aspects of building detailed and accurate reservoir models. Topics include the building of a geo-cellular reservoir model, history-matching of that model, as well as detailed analysis of geomechanical properties and of fault systems. This includes modelling of the responses of reservoir rocks and fault systems to pressure depletion.

Under 'Hazard assessment' we group seven papers that describe and analyse various techniques and models that attempt to predict the location and severity of production-induced earthquakes. This is closely linked to the 'Risk assessment' theme in which three papers analyse how different types of buildings and/or construction methods, in combination with variations in surface soil properties, respond to induced seismic events. Also included under this theme is an analysis of how induced seismic risk varies depending on variations in gas production rates.

Despite the impressive quantity of new scientific results, it is not yet possible to reliably predict, on a scientific basis, what the effect of variations in rates of gas production will be on induced seismicity. From the Regulator's perspective, induced seismicity must be carefully and continuously monitored and production rates adjusted should any agreed boundary conditions (e.g. frequency and/or magnitude of induced seismic events) be exceeded: i.e. an empirical approach.

However, from a scientific perspective our, as yet inadequate, understanding of the fundamental physical mechanisms at work in the Groningen reservoir rock means that it is important that we continue to pursue a proper understanding so that truly predictive models may be built. This issue is addressed in the paper 'Research into induced seismicity in the Groningen field – further studies'.

Should you wish to familiarise yourself with earlier publications about the Groningen field then we refer you to several earlier papers in *Geologie en Mijnbouw*. The papers by De Ruiter et al. (1967), Bor (1968), te Groen & Steenken (1968), Udink (1968), Van der Laan (1968), Willems (1968), Van Engen (1975), Doornhof (1992), Van Hasselt (1992) and Breunese & Rispens (1995) are a good starting point. The proceedings of the 'Groningen – Catalyst for the North West European Oil and Gas Industry' conference were also published in *Netherlands Journal of Geosciences / Geologie en Mijnbouw* (Donkert & Dijkhuis, 2001 and papers therein). That special issue provides a fairly comprehensive set of papers on the political, commercial and technical aspects of the Groningen field as viewed in 1999. Please note that all these publications can be accessed digitally through the KNGMG (Royal Geological and Mining Society of the Netherlands) website (kngmg.nl/njg).

We hope that this Editorial has whetted your appetite to read the, mostly technical, papers in this special issue, and even more importantly that it has given you an insight into the complexity of the subject. Finally, we, as guest editors of this volume, would like to thank the authors for their contributions, the many peer reviewers for their comments, and the *Netherlands Journal of Geosciences* for its help with publishing these state-of-the-art analyses of induced seismicity in the Groningen field. In particular, Johan ten Veen (editor-in-chief, *Netherlands Journal of Geosciences*) and Joost Roholl (TNO) have been instrumental in taking this work from an aspiration to a reality. Note that all publications in this *NJG* special issue are *open access* and can be freely downloaded via Cambridge University Press.

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