Identifying sweet spots for CO_2 injection in cemented sandstones

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Motivation

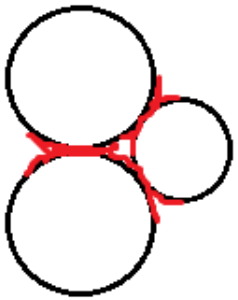
Injecting CO_2 into a formation might cause permanent changes to the rock framework. Can we quantify or, at least, categorize suitable injection intervals from well-log data?

What is a suitable injection interval?

- High porosity and permeability
- Stiff rock framework
  - Depends on porosity, mineralogy and arrangement of solid components at pore scale
  - Can resist forces from the injected CO_2

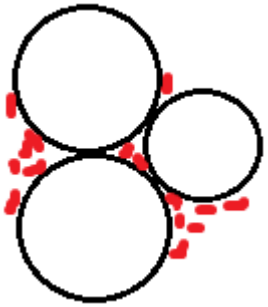
Cement type and impact on seismic parameters

Contact cement



- Act as «glue» on the grain contacts
- Increase stiffness (elastic modulies)

Non-contact cement
(Intragranular material)

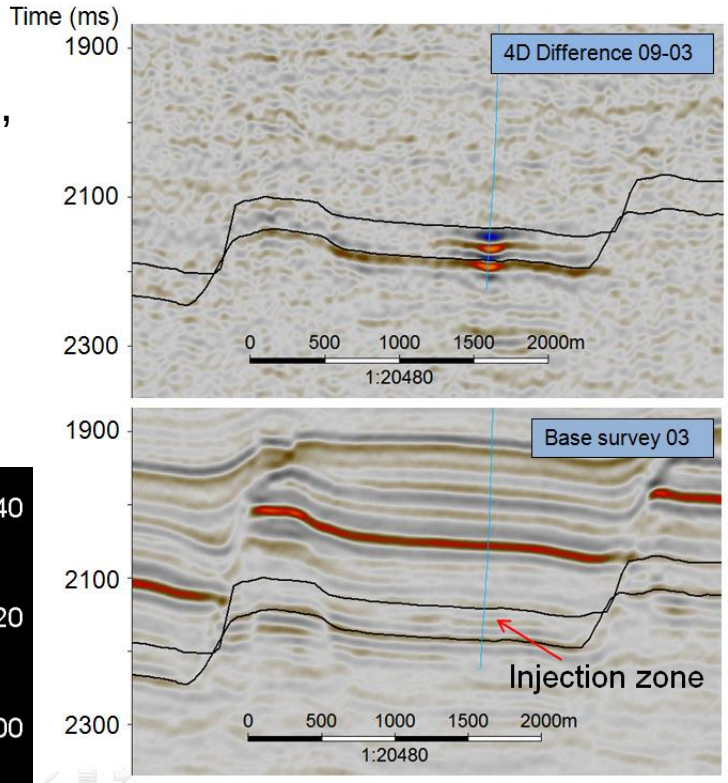


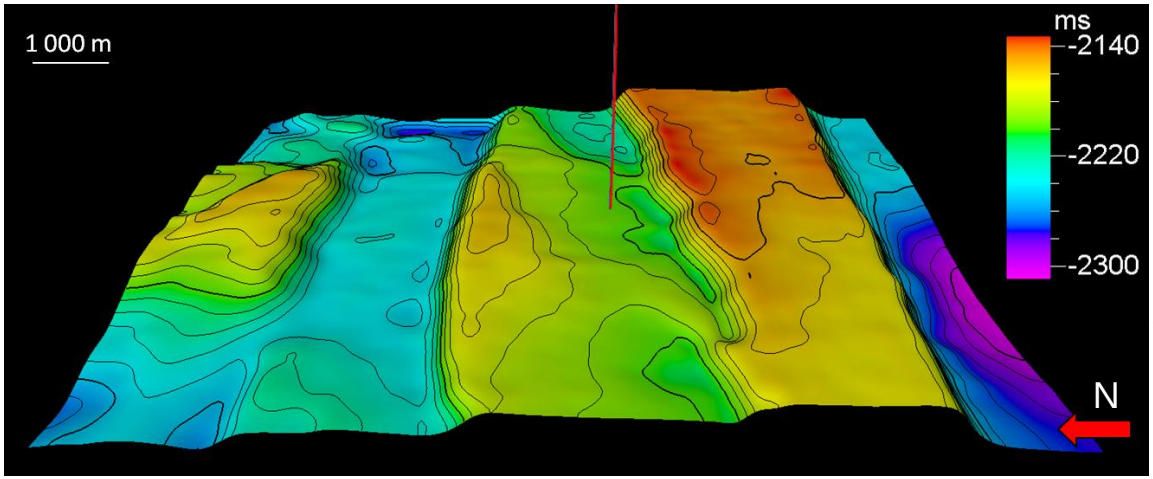
- Weakly affects stiffness but strongly reduces permeability due to clogging the large pores

=> Same porosity, big variation in permeability and stiffness

CO_2 injection in the Tubåen fm., Snøhvit Field

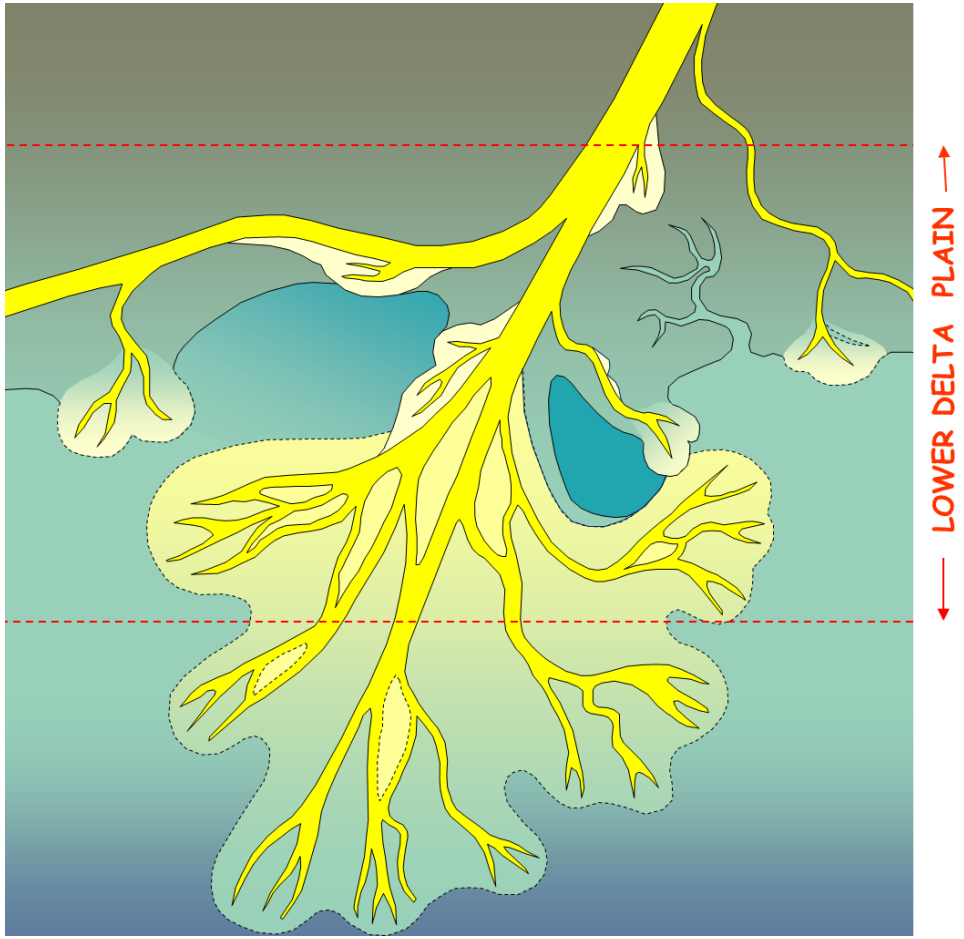
- Faults East-West, injection zone ~ 2 500 m wide
- 700-1100m uplift - present depth of 2.67 – 2.78 km, 110m thick
- Lower delta plain depositional environment with marine and tidal influence
- Injection April 2008-2011, stopped due to pressure build-up





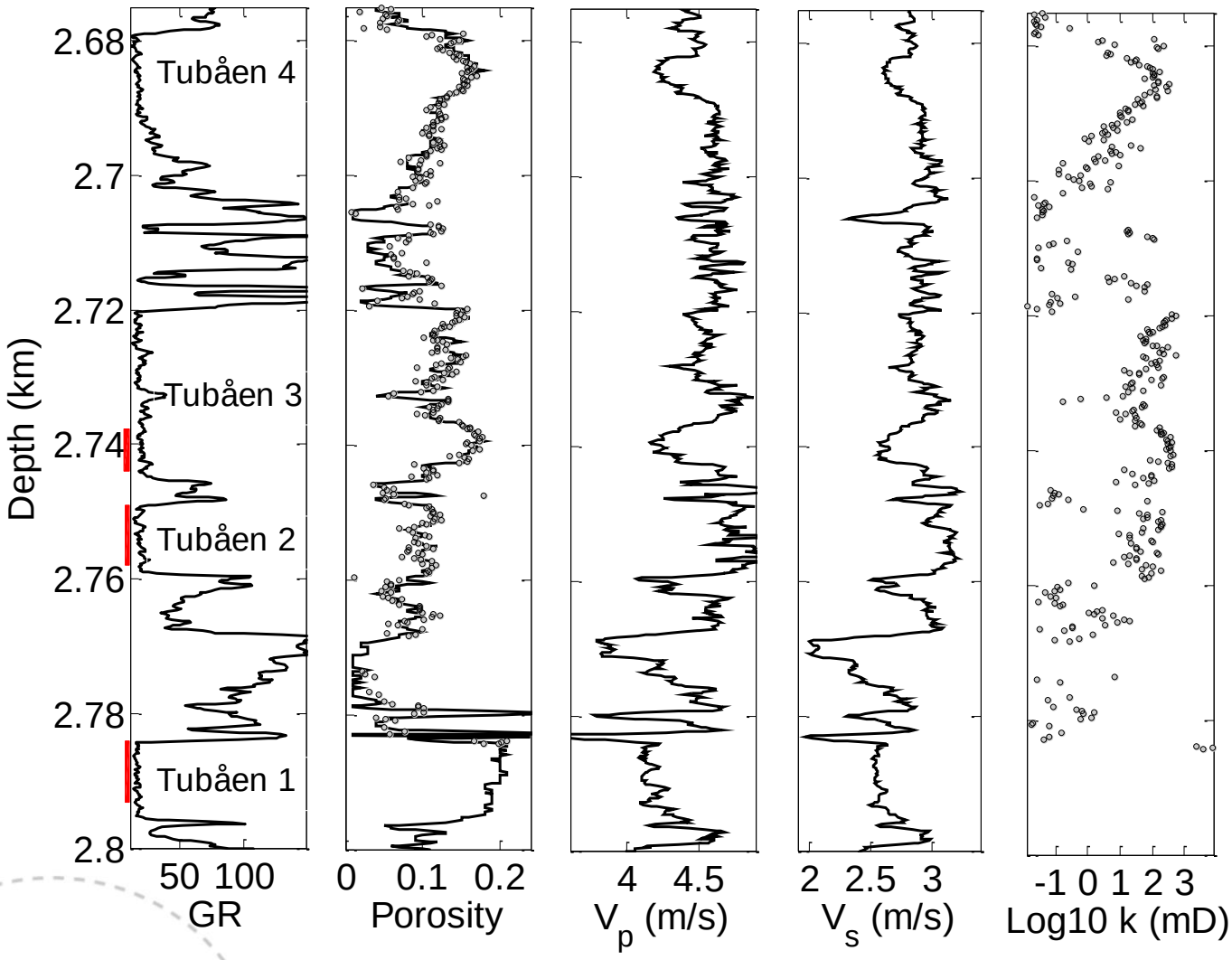
Topography of the reservoir in Tubåen formation. North direction is indicated by the arrow. The CO2-injection well is shown by the red solid line.

Geological setting in the Tubåen fm.



- Lower delta plain depositional environment with marine and tidal influence
  - Blocky intervals: multi distributary channel fill sediments
  - Upward coarsening intervals: distributary mouth bars and bayhead deltas
- Tidal and marine influence worsen grain sorting compared to well-sorted distributary channel sediment

Well logs



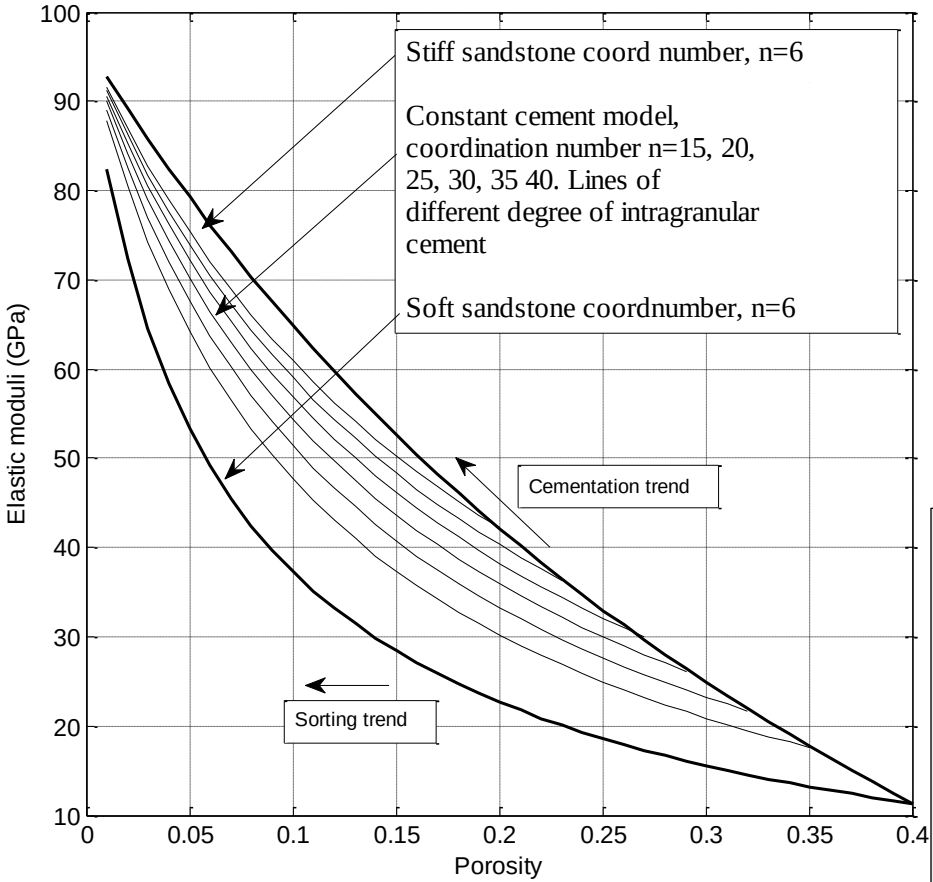
Four clean-sand intervals:

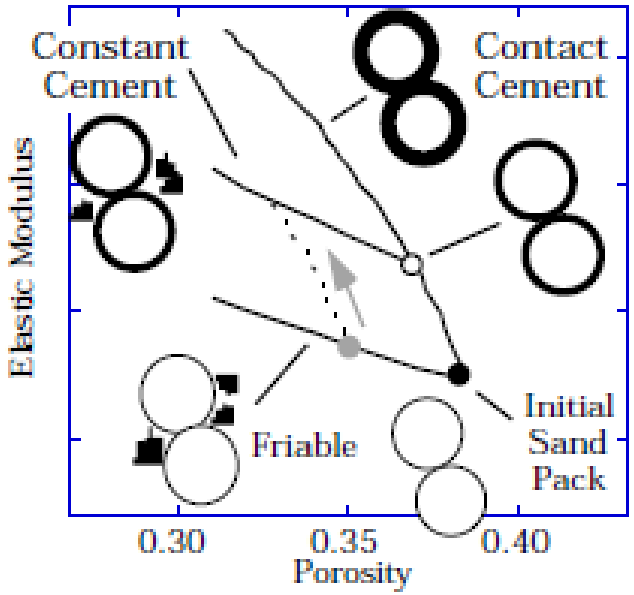
- Coarsening upwards Tubåen 4
- Blocky Tubåen 3
- Weakly coarsening upwards Tubåen 2
- Blocky Tubåen 1

Perforated intervals

Permeability from core analysis

The constant cement model, (*Avseth et al.*, 2000)



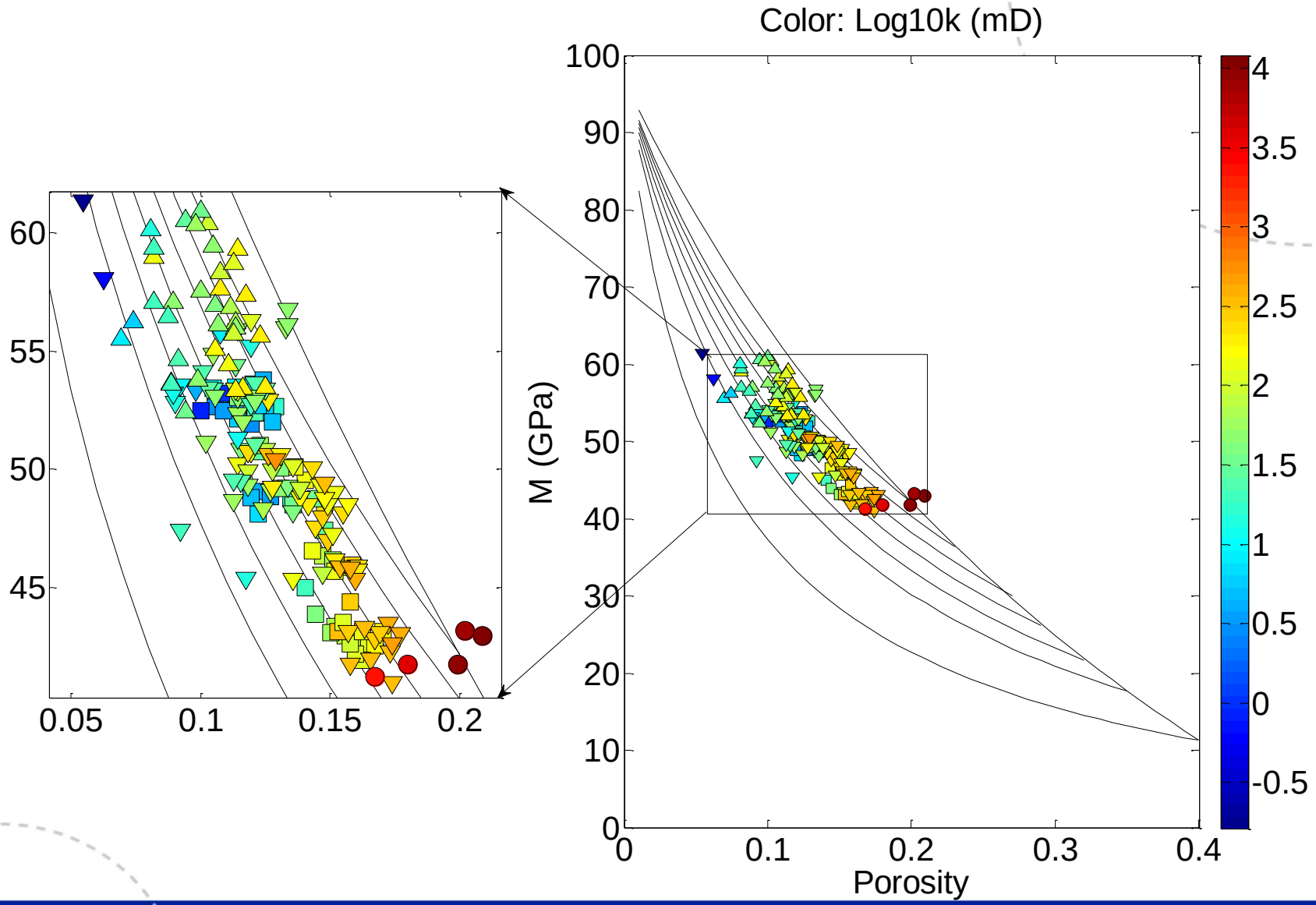


Can ascertain amount of contact cement versus fines in the pore space by matching modulus-porosity data with model curve

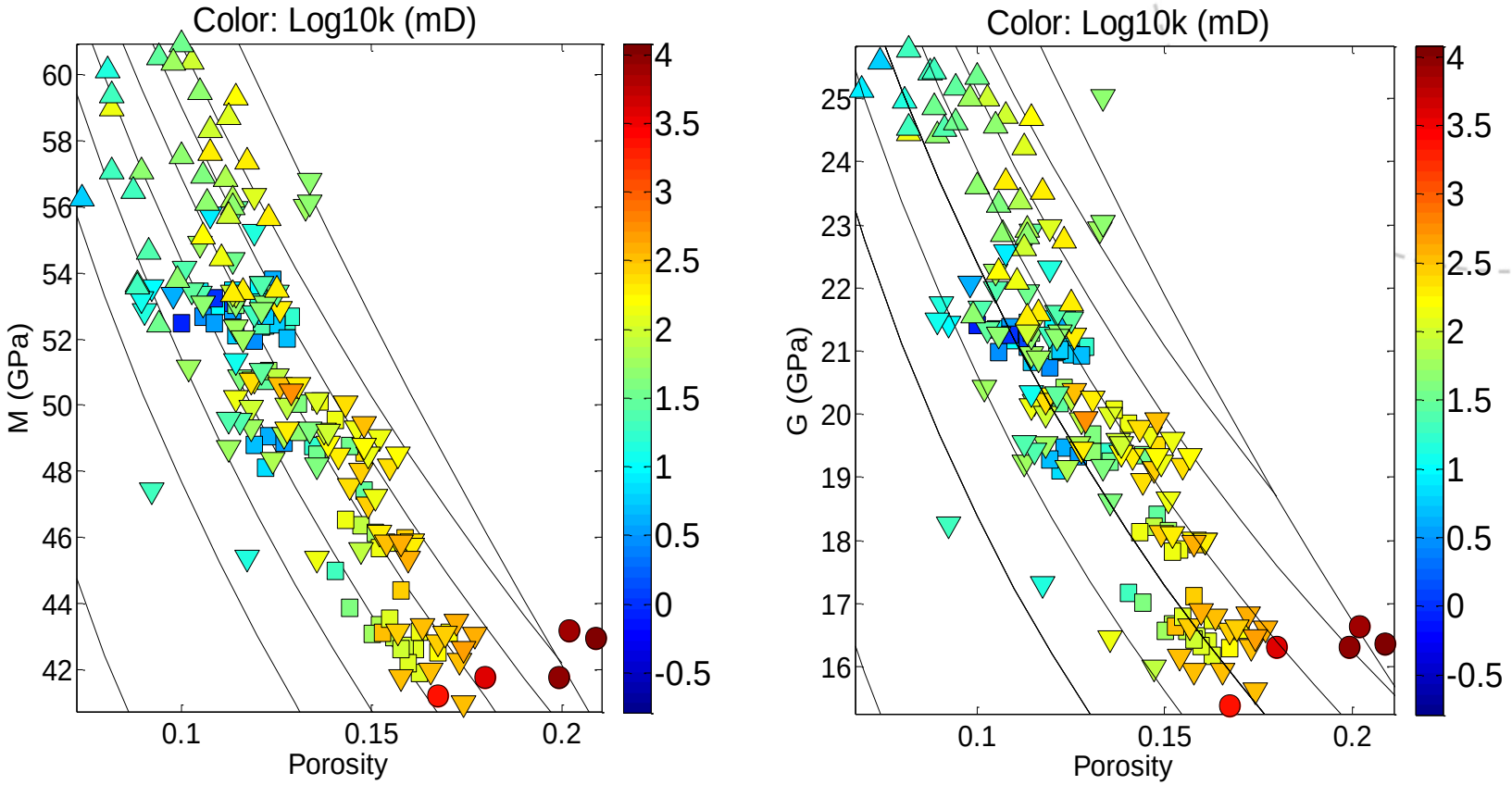
Assume initially contact-cemented rock

Constant contact-cement curves in the porosity versus elastic modulus plane

The constant cement model



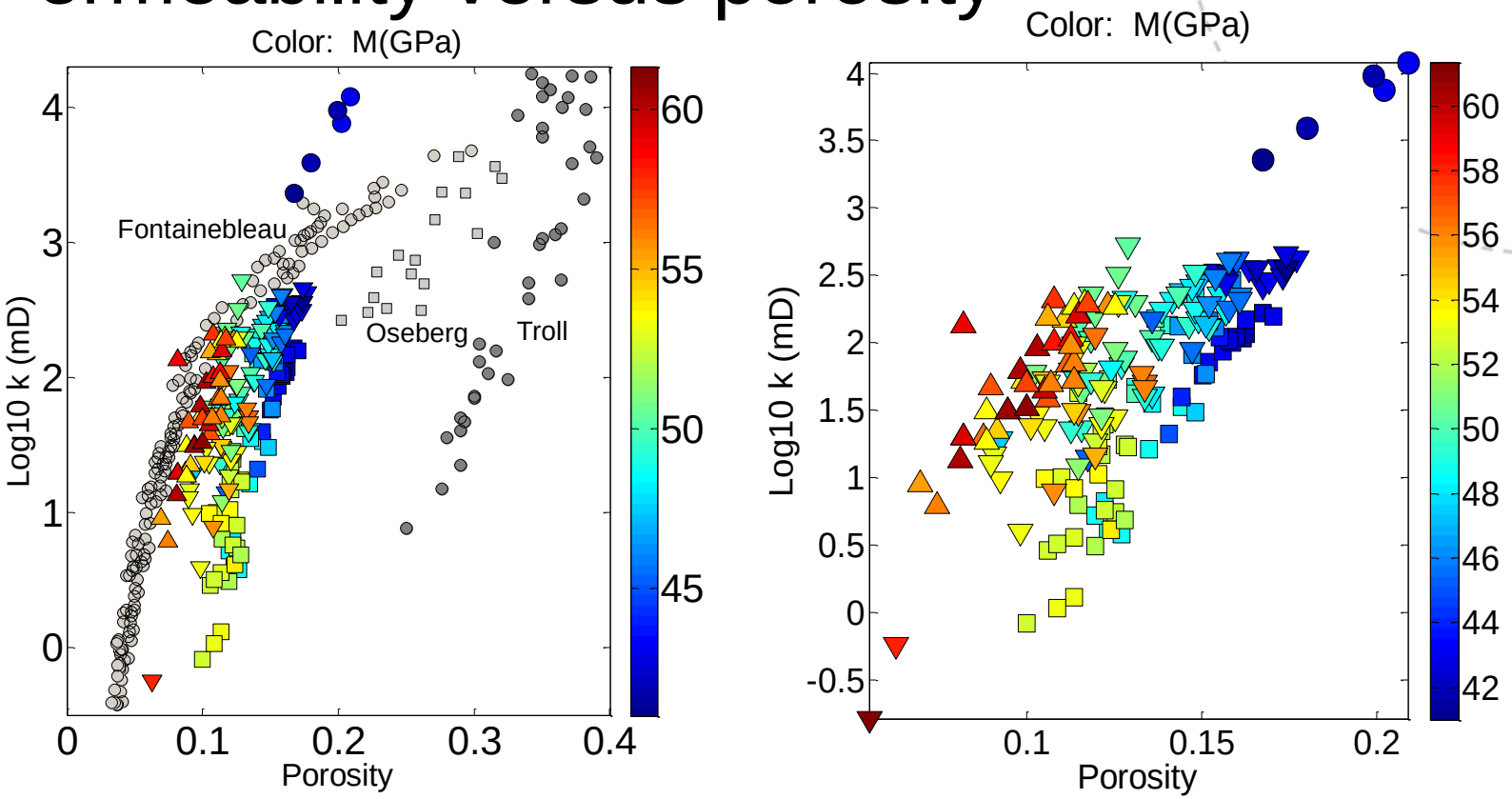
The constant cement model



Tubåen 1: ●,Tubåen 2: ▲,Tubåen 3: ▼,Tubåen 4: ■

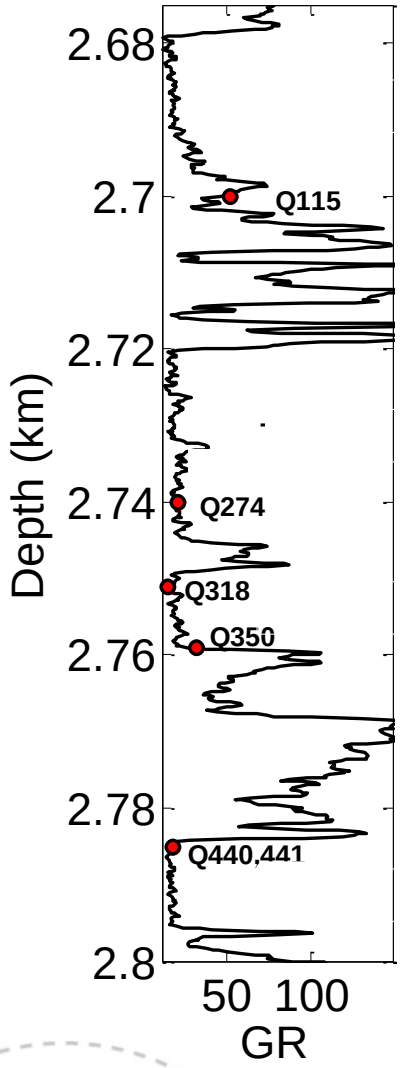
At the same porosity, stiffer sands have higher contact cement content than softer sand and, hence, the latter have more fines than the former, and, as a result, smaller permeability at the same porosity

Permeability versus porosity



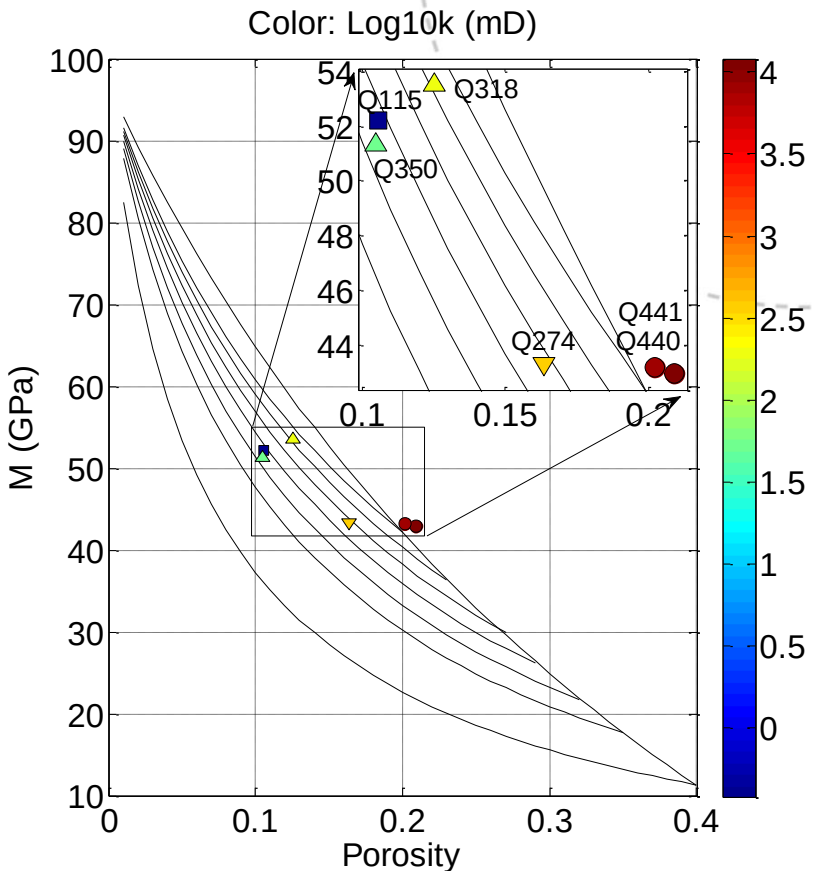
Tubåen 1 ●,Tubåen 2 ▲,Tubåen 3 ▼,Tubåen 4 ■
Higher-permeability samples have higher elastic moduli (***at the same porosity***) compared to lower permeability samples
Permeability sensitivity for modulus is decreasing with increasing porosity

Link to Petrophysics and Geology



Tubåen 4 - Q115
Tubåen 3 - Q274
Tubåen 2 - Q318 and Q350
Tubåen 1 - Q440 and Q441

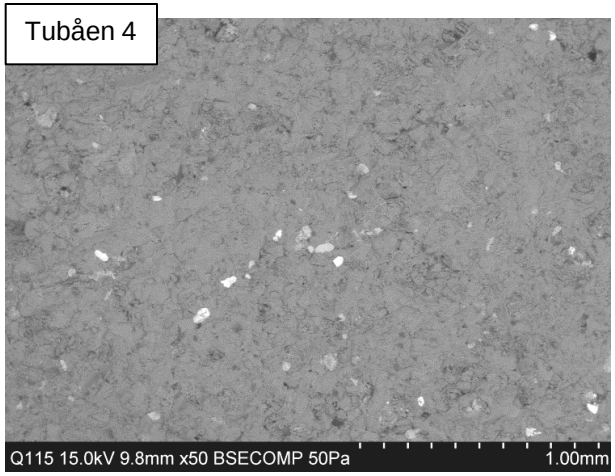
Tie into depositional setting of the formation:tidal and marine influence acts to worsen grain sorting compared to well-sorted distributary channel sediment



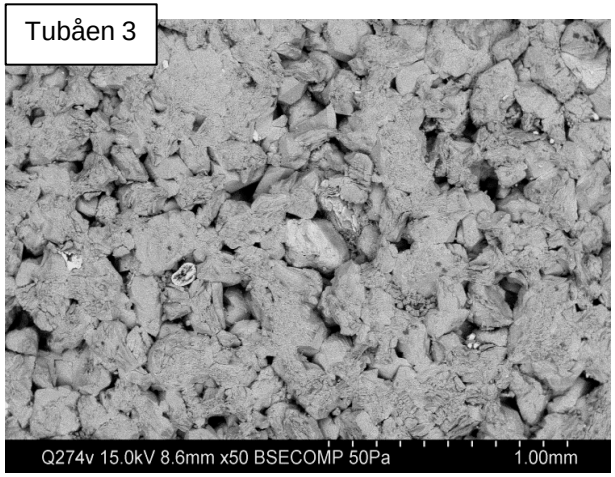
	Q 115	Q274	Q318	Q350	Q440	Q441
Porosity	11.0	17.0	13.0	10.9	21.7	21.0
Grain size	0.1	0.2	0.22	0.2	0.55	0.55
Sorting	Mod	Well/mod	Well	Well/mod	Well	Well
kH (mD)	0.4	354	186	56	12046	7534

VP-SEM Pictures

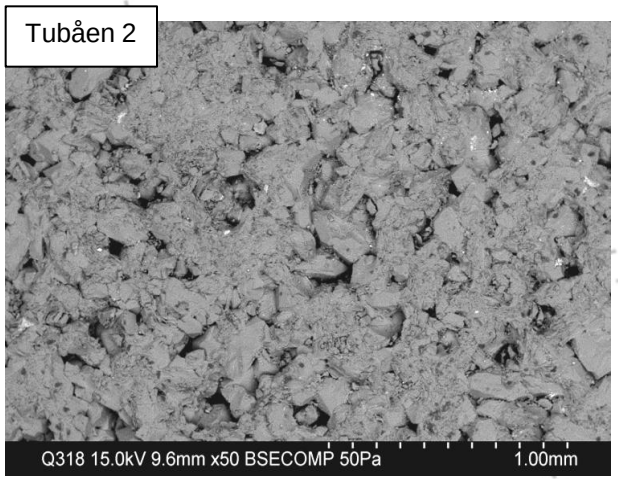
Tubåen 4



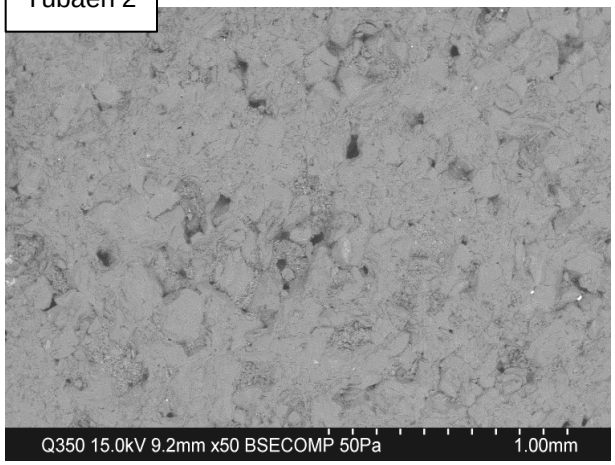
Tubåen 3



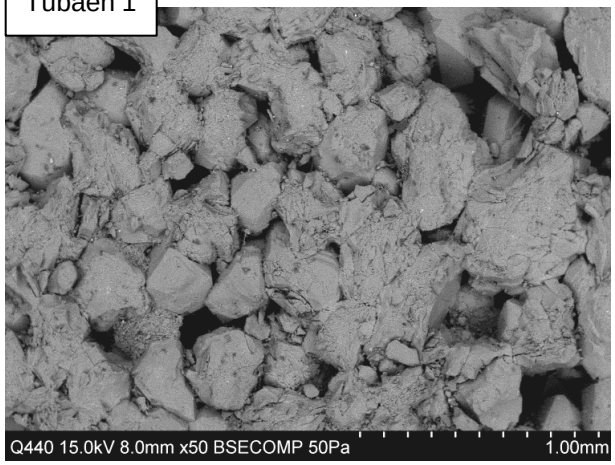
Tubåen 2



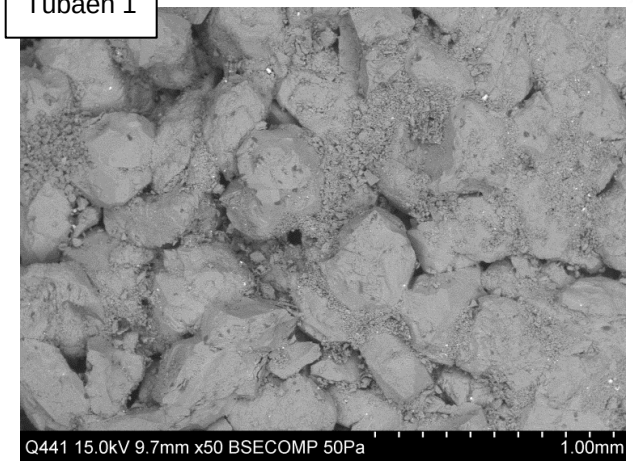
Tubåen 2



Tubåen 1



Tubåen 1



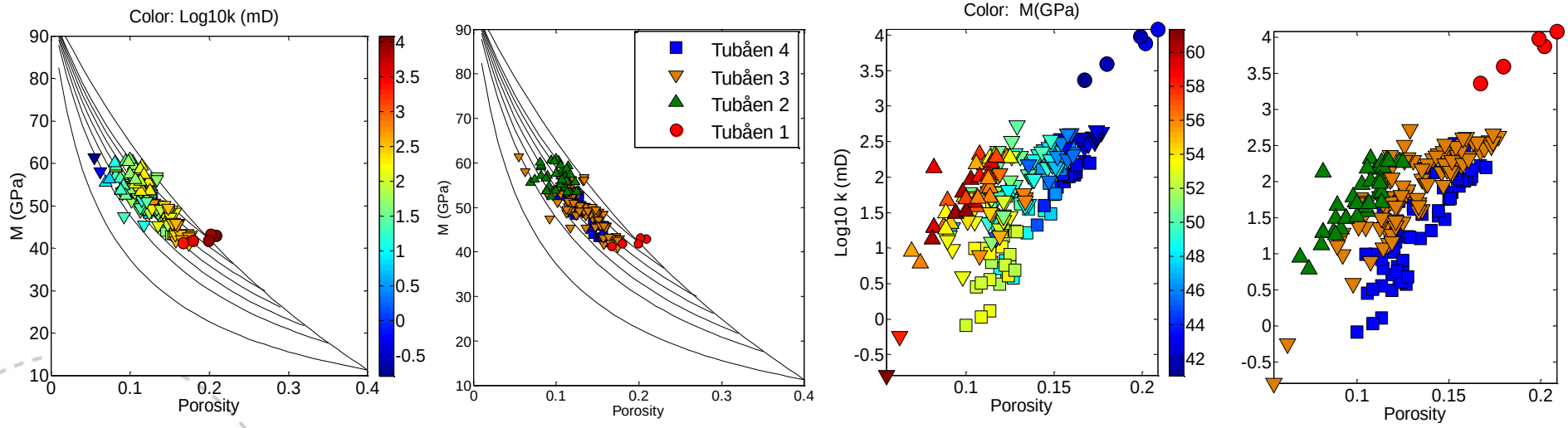
Sweetspots

At same porosity:

High compressional modulus ↔ High degree of contact cementation ↔High perm

Challenge to estimate velocity variations in a thin sand layer

Inversion to relate to seismic prioperties?



Discussion and Conclusions

- Link elastic properties and permeability
- At same porosity, stiffer sands have higher contact cement and less fines and, as a result, smaller permeability
- Permeability sensitivity for modulus decreasing with increasing porosity
- Good correlation with SEM and geology
- Fine grained particles dislodged due to CO_2 injection and clog pore space?
  - Irrelevant compared to cracking caused by high injection rate?
- Injected into the best suited intervals

Acknowledgments

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