Physical and chemical properties of rocks and well cement for CO_2 storage applications in a full-scale borehole simulator

Josephin Mühlbach[1*], Steffen Klumbach[2], Astrid Hirsch[3], Marco Kromer[3] and the COBRA Team **explore the findings of the COBRA (CO_2 Borehole Research Apparatus) project to see if it is possible to achieve safe geological CO_2 storage in depleted hydrocarbon reservoirs and deep saline aquifers.**

The storage of gases (methane, hydrogen, CO_2) or wastewater in deep geological formations requires an approved, long-term safe abandonment strategy. In this context, the long-time integrity of wells is essential for a safe and effective usage of the underground. The aim of the COBRA-project (**CO$_2$ Bo**rehole **R**esearch **A**pparatus) is to test borehole abandonment concepts and to evaluate potential leakage pathways in full-scale experiments. Furthermore, innovative monitoring technologies are developed and tested (for details see: http://www.planeterde.de/geotechnologien/aus-der-praxis/bohrloch-im-labor). The starting point of the project was to test the safety of well installations within the framework of a holistic greenhouse-gas reduction strategy. As Carbon Capture and Storage (CCS) Technologies are one of the few options to reduce CO_2 emissions substantially, the focus of the COBRA project is to study the sustainability of well installations under the influence of carbonic acid. COBRA is a joint project, involving both, geoscientists and engineers from five departments of the Karlsruhe Institute of Technology (KIT), Germany. Large-scale cementation experiments are combined with high-resolution corrosion studies involving well, borehole casing, cement, and natural rocks. The goal of this project is to study the corrosive alteration and leak tightness of this multiphase system. Hereby, special focus is given to the influence of cementation flaws in the abandonment plug. Three types of borehole simulators (from small to full size) are currently used, tested, or in construction. The biggest autoclave system is up to 13-m high, where all critical parts of a well can be exposed to carbonic acid at up to 80 bars and up to 100°C. Furthermore, a circulation system allows a continuous fluid circulation through a reaction chamber and offers the possibility of in situ fluid sampling in order to trace the changes in the fluid chemistry during the experiments. Mineralogical, geochemical and petrophysical investigations allow the quantitative characterization of the underlying processes and mechanisms of well degradation from the micrometre to full scale. The first results of the COBRA project were presented by COBRA PhD students at the SES conference in Pau, France 2013. This study involved the degradation of Triassic sandstones and Jurassic mudstones from Germany under the influence of a CO_2-brine fluid as well as its influence

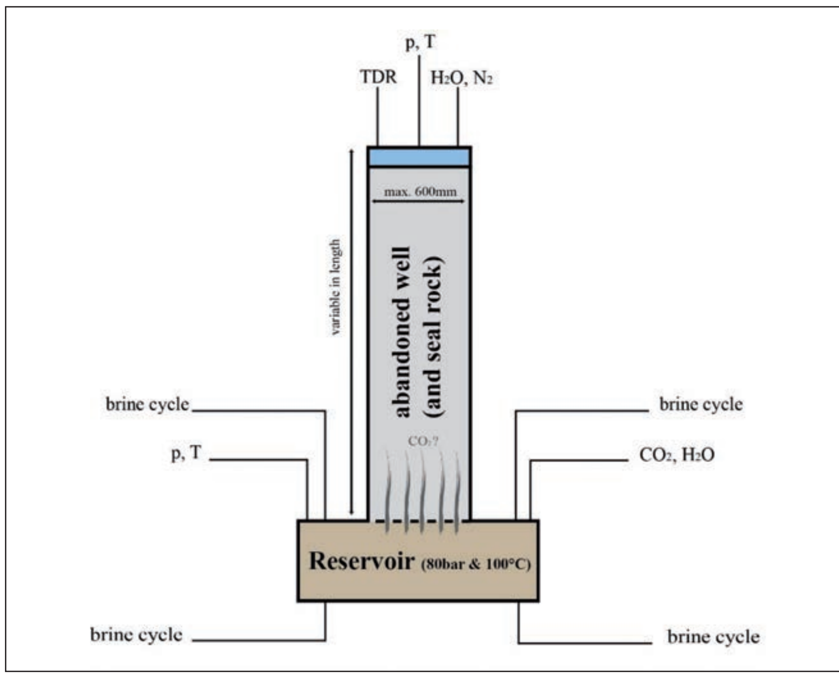

***Figure 1** Sketch of a COBRA full-scale borehole simulator.*

[1] *Institute of Mineralogy and Geochemistry, Karlsruhe Institute of Technology.*
[2] *Institute of Applied Geosciences, Karlsruhe Institute of Technology.*
[3] *Institute of Concrete Structures and Building Materials, Karlsruhe Institute of Technology.*
[*] *Corresponding author, E-mail: josephin.muehlbach@kit.edu*

on standard well cements. The next step of the project has started with long-term experiments. The authors thank the German Federal Ministry of Education and Research (BMBF) for funding this project through the GEOTECHNOLOGIEN Programme (www.geotechnologien.de).

Methods

Physical and chemical rock properties are characterised on small scale, in order to provide reference values for full-scale experiments. Petrophysical examinations thereby involve the determination of pore space portion by immersion weighing, characterisation of pore size distribution by mercury intrusion porosimetry, permeability from flow-through experiments, static and dynamic elastic properties from uniaxial and biaxial compression tests, complex elastic properties from dynamic mechanical thermal analysis and seismic velocities from ultrasonic measurements. Mineralogical and geochemical investigations comprise the identification of the elemental and mineral composition by X-ray diffractometry, (micro) X-ray fluorescence, and thin section analysis. Corrosion experiments with specific combinations of rock and cement in $scCO_2$ and H_2CO_3 serve to identify basic chemical reactions, changing the reservoir fluid chemistry.

First Results

Investigated rock specimens are Triassic sandstones (reservoir rocks, *e.g.* from Middle Buntsandstein and Upper Keuper) and a Jurassic mudstone (seal rock) from South-West Germany, as well as an API class G well cement. Middle Buntsandstein sandstone specimens show a mineral composition (after X-ray diffractometry) of quartz, feldspars, ankerite, hematite and undifferentiated clay minerals and a chemical composition of 94.5% SiO_2, 2.5% Al_2O_3, as well as 1.7% K_2O. Ultrasonic measurements mark a range of *p*-wave velocities from 2.7 km/s to 3.0 km/s and from 1.7 km/s to 2.0 km/s for *s*-waves, at ambient temperature (Fig. 2). The rock density is 2210 kg/m³. Sandstone from the Upper Keuper period mainly comprises 89.7% SiO_2, 5.9% Al_2O_3, and 1.8% CaO, resulting in a mineral composition of quartz, dolomite, calcite, mica and clay minerals. Its samples exhibit an average density of 2110 kg/m³, associated with a p-wave velocity of 2.6 km/s and 1.7 km/s for s-waves, at ambient temperature. The mudstone consists of 58.7% SiO_2, 23.1% Al_2O_3, 4.5% Fe_2O_3, 4.3% CaO, 3.2% K_2O, 2.1% MgO, and 1.1% TiO2 and has a mineral composition of quartz, dolomite, calcite, mica, pyrite, amphibole and clays.

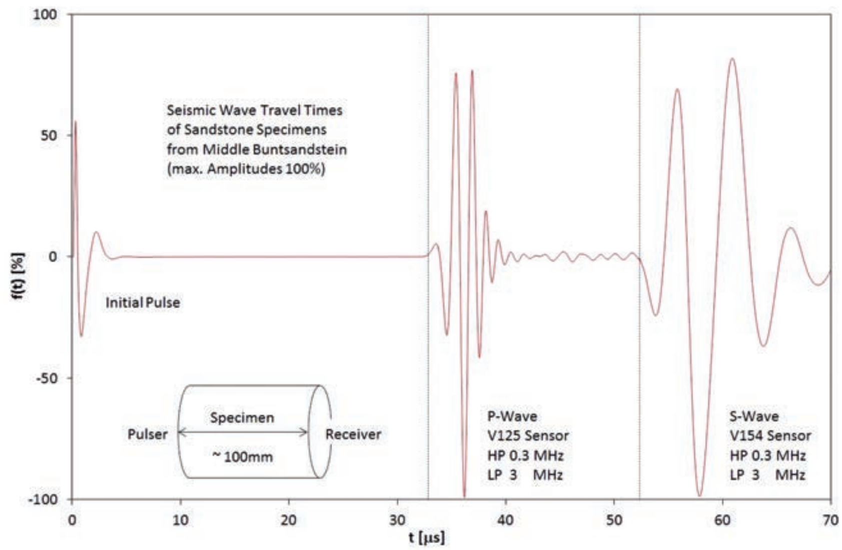

Figure 2 *Combined exemplary results from ultrasonic measurements.*

Outlook

During and after the injection of CO_2 into a reservoir, its integrity is an essential economic and ecological issue. The integrity of wellbores is critical on a much longer timeframe, because they have to guarantee a sealing of the different horizons in the underground even long after the injection phase. Whereas reservoir integrity is responding to mostly pressure-induced processes in the underground during usage, geochemical reactions are acting on a longer timeframe affecting the borehole integrity. Geochemical reactions that might change petrophysical properties and therefore affect reservoir and borehole integrity have to be investigated for different storage and sealing formations and tectonic situations of the storage site.

References

Haist, M., Soddemann, N., Hirsch, A., Klumbach, S., Müller, B., Schilling, F.R. and Müller, H.S. [2011] Cementing – Research Results and Future Challenges. GeoEnergy/gebo Conference Celle Drilling, Celle, Niedersachsen, Germany.

Hirsch, A., Haist, M. and Müller, H.S. [2013] Durability of borehole cements used in carbon dioxide capture and storage. In: Proceedings of the First International Conference on Concrete Sustainability (CD), Tokyo, Japan, S. 623 – 630.

Kromer, M., Klumbach, S., Hirsch, A. and the COBRA-Team. [2012] CO_2-Borlochverschluss-Versuchsanlage für eine sichere Speicherung des Treibhausgases CO2. KIT Energy Center Annual Meeting, Karlsruhe, Baden-Württemberg, Germany.

Mühlbach, J., Klumbach, S., Hirsch, A., Kromer, M. and the COBRA-Team. [2013] Physical and Chemical Properties of Rocks and Well Cement for CO_2-Storage Applications in A Full Scale Borehole Simulator: First Results of the COBRA-Project. EAGE Sustainable Earth Science Conference 2013, Pau, Aquitaine, France.

Schilling, F.R., Klumbach, S., Haist, M., Kromer, M., Hirsch, A., Bieberstein, A., Mutschler, T., Neumann, T. and Scheuermann, A. [2012] A New Borehole Simulator for Full Scale *In-Situ* Well Cementing Experiments Under Elevated *p-T*-Conditions. DGG Conference GeoHannover, Hannover, Niedersachsen, Germany.