Session 11A

Excavation Damaged Zone – 3

Chair: Till Popp / Jean-Dominique Barnichon
CLAY FORMATION
AT THE MEUSE/HAUTE-MARNE URL:
EVALUATION OF THE IMPACT OF RESIN
FILLED SLOTS ON FLOW PATHS
CHARACTERISTICS WITHIN THE EDZ

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INTRODUCTION
Andra is currently investigating the Callovo-Oxfordian argillaceous formation as a potential host rock for the deep disposal of high level radioactive waste at the Meuse/Haute-Marne URL (Andra, 2005). A large number of geomechanical and hydraulic measurements are performed in instrumented boreholes (Delay et al., 2006a and b). The purposes of the KEY experiment are the characterisation of the permeability and pore pressure field in the near vicinity of the drift at -490 m bgl, as well as the assessment of the impact of resin and bentonite filled slots on flow paths within the Excavation Damaged Zone (EDZ) and the Excavation disturbed Zone (EdZ).

EXPERIMENTAL PROCEDURES
The tests dedicated to the hydraulic characterization of the EDZ/EdZ were performed with gas or water in 12 short boreholes drilled down to 2 to 3.5 meters from the drift floor. The test procedure included several types of tests including single-hole tests (pulse, constant rate, etc.), multi-hole interference tests and dipole tracer tests. In addition, some of the tests were conducted again after days, weeks and months to investigate changes of the EDZ flow properties with time. The KEY experiment investigates in particular if resin filled slots would be able to interrupt pre-existing hydraulic connections between boreholes. Figure 1 presents a 3D view of the experimental boreholes and the three slots performed between the boreholes which reach a depth of 2 m from the drift floor.

RESULTS
The main results of the KEY experiments concern:

• The distribution of permeability and pressure around the drift; very heterogeneous properties could be identified depending on the position and orientation of the borehole as well as the distance from the drift. Close to the drift (<0.5 m) hydraulic conductivities up to 1.10\textsuperscript{-7} m/s were identified. However the values beyond around 1 m are usually in the order of 1.10\textsuperscript{-11} m/s and lower.

• Some insight in the saturation profile: Close to the drift, in relatively high permeable zones, the pressures within the monitoring intervals are close to atmospheric pressure, suggesting well connected and drastically desaturated conditions. The tests conducted with water between 0.7 and 3 m tests indicated strong under pressure conditions, which is due to capillary effects in likely partially saturated zones. Further away from the drift the interval pressure rise rapidly above atmospheric pressure, which demonstrates fully saturated conditions beyond around 3 meters from the drift.

• Feed back on the advantages and disadvantages of the methodologies and procedures applied; for instance interference tests and monitoring in neighbouring intervals can be easily conducted in many boreholes, however detecting no interferences between two boreholes does not mean that these borehole are not hydraulically connected. On the other side, the tracer tests can demonstrate in a reliable manner the
existence or absence of flow path between two intervals at a metric scale. However, the procedure in dipole of injection-extraction boreholes applied can not be conducted easily in many boreholes at the same time. Therefore a combination of both methods has to be selected to optimise the investigation of the flow paths within the EDZ.

Concerning the performance of the resin filled plugs, all the flow paths oriented along the drifts, and initially recognized prior to sawing the slots, appeared to be interrupted by the resin infill. However new vertical connections to the floor appeared in many boreholes, showing thus an increase of the EDZ with depth. Even a new discrete fracture, parallel to the slots crosses the KEY 1009 borehole, thus connecting 4 of the 6 monitoring intervals of this borehole.

References:
CARACTERIZATION AND EVOLUTION
OF EDZ BY EXTRACTION AND ANALYSES
OF NOBLE GASES IN PORE WATERS
IN THE URL AT THE MEUSE/HAUTE MARNE
URL SITE

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INTRODUCTION
The purpose of this work is to use noble gases as a tool to characterize the EDZ in the gallery walls in the
Underground Research Laboratory (URL) at the Meuse / Haute Marne site which is located at a depth of
490 m in the Callovo-oxfordien clay formation. This study is performed by measuring the concentrations
of all noble gases He, Ne, Ar, Kr, et Xe over the 18 months following the excavation of the gallery.

Most of the helium present in the rock is initially produced by α decay of U and Th in clay minerals and
then accumulates in pore waters. Helium diffuses through the EDZ and escapes toward the gallery. One of
the purposes of this work is to obtain detailed diffusion profiles of He versus depth perpendicular to the
gallery wall and to follow the evolution with time over 18 months. At the same time, all other noble gases
are analyzed to study the diffusion processes and the penetration of air occurring via microfractures created
by the development of the desaturated zone of the EDZ.

EXPERIMENTAL PROCEDURE
Drilled rock cores were sampled from 6 horizontal boreholes up to six meter depth made perpendicular to
the wall of the gallery 4d of the URL. Boreholes were drilled between October 2005 and October 2006
respectively 45, 73 days, 3, 6, 9 and 12 months after the excavation of the gallery. A last borehole is
planned in May 2007, 18 months after excavation. From each borehole, up to 12 samples are prepared for
noble gas analysis in order to obtain detailed concentration depth profiles.

The gas extraction from pore waters is done following the procedure proposed by Osenbrück et al, 1998.
Because the solubility of noble gases in water is very low, the sampling is done within 2h after drilling.
Prior to storage, about 1 to 2 cm of the rock in each direction is removed under pure N₂ atmosphere in
order to avoid parts that might have suffered degassing or penetration of air. Core samples of a typical
weight of 200g to 400g are placed in a vacuum-tight cell of about 450 cm³. In order to eliminate
contaminating residual air in the sample container, the cell is evacuated with a rotary pump and flushed
with pure nitrogen gas twice. Noble gas diffuses out of the pore waters over a period of at least 4 or
5 weeks. Then all extracted gases are transferred to a purification and separation line through a capillary
tube using water vapor as a gas carrier. Typical extraction yield are better than 99% for He and Ne and
than 98% for Ar, Kr, Xe. Noble gas abundances and isotopic ratios are measured on separate splits with a
VG Micromass 1200 (12 cm radius, 60° deflection angle) mass spectrometer. Absolute concentrations
are obtained with a precision of 1% to 2% for all noble gases by using isotopic dilution method.

Concentrations of all noble gases (He, Ne, Ar, Kr, Xe) have been already analyzed for this study in
46 samples from the six first boreholes.
RESULTS

Figure 1 presents \(^{4}\)He concentrations versus depth into the gallery wall, 5 days (FOR1100) after the excavation of the gallery and respectively after, 45 days (FOR1101), 73 days (FOR1103), 6 months (FOR1106), 9 months (FOR1109) and 12 months (FOR1112). All He concentrations measured after the first drilling (FOR1100) lead to a single depth profile (dashed line) indicating a steady state over almost a year. Starting from gallery wall and up to 0.9 m deep, He concentrations are very low suggesting a highly disturbed zone. Then they increase from a depth of 0.9m up to about 2.5m. At larger depths not affected by the EDZ, He concentrations are constant with a value of 595 \(10^{-7}\) cm\(^3\)/g of pore water, measured with a reproducibility better than 12\% (at 2 sigma taken into account 15 samples from different boreholes). This result clearly shows the EDZ changes rapidly within the first 45 days after excavation and that further evolutions are not noticeable over the following year. For comparison, He depth profiles measured in the Opalinus Clay at Mont Terri (Switzerland) are also plotted (Rübel et al., 2002). The remarkable agreement observed up to about 2.5 m deep suggests a similar development of the EDZ measured after 10 years at Mont Terri (Rubel et al., 2002). Concentrations in the unaltered zone appear to be significantly higher than in the Callovo-Oxfordian formation.

Regarding other noble gases, in the first 90cm deep an atmospheric Ne admixture is observed. At larger depth, Ne profiles are rather flat with relative variations less than 8\% in average, indicating no Ne diffusion losses or air penetration.

On the contrary Ar, Kr an Xe concentrations appear to be more variable from one sample to another one and show a significant enrichment, specially for Xe, relative to typical air saturated water abundances.

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References:


IN SITU GAS TEST FOR THE CHARACTERISATION OF EXCAVATION DISTURBED ZONE AT THE MEUSE/HAUTE-MARNE URL

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INTRODUCTION

Clay and clay-rich materials are considered as the geological and geotechnical barriers for the disposal of nuclear waste in many countries. In Germany the current investigations are concentrating in the characterisation of argillaceous rocks as alternative geological formations to rock salt, the optimisation of geotechnical barriers, and long-term safety analysis. Within the framework of the co-operation between BGR (Federal Institute for Geosciences and Natural Resources) and ANDRA (Agence Nationale Pour la Gestion des Dechets Radioactifs), BGR was involved in the ANDRA’s general experimental programme at the Underground Research Laboratory Meuse/Heute-Marne with the contributions of ‘permeability tests using a gaseous test medium’ and ‘seismic characterisation of excavation disturbed zone (EdZ)’.

The important factors concerning long-term safety are the hydraulic property of host rocks and the characterisation of the EdZ. To characterise the hydro-mechanical properties of the clay formation, hydraulic testing using nitrogen, both in the far-field and near-field, has been carried out. The monitored pressure developments were interpreted by a numerical one- and two-phase-flow code taking the pore water and capillary pressure into consideration. To understand the processes which are accompanied by excavation and testing, a coupled hydrological and mechanical model was used under consideration of swelling/shrinkage effect.

This paper documents the gas testing in six fan-shape arranged boreholes within the GKE-Gallery in the Bure underground laboratory. The interpreted permeability results correlate well with that from the core mapping of the fractures and the in situ seismic measurements.

EXPERIMENTAL CONCEPT AND RESULTS

The mechanical and hydro-geological properties of the clay formation are strongly determined by its anisotropic behaviour. The bedding of the argillite Callovo-Oxfordien formation at the Bure site is oriented quasi-horizontally. Therefore the test boreholes for the in situ permeability test in the gallery are direction-oriented, namely sub-horizontal and vertical boreholes. Additionally, in order to investigate the stress-dependent disturbed zone, fan-shape arranged boreholes were prepared for the seismic and permeability measurement. The diameter of the KEY-boreholes was 86 mm and the lengths of the KEY-boreholes varied between 4 and 20 metres.

The gas injection tests, using a double mechanical short-interval (10 cm) packer, were carried out immediately after the borehole seismic experiment together with video scanning about one week after the manufacture of the boreholes. The positions of the test locations were determined under consideration of the interpretation of the core mapping. Nitrogen gas was injected as test medium into the packer interval in the double packer system. Pulse tests with an injection pressure of 2 bars have generally been carried out in the unfractured zone. In case of a high rock permeability detected in the boreholes, constant rate tests were mostly performed. The test data were interpreted using a numerical one-phase (gas) and two-phase (gas-water) flow model of the numerical code RockFlow.
The zone around a drift may be damaged by excavation processes. Fractures in clay can be formed through the redistribution of rock stress and the change of water saturation through shrinkage. In fractured rock, the permeability is determined by fracture aperture and fracture frequency. A good correlation from packer testing, seismic measurement, borehole video scanning, and core mapping can be achieved (Fig. 1).

CONCLUSIONS
For saturated and unsaturated clay materials, both the hydraulic permeability and the degree of water saturation are important factors, which influence together with mechanical stress redistribution the deformation and damage mechanisms around underground openings. The extent of the excavation disturbed zone is about one diameter of the drift in the bedding direction and half diameter of that in the perpendicular direction to the bedding, which forms to an ellipse. The numerical coupled hydro-mechanical modelling taking swelling and shrinkage into consideration using the code RockFlow gives a similar picture about the extension of the high permeability zone around the drift. The results show that the drying process leads to shrinking of the material, which increases the porosity and finally the rock permeability. This feature was influenced strongly by both hydraulic and mechanical anisotropy. In order to determine the hydraulic anisotropy, a special packer system (slot-packer) which can be used for the hydraulic tests in different directions within a borehole has been developed and will be tested in the Mont Terri Laboratory.

References:
FLOW AND REACTIVE TRANSPORT MODEL OF A VENTILATION EXPERIMENT IN OPA LLINUS CLAY

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INTRODUCTION
During the construction and operational phase of a radioactive waste repository, underground drifts will be subject to ventilation, a fact that could cause rock de-saturation and oxidation. In order to evaluate these phenomena and their impact on rock properties, a ventilation experiment (VE) was performed on Opallinus Clay at the Mont Terri underground laboratory in Switzerland. Hydraulic and mechanical data were monitored during de-saturation and saturation stages. Chemical composition of waters were measured at the end of de-saturation and saturation phases by aqueous extracts.

MODEL RESULTS AND INTERPRETATION
Here we present a 1-D axy-symmetric multiphase (air + liquid water) flow and reactive transport model of VE which has been used to interpret hydrodynamic and geochemical data using INVERSE-FADES-CORE®D, a code developed within the context of the FEBEX Project (Samper et al., 2006; Zheng, 2006). The model slightly overestimates measured relative humidity near the rock interface after de-saturation, probably due to uncertainties in the turbulence factor used to calculate vapor flow. Chemical data from aqueous extract tests were interpreted using an inverse hydrochemical model solved with INVERSE-CORE®D (Dai & Samper, 2004). Numerically-interpretated aqueous extract data are compared to measured data and used to validate model predictions.

Computed concentrations reproduce the chemical evolution of most species. Model results indicate that anion exclusion is relevant for chloride which exhibits an accessible porosity of 50% of total porosity (Figure 1). Pyrite oxidation, dissolution of calcite and dolomite and cation exchange are the main chemical processes. pH in the unsaturated zone varies from 7.8 to 8 and is buffered by calcite (Figure 1). Sensitivity analyses to key hydrodynamic, transport and chemical parameters have been performed. One major conclusion drawn from models results is that changes in porosity of Opallinus clay in the unsaturated zone caused by oxidation and mineral dissolution/precipitation processes are smaller than 2%.

References:

Figure 1: Comparison of model results and measured data after resaturation in Phase 8 for Cl (top) and pH (bottom).