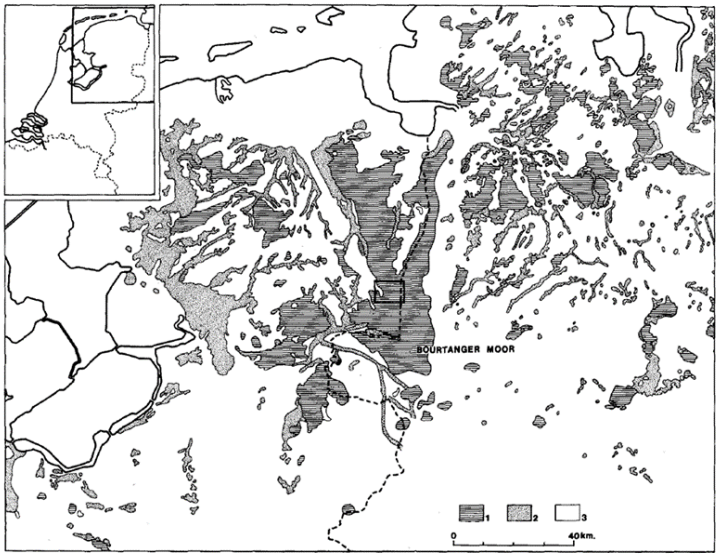
On the propagation of reaction fronts in aquifers – the Bourtanger Moor sites revisited after 20 years

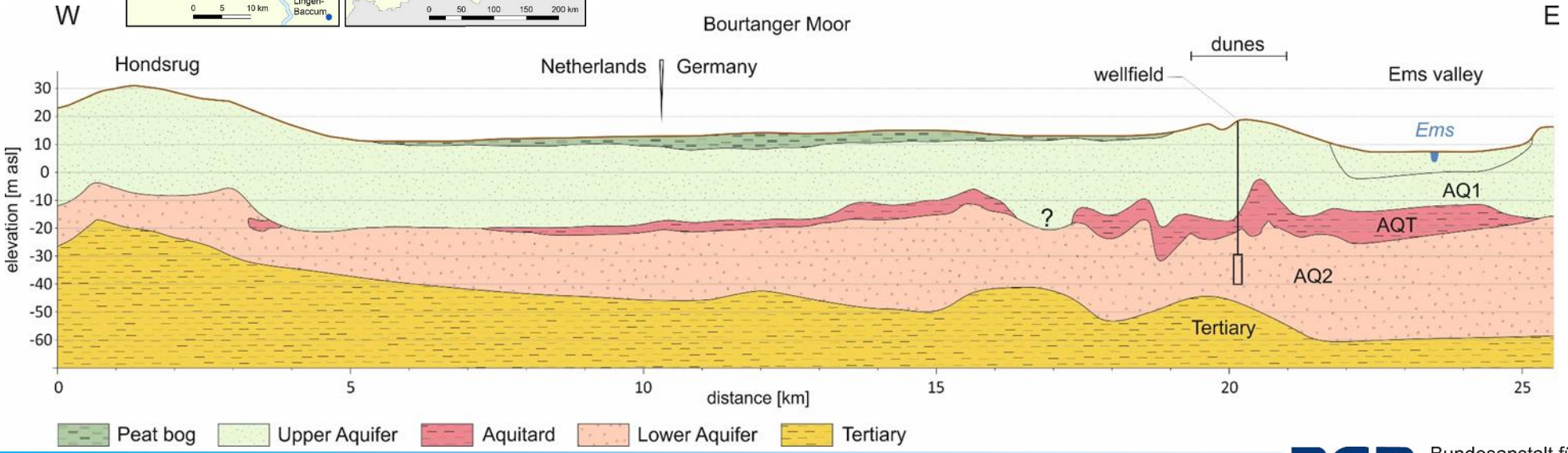
Georg Houben

Jens Gröger-Trampe, Paul Königer, Vincent Post

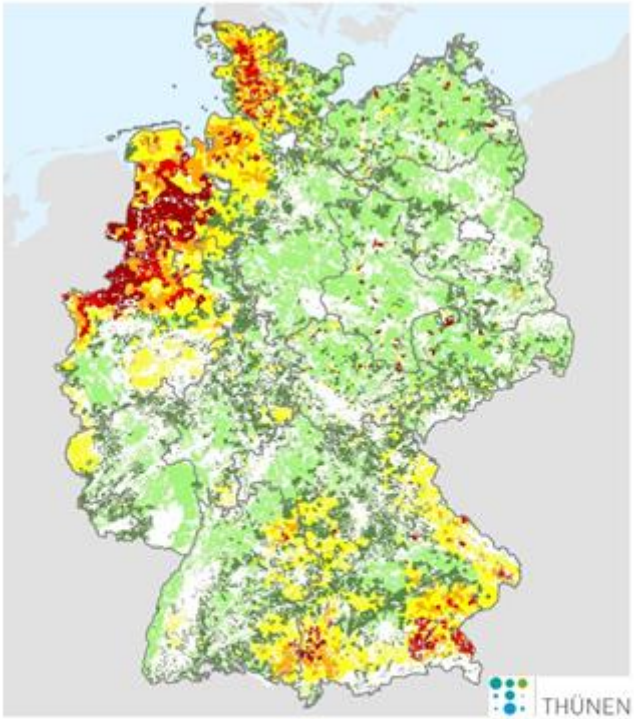
georg.houben@bgr.de

The Bourtanger Moor





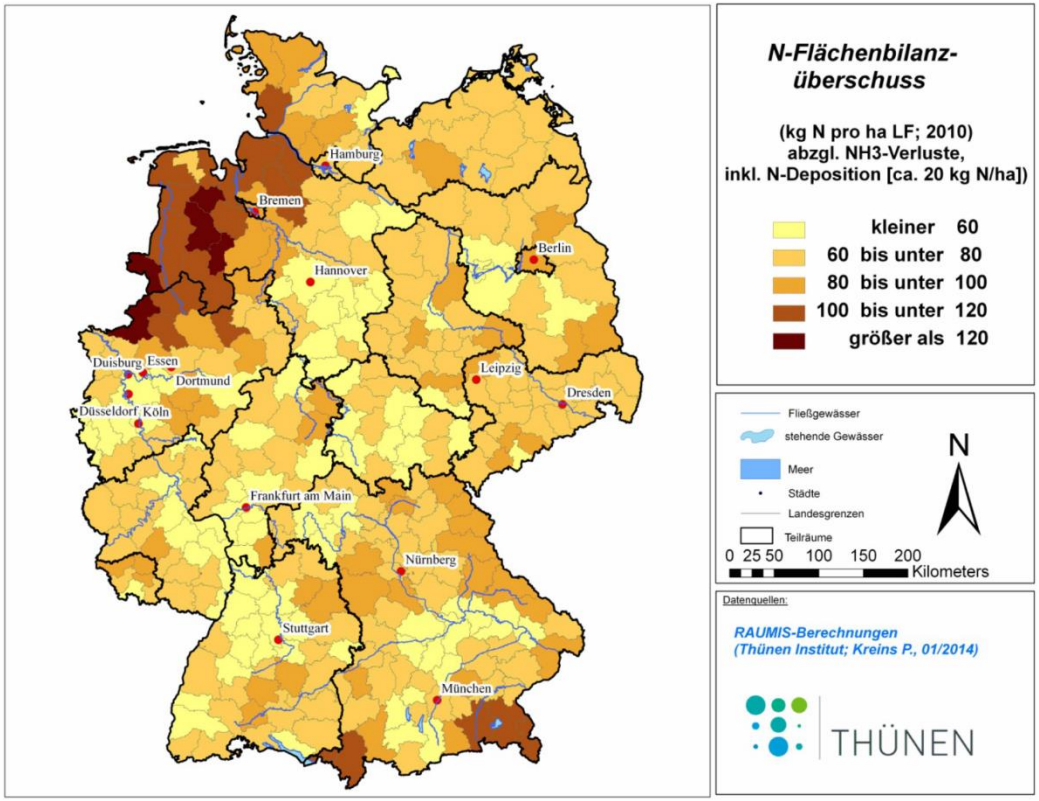
Problems (1): intensive farming



Cattle density per hectare

≤ 0,5 | > 0,5 bis 1,0 | > 1,0 bis 1,5 | > 1,5 bis 1,75 | > 1,75 bis 2,0 | > 2,0

Nitrogen surplus



Agricultural areas (sandy soils, deep ploughed)
high nitrate concentrations in groundwater (up to 125 mg/l)
high potassium concentrations in gw (up to 12 mg/l)

Problems (2): legacy of acidification (?)

Forested areas (“*acid rain*“)

- sandy soil
  - pH as low as pH 2.5
  - cation exchangers loaded with aluminum
- groundwater:
  - pH as low as pH 3.6
  - aluminum up to 1.2 mg/l

But: improvement expected (flue gas desulfurization installed during 1990s)

Now and then - main questions

How fast do the reaction fronts move?

PhD project RWTH Aachen: 1996-2000

- core drillings (agriculture, forest, peat bog): analysis of reactive components
- column experiments
- multi-level wells: hydrochemistry, stable isotopes,tritium, CFC dating
- 1D reactive transport modeling (PHREEQC) → front velocity prediction

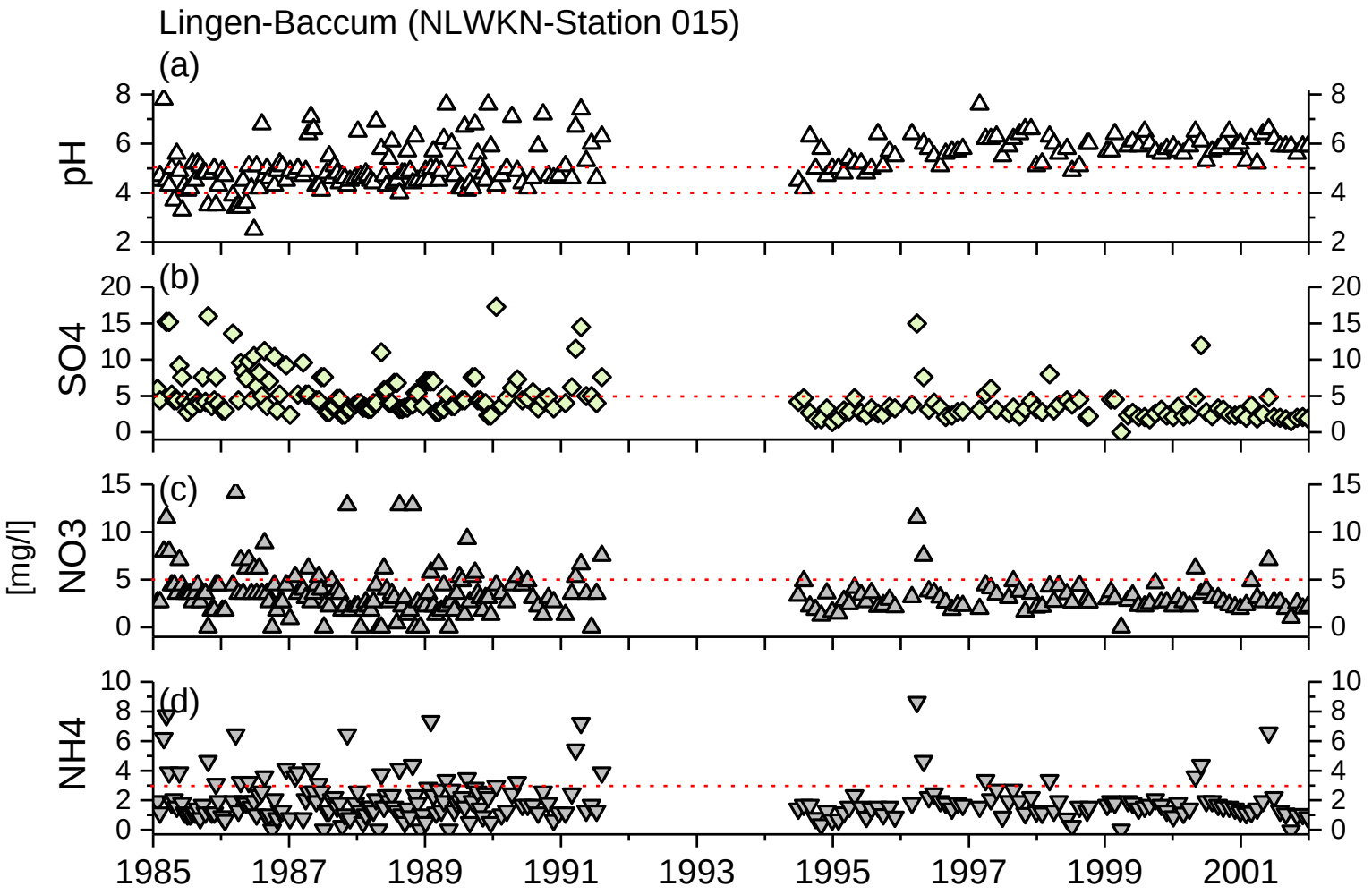
What has happened during the last 20 years?

Let´s do it all a again!

How accurate were the model predictions?

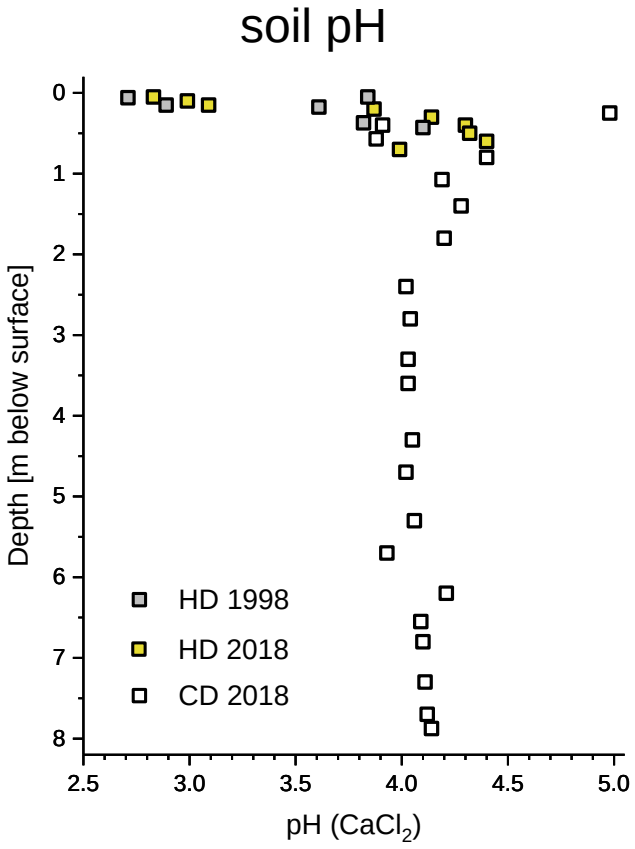
Did I really deserve my PhD degree?

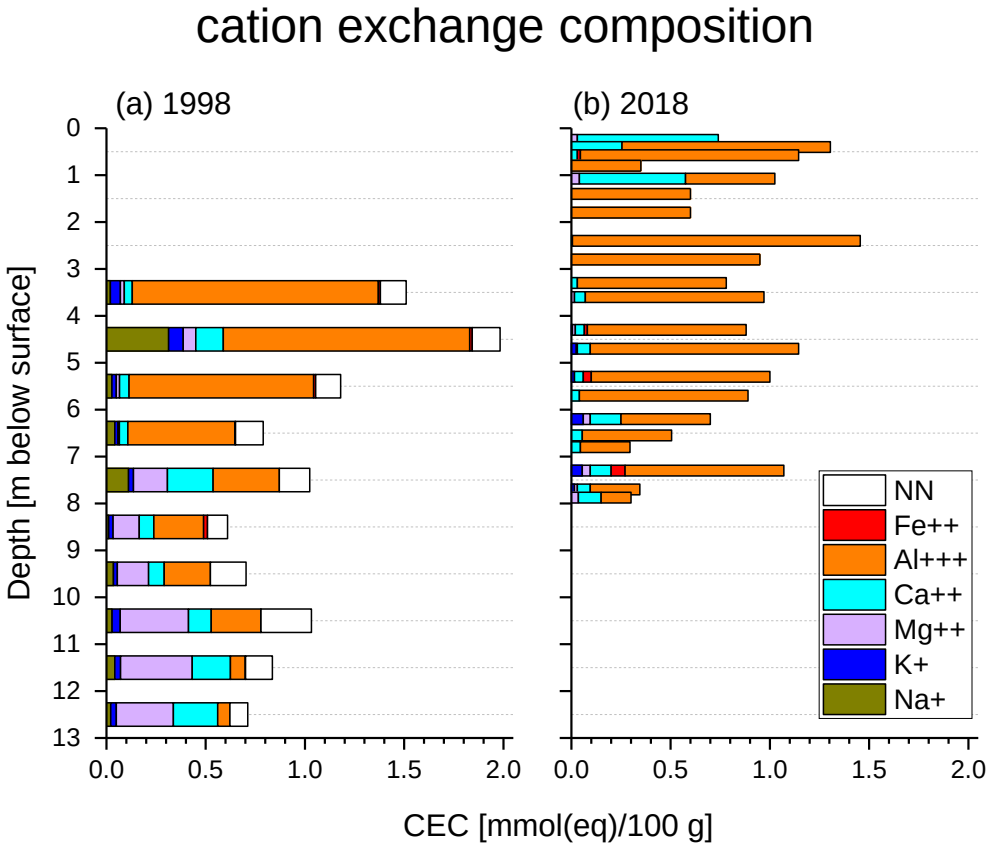
Development of rain water chemistry



Decrease of sulphate (sulphuric acid), rise of pH

Acidification of forest soils

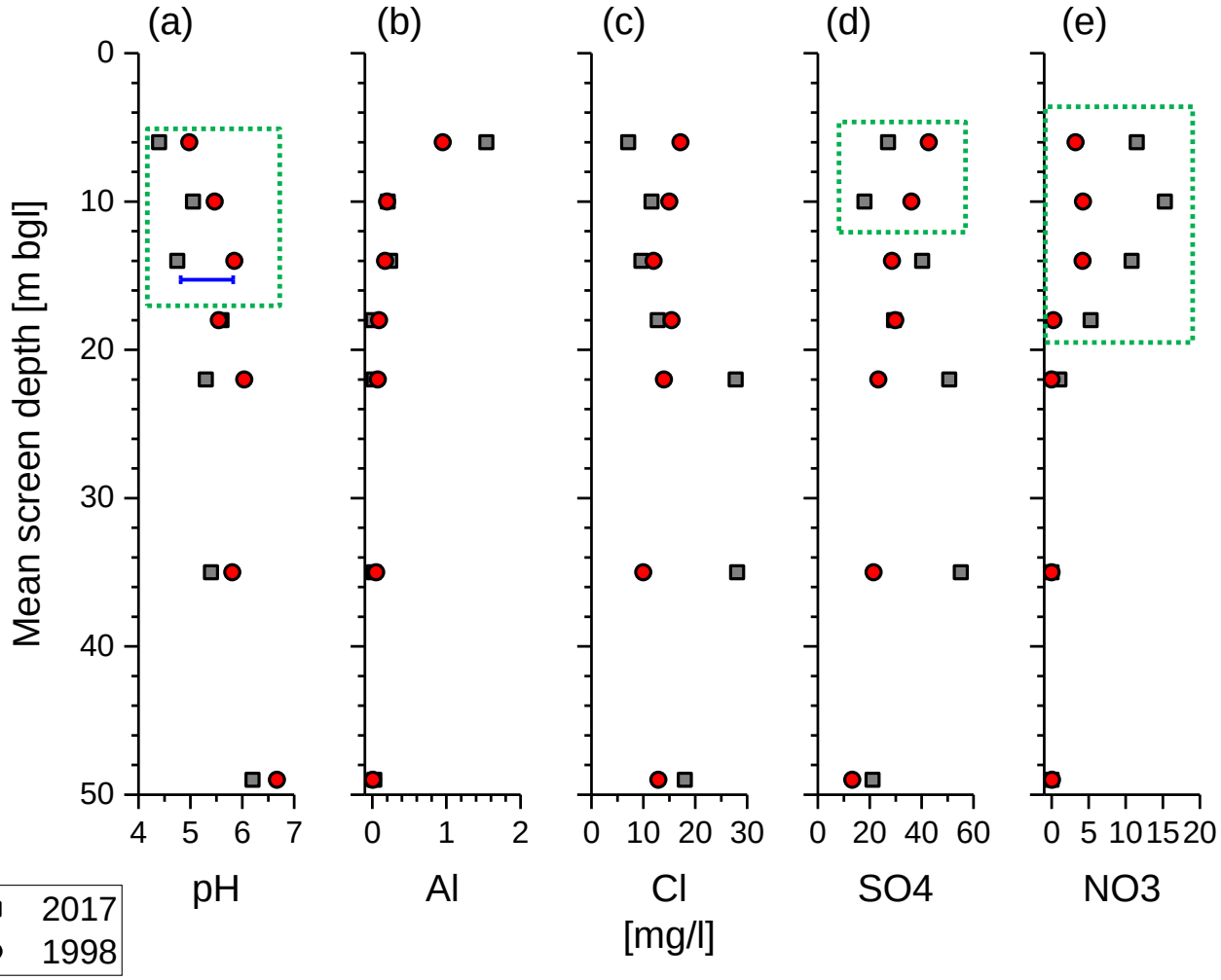


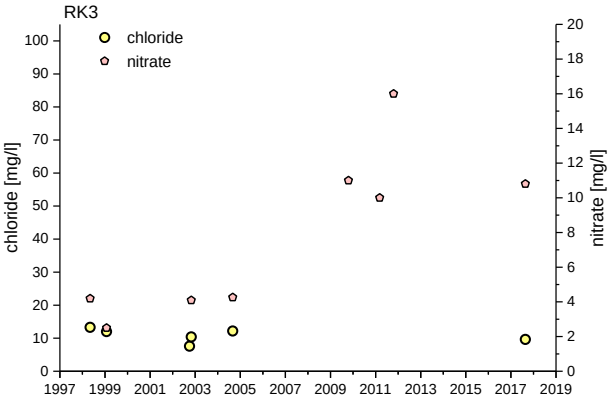


1 mmol(eq)/100 g ≈ 540 mg/l Al

HD = hand drilling
CD = core drilling

Forest site: acidification of groundwater



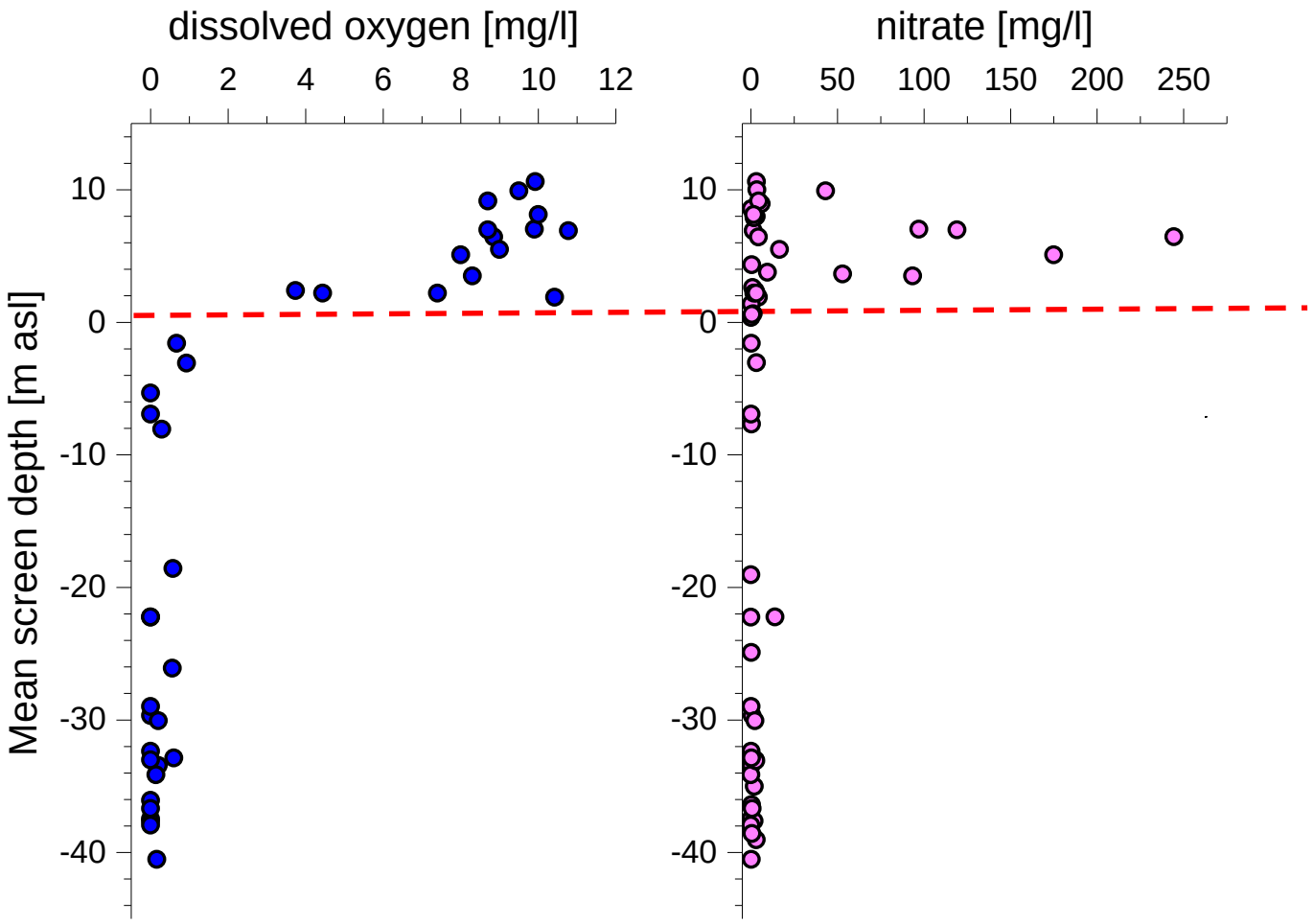


Upper screens:

- sulphate decrease
- pH decrease!
- aluminum increase
- nitrate increase

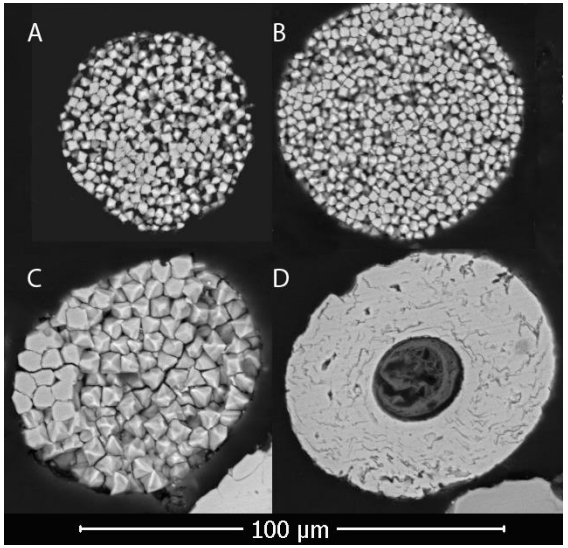
Nitrate source: golf course installed end of 1990s

Agricultural site: denitrification front 1998



(all observation wells)

Autotrophic denitrification via framboidal pyrite



Houben et al. (2001, 2017)

Depth of denitrification front: cores

1998: 11.40 m

2018: 11.26 m

Reaction front 2018 14 cm higher than 1998?

- flat terrain! no topography effect (4 m distance)
- natural variation?
- drilling artefact: core loss, compaction!

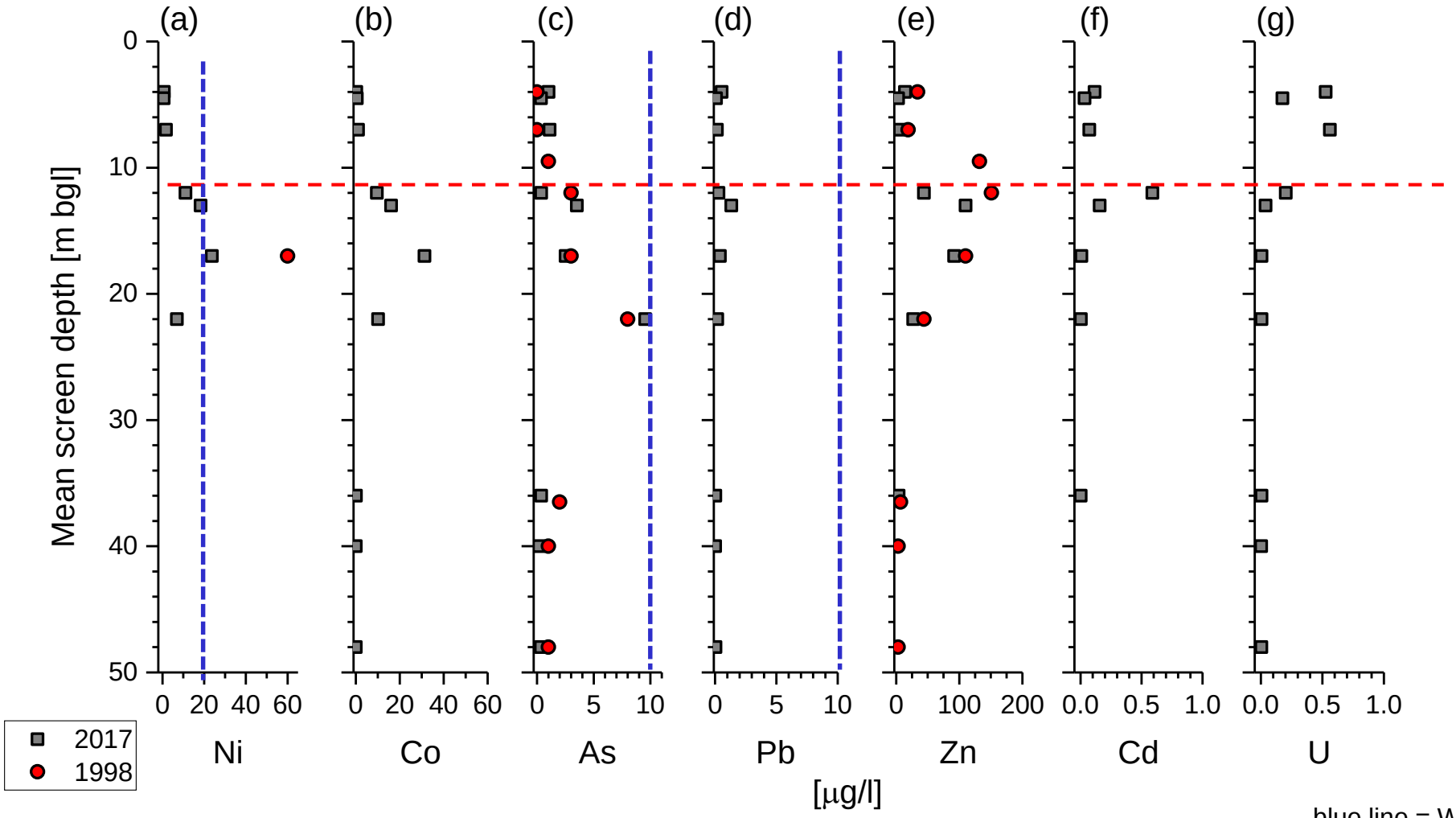
Marker horizont (charcoal) shows little vertical denitrification front propagation (1-2 cm)

→ front velocity ca. 0.5-1.0 mm/a

→ as predicted by models (Houben et al. 2001, 2017)

→ reason: relatively high pyrite content

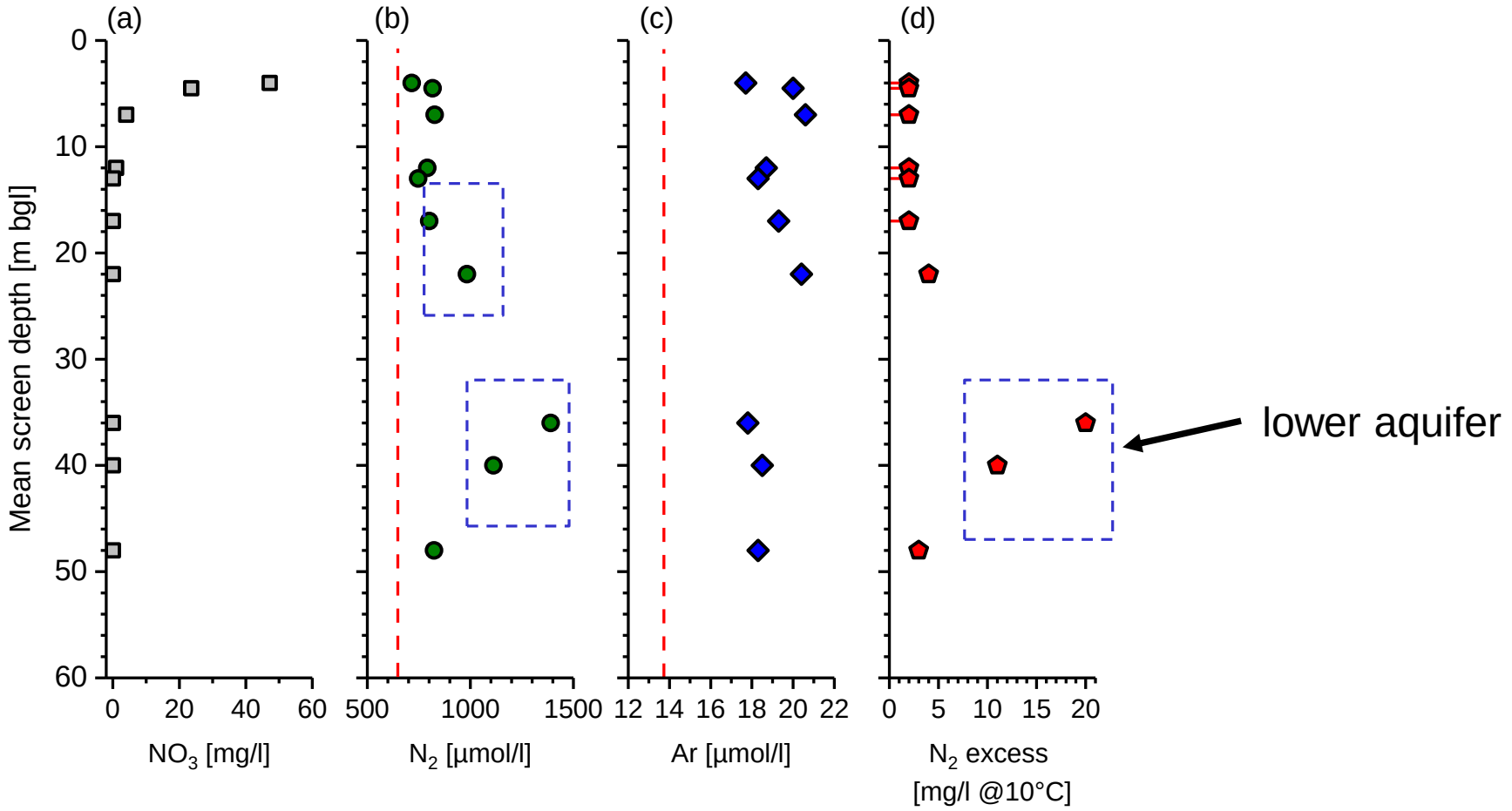
Agricultural site: gw trace elements 1998 vs. 2017



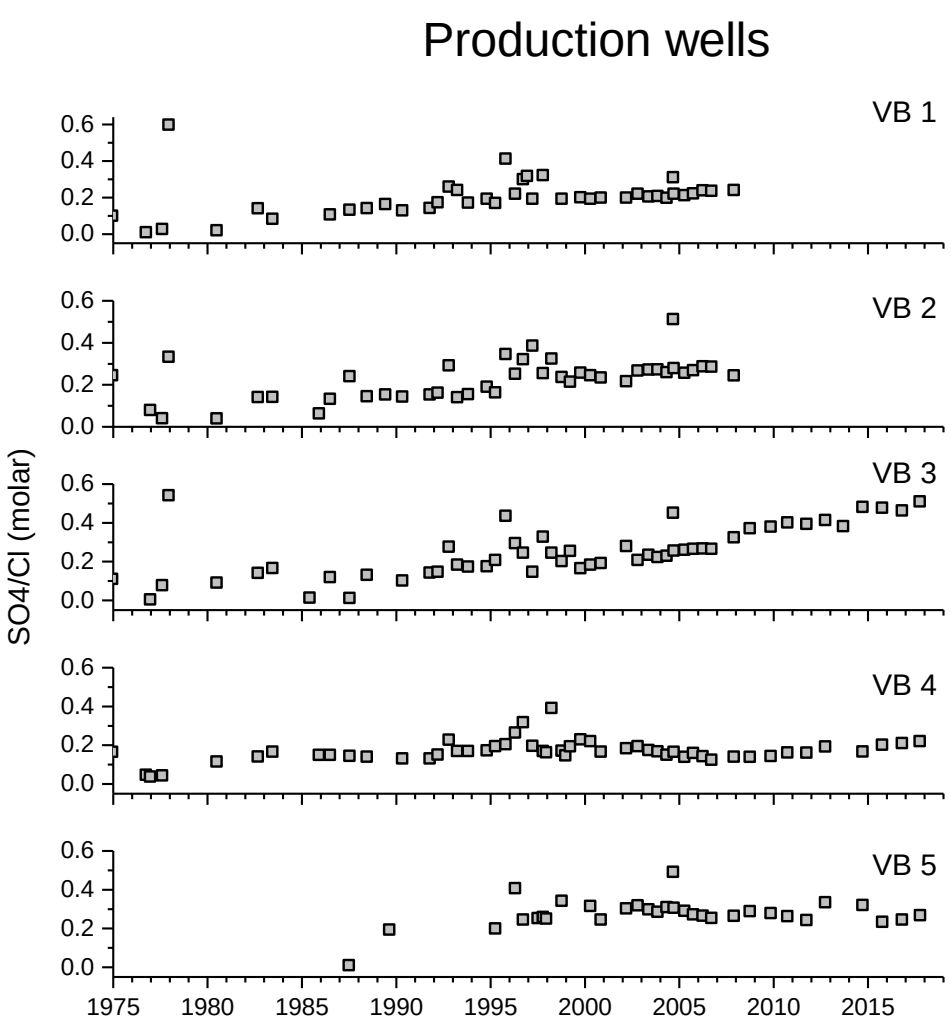
blue line = WHO limits

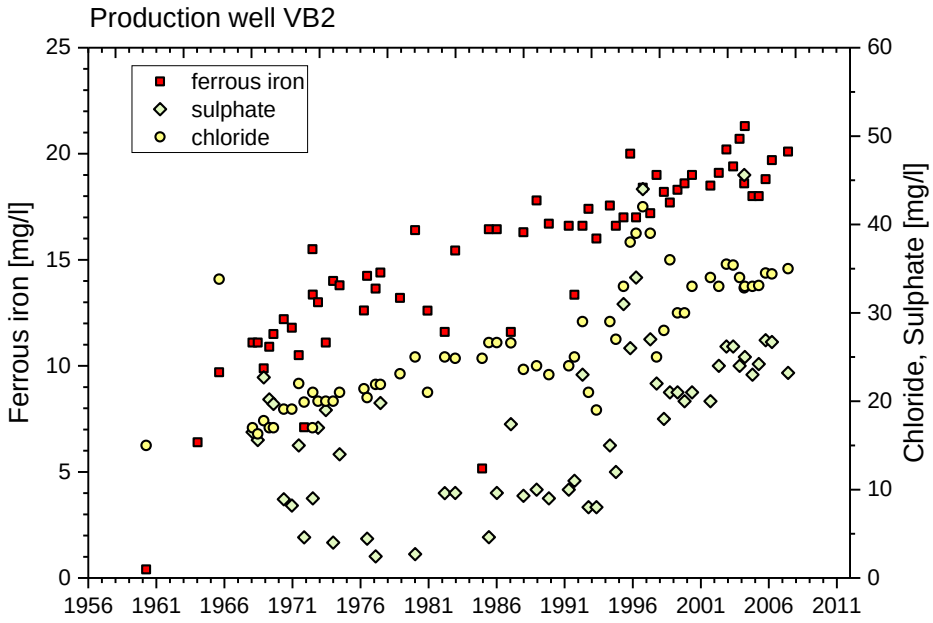
Nitrogen excess as denitrification indicator

N_2 - argon method



Hidden denitrification: not just an artefact



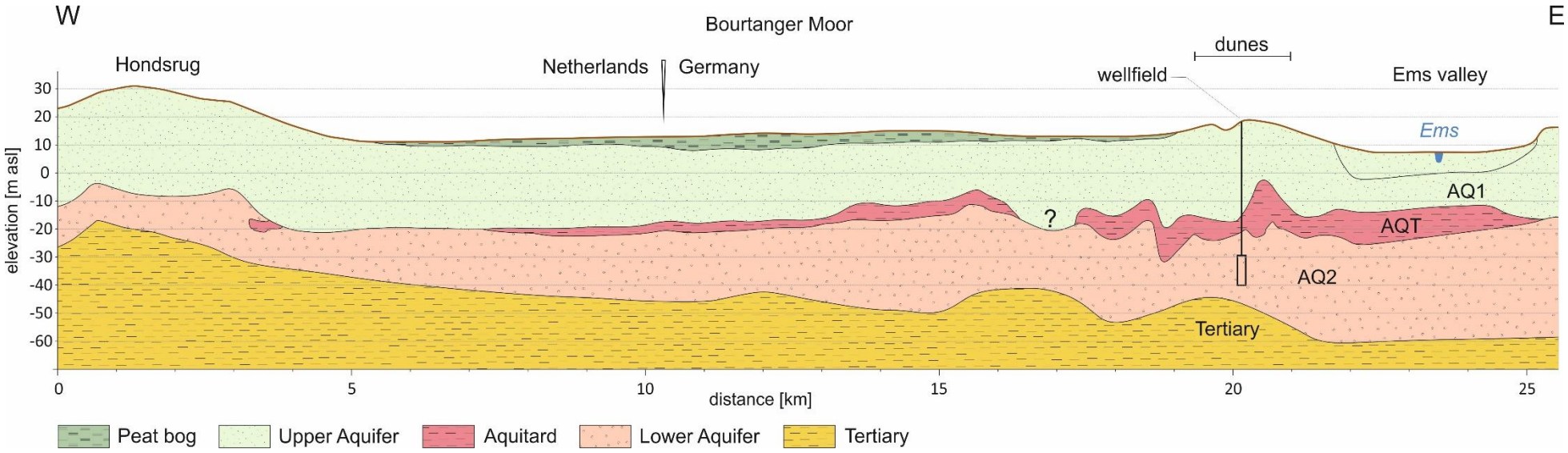


How much “hidden nitrate“?

N_2/Ar data: ca. 5-20 mg/l N_2 excess
→ 25-100 mg/l nitrate

Sulphate conc. multi-level wells:
ca. 50-150 mg/l sulphate
→ 45-135 mg/l nitrate

How does the “ghost nitrate“ get into lower aquifer?



Clay pinches out towards west
but: reducing conditions (bog)
→ low nitrate, low recharge

“Holes“ in aquitard?
Close to pumping wells:
water level difference
between aquifers: up to 2 m

Abandoned leaky boreholes?
No holes? Just flow through aquitard?

MODFLOW model on its way …

Conclusions (official)

- Reproducibility 1998 vs. 2017/18 surprisingly good ☺
  - despite different sampling & analysis techniques, different labs & people
- Forest site, acidification:
  - rain: pH and sulphuric acid input have improved markedly ☺
  - soil: pH and cation exchange composition show no improvement ☹
  - groundwater: pH and aluminum mobilisation deteriorated ☹
- Agricultural site: denitrification front propagation
  - very slow vertical propagation in upper aquifer, as predicted by models ☺
  - But: hidden denitrification in lower aquifer (flow through holes in aquitard?) 💣
- So, did I deserve my PhD? You decide …

Conclusions (inofficial) - 20 years later
Still haunted by the ghost of nitrate

“Antigonish” (based on a ghost story)

by William Hughes Mearns (1899)

"Yesterday, upon the stair,

I met a man who wasn't there!

He wasn't there again today,

Oh how I wish he'd go away!“

…

Anti-nitrogen (ode to nitrate)

by myself (2019)

“20 years ago, in my aquifer,

I analyzed a contaminant that wasn't there!

It wasn't there again today,

Oh how I wish this nitrate would go away!“

Thank you for your attention!

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Terrestrial sedimentary pyrites as a potential source of trace metal release to groundwater – A case study from the Emsland, Germany

Georg J. Houben*, Maria A. Sitnikova, Vincent E.A. Post

Federal Institute for Geosciences and Natural Resources (BGR), Stilleweg 2, D-30655 Hannover, Germany

Environmental Geology

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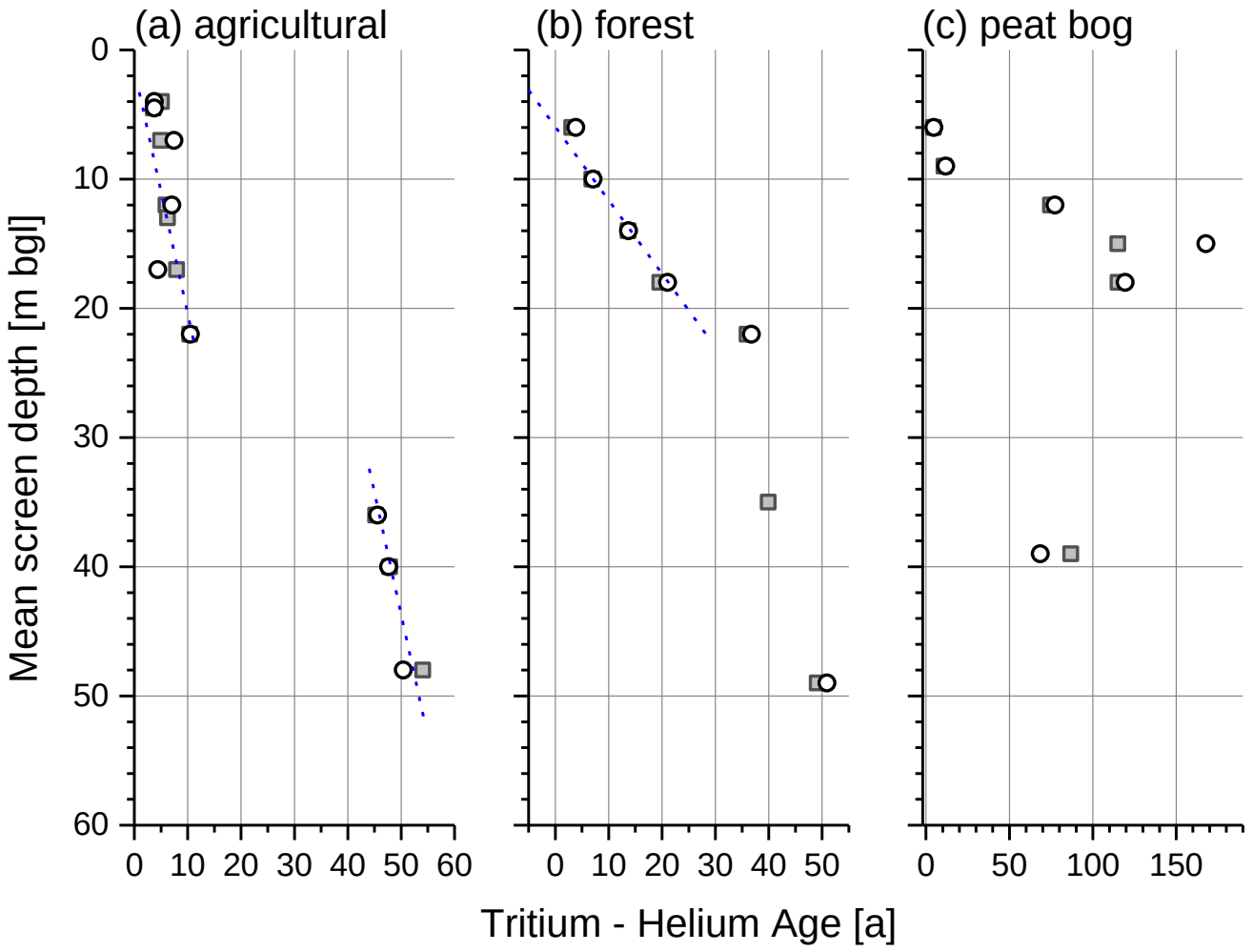
Cases and Solutions

Assessing the reactive transport of inorganic pollutants in groundwater of the Bourtanger Moor area (NW Germany)

G. J. Houben(✉) · A. Martiny · N. Bäßler · H.-R. Langguth · W. L. Plüger

More is on its way …

How old is the groundwater?



Stable isotopes