New Frontiers in Salt Research*

Peter A. Kukla[1], Janos L. Urai[1], and Frank Strozyk[1]

Search and Discovery Article #80706 (2019)**
Posted September 30, 2019

*Adapted from oral presentation given at 2019 AAPG Annual Convention and Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/80706Kukla2019

[1]RWTH Aachen University, Aachen, Germany (peter.kukla@emr.rwth-aachen.de)

Abstract

The German energy transition involves massive changes from nuclear power and coal fired power stations towards renewable energy sources. This “Energiewende” policy of the German Government poses great challenges for power and heat supply for industry and private households. A share of more than 50 percent renewable energy in the power sector requires large-scale energy storage. Oil and natural gas have been stored in salt caverns for decades as a national strategic energy reserve. Compressed air or hydrogen generated from surplus electricity of renewables can be stored there too. Brines generated during cavern development can be used in oilfield and geothermal operations or for chemical processes, e.g. chlorine electrolysis or lithium extraction. The development, operation and abandonment of the new generation of caverns poses important challenges and opportunities for salt research and development. In addition, new frontiers in salt energy systems include building the world’s largest natural battery storage system in salt caverns, and high-temperature liquid salt energy storage.

Germany holds the world’s largest subsurface storage capacity and at the same time an unprecedented wealth of subsurface information from a large number of salt mines. This 3D exposure offers unique opportunities for applied and integrated salt systems research. Despite the fact that salt research is more than 100 years old, there is much research need on how anisotropic salt successions behave under varying stress, pressure and temperature conditions. Geological research in this context has the unique opportunity to integrate structures and processes external and internal to the salt (stratigraphy, structure, pressure, fluids) and contribute to new storage and mining concepts and risk assessment of ventures in salt exploitation and engineering. For example, the coupling between fluid and gas occurrences and the lithologic and geomechanical structure of evaporites and the surrounding rocks are not well known. These new research results will also provide a solid basis for the safe and sustainable management – and ultimately the disposal – of radioactive waste, one of the grand challenges of our times. This contribution will summarise current approaches using geological, geochemical, and radiometric techniques to improve our understanding of structure and thermo-mechanical behaviour of salts through time from the Permian Zechstein Salt Basin in Germany and The Netherlands.

New Frontiers in Salt Research

Peter A. Kukla, Janos L. Urai, Frank Strozyk
RWTH Aachen University

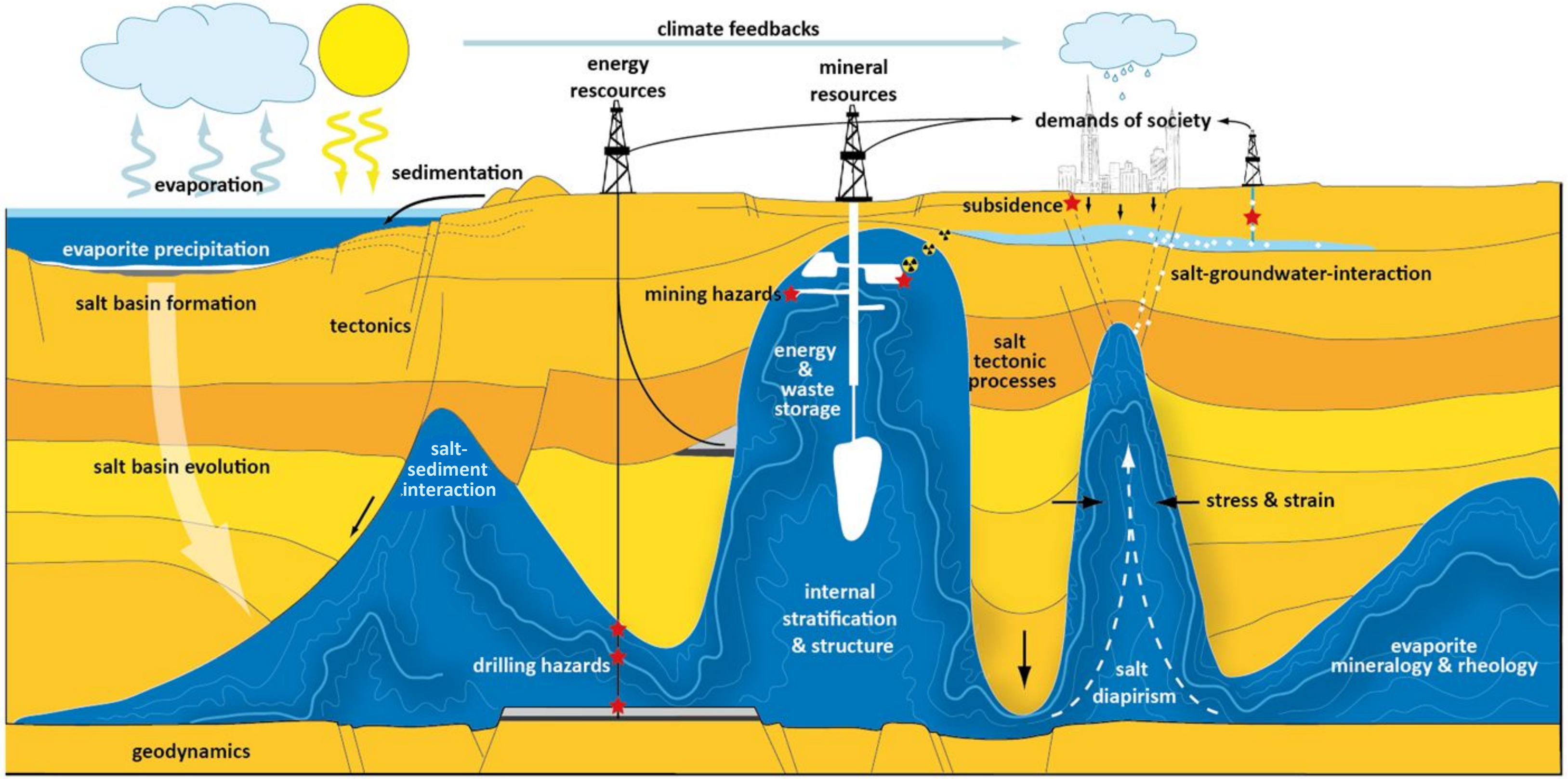
Main message

√ We need a better understanding of the anisotropy of layered evaporite successions and their geomechanics

√ We need a better understanding of permeability and fluid movement in salt

√ We need direct salt movement indicators

Why new frontiers?



Salts are essential for life. Salt is an increasingly versatile ingredient for many purposes and various industrial processes.

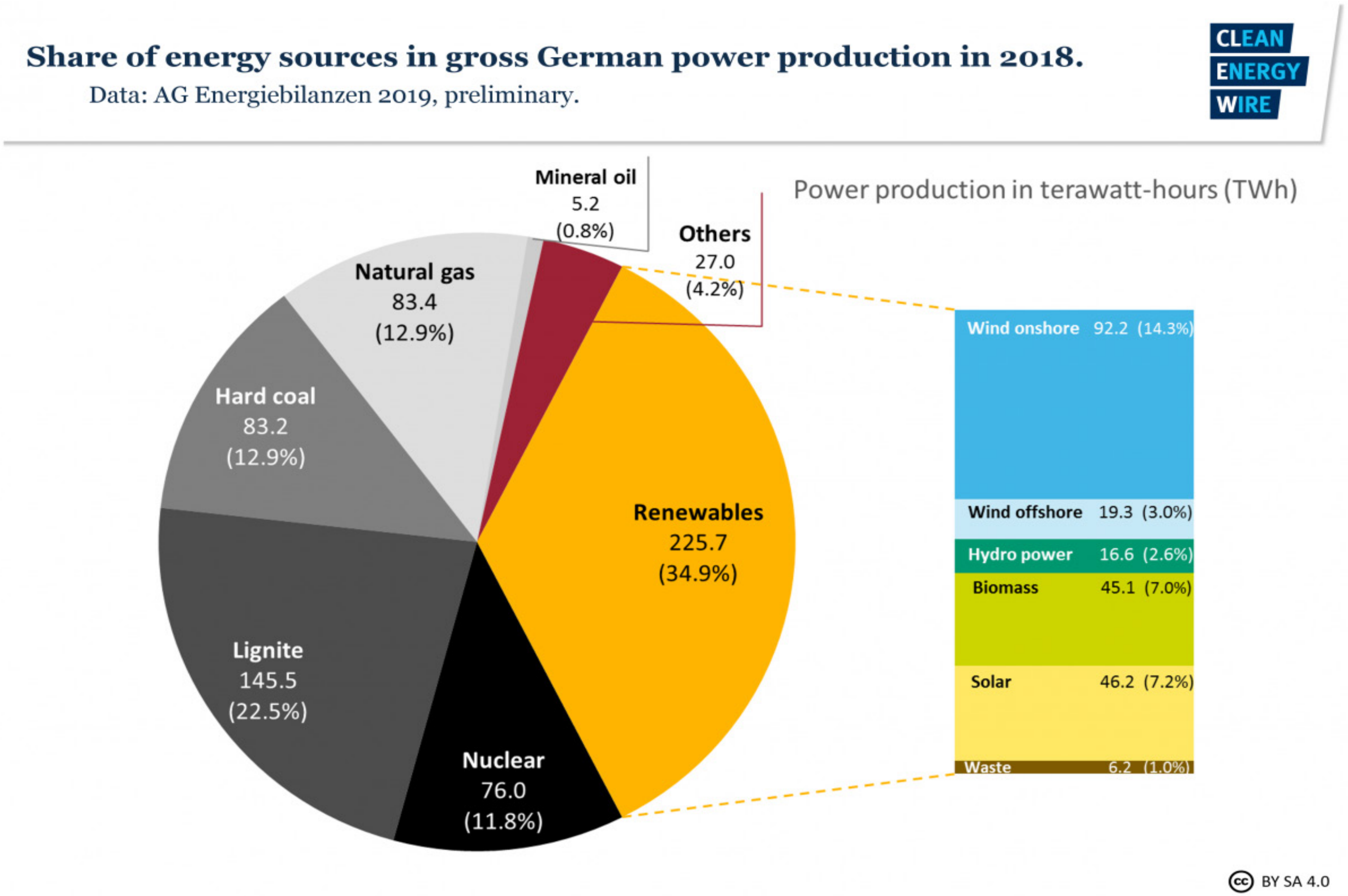
Salts are archives. Salt successions are the storyboards of our planet`s past, present and future.

Salts are risky. Excessive salt use bears risks for human health and the environment.

Salts are valuable. Worldwide sought after commodity.

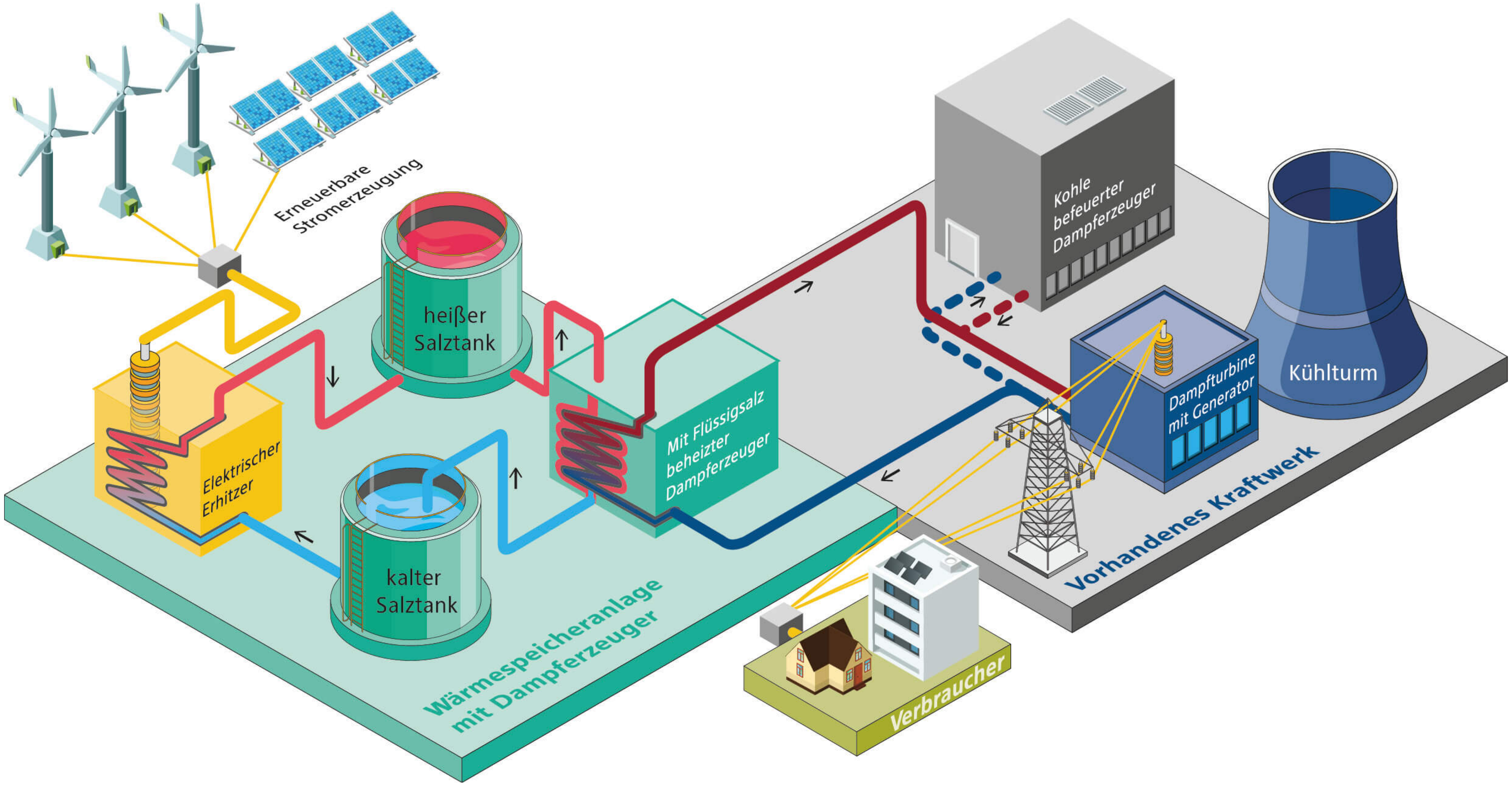
Salts drive innovation. Salt has become an important focus of industrial innovation.

German Power Sources



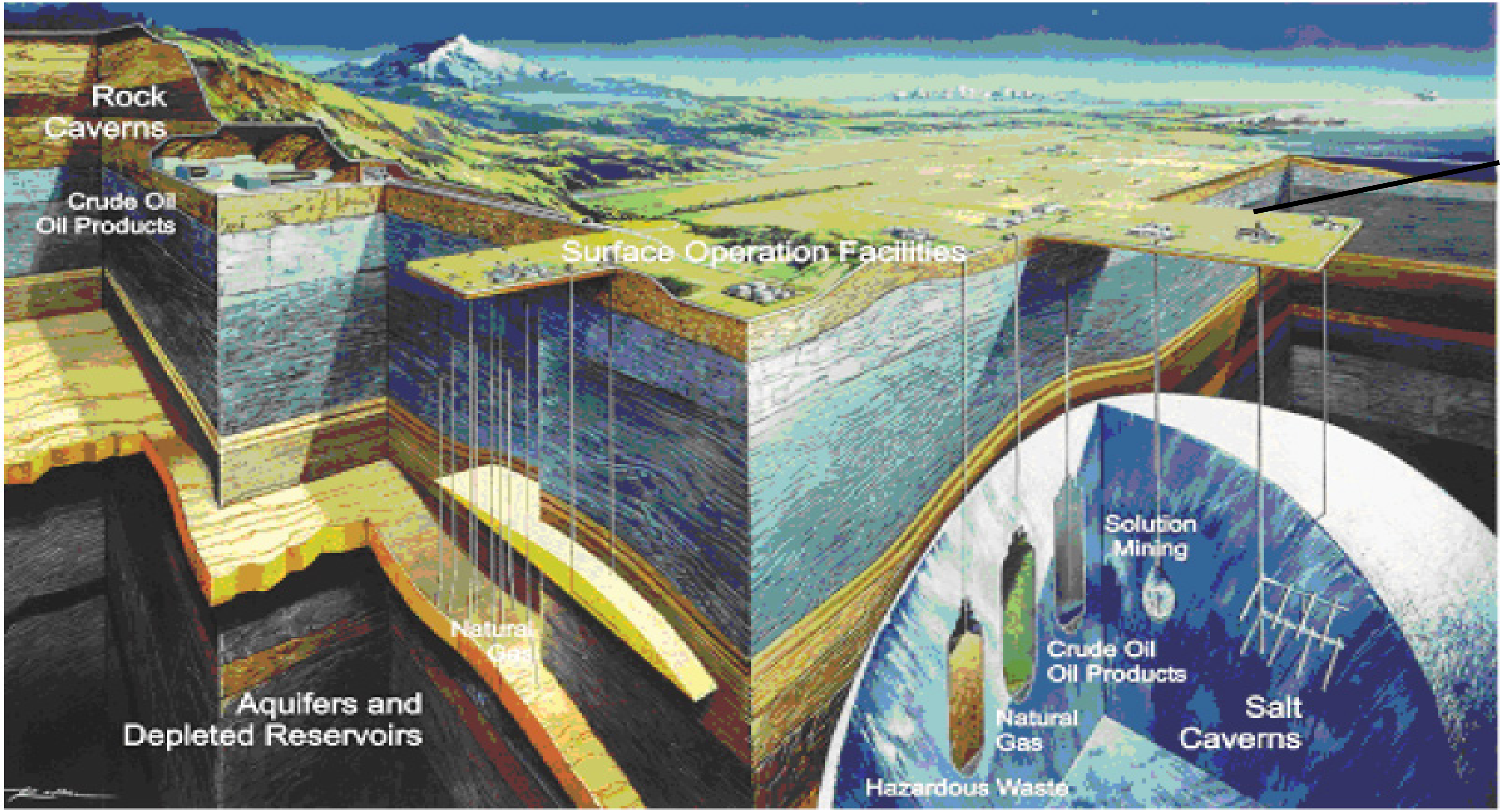
„Hot Salt“ Thermal Storage – from coal to salt

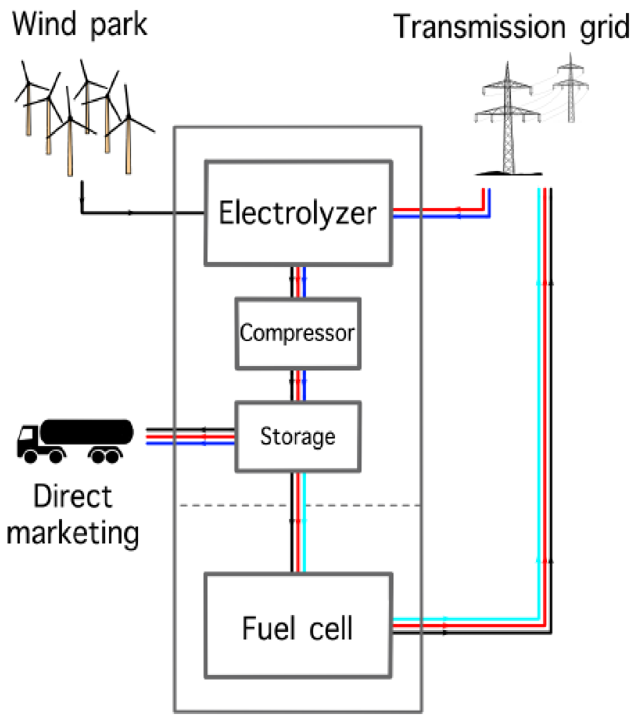
Liquid Salt Heat Storage Power Plant



https://www.en-former.com/kohlekraftwerk-als-waermespeicher/

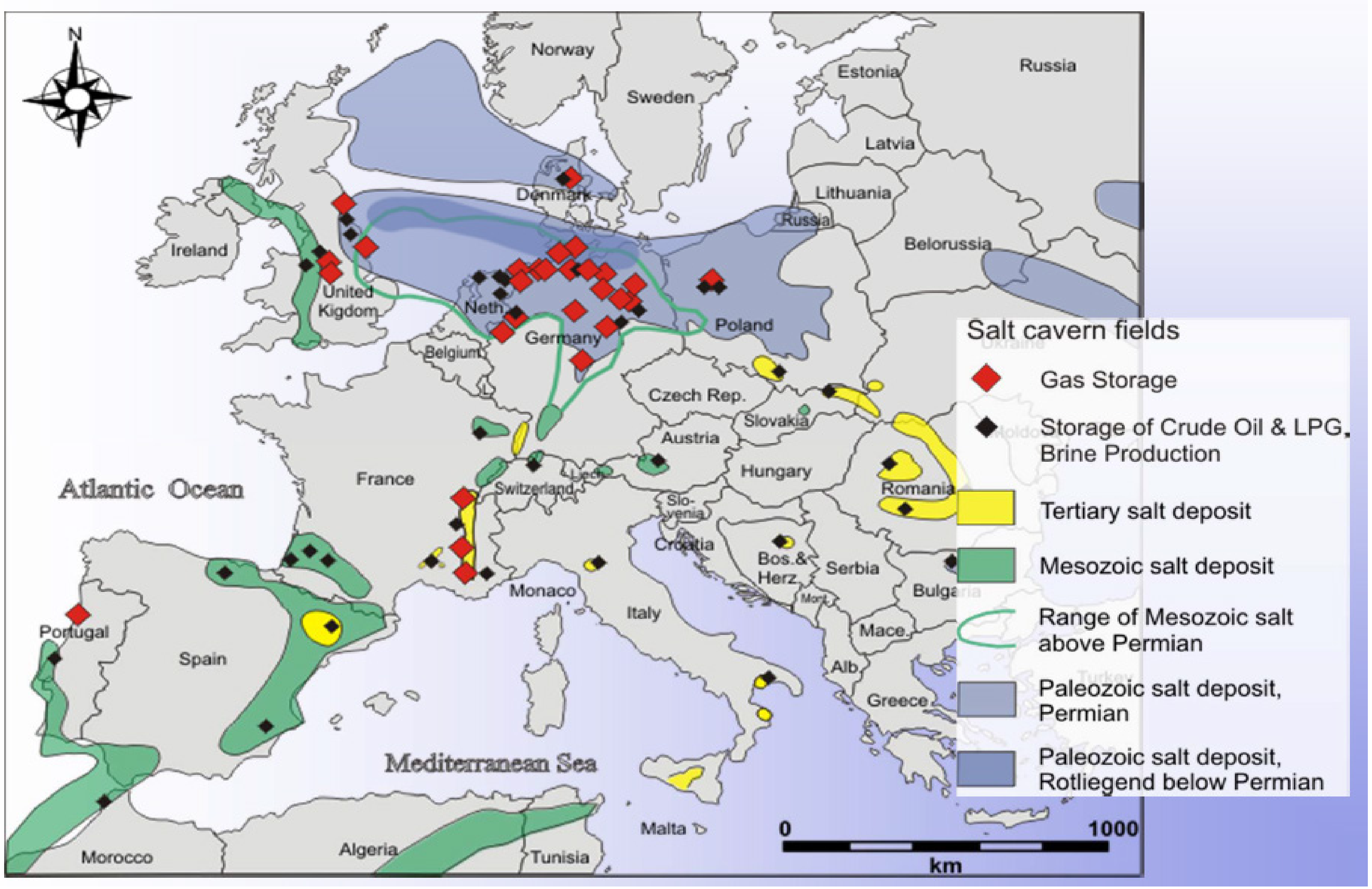
Energy Transition needs Underground Solution Mining & Storage Capacity





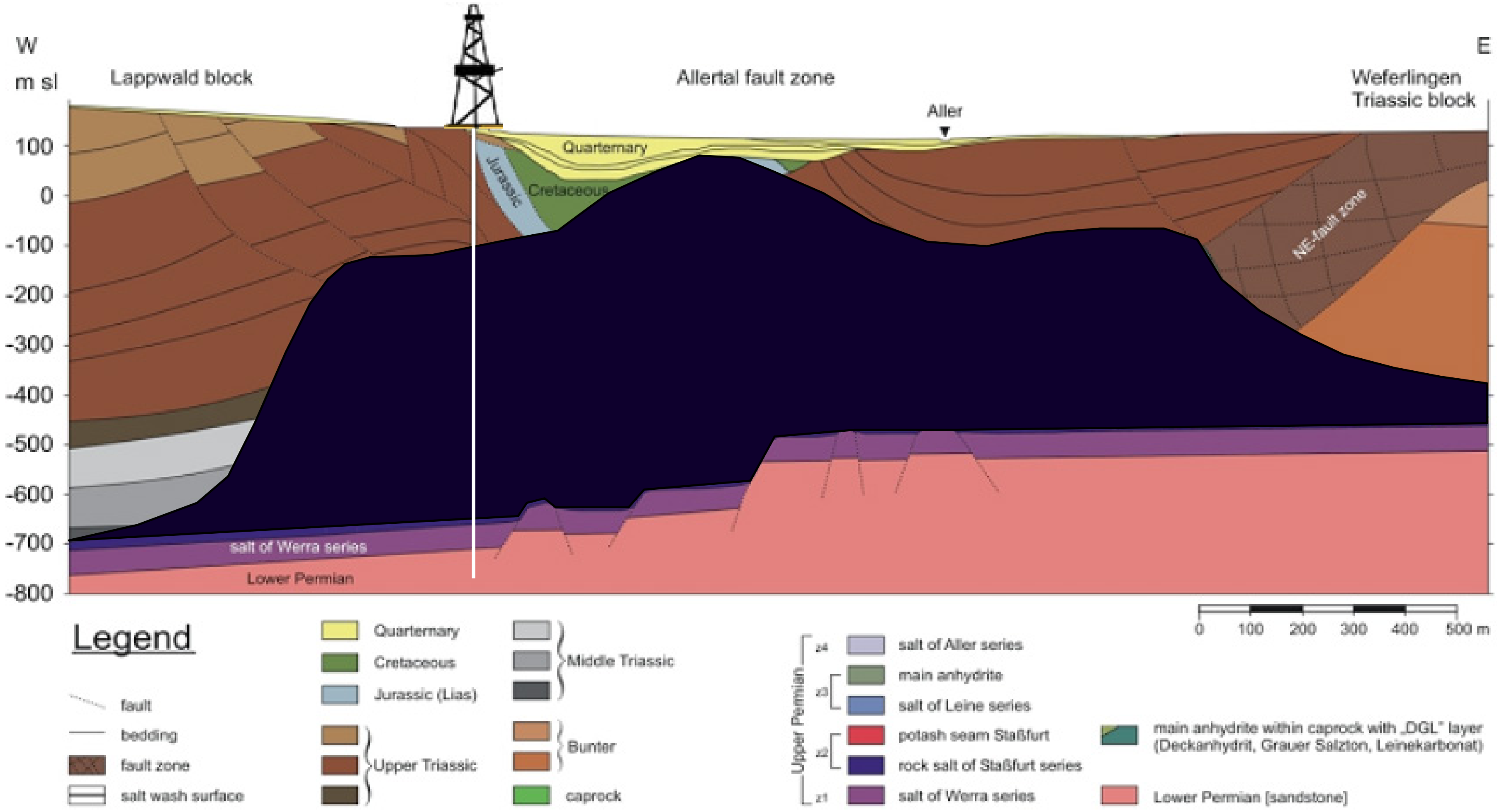
Courtesy of KBB Underground Technologies Inc.

The Role of Salt in future Energy Scenarios – the European venture



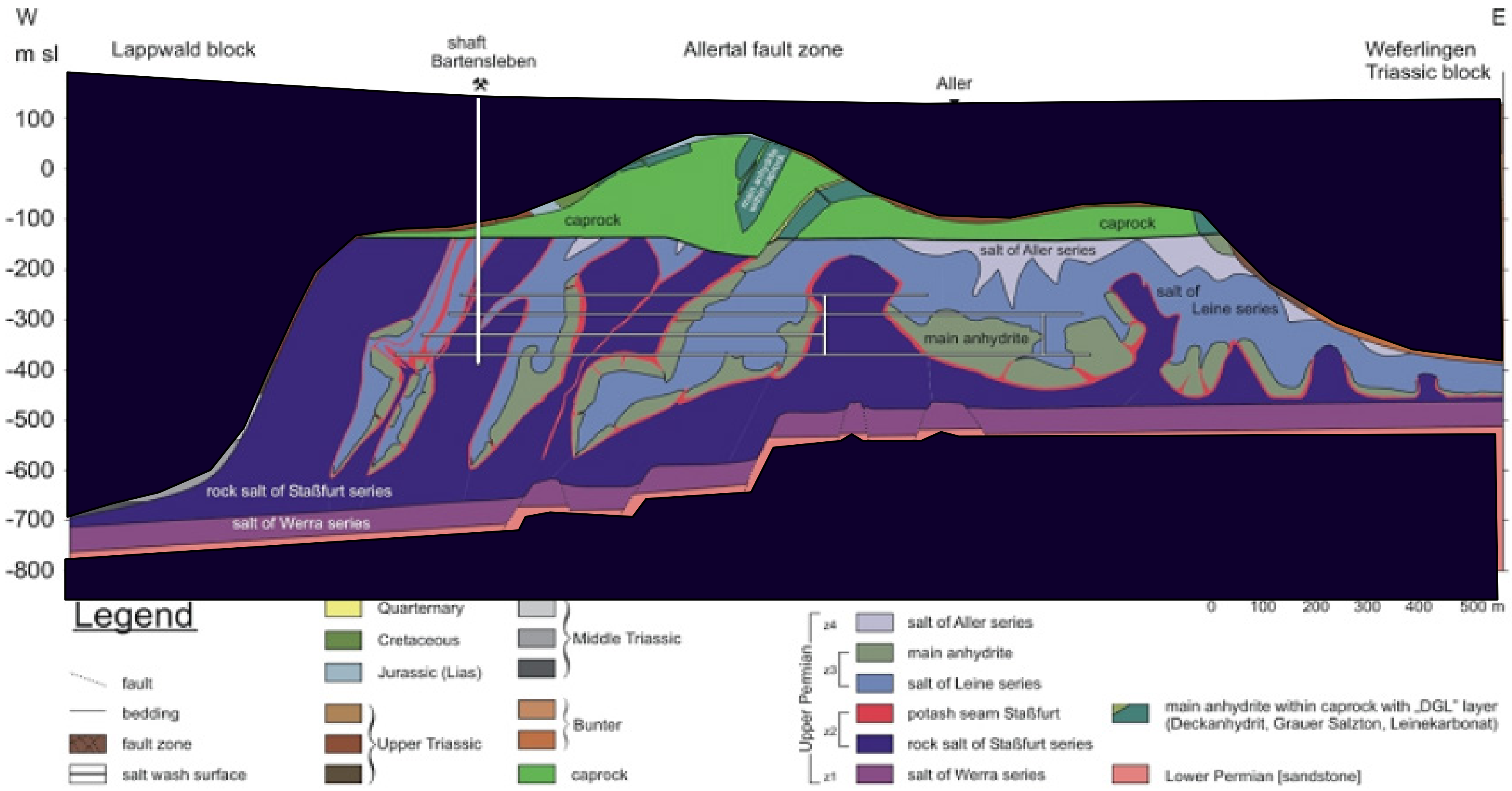
Courtesy of KBB Underground Technologies Inc.

Large salt bodies – the E&P view



Morsleben salt dome (courtesy Bundesanstalt für Strahlenschutz)

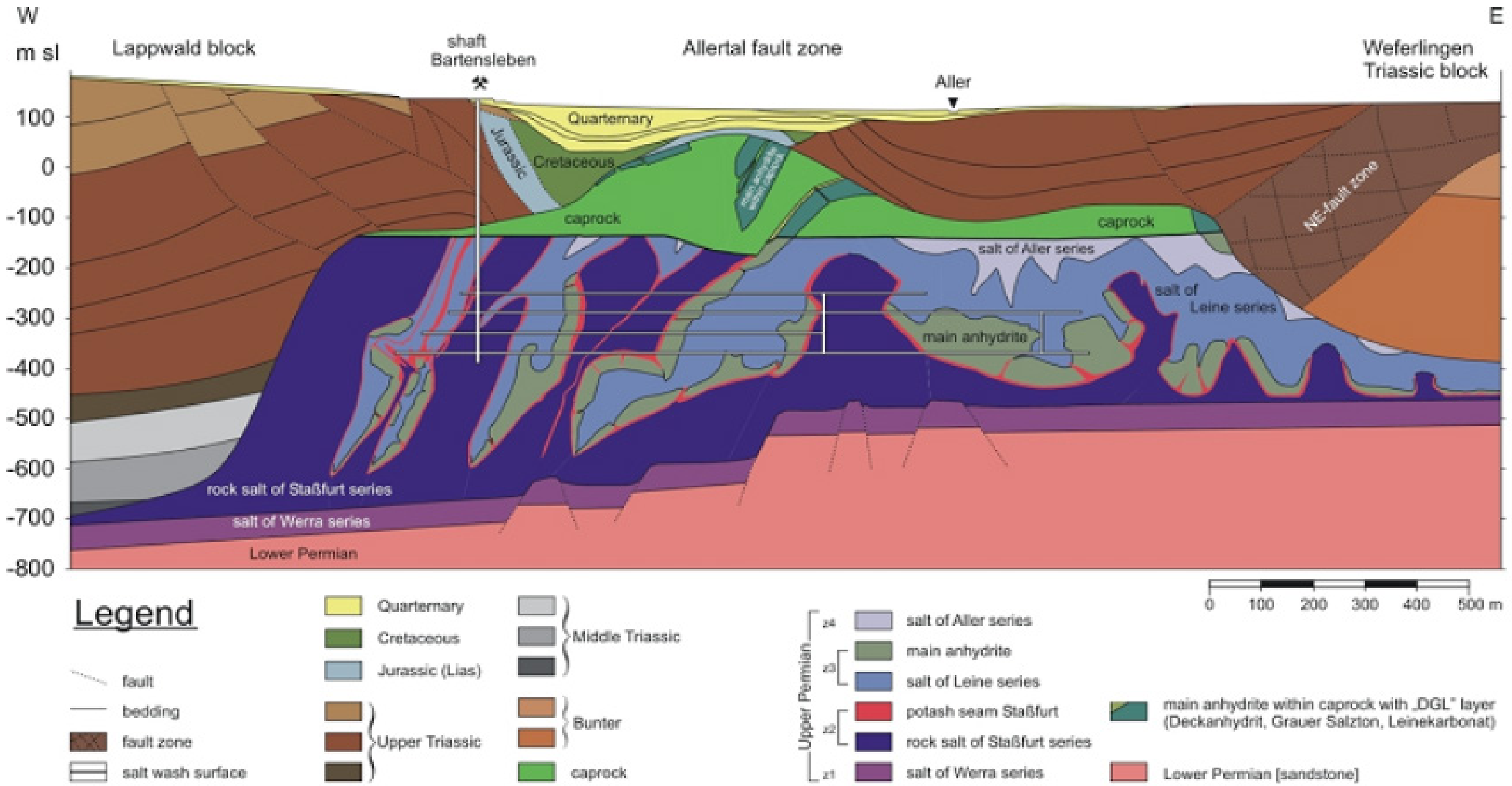
Internal structure of large salt bodies – the salt miners view



Morsleben salt dome (Bundesanstalt für Strahlenschutz)

Internal structure of salt bodies – the integrated view

Topseal strength, Drilling problems, Storage caverns, Salt mining



Morsleben salt dome   (Bundesanstalt für Strahlenschutz)

"A better understanding of the geology is necessary as pressure build-ups in layered evaporite sequences and pre-salt sediments as well as intra-salt brines and soft salts can pose hazardous and often unpredictable risks during drilling or underground mining."

(Elgstrand et al. 2017; Agasty et al. 2013; Andreiko et al. 2017; Birch 2007)

Multi-scale Salt Systems Research to support subsurface operations

Salt Rheology, Salt Geomechanics

What parameters influence the time-dependent damage evolution in salt rock?

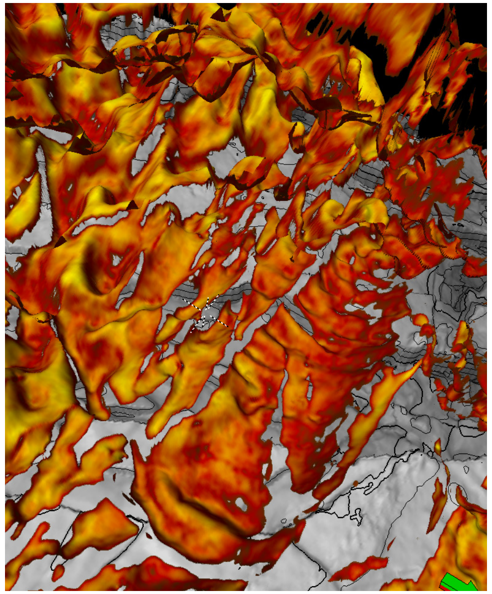
What is contributing to the mechanical weakening of halite-rich salt aggregates responsible for potential loss of integrity?

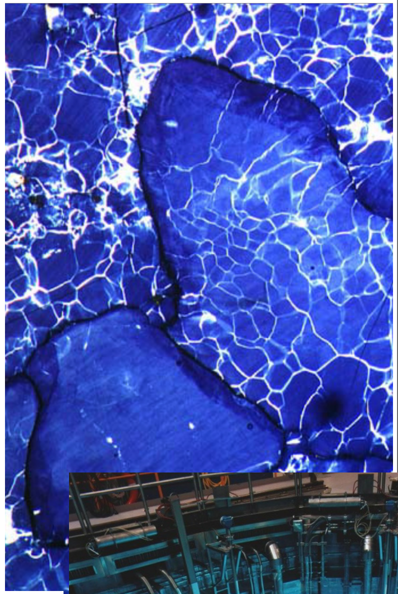
Which is the best extrapolation of the constitutive equations beyond the time scales accessible in the laboratory?

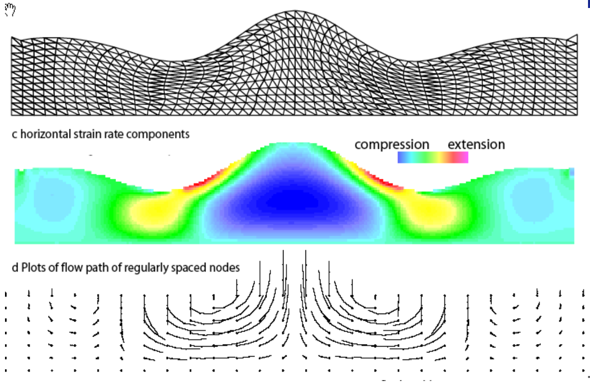
Are micro-scale observations and derived microphysics-based constitutive equations upscalable to explain the large-scale salt mobility?

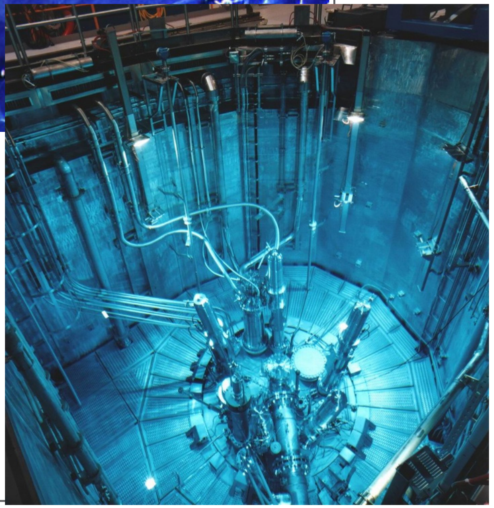
AAPG GTW Krakow April 2019

Multiscale analysis and simulation



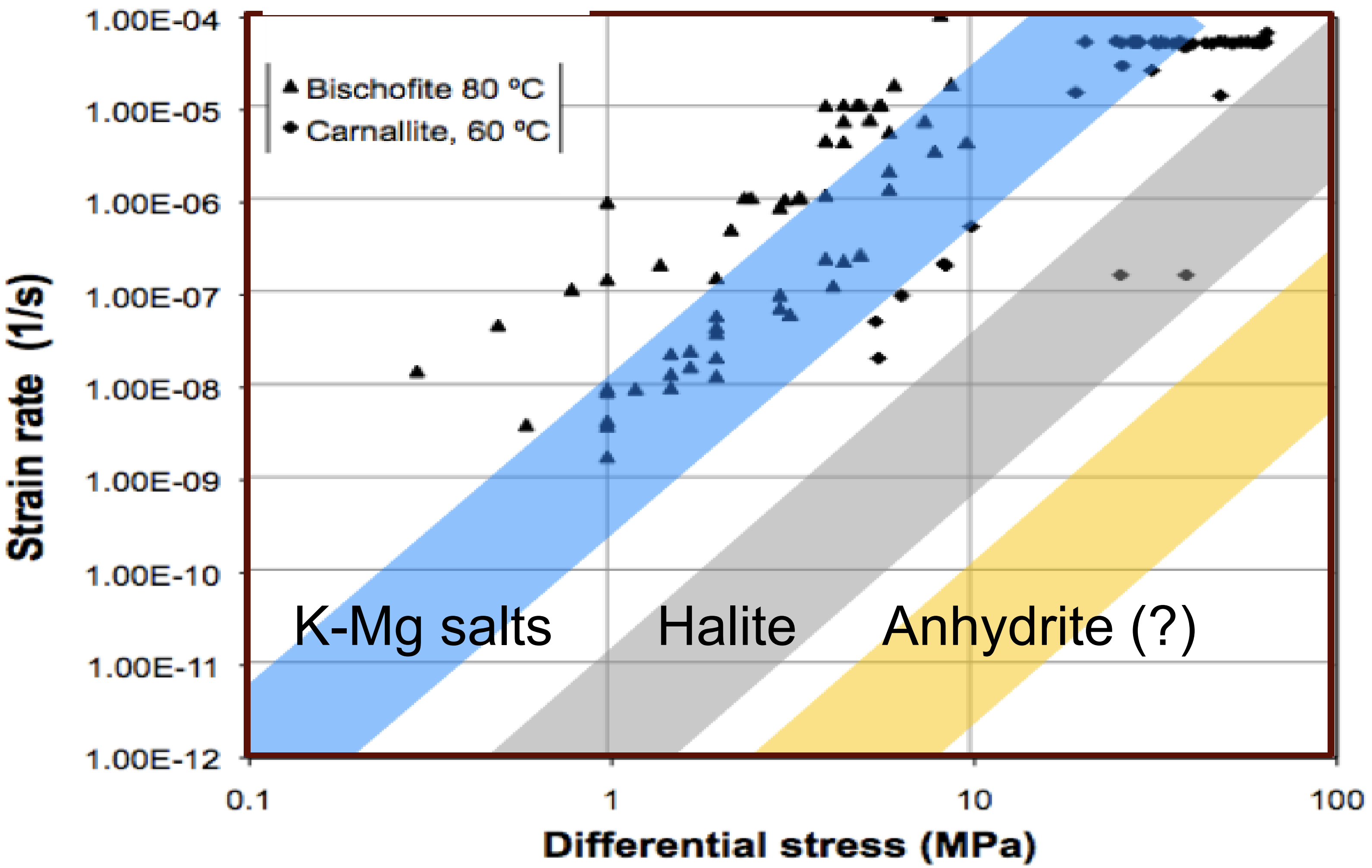




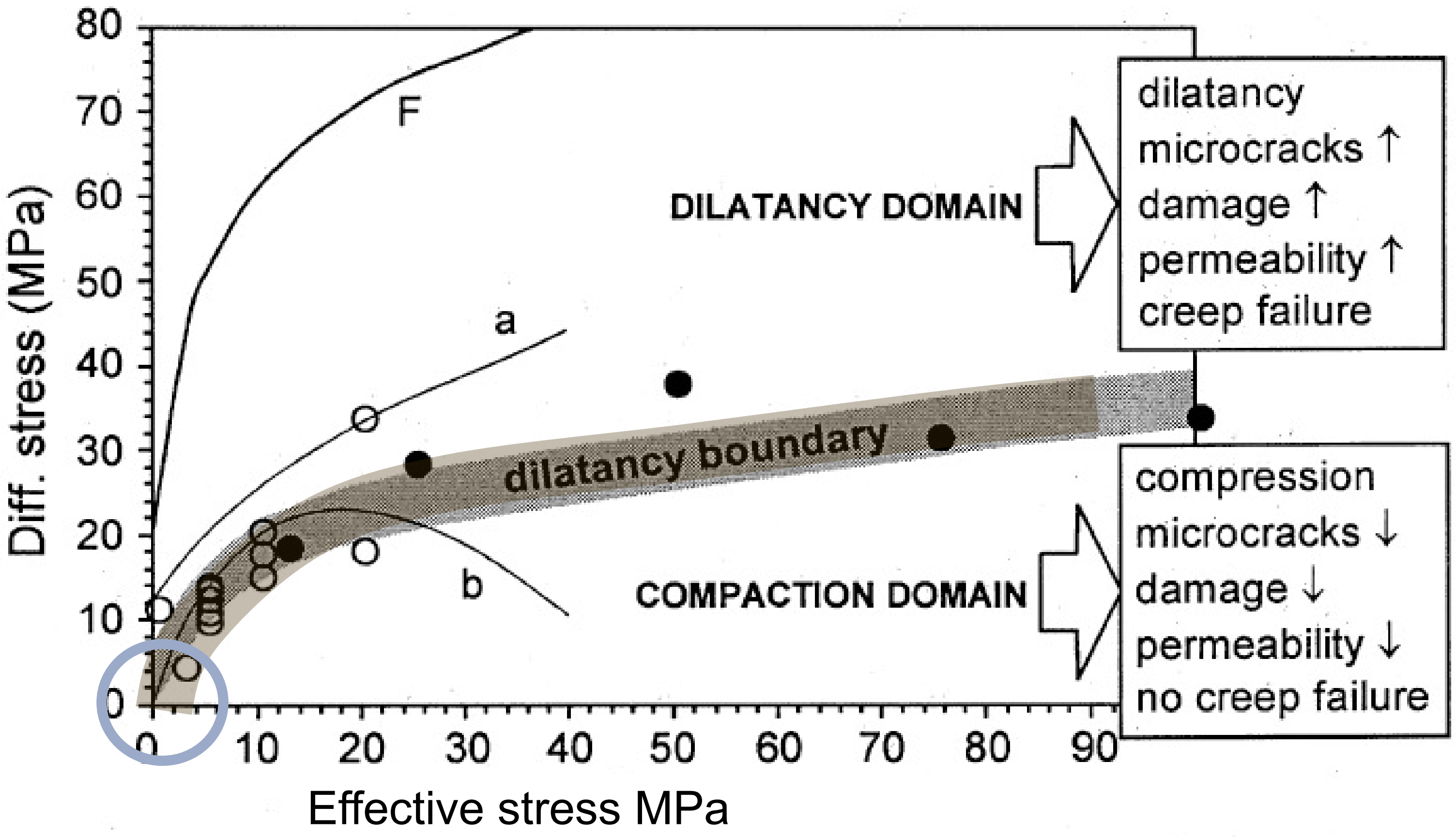


Rheology of different evaporites

More work is needed here!



Microphysics of salt - dilatancy conditions

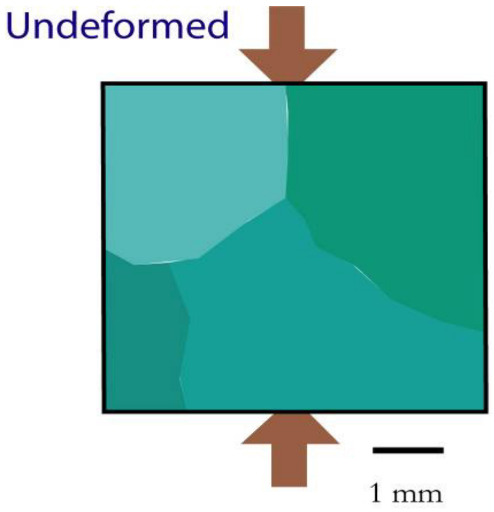


Schoenherr, J., Urai, J.L., Kukla, P.A., Littke, R., Schléder, Z., Larroque, J.-M., Newall, M.J., Al-Abry, N., Al-Siyabi, H.A., Rawahi, Z., 2007. Limits to the sealing capacity of rock salt: A case study of the infra-Cambrian Ara Salt from the South Oman salt basin. AAPG Bulletin 91, 1541–1557.

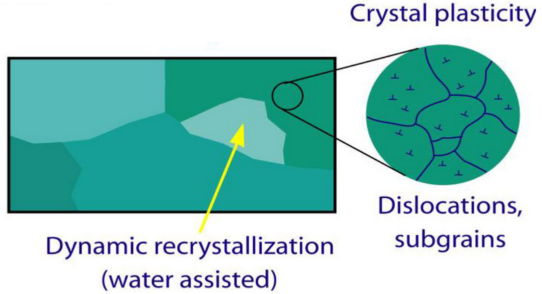
Popp, T., Kern, H., 2000. Monitoring the state of microfracturing in rock salt during deformation by combined measurements of permeability and P- and S- wave velocities. Physics and Chemistry of the Earth, Part A: Solid Earth and Geodesy 25, 149–154

Microphysics of salt - deformation mechanisms on a grain-scale

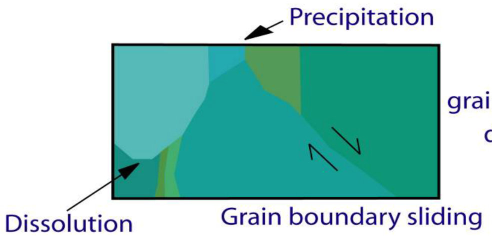
These can all operate simultaneously depending on micro fabric and physical conditions, and they are associated with very different mechanical and transport properties



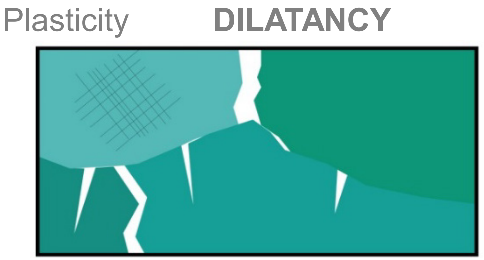
1. Dislocation creep

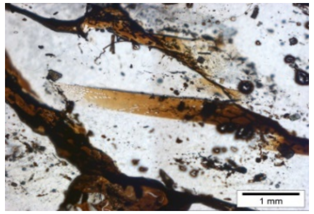


2. Pressure solution



3. Plasticity and **microcracking**

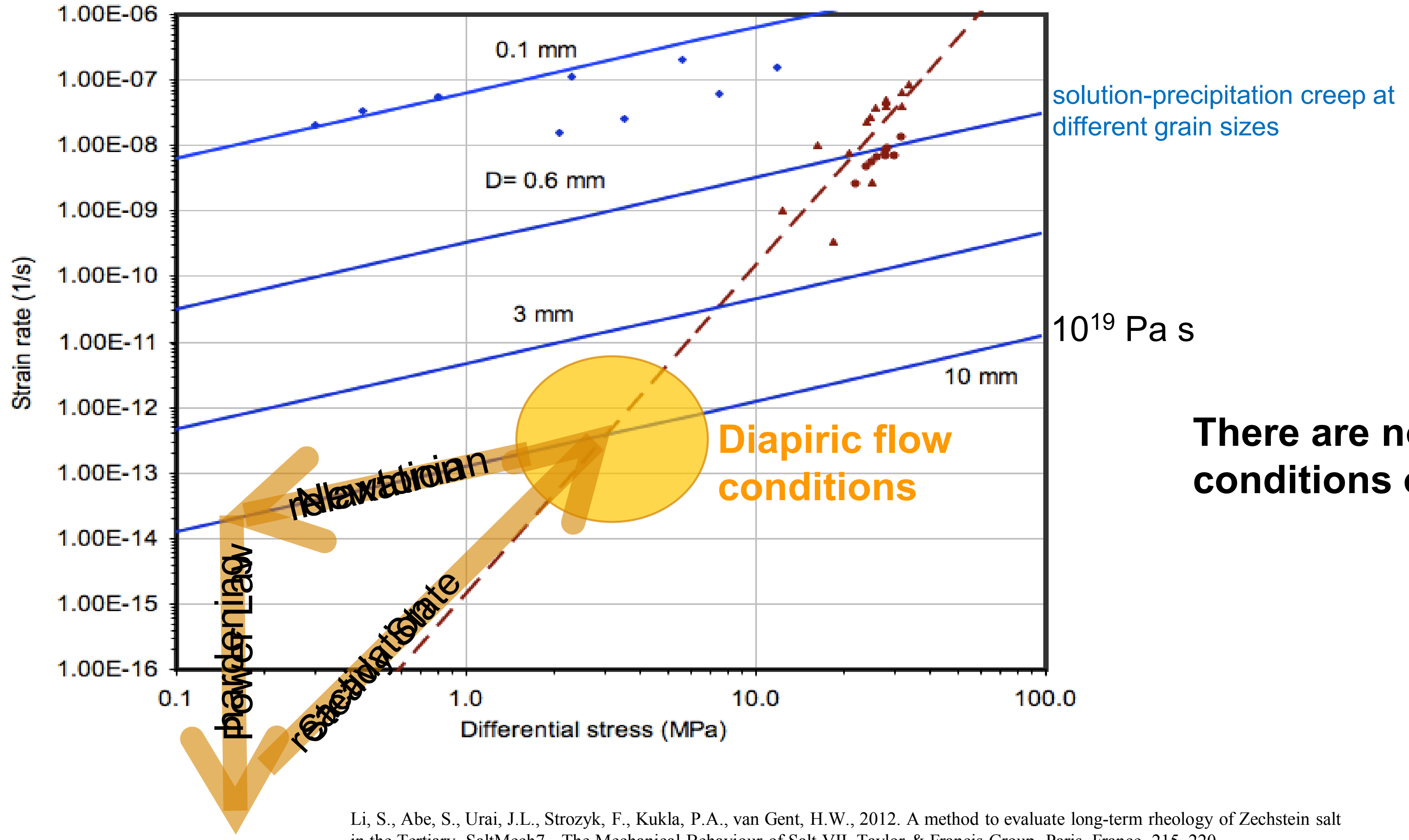




1. + 2. occur together during "normal” salt tectonics
3. in deep subsurface only under lithostatic fluid pressure
→ needs microstructural investigation

Urai, J.L., Schleder, Z., Spiers, C.J., Kukla, P.A., 2008. Flow and Transport Properties of Salt Rocks. Dynamics of Complex Intracontinental Basins: The Central European Basin System. Springer, 277–290.

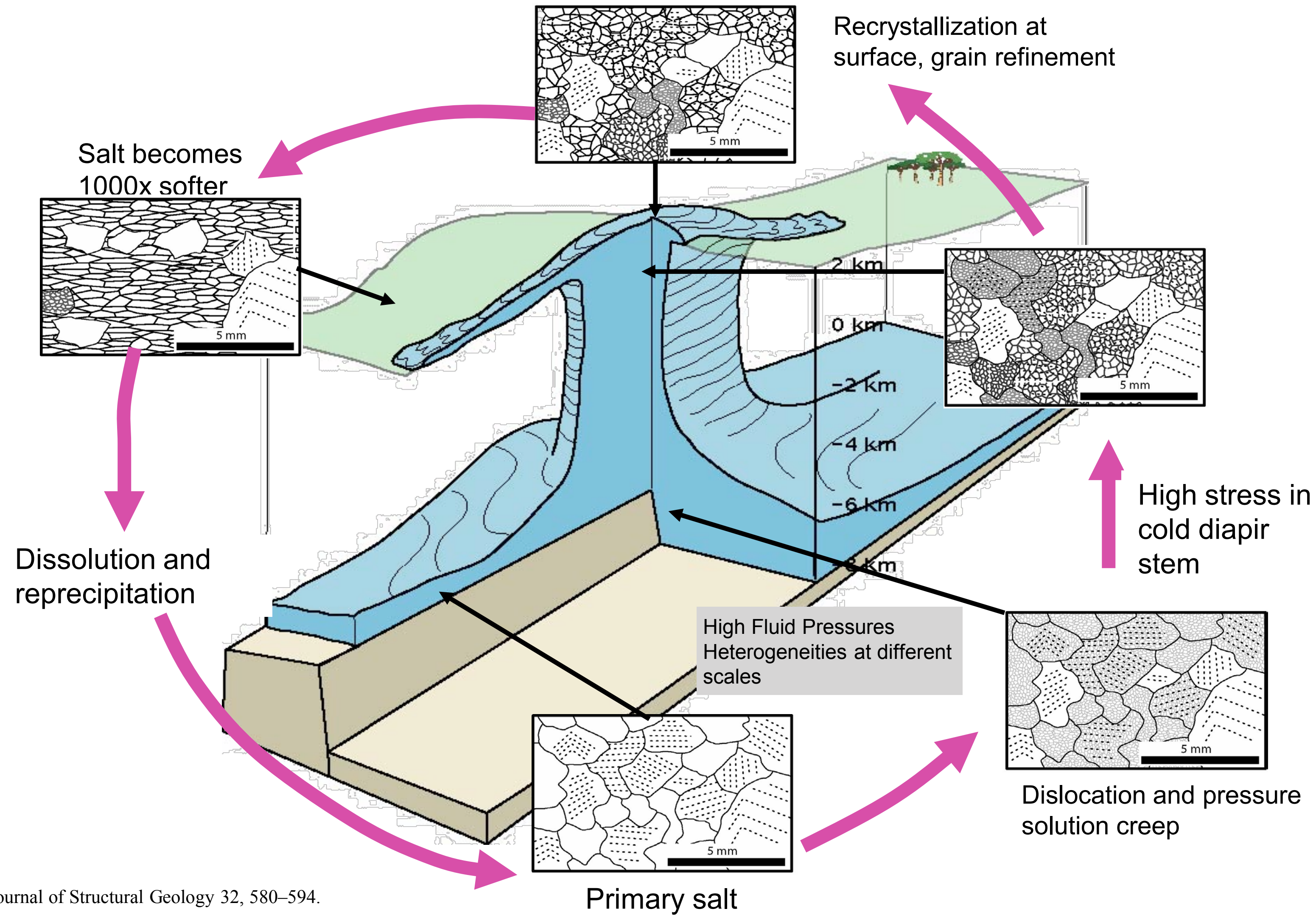
Rheological path of Halite at low temperature & different grain sizes



There are no experimental data at conditions of natural deformation

Li, S., Abe, S., Urai, J.L., Strozyk, F., Kukla, P.A., van Gent, H.W., 2012. A method to evaluate long-term rheology of Zechstein salt in the Tertiary. SaltMech7 - The Mechanical Behaviour of Salt VII. Taylor & Francis Group, Paris, France, 215–220.

The rocksalt cycle: rheology and microstructure



Desbois, G., Zavada, P., Schleder, Z., Urai, J.L., 2010.. Journal of Structural Geology 32, 580–594.

Salt permeation mechanisms

How impermeable is subsurface salt and does that change with depth?

Does halite typically control fluid migration due to its relative impermeability?

How common is it for fluids to move into and through evaporites?

Does salt seal hydrocarbons in diapir-flanking traps?

Do we know enough about the rock properties of different evaporite minerals and their contribution to thermodynamic behavior of salt sections?

Field example of slow preferential infiltration of brine along bedding planes in a shallow salt mine in the Carpathians, forming salt stalagtites

Halite permeability - empty brine pocket

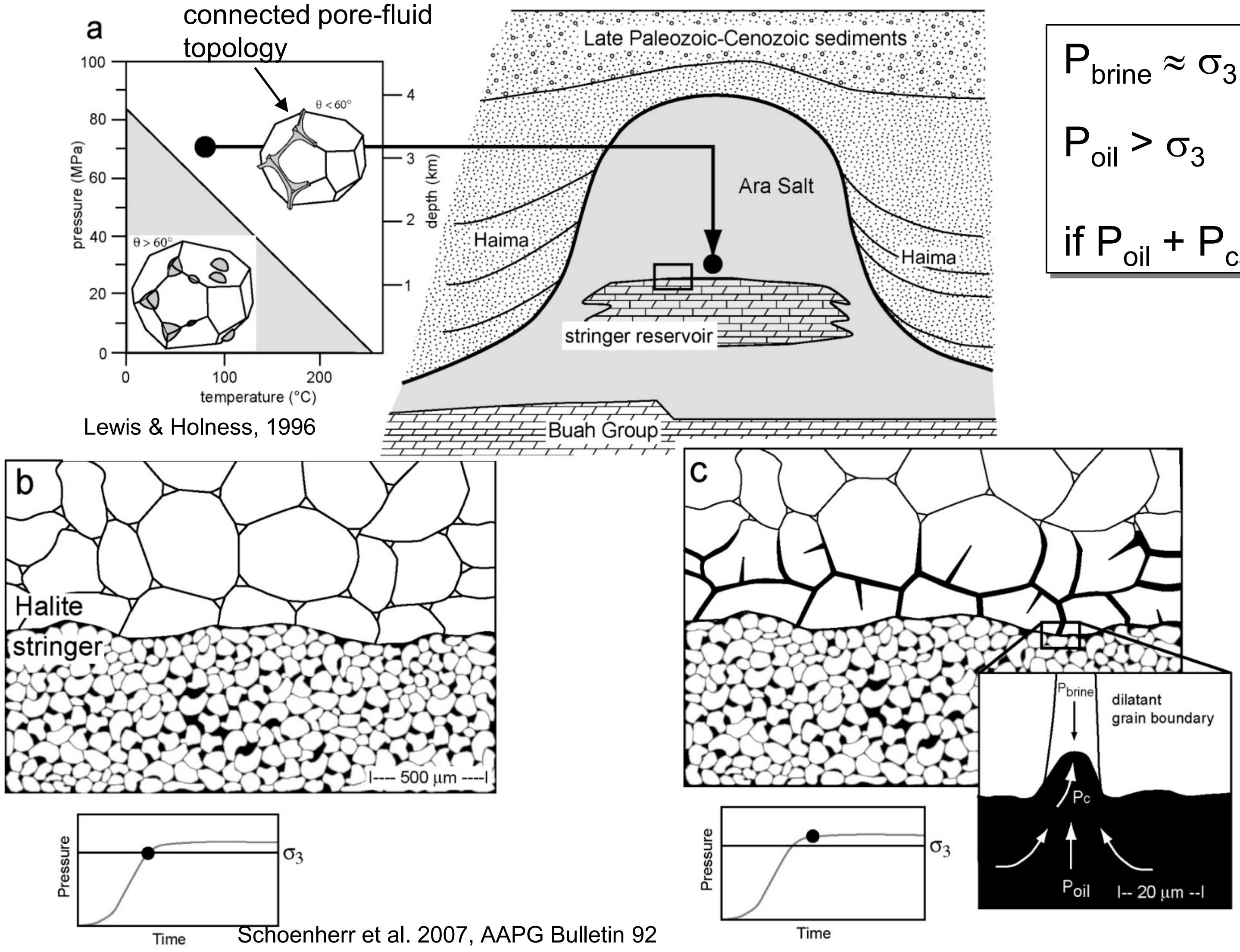
K+S Salt Mine Bernburg, Photo: Frank Strozyk

Leakage conditions of rock salt

$P_{brine} \approx \sigma_3$

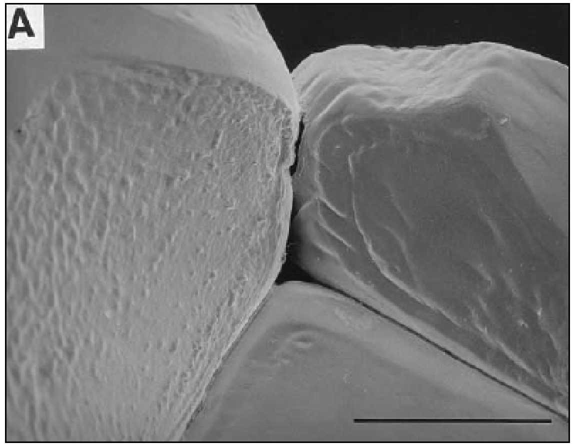
$P_{oil} > \sigma_3$

if $P_{oil} + P_{capillary} \rightarrow$ Salt dilates!



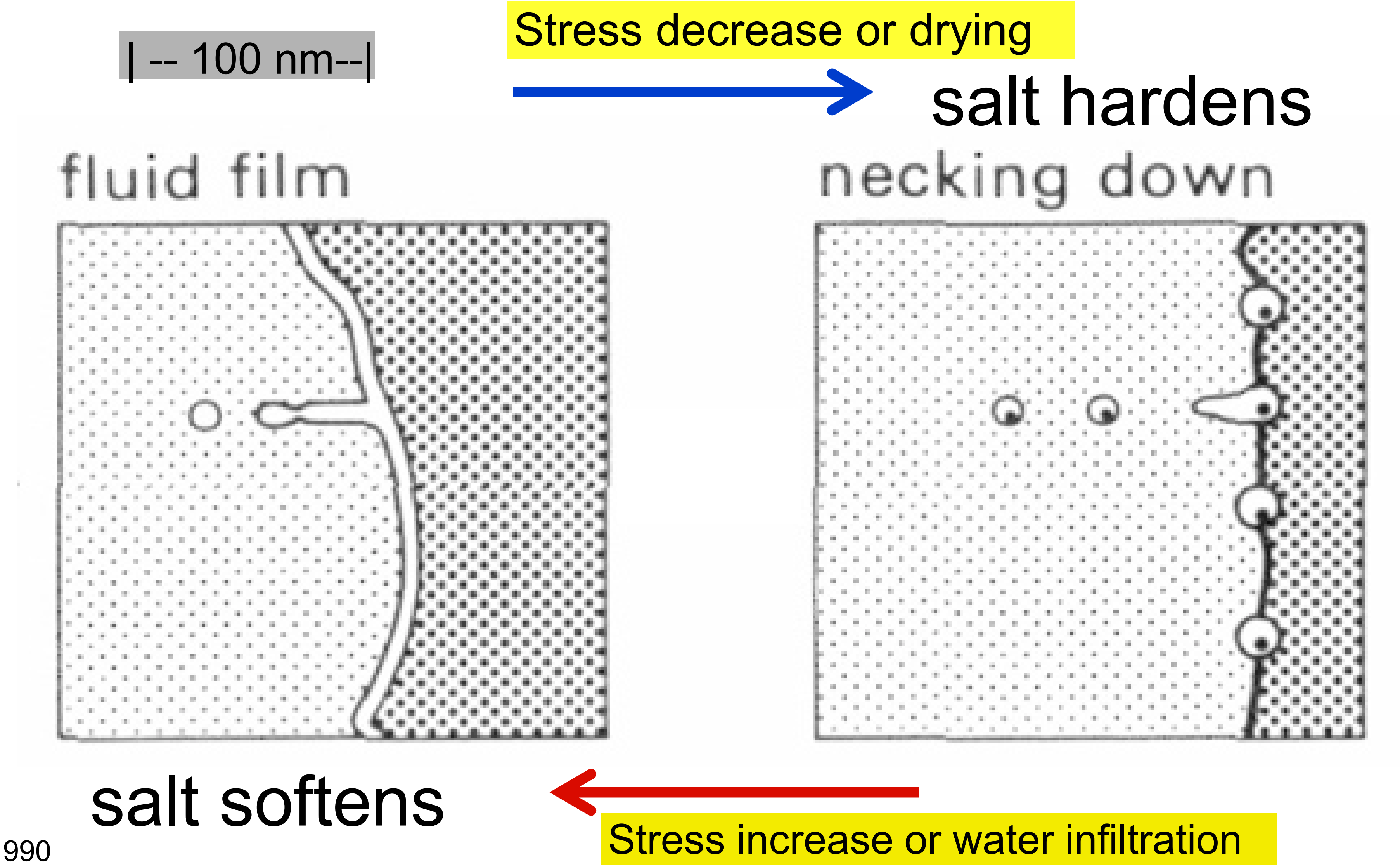
Lewis & Holness, 1996

Schoenherr et al. 2007, AAPG Bulletin 92



Lewis & Holness (1996)

Fluids and stress
The healing of grain boundaries



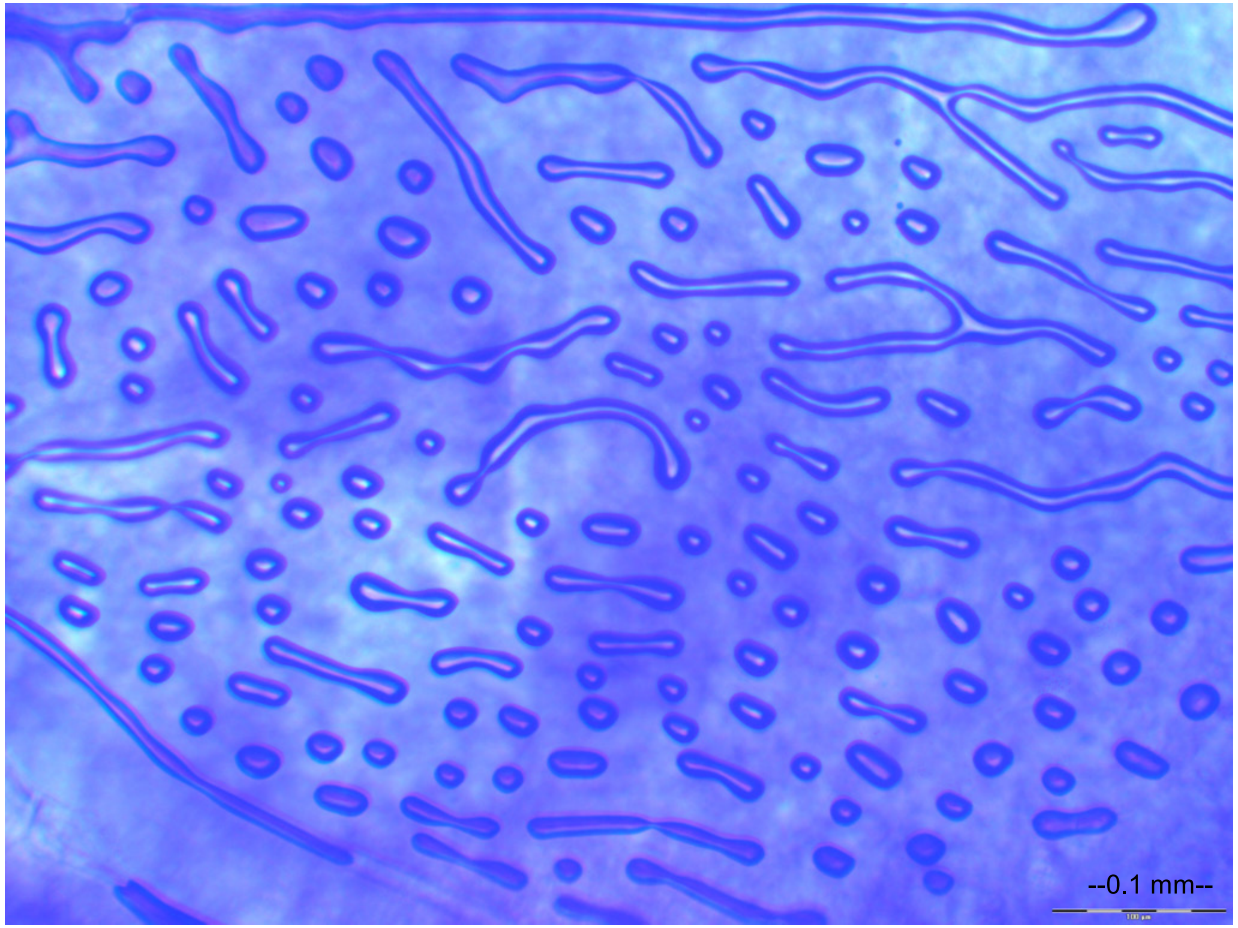
Drury and Urai, 1990

Grain Boundary fluid inclusions in Rock salt

isolated, thermodynamically equilibrated micropores, separated by solid state grain boundaries

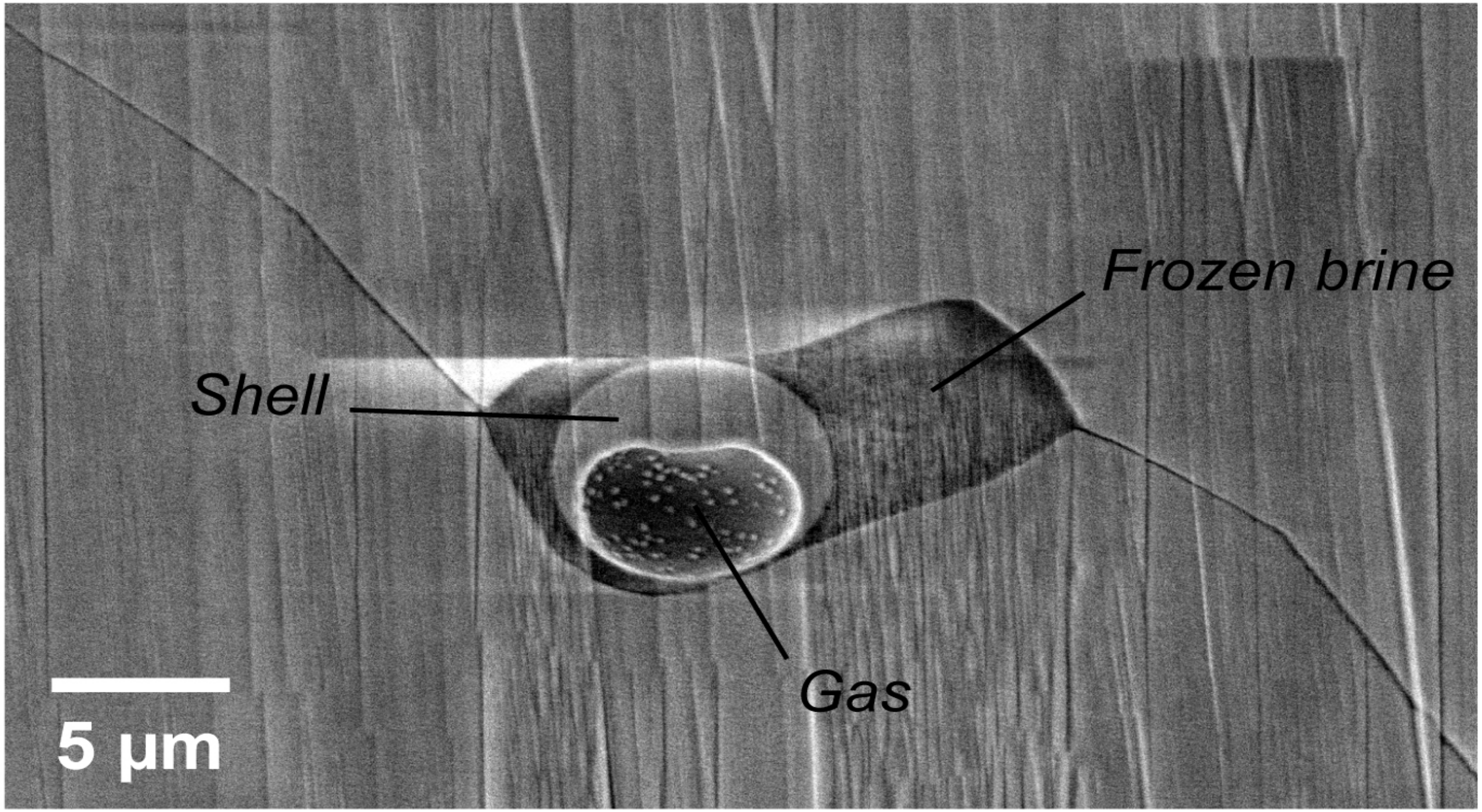
= low permeability
= good seal

As long as grain boundary structure is not disturbed



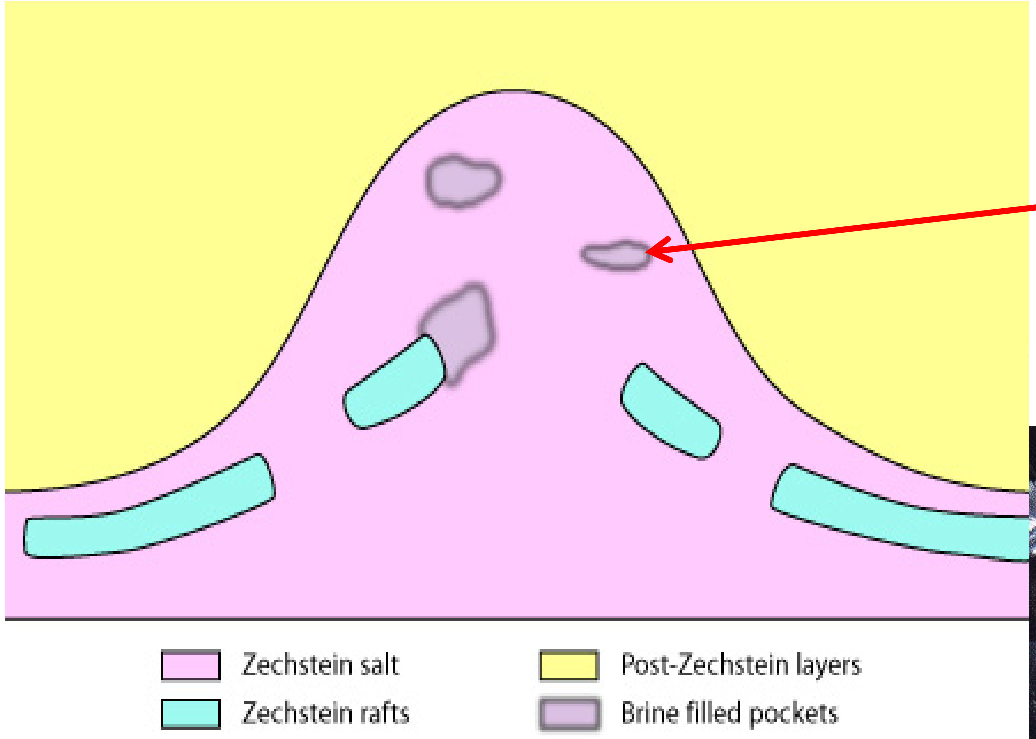
In-situ fluids in salt imaged in cryo-SEM

Desbois, G., Urai, J.L., Pérez-Willard, F., Radí, Z., Offern, S., Burkart, L., Kukla, P.A., Wollenberg, U., 2013. Argon broad ion beam tomography in a cryogenic scanning electron microscope: A novel tool for the investigation of representative microstructures in sedimentary rocks containing pore fluid. Journal of Microscopy 249, 215–235.



Using cryogenic Broad Ion beam milling, the grain boundary fluid films can be frozen, imaged and analysed.

Brine pockets & salt caves



Salt with brine (+gas) filled porosity

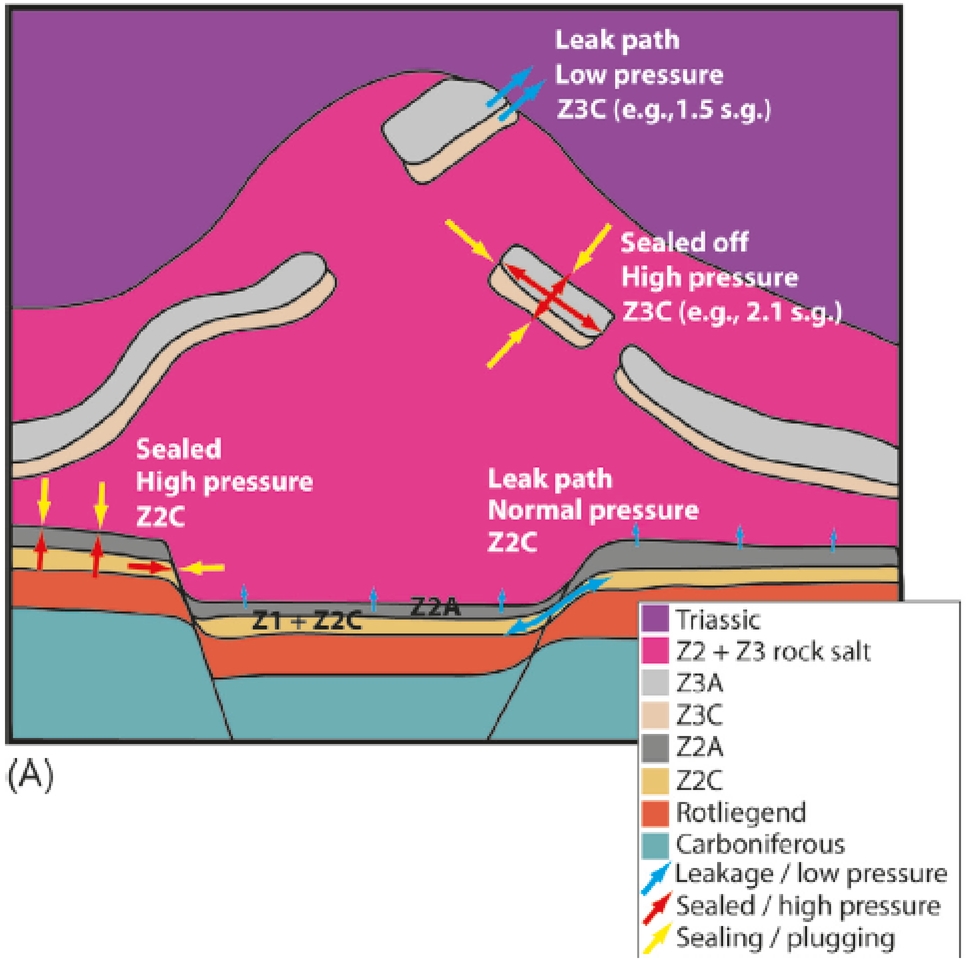
= **brine pockets**

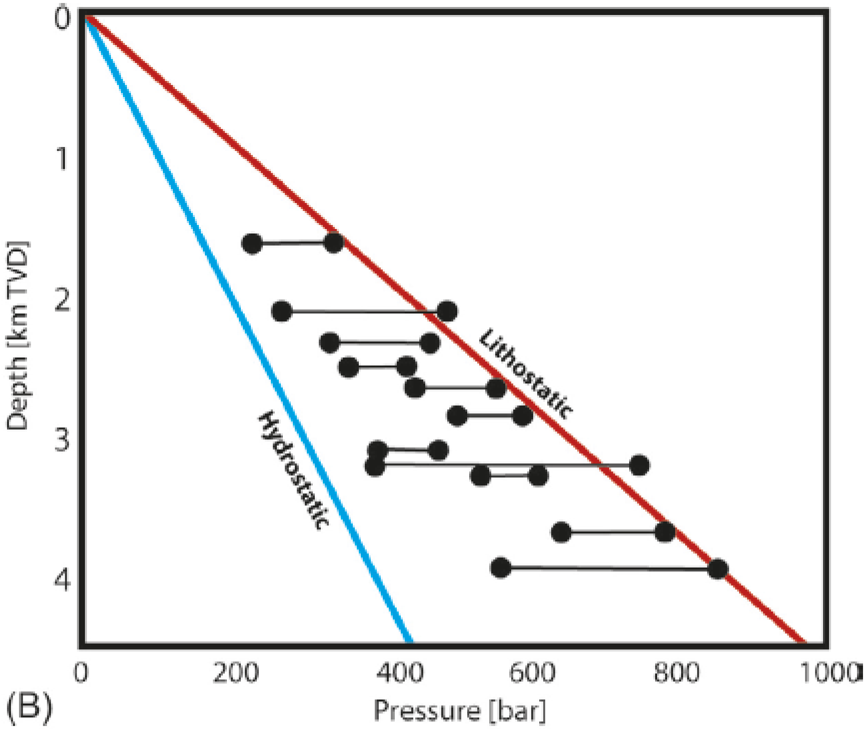
Open cavities with giant crystals on the walls filled with brine and gas

= **salt caves**

from Pippig 1992

Leakage and Drilling Issues - Zechstein Basin





Initial mud weight (dot on the left) and final mud weight (dot on the right) in Z3 stringer

Strozyk, 2018

What else is still needed? Timing of deformation – does geochemistry help?

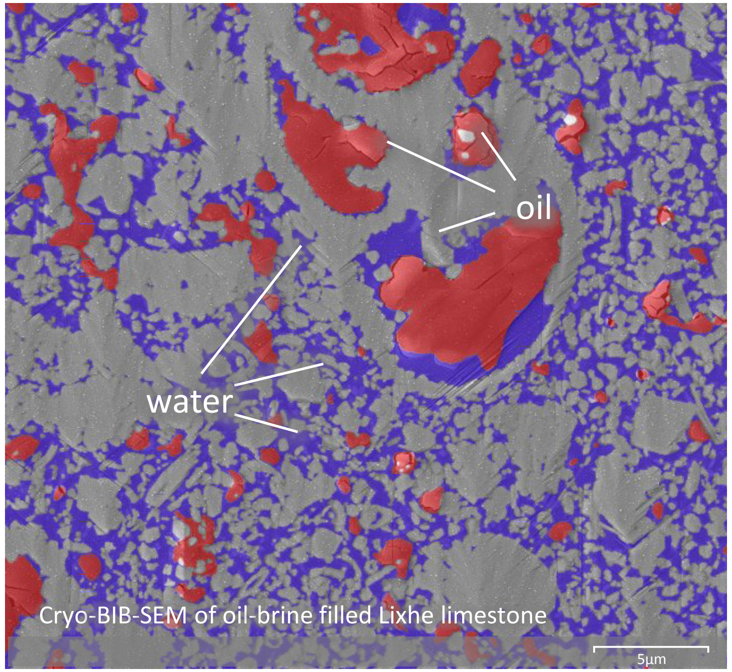
→ Direct geochemical indicators for salt movement and timing thereof

→ Needs integration of both structural and geochemical analysis to quantify tectonic stress

Methods:

→ Development of microanalytical LA-ICP-MS methods for salt minerals

→ Triple-halogen (Cl, Br, I) analysis of fluid inclusions



SUMMARY

→ Salt is an excellent energy (and waste) storage medium

→ The anisotropy of salt successions (LES) has been underestimated and it needs further quantification of the behaviour under varying stress, pressure and temperature conditions.

→ Integration of petrography, microstructure, geochemistry, modelling and laboratory tests will improve our understanding of key processes in and around salt bodies, which will largely improve mine and storage safety.

Schlumberger

Petroleum Development Oman LLC (PDO)

MINISTRY OF OIL & GAS

K+S

Deutsche Forschungsgemeinschaft DFG

NAM Bron van energie