



## Rock-Water Interaction

Institute of Geological Sciences  
University of Bern

[\(website\)](#)



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## LIST OF CURRENT AND COMPLETED PROJECTS

(AS OF SEPTEMBER 2016)

### QUICK LINKS:

- ⇒ [GEOCHEMISTRY OF AQUIFERS](#)
- ⇒ [GEOCHEMISTRY OF AQUITARDS](#)
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### GEOCHEMISTRY OF AQUIFERS

[\(website\)](#)

#### ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

#### HYDROCHEMISTRY, RESIDENCE TIME, GEOCHEMICAL EVOLUTION, AND FLOW PATHS OF GROUNDWATER IN NORTHERN SWITZERLAND AND SURROUNDING AREAS (NAGRA HYDROCHEMISTRY PROGRAM)

2000 - | Contact person: H. Niklaus Waber

*Waber, H.N., 2001. Hydrochemie. In: Nagra (2001) Sondierbohrung Benken Untersuchungsbericht. Nagra Technischer Bericht 00-01. Nagra Wettingen, Schweiz, 217-246*

*Waber, H.N., Gimmi, T., Pearson, F.J. and Gautschi, A., 2002. Hydrochemische und isotopehydrologische Charakterisierung der Grund- und Porenwässer. In: Nagra (2002) Projekt Opalinuston: Synthese der geowissenschaftlichen Untersuchungen. Nagra Technischer Bericht 02-03. Nagra, Wettingen, Schweiz, 195-211.*

*Nagra, 2014. SGT2, Geologische Grundlagen Dossier V: Hydrogeologische Verhältnisse. Nagra Technischer Bericht NTB 14-02. Nagra, Wettingen, Schweiz, 117 pp.*

Waber, H.N., Heidinger, M., Lorenz, G. and Traber, D., 2014. *Hydrochemie und Isotopenhydrogeologie von Tiefengrundwässern in der Nordschweiz und im angrenzenden Süddeutschland. Nagra Arbeitsbericht 13-63. Nagra, Wettingen, Switzerland, 247 pp.*

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### **GROUNDWATER CONTAMINATION AND REMEDIATION IN THE WADI SUQ AREA, SULTANATE OF OMAN (INST. GEOL. SCI. & RWI RESEARCH PROJECT)**

2003 - 2005 and 2010 - 2012 | Contact person: H. Niklaus Waber

The extent, degree and time evolution of groundwater contamination in Wadi Suq by copper mining and copper ore processing activities was characterised and remediation strategies were proposed.

*Wanner, P., Al-Sulaimani, M.Y.N., Waber, H.N. and Wanner, C., 2015. Assessing the environmental hazard of using seawater for ore processing at the Lasail mining site in the Sultanate of Oman. Mine Water Environ 34: 59-74.*

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### **GROUNDWATER HYDROGEOCHEMICAL INVESTIGATIONS AT FORSMARK SITE, SWEDEN (SKB, CHEMNET PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Groundwater circulating in the fracture networks of crystalline rocks have been analysed for their chemical, isotope and gas composition. Obtained results were used in combination with porewater data and hydraulic models to elaborate the regional hydrogeological evolution at Forsmark.

*Smellie, J.A.T., Tullborg, E.-L., Nilsson, A.C., Sandström, B., Waber, H.N., Gimeno, M. and Gascoyne, M., 2008. Explorative analyses of major components and isotopes. SDM Site Forsmark. SKB R-Report R-08-84, SKB, Stockholm, Sweden: 287 pp., available at [www.skb.se](http://www.skb.se).*

*Laaksoharju, M., Smellie, J.A.T., Tullborg, E.-L., Gimeno, M., Hallbeck, L., Molinero, J. and Waber, H.N., 2008. Bedrock hydrogeochemistry Forsmark. SDM Site Forsmark. SKB R-Report R-08-47, SKB, Stockholm, Sweden: 157 pp., available at [www.skb.se](http://www.skb.se).*

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### **GROUNDWATER HYDROGEOCHEMICAL INVESTIGATIONS AT LAXEMAR SITE, SWEDEN (SKB, CHEMNET PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Groundwater circulating in the fracture networks of crystalline rocks have been analysed for their chemical, isotope and gas composition. Obtained results were used in combination with porewater data and hydraulic models to elaborate the regional hydrogeological evolution at Laxemar.

*Laaksoharju, M., Smellie, J.A.T., Tullborg, E.-L., Wallin, B., Drake, H., Gascoyne, M., Gimeno, M., Gurban, I., Hallbeck, L., Molinero, J., Nilsson, A.C. and Waber, H.N., 2009. Bedrock hydrogeochemistry Laxemar. SDM-Site Laxemar. SKB R-Report R-08-93, SKB, Stockholm, Sweden: 201 pp., available at [www.skb.se](http://www.skb.se).*

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### **CHEMICAL AND ISOTOPIC COMPOSITION OF SEEPAGE WATER COLLECTED FROM BOREHOLES IN THE OPALINUS CLAY AND FROM SPRINGS IN SURROUNDING FORMATIONS AT THE MONT TERRI URL (MONT TERRI WS-A EXPERIMENT)**

1998 - 2002 | Contact person: H. Niklaus Waber

This project aimed at the characterisation of porewater in the Opalinus Clay by collecting seepage water from packer intervals in boreholes over very long time periods. Spring water discharging from higher transmissive surrounding lithologies were also investigated.

*Scholtis, A., Waber, H.N., Fierz, T., Degueldre, C., Laube, A. and Bauer-Plaindoux, C., 1999. WS-A Experiment: Water & Gas Sampling: Chemical and Isotopic Raw Data (28th to 29th April 1999) for: Boreholes BWS-A1, -A2, -A3, and -A6, Murchisonae-Concava-Beds Spring, Jurensis Marl Spring, Gryphitenkalk Spring. MTP Technical Note TN 99-67, International Mont Terri Project, St. Ursanne, Switzerland, 37 pp.*

*Waber, H.N., 1999. Mont Terri Project: Phase 3 Hydrochemical Data Review. In: Pearson, F. J., 1999, Geochemical Modelling and Synthesis (GM) Task: Results of Phase 4 Activities: MTP Technical Note TN 99-51, International Mont Terri Project, St. Ursanne, Switzerland, 17-33.*

*Langer, C.W. and Waber, H.N., 2000. WS-A Experiment: Water & Gas Sampling Phase 5: Chemical and Isotopic Raw Data for: Boreholes BWS-A1, -A2, -A3, and -A6. MTP Technical Note TN 2000-32, International Mont Terri Project, St. Ursanne, Switzerland, 22.*

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## **GROUNDWATER INVESTIGATIONS IN THE SULTANATE OF OMAN (PHD C. WEYHENMEYER, SNF PROJECT)**

1996 - 2002 | Contact person: H. Niklaus Waber

Groundwater collected from deep boreholes and springs in different areas of the Sultanate of Oman were investigated for their chemical, isotopic and noble gas composition to unravel their conditions of infiltration, geochemical evolution, residence and renewal times

*Weyhenmeyer C.E., Burns S.J., Waber H.N. Aeschbach-Hertig W., Kipfer R., Loosli H.H. and Matter A., 2000. Cool Glacial Temperatures and Changes in Moisture Source Recorded in Oman Groundwaters. Science 287: 842-845.*

*Weyhenmeyer C.E., Burns S.J., Waber H.N., Macumber P.G. and Matter A., 2002. Isotope Study of Moisture Sources, Recharge Areas and Groundwater Flowpaths within the Eastern Batinah Coastal Plain, Sultanate of Oman. Water Resour Res 38: 1184-2006.*

*Matter J.M., Waber H.N., Loew S. and Matter A., 2005. Recharge Areas and Geochemical Evolution of Groundwater in an Alluvial Aquifer System in the Sultanate of Oman. Hydrogeol. J 14: 203-224.*

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## **SYNTHESIS OF THE EPFL-AQUITYP PROJECT (PHD S. KILCHMANN, SNF PROJECT)**

1997 - 2001 | Contact person: H. Niklaus Waber

Basing on 4 previous PhD theses conducted at the EPFL, this project aimed at the typology of recent groundwaters from different aquifer environments based on geogenic tracer elements and to derive natural background concentrations of trace elements.

*Kilchmann S, Waber H.N., Parriaux A. and Bensimon M., 2004. Natural Tracers in recent groundwaters from different Alpine aquifers. Hydrogeol J 12, 643-661.*

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## **BINDING STATE OF PORE WATER IN CLAY-RICH MEDIA (CLAYWAT, AN OECD/NEA PROJECT)**

2016 - | Contact persons: Martin Mazurek, Thomas Gimmi

Physical and chemical methods are evaluated regarding information on the binding state and mobility of H<sub>2</sub>O in the nanometric pore space of argillaceous rocks. An analytical campaign comparing formations in different states of induration is conducted, with the aim to elaborate a consistent description of effects and processes.

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## **IDENTIFICATION OF GLACIAL MELTWATER IMPACT ON PORE WATER IN CRYSTALLINE ROCKS AT SAIMAA, SALPAUSSELKÄ, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2016 - | Contact person: H. Niklaus Waber

This project focuses on the identification of the penetration depth of glacial meltwater along different fracture networks into metamorphic crystalline rocks. At the chosen locality the glacier front remained stable for several hundreds of years during the LGM.

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## **WEATHERING AND DECOMPACTION OF OPALINUS CLAY: BOREHOLE AT LAUSEN, SWITZERLAND**

2015 - | Contact persons: Martin Mazurek, Paul Wersin

Effects of contact with meteoric water on the rock and its pore water are studied in a setting where Opalinus Clay is exposed on the surface. Effects of the infiltration of surficial waters along decompaction fractures are investigated.

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## **BENCHMARKING OF PORE-WATER CHARACTERISATION METHODS**

2015 - | Contact persons: Martin Mazurek, Daniel Rufer

Rock samples are equilibrated with waters of known composition in diffusion cells and then extracted and analysed by various techniques.

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## **DEVELOPMENT OF THE SQUEEZING METHOD OF PORE-WATER EXTRACTION**

2013 - | Contact person: Martin Mazurek

Quantities of pore water sufficient for chemical and isotopic analysis can be extracted from clays and shales by applying lithostatic pressures of 100-500 MPa. In collaboration with CRIEPI (Japan), the method is being further developed, and the results are evaluated by comparison with data obtained from independent methods.

*Mazurek, M., Oyama, T., Eichinger, F. & De Haller, A. (2013): Squeezing of pore water from core samples of DGR boreholes: Feasibility study. NWMO TR-2013-19, Nuclear Waste Management Organization, Toronto, Canada.*

Mazurek, M., Oyama, T., Wersin, P. & Alt-Epping, P. (2015): Pore-water squeezing from indurated shales. *Chemical Geology* 400, 106-121.

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## **ROCK AND POREWATER CHARACTERISATION ON DRILLCORES FROM THE DEEP BOREHOLE OF SCHLATTINGEN, SWITZERLAND**

2011 - | Contact person: Paul Wersin, Martin Mazurek, H. Niklaus Waber, Daniel Rufer

The geochemistry, mineralogy and gas composition in Opalinus Clay and other claystones are investigated.

*Wersin, P., Mazurek, M., Mäder, U.K., Gimmi, T., Rufer, D., Lerouge, C., Traber, D., 2016. Constraining porewater chemistry in a 250 m thick argillaceous rock sequence. Chemical Geology 434, 43-61.*

*Wersin, P., Mazurek, M., Waber, H.N., Mäder, U.K., Gimmi, T., Rufer, D., de Haller, A., 2013. Rock and porewater characterisation on drillcores from the Schlattingen borehole. Nagra Arbeitsbericht NAB 12-54.*

*Mazurek, M., Oyama, T., Wersin, P., Alt-Epping, P., 2015. Pore-water squeezing from indurated shales. Chem. Geol. 400, 106-121.*

*Wersin, P., Waber, H.N., Mazurek, M., Mäder, U.K., Gimmi, T., Rufer, D., Traber, D., 2013. Resolving Cl and SO<sub>4</sub> profiles in a clay-rich rock sequence. Procedia Earth and Planetary Science 7, 892 - 895.*

*Rufer, D. and Waber, H.N. (2015): Noble and reactive gas data of porewaters and rocks from the Schlattingen borehole SLA-1. NAGRA ARBEITSBERICHT NAB 15-12, Nagra, Wettingen*

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## **ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING**

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

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## **PORE WATER CHARACTERISATION - METHOD COMPARISON AND INVESTIGATION OF INTERFACE TO ADJACENT AQUIFER (NWMO PROJECT AND MONT TERRI DB-A EXPERIMENT)**

2013 - 2016    Contact person: H. Niklaus Waber, Daniel Rufer

Natural chemical, isotopic and noble gas tracers are quantified in porewater of drillcore material from the 250 m long borehole BDB1. Major focus is given on the detailed investigation of the porewater-groundwater exchange at the interface between Opalinus Clay and Passwang Formation.

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## **EVALUATION AND COMPARISON OF PORE-WATER EXTRACTION TECHNIQUES IN ARGILLACEOUS ROCKS (MONT TERRI DB-A EXPERIMENT)**

2015 - 2016 | Contact person: Martin Mazurek

Five laboratories sampled rock cores from a 250 m long borehole at Mont Terri, with the aim to characterise the chemical and isotopic composition of pore water. The results are compared, and observed differences are rationalised.

*Mazurek, M., Al, T., Celejewski, M., Clark, I. D., Fernandez, A. M., Kennell-Morrison, L., Matray, J. M., Murseli, S., Oyama, T., Qiu, S., Rufer, D., St-Jean, G., Waber, H. N. & Yu, C. (2016): Mont Terri Project: Comparison of pore-water investigations conducted by several laboratories on materials from the BDB-1 borehole. Mont Terri Technical Report, Mont Terri Consortium, St. Ursanne, Switzerland (in press).*

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## **FURTHER DEVELOPMENT OF THE DIFFUSIVE-EXCHANGE TECHNIQUE TO ANALYSE THE ISOTOPIC COMPOSITION OF PORE WATERS**

2012 - 2016 | Contact person: Martin Mazurek

While this technique is well established in the study of low-salinity environments, various adaptations are needed in order to make the method applicable to brine systems, such as those encountered in the Palaeozoic sedimentary sequence of southern Ontario.

*De Haller, A., Hobbs, M. & Spangenberg, J. E. (in review by Chemical Geology): Adapting the diffusive exchange method for stable isotope analysis of pore water to brine-saturated rocks.*

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## **PALAEOHYDROGEOLOGICAL EVOLUTION AND SELF-SEALING OF FAULTS (MONT TERRI SF EXPERIMENT)**

2010 - 2016 | Contact person: Martin Mazurek

Fluid evolution is investigated using knowledge about current pore-water composition and its spatial distribution, together with signatures of palaeo-fluids recorded in veins. The data are integrated with independent information on the regional geological evolution and erosion history.

*De Haller, A., Mazurek, M., Spangenberg, J., Möri, A. (2014): SF (Self-sealing of faults and paleo-fluid flow): Synthesis report. Mont Terri Technical Report 2008-02, Mont Terri Consortium, St. Ursanne, Switzerland.*

*Mazurek, M. & De Haller, A. (in press): Pore-water evolution and solute-transport mechanisms in Opalinus Clay at Mont Terri and Mont Russelin (Canton Jura, Switzerland). Swiss Journal of Geosciences.*

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## **CHARACTERISATION OF DEEP-SEATED MATRIX PORE WATER, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2011 - 2015 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of metamorphic crystalline rocks has been extracted from rock samples from a 1000 m deep borehole by diffusion experiments. Obtained results of natural chemical, isotope and noble gas tracers were used to elaborate the palaeo-hydrogeological evolution of the site with a main focus of possibly upconing saline water.

*Eichinger, F., Rufer, D. and Waber, H.N., 2015. Matrix Porewater and Gases in Porewater in Olkiluoto Bedrock from Drilling OL-KR56. Posiva Working Report WR 2015-xx. Posiva Oy, Olkiluoto, Finland, 100 pp, available at [www.posiva.fi](http://www.posiva.fi).*

*Rufer, D., Waber, H.N., Eichinger, F. and Pitkänen, P. (accepted). Helium in porewater and rocks of crystalline bedrock from the Fennoscandian Shield, Olkiluoto (Finland). Procedia Earth Plan Sci.*

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## **SYNTHESIS OF PALAEOHYDROGEOLOGICAL EVOLUTION OF THE OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2010 - 2014 | Contact person: H. Niklaus Waber

This project synthesised the insights gained so far about the palaeohydrogeological evolution of the Olkiluoto site based on data obtained from geological, hydrochemical, hydraulic and porewater investigations.

*Smellie, J.A.T., Pitkänen, P., Koskinen, L., Aaltonen, I., Eichinger, F., Waber, H.N., Sahlstedt, E., Siitari-Kauppi, M., Karhu, J., Löfman, J. and Poteri, A. (2014). Evolution of the Olkiluoto Site: Palaeohydrogeochemical Considerations. Posiva Working Report WR 2014-27. Posiva Oy, Olkiluoto, Finland, 222 pp., available at [www.posiva.fi](http://www.posiva.fi).*

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## **GEOCHEMICAL CHARACTERISATION OF THE EFFINGEN MEMBER AND ITS PORE WATERS**

2009 - 2013 | Contact person: Martin Mazurek

Understanding the interactions between rock, pore and ground water in a sequence of interlayered marls and limestones.

*Mazurek, M., Waber, H.N., Mäder, U.K., Gimmi, T., De Haller, A. & Koroleva, M. (2012). Geochemical synthesis for the Effingen Member in boreholes at Oftringen, Gösgen and Küttigen. Nagra Technical Report NTB 12-07, Nagra, Wettingen, Switzerland.*

*Klump, S., Waber, H.N., Koroleva, M., Eichinger, L., Lorenz, G., Albert, W., Frieg, B. and Gautschi, A., 2008. EWS-Bohrungen Küttigen - Synthese der geologischen und hydrogeologischen Untersuchungen. Nagra Arbeitsbericht 08-12. Nagra, Wettingen, Schweiz, 50 pp.*

*Waber, H.N., 2008. Borehole Oftringen: Mineralogy, Porosimetry, Geochemistry, Pore Water Chemistry. Nagra Arbeitsbericht 08-18. H. N. Waber. Wettingen, Switzerland, Nagra: 276.*

*De Haller, A., Tarantola, A., Mazurek, M. & Spangenberg, J. (2011): Fluid flow through the sedimentary cover in northern Switzerland recorded by calcite-celestite veins (Oftringen borehole, Olten). Swiss Journal of Geosciences 104, 493 - 506.*

*Waber, H.N., Mäder, U., Mazurek, M. and Koroleva, M., 2012. Borehole Gösgen KB5a: Mineralogy, Porosimetry and Pore Water Chemistry of the Effingen Member. Nagra Arbeitsbericht 09-20, Nagra, Wettingen, Schweiz, 72 pp.*

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## **PORE-WATER STUDIES IN THE PALAEOZOIC SEQUENCE OF SOUTHERN ONTARIO, CANADA**

2006 - 2011 | Contact person: Martin Mazurek

Characterisation of brines in the Devonian to Cambrian sequence, based on core materials from deep boreholes drilled by NWMO.

Clark, I.D., Al, T., Jensen, M., Kennell, L., Mazurek, M., Mohapatra, R. & Raven, K.G. (2013): Paleozoic-aged brine and authigenic helium preserved in an Ordovician shale aquiclude. *Geology*, doi:10.1130/G34372.1

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## **INTERPRETATION AND MODELLING OF NATURAL TRACER PROFILES ACROSS ARGILLACEOUS ROCKS (CLAYTRAC, AN OECD/NEA PROJECT)**

2005 - 2011 | Contact person: Martin Mazurek

Existing data pertinent to conservative tracers in pore waters from 9 sites are evaluated and modelled. Objectives are the identification of the dominant solute-transport process and the use of tracer data as archives of the palaeo-hydrogeological evolution.

*Mazurek, M., Alt-Epping, P., Bath, A., Gimmi, T. & Waber, H. N. 2009: Natural tracer profiles across argillaceous formations: The CLAYTRAC project. OECD/NEA report 6253, OECD Nuclear Energy Agency, Paris, France, 358 pp.*

*Mazurek, M., Alt-Epping, P., Bath, A., Gimmi, T., Waber, H. N., Buschaert, S., De Cannière, P., De Craen, M., Gautschi, A., Savoye, S., Vinsot, A., Wemaere, I. & Wouters, L. 2011: Natural tracer profiles across argillaceous formations. *Applied Geochemistry* 26, 1035 - 1064*

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## **POREWATER INVESTIGATIONS IN THE PARIS BASIN AT THE SITE MEUSE-HAUTE MARNE II (ANDRA SITE INVESTIGATION PROJECT)**

2008 - 2010 | Contact person: H. Niklaus Waber

Conservative parameters of the porewater (Cl, Br,  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , He) residing in the pore space of low-permeability sedimentary rocks have been determined by indirect methods based on drillcore material from a 2000 m deep borehole. Obtained results were used to elaborate the solute transport across the entire Mesozoic sedimentary sequence in the Paris basin and the palaeo-hydrogeological evolution.

*Waber, H.N., 2012. Laboratoire de Recherche Souterrain Meuse / Haute-Marne - Geochemical Data of Borehole EST433. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 86 pp.*

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## **POREWATER INVESTIGATIONS AT OLKILUOTO SITE, FINLAND (PHD F. EICHINGER; POSIVA SITE CHARACTERISATION PROJECT)**

2005 - 2010 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of metamorphic crystalline rocks has been extracted from rock samples of 3 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeo-hydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

*Eichinger, F., Waber, H.N. and Smellie, J.A.T. (2006). Characterisation of Matrix Pore Water at the Olkiluoto Investigations Site, Finland. Posiva Working Report WR 2006-103. Posiva Oy, Olkiluoto, Finland, 161 pp, available at [www.posiva.fi](http://www.posiva.fi).*

*Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. and Smellie, J.A.T., 2010. Characterisation of Matrix Pore Water and Fluid Inclusions in Olkiluoto Bedrock from Drilling OL-KR47. Posiva Working Report WR 2010-58. Posiva Oy, Olkiluoto, Finland, 140 pp, available at [www.posiva.fi](http://www.posiva.fi).*



Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. and Smellie, J.A.T., 2013. Chemistry and dissolved gases of matrix pore water and fluid inclusions in Olkiluoto bedrock from drillhole ONK-PH9. Posiva Working Report WR 2011-63. Posiva Oy, Olkiluoto, Finland, 168 pp, available at [www.posiva.fi](http://www.posiva.fi).

Eichinger, F., Waber, H.N. and Smellie, J.A.T., 2013. Matrix pore water in low-permeable crystalline bedrock: An archive for the palaeohydrogeological evolution of the Olkiluoto Investigation Site. *Proceedings of Isotopes in Hydrology, marine ecosystems and climate change studies Vol. 1, Monaco 27 March-1 April 2011, IAEA, Vienna: 73-82.*

Eichinger, F., Waber, H.N. and Smellie, J.A.T., 2013. Origin and evolution of reactive and noble gases dissolved in matrix pore water. *Proceedings of Isotopes in Hydrology, marine ecosystems and climate change studies Vol. 2, Monaco 27 March-1 April 2011, IAEA, Vienna: 99-107.*

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## **STUDY OF NATURAL TRACER PROFILES IN OPALINUS CLAY OF THE MONT RUSSELIN TUNNEL (IN THE FRAME OF THE EU FP6 FUNMIG PROJECT & MONT TERRI NT EXPERIMENT)**

2005 - 2010 | Contact person: Martin Mazurek

Data acquisition, interpretation and modelling of tracer profiles in the frame of the FP6 FUNMIG Project

*Koroleva, M., Alt-Epping, P. & Mazurek, M. (2011): Large-scale tracer profiles in a deep claystone formation (Opalinus Clay at Mont Russelin, Switzerland): implications for solute transport processes and transport properties of the rock. Chemical Geology 280, 284 - 296*

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## **POREWATER INVESTIGATIONS AT FORSMARK SITE, SWEDEN (SKB SITE INVESTIGATION PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of crystalline rocks has been extracted from rock samples of 5 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeohydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

*Waber H.N., Gimmi T. and Smellie, J.A.T., 2011. Effects of drilling and stress release on hydraulic properties and porewater chemistry of crystalline rocks. J Hydrol 405: 316-332.*

*Waber, H.N., Gimmi, T. and Smellie, J.A.T., 2009. Porewater in the rock matrix. SDM-Site Forsmark. SKB R-Report R-09-14, SKB, Stockholm, Sweden: 107 pp., available at [www.skb.se](http://www.skb.se).*

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## **POREWATER INVESTIGATIONS AT LAXEMAR SITE, SWEDEN (SKB SITE INVESTIGATION PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of crystalline rocks has been extracted from rock samples of 4 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeohydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

Waber H.N., Gimmi T. and Smellie, J.A.T., 2012. Reconstruction of palaeoinfiltration during the Holocene using porewater Data (Laxemar, Sweden). *Geochim Cosmochim Acta* 94: 109-127.

Waber, H.N., Gimmi, T., deHaller, A. and Smellie, J.A.T., 2009. Porewater in the rock matrix. SDM-Site Laxemar. SKB R-Report R-08-112, SKB, Stockholm, Sweden: 93 pp., available at [www.skb.se](http://www.skb.se).

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## **HELIUM IN POREFLUIDS (SNF SCOPUS PROJECT)**

2002 - 2009 | Contact person: H. Niklaus Waber

This SNF-SCOPES project focused on the migration of helium from water into natural quartz crystals to elaborate a new dating technique for very old pore- and groundwaters.

*Lehmann B., Waber H.N. Tolstikhin I., Kamensky I. Gannibal M. Kalashnikov E. and Pevzner B., 2003. Helium in solubility equilibrium with quartz and porefluids in rocks - a new approach in hydrology. Geophys Res Letters 30: 1128-1131*

*Tolstikhin I., Gannibal M., Tarakanov S., Pevzner, B., Lehmann B.E., Ihly B. and Waber H.N., 2005. Helium transfer from water into quartz crystals: A new approach for porewater dating. Earth Planet Sci Lett 238: 31-41.*

*Tolstikhin I.N., Waber H.N. Kamensky I.L., Loosli H.H., Skiba V.I. and Gannibal M. A., 2011. Production, redistribution and loss of helium and argon isotopes in a thick sedimentary aquitard-aquifer system (Molasse Basin, Switzerland). Chem Geol 286: 48-58.*

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## **GEOSCIENTIFIC INVESTIGATIONS ON CORE MATERIALS FROM THE BENKEN BOREHOLE (IN THE FRAME OF NAGRA'S "DEMONSTRATION OF DISPOSAL FEASIBILITY" PROJECT)**

1999 - 2008 | Contact persons: Martin Mazurek, H. Niklaus Waber, Thomas Gimmi

Integrated project aiming at the geological, geochemical and hydrogeological characterisation of the Mesozoic sedimentary sequence of NE Switzerland

*Lerouge, C., Grangeon, S., Claret, F., Gaucher E.C., Blanc P., Guerrot, C., Flehoc C., Wille, G. & Mazurek, M. (2014): Mineralogical and isotopic record of diagenesis from the Opalinus Clay formation at Benken, Switzerland: Implications for the modeling of pore-water chemistry in a clay formation. Clays and Clay Minerals 62, 286-312.*

*Nagra 2002: Projekt Opalinuston - Synthese der geowissenschaftlichen Untersuchungsergebnisse. Nagra Technical Report NTB 02-03, Nagra, Switzerland, 659 pp. + Appendices.*

*Mazurek, M., Hurford, A. J. & Leu, W. 2006: Unravelling the multi-stage burial history of the Swiss Molasse Basin: Integration of apatite fission track, vitrinite reflectance and biomarker isomerisation analysis. Basin Research 18, 27-50*

*Elie, M. & Mazurek, M. 2008: Biomarker transformations as constraints for the depositional environment and for maximum temperatures during burial of Opalinus Clay and Posidonia Shale in northern Switzerland. Applied Geochemistry 23, 3337 - 3354*

*Gimmi, T., Waber, H.N., Gautschi, A. and Rübél, A. (2007), Stable water isotopes in pore water of Jurassic argillaceous rocks as tracers for solute transport over large spatial and temporal scales, Water Resour. Res., 43, W04410, doi:10.1029/2005WR004774.*

*P. Marschall, S. Horseman, and T. Gimmi (2005). Characterisation of gas transport properties of the Opalinus Clay, a potential host rock formation for radioactive waste disposal. Oil & Gas Science and Technology - Rev. IFP, 60(1), 121-139.*

Gimmi, T. and Waber, H.N., 2004. Modelling of tracer profiles in pore water of argillaceous rocks in the Benken borehole: Stable water isotopes, chloride, and chlorine isotopes. Nagra Technical Report 04-05. Nagra, Wettingen, Switzerland, 91 pp.

Pearson, F.J. and Waber, H.N., 2002. Geochemie des Porenwassers im Wirtgestein. In: Nagra (2002), Projekt Opalinuston: Synthese der geowissenschaftlichen Untersuchungen. Nagra Technischer Bericht 02-03. Nagra, Wettingen, Schweiz, 368-379.

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## POREWATER INVESTIGATIONS IN THE UPPER FRESH WATER MOLASSE

2005 - 2007 | Contact person: H. Niklaus Waber

Koroleva, M., Waber, H.N., Mazurek, M. and Bigler, T. (2007). Borehole Üetliberg: Mineralogical and pore water studies. Nagra Arbeitsbericht 07-07. Nagra, Wettingen, Schweiz, 59 pp.

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## POREWATER INVESTIGATIONS IN THE PARIS BASIN AT THE SITE MEUSE-HAUTE MARNE I (ANDRA SITE INVESTIGATION PROJECT)

2003 - 2005 | Contact person: H. Niklaus Waber

Conservative parameters of the porewater (Cl, Br,  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , He) residing in the pore space of low-permeability argillaceous sedimentary rocks have been determined by indirect methods based on drillcore material from 4 different boreholes. Obtained results were used to elaborate the solute transport across the Callovo-Oxfordian shale (Cox) and the palaeo-hydrogeological evolution of the site.

Bigler, T., Ihly, B., Lehmann, B.E. and Waber, H.N., 2005. Helium Production and Transport in the Low-Permeability Callovo-Oxfordian Shale at the Site Meuse/Haute Marne, France. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 40 pp.

Waber, H.N., 2005. Laboratoire de Recherche Souterrain Meuse / Haute-Marne - Chloride,  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  in Pore Water of the Callovo-Oxfordian and Surrounding Rock Formations. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 83 pp.

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## GEOCHEMICAL MODELLING AND SYNTHESIS (GM) TASK, MONT TERRI URL (MONT TERRI WS EXPERIMENT)

2000 - 2003 | Contact person: H. Niklaus Waber

This project aimed at a comprehensive synthesis of porewater characterisation in the argillaceous Opalinus Clay and the various applied porewater extraction and modelling approaches to derive the complete chemistry of the in-situ porewater.

Waber, H.N., 2001. Mont Terri Project: Phase 4 & 5 Hydrochemical Data Review. In: Pearson, F. J., D. Arcos, B. Jordi, A.-M. Fernández, E. Gaucher, J. Peña, B. Sanjuan, J. Turrero, H.N. Waber, L. Griffault, J.-Y. Boisson, H.-E. Gäbler, A. Gautschi and P. Hernán Reguera, 2001, Compilation of Aqueous Geochemistry Data Collected During Phases 4 and 5, Rock Property Data from All Phases and Results of Phase 5 Geochemical Modelling. MTP Technical Note TN 2000-36, International Mont Terri Project, St. Ursanne, Switzerland, 5-52.

Fernández, A.M., Bath, A., Waber, H.N. and Oyama, T., 2003. Water Sampling by Squeezing Drillcore. In: Pearson, F.J. et al. (eds.), Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 171-199, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Gaucher, E.C., Fernández, A.M. and Waber, H.N., 2003. Rock and Mineral Characterisation of the Opalinus Clay Formation. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 281-303, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Griffault, L., Bauer, C., Waber, H.N., Pearson, F.J., Fierz, T., Scholtis, A., Degueldre, C. and Eichinger, L., 2003. Water Sampling and Analyses for Boreholes and Seepages. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 142-170, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson, F.J., Arcos, D., Gaucher, E.C. and Waber, H.N., 2003. Pore Water Chemistry and Geochemical Modelling. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 67-104, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson, F.J., Fernández, A.M., Gaboriau, H., Waber, H.N. and Bath, A., 2003. Porosity and Water Content of Mont Terri Claystones. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 294-319, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson F.J., Arcos, D., Bath A., Boisson J.-Y., Fernández A.M., Gaebler H.E., Gaucher E., Gautschi A., Griffault L., Hernan P. and Waber H.N. (eds.) 2003. *Mont Terri Project - Geochemistry of water in the Opalinus Clay formation at the Mont Terri Rock Laboratory - Synthesis Report*. Reports of the Swiss Federal Office for Water and Geology, Geology Series, No. 5, Bern, Switzerland, 319 p, available at [www.mont-terri.ch](http://www.mont-terri.ch)

Waber, H.N. 2003. Gases in Borehole Headspace. *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 269-280, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Waber, H.N., Gaucher, E.C., Fernández, A.M. and Bath, A., 2003. Aqueous Leachates and Cation Exchange Properties of Mont Terri Claystones. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 200-237, available at [www.mont-terri.ch](http://www.mont-terri.ch).

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## **POREWATER INVESTIGATIONS AND GEOCHEMICAL CHARACTERISATION OF OPALINUS CLAY AT THE MONT TERRI URL (MONT TERRI WS-A & WS-B EXPERIMENTS)**

1998 - 2003 | Contact person: H. Niklaus Waber

Complementary to long-term seepage water collection indirect methods to extract porewater from the low-permeable Opalinus Clay were tested and supported by geochemical investigations on the rock.

Waber, H.N., 1999. *WS-B Experiment: Isotope Analyses of Sulfate Vein Minerals from the Opalinus Clay at Mont Terri*. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 7 pp.

Waber, H.N. and Oyama, T., 2000. *WS-A Experiment: Feasibility Study of Porewater Squeezing as a Function of Pressure*. MTP Technical Note TN 2000-23, International Mont Terri Project, St. Ursanne, Switzerland, 37 pp.

Waber, H.N. and Schürch, R., 2000. *WS-A Experiment: Fracture Mineralogy and Geochemistry as Constraints on Porewater Composition*. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 27pp.

Waber, H.N., 2002. *WS-B Experiment: Derivation of in-situ porewater compositions in the Opalinus Clay at Mont Terri, based on rock geochemical properties*. MTP Technical Note TN 99-24, International Mont Terri Project, St. Ursanne, Switzerland, 49 pp.

## MODELLING SULPHIDE FLUXES IN THE NEARFIELD OF HIGH-LEVEL WASTE REPOSITORIES

2016 - | Contact person: Paul Wersin, Peter Alt-Epping, Marek Pekala

We develop and apply reactive transport models for assessing sulphide fluxes and their impact on metal canister corrosion for different repository designs. We also support laboratory and in-situ tests being developed by our Finnish partners.

*Wersin, P., Jenni, Mäder U. (2014). ABM Experiment (Test Package 1): A feasibility study on iron-bentonite interaction in block 3, Nagra Arbeitsbericht NAB 14-24, Wettingen, Switzerland.*

*Wersin, P., Pitkänen, P., Alt-Epping, P., Román-Ross, G., Smith, P., Snellman, M., Trincherro, P., Filby, A., Kiczka, M., Sulphide Fluxes in the Spent Nuclear Fuel Repository at Olkiluoto, POSIVA Report 2014-1, Finland.*

*Wersin, P., Jenni A., Mäder U. (2015). Interaction of corroding iron with bentonite in the ABM1 experiment at Äspö, Sweden: a microscopic approach. Clays & Clay Minerals 63: 51-68.*

*Wersin, P., Alt-Epping, P., Pekala, M., Pitkänen, P., Snellman M.(accepted). Modelling sulfide fluxes and Cu canister corrosion rates in the engineered barrier system of a spent fuel repository. Procedia Earth Plan Sci.*

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## BENCHMARKING OF PORE-WATER CHARACTERISATION METHODS

2015 - | Contact persons: Martin Mazurek, Daniel Rufer

Rock samples are equilibrated with waters of known composition in diffusion cells and then extracted and analysed by various techniques.

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## CHARACTERISATION OF DIFFUSIVITY AND POREWATER IN A FRACTURE PROFILE, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)

2015 - | Contact person: H. Niklaus Waber

This project is a collaboration between Hydroisotop GmbH (Germany) and the University of Helsinki (Finland) and focuses on the comparison of transport parameters (accessible porosity, diffusion coefficients) derived by out-diffusion and through-diffusion experiments conducted on metamorphic crystalline rocks.

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## SIMULATION OF LONG-TERM DIFFUSION OF TRACERS IN OPALINUS CLAY (MONT TERRI DR-B EXPERIMENT)

2015 - | Contact person: Thomas Gimmi

Development of a new measurement technology for field tracer experiments and application of this technique to explore the long-term diffusion of a salt tracer in Opalinus Clay in the Mont Terri underground rock laboratory. RWI is one of several contributors to this project.

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### **DIFFUSION OF ANIONS IN CLAYSTONES (PHD C. WIGGER, ANPOR)**

2014 - | Contact person: Thomas Gimmi

Investigation of the diffusion of anions and notably the accessibility of the pore water to anions as a function of the ionic strength of the pore solution in various low-permeability rocks. In cooperation with the Laboratory for Waste Management LES, Paul Scherrer Institute.

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### **POROSITY AND STRUCTURAL CHANGES AT CEMENT/CLAY INTERFACES AND THEIR RELATION TO TRANSPORT PROPERTIES (PHD A. SHAFIZADEH)**

2012 - | Contact person: Thomas Gimmi

Investigation of changes of porosity and transport properties at cement/clay interfaces by tracer experiments and neutron imaging. In cooperation with the Laboratory for Waste Management LES, Paul Scherrer Institute.

*Shafizadeh, A., Gimmi, T., Van Loon, L., Kaestner, A., Lehmann, E., Maeder, U., Churakov, S. (2015). Quantification of water content across a cement-clay interface using high resolution neutron radiography,*

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### **ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING**

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

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### **BENTONITE UNDER DIFFERENT GEOCHEMICAL CONDITIONS**

2006 - | Contact person: Andreas Jenni

Infiltration of bentonite cores provides data increasing the fundamental understanding of chemical and mineralogical reactions, transport mechanisms, and mechanical response to changes in pore water.

*Alt-Epping, P., Tournassat, C., Rasouli, P., Steefel, C.I., Mayer, K.U., Jenni, A., Mäder, U., Sengor, S.S., Fernández, R., 2014. Benchmark reactive transport simulations of a column experiment in compacted bentonite with multispecies diffusion and explicit treatment of electrostatic effects. *Comput Geosci*, 1-16.*

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### **PORE WATER CHARACTERISATION - METHOD COMPARISON AND INVESTIGATION OF INTERFACE TO ADJACENT AQUIFER (NWMO PROJECT AND MONT TERRI DB-A EXPERIMENT)**

2013 - 2016 | Contact person: H. Niklaus Waber, Daniel Rufer

A detailed investigation of the geochemical boundary conditions in groundwaters and porewaters at the interface between Opalinus Clay and an adjacent aquifer encountered in the Passwang-Formation.

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## **EXPERIMENTAL CHARACTERIZATION AND QUANTIFICATION OF CEMENT-BENTONITE INTERACTION USING CORE INFILTRATION TECHNIQUES COUPLED WITH X-RAY TOMOGRAPHY (PHD F. DOLDER)**

2011 - 2015 | Contact person: Andreas Jenni, Urs Mäder

*Dolder, F., Mäder, U., Jenni, A., Schwendener, N., 2014. Experimental characterization of cement-bentonite interaction using core infiltration techniques and 4d computed tomography. Phys. Chem. Earth, Parts A/B/C 70-71, 104-113.*

*Dolder, F., Mäder, U., Jenni, A., Münch, B., in press. Alteration of MX-80 bentonite backfill material by high-pH cementitious fluids under lithostatic conditions - An experimental approach using core infiltration techniques. In: Radioactive Waste Confinement: Clays in Natural and Engineered Barriers, Geological Society Special Publications.*

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## **WATER-MONTMORILLONITE SYSTEMS: NEUTRON SCATTERING AND TRACER THROUGH-DIFFUSION STUDIES (PHD M. BESTEL)**

2009 - 2014 | Contact person: Thomas Gimmi

Distinguishing different water populations and relating it to water and Na<sup>+</sup> diffusion coefficients in clay samples, measured by tracer experiments and neutron time-of-flight analysis. In cooperation with the Laboratory for Neutron Scattering LNS and Laboratory for Waste Management LES, Paul Scherrer Institute.

*M. Bestel (2014). Water-montmorillonite systems: Neutron scattering and tracer through-diffusion studies. Dissertation, Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, May 2014.*

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## **ANISOTROPIC DIFFUSION OF A SUITE OF TRACERS IN OPALINUS CLAY (MONT TERRI DR EXPERIMENT)**

2006 - 2014 | Contact person: Thomas Gimmi, Paul Wersin

A 4-year multi-tracer field diffusion test in the Mont Terri underground rock laboratory aiming at determining the sorption and diffusion behavior, including the diffusion anisotropy, of a suite of tracers in Opalinus Clay at comparably low pore water salinity. RWI was one of several contributors to this project.

*Gimmi, T., Leupin, O.X., Eikenberg, J., Glaus, M.A., Van Loon, L.R., Waber, H.N., Wersin, P., Wang, H.A.O., Grolimund, D., Borca, C.N., Dewonck, S., Wittebroodt, C. (2014). Anisotropic diffusion at the field scale in a 4-year multi-tracer diffusion and retention experiment - I: Insights from the experimental data. Geochimica Et Cosmochimica Acta 125, 373-393, <http://dx.doi.org/10.1016/j.gca.2013.10.014>*

*Naves, A., J. Samper, T. Gimmi (2012). Identifiability of diffusion and sorption parameters from in situ diffusion experiments by using simultaneously tracer dilution and claystone data. Journal of Contaminant Hydrology, 142-143, 63-74, DOI: 10.1016/j.jconhyd.2012.09.005*

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## **POREWATER INVESTIGATIONS IN CRYSTALLINE ROCKS LOCATED IN PERMAFROST ENVIRONMENTS (THE GREENLAND ANALOGUE PROJECT)**

2011 - 2013 | Contact person: H. Niklaus Waber

*Eichinger, F. and Waber, H.N., 2013. Matrix Porewater in Crystalline Rocks: Extraction and Analysis. NWMO Technical Report TR 2013-23, NWMO, Toronto, Canada: 94 pp, available at [www.nwmo.ca](http://www.nwmo.ca).*

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## **POREWATER DRILLING FLUID CONTAMINATION PROJECT, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2010 - 2013 | Contact person: H. Niklaus Waber

The effect of possible contamination by drilling fluid of drillcore samples used for porewater investigations has been assessed by drilling with a traced drilling fluid and monitoring the elution of the tracer during out-diffusion. Embedded in a MSc Thesis (D.B. Meier), obtained results were used to quantify the changes induced by the drilling process of the derived transport parameters (accessible porosity, diffusion coefficients) of the different metamorphic rock types.

*Eichinger, F., Meier, D.B. and Waber, H.N., 2015. Matrix pore water in Olkiluoto bedrock from drilling OL-KR54 and OL-KR55 - Chemical and isotopic characterisation and evaluation of contamination by drilling fluid. Posiva Working Report WR 2014-66. Posiva Oy, Olkiluoto, Finland, 129 pp, available at [www.posiva.fi](http://www.posiva.fi).*

*Meier D.B., Waber, H.N., Gimmi, T., Eichinger, F. and Diamond, L.W., 2015. Reconstruction of in-situ porosity and porewater compositions of low-permeability crystalline rocks: Magnitude of artefacts induced by drilling and sample recovery. J Contam Hydrol 183: 55-71.*

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## **METHOD COMPARISON FOR POREWATER CHARACTERISATION TECHNIQUES, SC FORSMARK, SWEDEN (SKB SITE CHARACTERISATION PROJECT)**

2011 - 2012 | Contact person: H. Niklaus Waber

Extraction of porewater residing in the low-permeability rock matrix by out-diffusion has been compared to ultra-centrifugation approaches.

*Waber, H.N. and Smellie, J.A.T., 2012. Forsmark site characterisation. Borehole KFM22 and KFM23: Derivation of porewater data by diffusion experiments. SKB P-Report P-12-18, SKB, Stockholm, Sweden: 37 pp., available at [www.skb.se](http://www.skb.se).*

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## **HELIUM IN POREFLUIDS (SNF SCOPUS PROJECT)**

2002 - 2009 | Contact person: H. Niklaus Waber

This SNF-SCOPES project focused on the migration of helium from water into natural quartz crystals to elaborate a new dating technique for very old pore- and groundwaters.

*Lehmann B., Waber H.N. Tolstikhin I., Kamensky I. Gannibal M. Kalashnikov E. and Pevzner B., 2003. Helium in solubility equilibrium with quartz and porefluids in rocks - a new approach in hydrology. Geophys Res Letters 30: 1128-1131*

*Tolstikhin I., Gannibal M., Tarakanov S., Pevzner, B., Lehmann B.E., Ihly B. and Waber H.N., 2005. Helium transfer from water into quartz crystals: A new approach for porewater dating. Earth Planet Sci Lett 238: 31-41.*

*Tolstikhin I.N., Waber H.N. Kamensky I.L., Loosli H.H., Skiba V.I. and Gannibal M. A., 2011. Production, redistribution and loss of helium and argon isotopes in a thick sedimentary aquitard-aquifer system (Molasse Basin, Switzerland). Chem Geol 286: 48-58.*

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## **FIELD INVESTIGATION OF TRACER DIFFUSION IN OPALINUS CLAY (MONT TERRI DI-A2 EXPERIMENT)**

2001 - 2009 | Contact person: Paul Wersin, Thomas Gimmi

One-year field diffusion test in the Mont Terri underground rock laboratory aiming at determining the transport characteristics of mobile and sorbing tracers in Opalinus Clay. RWI was one of several contributors to this project.

*Wersin, P., Soler, J.M., Van Loon, L., Eikenberg, J., Baeyens, B., Grolimund, D., Gimmi, T., Dewonck, S. (2008). Diffusion of HTO, Br-, I-, Cs+, 85Sr2+ and 60Co2+ in a Clay Formation: Results and Modelling from an In Situ Experiment in Opalinus Clay. Applied Geochemistry 23 (4), 678-691*

*Soler, J.M., Wersin, P., Leupin, O.X., 2013. Modeling of Cs+ diffusion and retention in the DI-A2 experiment (Mont Terri). Uncertainties in sorption and diffusion parameters. Applied Geochemistry 33, 191-198*

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## **WATER DIFFUSION THROUGH COMPACTED CLAYS ANALYZED BY NEUTRON SCATTERING AND TRACER EXPERIMENTS (PHD F. GONZÁLEZ SÁNCHEZ)**

2004 - 2007 | Contact person: Thomas Gimmi

Comparing local diffusion coefficients in clay samples measured by quasi-elastic neutron scattering with macroscopic diffusion coefficients measured by HTO tracer experiments. In cooperation with the Laboratory for Neutron Scattering LNS and Laboratory for Waste Management LES, Paul Scherrer Institute.

*F. González Sánchez (2007). Water diffusion through compacted clays analyzed by neutron scattering and tracer experiments. Dissertation, Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, Nov. 2007.*

*González Sánchez, F., Jurányi, F., Van Loon, L., Gimmi, T. (2007). Translational diffusion of water in compacted clay systems. European Physical Journal-Special Topics 141, 65-68.*

*González Sánchez, F., Jurányi, F., Gimmi, T., Van Loon, L., Seydel, T., Unruh, T. (2008). Dynamics of supercooled water in highly compacted clays studied by neutron scattering. Journal of Physics-Condensed Matter 20(41), 415102, doi: 10.1088/0953-8984/20/41/415102*

*González Sánchez, F., Jurányi, F., Gimmi, T., Van Loon, L., Unruh, T., Diamond, L.W. (2008). Translational diffusion of water and its dependence on temperature in charged and uncharged clays: A neutron scattering study. Journal of Chemical Physics 129, 174706, DOI: 10.1063/1.3000638.*

*González Sánchez, F., Van Loon, L.R., Gimmi, T., Jakob, A., Glaus, M.A., Diamond, L.W. (2008). Self-diffusion of water and its dependence on temperature and ionic strength in highly compacted montmorillonite, illite and kaolinite. Applied Geochemistry 23, 3840-3851, doi:10.1016/j.apgeochem.2008.08.008*

*González Sánchez, F., Gimmi, T., Jurányi, F., Van Loon, L., Diamond, L.W. (2009). Linking the Diffusion of Water in Compacted Clays at Two Different Time Scales: Tracer Through-Diffusion and Quasielastic Neutron Scattering. Environmental Science & Technology 43, 3487-3493, DOI: 10.1021/es8035362*

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## **MATRIX FLUID CONTINUATION (MFC) PROJECT, ÄSPÖ URL, SWEDEN (ÄSPÖ MATRIX FLUID EXPERIMENT)**

2004 - 2006 | Contact person: H. Niklaus Waber

Continuation of the long-term groundwater sampling from very low-transmissive fractures and the long-term hydraulic monitoring of the fractures.

Waber H.N. and Smellie, J.A.T., 2008. Characterisation of pore water in crystalline rocks. *Appl Geochem* 23: 1834-1861.

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### **FIELD INVESTIGATION OF TRACER DIFFUSION IN OPALINUS CLAY (MONT TERRI DI-A1 EXPERIMENT)**

2000 - 2006 | Contact person: Paul Wersin, Thomas Gimmi

One-year field diffusion test in the Mont Terri underground rock laboratory aiming at determining the transport characteristics of mobile and sorbing tracers in Opalinus Clay. RWI was one of several contributors to this project.

*L.R. Van Loon, P. Wersin, J.M. Soler, J. Eikenberg, Th. Gimmi, P. Hernan, S. Dewonck, and S. Savoye (2004). In-situ diffusion of HTO,  $^{22}\text{Na}^+$ ,  $\text{Cs}^+$  and I- in Opalinus Clay at the Mont Terri underground rock laboratory. *Radiochim. Acta*, 92, 757-763*

*P. Wersin, L.R. Van Loon, J.M. Soler, A. Yllera, J. Eikenberg, Th. Gimmi, P. Hernán and J.-Y. Boisson (2004). Long-term diffusion experiment at Mont Terri: first results from field and laboratory data. *Applied Clay Science* 26(1-4), 123-135*

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### **MATRIX FLUID (MF) PROJECT, ÄSPÖ URL, SWEDEN (ÄSPÖ MATRIX FLUID EXPERIMENT)**

1999 - 2004 | Contact person: H. Niklaus Waber

The different types of pore fluid residing in the low-permeable matrix of crystalline rocks have been characterised including long-term groundwater sampling from very low-transmissive fractures and - for the first time - extraction of porewater residing in the connected pore space of the rock matrix.

*Smellie, J.A.T., Waber, H.N. and Frøpe, S.K., 2003. Matrix fluid chemistry experiment. Final Report. SKB Technical Report TR-03-18. SKB, Stockholm, Sweden, 377 pp., available at [www.skb.se](http://www.skb.se).*

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### **POREWATER INVESTIGATIONS AND GEOCHEMICAL CHARACTERISATION OF OPALINUS CLAY AT THE MONT TERRI URL (MONT TERRI WS-A & WS-B EXPERIMENTS)**

1998 - 2003 | Contact person: H. Niklaus Waber

Complementary to long-term seepage water collection indirect methods to extract porewater from the low-permeable Opalinus Clay were tested and supported by geochemical investigations on the rock.

*Waber, H.N., 1999. WS-B Experiment: Isotope Analyses of Sulfate Vein Minerals from the Opalinus Clay at Mont Terri. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 7 pp.*

*Waber, H.N. and Oyama, T., 2000. WS-A Experiment: Feasibility Study of Porewater Squeezing as a Function of Pressure. MTP Technical Note TN 2000-23, International Mont Terri Project, St. Ursanne, Switzerland, 37 pp.*

*Waber, H.N. and Schürch, R., 2000. WS-A Experiment: Fracture Mineralogy and Geochemistry as Constraints on Porewater Composition. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 27pp.*

*Waber, H.N., 2002. WS-B Experiment: Derivation of in-situ porewater compositions in the Opalinus Clay at Mont Terri based on rock geochemical properties. MTP Technical Note TN 99-24, International Mont Terri Project, St. Ursanne, Switzerland, 49 pp.*

## MODELLING SULPHIDE FLUXES IN THE NEARFIELD OF HIGH-LEVEL WASTE REPOSITORIES

2016 - | Contact person: Paul Wersin, Peter Alt-Epping, Marek Pekala

We develop and apply reactive transport models for assessing sulphide fluxes and their impact on metal canister corrosion for different repository designs. We also support laboratory and in-situ tests being developed by our Finnish partners.

*Wersin, P., Jenni, Mäder U. (2014). ABM Experiment (Test Package 1): A feasibility study on iron-bentonite interaction in block 3, Nagra Arbeitsbericht NAB 14-24, Wetingen, Switzerland.*

*Wersin, P., Pitkänen, P., Alt-Epping, P., Román-Ross, G., Smith, P., Snellman, M., Trincherro, P., Filby, A., Kiczka, M., Sulphide Fluxes in the Spent Nuclear Fuel Repository at Olkiluoto, POSIVA Report 2014-1, Finland.*

*Wersin, P., Jenni A., Mäder U. (2015). Interaction of corroding iron with bentonite in the ABM1 experiment at Äspö, Sweden: a microscopic approach. Clays & Clay Minerals 63: 51-68.*

*Wersin, P., Alt-Epping, P., Pekala, M., Pitkänen, P., Snellman M.(accepted). Modelling sulfide fluxes and Cu canister corrosion rates in the engineered barrier system of a spent fuel repository. Procedia Earth Plan Sci.*

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## MODELLING CHEMICAL-MECHANICAL COUPLING IN BENTONITE

2015 - | Contact person: Andreas Jenni, Paul Wersin

The challenging task of chemical-mechanical (CM) coupling in bentonite is assessed together with a team from the Universidad de Castilla-La Mancha by combining reactive transport and mechanical modelling.

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## SIMULATION OF LONG-TERM DIFFUSION OF TRACERS IN OPALINUS CLAY (MONT TERRI DR-B EXPERIMENT)

2015 - | Contact person: Thomas Gimmi

Development of a new measurement technology for field tracer experiments and application of this technique to explore the long-term diffusion of a salt tracer in Opalinus Clay in the Mont Terri underground rock laboratory. RWI is one of several contributors to this project.

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## EFFECT OF IONIC STRENGTH OF PORE SOLUTION ON ION TRANSPORT IN OPALINUS CLAY (MONT TERRI DR-A EXPERIMENT)

2011 - | Contact person: Thomas Gimmi, H. Niklaus Waber

A diffusion experiment in the Mont Terri underground rock laboratory intentionally perturbed by a high-ionic strength solution in order to provoke a reaction and test the modeling capability of various reactive transport codes on these data. RWI is one of several contributors to this project.

*Soler, J.M., Leupin, O.X., Gimmi, T., and Van Loon, L.R. (2014). The DR-A in-situ diffusion experiment at Mont Terri: Effects of changing salinity on diffusion and retention properties. Mater. Res. Soc. Symp. Proc., 1665, 63-69, DOI: 10.1557/opl.2014.629*

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## **BENCHMARKING REACTIVE TRANSPORT CODES: SUBSURFACE ENVIRONMENTAL SIMULATION BENCHMARKING WORKSHOP SERIES (SSBENCH)**

2011 - | Contact person: Peter Alt-Epping

SSBench is an initiative for benchmarking subsurface environmental simulation methods focusing on reactive transport processes. Since the kick-off meeting at LBNL in Berkeley, USA, in 2011, members of the RWI group at the University of Bern have proposed and/or participated in benchmark simulations for reactive transport codes.

*Mayer, K.U., Alt-Epping, P., Jacques, D., Arora, B., Steefel, C.I., 2015, Benchmark problems for reactive transport modeling of the generation and attenuation of acid rock drainage. Computational Geosciences. doi:10.1007/s10596-015-9476-9*

*Alt-Epping, P., Tournassat, C., Rasouli, P., Steefel, C. I., Mayer, K. U., Jenni, A., Mäder, U., Sengor, S. S., Fernandez, R., 2014, Benchmark reactive transport simulations of a column experiment in compacted bentonite with multispecies diffusion and explicit treatment of electrostatic effects. Computational Geosciences. doi:10.1007/s10596-014-9451-x*

*Wanner, C., Druhan, J., Amos, R., Alt-Epping, P., Steefel, C., 2014, Benchmarking the simulation of Cr isotope fractionation. Computational Geosciences 19, 497-521. doi:10.1007/s10596-014-9436-9*

*Xie, M., Mayer, K. U., Claret, F., Alt-Epping, P., Jacques, D., Steefel, C.I., Chiaberge, C., Simunek, J., 2014, Implementation and evaluation of permeability-porosity and tortuosity-porosity relationships linked to mineral dissolution-precipitation. Computational Geosciences. doi:10.1007/s10596-014-9458-3*

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## **ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING**

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

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## **UP-SCALING TRANSPORT COEFFICIENTS IN CLAYS**

2004 - | Contact person: Thomas Gimmi

Up-scaling of diffusion coefficients in clays from the atomistic to the continuum scale, and investigation of effects of sorbed but mobile cations on effective diffusion coefficients at the macroscopic scale in clays. Joint project with Laboratory for waste management LES, Paul Scherrer Institute.

*Churakov, S.V., and Th. Gimmi (2011). Up-scaling of molecular diffusion coefficients in clays: A two-scale approach. J. Phys. Chem. C, 115, 6703-6714, DOI: 10.1021/jp112325n*

*Gimmi, T., and G. Kosakowski (2011). How mobile are sorbed cations in clays and clay rocks? Environ. Sci. Technol. 2011, 45, 1443-1449. DOI: 10.1021/es1027794*

*Tyagi, M., T. Gimmi, S.V. Churakov (2013). Multi-scale micro-structure generation strategy for up-scaling transport in clays. Advances in Water Resources, 59, 181-195, DOI: 10.1016/j.advwatres.2013.06.002*

Altmann, S., Tournassat, C., Goutelard, F., Parneix, J-C., Gimmi, T., Maes, N., Diffusion-driven transport in clayrock formations. *Applied Geochemistry*, 27(2) (2012) 463-478, doi: 10.1016/j.apgeochem.2011.09.015

Churakov, S.V., Gimmi, T., Unruh, T., Van Loon, L.R., Juranyi, F. (2014). Resolving diffusion in clays at different timescales: Combination of experimental and modelling approaches. *Applied Clay Science* 96, 36-44. <http://dx.doi.org/10.1016/j.clay.2014.04.030>

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## **CEMENT - CLAY INTERACTION (MONT TERRI CI EXPERIMENT)**

2004 - | Contact person: Andreas Jenni

Long - term experiment providing time-resolved interface material of different cementitious materials, Opalinus Clay, and bentonite, the basis for multi-national development of novel analytical and modelling techniques.

Jenni, A., Mäder, U., Lerouge, C., Gaboreau, S., Schwyn, B., 2014. In situ interaction between different concretes and Opalinus Clay. *Phys. Chem. Earth, Parts A/B/C* 70-71, 71-83.

Jenni, A., Mäder, U., 2014. CI (cement clay interaction) experiment: SEM/EDX characterisation of concrete/Opalinus Clay interfaces from 2nd sampling campaign and comparison to state after 1st sampling, TN 2014-82, Mont Terri Project, St. Ursanne, Switzerland.

Dähn, R., Popov, D., Schaub, P., Pattison, P., Grolimund, D., Mäder, U., Jenni, A., Wieland, E., 2014. X-ray micro-diffraction studies of heterogeneous interfaces between cementitious materials and geological formations. *Phys. Chem. Earth, Parts A/B/C* 70-71, 96-103.

Mäder, U., 2006. CI experiment: Experimental design and technical implementation plan for the field experiment, TN 2006-27, Mont Terri Project, St. Ursanne, Switzerland.

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## **PREDICTION OF THE EVOLUTION OF MINERALOGY AND POREWATER COMPOSITION OF THE BUFFER AND BACKFILL SYSTEM AT OLKILUOTO**

2014 - 2016 | Contact person: Peter Alt-Epping, Paul Wersin

In this project we have constructed 3D reactive transport models of the near-field at Olkiluoto. The simulations involve coupled thermal, hydraulic and chemical processes and are aimed at gaining a better understanding of evolution of the system in terms of mineralogy and pore water composition.

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## **PREDICTION OF WATER/ROCK INTERACTION AND POROSITY EVOLUTION IN A GRANITOID-HOSTED ENHANCED GEOTHERMAL SYSTEM**

2012 - 2014 | Contact person: Peter Alt-Epping

We constructed reactive transport models of the (abandoned) enhanced geothermal system at Basel, Switzerland. The model was constrained by data collected during the drilling campaign. Simulations were carried to predict fluid-rock reactions in the granitoid host rock during stimulation and operation, permeability changes in the reservoir rock resulting from mineral dissolution/precipitation reactions, the risk of mineral scaling in the wells and surface installations and the implications of incipient corrosion.

Diamond, L.W., Alt-Epping, P., 2014, Predictive modelling of mineral scaling, corrosion and the performance of solute geothermometers in a granitoid-hosted, enhanced geothermal system. *Applied Geochemistry* 51, 216-228.

*Alt-Epping, P., Diamond, L.W., Häring, M. O., Ladner F., Meier, D. B., (2013), Prediction of water/rock interaction and porosity evolution in a granitoid-hosted enhanced geothermal system, using constraints from the 5 km Basel-1 well. Applied Geochemistry, 38, 121-133.*

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### **ANISOTROPIC DIFFUSION OF A SUITE OF TRACERS IN OPALINUS CLAY (MONT TERRI DR EXPERIMENT)**

2006 - 2014 | Contact person: Thomas Gimmi, Paul Wersin

A 4-year multi-tracer field diffusion test in the Mont Terri underground rock laboratory aiming at determining the sorption and diffusion behavior, including the diffusion anisotropy, of a suite of tracers in Opalinus Clay at comparably low pore water salinity. RWI was one of several contributors to this project.

*Gimmi, T., Leupin, O.X., Eikenberg, J., Glaus, M.A., Van Loon, L.R., Waber, H.N., Wersin, P., Wang, H.A.O., Grolimund, D., Borca, C.N., Dewonck, S., Wittebroodt, C. (2014). Anisotropic diffusion at the field scale in a 4-year multi-tracer diffusion and retention experiment - I: Insights from the experimental data. Geochimica Et Cosmochimica Acta 125, 373-393, <http://dx.doi.org/10.1016/j.gca.2013.10.014>*

*Naves, A., J. Samper, T. Gimmi (2012). Identifiability of diffusion and sorption parameters from in situ diffusion experiments by using simultaneously tracer dilution and claystone data. Journal of Contaminant Hydrology, 142-143, 63-74, DOI: 10.1016/j.jconhyd.2012.09.005*

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### **GEOTHERMAL WATER AT BAD BLUMAU, AUSTRIA (RWI RESEARCH PROJECT)**

2007 - 2008 | Contact person: H. Niklaus Waber

The thermal water supplying the spa at Bad Blumau was hydrochemically characterised and better understanding of its evolution and an improvement of its production was aimed at by applying geochemical modelling strategies. The models were used to constrain chemical and thermal properties of the reservoir and to predict the consequences of reinjecting a cooled, CO<sub>2</sub>-depleted fluid and of mineral scaling in the wells and surface installations, and to help find geochemical indicators of incipient corrosion.

*Waber, H.N., Alt-Epping, P. and Eichinger L., 2008. Hydrochemistry and geochemical modelling of thermal water, Bad Blumau, Austria. RWI Technical Report TR 08-01, Institute of Geological Sciences, University of Bern, Switzerland, 41 pp.*

*Alt-Epping P., Waber, H.N., Diamond L.W. and Eichinger L., 2013. Reactive transport modelling of the geothermal system at Bad Blumau, Austria: Implications of the combined extraction of heat and CO<sub>2</sub>. Geothermics 45: 18-30.*

## **FLUID INCLUSIONS IN MINERALS**

[\(website\)](#)

### **ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING**

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

## **BINDING STATE OF PORE WATER IN CLAY-RICH MEDIA (CLAYWAT, AN OECD/NEA PROJECT)**

2016 - | Contact persons: Martin Mazurek, Thomas Gimmi

Physical and chemical methods are evaluated regarding information on the binding state and mobility of H<sub>2</sub>O in the nanometric pore space of argillaceous rocks. An analytical campaign comparing formations in different states of induration is conducted, with the aim to elaborate a consistent description of effects and processes.

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## **MODELLING SULPHIDE FLUXES IN THE NEARFIELD OF HIGH-LEVEL WASTE REPOSITORIES**

2016 - | Contact person: Paul Wersin, Peter Alt-Epping, Marek Pekala

We develop and apply reactive transport models for assessing sulphide fluxes and their impact on metal canister corrosion for different repository designs. We also support laboratory and in-situ tests being developed by our Finnish partners.

*Wersin, P. Pitkänen, P., Alt-Epping, P., Román-Ross, G., Smith, P., Snellman, M., Trincherro, P., Filby, A., Kiczka, M., Sulphide Fluxes in the Spent Nuclear Fuel Repository at Olkiluoto, POSIVA Report 2014-1, Finland.*

*Wersin, P., Alt-Epping, P., Pekala, M., Pitkänen, P., Snellman M.(accepted). Modelling sulfide fluxes and Cu canister corrosion rates in the engineered barrier system of a spent fuel repository. Procedia Earth Plan Sci.*

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## **IDENTIFICATION OF GLACIAL MELTWATER IMPACT ON PORE WATER IN CRYSTALLINE ROCKS AT SAIMAA, SALPAUSSELKÄ, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2016 - | Contact person: H. Niklaus Waber

This project focuses on the identification of the penetration depth of glacial meltwater along different fracture networks into metamorphic crystalline rocks. At the chosen locality the glacier front remained stable for several hundreds of years during the LGM.

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## **GASES IN THE REPOSITORY (MONT TERRI FE-GAS EXPERIMENT)**

2016 - | Contact person: Yama Tomonaga, Paul Wersin

The evolution of gases and redox conditions are evaluated in the Full-scale Emplacement Experiment (FE) in the Mont Terri Rock Laboratory.

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## **WEATHERING AND DECOMPACTION OF OPALINUS CLAY: BOREHOLE AT LAUSEN, SWITZERLAND**

2015 - | Contact persons: Martin Mazurek, Paul Wersin

Effects of contact with meteoric water on the rock and its pore water are studied in a setting where Opalinus Clay is exposed on the surface. Effects of the infiltration of surficial waters along decompaction fractures are investigated.

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## **BENCHMARKING OF PORE-WATER CHARACTERISATION METHODS**

2015 - | Contact persons: Martin Mazurek, Daniel Rufer

Rock samples are equilibrated with waters of known composition in diffusion cells and then extracted and analysed by various techniques.

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## **ANALYSIS OF IRON-BENTONITE INTERFACES**

2013 - | Contact person: Paul Wersin, Jebril Hadi, Andreas Jenni

Iron-bentonite interaction is assessed by microscopic and spectroscopic methods on samples from the ABM Experiment at the Äspö Hard Rock Laboratory and the FEBEX-DP Experiment in the Grimsel Test Site (CH).

*Wersin, P., Jenni, Mäder U. (2014). ABM Experiment (Test Package 1): A feasibility study on iron-bentonite interaction in block 3, Nagra Arbeitsbericht NAB 14-24, Wettingen, Switzerland.*

*Wersin, P., Jenni A., Mäder U. (2015). Interaction of corroding iron with bentonite in the ABM1 experiment at Äspö, Sweden: a microscopic approach. Clays & Clay Minerals 63: 51-68.*

*Hadi, J., Wersin, P., Jenni, A., Svensson, D., Sellin, P. & Leupin, O. (2015) Iron-Clay Redox Interactions in the ABM2 Experiment (Aspö, Sweden). Goldschmidt Abstracts 2015, 1142.*

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## **MODELLING CHEMICAL-MECHANICAL COUPLING IN BENTONITE**

2015 - | Contact person: Andreas Jenni, Paul Wersin

The challenging task of chemical-mechanical (CM) coupling in bentonite is assessed together with a team from the Universidad de Castilla-La Mancha by combining reactive transport and mechanical modelling.

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## **ANALYSIS OF SULPHATE AND CARBONATE MINERALS IN OPALINUS CLAY (MONT TERRI GD EXPERIMENT)**

2015 - | Contact person: Paul Wersin, Marek Pekala

The mineral chemistry of carbonate and sulphate minerals in the Opalinus Clay in the Mont Terri Rock Laboratory (GD Experiment) is investigated.

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## **CHARACTERISATION OF DIFFUSIVITY AND POREWATER IN A FRACTURE PROFILE, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2015 - | Contact person: H. Niklaus Waber

This project is a collaboration between Hydroisotop GmbH (Germany) and the University of Helsinki (Finland) and focuses on the comparison of transport parameters (accessible porosity, diffusion coefficients) derived by out-diffusion and through-diffusion experiments conducted on metamorphic crystalline rocks.

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## **SIMULATION OF LONG-TERM DIFFUSION OF TRACERS IN OPALINUS CLAY (MONT TERRI DR-B EXPERIMENT)**

2015 - | Contact person: Thomas Gimmi

Development of a new measurement technology for field tracer experiments and application of this technique to explore the long-term diffusion of a salt tracer in Opalinus Clay in the Mont Terri underground rock laboratory. RWI is one of several contributors to this project.

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## **DIFFUSION OF ANIONS IN CLAYSTONES (PHD C. WIGGER, ANPOR)**

2014 - | Contact person: Thomas Gimmi

Investigation of the diffusion of anions and notably the accessibility of the pore water to anions as a function of the ionic strength of the pore solution in various low-permeability rocks. In cooperation with the Laboratory for Waste Management LES, Paul Scherrer Institute.

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## **DEVELOPMENT OF THE SQUEEZING METHOD OF PORE-WATER EXTRACTION**

2013 - | Contact person: Martin Mazurek

Quantities of pore water sufficient for chemical and isotopic analysis can be extracted from clays and shales by applying lithostatic pressures of 100-500 MPa. In collaboration with CRIEPI (Japan), the method is being further developed, and the results are evaluated by comparison with data obtained from independent methods.

*Mazurek, M., Oyama, T., Eichinger, F. & De Haller, A. (2013): Squeezing of pore water from core samples of DGR boreholes: Feasibility study. NWMO TR-2013-19, Nuclear Waste Management Organization, Toronto, Canada.*

*Mazurek, M., Oyama, T., Wersin, P. & Alt-Epping, P. (2015): Pore-water squeezing from indurated shales. Chemical Geology 400, 106-121.*

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## **POROSITY AND STRUCTURAL CHANGES AT CEMENT/CLAY INTERFACES AND THEIR RELATION TO TRANSPORT PROPERTIES (PHD A. SHAFIZADEH)**

2012 - | Contact person: Thomas Gimmi

Investigation of changes of porosity and transport properties at cement/clay interfaces by tracer experiments and neutron imaging. In cooperation with the Laboratory for Waste Management LES, Paul Scherrer Institute.

*Shafizadeh, A., Gimmi, T., Van Loon, L., Kaestner, A., Lehmann, E., Maeder, U., Churakov, S. (2015). Quantification of water content across a cement-clay interface using high resolution neutron radiography,*

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## **EFFECT OF IONIC STRENGTH OF PORE SOLUTION ON ION TRANSPORT IN OPALINUS CLAY (MONT TERRI DR-A EXPERIMENT)**

2011 - | Contact person: Thomas Gimmi, H. Niklaus Waber

A diffusion experiment in the Mont Terri underground rock laboratory intentionally perturbed by a high-ionic strength solution in order to provoke a reaction and test the modeling capability of various reactive transport codes on these data. RWI is one of several contributors to this project.

*Soler, J.M., Leupin, O.X., Gimmi, T., and Van Loon, L.R. (2014). The DR-A in-situ diffusion experiment at Mont Terri: Effects of changing salinity on diffusion and retention properties. Mater. Res. Soc. Symp. Proc., 1665, 63-69, DOI: 10.1557/opl.2014.629*

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## **ROCK AND POREWATER CHARACTERISATION ON DRILLCORES FROM THE DEEP BOREHOLE OF SCHLATTINGEN, SWITZERLAND**

2011 - | Contact person: Paul Wersin, Martin Mazurek, H. Niklaus Waber, Daniel Rufer

The geochemistry, mineralogy and gas composition in Opalinus Clay and other claystones are investigated.

*Wersin, P., Mazurek, M., Mäder, U.K., Gimmi, T., Rufer, D., Lerouge, C., Traber, D., 2016. Constraining porewater chemistry in a 250 m thick argillaceous rock sequence. Chemical Geology 434, 43-61.*

*Wersin, P., Mazurek, M., Waber, H.N., Mäder, U.K., Gimmi, T., Rufer, D., de Haller, A., 2013. Rock and porewater characterisation on drillcores from the Schlattingen borehole. Nagra Arbeitsbericht NAB 12-54.*

*Mazurek, M., Oyama, T., Wersin, P., Alt-Epping, P., 2015. Pore-water squeezing from indurated shales. Chem. Geol. 400, 106-121.*

*Wersin, P., Waber, H.N., Mazurek, M., Mäder, U.K., Gimmi, T., Rufer, D., Traber, D., 2013. Resolving Cl and SO<sub>4</sub> profiles in a clay-rich rock sequence. Procedia Earth and Planetary Science 7, 892 - 895.*

*Rufer, D. and Waber, H.N. (2015): Noble and reactive gas data of porewaters and rocks from the Schlattingen borehole SLA-1. NAGRA ARBEITSBERICHT NAB 15-12, Nagra, Wettingen*

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## **ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING**

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

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## BENTONITE UNDER DIFFERENT GEOCHEMICAL CONDITIONS

2006 - | Contact person: Andreas Jenni

Infiltration of bentonite cores provides data increasing the fundamental understanding of chemical and mineralogical reactions, transport mechanisms, and mechanical response to changes in pore water.

*Alt-Epping, P., Tournassat, C., Rasouli, P., Steefel, C.I., Mayer, K.U., Jenni, A., Mäder, U., Sengor, S.S., Fernández, R., 2014. Benchmark reactive transport simulations of a column experiment in compacted bentonite with multispecies diffusion and explicit treatment of electrostatic effects. Comput Geosci, 1-16.*

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## UP-SCALING TRANSPORT COEFFICIENTS IN CLAYS

2004 - | Contact person: Thomas Gimmi

Up-scaling of diffusion coefficients in clays from the atomistic to the continuum scale, and investigation of effects of sorbed but mobile cations on effective diffusion coefficients at the macroscopic scale in clays. Joint project with Laboratory for waste management LES, Paul Scherrer Institute.

*Churakov, S.V., and Th. Gimmi (2011). Up-scaling of molecular diffusion coefficients in clays: A two-scale approach. J. Phys. Chem. C, 115, 6703-6714, DOI: 10.1021/jp112325n*

*Gimmi, T., and G. Kosakowski (2011). How mobile are sorbed cations in clays and clay rocks? Environ. Sci. Technol. 2011, 45, 1443-1449. DOI: 10.1021/es1027794*

*Tyagi, M., T. Gimmi, S.V. Churakov (2013). Multi-scale micro-structure generation strategy for up-scaling transport in clays. Advances in Water Resources, 59, 181-195, DOI: 10.1016/j.advwatres.2013.06.002*

*Altmann, S., Tournassat, C., Goutelard, F., Parneix, J-C., Gimmi, T., Maes, N., Diffusion-driven transport in clayrock formations. Applied Geochemistry, 27(2) (2012) 463-478, doi: 10.1016/j.apgeochem.2011.09.015*

*Churakov, S.V, Gimmi, T., Unruh, T., Van Loon, L.R., Juranyi, F. (2014). Resolving diffusion in clays at different timescales: Combination of experimental and modelling approaches. Applied Clay Science 96, 36-44. <http://dx.doi.org/10.1016/j.clay.2014.04.030>*

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## CEMENT - CLAY INTERACTION (MONT TERRI CI EXPERIMENT)

2004 - | Contact person: Andreas Jenni

Long - term experiment providing time-resolved interface material of different cementitious materials, Opalinus Clay, and bentonite, the basis for multi-national development of novel analytical and modelling techniques.

*Jenni, A., Mäder, U., Lerouge, C., Gaboreau, S., Schwyn, B., 2014. In situ interaction between different concretes and Opalinus Clay. Phys. Chem. Earth, Parts A/B/C 70-71, 71-83.*

*Jenni, A., Mäder, U., 2014. CI (cement clay interaction) experiment: SEM/EDX characterisation of concrete/Opalinus Clay interfaces from 2nd sampling campaign and comparison to state after 1st sampling, TN 2014-82, Mont Terri Project, St. Ursanne, Switzerland.*

*Dähn, R., Popov, D., Schaub, P., Pattison, P., Grolimund, D., Mäder, U., Jenni, A., Wieland, E., 2014. X-ray micro-diffraction studies of heterogeneous interfaces between cementitious materials and geological formations. Phys. Chem. Earth, Parts A/B/C 70-71, 96-103.*

Mäder, U., 2006. *CI experiment: Experimental design and technical implementation plan for the field experiment, TN 2006-27, Mont Terri Project, St. Ursanne, Switzerland.*

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## **HYDROCHEMISTRY, RESIDENCE TIME, GEOCHEMICAL EVOLUTION, AND FLOW PATHS OF GROUNDWATER IN NORTHERN SWITZERLAND AND SURROUNDING AREAS (NAGRA HYDROCHEMISTRY PROGRAM)**

2000 - | Contact person: H. Niklaus Waber

*Waber, H.N., 2001. Hydrochemie. In: Nagra (2001) Sondierbohrung Benken Untersuchungsbericht. Nagra Technischer Bericht 00-01. Nagra Wettingen, Schweiz, 217-246*

*Waber, H.N., Gimmi, T., Pearson, F.J. and Gautschi, A., 2002. Hydrochemische und isotopehydrologische Charakterisierung der Grund- und Porenwässer. In: Nagra (2002) Projekt Opalinuston: Synthese der geowissenschaftlichen Untersuchungen. Nagra Technischer Bericht 02-03. Nagra, Wettingen, Schweiz, 195-211.*

*Nagra, 2014. SGT2, Geologische Grundlagen Dossier V: Hydrogeologische Verhältnisse. Nagra Technischer Bericht NTB 14-02. Nagra, Wettingen, Schweiz, 117 pp.*

*Waber, H.N., Heidinger, M., Lorenz, G. and Traber, D., 2014. Hydrochemie und Isotopenhydrogeologie von Tiefengrundwässern in der Nordschweiz und im angrenzenden Süddeutschland. Nagra Arbeitsbericht 13-63. Nagra, Wettingen, Switzerland, 247 pp.*

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## **PORE WATER CHARACTERISATION - METHOD COMPARISON AND INVESTIGATION OF INTERFACE TO ADJACENT AQUIFER (NWMO PROJECT AND MONT TERRI DB-A EXPERIMENT)**

2013 - 2016 | Contact person: H. Niklaus Waber, Daniel Rufer

A detailed investigation of the geochemical boundary conditions in groundwaters and porewaters at the interface between Opalinus Clay and an adjacent aquifer encountered in the Passwang-Formation.

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## **EVALUATION AND COMPARISON OF PORE-WATER EXTRACTION TECHNIQUES IN ARGILLACEOUS ROCKS (MONT TERRI DB-A EXPERIMENT)**

2015 - 2016 | Contact person: Martin Mazurek

Five laboratories sampled rock cores from a 250 m long borehole at Mont Terri, with the aim to characterise the chemical and isotopic composition of pore water. The results are compared, and observed differences are rationalised.

*Mazurek, M., Al, T., Celejewski, M., Clark, I. D., Fernandez, A. M., Kennell-Morrison, L., Matray, J. M., Murseli, S., Oyama, T., Qiu, S., Rufer, D., St-Jean, G., Waber, H. N. & Yu, C. (2016): Mont Terri Project: Comparison of pore-water investigations conducted by several laboratories on materials from the BDB-1 borehole. Mont Terri Technical Report, Mont Terri Consortium, St. Ursanne, Switzerland (in press).*

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## **SHOTCRETE - OPALINUS CLAY INTERFACE (MONT TERRI FE EXPERIMENT)**

2015 - 2016 | Contact person: Andreas Jenni

The interface of a shotcrete applied to the Opalinus Clay tunnel wall under real conditions is characterised, and can be compared with interfaces from more constrained experiments.

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## **PREDICTION OF THE EVOLUTION OF MINERALOGY AND POREWATER COMPOSITION OF THE BUFFER AND BACKFILL SYSTEM AT OLKILUOTO**

2014 - 2016 | Contact person: Peter Alt-Epping, Paul Wersin

In this project we have constructed 3D reactive transport models of the near-field at Olkiluoto. The simulations involve coupled thermal, hydraulic and chemical processes and are aimed at gaining a better understanding of evolution of the system in terms of mineralogy and pore water composition.

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## **FURTHER DEVELOPMENT OF THE DIFFUSIVE-EXCHANGE TECHNIQUE TO ANALYSE THE ISOTOPIC COMPOSITION OF PORE WATERS**

2012 - 2016 | Contact person: Martin Mazurek

While this technique is well established in the study of low-salinity environments, various adaptations are needed in order to make the method applicable to brine systems, such as those encountered in the Palaeozoic sedimentary sequence of southern Ontario.

*De Haller, A., Hobbs, M. & Spangenberg, J. E. (in review by Chemical Geology): Adapting the diffusive exchange method for stable isotope analysis of pore water to brine-saturated rocks.*

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## **PALAEOHYDROGEOLOGICAL EVOLUTION AND SELF-SEALING OF FAULTS (MONT TERRI SF EXPERIMENT)**

2010 - 2016 | Contact person: Martin Mazurek

Fluid evolution is investigated using knowledge about current pore-water composition and its spatial distribution, together with signatures of palaeo-fluids recorded in veins. The data are integrated with independent information on the regional geological evolution and erosion history.

*De Haller, A., Mazurek, M., Spangenberg, J., Möri, A. (2014): SF (Self-sealing of faults and paleo-fluid flow): Synthesis report. Mont Terri Technical Report 2008-02, Mont Terri Consortium, St. Ursanne, Switzerland.*

*Mazurek, M. & De Haller, A. (in press): Pore-water evolution and solute-transport mechanisms in Opalinus Clay at Mont Terri and Mont Russelin (Canton Jura, Switzerland). Swiss Journal of Geosciences.*

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## **EXPERIMENTAL CHARACTERIZATION AND QUANTIFICATION OF CEMENT-BENTONITE INTERACTION USING CORE INFILTRATION TECHNIQUES COUPLED WITH X-RAY TOMOGRAPHY (PHD F. DOLDER)**

2011 - 2015 | Contact person: Andreas Jenni, Urs Mäder

*Dolder, F., Mäder, U., Jenni, A., Schwendener, N., 2014. Experimental characterization of cement-bentonite interaction using core infiltration techniques and 4d computed tomography. Phys. Chem. Earth, Parts A/B/C 70-71, 104-113.*

*Dolder, F., Mäder, U., Jenni, A., Münch, B., in press. Alteration of MX-80 bentonite backfill material by high-pH cementitious fluids under lithostatic conditions - An experimental approach using core infiltration techniques. In: Radioactive Waste Confinement: Clays in Natural and Engineered Barriers, Geological Society Special Publications.*

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## **CHARACTERISATION OF DEEP-SEATED MATRIX PORE WATER, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2011 - 2015 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of metamorphic crystalline rocks has been extracted from rock samples from a 1000 m deep borehole by diffusion experiments. Obtained results were used to elaborate the palaeo-hydrogeological evolution of the site with a main focus of possibly upconing saline water.

*Eichinger, F., Rufer, D. and Waber, H.N., 2015. Matrix Porewater and Gases in Porewater in Olkiluoto Bedrock from Drilling OL-KR56. Posiva Working Report WR 2015-xx. Posiva Oy, Olkiluoto, Finland, 100 pp, available at [www.posiva.fi](http://www.posiva.fi).*

*Rufer, D., Waber, H.N., Eichinger, F. and Pitkänen, P. (accepted). Helium in porewater and rocks of crystalline bedrock from the Fennoscandian Shield, Olkiluoto (Finland). Procedia Earth Plan Sci.*

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## **SYNTHESIS OF PALAEOHYDROGEOLOGICAL EVOLUTION OF THE OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2010 - 2014 | Contact person: H. Niklaus Waber

This project synthesised the insights gained so far about the palaeohydrogeological evolution of the Olkiluoto site based on data obtained from geological, hydrochemical, hydraulic and porewater investigations.

*Smellie, J.A.T., Pitkänen, P., Koskinen, L., Aaltonen, I., Eichinger, F., Waber, H.N., Sahlstedt, E., Siitari-Kauppi, M., Karhu, J., Löfman, J. and Poteri, A. (2014). Evolution of the Olkiluoto Site: Palaeohydrogeochemical Considerations. Posiva Working Report WR 2014-27. Posiva Oy, Olkiluoto, Finland, 222 pp., available at [www.posiva.fi](http://www.posiva.fi).*

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## **WATER-MONTMORILLONITE SYSTEMS: NEUTRON SCATTERING AND TRACER THROUGH-DIFFUSION STUDIES (PHD M. BESTEL)**

2009 - 2014 | Contact person: Thomas Gimmi

Distinguishing different water populations and relating it to water and Na<sup>+</sup> diffusion coefficients in clay samples, measured by tracer experiments and neutron time-of-flight analysis. In cooperation with the Laboratory for Neutron Scattering LNS and Laboratory for Waste Management LES, Paul Scherrer Institute.

*M. Bestel (2014). Water-montmorillonite systems: Neutron scattering and tracer through-diffusion studies. Dissertation, Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, May 2014.*

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## **ANISOTROPIC DIFFUSION OF A SUITE OF TRACERS IN OPALINUS CLAY (MONT TERRI DR EXPERIMENT)**

2006 - 2014 | Contact person: Thomas Gimmi, Paul Wersin

A 4-year multi-tracer field diffusion test in the Mont Terri underground rock laboratory aiming at determining the sorption and diffusion behavior, including the diffusion anisotropy, of a suite of tracers in Opalinus Clay at comparably low pore water salinity. RWI was one of several contributors to this project.

*Gimmi, T., Leupin, O.X., Eikenberg, J., Glaus, M.A., Van Loon, L.R., Waber, H.N., Wersin, P., Wang, H.A.O., Grolimund, D., Borca, C.N., Dewonck, S., Wittebroodt, C. (2014). Anisotropic diffusion at the field scale in a 4-year multi-tracer diffusion and retention experiment - I: Insights from the experimental data. *Geochimica Et Cosmochimica Acta* 125, 373-393, <http://dx.doi.org/10.1016/j.gca.2013.10.014>*

*Naves, A., J. Samper, T. Gimmi (2012). Identifiability of diffusion and sorption parameters from in situ diffusion experiments by using simultaneously tracer dilution and claystone data. *Journal of Contaminant Hydrology*, 142-143, 63-74, DOI: 10.1016/j.jconhyd.2012.09.005*

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## **POREWATER INVESTIGATIONS IN CRYSTALLINE ROCKS LOCATED IN PERMAFROST ENVIRONMENTS (THE GREENLAND ANALOGUE PROJECT)**

2011 - 2013 | Contact person: H. Niklaus Waber

*Eichinger, F. and Waber, H.N., 2013. Matrix Porewater in Crystalline Rocks: Extraction and Analysis. NWMO Technical Report TR 2013-23, NWMO, Toronto, Canada: 94 pp, available at [www.nwmo.ca](http://www.nwmo.ca).*

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## **POREWATER DRILLING FLUID CONTAMINATION PROJECT, OLKILUOTO SITE, FINLAND (POSIVA SITE CHARACTERISATION PROJECT)**

2010 - 2013 | Contact person: H. Niklaus Waber

The effect of possible contamination by drilling fluid of drillcore samples used for porewater investigations has been assessed by drilling with a traced drilling fluid and monitoring the elution of the tracer during out-diffusion. Embedded in a MSc Thesis (D.B. Meier), obtained results were used to quantify the changes induced by the drilling process of the derived transport parameters (accessible porosity, diffusion coefficients) of the different metamorphic rock types.

Eichinger, F., Meier, D.B. and Waber, H.N., 2015. Matrix pore water in Olkiluoto bedrock from drilling OL-KR54 and OL-KR55 - Chemical and isotopic characterisation and evaluation of contamination by drilling fluid. Posiva Working Report WR 2014-66. Posiva Oy, Olkiluoto, Finland, 129 pp, available at [www.posiva.fi](http://www.posiva.fi).

Meier D.B., Waber, H.N., Gimmi, T., Eichinger, F. and Diamond, L.W., 2015. Reconstruction of in-situ porosity and porewater compositions of low-permeability crystalline rocks: Magnitude of artefacts induced by drilling and sample recovery. *J Contam Hydrol* 183: 55-71.

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## **GEOCHEMICAL CHARACTERISATION OF THE EFFINGEN MEMBER AND ITS PORE WATERS**

2008 - 2013 | Contact person: Martin Mazurek, H. Niklaus Waber

Understanding the interactions between rock, pore and ground water in a sequence of interlayered marls and limestones.

Mazurek, M., Waber, H.N., Mäder, U.K., Gimmi, T., De Haller, A. & Koroleva, M. (2012). *Geochemical synthesis for the Effingen Member in boreholes at Oftringen, Gösigen and Küttigen. Nagra Technical Report NTB 12-07, Nagra, Wettingen, Switzerland.*

Klump, S., Waber, H.N., Koroleva, M., Eichinger, L., Lorenz, G., Albert, W., Frieg, B. and Gautschi, A., 2008. *EWS-Bohrungen Küttigen - Synthese der geologischen und hydrogeologischen Untersuchungen. Nagra Arbeitsbericht 08-12. Nagra, Wettingen, Schweiz, 50 pp.*

Waber, H.N., 2008. *Borehole Oftringen: Mineralogy, Porosimetry, Geochemistry, Pore Water Chemistry. Nagra Arbeitsbericht 08-18. H. N. Waber. Wettingen, Switzerland, Nagra: 276.*

De Haller, A., Tarantola, A., Mazurek, M. & Spangenberg, J. (2011): *Fluid flow through the sedimentary cover in northern Switzerland recorded by calcite-celestite veins (Oftringen borehole, Olten). Swiss Journal of Geosciences 104, 493 - 506.*

Waber, H.N., Mäder, U., Mazurek, M. and Koroleva, M., 2012. *Borehole Gösigen KB5a: Mineralogy, Porosimetry and Pore Water Chemistry of the Effingen Member. Nagra Arbeitsbericht 09-20, Nagra, Wettingen, Schweiz, 72 pp.*

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## **METHOD COMPARISON FOR POREWATER CHARACTERISATION TECHNIQUES, SC FORSMARK, SWEDEN (SKB SITE CHARACTERISATION PROJECT)**

2011 - 2012 | Contact person: H. Niklaus Waber

Extraction of porewater residing in the low-permeability rock matrix by out-diffusion has been compared to ultra-centrifugation approaches.

Waber, H.N. and Smellie, J.A.T., 2012. *Forsmark site characterisation. Borehole KFM22 and KFM23: Derivation of porewater data by diffusion experiments. SKB P-Report P-12-18, SKB, Stockholm, Sweden: 37 pp., available at [www.skb.se](http://www.skb.se).*

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## **PORE-WATER STUDIES IN THE PALAEOZOIC SEQUENCE OF SOUTHERN ONTARIO, CANADA**

2006 - 2011 | Contact person: Martin Mazurek

Characterisation of brines in the Devonian to Cambrian sequence, based on core materials from deep boreholes drilled by NWMO.



Clark, I.D., Al, T., Jensen, M., Kennell, L., Mazurek, M., Mohapatra, R. & Raven, K.G. (2013): Paleozoic-aged brine and authigenic helium preserved in an Ordovician shale aquiclude. *Geology*, doi:10.1130/G34372.1

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## **INTERPRETATION AND MODELLING OF NATURAL TRACER PROFILES ACROSS ARGILLACEOUS ROCKS (CLAYTRAC, AN OECD/NEA PROJECT)**

2005 - 2011 | Contact person: Martin Mazurek

Existing data pertinent to conservative tracers in pore waters from 9 sites are evaluated and modelled. Objectives are the identification of the dominant solute-transport process and the use of tracer data as archives of the palaeo-hydrogeological evolution.

*Mazurek, M., Alt-Epping, P., Bath, A., Gimmi, T. & Waber, H. N. 2009: Natural tracer profiles across argillaceous formations: The CLAYTRAC project. OECD/NEA report 6253, OECD Nuclear Energy Agency, Paris, France, 358 pp.*

*Mazurek, M., Alt-Epping, P., Bath, A., Gimmi, T., Waber, H. N., Buschaert, S., De Cannière, P., De Craen, M., Gautschi, A., Savoye, S., Vinsot, A., Wemaere, I. & Wouters, L. 2011: Natural tracer profiles across argillaceous formations. *Applied Geochemistry* 26, 1035 - 1064*

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## **POREWATER INVESTIGATIONS IN THE PARIS BASIN AT THE SITE MEUSE-HAUTE MARNE II (ANDRA SITE INVESTIGATION PROJECT)**

2008 - 2010 | Contact person: H. Niklaus Waber

Conservative parameters of the porewater (Cl, Br,  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , He) residing in the pore space of low-permeability sedimentary rocks have been determined by indirect methods based on drillcore material from a 2000 m deep borehole. Obtained results were used to elaborate the solute transport across the entire Mesozoic sedimentary sequence in the Paris basin and the palaeo-hydrogeological evolution.

*Waber, H.N., 2012. Laboratoire de Recherche Souterrain Meuse / Haute-Marne - Geochemical Data of Borehole EST433. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 86 pp.*

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## **POREWATER INVESTIGATIONS AT OLKILUOTO SITE, FINLAND (PHD F. EICHINGER; POSIVA SITE CHARACTERISATION PROJECT)**

2005 - 2010 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of metamorphic crystalline rocks has been extracted from rock samples of 3 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeo-hydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

*Eichinger, F., Waber, H.N. and Smellie, J.A.T. (2006). Characterisation of Matrix Pore Water at the Olkiluoto Investigations Site, Finland. Posiva Working Report WR 2006-103. Posiva Oy, Olkiluoto, Finland, 161 pp, available at [www.posiva.fi](http://www.posiva.fi).*

*Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. and Smellie, J.A.T., 2010. Characterisation of Matrix Pore Water and Fluid Inclusions in Olkiluoto Bedrock from Drilling OL-KR47. Posiva Working Report WR 2010-58. Posiva Oy, Olkiluoto, Finland, 140 pp, available at [www.posiva.fi](http://www.posiva.fi).*

Eichinger, F., Hämmerli, J., Waber, H.N., Diamond, L.W. and Smellie, J.A.T., 2013. Chemistry and dissolved gases of matrix pore water and fluid inclusions in Olkiluoto bedrock from drillhole ONK-PH9. Posiva Working Report WR 2011-63. Posiva Oy, Olkiluoto, Finland, 168 pp, available at [www.posiva.fi](http://www.posiva.fi).

Eichinger, F., Waber, H.N. and Smellie, J.A.T., 2013. Matrix pore water in low-permeable crystalline bedrock: An archive for the palaeohydrogeological evolution of the Olkiluoto Investigation Site. *Proceedings of Isotopes in Hydrology, marine ecosystems and climate change studies Vol. 1, Monaco 27 March-1 April 2011, IAEA, Vienna: 73-82.*

Eichinger, F., Waber, H.N. and Smellie, J.A.T., 2013. Origin and evolution of reactive and noble gases dissolved in matrix pore water. *Proceedings of Isotopes in Hydrology, marine ecosystems and climate change studies Vol. 2, Monaco 27 March-1 April 2011, IAEA, Vienna: 99-107.*

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### **STUDY OF NATURAL TRACER PROFILES IN OPALINUS CLAY OF THE MONT RUSSELIN TUNNEL (IN THE FRAME OF THE EU FP6 FUNMIG PROJECT & MONT TERRI NT EXPERIMENT)**

2005 - 2010 | Contact person: Martin Mazurek

Data acquisition, interpretation and modelling of tracer profiles in the frame of the FP6 FUNMIG Project

*Koroleva, M., Alt-Epping, P. & Mazurek, M. (2011): Large-scale tracer profiles in a deep claystone formation (Opalinus Clay at Mont Russelin, Switzerland): implications for solute transport processes and transport properties of the rock. Chemical Geology 280, 284 - 296*

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### **POREWATER INVESTIGATIONS AT FORSMARK SITE, SWEDEN (SKB SITE INVESTIGATION PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of crystalline rocks has been extracted from rock samples of 5 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeohydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

*Waber H.N., Gimmi T. and Smellie, J.A.T., 2011. Effects of drilling and stress release on hydraulic properties and porewater chemistry of crystalline rocks. J Hydrol 405: 316-332.*

*Waber, H.N., Gimmi, T. and Smellie, J.A.T., 2009. Porewater in the rock matrix. SDM-Site Forsmark. SKB R-Report R-09-14, SKB, Stockholm, Sweden: 107 pp., available at [www.skb.se](http://www.skb.se).*

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### **GROUNDWATER HYDROGEOCHEMICAL INVESTIGATIONS AT FORSMARK SITE, SWEDEN (SKB, CHEMNET PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Groundwater circulating in the fracture networks of crystalline rocks have been analysed for their chemical, isotope and gas composition. Obtained results were used in combination with porewater data and hydraulic models to elaborate the regional hydrogeological evolution at Forsmark.

*Smellie, J.A.T., Tullborg, E.-L., Nilsson, A.C., Sandström, B., Waber, H.N., Gimeno, M. and Gascoyne, M., 2008. Explorative analyses of major components and isotopes. SDM Site Forsmark. SKB R-Report R-08-84, SKB, Stockholm, Sweden: 287 pp., available at [www.skb.se](http://www.skb.se).*

*Laaksoharju, M., Smellie, J.A.T., Tullborg, E.-L., Gimeno, M., Hallbeck, L., Molinero, J. and Waber, H.N., 2008. Bedrock hydrogeochemistry Forsmark. SDM Site Forsmark. SKB R-Report R-08-47, SKB, Stockholm, Sweden: 157 pp., available at [www.skb.se](http://www.skb.se).*

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#### **POREWATER INVESTIGATIONS AT LAXEMAR SITE, SWEDEN (SKB SITE INVESTIGATION PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Porewater residing in the low-permeable matrix of crystalline rocks has been extracted from rock samples of 4 deep boreholes by diffusion experiments. Obtained results were used to elaborate the palaeo-hydrogeological evolution of the site, the effectiveness of matrix diffusion as a potential retardation for radionuclides and to derive transport parameters (accessible porosity, diffusion coefficients) for the rock matrix.

*Waber H.N., Gimmi T. and Smellie, J.A.T., 2012. Reconstruction of palaeoinfiltration during the Holocene using porewater Data (Laxemar, Sweden). Geochim Cosmochim Acta 94: 109-127.*

*Waber, H.N., Gimmi, T., deHaller, A. and Smellie, J.A.T., 2009. Porewater in the rock matrix. SDM-Site Laxemar. SKB R-Report R-08-112, SKB, Stockholm, Sweden: 93 pp., available at [www.skb.se](http://www.skb.se).*

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#### **GROUNDWATER HYDROGEOCHEMICAL INVESTIGATIONS AT LAXEMAR SITE, SWEDEN (SKB, CHEMNET PROJECT)**

2004 - 2009 | Contact person: H. Niklaus Waber

Groundwater circulating in the fracture networks of crystalline rocks have been analysed for their chemical, isotope and gas composition. Obtained results were used in combination with porewater data and hydraulic models to elaborate the regional hydrogeological evolution at Laxemar.

*Laaksoharju, M., Smellie, J.A.T., Tullborg, E.-L., Wallin, B., Drake, H., Gascoyne, M., Gimeno, M., Gurban, I., Hallbeck, L., Molinero, J., Nilsson, A.C. and Waber, H.N., 2009. Bedrock hydrogeochemistry Laxemar. SDM-Site Laxemar. SKB R-Report R-08-93, SKB, Stockholm, Sweden: 201 pp., available at [www.skb.se](http://www.skb.se).*

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#### **FIELD INVESTIGATION OF TRACER DIFFUSION IN OPALINUS CLAY (MONT TERRI DI-A2 EXPERIMENT)**

2001 - 2009 | Contact person: Paul Wersin, Thomas Gimmi

One-year field diffusion test in the Mont Terri underground rock laboratory aiming at determining the transport characteristics of mobile and sorbing tracers in Opalinus Clay. RWI was one of several contributors to this project.

*Wersin, P., Soler, J.M., Van Loon, L., Eikenberg, J., Baeyens, B., Grolimund, D., Gimmi, T., Dewonck, S. (2008). Diffusion of HTO, Br<sup>-</sup>, I<sup>-</sup>, Cs<sup>+</sup>, <sup>85</sup>Sr<sup>2+</sup> and <sup>60</sup>Co<sup>2+</sup> in a Clay Formation: Results and Modelling from an In Situ Experiment in Opalinus Clay. Applied Geochemistry 23 (4), 678-691*

*Soler, J.M., Wersin, P., Leupin, O.X., 2013. Modeling of Cs<sup>+</sup> diffusion and retention in the DI-A2 experiment (Mont Terri). Uncertainties in sorption and diffusion parameters. Applied Geochemistry 33, 191-198*

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## **GEOSCIENTIFIC INVESTIGATIONS ON CORE MATERIALS FROM THE BENKEN BOREHOLE (IN THE FRAME OF NAGRA'S "DEMONSTRATION OF DISPOSAL FEASIBILITY" PROJECT)**

1999 - 2008 | Contact persons: Martin Mazurek, H. Niklaus Waber, Thomas Gimmi

Integrated project aiming at the geological, geochemical and hydrogeological characterisation of the Mesozoic sedimentary sequence of NE Switzerland

*Lerouge, C., Grangeon, S., Claret, F., Gaucher E.C., Blanc P., Guerrot, C., Flehoc C., Wille, G. & Mazurek, M. (2014): Mineralogical and isotopic record of diagenesis from the Opalinus Clay formation at Benken, Switzerland: Implications for the modeling of pore-water chemistry in a clay formation. Clays and Clay Minerals 62, 286-312.*

*Nagra 2002: Projekt Opalinuston - Synthese der geowissenschaftlichen Untersuchungsergebnisse. Nagra Technical Report NTB 02-03, Nagra, Switzerland, 659 pp. + Appendices.*

*Mazurek, M., Hurford, A. J. & Leu, W. 2006: Unravelling the multi-stage burial history of the Swiss Molasse Basin: Integration of apatite fission track, vitrinite reflectance and biomarker isomerisation analysis. Basin Research 18, 27-50*

*Elie, M. & Mazurek, M. 2008: Biomarker transformations as constraints for the depositional environment and for maximum temperatures during burial of Opalinus Clay and Posidonia Shale in northern Switzerland. Applied Geochemistry 23, 3337 - 3354*

*Gimmi, T., Waber, H.N., Gautschi, A. and Rübel, A. (2007), Stable water isotopes in pore water of Jurassic argillaceous rocks as tracers for solute transport over large spatial and temporal scales, Water Resour. Res., 43, W04410, doi:10.1029/2005WR004774.*

*P. Marschall, S. Horseman, and T. Gimmi (2005). Characterisation of gas transport properties of the Opalinus Clay, a potential host rock formation for radioactive waste disposal. Oil & Gas Science and Technology - Rev. IFP, 60(1), 121-139.*

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## **POREWATER INVESTIGATIONS IN THE UPPER FRESH WATER MOLASSE**

2005 - 2007 | Contact person: H. Niklaus Waber

*Koroleva, M., Waber, H.N., Mazurek, M. and Bigler, T. (2007). Borehole Üetliberg: Mineralogical and pore water studies. Nagra Arbeitsbericht 07-07. Nagra, Wettingen, Schweiz, 59 pp.*

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## **WATER DIFFUSION THROUGH COMPACTED CLAYS ANALYZED BY NEUTRON SCATTERING AND TRACER EXPERIMENTS (PHD F. GONZÁLEZ SÁNCHEZ)**

2004 - 2007 | Contact person: Thomas Gimmi

Comparing local diffusion coefficients in clay samples measured by quasi-elastic neutron scattering with macroscopic diffusion coefficients measured by HTO tracer experiments. In cooperation with the Laboratory for Neutron Scattering LNS and Laboratory for Waste Management LES, Paul Scherrer Institute.

*F. González Sánchez (2007). Water diffusion through compacted clays analyzed by neutron scattering and tracer experiments. Dissertation, Philosophisch-naturwissenschaftlichen Fakultät der Universität Bern, Nov. 2007.*

*González Sánchez, F., Jurányi, F., Van Loon, L., Gimmi, T. (2007). Translational diffusion of water in compacted clay systems. European Physical Journal-Special Topics 141, 65-68.*

González Sánchez, F., Jurányi, F., Gimmi, T., Van Loon, L., Seydel, T., Unruh, T. (2008). Dynamics of supercooled water in highly compacted clays studied by neutron scattering. *Journal of Physics-Condensed Matter* 20(41), 415102, doi: 10.1088/0953-8984/20/41/415102

González Sánchez, F., Jurányi, F., Gimmi, T., Van Loon, L., Unruh, T., Diamond, L.W. (2008). Translational diffusion of water and its dependence on temperature in charged and uncharged clays: A neutron scattering study. *Journal of Chemical Physics* 129, 174706, DOI: 10.1063/1.3000638.

González Sánchez, F., Van Loon, L.R., Gimmi, T., Jakob, A., Glaus, M.A., Diamond, L.W. (2008). Self-diffusion of water and its dependence on temperature and ionic strength in highly compacted montmorillonite, illite and kaolinite. *Applied Geochemistry* 23, 3840-3851, doi:10.1016/j.apgeochem.2008.08.008

González Sánchez, F., Gimmi, T., Jurányi, F., Van Loon, L., Diamond, L.W. (2009). Linking the Diffusion of Water in Compacted Clays at Two Different Time Scales: Tracer Through-Diffusion and Quasielastic Neutron Scattering. *Environmental Science & Technology* 43, 3487-3493, DOI: 10.1021/es8035362

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### **MATRIX FLUID CONTINUATION (MFC) PROJECT, ÄSPÖ URL, SWEDEN (ÄSPÖ MATRIX FLUID EXPERIMENT)**

2004 - 2006 | Contact person: H. Niklaus Waber

Continuation of the long-term groundwater sampling from very low-transmissive fractures and the long-term hydraulic monitoring of the fractures.

*Waber H.N. and Smellie, J.A.T., 2008. Characterisation of pore water in crystalline rocks. Appl Geochem 23: 1834-1861.*

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### **FIELD INVESTIGATION OF TRACER DIFFUSION IN OPALINUS CLAY (MONT TERRI DI-A1 EXPERIMENT)**

2000 - 2006 | Contact person: Paul Wersin, Thomas Gimmi

One-year field diffusion test in the Mont Terri underground rock laboratory aiming at determining the transport characteristics of mobile and sorbing tracers in Opalinus Clay. RWI was one of several contributors to this project.

*L.R. Van Loon, P. Wersin, J.M. Soler, J. Eikenberg, Th. Gimmi, P. Hernan, S. Dewonck, and S. Savoye (2004). In-situ diffusion of HTO,  $^{22}\text{Na}^+$ ,  $\text{Cs}^+$  and  $\text{I}^-$  in Opalinus Clay at the Mont Terri underground rock laboratory. *Radiochim. Acta*, 92, 757-763*

*P. Wersin, L.R. Van Loon, J.M. Soler, A. Yllera, J. Eikenberg, Th. Gimmi, P. Hernán and J.-Y. Boisson (2004). Long-term diffusion experiment at Mont Terri: first results from field and laboratory data. *Applied Clay Science* 26(1-4), 123-135*

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### **POREWATER INVESTIGATIONS IN THE PARIS BASIN AT THE SITE MEUSE-HAUTE MARNE I (ANDRA SITE INVESTIGATION PROJECT)**

2003 - 2005 | Contact person: H. Niklaus Waber

Conservative parameters of the porewater (Cl, Br,  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , He) residing in the pore space of low-permeability argillaceous sedimentary rocks have been determined by indirect methods based on drillcore material from 4 different boreholes. Obtained results were used to elaborate the solute transport across the Callovo-Oxfordian shale (Cox) and the palaeo-hydrogeological evolution of the site.

Bigler, T., Ihly, B., Lehmann, B.E. and Waber, H.N., 2005. Helium Production and Transport in the Low-Permeability Callovo-Oxfordian Shale at the Site Meuse/Haute Marne, France. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 40 pp.

Waber, H.N., 2005. Laboratoire de Recherche Souterrain Meuse / Haute-Marne - Chloride,  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  in Pore Water of the Callovo-Oxfordian and Surrounding Rock Formations. Nagra Arbeitsbericht. Nagra, Wettingen, Switzerland, 83 pp.

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## **MATRIX FLUID (MF) PROJECT, ÄSPÖ URL, SWEDEN (ÄSPÖ MATRIX FLUID EXPERIMENT)**

1999 - 2004 | Contact person: H. Niklaus Waber

The different types of pore fluid residing in the low-permeable matrix of crystalline rocks have been characterised including long-term groundwater sampling from very low-transmissive fractures and - for the first time - extraction of porewater residing in the connected pore space of the rock matrix.

Smellie, J.A.T., Waber, H.N. and Frappe, S.K., 2003. Matrix fluid chemistry experiment. Final Report. SKB Technical Report TR-03-18. SKB, Stockholm, Sweden, 377 pp., available at [www.skb.se](http://www.skb.se).

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## **GEOCHEMICAL MODELLING AND SYNTHESIS (GM) TASK, MONT TERRI URL (MONT TERRI WS EXPERIMENT)**

2000 - 2003 | Contact person: H. Niklaus Waber

This project aimed at a comprehensive synthesis of porewater characterisation in the argillaceous Opalinus Clay and the various applied porewater extraction and modelling approaches to derive the complete chemistry of the in-situ porewater.

Waber, H.N., 2001. Mont Terri Project: Phase 4 & 5 Hydrochemical Data Review. In: Pearson, F.J., D. Arcos, B. Jordi, A.-M. Fernández, E. Gaucher, J. Peña, B. Sanjuan, J. Turrero, H.N. Waber, L. Griffault, J.-Y. Boisson, H.-E. Gäbler, A. Gautschi and P. Hernán Reguera, 2001, *Compilation of Aqueous Geochemistry Data Collected During Phases 4 and 5, Rock Property Data from All Phases and Results of Phase 5 Geochemical Modelling*. MTP Technical Note TN 2000-36, International Mont Terri Project, St. Ursanne, Switzerland, 5-52.

Fernández, A.M., Bath, A., Waber, H.N. and Oyama, T., 2003. Water Sampling by Squeezing Drillcore. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 171-199, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Gaucher, E.C., Fernández, A.M. and Waber, H.N., 2003. Rock and Mineral Characterisation of the Opalinus Clay Formation. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 281-303, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Griffault, L., Bauer, C., Waber, H.N., Pearson, F.J., Fierz, T., Scholtis, A., Degueldre, C. and Eichinger, L., 2003. Water Sampling and Analyses for Boreholes and Seepages. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 142-170, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson, F.J., Arcos, D., Gaucher, E.C. and Waber, H.N., 2003. Pore Water Chemistry and Geochemical Modelling. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 67-104, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson, F.J., Fernández, A.M., Gaboriau, H., Waber, H.N. and Bath, A., 2003. Porosity and Water Content of Mont Terri Claystones. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 294-319, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Pearson F.J., Arcos, D., Bath A., Boisson J.-Y., Fernández A.M., Gaebler H.E., Gaucher E., Gautschi A., Griffault L., Hernan P. and Waber H.N. (eds.) 2003. *Mont Terri Project - Geochemistry of water in the Opalinus Clay formation at the Mont Terri Rock Laboratory - Synthesis Report*. Reports of the Swiss Federal Office for Water and Geology, Geology Series, No. 5, Bern, Switzerland, 319 p, available at [www.mont-terri.ch](http://www.mont-terri.ch)

Waber, H.N. 2003. Gases in Borehole Headspace. *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 269-280, available at [www.mont-terri.ch](http://www.mont-terri.ch).

Waber, H.N., Gaucher, E.C., Fernández, A.M. and Bath, A., 2003. Aqueous Leachates and Cation Exchange Properties of Mont Terri Claystones. In: Pearson, F.J. et al. (eds.), *Mont Terri Project - Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Rock Laboratory*. Geology Series No. 5, Federal Office of Water and Geology (FOWG), Bern, Switzerland: 200-237, available at [www.mont-terri.ch](http://www.mont-terri.ch).

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## **EVALUATION OF FEPS (FEATURES, EVENTS AND PROCESSES) SPECIFIC TO ARGILLACEOUS MEDIA (FEP-CAT, AN OECD/NEA PROJECT)**

1999 - 2003 | Contact person: Martin Mazurek

FEP analysis is an important to assess the safety of deep geological repositories for nuclear waste. FEPs specific to clays and shales are characterised from both the scientific and safety-related perspectives.

Mazurek, M., Pearson, F. J., Volckaert, G. & Bock, H. 2003: *FEP-CAT Project: Features, Events and Processes Evaluation Catalogue for Argillaceous Media*. OECD/NEA report 4437, OECD Nuclear Energy Agency, Paris, France, 376 pp.

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## **POREWATER INVESTIGATIONS AND GEOCHEMICAL CHARACTERISATION OF OPALINUS CLAY AT THE MONT TERRI URL (MONT TERRI WS-A & WS-B EXPERIMENTS)**

1998 - 2003 | Contact person: H. Niklaus Waber

Complementary to long-term seepage water collection indirect methods to extract porewater from the low-permeable Opalinus Clay were tested and supported by geochemical investigations on the rock.

Waber, H.N., 1999. *WS-B Experiment: Isotope Analyses of Sulfate Vein Minerals from the Opalinus Clay at Mont Terri*. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 7 pp.

Waber, H.N. and Oyama, T., 2000. *WS-A Experiment: Feasibility Study of Porewater Squeezing as a Function of Pressure*. MTP Technical Note TN 2000-23, International Mont Terri Project, St. Ursanne, Switzerland, 37 pp.

Waber, H.N. and Schürch, R., 2000. *WS-A Experiment: Fracture Mineralogy and Geochemistry as Constraints on Porewater Composition*. MTP Technical Note TN 99-23, International Mont Terri Project, St. Ursanne, Switzerland, 27pp.

Waber, H.N., 2002. *WS-B Experiment: Derivation of in-situ porewater compositions in the Opalinus Clay at Mont Terri based on rock geochemical properties*. MTP Technical Note TN 99-24, International Mont Terri Project, St. Ursanne, Switzerland, 49 pp.



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## CHEMICAL AND ISOTOPIC COMPOSITION OF SEEPAGE WATER COLLECTED FROM BOREHOLES IN THE OPALINUS CLAY AND FROM SPRINGS IN SURROUNDING FORMATIONS AT THE MONT TERRI URL (MONT TERRI WS-A EXPERIMENT)

1998 - 2002 | Contact person: H. Niklaus Waber

This project aimed at the characterisation of porewater in the Opalinus Clay by collecting seepage water from packer intervals in boreholes over very long time periods. Spring water discharging from higher transmissive surrounding lithologies were also investigated.

*Scholtis, A., Waber, H.N., Fierz, T., Degueldre, C., Laube, A. and Bauer-Plaindoux, C., 1999. WS-A Experiment: Water & Gas Sampling: Chemical and Isotopic Raw Data (28th to 29th April 1999) for: Boreholes BWS-A1, -A2, -A3, and -A6, Murchisonae-Concava-Beds Spring, Jurensis Marl Spring, Gryphitenkalk Spring. MTP Technical Note TN 99-67, International Mont Terri Project, St. Ursanne, Switzerland, 37 pp.*

*Waber, H.N., 1999. Mont Terri Project: Phase 3 Hydrochemical Data Review. In: Pearson, F. J., 1999, Geochemical Modelling and Synthesis (GM) Task: Results of Phase 4 Activities: MTP Technical Note TN 99-51, International Mont Terri Project, St. Ursanne, Switzerland, 17-33.*

*Langer, C.W. and Waber, H.N., 2000. WS-A Experiment: Water & Gas Sampling Phase 5: Chemical and Isotopic Raw Data for: Boreholes BWS-A1, -A2, -A3, and -A6. MTP Technical Note TN 2000-32, International Mont Terri Project, St. Ursanne, Switzerland, 22.*

## CO<sub>2</sub> SEQUESTRATION

[\(website\)](#)

### ASSESSING THE FEASIBILITY OF CO<sub>2</sub> SEQUESTRATION IN SWITZERLAND: NUMERICAL MODELLING

2010 - | Contact person: Peter Alt-Epping

This project was initiated by the “Bundesamt für Energie” (Swiss Federal Office of Energy) in Switzerland to help assess the feasibility of CO<sub>2</sub> sequestration in Switzerland. Constructing numerical models of CO<sub>2</sub> sequestration constrained by experiments and field observations is now an important research effort within the framework of the Swiss Competence Center for Energy Research, SCCER-SoE (<http://www.sccer-soe.ch>)

## GEOHERMAL ENERGY

[\(website\)](#)

### GEOHERMAL WATER IN THE GRIMSEL AREA, SWITZERLAND (INST. GEOL. SCI. RESEARCH PROJECT)

2014 - | Contact person: H. Niklaus Waber

Various occurrences of thermal water in the crystalline rocks of the Aar-Massive in the Grimsel area are chemically and isotopically characterised in order to unravel their evolution in the deep underground.

*Waber, H.N., Schneeberger, R., Mäder, U. and Wanner, C. (accepted). Constraints on evolution and residence time of geothermal water in granitic rocks at Grimsel (Switzerland). Procedia Earth Plan Sci.*

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## **PREDICTION OF WATER/ROCK INTERACTION AND POROSITY EVOLUTION IN A GRANITOID-HOSTED ENHANCED GEOTHERMAL SYSTEM**

2012 - 2014 | Contact person: Peter Alt-Epping

We constructed reactive transport models of the (abandoned) enhanced geothermal system at Basel, Switzerland. The model was constrained by data collected during the drilling campaign. Simulations were carried to predict fluid-rock reactions in the granitoid host rock during stimulation and operation, permeability changes in the reservoir rock resulting from mineral dissolution/precipitation reactions, the risk of mineral scaling in the wells and surface installations and the implications of incipient corrosion.

*Diamond, L.W., Alt-Epping, P., 2014, Predictive modelling of mineral scaling, corrosion and the performance of solute geothermometers in a granitoid-hosted, enhanced geothermal system. Applied Geochemistry 51, 216-228.*

*Alt-Epping, P., Diamond, L.W., Häring, M. O., Ladner F., Meier, D. B., (2013), Prediction of water/rock interaction and porosity evolution in a granitoid-hosted enhanced geothermal system, using constraints from the 5 km Basel-1 well. Applied Geochemistry, 38, 121-133.*

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## **GEOTHERMAL WATER AT BAD BLUMAU, AUSTRIA (RWI RESEARCH PROJECT)**

2007 - 2008 | Contact person: H. Niklaus Waber

The thermal water supplying the spa at Bad Blumau was hydrochemically characterised and better understanding of its evolution and an improvement of its production was aimed at by applying geochemical modelling strategies. The models were used to constrain chemical and thermal properties of the reservoir and to predict the consequences of reinjecting a cooled, CO<sub>2</sub>-depleted fluid and of mineral scaling in the wells and surface installations, and to help find geochemical indicators of incipient corrosion.

*Waber, H.N., Alt-Epping, P. and Eichinger L., 2008. Hydrochemistry and geochemical modelling of thermal water, Bad Blumau, Austria. RWI Technical Report TR 08-01, Institute of Geological Sciences, University of Bern, Switzerland, 41 pp.*

*Alt-Epping P., Waber, H.N., Diamond L.W. and Eichinger L., 2013. Reactive transport modelling of the geothermal system at Bad Blumau, Austria: Implications of the combined extraction of heat and CO<sub>2</sub>. Geothermics 45: 18-30.*

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