GEOCHEMICAL PROGRAM OF THE MONT TERRI PROJECT : SUMMARY OF RESULTS AND CONCLUSIONS

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The Mont Terri geochemical program successfully achieved its goals of characterising and identifying controls on *in situ* pore water chemistry, describing transport processes and the geochemical evolution at the site, and evaluating practical techniques for characterising pore water in clay rock. Both field and laboratory techniques were investigated, and geochemical modelling was employed to provide a synthesis of the data collected and evaluate their internal consistency. A comprehensive report on the geochemical results has been prepared (Pearson *et al.* 2002).

The field procedures tested were *in situ* sampling from sealed boreholes and techniques for collecting core for laboratory studies. The laboratory studies included squeezing at pressures from below 75 to 512 MPa and characterisation of the mineralogical, chemical, isotopic and physical properties of the core itself. Selected components were measured by aqueous leaching, vacuum extraction (noble gases, O, H isotopes) and diffusive equilibration (O, H isotopes).

Detailed information on pore water was available from three upwardly-drilled, packed-off boreholes. Core material from these boreholes and from a series of boreholes along a cross-section through the entire formation and the adjacent limestone formations was studied in the laboratory.

The properties of the Opalinus Clay at Mont Terri are such that all experiments succeeded. Thus, it was possible not only to develop a detailed, confident understanding of the pore water geochemistry but to evaluate how each technique contributed to that understanding and how well it would have succeeded on its own. This is the transfer value of the Mont Terri project because other rock units of very low-permeability that are studied may well have properties such that only one or two of the techniques will be successful.

A number of conclusions were drawn about the data collection techniques.

Water samples from boreholes represent *in situ* pore water with minimum artefacts. Water squeezed from rock cores can also give valuable data for major, non-reactive solutes and stable isotopes. Perturbations strongly affect pH, redox, alkalinity and other solutes, and dissolved gases, unless great care is taken during borehole construction, instrumentation and sealing, and in anaerobic handling and preservation of drill core. Comprehensive analyses are needed to obtain data to evaluate perturbations. Various required supporting studies include: mineralogy and surface area measurements, water contents and porosity measurements, leaching studies and exchangeable cation analyses and innovative experiments with drill cores such as laboratory pCO_2 measurements.

A number of uncertainties remain including the redox state of pore waters, the pH, alkalinity and pCO_2 controls in the most saline waters, and the details of the processes that control K, Mg, Fe, Mn, NH_4, and other minor solutes. In spite of these, the overall agreement between modelled and measured values is very good, suggesting that a sound basic understanding of chemistry has been developed.
Profiles of chloride, O, H and Cl stable isotopes, He concentrations and $^{40}Ar/^{36}Ar$ ratios across the Opalinus Clay indicate that diffusion has controlled the movement of solutes and water molecules for millions of years. The present state of development of the pore water compositions can be related to the regional palaeo-hydrogeology, especially to Jura uplift and erosion and ingress of meteoric water. The basic model is of progressive dilution of seawater since deposition, but various aspects of the geochemical interpretation indicate that the system has a more complex history influenced by specific paleo-hydrogeological events.
The Mont Terri experience shows that if the formation properties allow borehole samples to be collected, the *in situ* pore water chemistry can be found with some confidence. If only squeezed samples are available, *in situ* chemistry can also be found, although with less confidence, using geochemical modelling, provided pCO_2, mineralogical and cation exchange data are available. Finally, if only leaching data are available, modelling is still possible if the Cl porosity of the formation can be determined.

Pearson, F. J., Arcos, D., Bath, A., Boisson, J. Y., Fernández, A. Ma., Gäbler, H.-E., Gaucher, E., Gautschi, A., Griffault, L., Hernán, P., and Waber, H. N., 2002, Geochemistry of Water in the Opalinus Clay Formation at the Mont Terri Laboratory: Bern, Switzerland, Federal Office for Water and Geology (FOWG), Geology Series 5, *in review*.