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US/German Collaboration in Salt Repository Research, Design, and Operation

Frank Hansen, Ph.D. PE

Sandia National Laboratories

U.S. Nuclear Waste Technical Review Board Meeting

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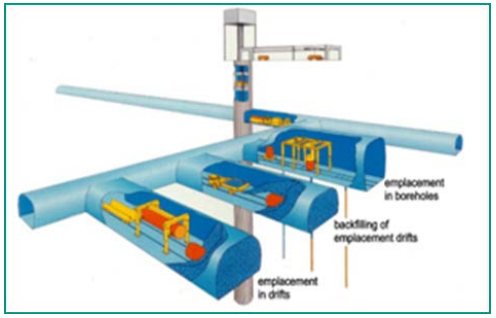
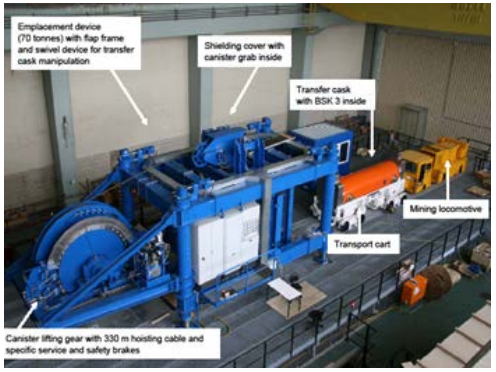
Accumulation of Expertise in the Past Decades

- *Techniques for waste emplacement were developed (direct disposal, reference repository concept)*
- *Feasibility of borehole emplacement of spent fuel was shown*
- *Instruments, tools, and methodologies for modeling and safety analysis were substantially further developed and have been applied in several exercises*





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Accumulation of Expertise in the Past Decades

- *In the US the Waste Isolation Pilot Plant (WIPP) is operational.*

  Very successful since 1999.
- *In Germany underground disposal facilities for chemical-toxic wastes are licensed and are operational for years*
- *Salt mining is a world-wide, proven and reliable technology*
- *Rock salt is highly suitable for hosting a repository for heat-generating nuclear waste*

Hansen, F.D. and C.D. Leigh. 2011. *Salt Disposal of Heat-Generating Nuclear Waste*. SAND2011-0161, Sandia National Laboratories Albuquerque New Mexico.

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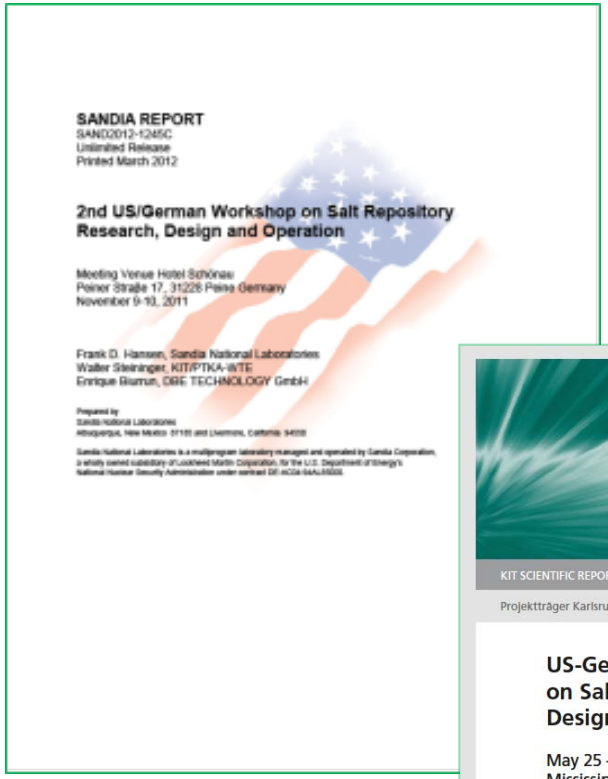
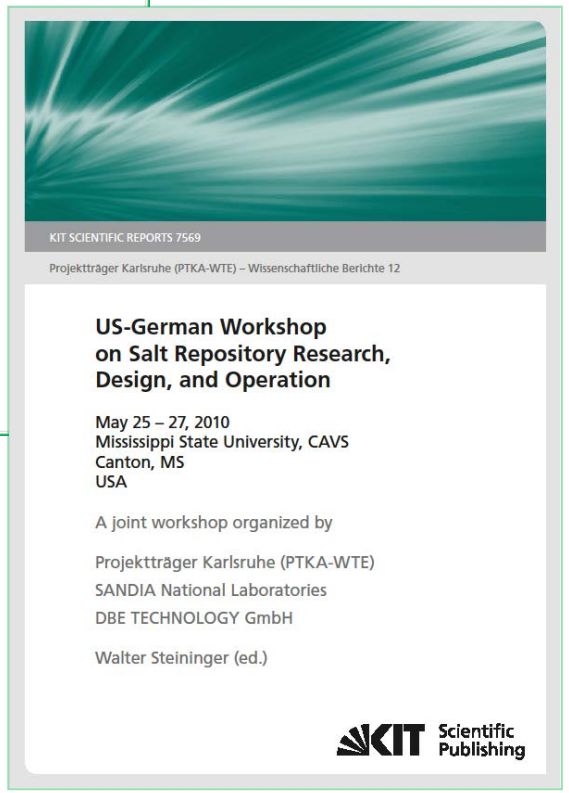
Benefits of the Strategic Partnership in National and International Cooperation

- **Collaboration hibernated for more than 10 years because of a German moratorium**

- **Topics emphasized**
  - Safety Case
  - Salt repository concepts & designs
  - Modeling of groundwater flow and radionuclide transport
  - Geotechnical barriers
  - Site characterization & host rock characterization





http://www.sandia.gov/SALT/SALT_Home.html

Accomplishments and Ongoing Activities

- *Collaboration in the Joint Project on "benchmarking constitutive models for rock salt" (Sandia & German organizations)*
- *Contributions to conferences and workshops (American Rock Mechanics Association, Salt Lake City, Mechanical Behavior of Salt Symposia, Paris, Waste Management ´13, Phoenix)*
- *Collaboration is also performed in European Commission Seventh Framework Program "Monitoring Developments for Safe Repository Operation and Staged Closure" (MoDeRn)*
- *Collaboration/information exchange in the area of safety case*
- *Planned common joint activity in the framework of the IGD-TP (Implementing Geological Disposal - Technology Platform)*
- *Workshops on actinide brine chemistry (ABC) with Los Alamos National Laboratory*

Steininger, W., F.D. Hansen, E. Biurrun and W. Bollingerfehr. 2013. *US/German Collaboration in Salt Repository Research, Design and Operation*. WM2013 Conference, February 24-28, 2013, Phoenix, Arizona, USA.

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Accomplishments and Ongoing Activities

- *2011 Memorandum of Understanding between the German Ministry and US-Department of Energy [Environment Management (EM) and Nuclear Energy (NE)]*
- *Founding of the Nuclear Energy Agency "Salt Club" (Participants: Germany, US, The Netherlands, Poland)*
- *Natural analogues workshop for rock salt*
- *Features, Events, and Procedures (FEP) catalogue for rock salt*
- *State-of-the-art report on salt reconsolidation*
- *Salt knowledge archive*

Kuhlman, K. L., S. Wagner, D. Kicker, R. Kirkes, C. Herrick, D. Guerin. 2012. Review and Evaluation of Salt R&D Data for Disposal of Nuclear Waste in Salt. Fuel Cycle Research & Development. FCRD-UFD-2012-000380. SAND2012-8808P

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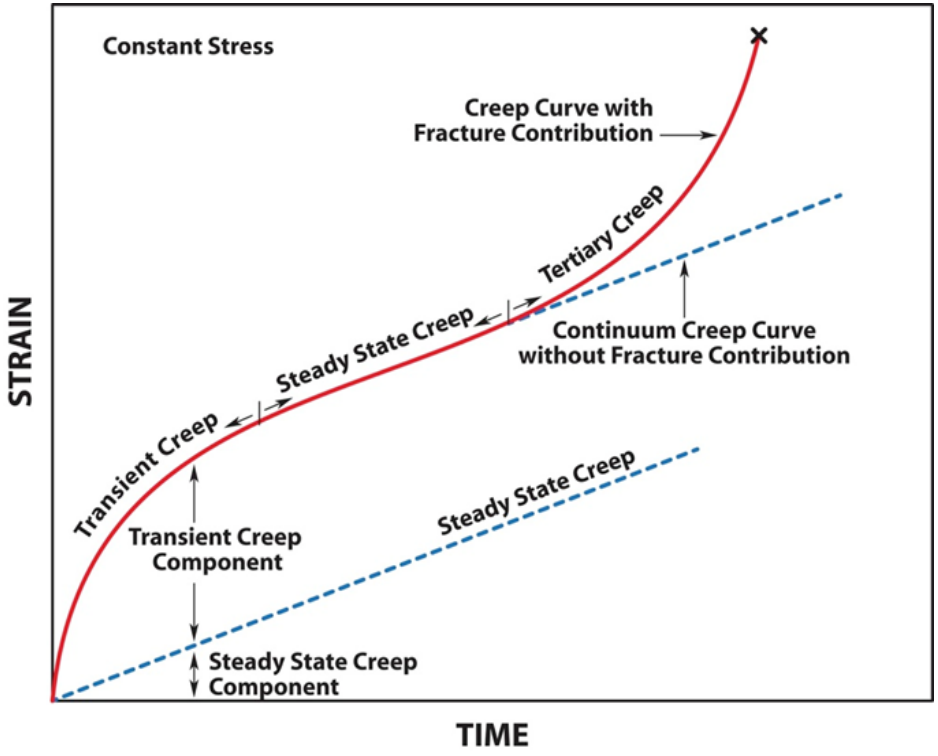
Isochoric Deformation of Salt

Classic strain-time creep curve

- ***Dislocation multiplication***
- ***Glide***
- ***Cross slip***
- ***Climb***
- ***Recrystallization/annealing***



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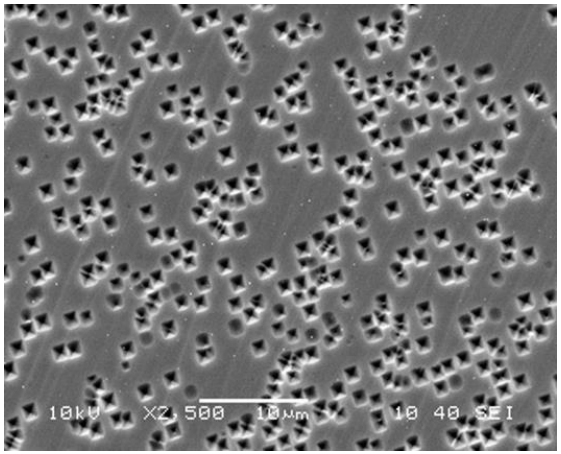
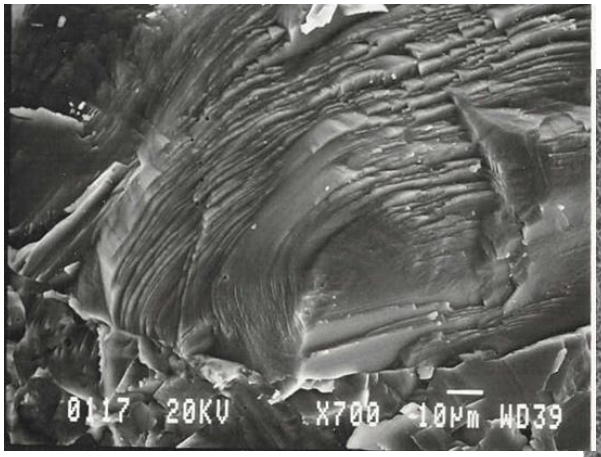
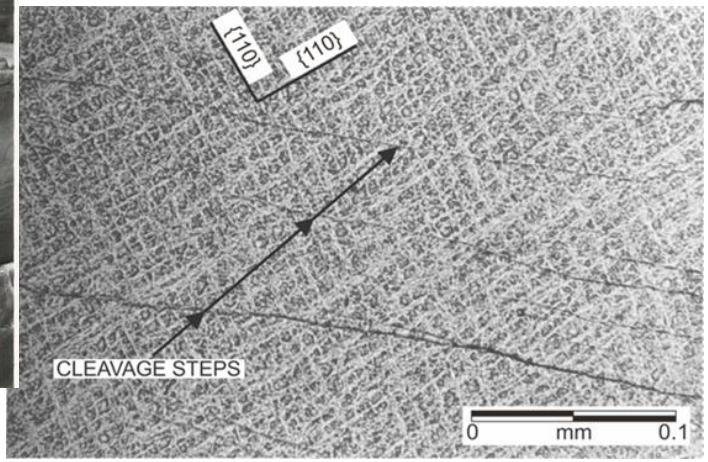
Isochoric Deformation of Salt Mechanisms



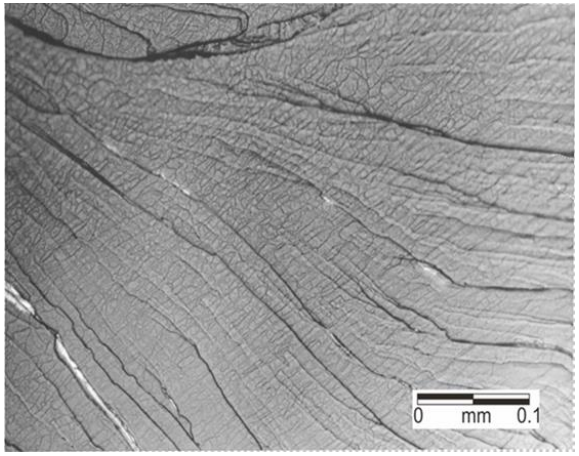
Dislocations



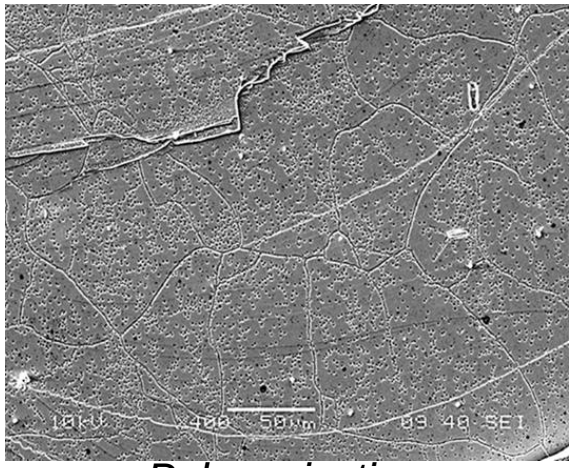
Glide



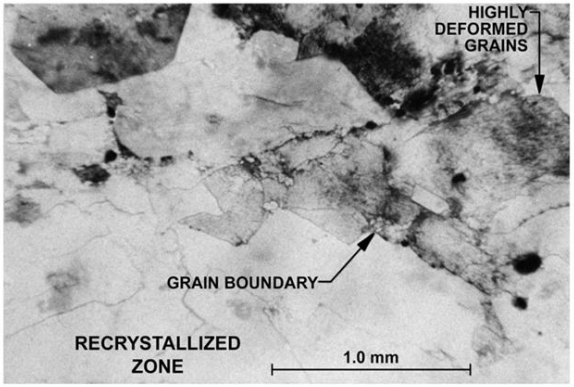
Cross Slip



Cross Slip and Climb



Polygonization



Recrystallization

Hansen, F. D. 2014 in preparation. *Isochoric Deformation of Salt.* American Rock Mechanics Association. Minneapolis MN.

German Testing of WIPP Salt

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
0,2	1,00E-05	27	1	2
0,5	1,00E-05	27	1	2
1	1,00E-05	27	1	2
2	1,00E-05	27	1	2
3	1,00E-05	27	1	2
5	1,00E-05	27	1	2
20	1,00E-05	27	1	2
			Σ = 7	Σ = 14

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
0,2	1,00E-05	60	1	2
0,5	1,00E-05	60	1	2
1	1,00E-05	60	1	2
2	1,00E-05	60	1	2
3	1,00E-05	60	1	2
5	1,00E-05	60	1	2
20	1,00E-05	60	1	2
			Σ = 7	Σ = 14

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
0,2	1,00E-05	100	1	2
0,5	1,00E-05	100	1	2
1	1,00E-05	100	1	2
2	1,00E-05	100	1	2
3	1,00E-05	100	1	2
5	1,00E-05	100	1	2
20	1,00E-05	100	1	2
			Σ = 7	Σ = 14

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
0,2	1,00E-06	27	1	2
0,5	1,00E-06	27	1	2
1	1,00E-06	27	1	2
2	1,00E-06	27	1	2
3	1,00E-06	27	1	2
5	1,00E-06	27	1	2
20	1,00E-06	27	1	2
			Σ = 7	Σ = 14

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
0,2	1,00E-04	27	1	1
1	1,00E-04	27	1	1
2	1,00E-04	27	1	1
5	1,00E-04	27	1	1
20	1,00E-04	27	1	1
			Σ = 5	Σ = 5

σ_3 MPa	strain rate 1/s	T °C	quantity/lab pure salt -IfG	quantity/lab clay salt -TUC
?	?	?	1	2
?	?	?	1	2
?	?	?	1	2
?	?	?	1	2
?	?	?	1	2
?	?	?	1	2
?	?	?	1	2
			Σ =7	Σ = 8

σ_3 MPa	σ_{eq} MPa	T °C	load level -	duration d	loading / unloading	above/below dilation strength	quantity pure salt	quantity clay salt	lab -
20	>10	27	2	60/60	L/U	b/b	2	3	IfG
20	>10	60	2	60/60	L/U	b/b	5	5	IfG
20	>10	80	2	60/60	L/U	b/b	1	2	IfG
20	<10	60	1	120	L	b	2	2	IfG
20		27/60/80	3	60/60/60	L/L/L	b	1	2	TUC
5	>35	27	1		L	a	1	0	TUC
different	different	27	4	60/60/30/30	L/L/L/L	b/b/a/a	2	3	TUC
?	?	?	?	?	?	?	3	3	IfG / TUC
							Σ = 17	Σ = 20	

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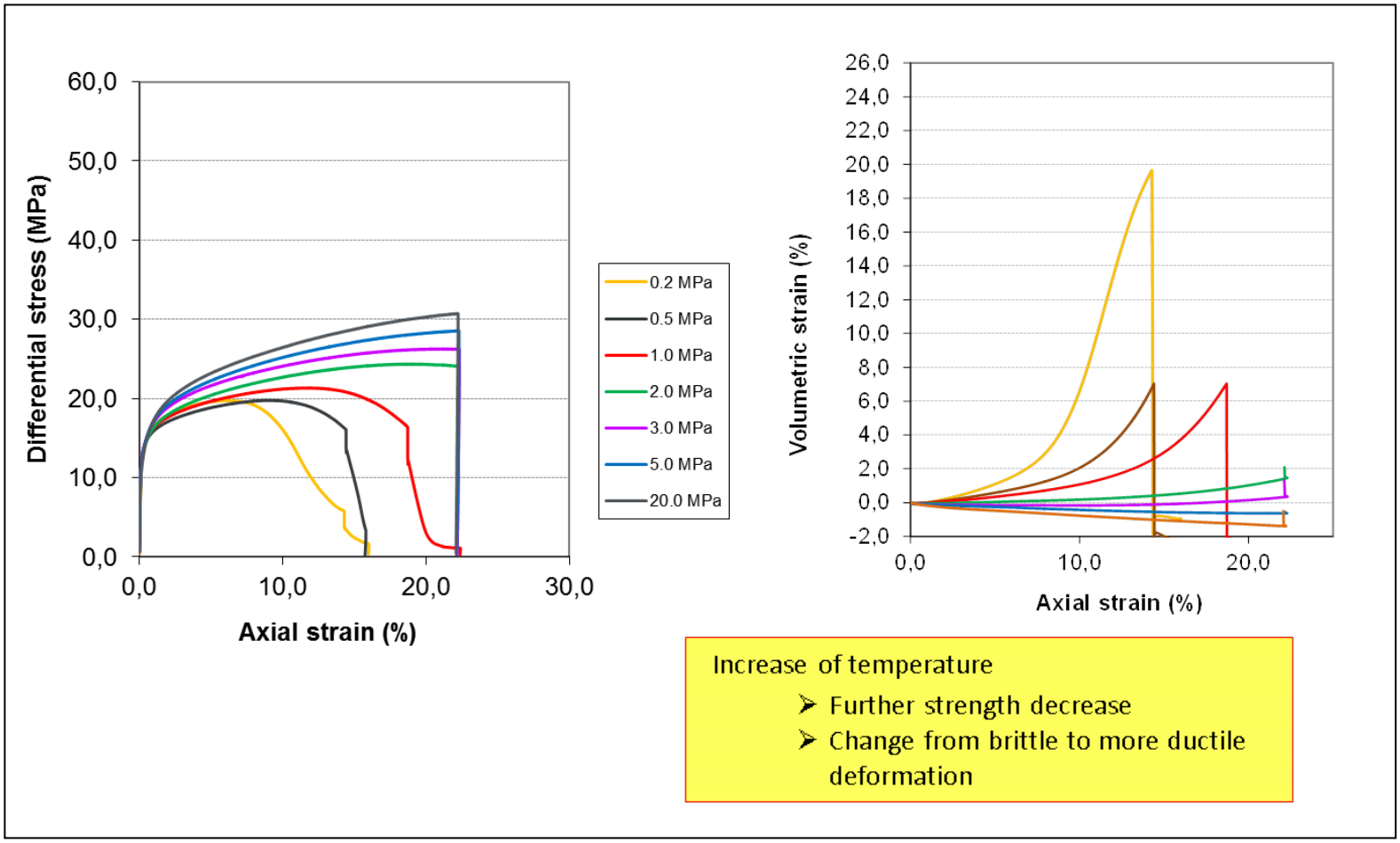
WIPP Salt Sent to German Research Centers

Triaxial Strength Tests ($1 \cdot 10^{-5} s^{-1}$, 100 ° C)



Salzer, K., D. Naumann, R.-M. Günther & T. Popp. 2013. Status of Laboratory Tests on WIPP-salt. 4th US-German Workshop on Salt Repository Research, Design and Operation, September 17-18, 2013. Berlin, Germany.

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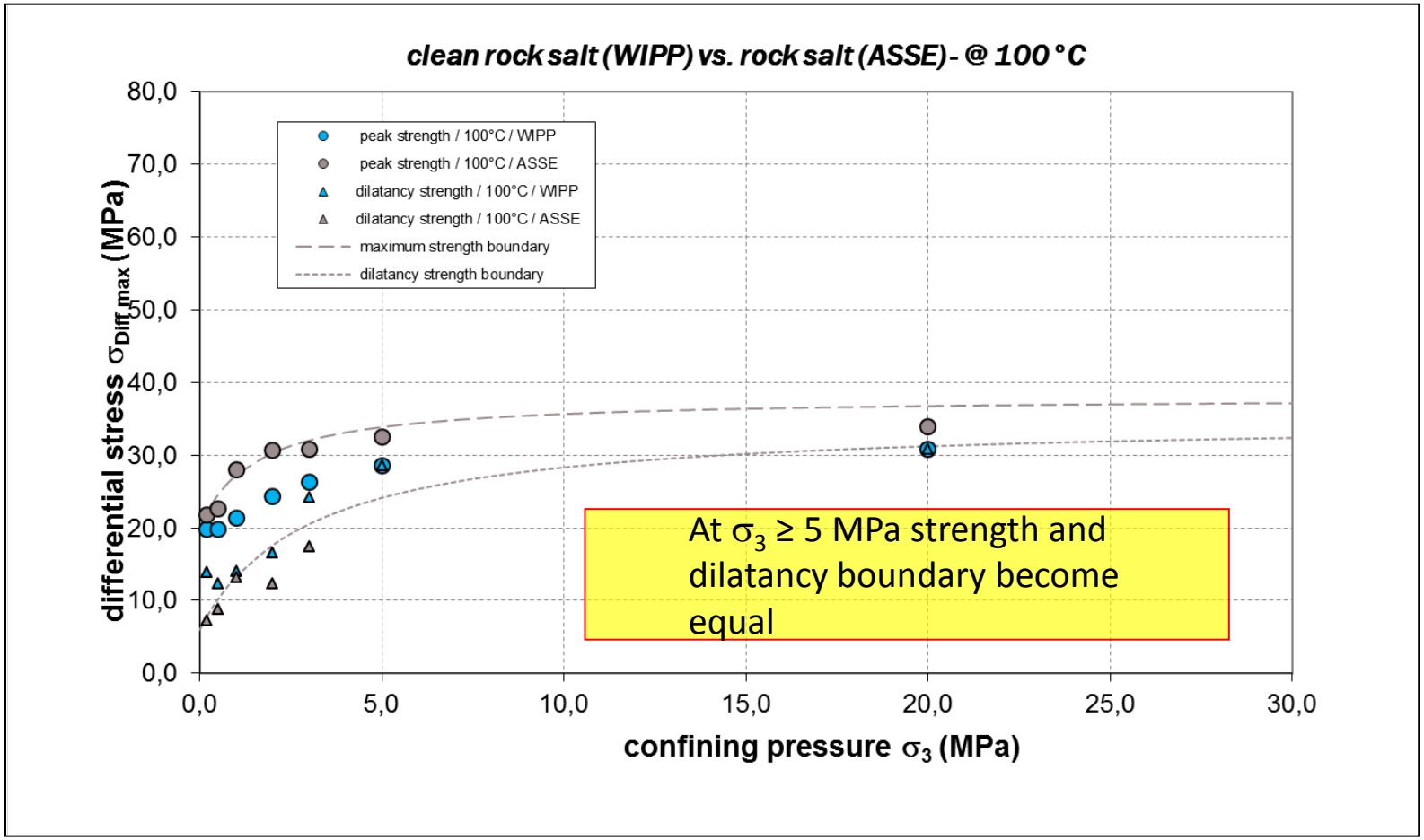
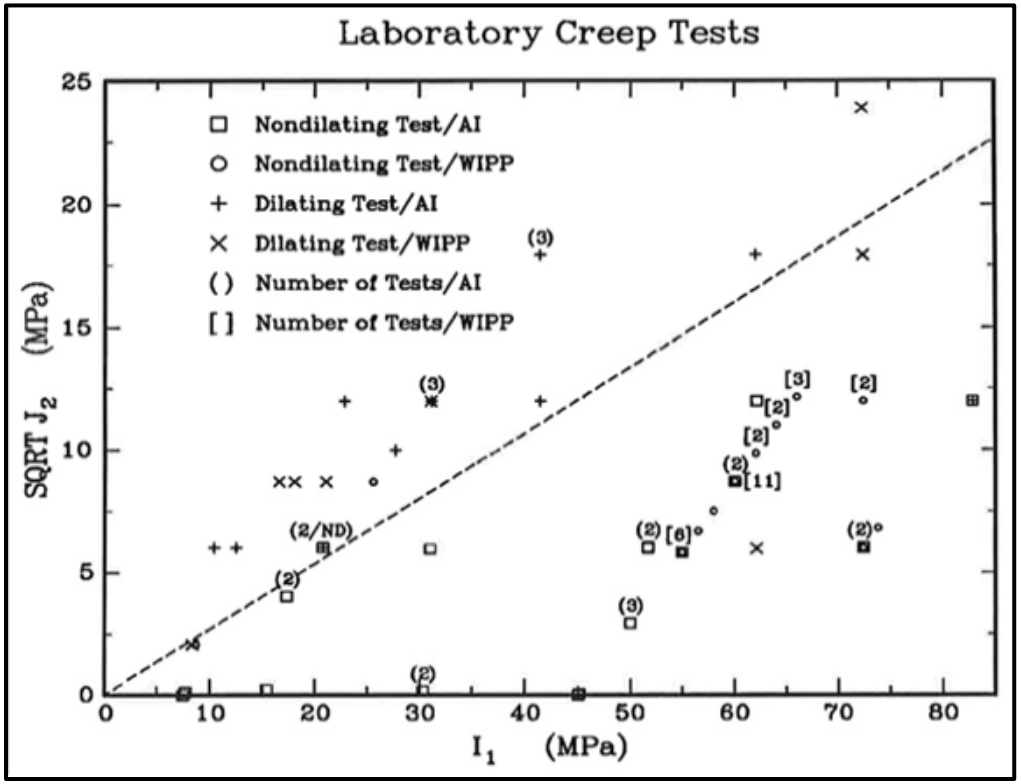
Triaxial Strength Tests ($1 \cdot 10^{-5} s^{-1}$, 100 ° C)



Salzer, K., D. Naumann, R.-M. Günther & T. Popp. 2013. Status of Laboratory Tests on WIPP-salt. 4th US-German Workshop on Salt Repository Research, Design and Operation, September 17-18, 2013. Berlin, Germany.

Laboratory Creep Tests



Hansen, F. D. 2003. *The Disturbed Rock Zone at the Waste Isolation Pilot Plant.* Sandia National Laboratories, Albuquerque, NM. SAND2003-3407.

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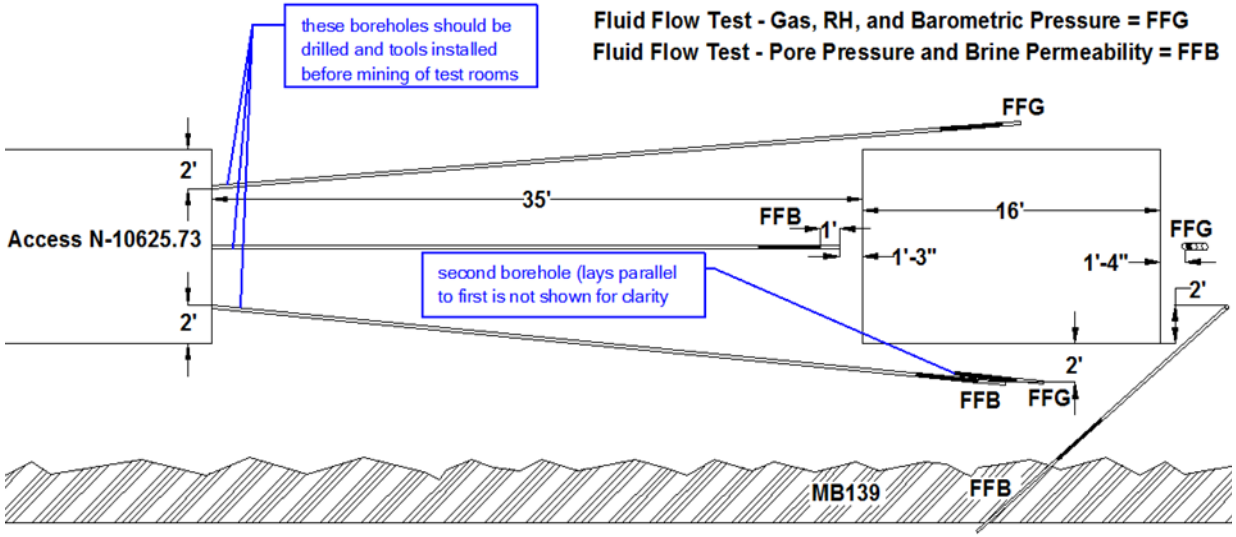
Evolution of the WIPP URL Setting



Determination of undisturbed salt properties, measurement of evolution, and quantification of boundary conditions

Hansen, F.D., C.L. Howard, K.L. Kuhlman, 2013. Mechanical, Hydrological, and Thermal Characteristics of the WIPP URL Test Bed ERMS 561306. Sandia National Laboratories, Carlsbad, New Mexico.

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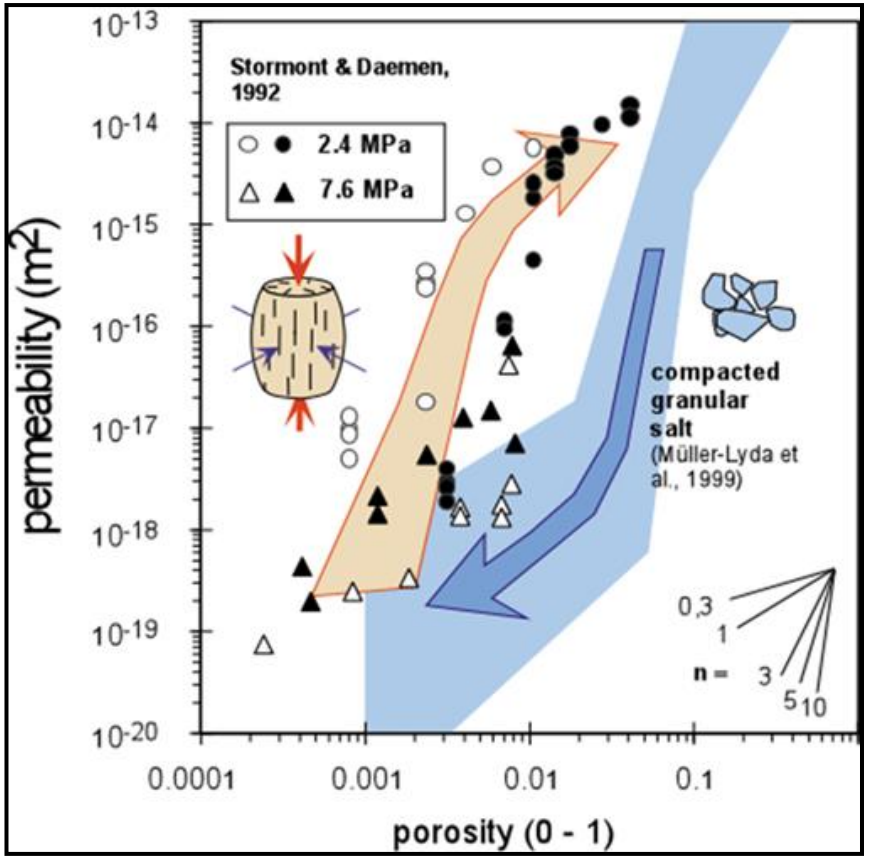
Salt Reconsolidation: Principles and Applications

Hansen, F.D. 2014 – In Progress. *Salt Reconsolidation: Principles and Applications.*

Frank Hansen[1)], Till Popp[2)], Klaus Wieczorek[3)], Dieter Stührenberg[4)]

[1)] Sandia National Laboratories, Albuquerque, New Mexico, USA
[2)] Institute for Geomechanics (IfG), Leipzig, Germany
[3)] Gesellschaft für Andlagen-und Reaktorsicherheit (GRS Braunschweig), Braunschweig, Germany
[4)] Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany



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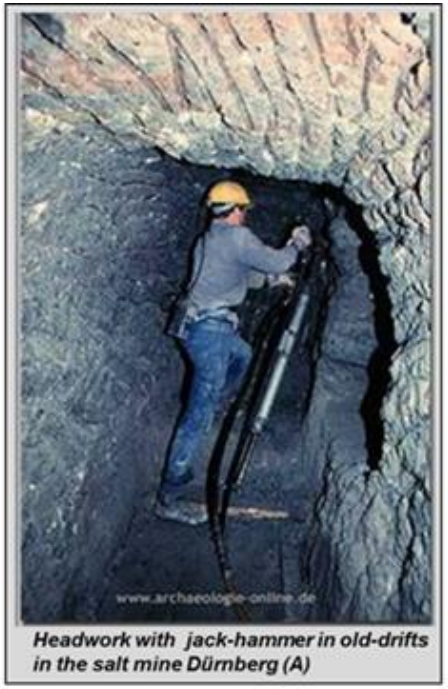
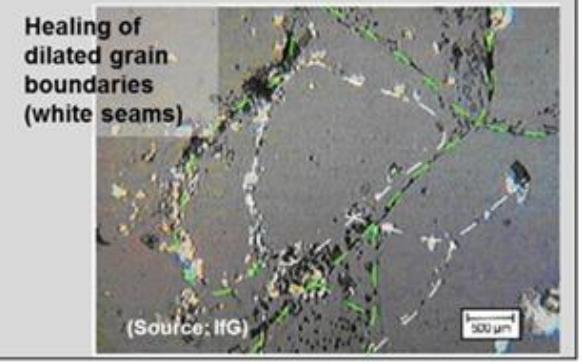
In Situ Analogues



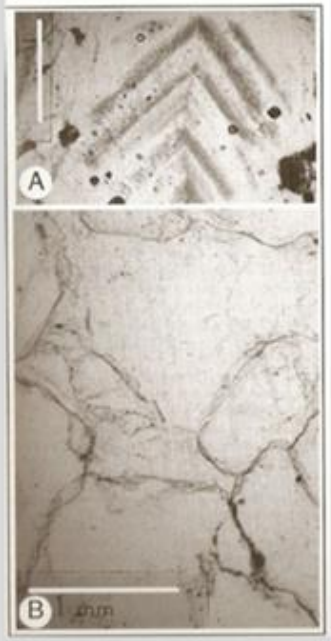
Headwork with jack-hammer in old-drifts in the salt mine Dürnberg (A)

a)

b)



c)



A) Chevron-structures due to grain grow by precipitation
B) B) 120° polygon-structures developed by recrystallisation

d)

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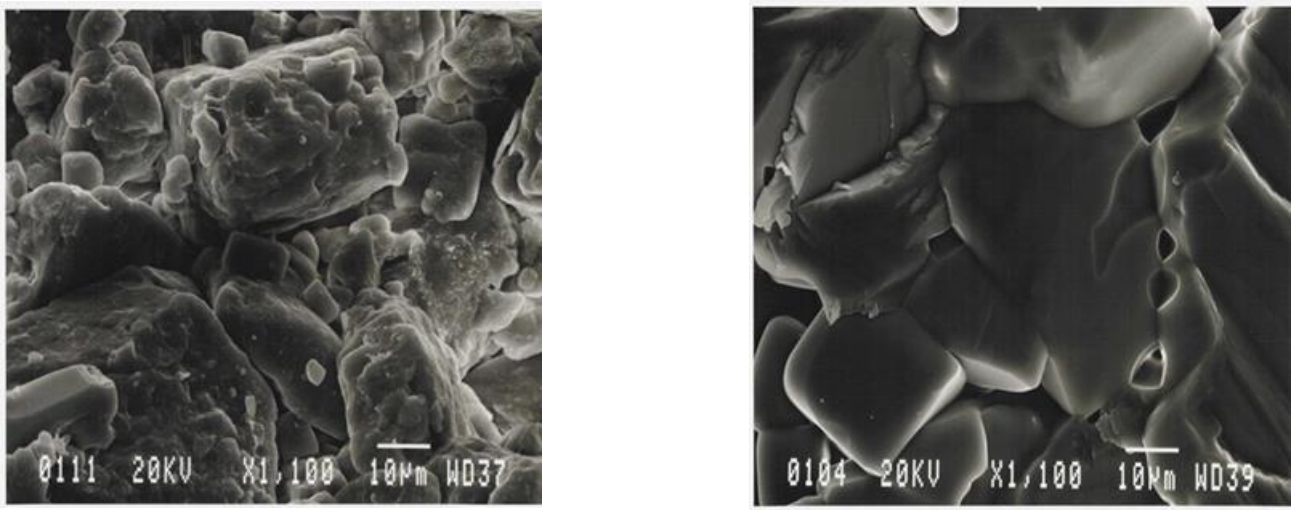
Salt Consolidation for WIPP Shaft Seals



Dynamically compacted WIPP salt (left) and reconsolidated (right)

- ***What final porosity of crushed salt is necessary to achieve an efficient seal and at which time can it be reached?***
- ***Capability of additives such as moisture and clay can be optimized for construction and attainment of sealing properties***
- ***The nature of testing fluids (brine or gas) and the resultant permeability/porosity relationships warrant further examination***
- ***Further analogue experiences from underground sources is imperative***
- ***The role of granular salt backfill in repository safety concepts is site specific***

Hansen, F.D. and M.K. Knowles. 1999. *Design and Analysis of a Shaft Seal System for the Waste Isolation Pilot Plant*. Sandia National Laboratories, Albuquerque, NM. SAND99-0904J.

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Ongoing US/German Collaboration

http://www.sandia.gov/SALT/SALT_Home.html

- Safety Case for Heat-Generating Waste Disposal in Salt
- Plugging and Sealing
- Salt Mechanics Modeling
- Repository Design and Use of the WIPP URL
- Geochemistry, Microbes, and Hydrogeology

Hansen, F.D., W. Steininger, and E. Biurrun. 2014. *Proceedings of the 4th US/German Workshop on Salt Repository Research, Design, and Operation*. Prepared for U.S. Department of Energy Used Fuel Disposition Campaign. FCRD-UFD-2014.000335. Sandia National Laboratories. Albuquerque, New Mexico.

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Future R&D German Perspective

- Domal salt uplift, subrosion, and glacial channels
- Compaction of crushed salt
- Knowledge of mass transport and two-phase flow
- Retrievability—geotechnical barriers and excavation damage zone
- Numerical modeling geologic barrier integrity
- Conceptual improvements of the safety demonstration

Reference: Gesellschaft für Anlagen- und Reaktorsicherheit mbH, "Vorläufige Sicherheitsanalyse für den Standort Gorleben," Köln, 2012. http://www.grs.de/vorlaeufige-sicherheitsanalyse-gorleben-vsg