Even voorstellen…

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- Universitair Docent in Petrofysica
- Department of Geoscience and Engineering
- Faculteit van Civiele Techniek en Geowetenschappen – TU Delft

- 8 jaar in buitenland gewoond
- Nu 5 jaar in Delft

- Getrouwd, 2 zonen (7 en 1 jr)

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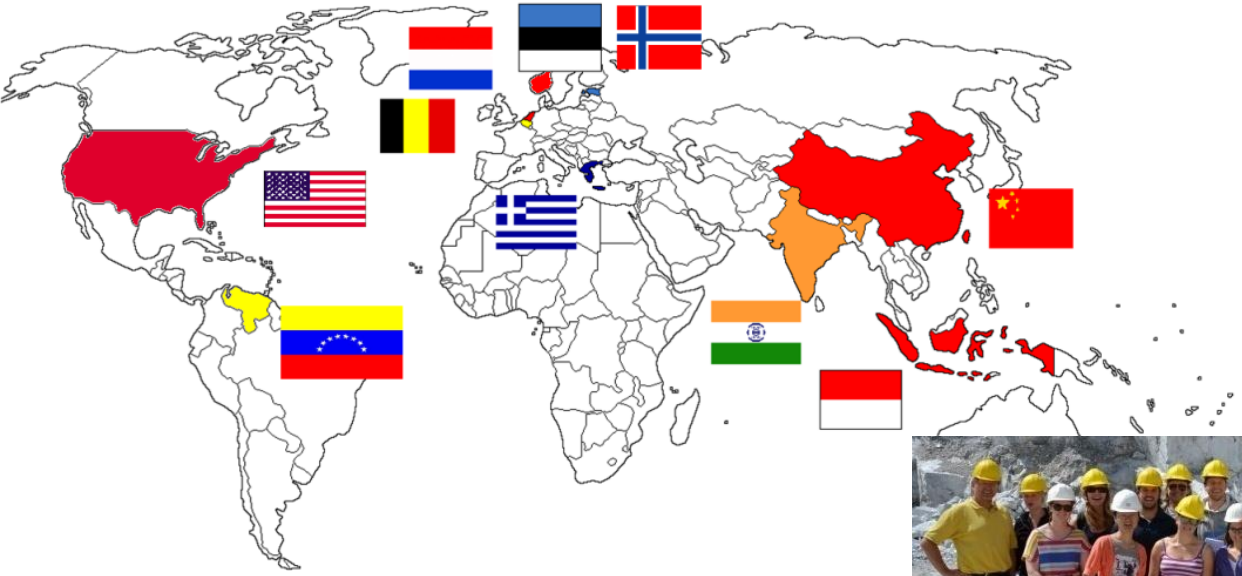
Wat doe ik in Delft?

- Onderwijs
  - BSc Studenten Technische Aardwetenschappen
  - MSc Studenten Petroleum Engineering and Reservoir Geology

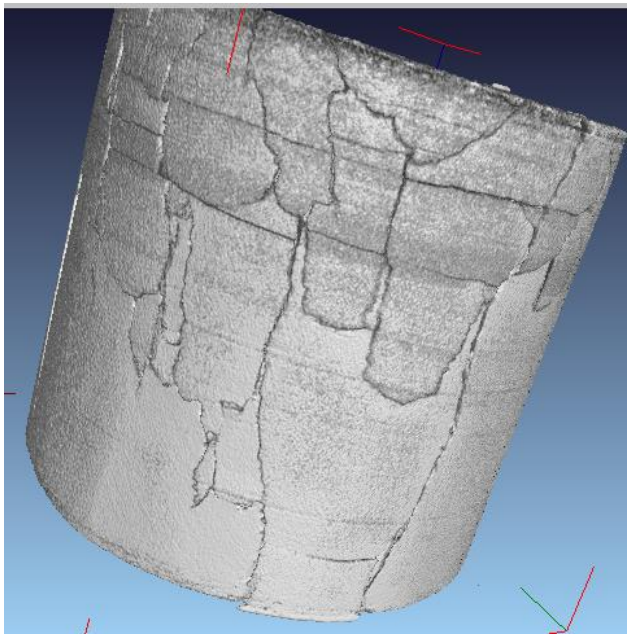
  - Begeleiden van afstudeerstudenten



Wat doe ik in Delft?

- **Onderzoek**
  - Experimenteel gesteente mechanisch onderzoek
  - 3D visualiseren van gesteentes

Doel: begrijpen van scheurvormingsprocessen



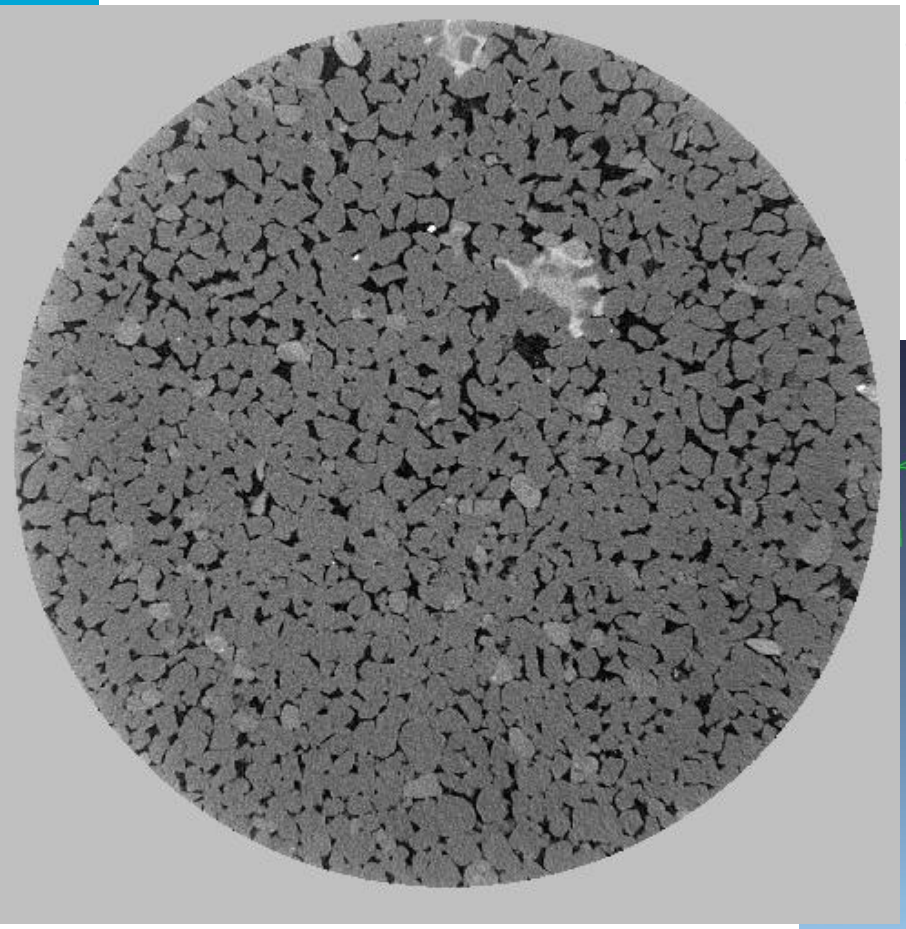
Toepassingsgebieden:

- Fundamenteel onderzoek
- Geothermie
- Olie/gas winning
- CO2 opslag
- Aardbevingen

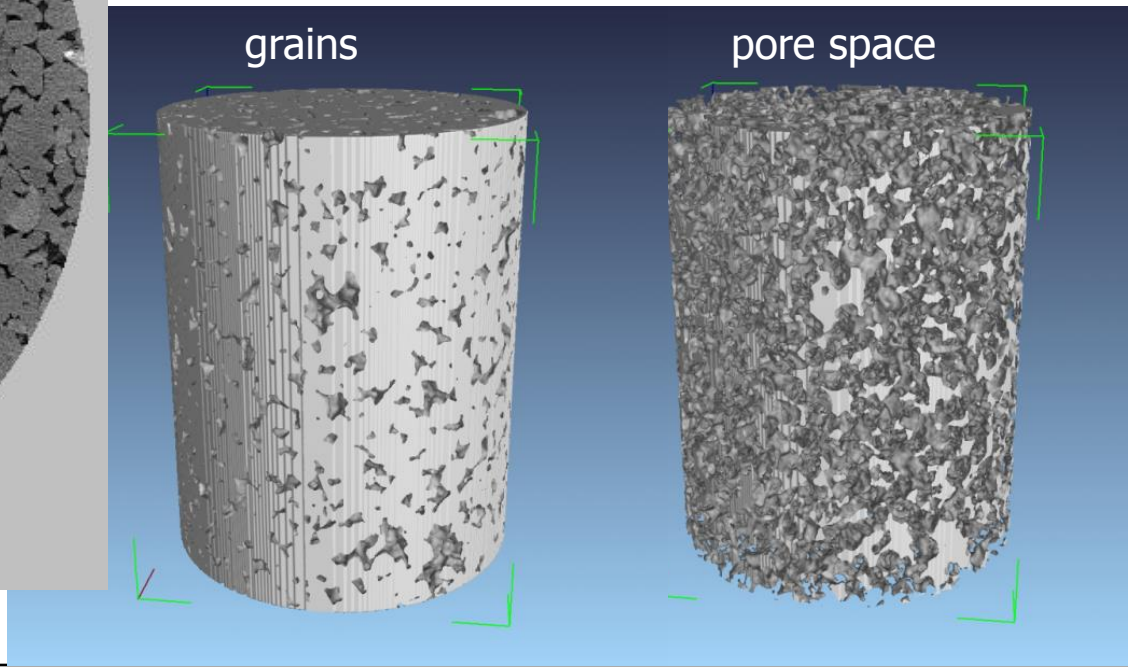
Vandaag

- Onze ondergrond en onstaan van gas reservoirs
- Het Ternaard gas veld
- Gaswinning en Aardbevingen en Bodemdaling
- Slot opmerkingen

Hoe ziet de ondergrond eruit?



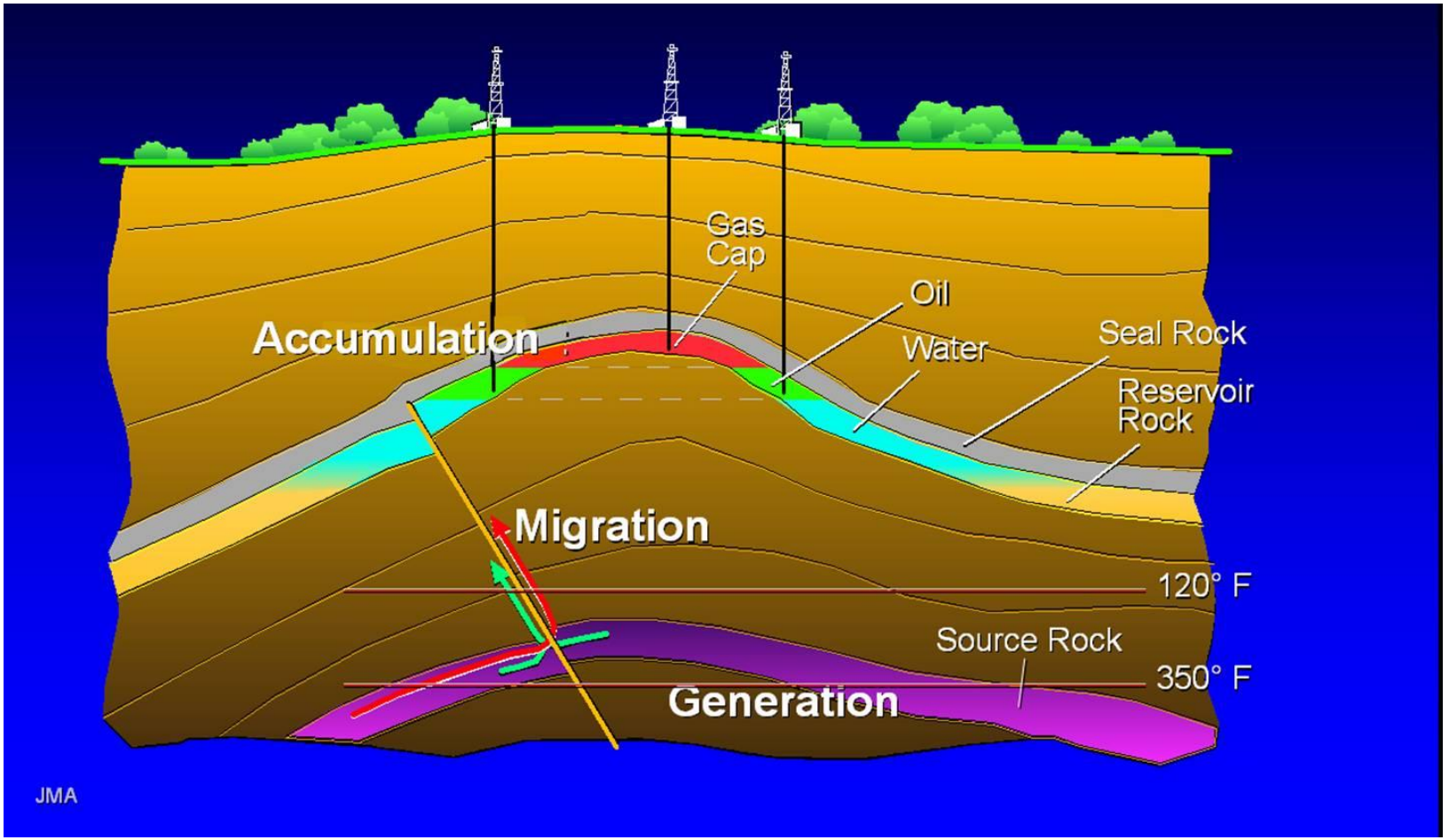
- Zandsteen
- Holle ruimtes (porositeit) gevuld met olie/gas
- Holle ruimtes 200 μm groot (0.2 mm)



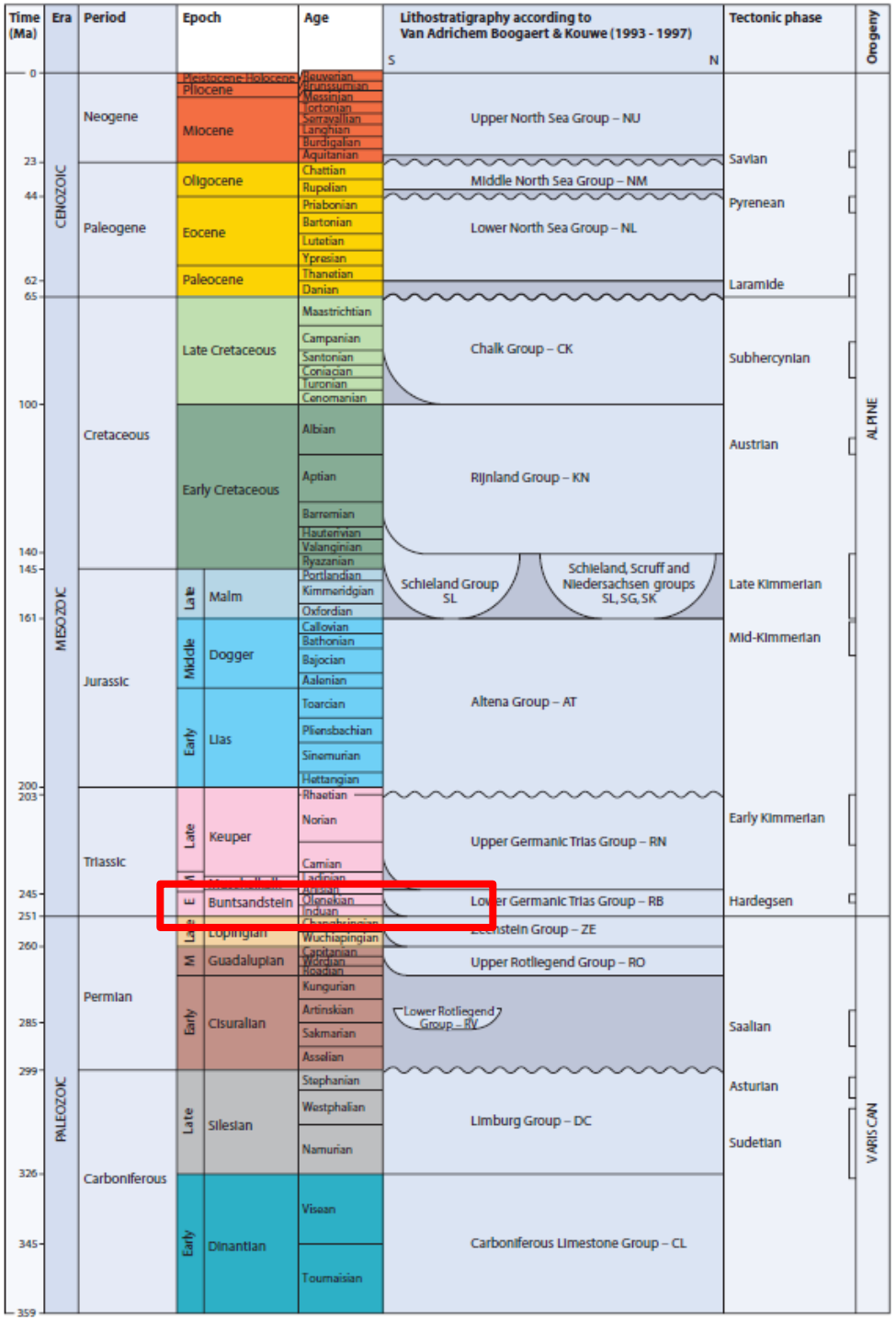
Zandsteen

Bad Bentheim, Duitsland

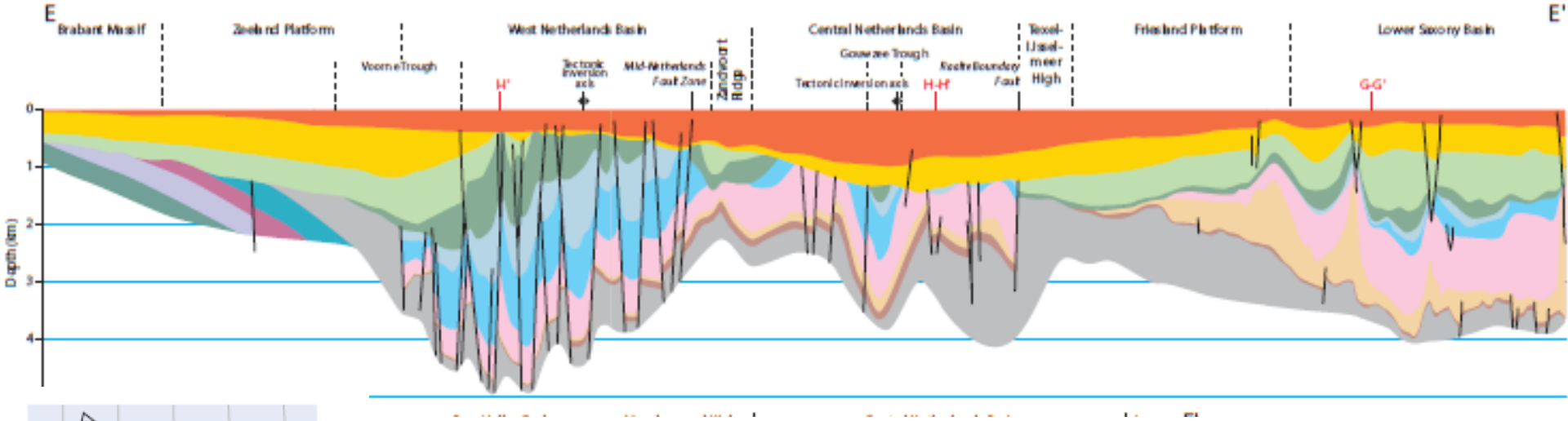
Boring tot 2-5 km diepte

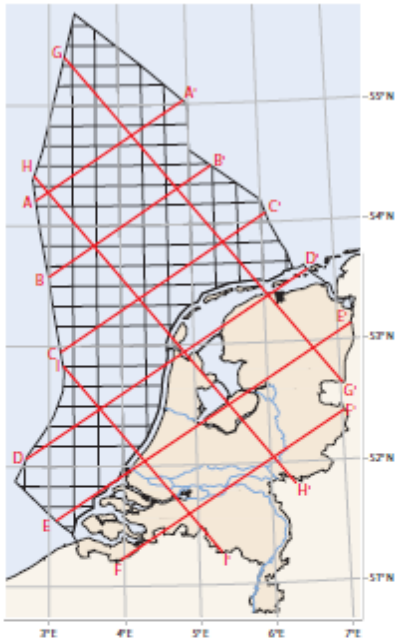


Stratigrafische kolom van NL



Duin et al., 2006





Upper North Sea Group
Lower and Middle North Sea groups
Chalk Group
Rijnland Group
Schieland, Scruff and Niedersachsen groups
Altena Group
Lower and Upper Germanic Trias groups
Zechstein Group
Lower and Upper Rotliegend groups
Limburg Group

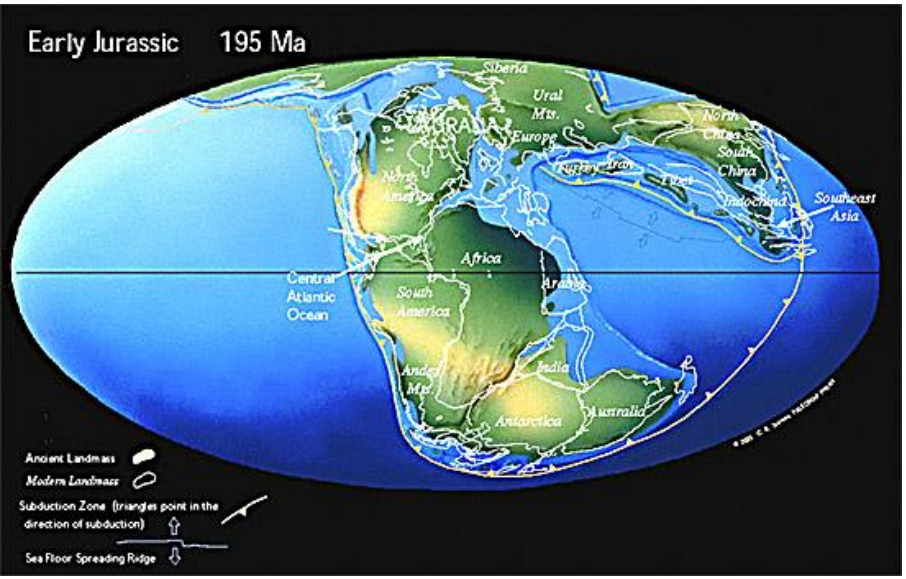
Ondergrond van Nederland

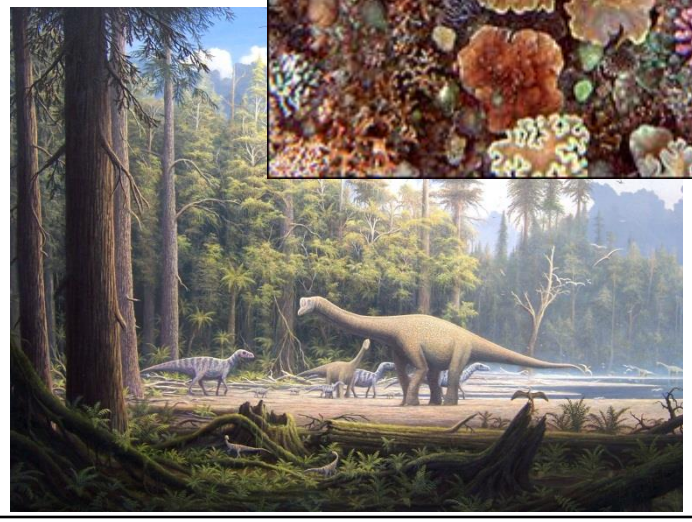
Duin et al., 2006

Hoe wordt gas of olie gevormd?

1. Moedergesteente

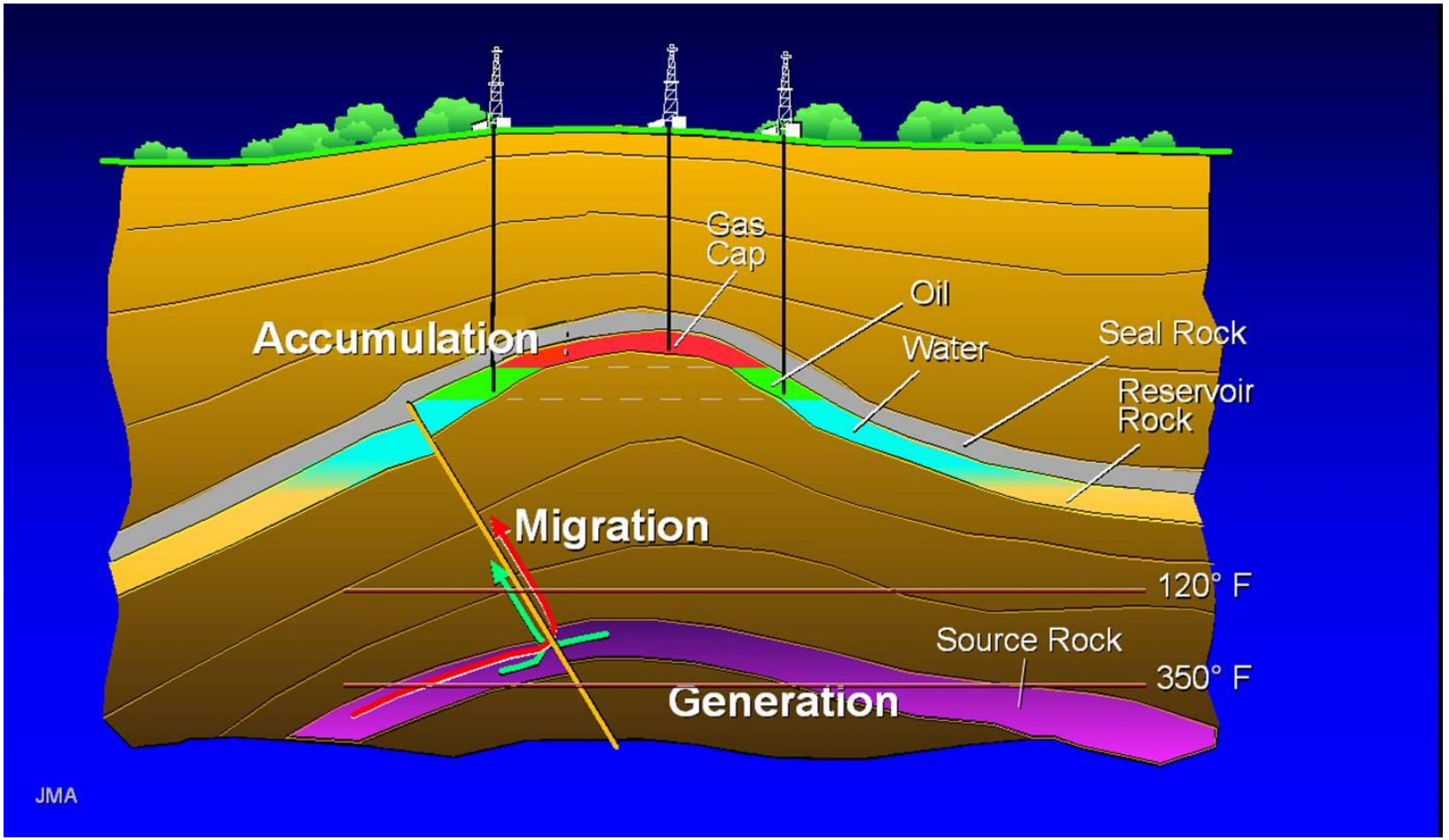
~175-300 million years ago



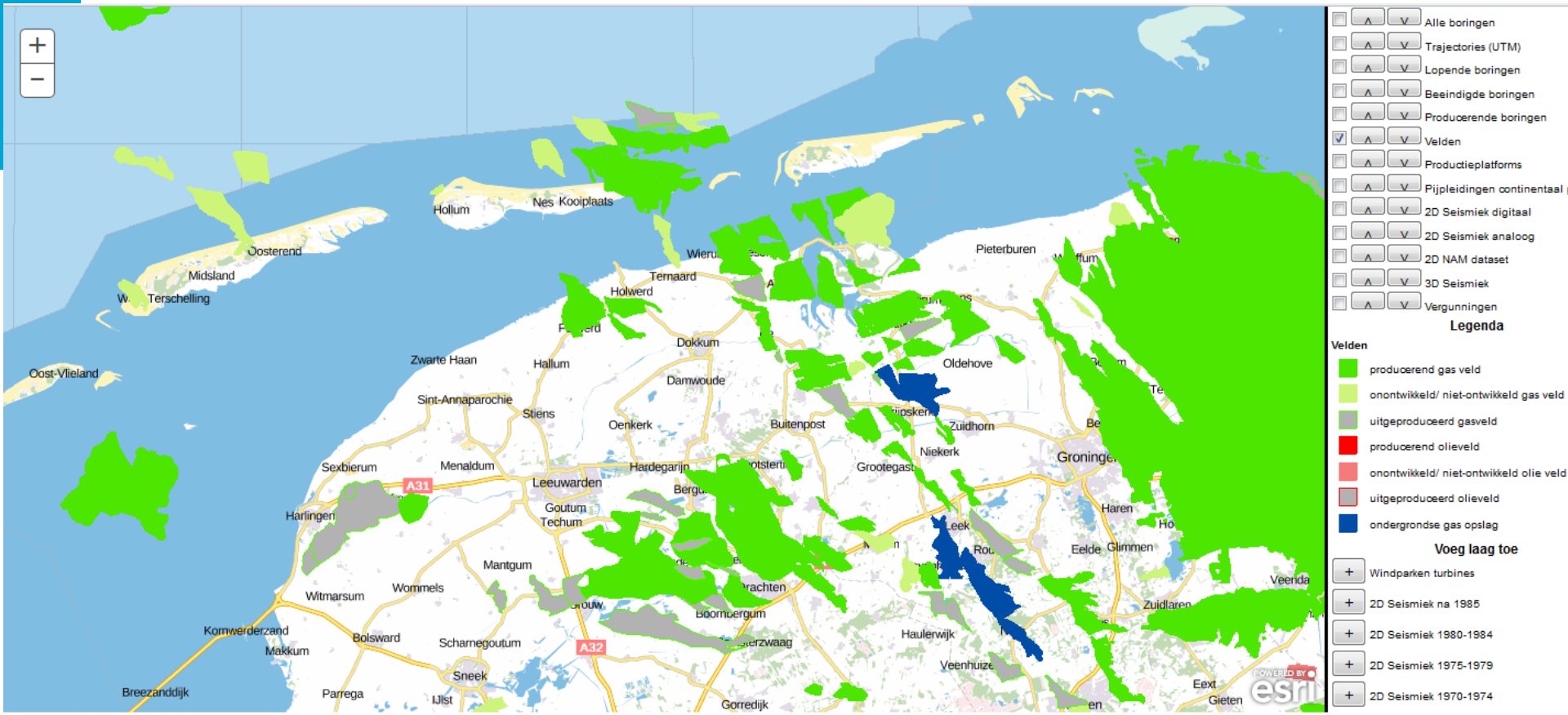


- *Warm & High sea level*
- *Abundant marine deposits / Tropical forests*
- *Organic-rich limestones, clays etc.*

Boring tot 2-5 km diepte



Gasvelden in NL



Gasvelden in NL

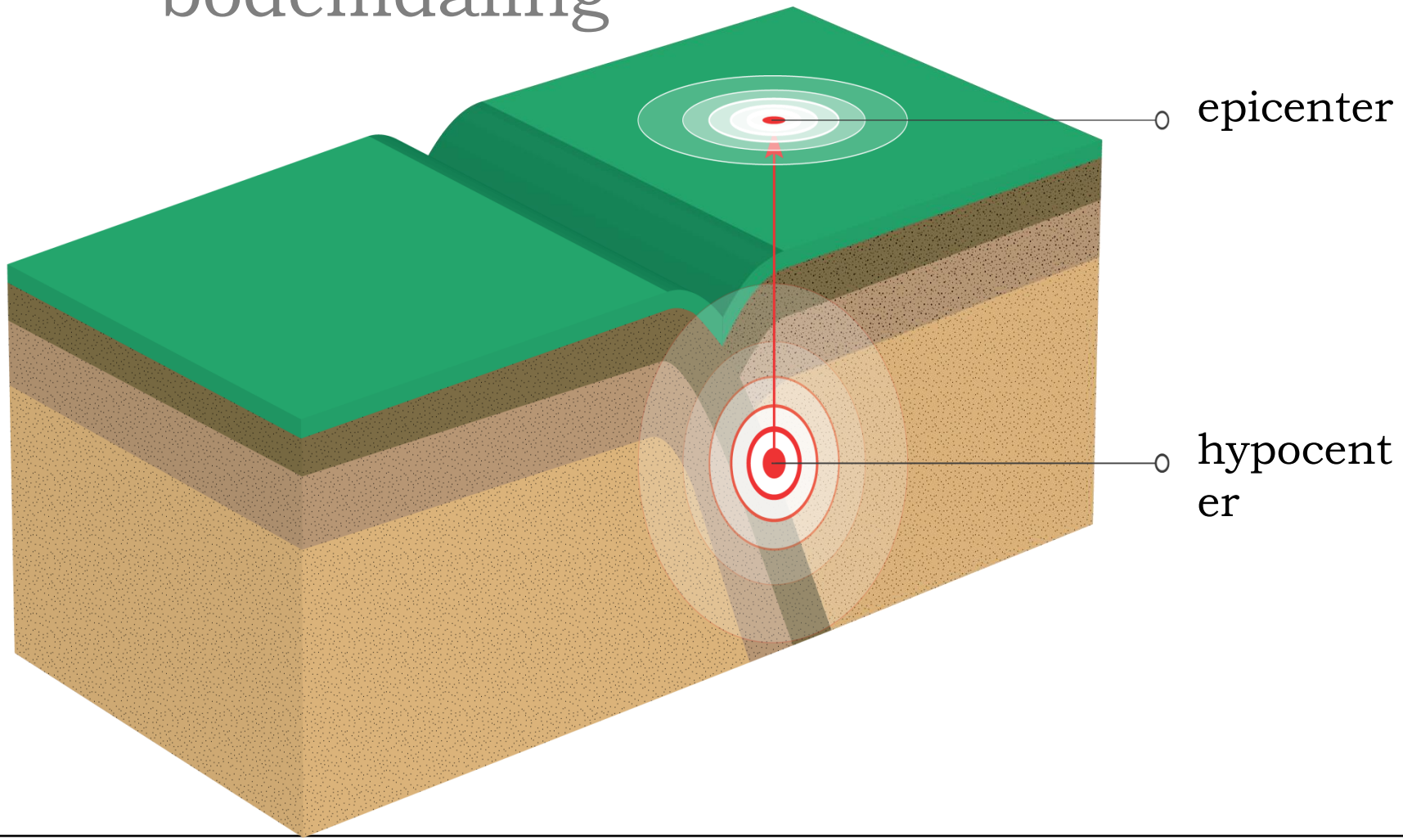
Ternaard gas veld

- Upper Slochteren zandsteen (Perm ouderdom)
- Zandsteen onder de Zechstein zout formatie

- Langwerpig N-Z reservoir ('structurally defined')
- Dikte: ~104 m
- Porositeit: ~14.4%
- Permeabiliteit: ~ 1.6 mD
- 4 Miljard kubieke meter gas

Factsheet Ternaard from nlog.nl (TNO & Ministerie van Economische Zaken)

Gaswinning en aardbevingen bodemdaling



Natural and Induced Earthquakes

high natural stress build-up

low natural stress build-up

Japan, Italy, New Zealand and 1992 Roermond (NL)

Basel (geothermal) Blackpool (shale gas)

waste water injection (Oklahoma)

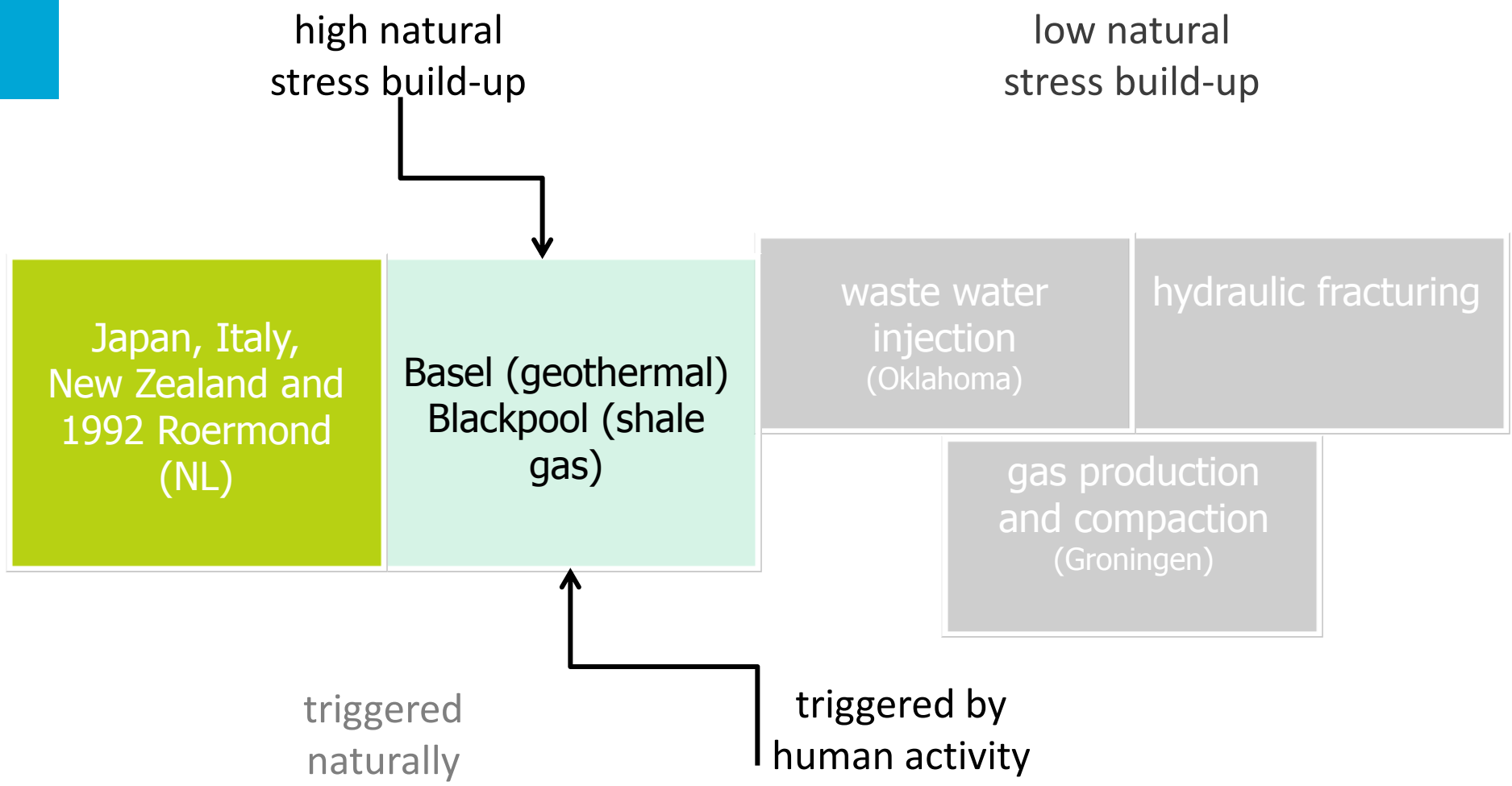
hydraulic fracturing

gas production and compaction (Groningen)

triggered naturally

triggered by human activity

Natural and Induced Earthquakes



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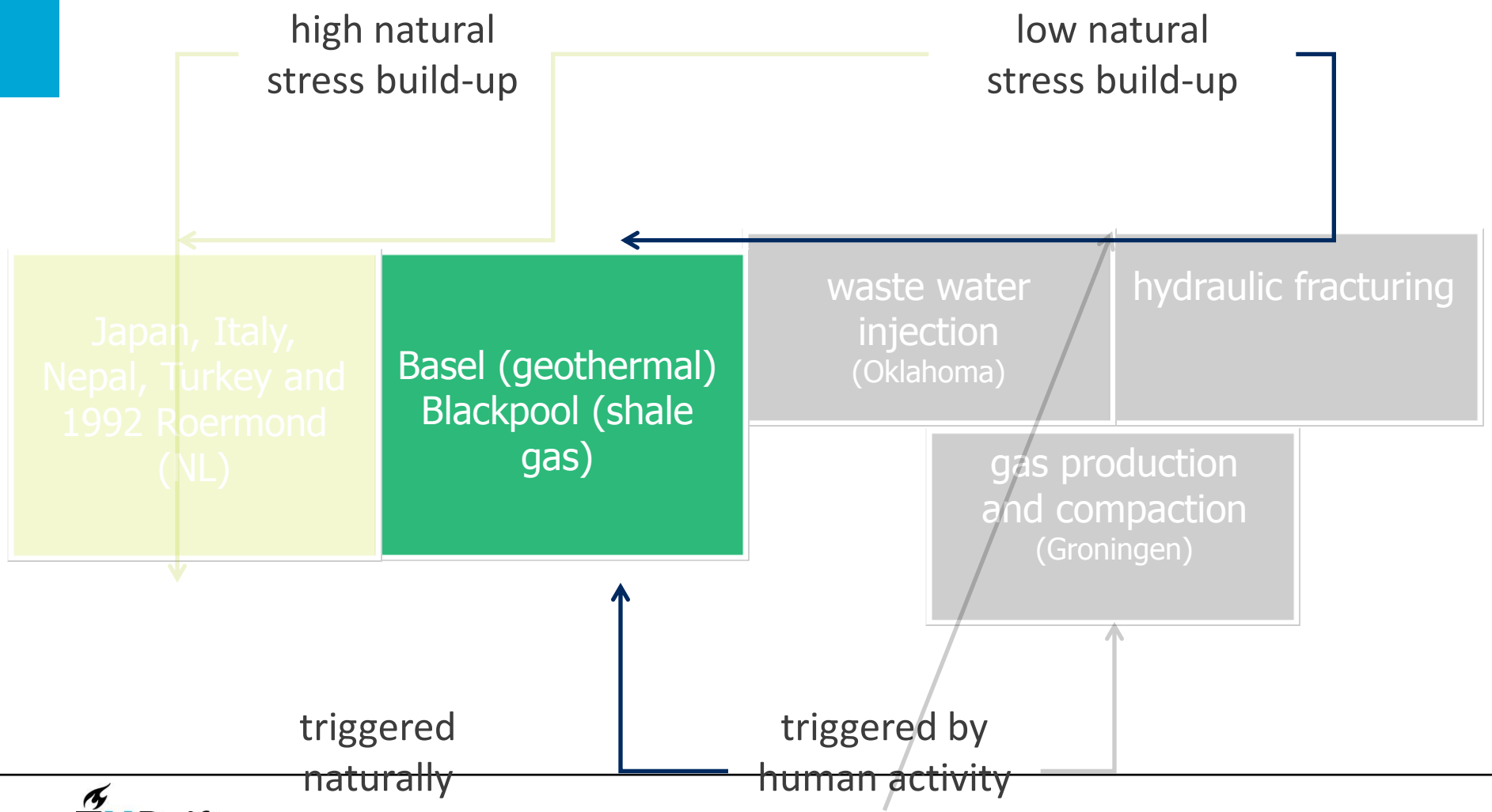
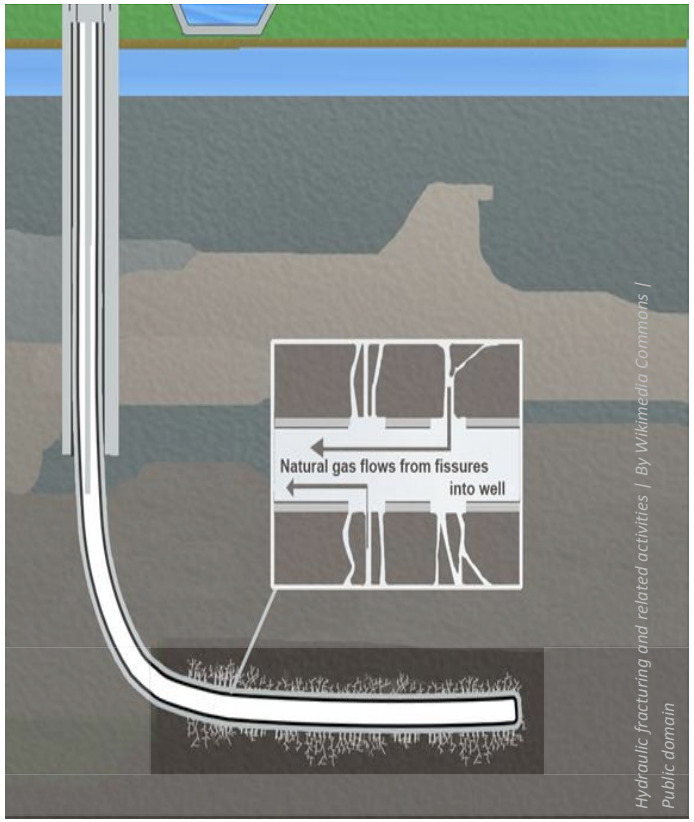
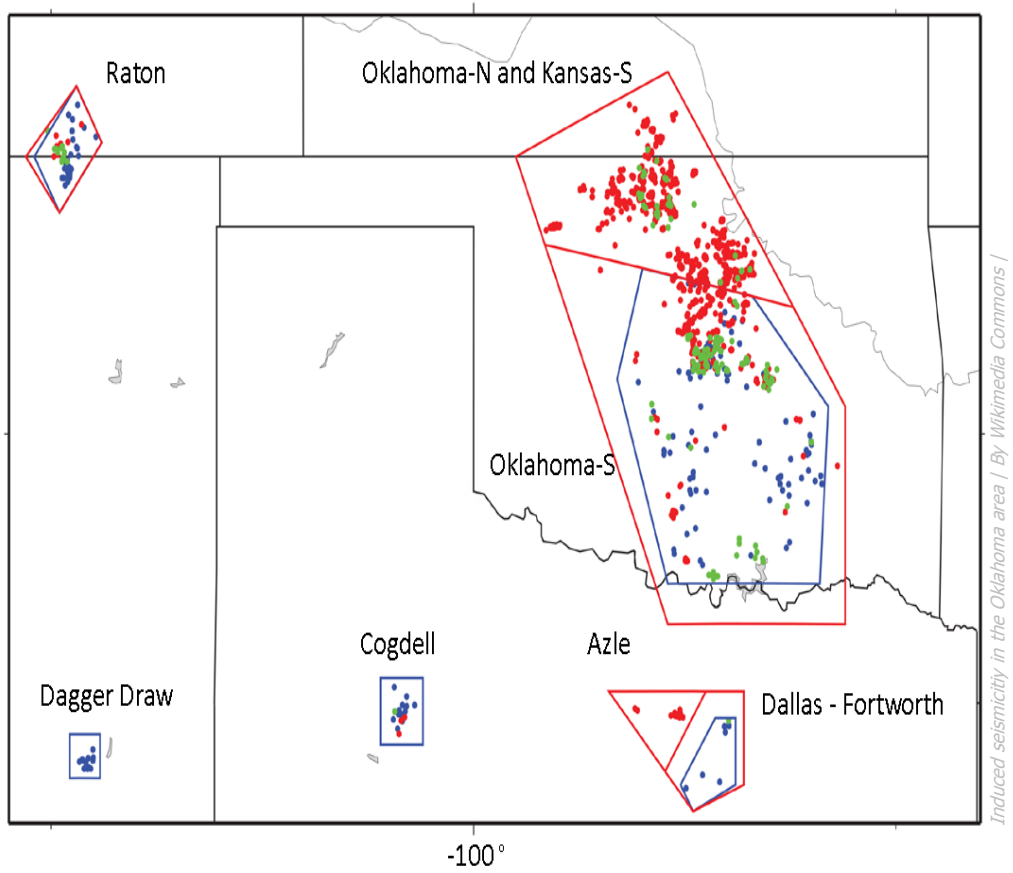


Voorbeelden

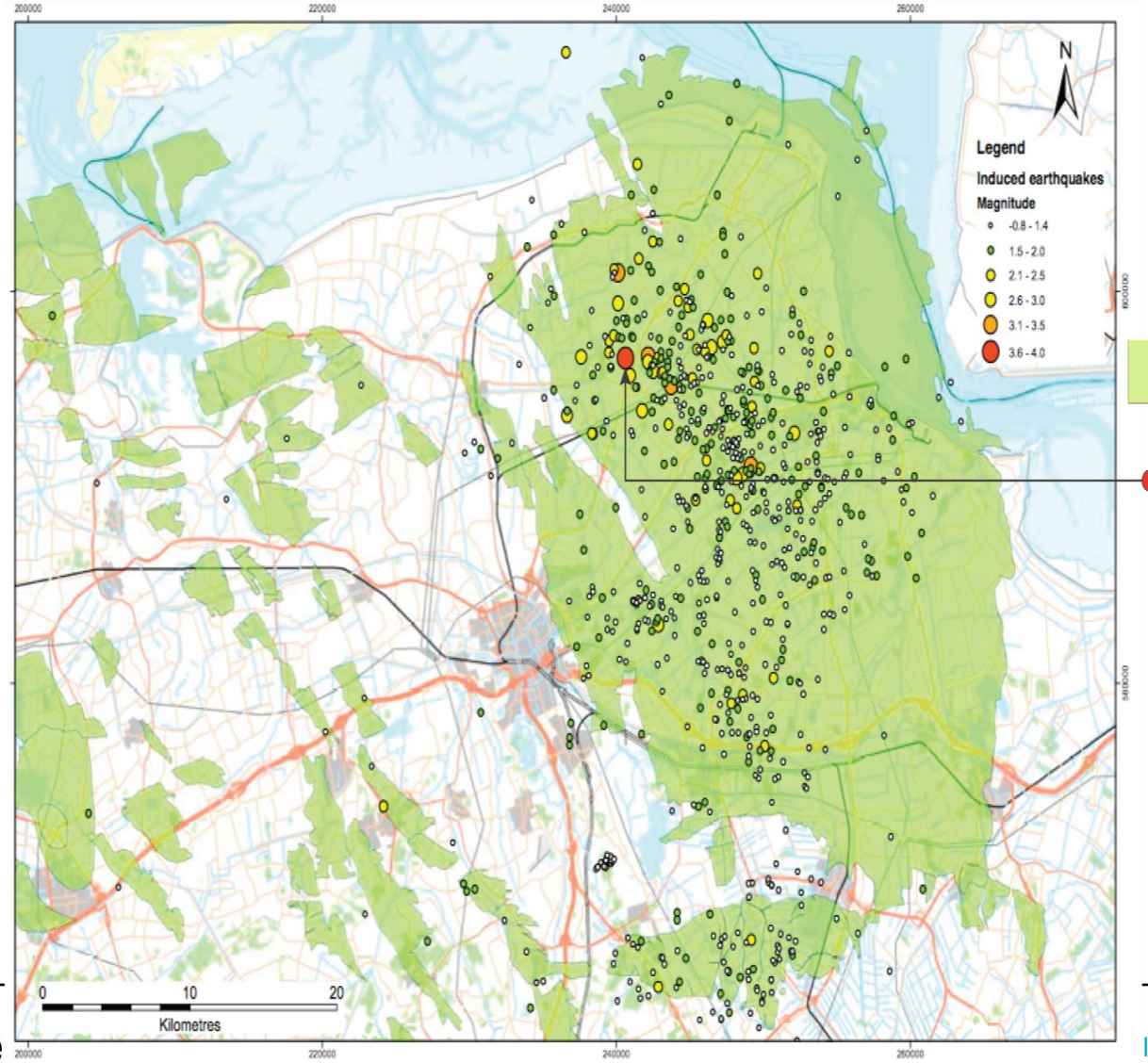


hydraulic fracturing



waste water injection

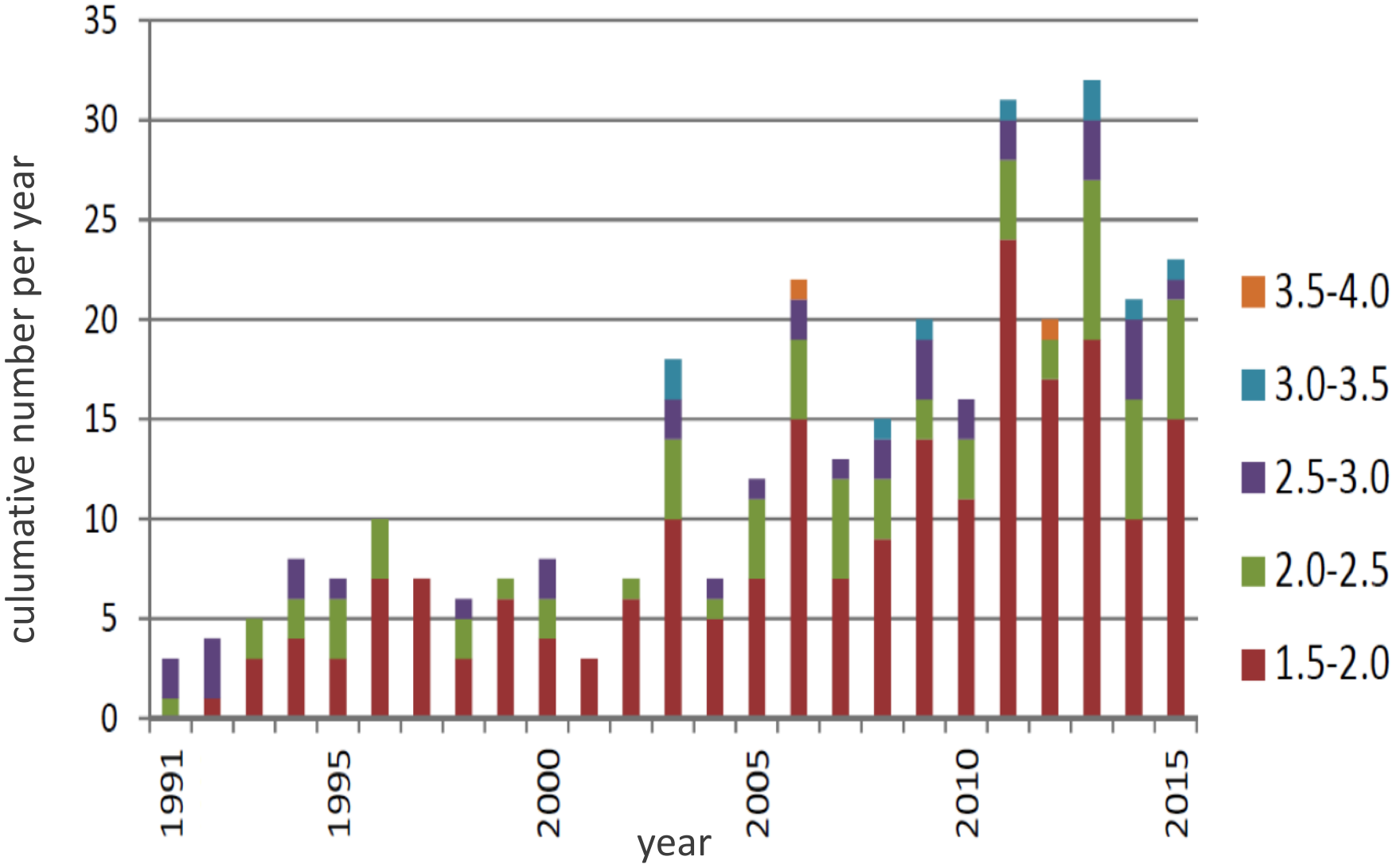
Recording of Earthquakes since 1996



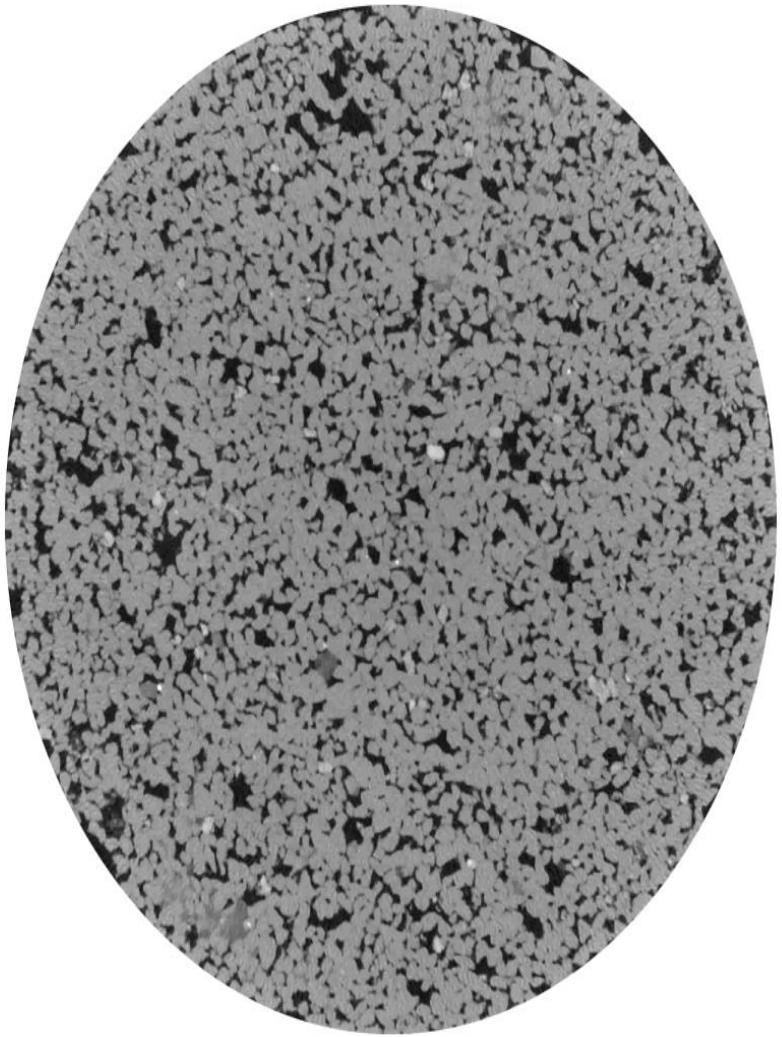
gas fields

2012
Huizinge
M3.6

Activity Rate in Groningen



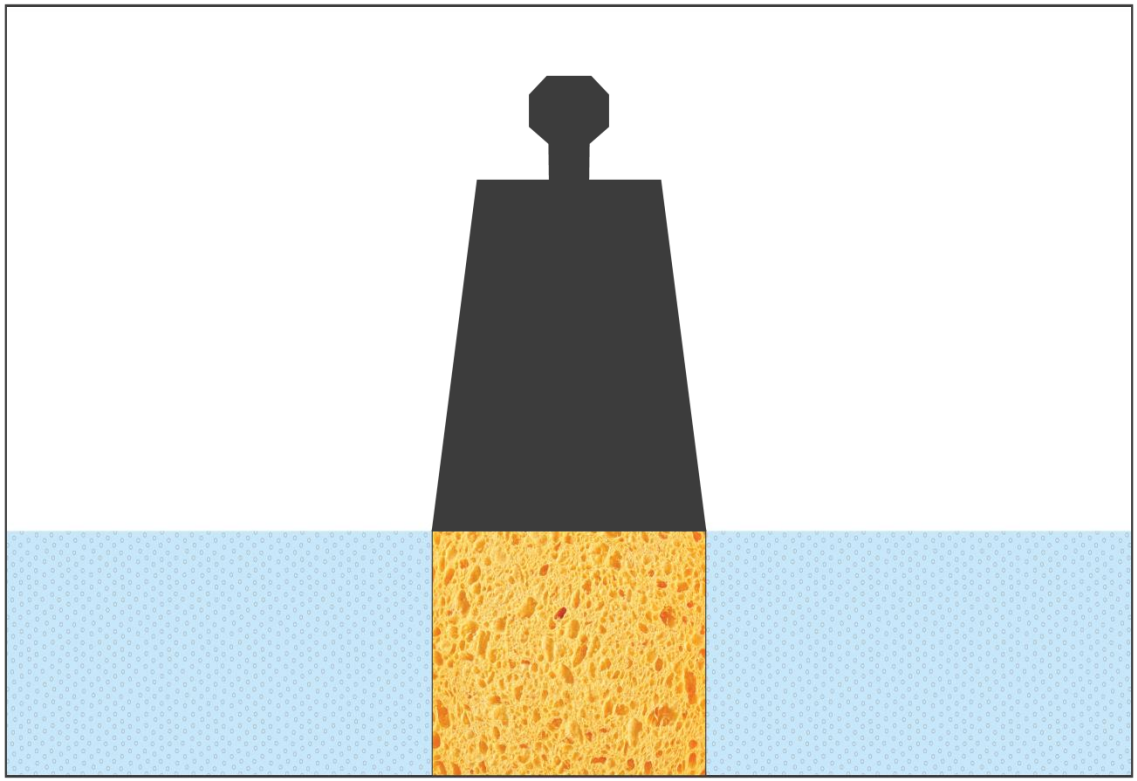
Wat is compactie?

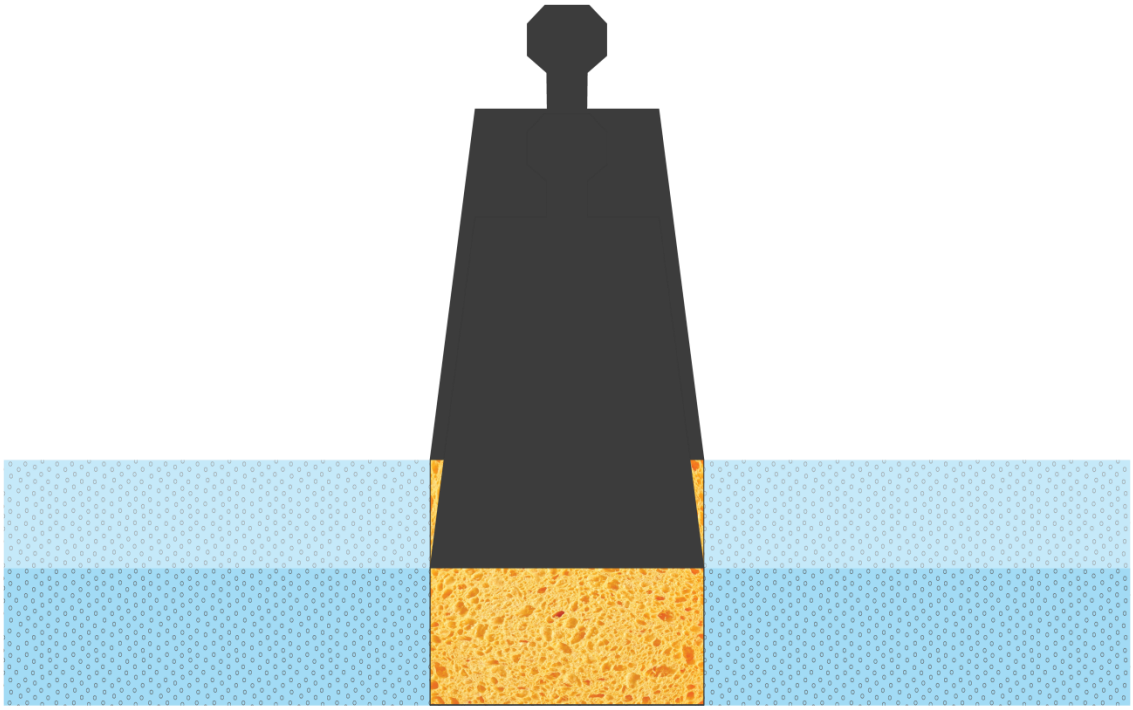


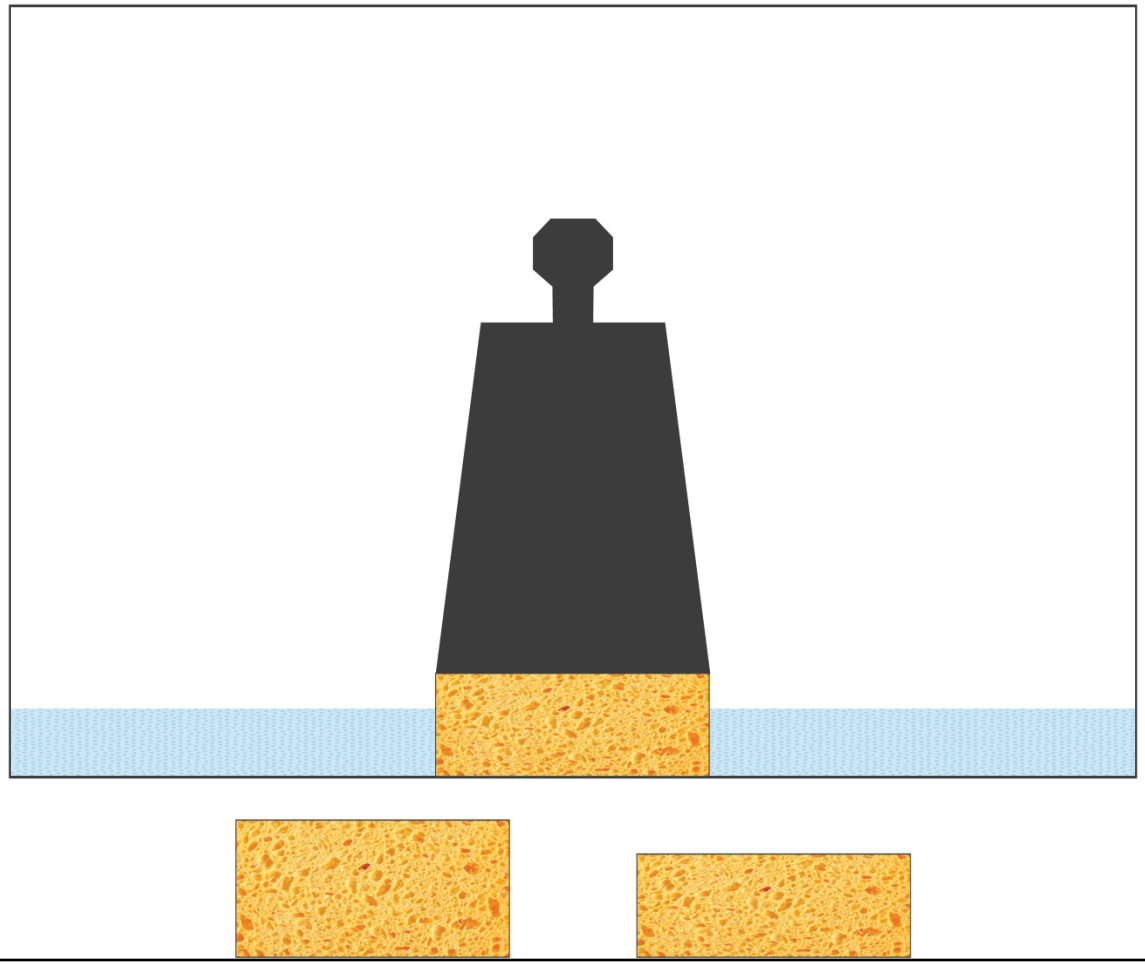
cross section

pores

grains






before compaction
after compaction

Compactie

1.	Gesteente compressibiliteit	
2.	Porositeit van het gesteente	14.4%
3.	Dikte van de laag	~104 m
4.	Afname van gas druk in het reservoir	

Compactie voorspellingen

$$\Delta t = \Delta\sigma' * c * h$$

Δt = compaction (reduction in reservoir thickness)
$\Delta\sigma'$ = change in the vertical effective stress
c = reservoir compressibility (rock type and porosity)
h = thickness of the reservoir

4. Methods of prediction

Given the impact that compaction and subsidence can have, as well as the potentially large costs associated with remediation, significant efforts have gone into improving predictive methods. As shown originally in Fig. 1, a simple one-dimensional estimate of compaction is given by Eq.(1):

Compaction, $\Delta t = \Delta\sigma_v' * c * h$ (1)

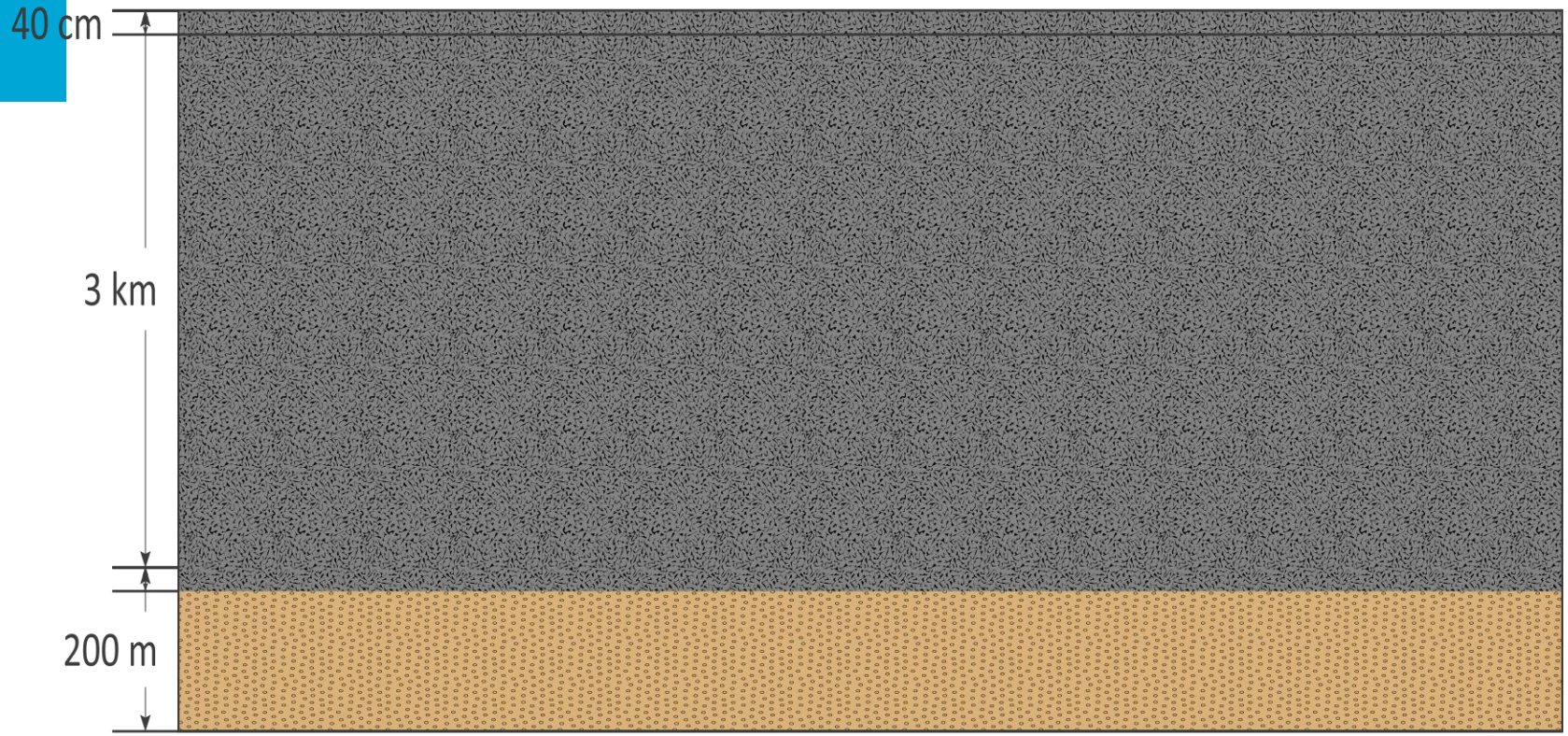
Here, the total reduction in reservoir thickness, Δt, is a direct function of the change in the vertical effective stress, $\Delta\sigma_v'$, multiplied by reservoir compressibility, c, and reservoir thickness, h. Building upon this, Geertsma developed analytical equations, called the Nucleus of Strain method, for estimating reservoir compaction and surface subsidence (Geertsma, 1972 and Geertsma, 1973). Equation (2) shows the basic formulation for subsidence from a nucleus of strain that Geertsma later extended to the case of a disc-shaped reservoir at some depth:

$$\textit{Subsidence, } u_z^+(r,0) = -\frac{c_m(1-\nu)}{\pi}\frac{c}{(r^2+c^2)^{3/2}} \quad (2)$$

where $u_z(r,0)$ represents surface subsidence at some arbitrary location a horizontal distance r from a point of compaction, c_m is the uniaxial compaction coefficient and is analogous to material compressibility multiplied by the effective stress change and layer thickness, ν is Poisson's ratio, and c is the vertical depth from the surface to the point of compaction. In addition to subsidence estimates, the method also attempted to account for the potential change in the total vertical stress acting on the reservoir as

Nagel 2001

Compactie in Groningen



after gas production

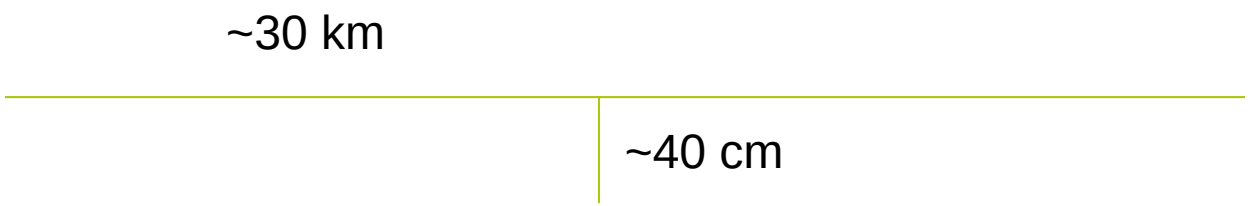
before gas production

compaction

Bodemdaling

- Afname in gas druk leidt tot compactie in het reservoir
- Compactie in het reservoir leidt tot bodemdaling

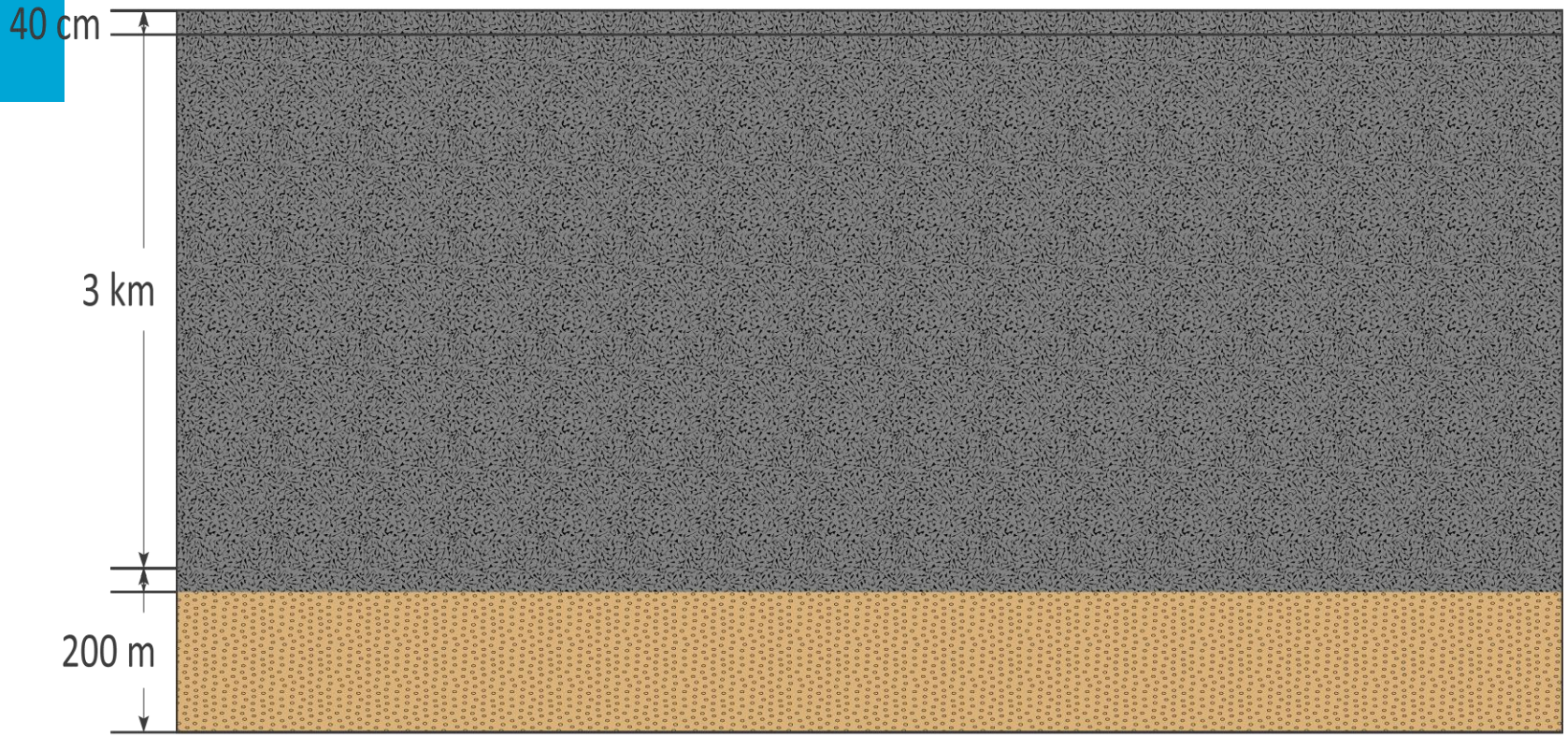
- Bodemdaling door gas productie leidt niet tot scheuren in gebouwen etc.



Tilt = 0.002°

- Bodemdaling kan wel om maatregelen vragen met betrekking tot dam / dijk hoogtes, veranderingen in eco milieu in Waddenzee.
- De te verwachten bodemdaling is goed te voorspellen.

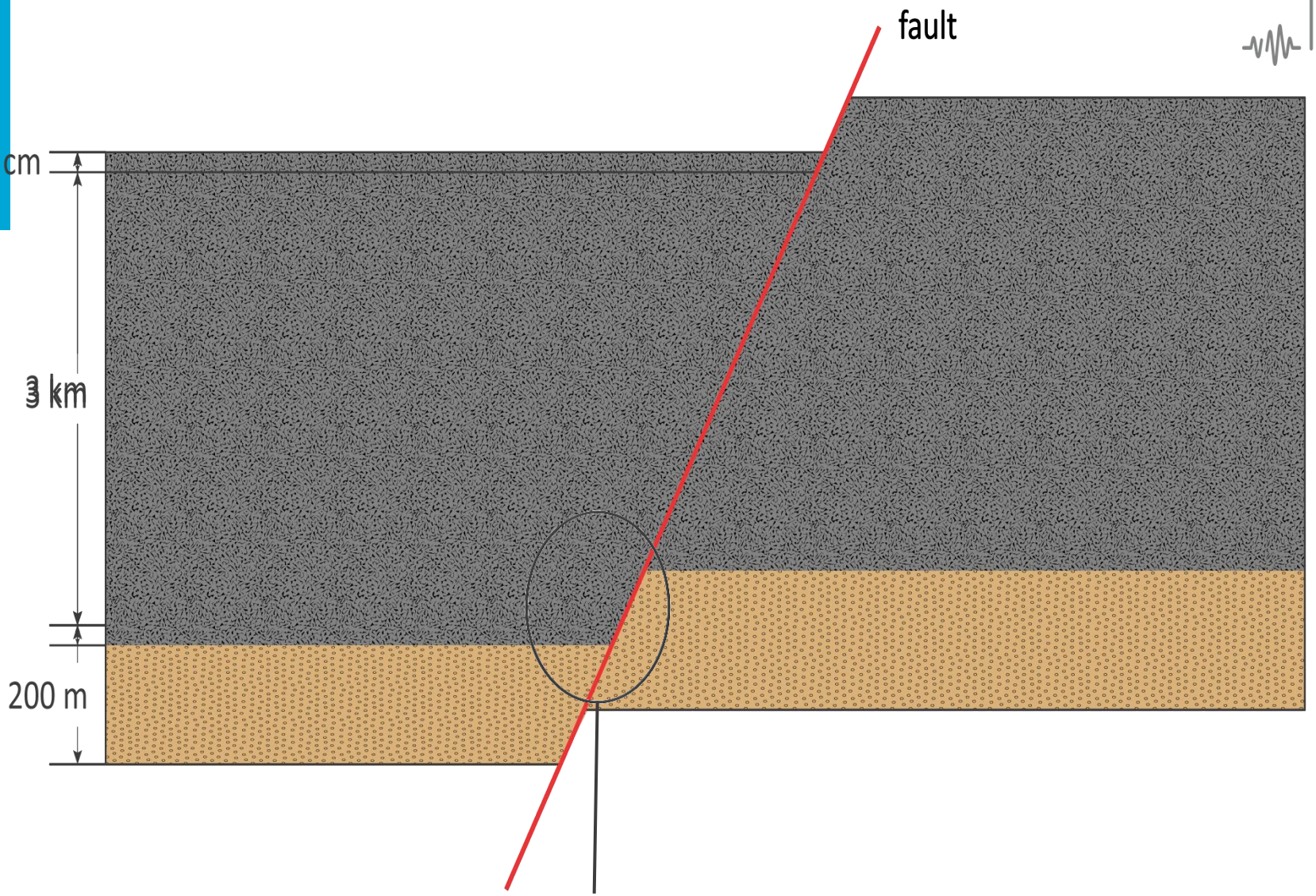
Compactie en aardbevingen

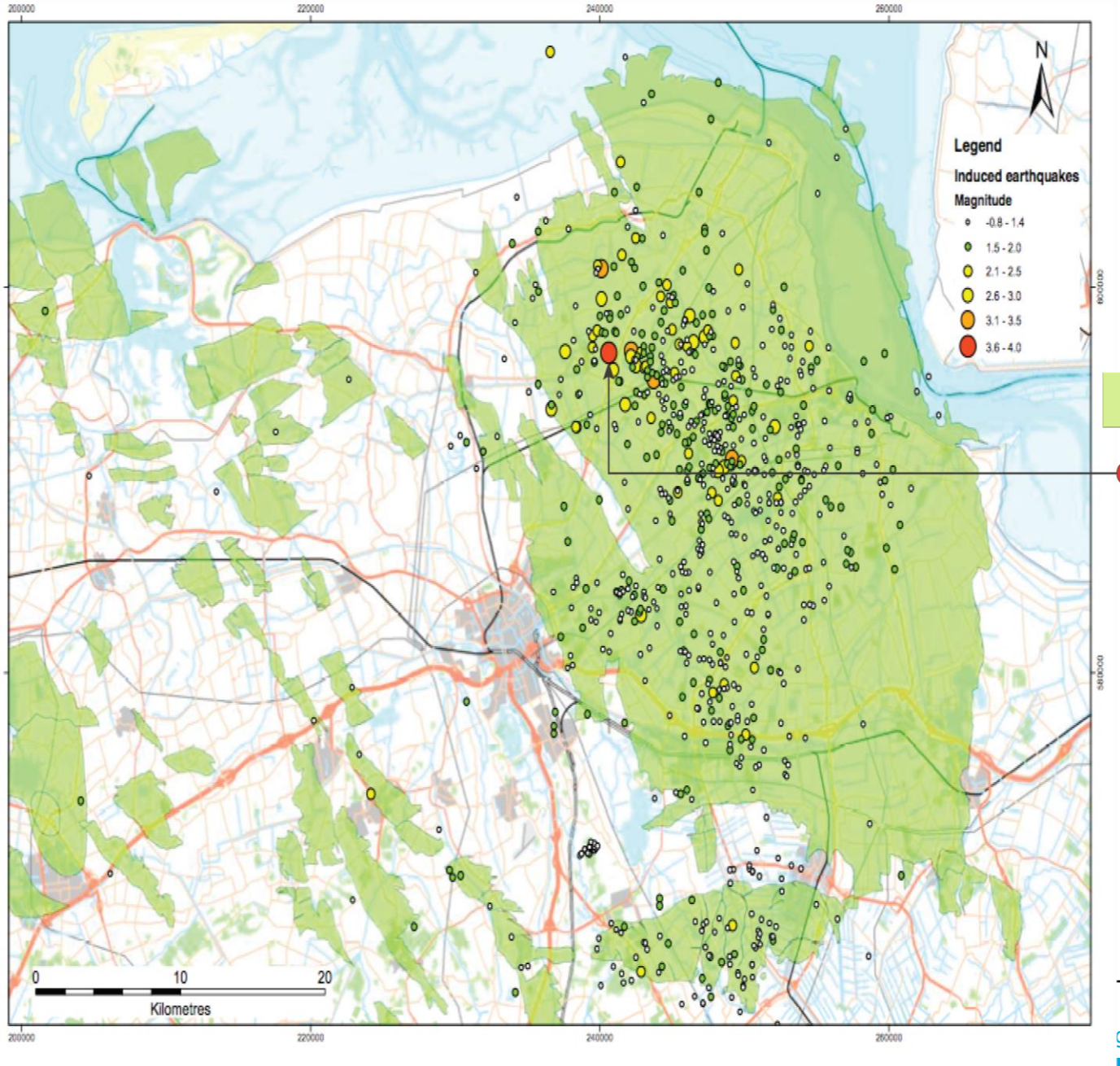


after gas production

before gas production

compaction


fault
40 cm
3 km
200 m



gas fields

2012
Huizinge
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Tot slot - conclusies

Gasreservoirs

- Ternaard in zandsteen van de Upper Slochteren Formatie
- ~4 miljard kubieke meter

Bodemdaling

- Bodemdaling door gaswinning door compactie tgv afname in gas druk.
- Mate van bodemdaling goed te voorspellen.
- Maatregelen voor dam/dijk hoogtes etc.

Aardbevingen

- Aardbevingen door gas winning veroorzaakt door differentiele compactie in het reservoir (breuk gerelateerd)
- Gas velden met seismiciteit (Groningen), maar er zijn ook gas velden zonder seismiciteit

Tot slot - Mijn advies

Informatie

- Open dialoog en informatieuitwisseling belangrijk
- Vraag om informatie en begrijp de processen
- Doe dat ook regelmatig!

Monitoring

- Meten is weten! Een monitoringsprogramma kan bepalen of/hoeveel bv. bodemdaling plaatsvindt, of aardbevingen plaatsvinden etc.
- Belangrijk om monitoringsprogramma te starten **voor** start van productie want alleen dan is de uitgangsituatie bekend