Swiss J Geosci (2017) 110:405–411
DOI 10.1007/s00015-017-0267-2

Twenty years of research at the Mont Terri rock laboratory: what we have learnt

Paul Bossart[1]

Received: 3 February 2017 / Accepted: 20 February 2017 / Published online: 7 March 2017

Abstract The 20 papers in this Special Issue address questions related to the safe deep geological disposal of radioactive waste. Here we summarize the main results of these papers related to issues such as: formation of the excavation damaged zone, self-sealing processes, thermo-hydro-mechanical processes, anaerobic corrosion, hydrogen production and effects of microbial activity, and transport and retention processes of radionuclides. In addition, we clarify the question of transferability of results to other sites and programs and the role of rock laboratories for cooperation and training. Finally, we address the important role of the Mont Terri rock laboratory for the public acceptance of radioactive waste disposal.

Keywords Opalinus Clay · Deep geological disposal of radioactive waste · Safety relevant processes · Transferability of results · Cooperation and training · Public acceptance

1 Summarizing the key results of the 20 papers in this Special Issue

1.1 Development of investigation techniques

Numerous methods and investigation techniques have been developed in the Mont Terri rock laboratory, mainly for the characterization of claystone like the Opalinus Clay (Bossart and Thury 2007; Delay et al. 2014). Examples are: a methodology for geochemical characterization of porewaters (Pearson et al. 2003), a new technique for in situ diffusion and retention of radionuclides (Wersin et al. 2004), and new geophysical methods for testing the generation and self-sealing of the excavation disturbed and damaged zones in argillaceous rocks (Schuster et al. 2017). One of the major benefits for the Mont Terri Project Partners is the experience gained from these investigations in the Mont Terri rock laboratory. This can be used for the development and planning of new site investigations and characterization programs. Furthermore, these techniques and methodologies can be also transferred for development of new underground rock facilities in other countries.

1.2 Properties of Opalinus Clay at Mont Terri

The following properties are a somewhat arbitrary selection. They are important for the Swiss deep geological disposal concept, but may not have the same relevance in other countries with different disposal concepts.

- Lithology and tectonics: Opalinus Clay as exposed in the region of the Mont Terri rock laboratory is a homogeneous, extended claystone formation with a pronounced bedding anisotropy. It is an over-consolidated claystone exhibiting shaly, sandy, and carbonate-rich facies. The shaly and sandy facies evidence a mineral composition of 30–80% clay minerals (where about 10% consist of smectite-illite mixed-layer minerals), 10–44% quartz, and 4–35% carbonates. The sedimentary age is of Toarcian/Aalenian age (ca. 174 Ma, Hostettler et al. 2017). The whole 130 m-thick sequence was deposited in a shallow sea in less

Editorial handling: A. G. Milnes.

✉ Paul Bossart
paul.bossart@swisstopo.ch

1 Federal Office of Topography swisstopo, Seftigenstrasse 264, 3084 Wabern, Switzerland

than 1 million years. Numerous tectonically deformed zones at different scales result from fault-bend fold thrusting with a shortening of almost 3 km (Nussbaum et al. 2017).
- Hydrogeological properties: Opalinus Clay is considered as an aquiclude, over- and underlain by aquifers. Total physical porosity is on the order of 18 vol%. The mean pore diameter is ca. 40 nm. The pore-space in pristine Opalinus Clay is water-saturated and hydraulic conductivity varies between 2×10^{-14} and 7×10^{-12} m/s (Yu et al. 2017). Under normal hydraulic gradients, the free pore-water does not flow (Pearson et al. 2003). Permeability in Opalinus Clay seems not to be affected by tectonic deformations due to the partial self-sealing of open fractures with calcite, quartz, celestine, and fault-gouge material (Jaeggi et al. 2017).
- Geochemical properties: Opalinus Clay pore-water is of Na–Cl–SO_4 type and, according to measured Cl^-/Br^- ratios, evidences a seawater signature (Pearson et al. 2003). The age of this marine pore-water is younger than the 174 Ma sedimentation age, and is associated with the upper Eocene and Oligocene/Miocene marine incursions into the region of the future folded Jura (Clauer et al. 2017; Mazurek and de Haller 2017). Reducing conditions occur in pristine Opalinus Clay. There is a considerable sorption potential, which is based on the high total specific surface (mean of 130 m^2/g) and on the reactivity of the clay minerals. Thus Opalinus Clay considerably retards the transport of radionuclides.
- Rock-mechanical properties: Opalinus Clay behaves as a mechanically transverse isotropic material. Deformation mechanism is cataclastic flow at low effective confining pressures, low temperatures, and high strain rates (e.g. conditions as they might be at a real repository in the Opalinus Clay) (Nüesch 1991). The claystone swells on contact with water, with swelling-expansion and pressures perpendicular to the bedding of up to 10% and 1 MPa respectively. The uniaxial compressive strength of saturated Opalinus Clay varies between 10 (shaly facies) and 35 MPa (sandy and carbonate rich facies). Desaturated Opalinus Clay shows shrinkage cracks and significantly increased compressive strengths and stiffness (Ziefle et al. 2017). Rheologically, the shaly facies behaves as a "soil-like" clay shale (Amann et al. 2017).

1.3 Generation of the excavation damaged zone (EDZ) and processes related to self-sealing

- Permeabilities and transmissivities of newly generated EDZ fractures are orders of magnitudes higher compared to those of the undisturbed Opalinus Clay (Bossart et al. 2004; Marschall et al. 2017).
- Mini-seismic investigations in radial boreholes around the tunnel yielded reduced seismic P-wave velocities and amplitudes compared with undisturbed claystone (Schuster et al. 2017).
- Self-sealing of the EDZ fracture network occurs during re-saturation of tunnel walls, where pore-water driven by hydraulic gradients is flowing into the fracture network. Both swelling of clay minerals (mainly smectite-illite mixed layers) in the EDZ fractures and mechanical fracture closure by the swelling bentonite contribute to self-sealing. Simultaneously, hydraulic transmissivities decrease and P-wave velocity increases (Bossart et al. 2004; Marschall et al. 2017; Schuster et al. 2017).
- The road header technique without water has shown to allow for a precise and smooth excavation, minimizing development of the EDZ.

1.4 Thermo-hydro-mechanical (THM) processes

- Although temperatures applied in the heater experiments are in the order of 100 °C and thus rather high, temperature and pore-water increases in the Opalinus Clay are moderate due to rapid thermal attenuation with distance and the isolating nature of the artificial bentonite barrier (Gens et al. 2017; Mueller et al. 2017). A thermally induced damaged zone (TDZ) in the Opalinus Clay is theoretically possible (e.g. increased hydraulic conductivities). So far, there is no evidence for such a TDZ, even though in one experiment the Opalinus Clay was exposed to temperatures >100 °C.
- Interaction of buffer with host rock causes additional effects (e.g. heterogeneous saturation of granular bentonite by preferential flow paths through the EDZ) that cannot always be quantified or even anticipated from small-scale laboratory tests. THM in situ testing of the integrated buffer/rock or seal/rock system is an important element contributing to an integrated system understanding (Wieczorek et al. 2017).
- Conceptual models and coupled constitutive equations for adequate design and prediction calculations have been developed (Laloui 2013; Gens et al. 2017). These give useful insights into the THM system response.

1.5 Corrosion-related processes

- Corrosion rates of different steels in contact with clay or bentonite decrease with time due to growth of corrosion products on the steel surfaces (Necib et al. 2017).

- Anaerobic corrosion of steel occurs as a result of redox reactions that generate molecular hydrogen. After hydrogen is experimentally injected into Opalinus Clay, its concentration decreases sharply, most probably due to sulphate-reducing bacteria that foster reduction of sulphates to sulphides (Vinsot et al. 2014, 2017).

1.6 Microbial activity

- Microbial reproduction in pristine Opalinus Clay is strongly limited due to the very small mean pore-diameter (ca. 40 nm), low water activity, and the recalcitrant nature of the organic matter.
- Compacted bentonite also limits microbial activity. Thus, microbially induced corrosion can be controlled by the dry density of the bentonite buffer (Necib et al. 2017; Mueller et al. 2017).
- Microorganisms in a clay environment will affect geochemical conditions and processes in a repository (e.g. the redox and pH conditions, anaerobic steel corrosion, and production and consumption of reaction products (Leupin et al. 2017a; Bleyen et al. 2017) if the conditions allow for it (e.g. water availability, sufficient pores space and nutrients).

1.7 Interaction of Opalinus Clay with high-pH cement fluids

- The CI experiment shows that the extent of the alteration zone within Opalinus Clay is limited (mm- to cm-range). There is a well-defined reaction zone within the cement matrix, the latter is more extensive in low-alkali cement. The interfaces show de-calcification and overprint a carbonate alteration, resulting in a porosity reduction (Maeder et al. 2017).
- First results indicate that low-alkali cementitious products do not minimise the extent of reactions between Opalinus Clay and cementitious materials. Currently there is no clear advantage of substituting OPC (ordinary Portland cement) by low-alkali cements (Maeder et al. 2017).

1.8 Diffusion processes in Opalinus Clay

- Diffusion is the main transport process in the Opalinus Clay at Mont Terri, even in tectonically deformed fault zones and self-sealed EDZ. This has been evidenced by interpreting natural tracer profiles in and around the Mont Terri rock laboratory (assessing the kilometre scale, and timescale of several millions of years), and by field experiments (assessing the centimetre to decimetre scale, and timescale of 1–5 years) (Mazurek and de Haller 2017; Leupin et al. 2017b).
- Due to anion exclusion, the diffusive flux of anions (e.g. I^-, Br^-) is lower than that of water tracers (HTO, HDO), while that of cations (e.g. Sr^{2+}, Cs^+) tends to be higher (Leupin et al. 2017b).
- There is a significant anisotropy effect: diffusion coefficients parallel to bedding planes are 3–5 times higher than normal to bedding planes.
- There seems to be no scale effect: diffusion and sorption parameters of in situ experiments are consistent with those obtained from small-scale laboratory tests.

2 Transferability of results

2.1 What can, and what cannot, be transferred?

A good discussion of what is transferable and not has been presented by Mazurek et al. (2008). In Sect. 2.1, we refer mainly to their findings and conclusions.

The mineralogy, porosity and pore size distributions at many claystone sites are similar and comparable (e.g. Opalinus Clay at Mont Terri and the Callovian-Oxfordian claystone at Meuse/Haute Marne, in the Paris basin of France). The same is true for the chemical type and evolution of their pore-waters. Hydraulic conductivities and diffusion coefficients are often in comparable ranges. Many claystone-formations are compacted and even over-consolidated, and thus rockmechanical parameters show similar ranges.

However, we have to be prudent when comparing clay sites, or transferring information from one site to another. Discrepancies at different claystone sites may be more pronounced than similarities, i.e. when Opalinus Clay is compared with the Toarcian–Domerian claystone at the rock laboratory in Tournemire, southern France (higher over-consolidation, exposed to higher temperatures than Opalinus Clay), or when it is compared with the more plastically behaving Boom Clay of the Hades rock laboratory in Mol, Belgium. Different sedimentary conditions leading to different coarser- or finer grained clastic material and thus to different clay mineralogy, different diagenetic histories, all leading to different degrees of cementation, followed by different burial depth and uplift histories. In turn, these lead to different degrees of compaction and pore-size distributions. Finally, different tectonic evolutions of the claystones at different sites can lead to different deformation fabrics and present-day stress fields. When we want to transfer processes and even individual parameters to other claystone sites, a good knowledge of mineralogy, of the diagenetic evolution, burial and erosion history, and the tectonic and metamorphic development of a site are essential to assess the transferability.

Finally, we conclude that transferability to other claystone sites is possible among weakly consolidated formations with similar mineralogy and porosity distributions. Highly compacted and highly over-consolidated claystone formations limit the transferability from lesser compacted formations, such as the Opalinus Clay. Transferability may also be restricted among formations with different mineralogical compositions and porosities, and with different pore-water chemistries and different present-day stress fields.

2.2 Transferability to the potential sites of Northern Switzerland

In the framework of the Swiss Sectorial Plan, Nagra proposed three locations where high-level radioactive waste could be stored in the Opalinus Clay (Nagra 2010): Jura-Ost, Nördlich Lägern, and Zürich Nordost in the Cantons of Aargau, Thurgau, and Zurich in northern Switzerland. The siting depth of these sites ranges between 400 and 900 m below the surface, which is considerably deeper than the overburden at Mont Terri rock laboratory (280 m). The Opalinus Clay at Mont Terri has a unique burial geology (the formation was subjected to two burial stages, and maximum burial to ca. 1350 m below surface occurred in the late Cretaceous, see Mazurek et al. 2006), a different uplift and erosion history, and a present-day stress field, all of which differ from the situation in northern Switzerland. Thus, results from the Mont Terri rock laboratory cannot be transferred and applied without restriction to the proposed sites of Northern Switzerland.

On the other hand, hydrogeological, geomechanical, and geochemical processes identified at Mont Terri are indeed at least partially transferrable; for example, processes related to the formation of an excavation damaged zone when tunneling in Opalinus Clay, or the processes related to the diffusion and retention of radionuclides. Based on different consolidation histories, present-day depths and stress fields at the different sites, some characteristic parameters may be different, such as the total physical porosity, hydraulic conductivity, mechanical strength and elastic moduli, and diffusion coefficients. However, when borehole and test data at proposed disposal sites are available, it will be possible to correlate and adapt parameters. For instance, effective porosity and hydraulic conductivity values derived from the Benken borehole in the Zürich Nordost region are systematically lower than those found at Mont Terri due to deeper burial of the Opalinus Clay in Northern Switzerland. Modelling plays an important role when applying results to other potential sites. Critical to such modeling are clear definitions and good estimates of model parameters for the different sites with their different geological consolidation histories.

3 Cooperation and training

Over the last 20 years scientists, engineers, technicians and contractors from the Mont Terri project partners have planned, financed, and realised experiments in the Mont Terri rock laboratory. Universities and research organisations from different countries are largely involved in the experimental programmes. Their students and trainees are co-funded by the Mont Terri project partners. Up to date, a total of 9 master theses and 22 PhDs were completed or are still going on (in situ experiments, laboratory experiments on clay samples, modelling). The EU and SERI (Swiss State Secretariat for Education, Research and Innovation) financially supported parts of the experiments. The Mont Terri project partners and research institutions have gained extensive knowledge and know-how, and have developed standards for quality and control.

Transfer of information and knowledge among scientists over two decades of experiments in underground argillaceous research laboratories such as Meuse/Haute Marne in France, Hades in Belgium, and Mont Terri in Switzerland, can only be done properly through direct interaction among partners over extended periods of time and by allowing the teams to develop their own expertise (Delay et al. 2014). One can document processes, parameters, and even procedures on how to carry out different kinds of tests. However, such documentation is not enough: tacit knowledge is the kind of know-how that is difficult to transfer to another person by means of documenting or reporting on it. Rock laboratories are thus key elements to perpetrate valuable tacit knowledge. Junior staff receive apprenticeships and are trained by experienced senior scientists and technicians who have worked for many years in rock laboratories. The IAEA (International Atomic Energy Agency) offers and finances fellowships in rock laboratories where scientists and technicians from other countries can learn and achieve their skills.

Thus all rock laboratories have created working groups for exchanging information and seeking international cooperation, either at the level of programme strategies, evaluation of results, or scientific topics. Within that process, the Mont Terri Project has played a major role through the creation of working groups, especially in geochemistry and rock mechanics.

We conclude that rock laboratories provide (i) privileged access to specific information (ii) partners that share resources needed to run in situ experiments (iii) interesting opportunities for the education and formation of students.

Rock laboratories will prevail in the future to train students, junior staff and specialists that are needed, for instance, to realise safe geological disposal systems, CO_2 storage projects, or other related topics that rely on the unique properties of indurated clay rocks.

4 Public acceptance

Rock laboratories are also essential elements in the dissemination of information and communication policy among implementers, safety authorities, and regulators. People visiting these facilities get an impression of the underground works and the different types of scientific and engineering experiments. Especially important are open days allowing stakeholders to contact scientist and engineers, ask detailed questions about repository concepts and technical issues, and also discuss phenomena and time scales that cannot easily be comprehended. During such visits, people can build an educated opinion about geological disposal in a neutral and informed manner. As in all of the communications from Mont Terri rock laboratory, we express what has been learnt and the domains within which these apply in an understandable, neutral, and scientific fashion.

Since 2011, swisstopo, Nagra, and ENSI have been operating the Mont Terri visitors center. About 4000–5000 persons visit the Mont Terri rock laboratory each year. These visits contribute essentially to the acceptance and credibility of the research in the context of deep geological disposal of radioactive waste. Critics and supporters of deep geological disposal will be informed about the national and international developments of deep geological disposal and they can exchange their ideas and opinions.

5 Conclusions

The Mont Terri rock laboratory has considerably contributed to the safety and technical feasibility of geological repositories and process understanding related to e.g. formation of the Opalinus Clay, its properties as cap rock, etc. In view of long-term safety of geological repository in a clay rock environment, the advantages of claystone formations such as the Opalinus Clay are threefold: (1) claystone formations exhibit an extensive retention potential for sorbing radionuclides due to the large reactive surface areas of clay minerals. The major part of radionuclides will be sorbed onto clay mineral surfaces. (2) Non- or weakly-sorbing radionuclides are transported through Opalinus Clay by molecular diffusion (in undeformed Opalinus Clay and tectonic fault zones). (3) Opalinus Clay reveals distinct self-sealing properties due its smectite-illite mixed-layer clay minerals. Interconnected fracture networks, which are formed in the EDZ during repository construction or possibly generated in the future by earthquakes, will self-seal in relatively short time spans. Thus rapid advective radionuclide transport along preferential flow paths (e.g. through EDZ fracture network) out of the repository into the biosphere is unlikely.

The weaknesses of Opalinus Clay are twofold. (1) Heat-conductivity of Opalinus Clay is rather small when compared to other host rocks. Heating of Opalinus Clay >100 °C in a high-level waste repository might create a thermally induced damaged zone and/or reduce the sorption capacity. (2) Construction of a repository at greater depths (e.g. at 800 m depth) could result in a more extended EDZ and high tunnel convergences. Both weaknesses can be reduced with adequate measures, such as ensuring enough distance between emplacement galleries to avoid overheating, and engineered lining measures that guarantee short term stability of the access galleries.

In conclusion, the methodologies developed, experience gained, and experimental results achieved in the Mont Terri rock laboratory have increased our general knowledge of the complex behaviour of argillaceous formations in response to coupled hydrogeological, mechanical, thermal, chemical, and biological processes. The research we have carried out at Mont Terri over the last 20 years provides invaluable information on repository evolution and yields strong arguments supporting a sound safety case for a repository in argillaceous formations (Bossart et al. 2017). Although extrapolating results to similar potential sites elsewhere must always be applied with care, many general findings from Mont Terri may also be valid at other potential sites in other countries for the deep geological disposal of radioactive waste.

Acknowledgements Olivier Leupin (Nagra), Martin Herfort (ENSI), and Geoffrey Milnes (Scientific Editor of SJG) are kindly thanked for their constructive review of this manuscript. Roy Freeman is thanked for improving the English.

References

Amann, F., Wild, K.M., Loew, S., Yong, S., Thoeny, R., & Frank, E. (2017). Geomechanical behaviour of Opalinus Clay at multiple scales. Results from Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–21. doi:10.1007/s00015-016-0245-0 (**this issue**).

Bleyen, N., Smets, S., Small, J., Moors, H., Leys, N, Albrecht, A., De Cannière, P., Schwyn, B., Wittebroodt, C., & Valcke, E. (2017). Impact of the electron donor on in situ microbial nitrate reduction in Opalinus Clay. Results from the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–20. doi:10.1007/s00015-016-0256-x (**this issue**).

Bossart, P., Bernier, F., Birkholzer, J., Bruggeman, C., Connolly, P., Dewonck, S., Fukaya, M., Herfort, M., Jensen, M., Matray, J-M., Mayor, J. C., Moeri, A., Oyama, T., Schuster, K., Shigeta, N., Vietor, T., & Wieczorek, K. (2017). Mont Terri rock laboratory, 20 years of research: introduction, site characteristics and overview of experiments. *Swiss Journal of Geosciences, 110*. doi:10.1007/s00015-016-0236-1 (**this issue**).

Bossart, P., & Thury, M. (2007). Research in the Mont Terri Rock laboratory: quo vadis? *Physics and Chemistry of the Earth, 32,* 19–31.

Bossart, P., Trick, T., Meier, P.M., & Mayor, J.-C. (2004). Structural and hydrogeological characterization of the excavation-disturbed zone in the Opalinus Clay (Mont Terri Project, Switzerland). *Applied Clay Science. [Online] 26*(1–4), 429–448. doi:10.1016/j.clay.2003.12.018.

Clauer, N., Techer, I., Nussbaum, C., & Laurich, B. (2017). Geochemical signature of paleofluids in microstructures from "Main Fault" in the Opalinus Clay of the Mont Terri rock laboratory, Switzerland. *Swiss Journal of Geosciences*, *110*, 1–24. doi:10.1007/s00015-016-0253-0 (**this issue**).

Delay, J., Bossart, P., Ling, L. X., Blechschmidt, I., Ohlsson, M., Vinsot, A., et al. (2014). Three decades of underground research laboratories: what have we learned? *Geological Society, London, Special Publications, 400*(1), 7–32.

Gens, A., Wieczorek, K., Gaus, I., Garitte, B., Mayor, J. C., Schuster, K., Armand, G., García-Siñeriz, J-L., & Trick, T. (2017). Performance of the Opalinus Clay under thermal loading. Experimental results from Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–18. doi:10.1007/s00015-016-0258-8 (**this issue**).

Hostettler, B., Reisdorf, A. G., Jaeggi, D., Deplazes, G., Bläsi, H.-R., Morard, A., Feist-Burkhardt, S., Waltschew, A., Dietze, V., & Menkveld-Gfeller, U. (2017). Litho- and biostratigraphy of the Opalinus Clay and bounding formations in the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–15. doi:10.1007/s00015-016-0250-3 (**this issue**).

Jaeggi, D., Laurich, B., Nussbaum, C., Schuster, K., & Connolly, P. (2017). Tectonic structure of the "Main Fault" in the Opalinus Clay, Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–18. doi:10.1007/s00015-016-0243-2 (**this issue**).

Laloui, L. (2013). Mechanics of Unsaturated Geomaterials, p. 381. UK: Wiley-ISTE. ISBN: 978-1-118-61676-5.

Leupin, O. X, Bernier-Latmani, R., Bagnoud, A., Moors, H., Leys, N., Wouters, K., & Stroes-Gascoyne, S. (2017a). Fifteen years of microbiological investigation in Opalinus Clay at the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–12. doi:10.1007/s00015-016-0255-y (**this issue**).

Leupin, O. X., Van Loon, L. R., Gimmi, T., Wersin, P., & Soler, J. M. (2017b). Exploring diffusion and sorption processes at the Mont Terri rock laboratory: lessons learned from 20 years of field research. *Swiss Journal of Geosciences*, *110*. doi:10.1007/s00015-016-0254-z (**this issue**).

Mäder, U., Jenni, A., Lerouge, C., Gaboreau, S., Miyoshi, S., Kimura, Y., Cloet, V., Fukaya, M., Claret, F., Otake, T., Shibata, M., & Lothenbach, B. (2017). 5-Year chemico-physical evolution of concrete-claystone interfaces, Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–21. doi:10.1007/s00015-016-0240-5 (**this issue**).

Marschall, P., Giger, S., De La Vassière, R., Shao, H., Leung, H., Nussbaum, C., Trick, T., Lanyon, B., Senger, R., Lisjak, A., & Alcolea, A. (2017). Hydro-mechanical evolution of the EDZ as transport path for radionuclides and gas: insights from the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–22. doi:10.1007/s00015-016-0246-z (**this issue**).

Mazurek, M., & de Haller, A. (2017). Pore-water evolution and solute-transport mechanisms in Opalinus Clay at Mont Terri and Mont Russelin (Canton Jura, Switzerland). *Swiss Journal of Geosciences*, *110*, 1–21. doi:10.1007/s00015-016-0249-9 (**this issue**).

Mazurek, M., Gautschi, A., Marschall, P., Vigneron, G., Lebon, P., & Delay, J. (2008). Transferability of geoscientific information from various sources (study sites, underground rock laboratories, natural analogues) to support safety cases for radioactive waste repositories in argillaceous formations. *Physics and Chemistry of Earth, Parts A/B/C, 33,* 95–105.

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.

Mueller, H. R., Garitte, B., Vogt, T., Köhler, S., Sakaki, T., Weber, H., Spillmann, T., Hertrich, M., Becker, J. K., Giroud, N., Cloet, V., Diomidis N., & Vietor, T. (2017). Implementation of the full-scale emplacement (FE) experiment at the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences, 110*, 1–20. doi:10.1007/s00015-016-0251-2 (**this issue**).

Nagra (2010). Beurteilung der geologischen Unterlagen für die provisorischen Sicherheitsanalysen in SGT Etappe 2. Klärung der Notwendigkeit ergänzender geologischer Untersuchungen. *Nagra Technical Report*, 10-01, 44 pp. Nagra, Wettingen, Switzerland. http://www.nagra.ch.

Necib, S., Diomidis, N., Keech, P., & Nakayama, M. (2017). Corrosion of carbon steel in clay environments relevant to radioactive waste geological disposals, Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences, 110*, 1–14. doi:10.1007/s00015-016-0259-7 (**this issue**).

Nüesch, R. (1991). Das mechanische Verhalten von Opalinuston. *Ph.D. dissertation* No. 9349, ETH Zurich, Switzerland, 294 pp.

Nussbaum, C., Kloppenburg, A., Caër, T., & Bossart, P. (2017). Tectonic evolution around the Mont Terri rock laboratory, northwestern Swiss Jura: constraints from kinematic forward modelling. *Swiss Journal of Geosciences*, *110*, 1–28. doi:10.1007/s00015-016-0248-x (**this issue**).

Pearson, F. J., Arcos, D., Bath, A., Boisson, J.-Y., Fernandez, A., Gaebler, H.-E., Gaucher, E., Gautschi, A., Griffault, L., Hernan, P., & Waber, H. N. (2003). Geochemistry of water in the Opalinus Clay formation at the Mont Terri Rock Laboratory (Synthesis Report). *Geological Report*, No. 5, 321 pp. Federal Office of Topography (swisstopo), Wabern, Switzerland. http://www.mont-terri.ch.

Schuster, K., Amann, F., Yong, S., Bossart, P., & Connolly, P. (2017). High-resolution mini-seismic methods applied in the Mont Terri rock laboratory. *Swiss Journal of Geosciences*, *110*, 1–19. doi:10.1007/s00015-016-0241-4 (**this issue**).

Vinsot, A., Appelo, C. A. J., Lundy, M., Wechner, S., Cailteau-Fischbach, C., de Donato, P., Pironon, J., Lettry, Y., Lerouge, C., & De Cannière, P. (2017). Natural gas extraction and artificial gas injection experiments in Opalinus Clay, Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–16. doi:10.1007/s00015-016-0244-1 (**this issue**).

Vinsot, A., Appelo, C. A. J., Lundy, M., Wechner, S., Lettry, Y., Lerouge, C., et al. (2014). In situ diffusion test of hydrogen gas in the Opalinus Clay. *Geological Society, London, Special Publications, 400*(1), 563–578.

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

Wieczorek, K., Gaus, I., Mayor, J.C., Schuster, K., García-Siñeriz, J-L., & Sakaki, T. (2017). In-situ experiments on bentonite-based buffer and sealing materials at the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–16.doi:10.1007/s00015-016-0247-y (**this issue**).

Yu, C., Matray, J.-M., Gonçalvès, J., Jaeggi, D., Gräsle, W., Wieczorek, K., Vogt, T., & Sykes, E. (2017). Comparative study of methods to estimate hydraulic parameters in the hydraulically undisturbed Opalinus Clay (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–20. doi:10.1007/s00015-016-0257-9 (**this issue**).

Ziefle, G., Matray, J-M., Maßmann, J., & Moeri, A. (2017). Coupled hydraulic-mechanical simulation of seasonally induced processes in the Mont Terri rock laboratory (Switzerland). *Swiss Journal of Geosciences*, *110*, 1–18. doi:10.1007/s00015-016-0252-1 (**this issue**).