



Staatstoezicht op de Mijnen
Ministerie van Economische Zaken
en Klimaat

UHS in salt – view and lessons from a mining authority

Heijn van Gent

State Supervision of Mines / SSM

Ingeokring Autumn Symposium "Salt of the earth"
TU Delft, November 2023



Mission of SSM

The State Supervision of Mines is committed to **human safety** and **the protection of the environment** during energy production and the use of the subsurface, **now and in the future.**



Core activities of SSM

Supervision and enforcement

- › Inspections and investigation
- › From conversation to penalty: behavioral change

Advising the Minister

- › Demanded: assessment of production plans, permits
- › Unsolicited: reflective supervision, policy, legislation

Communication and knowledge exchange

- › Local authorities
- › Public / press
- › Scientific research





Lessons from salt mining activities in the Netherlands

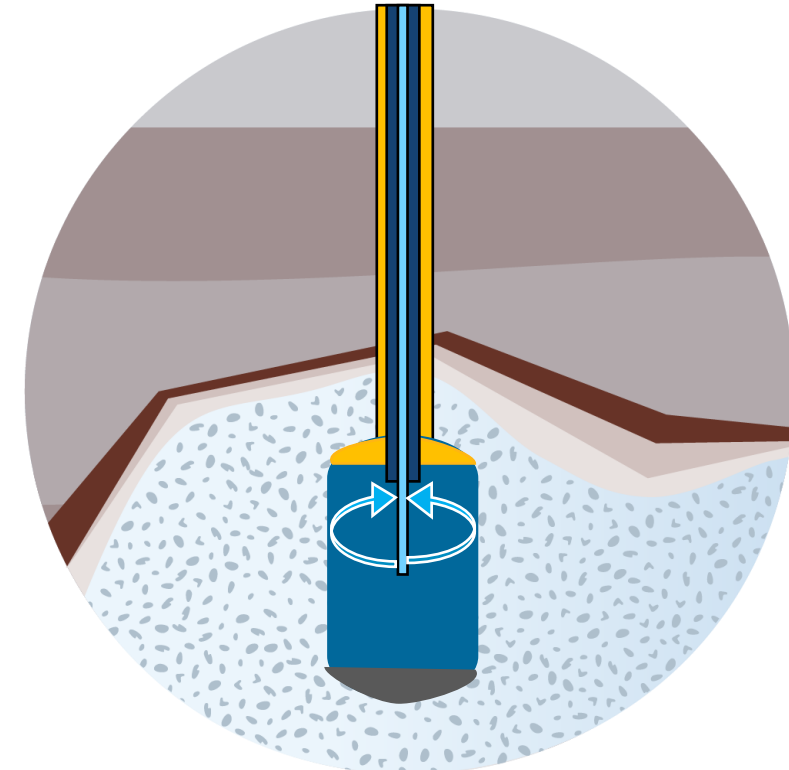
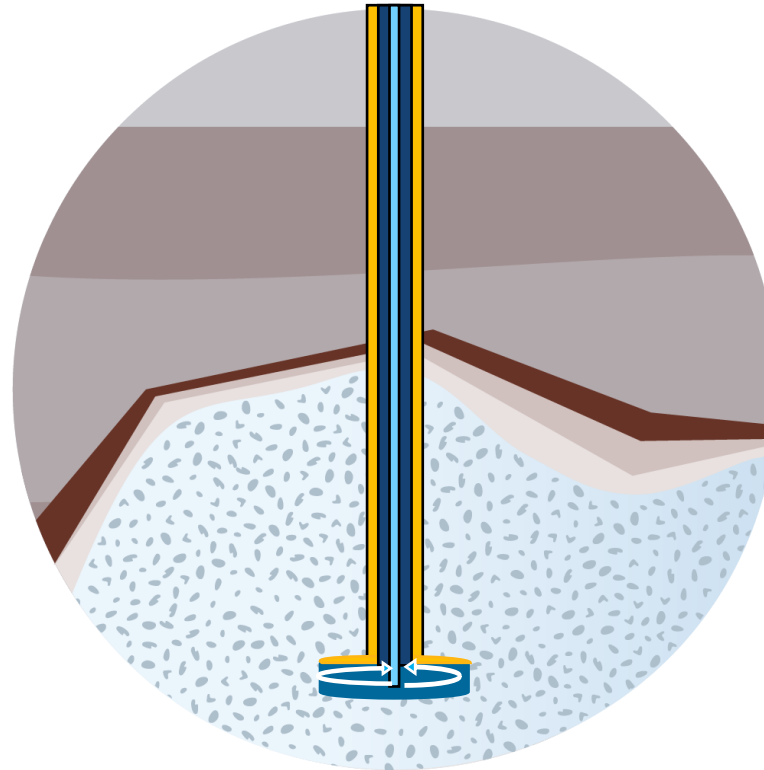
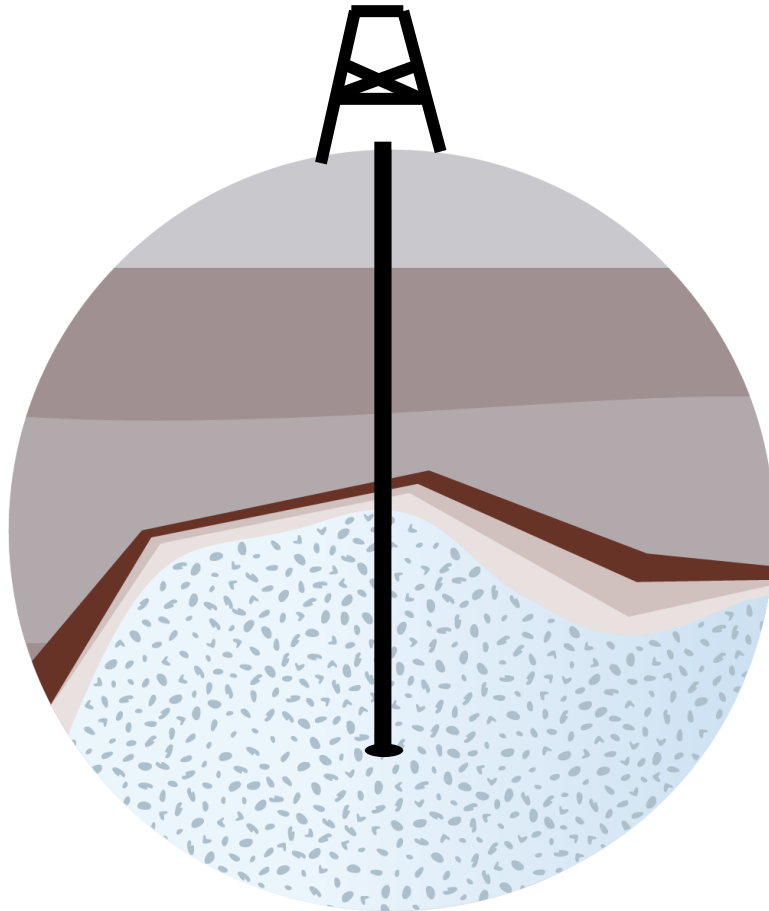
-on dogma's and paradigms





How salt is mined in the Netherlands?

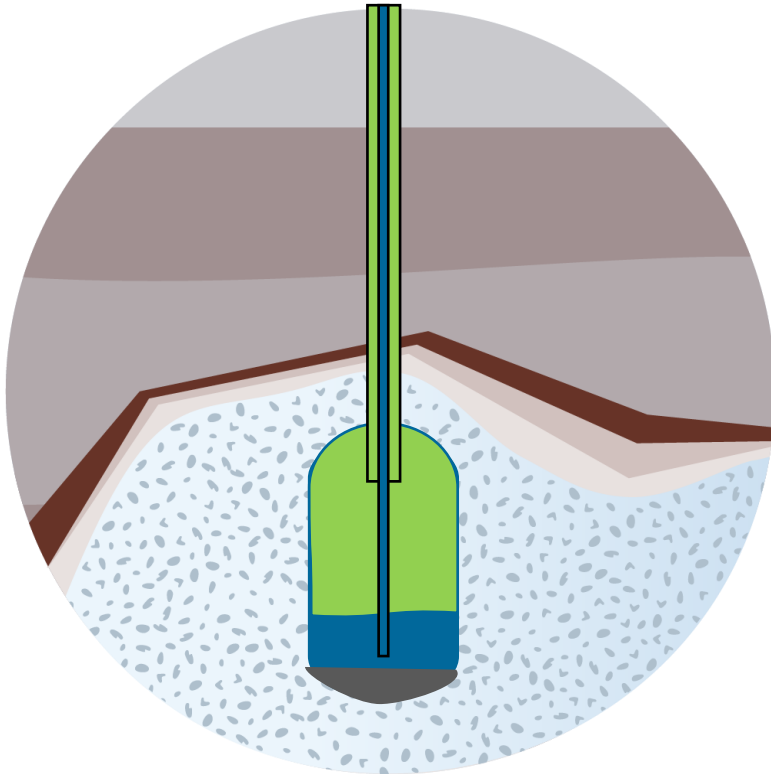
Cavern creation and production
(up to 10's of years)



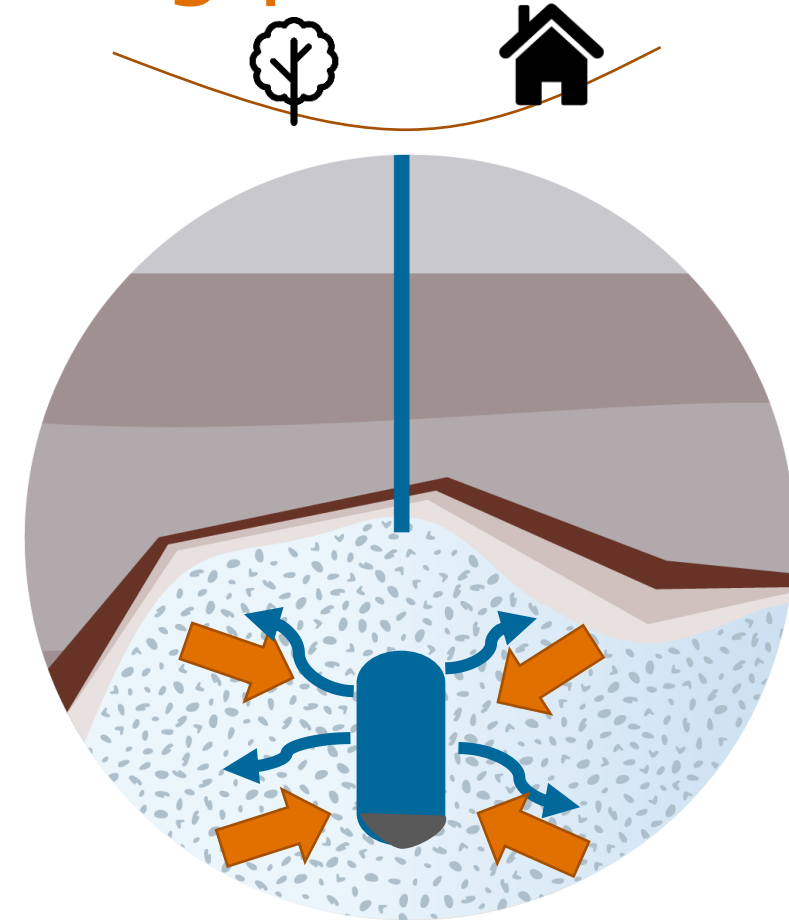
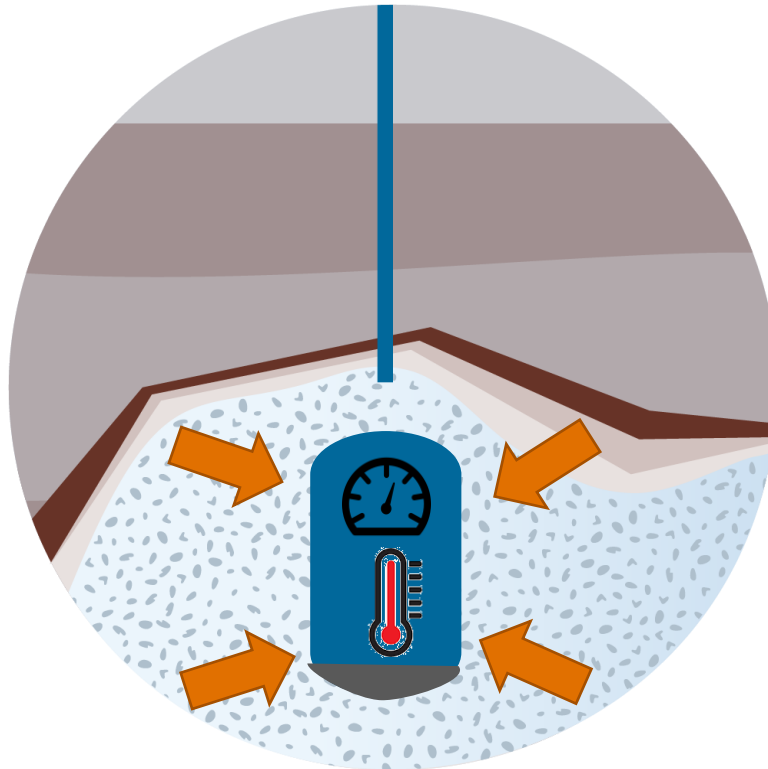


Storage, abandonment & postmining phase

Storage
(10's of years)



Abandonment and postmining
(100's -1000's of years)





Quiz: How small are the smallest cavernes (in NL)?





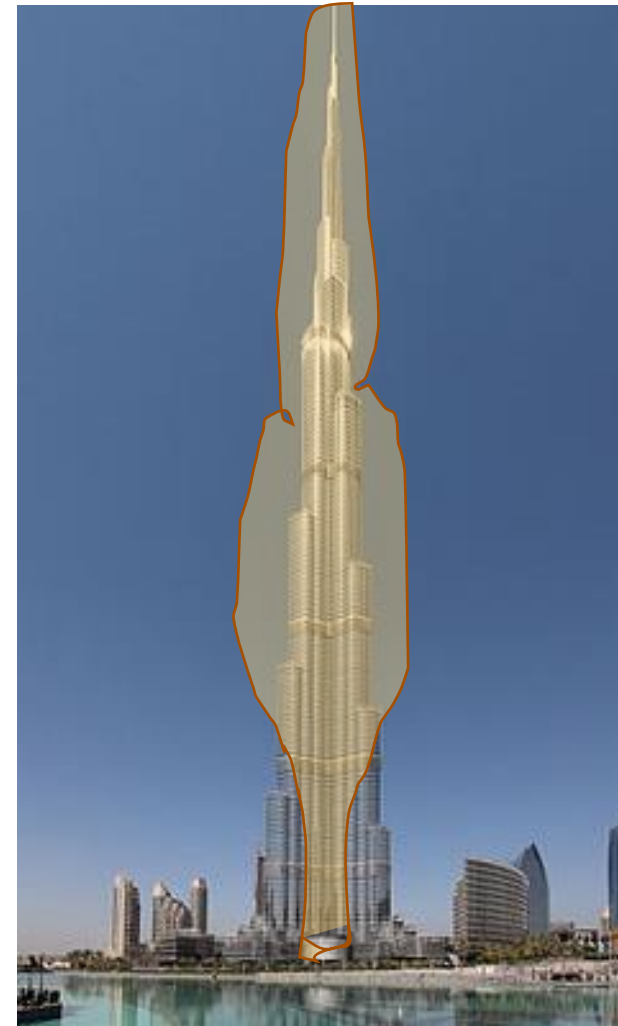
Quiz: How tall are the largest cavernes (in NL)?



Euromast (185 m)



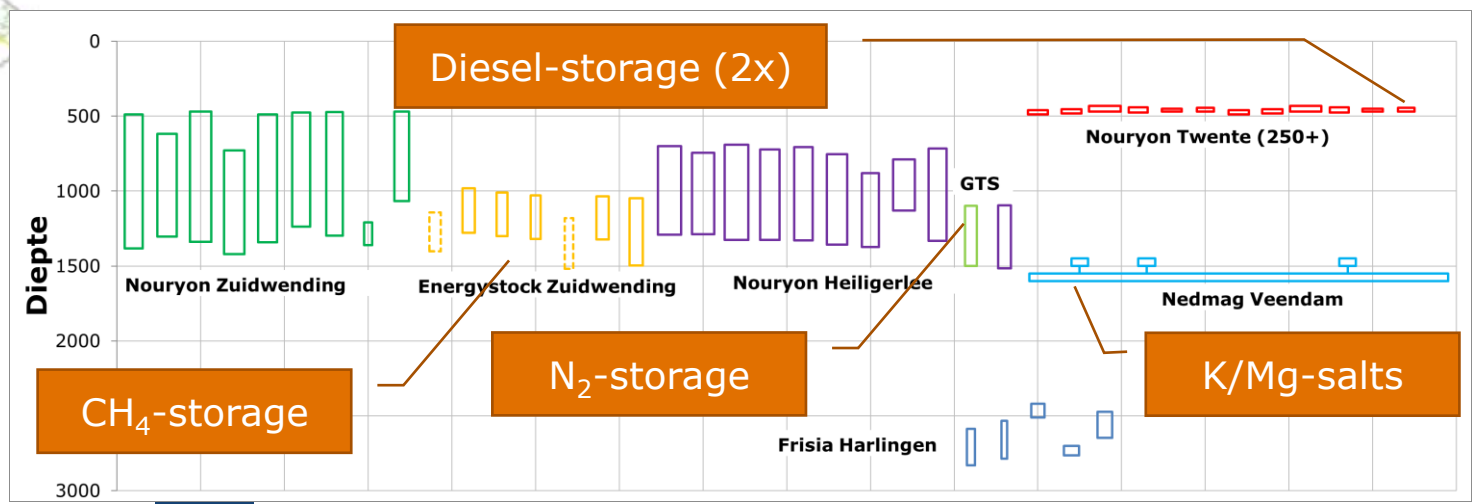
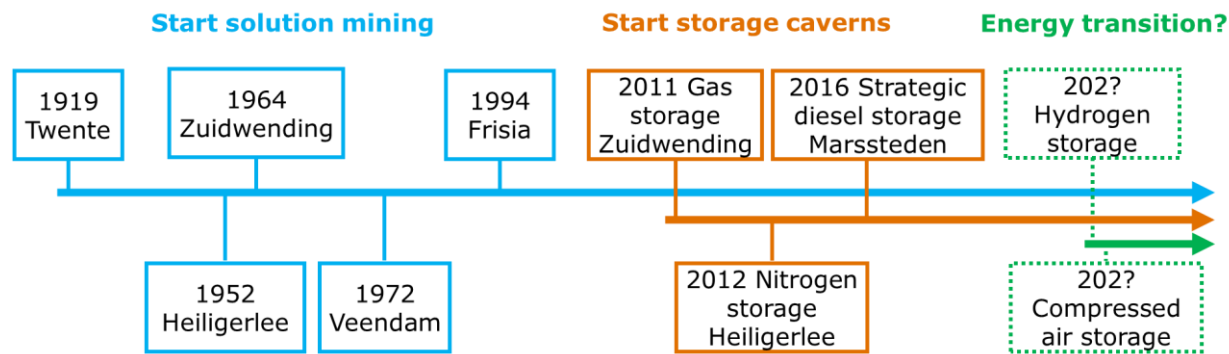
Eiffeltoren (324 m)



Burj Khalifa (829 m)



Caverns in the Netherlands - a family portrait





“Salt is the perfect seal!”

- nearly every geologist in the not-so-distant past
(paraphrased)

“Salt is quite a good seal!!”

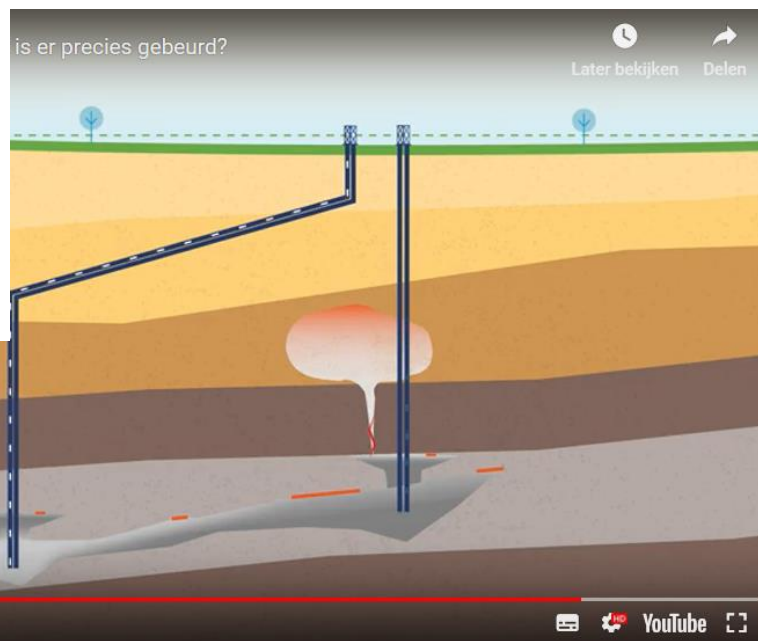
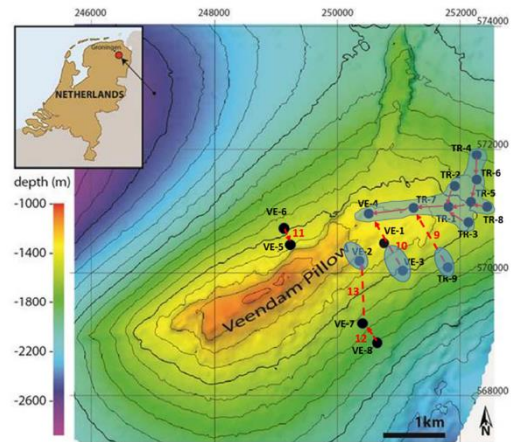
- Current position of SodM
(paraphrased)



Veendam – Leakage 20 april 2018

DAGBLAD VAN HET NOORDEN

YouTube: Zoutveld Tripscompagnie: wat is er precies gebeurd?
https://www.youtube.com/watch?v=J4BH_OcWs1k

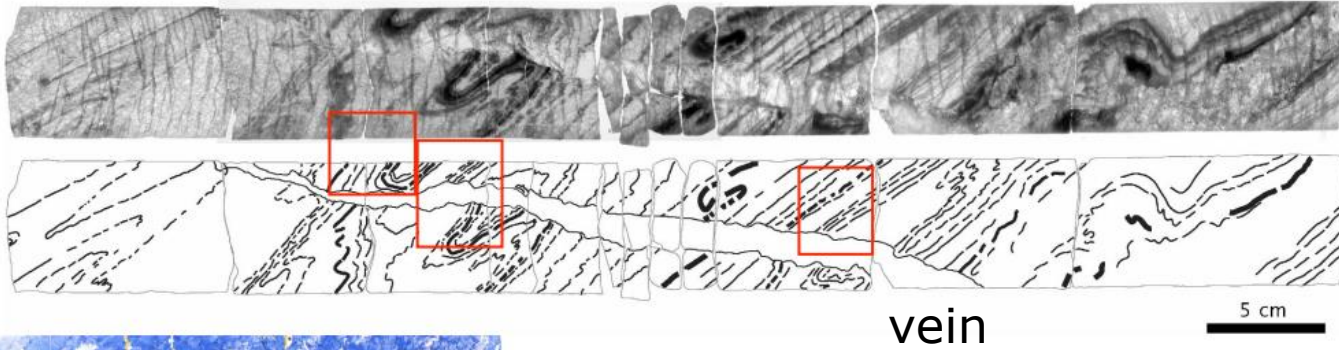


→ **Result:** accelerated subsidence and leakage of 100k m³ brine (and diesel) above the deepest seal

→ **Conclusion:** salt can fracture! How does this impact on abandonment and cyclic loading?

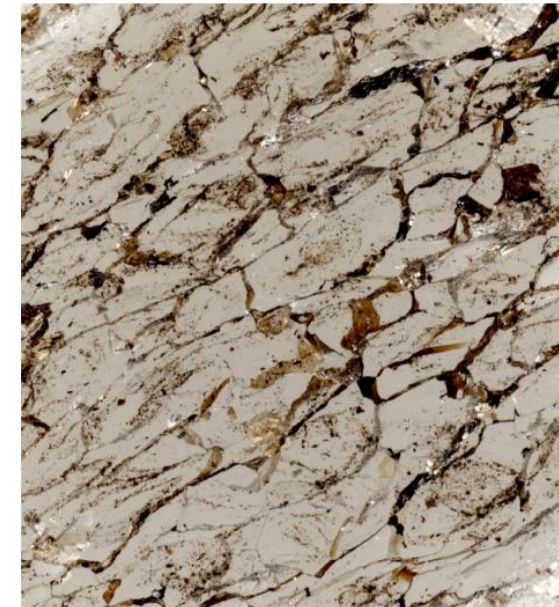


Natural examples of salt as an imperfect seal



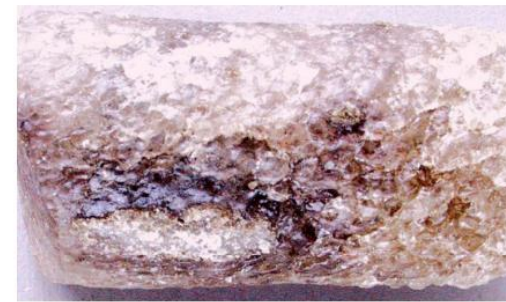
vein

5 cm



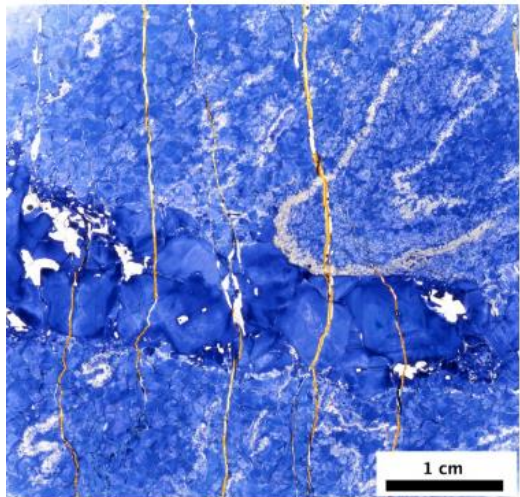
thin section

1 cm

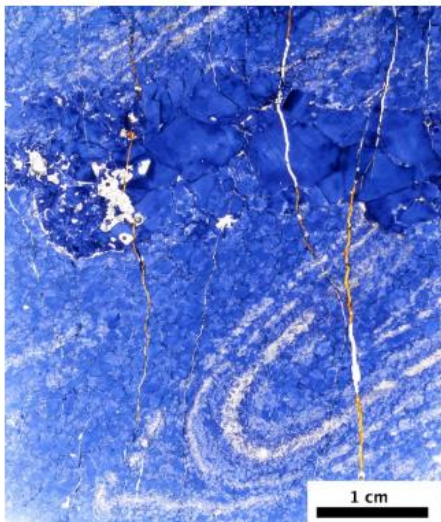


2 cm

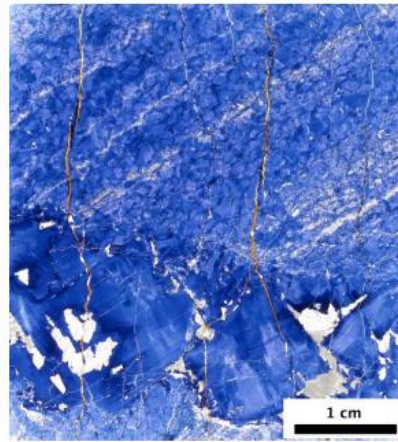
Fluid flow after main phase of deformation.



1 cm



1 cm



1 cm

Schoenherr et al. (2007)

Schleder et al. (2008)

KEM-17 (2020) – Risks of cavern abandonment



Salt mining, business as usual?

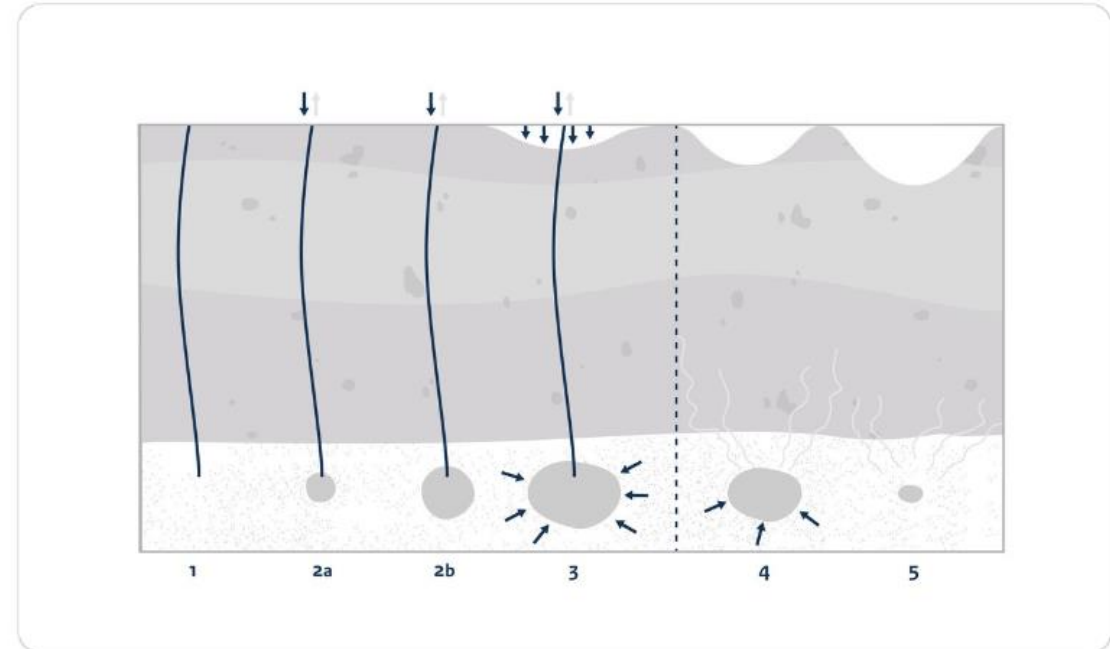
www.sodm.nl
www.sodm.nl/documenten/rapporten/2020/02/11/onderzoek-langetermijnrisicos-afsluiten-zoutcavernes



SodM
@sodmnl

Volgen

Wat gebeurt er met de achterblijvende pekkel in de diepe ondergrond nadat een zoutcaverne afgesloten is? SodM heeft hier wetenschappelijk onderzoek naar laten doen. [sodm.nl/actueel/nieuws...](https://www.sodm.nl/actueel/nieuws...)



01:35 - 11 feb. 2020

5 retweets 1 vind-ik-leuk





“Salt is homogenous!”

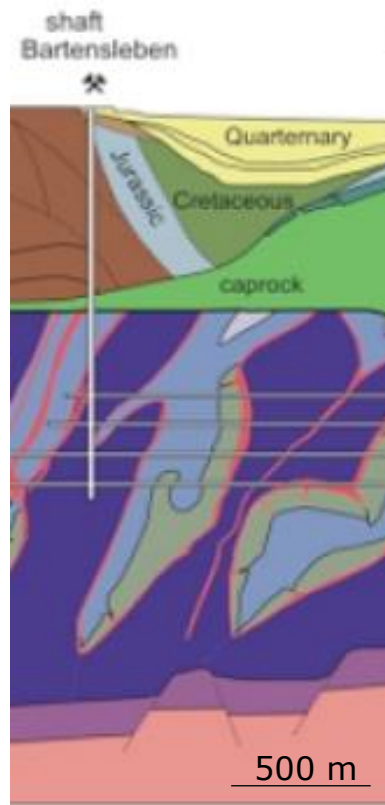
- nearly every (O&G) geologist in the not-so-distant past
(paraphrased)

“There is no such thing as homogenous salt!”

- Current position of SodM
(paraphrased)



Why is internal heterogeneity important?



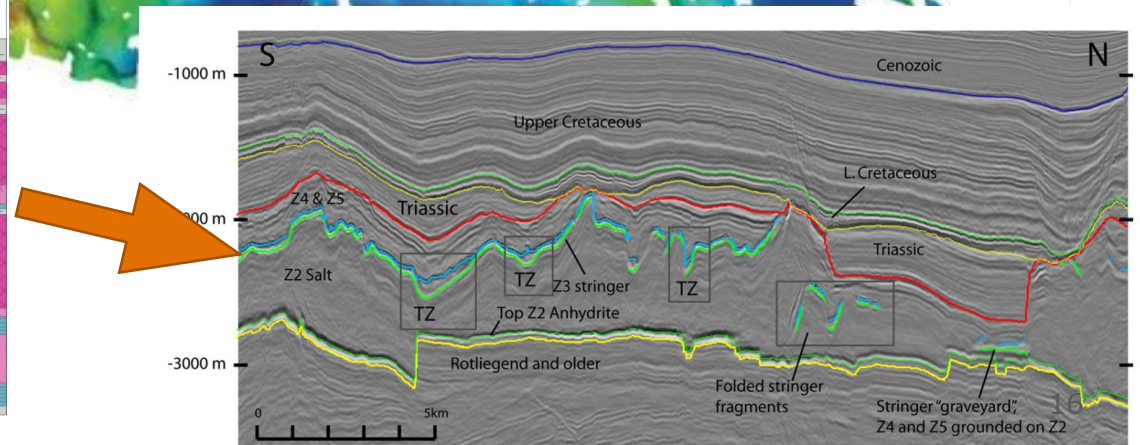
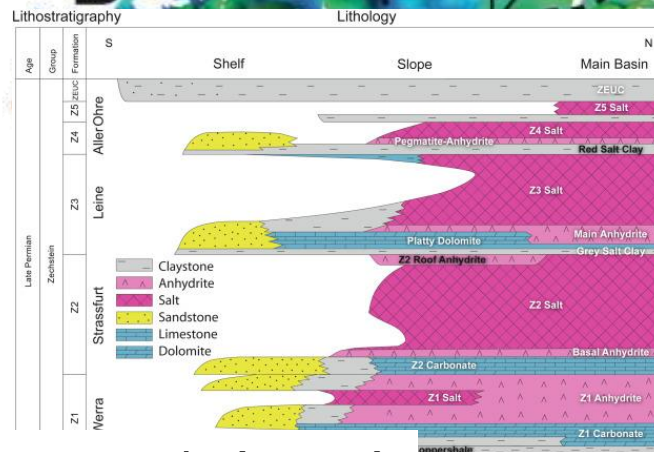
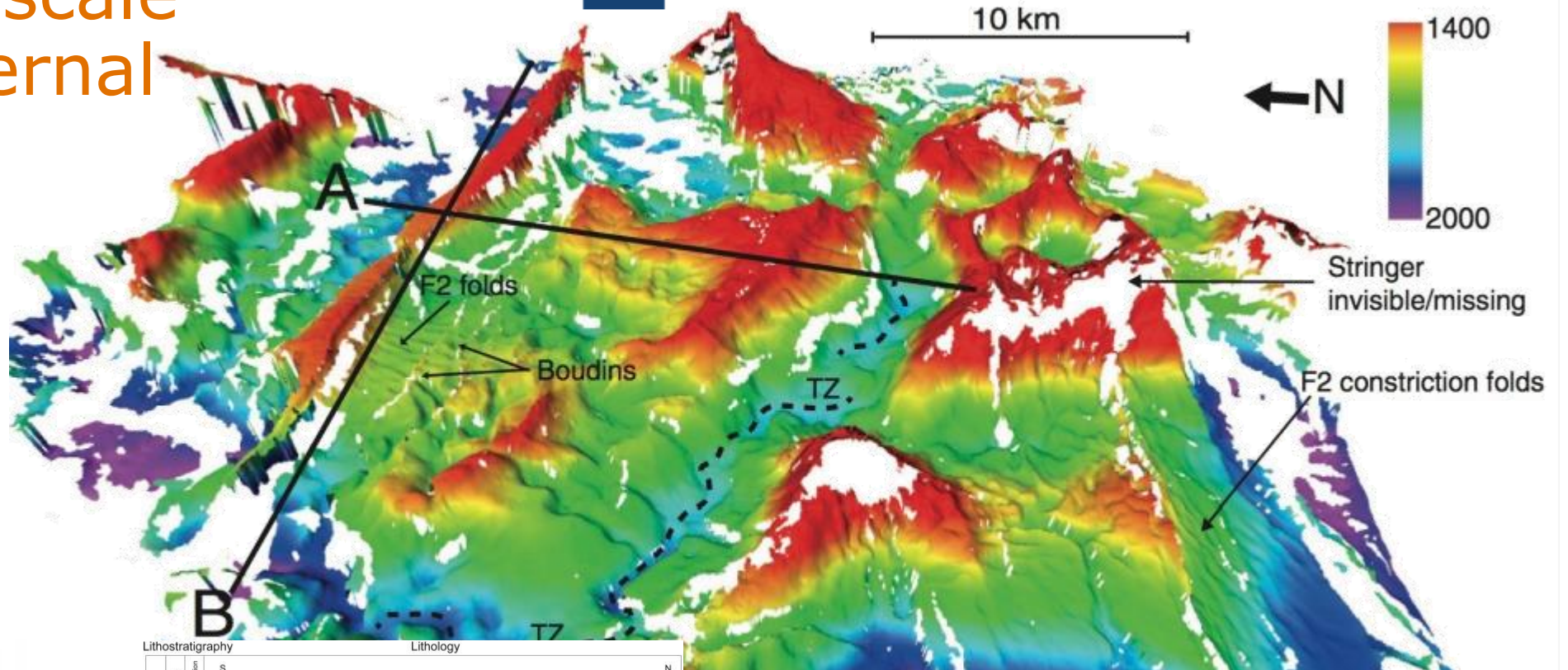
- > Unwanted chemical/ biochemical reactions
 - $\text{H}_2 + \text{anhydrite} + \text{S}^*\text{-microbes} = \text{H}_2\text{S} (!)$
- > Different geomechanical behaviors
 - Creep rates
 - Fracture strength & Seal integrity
- > Drilling & operational risks
- > Leaching efficiency & cavern shapes
- > Permeation efficiency
 - Important after abandonment
- > Predicting subsidence

* Sulphur-reducing

Salt is heterogeneous at all scales



First large scale look at internal structure above Groningen gasfield



Van Gent et al. (2011)



Danmark: Tostrup

- > Proximity of production cavern to massive anhydrite beds not identified pre-drill (cores).
- > During leaching sonars were taken
- > Between 3rd and 4th sonar a portion of the wall collapsed and buried the brine production point
 - Operational effect, no safety issue

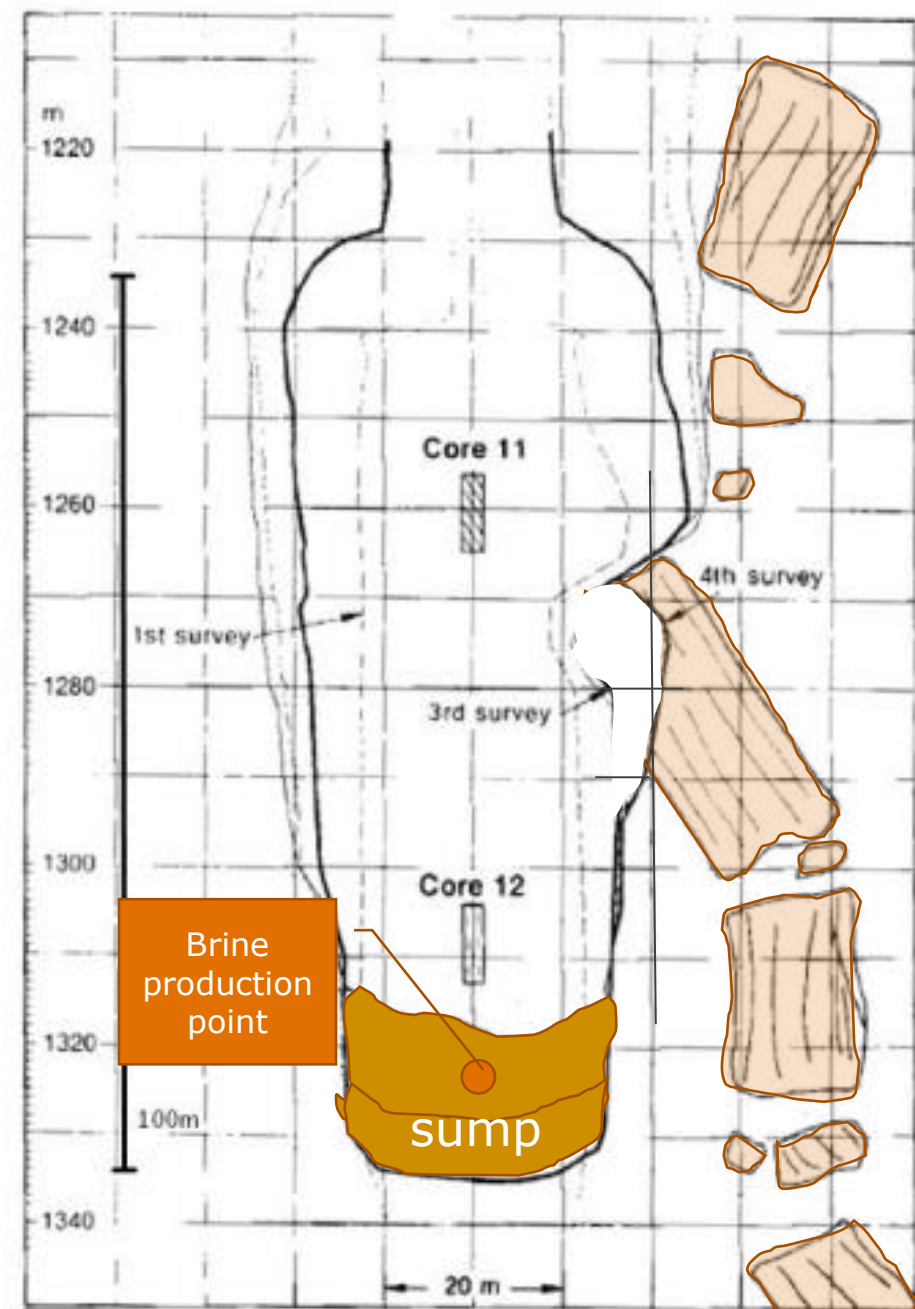
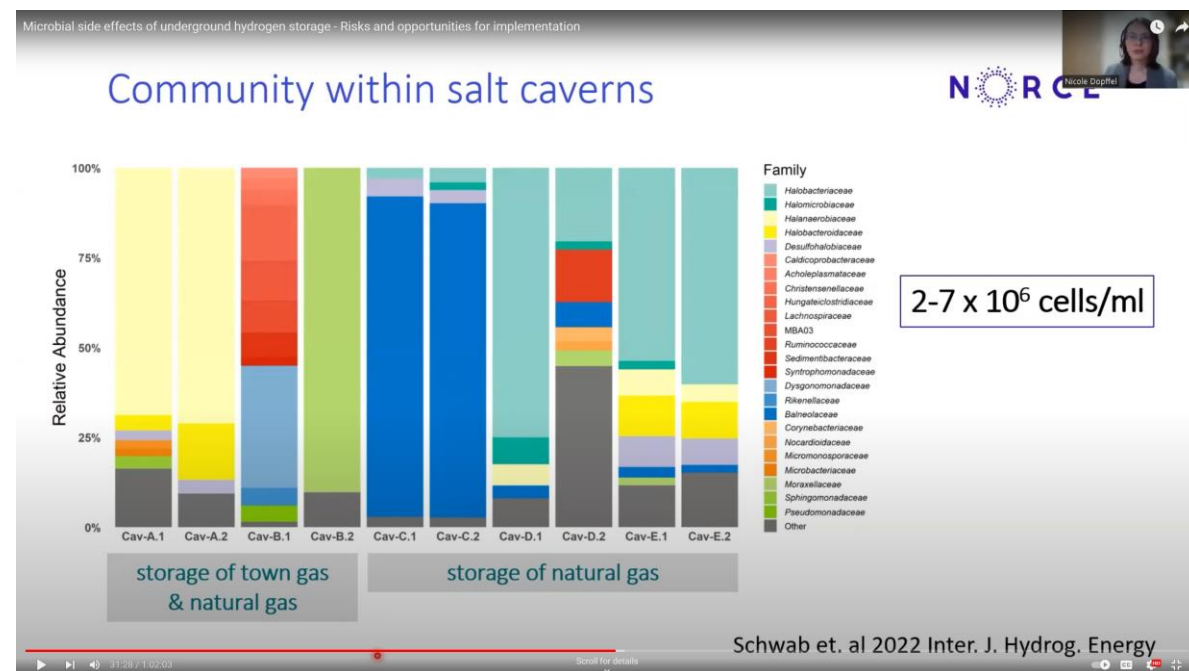
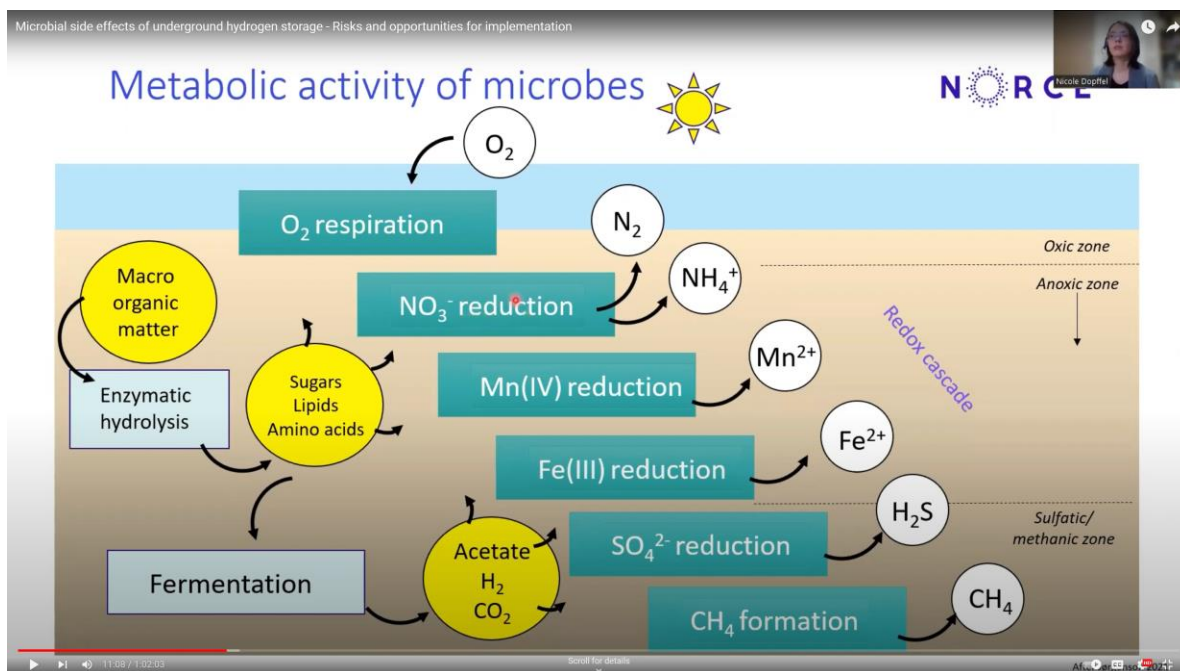


Figure 10 Cavern TO-9 in the Tostrup salt dome, Denmark. From Jacobsen & Nielsen (1992).



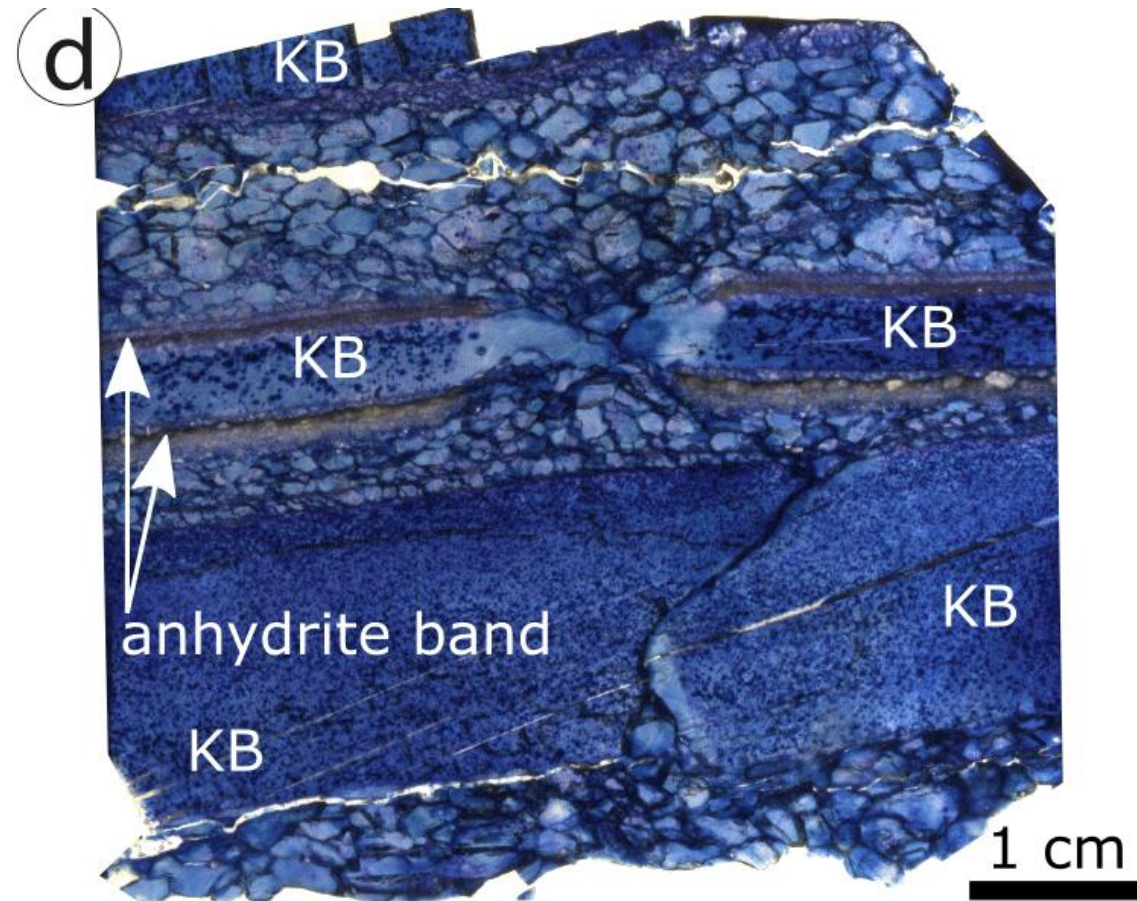
Side note: on microbes in salt caverns



Nicole Dopffel, Ph. D., Senior Researcher, Norwegian Research Institute - NORCE, Norway
Microbial side effects of underground hydrogen storage - Risks and opportunities for implementation
Bureau of Economic Geology – Youtube.com



A different kind of heterogeneity: grainsize



Barabasch, J., et al. , Solid Earth, 14, 271–291, 2023.

<https://doi.org/10.5194/se-14-271-2023>

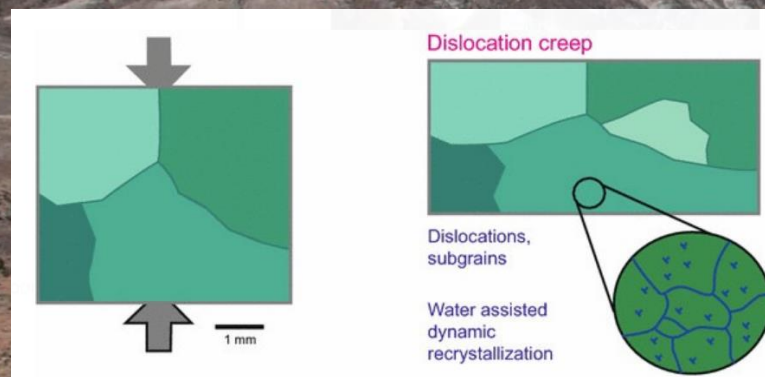


In Memoriam: Janos Urai *or: how salt behaves at geogical stresses*



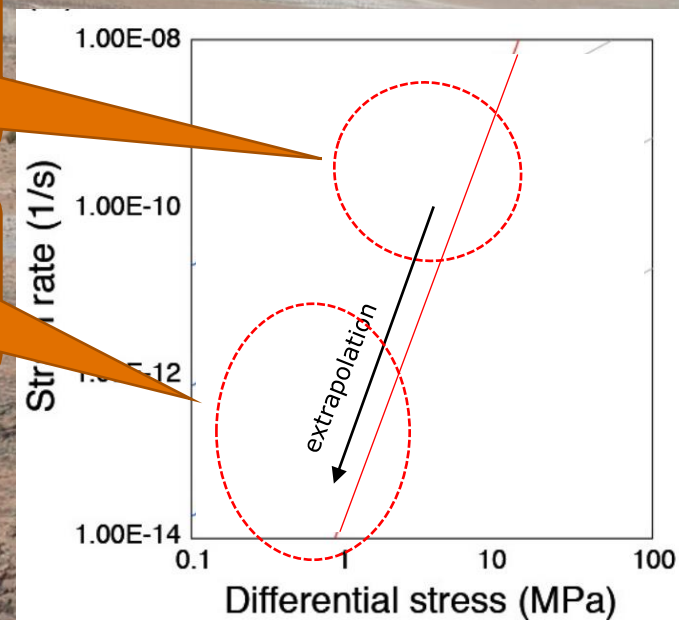


In Memoriam: Janos Urai or: how salt behaves at geological stresses



Realm of "practical lab measurements"
(roughly 1 PhD thesis long)

Realm of natural, "non-tectonically stressed" salt



Dislocation creep

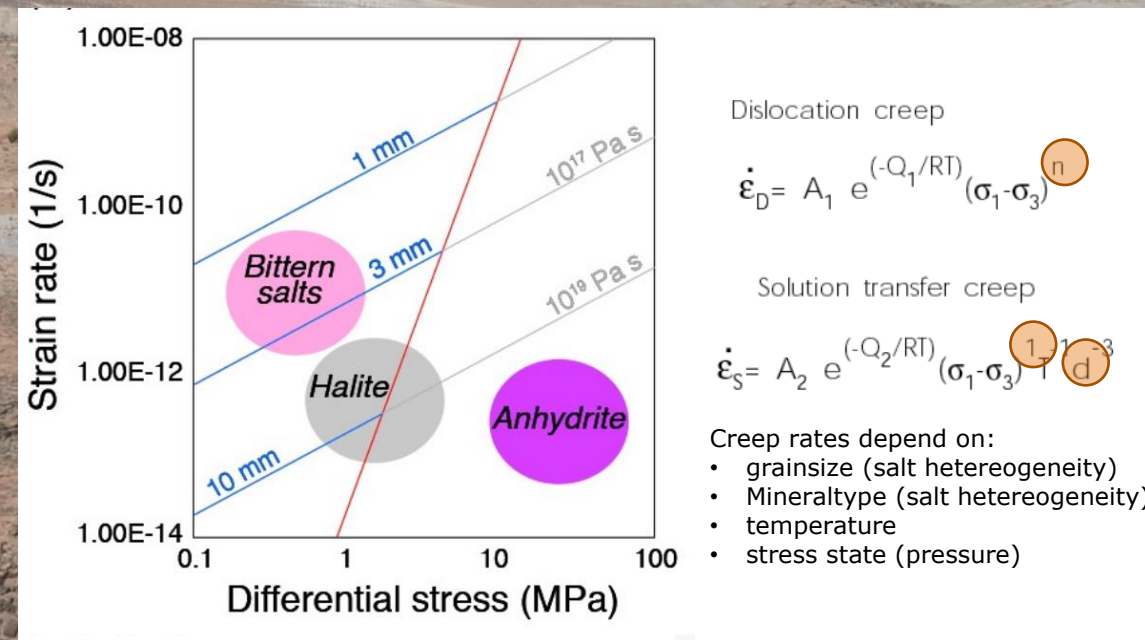
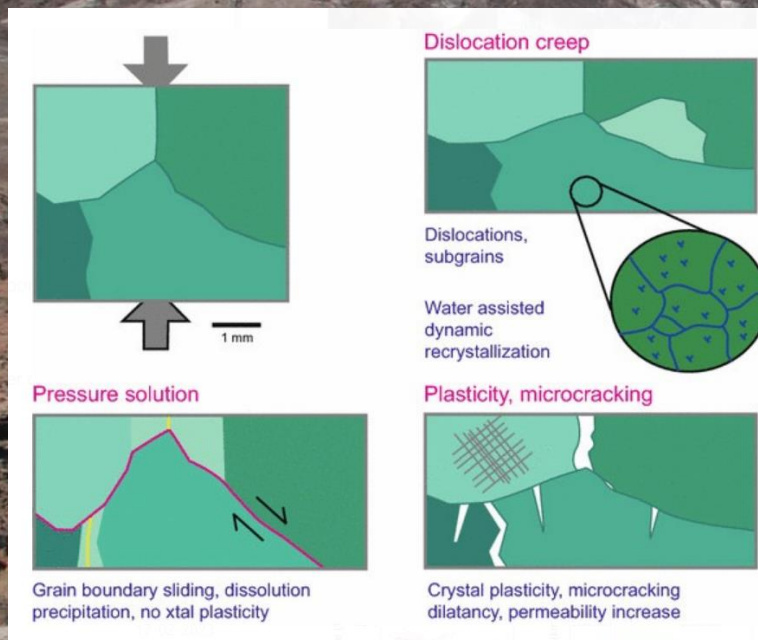
$$\dot{\epsilon}_D = A_1 e^{(-Q_1/RT)} (\sigma_1 - \sigma_3)^n$$

Creep rates depend on:

- grainsize (salt heterogeneity)
- Mineral type (salt heterogeneity)
- temperature
- stress state (pressure)

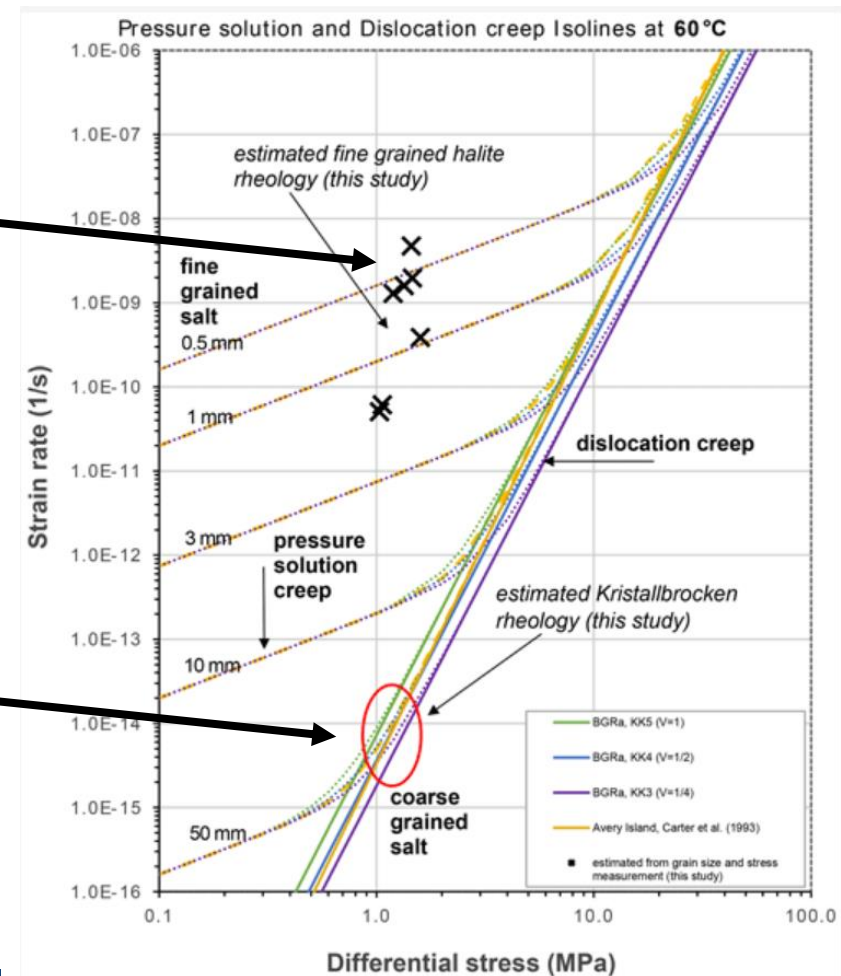
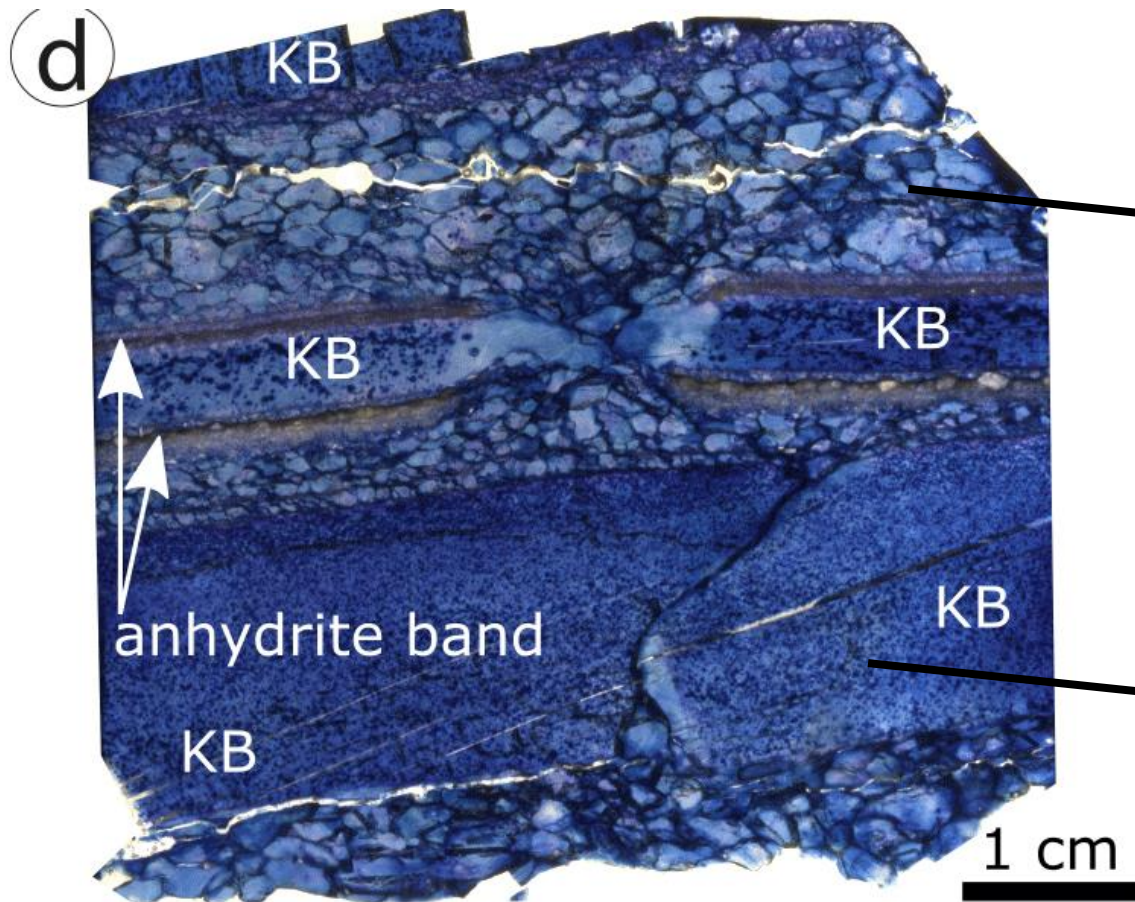


In Memoriam: Janos Urai or: how salt behaves at geological stresses





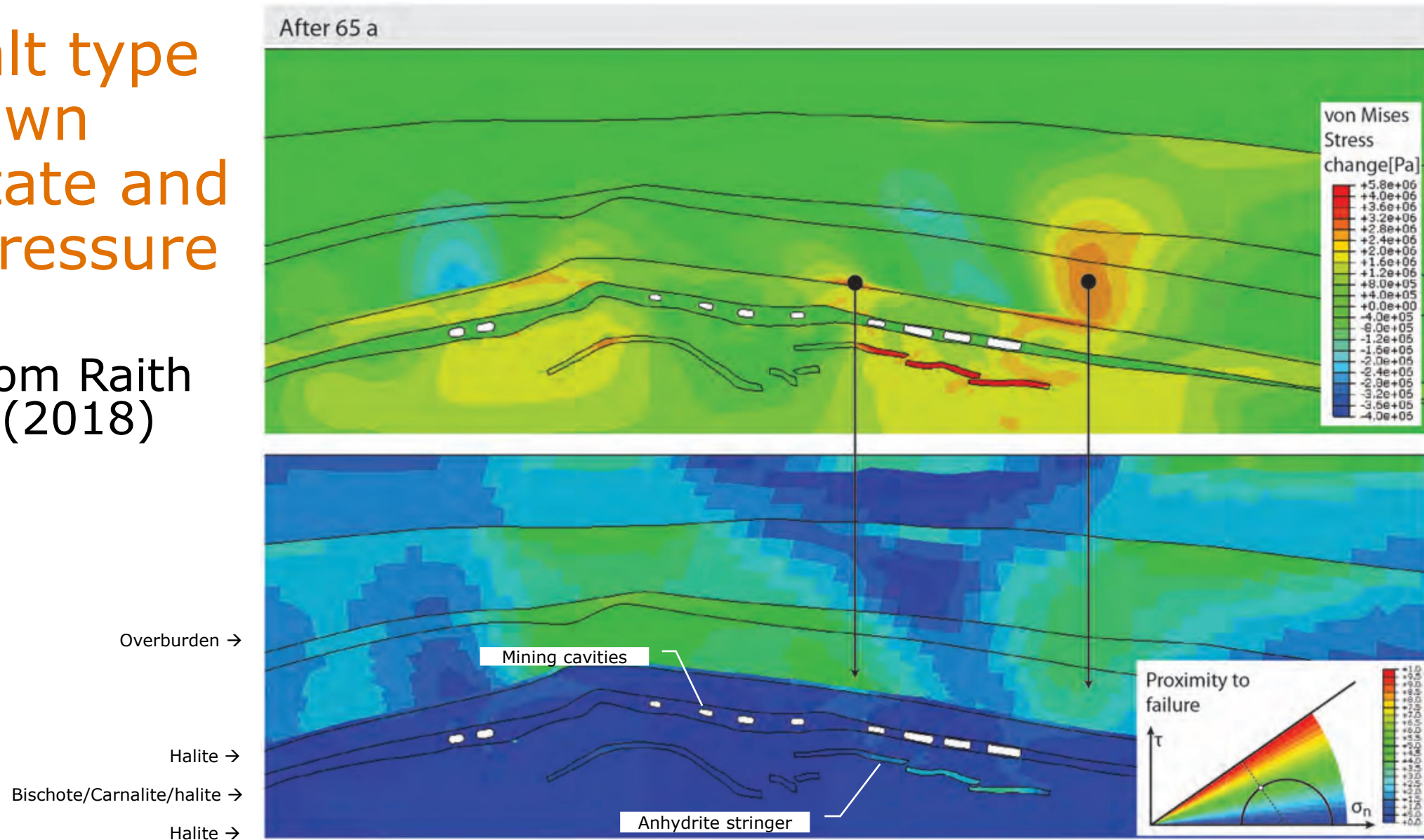
The effect of grainsize on creep rates





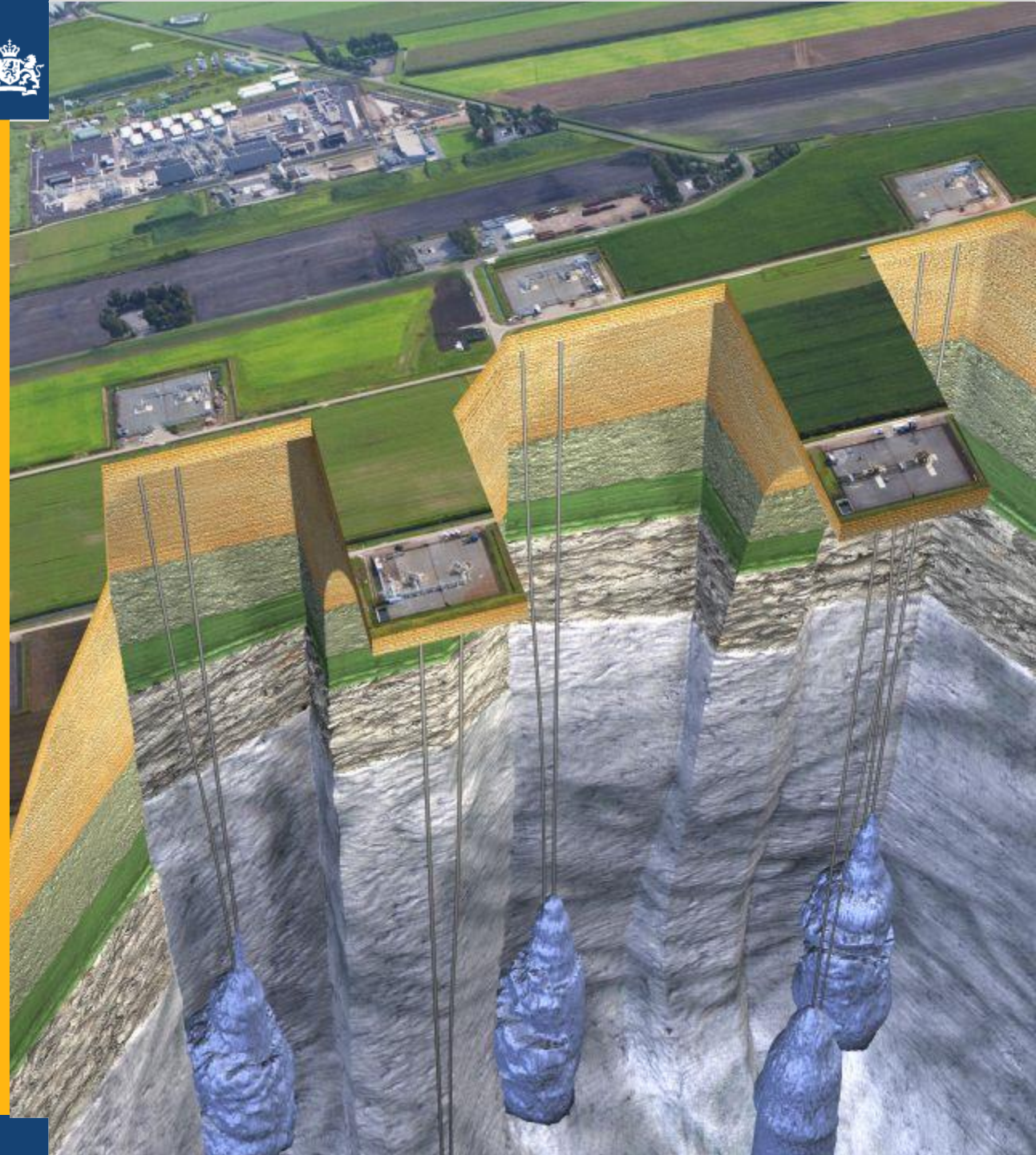
Every salt type has its own stress state and failure pressure

› Image from Raith and Urai (2018)





What do these lessons mean for UHS (in salt caverns)?





2021 - Risk analysis (internship)

Spindletop, Texas, United States of America

| | | | |
|-------------------|---|----------------|--|
| Storage | 1. Brine supply 2. Hydrocarbons (LPG) 3. Hydrogen (95%) 4. Natural gas | Activity | Active |
| Number of caverns | 1. 1 2. 1 3. 1 4. 8 | Salt structure | Salt dome |
| Depth of cavern | 3. 1340m | Operator | 1. Texas Brine Company, LLC 2. Coastal Caverns Inc. 3. Air Liquide 4. 3 operators |
| Individual volume | 3. 906000 m ³ | | |

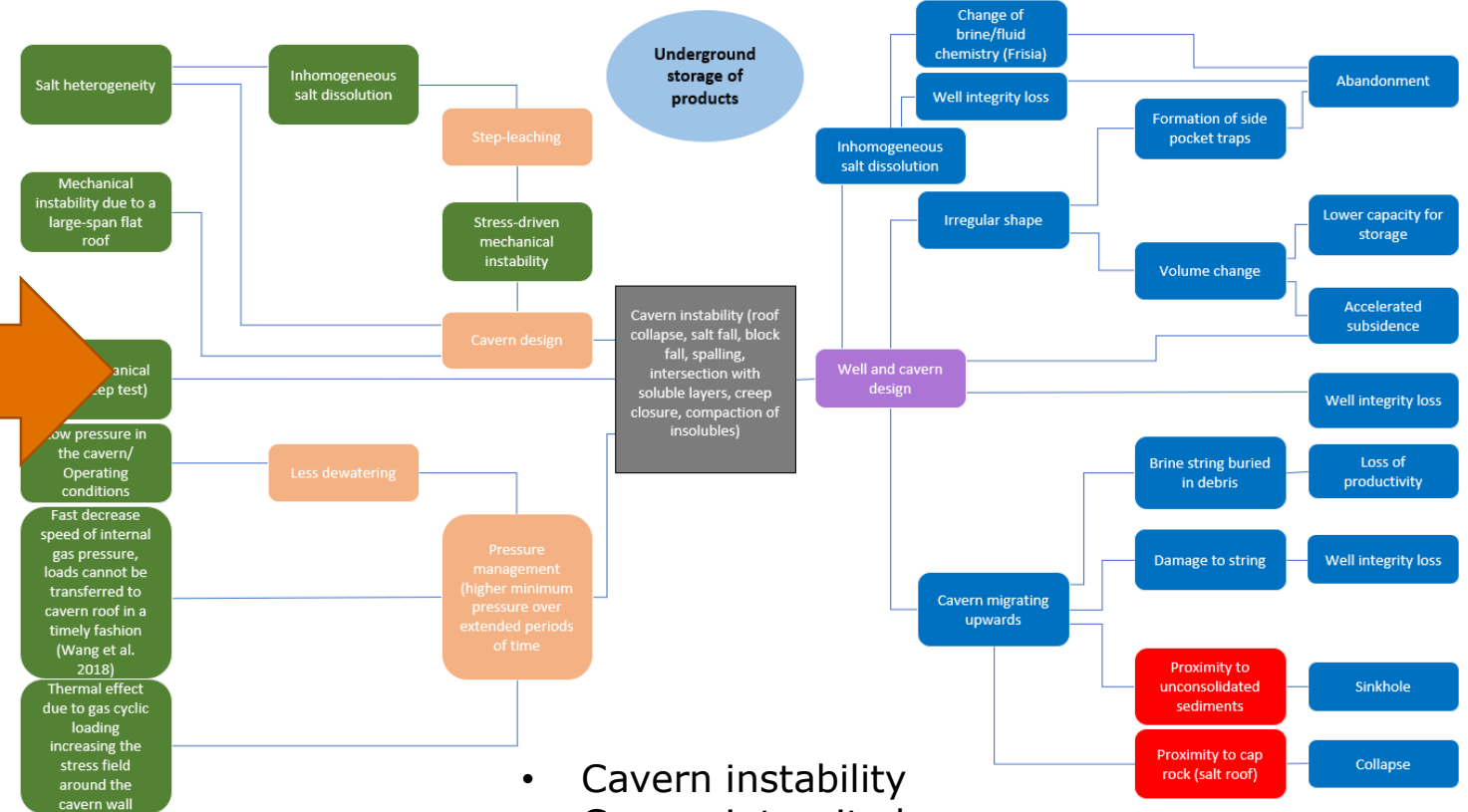
The Spindletop salt dome is located in Jefferson county, Texas. The dome is part of the Gulf Coast basin and the depth to the top of the salt is 336m. 6 operators have 11 caverns in this salt dome.

In 2001 a gas storage cavern and a brine production cavern became interconnected, which is a "significant unanticipated geomechanical development" (Johnson, 2003).

References: (Brouard, 2019; Caglayan et al., 2020; Horváth et al., 2018; Johnson, 2003; Zivar et al., 2020)

Figure 1.20 Showing the caverns Centana 1 and Gladys 2, which became interconnected, from (Johnson, 2003).

| | |
|---------------------|--|
| Incident | Hydraulic connection, 2001 |
| Cause | Cause debated: "It is unknown whether the gas is migrating through an induced fracture, a fault plane or a seam of porous and permeable salt intersecting both caverns at an unknown altitude" (Johnson, 2003) |
| Top event | Cavern integrity loss (hydraulic connection between caverns, a brine production cavern and a gas storage cavern) |
| Mitigation measures | Flaring off gas |
| Effects | Remaining gas inventory was recovered and flared, loss of product, several brine production wells have been abandoned and plugged |
| References | (Brouard, 2019; Caglayan et al., 2020; Horváth et al., 2018; Johnson, 2003) |

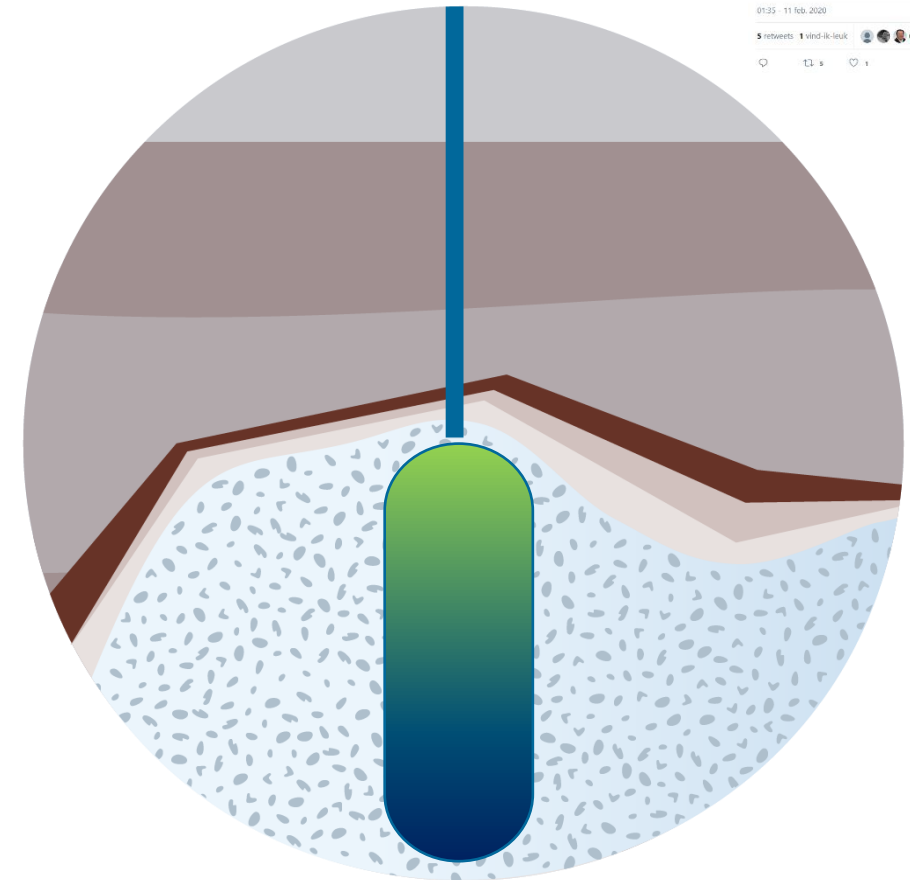


- Cavern instability
- Cavern integrity loss
- Well integrity loss
- Well control loss
- Pipeline integrity loss



Underground storage

- > **Salt is not always a perfect seal**
- > **Salt is not homogeneous**
 - (both in grain size and composition)
 - Some of these heterogeneities have (some) porosity and permeability
- > Effect of low stress and changes in pressure is not fully understood
- > Chemical and **microbially assisted** reactions between stored medium and steel and non-halite rocks
- > *Social acceptance and perceived risks*





Thanks for your attention

- > Contact with SSM
www.sodm.nl/contact
- > Questions?

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