ghgt-13

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13th International Conference on
Greenhouse Gas Control Technologies

November 14th - 18th, 2016
SwissTech Convention Center - Lausanne, Switzerland

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[a]*Czech Geological Survey, branch Brno, Leitnerova 22, 658 69 Brno, Czech Republic*

[b]*International Research Institute of Stavanger, Prof. Olav Hanssensvei 15, 4021 Stavanger, Norway*

LBr-1 – RESEARCH CO_2 STORAGE PILOT IN THE CZECH REPUBLIC

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

INTRODUCTION

LBr-1 is a small depleted hydrocarbon field in the Czech part of the Vienna Basin. Within REPP-CO2, a Czech-Norwegian research project, a consortium of 7 partners is making the first steps towards obtaining a storage permit and realization of CO_2 injection in future. The work includes collecting the necessary data; conducting laboratory investigations; constructing a three-dimensional geological model of the storage complex, developing dynamic models to be used for simulation of the CO_2 injection phase and post-injection one; executing a risk analysis, and compiling a monitoring plan. Further project activities focus on methodological research of CO_2 geological storage, professional capacity building at Czech partner institutions, and knowledge dissemination.

STORAGE SITE

The LBr-1 site, chosen as the storage pilot, was produced in 1960s-1970s. The field is situated in the Vienna Basin, in the south-eastern part of the Czech Republic (Fig. 1).

The geological target for CO_2 storage is the Miocene (Badenian) oil- and gas-bearing sandstone sediments at a depth of ca. 1100 m together with the adjacent aquifer. The productive sandstone beds are part of the Láb horizon (Middle Badenian). The reservoir represents a combination of a stratigraphic and tectonic trap, sealed by an impermeable clayey caprock.

Fig. 1. Situation of the LBr-1 site (left) and satellite image of the site (right) with outline of the reservoir area (yellow polygon) and legacy wells (yellow dots). The reservoir is ca. 3 km long and max. 600 m wide.

BUILDING THE 3D GEOLOGICAL MODEL

The newly built 3D geological model is based on re-evaluated well logs, core samples and new 3D seismic data interpretation as well as archival reports and publications. The age and quality of the archival data and core material caused complications in the data processing and interpretation.

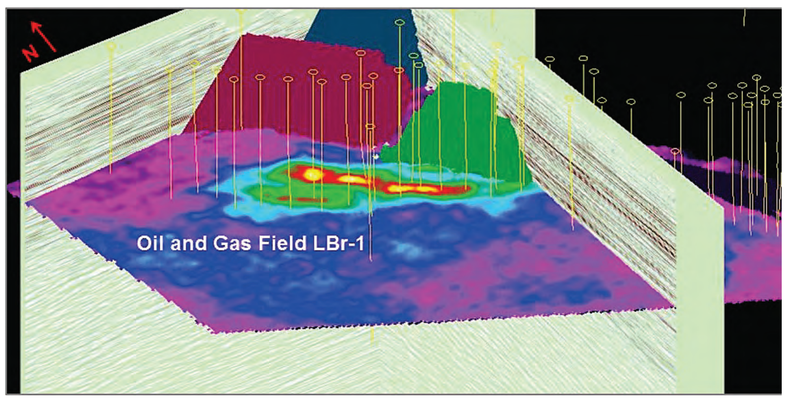


Fig. 2. Example of integration of seismic and well log data – cut of seismic section with SP well log curves (violet) and interpreted horizons. The depth range of the section is ca. 750–1170 m.

Marker horizons were identified and correlated in 56 well logs. Depositional facies evolution was characterized in time and space from e.g. upward coarsening or fining trends as well as core samples examination. Then the well logs were integrated with the seismic data. Finally, the 3D geological model was constructed with surfaces, faults and lithological pinch-outs (Fig. 2). The new interpretation has brought a new insight in the geometry and properties of the reservoir.

DYNAMIC MODELLING

A material balanced model was built in order to estimate aquifer properties and potential CO_2 storage volume based on the production history (Fig. 3). The aquifer properties (volume and productivity) were adjusted to match the observed reservoir pressures. Three cases (optimistic, reference, pessimistic) were developed to account for uncertainty in production data.

Full field reservoir model was build based on new geology and laboratory study. The model was history matched and would be used to evaluate storage potential under three key scenarios: pure storage without pressure relief; pressure relief by water production; EOR (enhanced oil recovery), where storage is preceded with enhanced hydrocarbons production. Optimal injection strategy is evaluated.

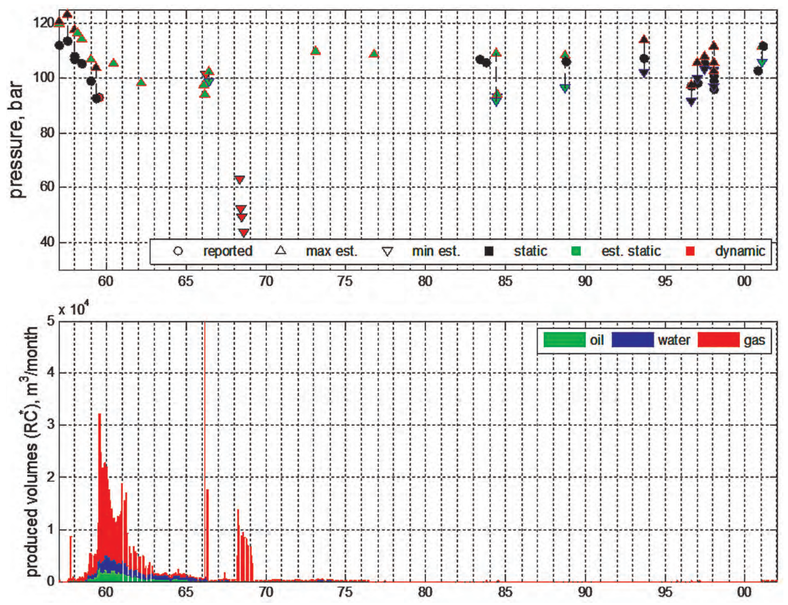


Fig. 3. Historical pressure measurements (upper plot) and production rates (lower) in reservoir conditions vs. time.

RISK ANALYSIS

The risk analysis of the LBr-1 field is based on the bow-tie approach to identify leakage causes and pathways, preventive and mitigating barriers and human operational and environmental consequences of different CO_2 leakage scenarios.

The most important risk elements are more than 100 legacy exploration and production wells, 25 of them directly penetrating the target reservoir horizon (Fig. 4a).

All wells have been abandoned at the end of the production (Fig. 4b), and some of them are currently subject of a re-abandonment project.

The risk these wells represent for CO_2 storage, as well as the possibility to use the existing wells for CO_2 injection and/or monitoring were studied.

A generalized approach to the methodology and the quantitative risk assessment is provided, including evaluations of flow capabilities along faults, leakage detection and prevention capabilities of the site, and environmental impact scenarios.

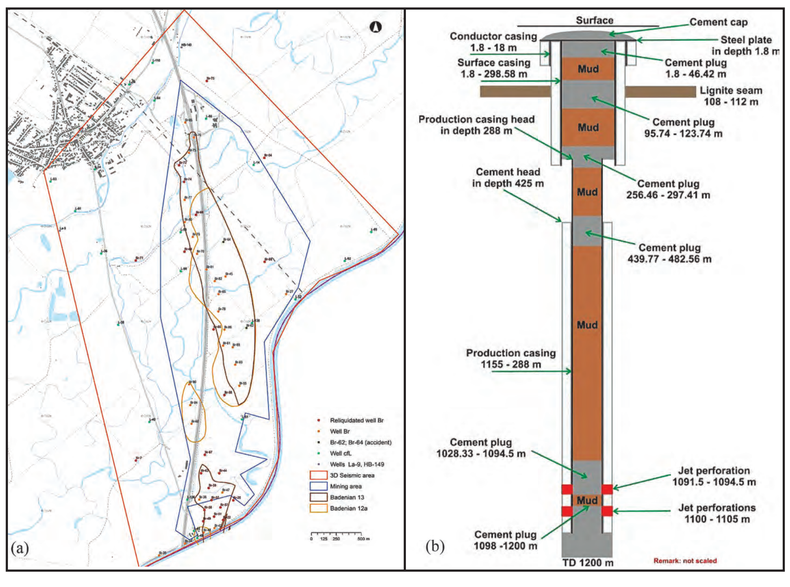


Fig. 4. (a) Site map with locations of legacy exploration and production wells on top of production horizons (Badenian 12a and Badenian 13); (b) Diagram of the Br-73 well design after abandonment.

CONCLUSIONS

The REPP-CO2 project represents the first step in development of the LBr-1 site towards a research CO_2 storage pilot in the Czech Republic. Fundamental milestones of site assessment, site characterisation, CO_2 injection simulation and risk analysis have been achieved, and plans for further stages of site development have been elaborated.

The work is now continuing within the ENOS project funded by the EC within the Horizon 2020 programme, with the final vision to start CO_2 injection around 2020.

ACKNOWLEDGEMENTS

The REPP-CO2 project is supported by a grant from Norway within the CZ08 Programme of Norway Grants 2009-2014. The authors would like to acknowledge more than 100 other project participants from their own and partner institutions for their contribution to the project and results presented here. Special thanks are given to MND, a.s. for provision of LBr-1 archive site data.

Juraj Franců*[a], Miroslav Pereszlényi[a], Fridtjof Riis[b], Ondřej Prokop[a], Lukáš Jurenka[a], Vít Hladík[a], Oldřich Krejčí[a]

[a] *Czech Geological Survey, branch Brno, Leitnerova 22, 658 69 Brno, Czech Republic*
[b] *International Research Institute of Stavanger, Prof. Olav Hanssensvei 15, 4021 Stavanger, Norway*

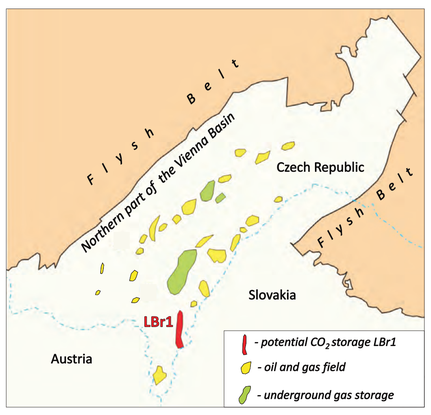
3D GEOLOGICAL MODEL OF POTENTIAL CO_2 STORAGE: ABANDONED OIL AND GAS FIELD LBR-1 IN THE VIENNA BASIN

13th International Conference on Greenhouse Gas Control Technologies, GHGT-13, 14-18 November 2016, Lausanne, Switzerland

INTRODUCTION

Vienna Basin VB is one of the most mature areas in the Central Europe in terms of the oil and gas exploration: over 1,900 deep wells were drilled in the Czech part of the VB and over 1000 km of 2D and about 350 km^2 of 3D seismic surveys have been measured. 18 oil and gas fields were discovered, 3.9 million tons of oil and 3 billion m^3 of gas have been recovered. By 2000, the majority of the known oil and gas fields were close to depletion. The most suitable ones were converted to underground gas storages.
Here we test if the small and medium-sized depleted oil and gas fields would be suitable for CO_2 geological storage and whether the storage can possibly be combined with CO_2-driven enhanced oil recovery (EOR).

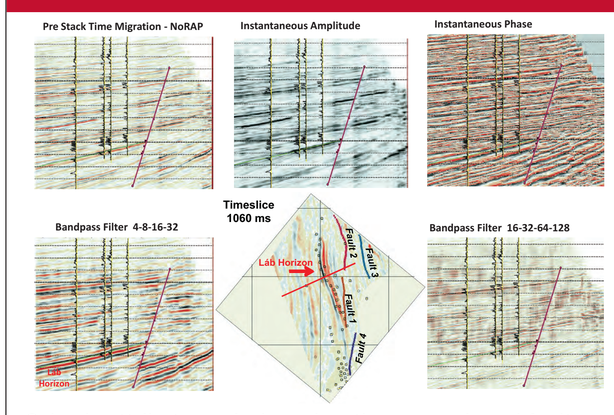
The Czech-Norwegian REPP-CO2 research project evaluates jointly one of the depleted oil and gas fields - LBr-1, where exploration and exploitation was carried out in the 1960s - 1970s .



Position of the abandoned oil and gas field LBr-1 in the Northern Vienna basin

Our 3D geological model of the LBr-1 site is presented more in detail as a basis for the assessment of the site suitability for geological storage of fluids like natural gas or CO_2. The main focus is dedicated to the integration of the old well- and related disseminated archive data with results arising from new 3D seismic survey interpretation.

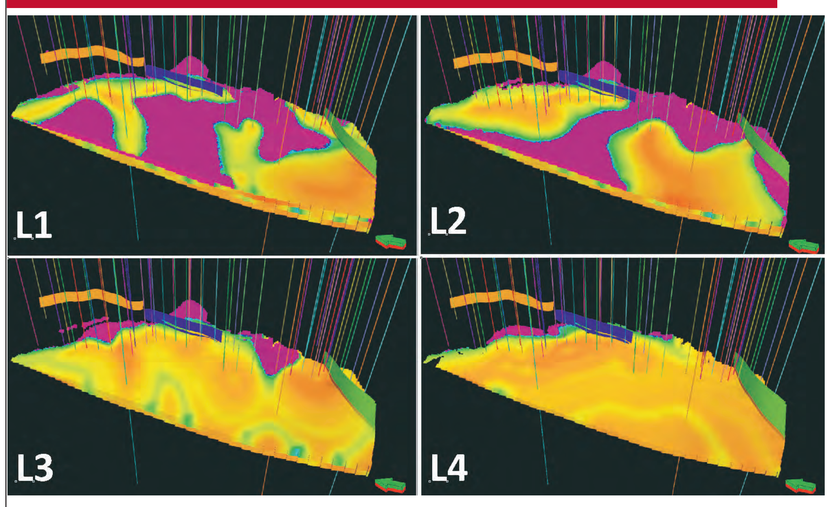
ANALYSIS AND MODELING OF FAULTS



Faults and their shapes are visible in the seismic lines as abrupt termination and change in the dip of the reflections. Clear N-S fault system was identified with through of 10 - 20 m, which fades towards N and S.

Seismic attribute analysis makes the reservoir and faults much better visible

PETROPHYSICAL MODEL



3D model of the storage complex: permeability in the partial L1-L4 layers of the Lab horizon. Impermeable shale is shown in purple Because there were practically no lab petrophysical analytical data of the core samples, the well log data were used to calculate the porosity and permeability. They served as a basis for construction of porosity and permeability maps of the partial sands L1-L4 of the Lab horizon.

CONCLUSIONS

1. Small reserves, complex lithology, variable petrophysical properties and narrow elongated shape of the reservoir are not favourable for conversion of the LBr-1 reservoir to an economic underground natural gas storage . On the other hand, the geological 3D model suggests use of the LBr-1 North as a suitable CO_2 geological storage pilot.

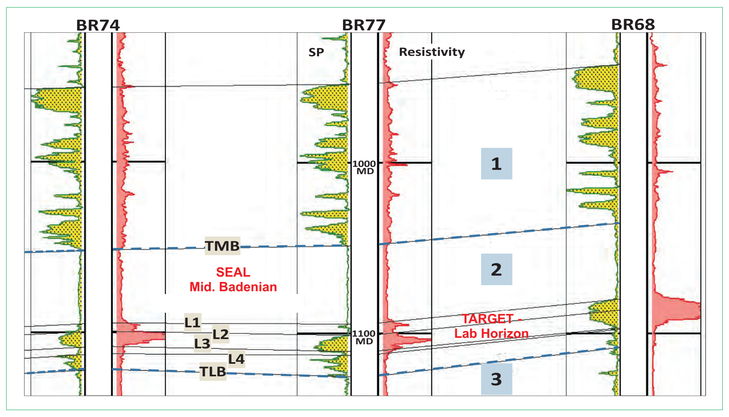
2. The interpreted small-scale faults have no significant negative impact on seal integrity and the risk of gas leaks is low.

3. Potential spill points are identified; they represent key information for subsequent dynamic simulations of CO_2 injection, determining the maximum quantity of possibly stored CO_2.

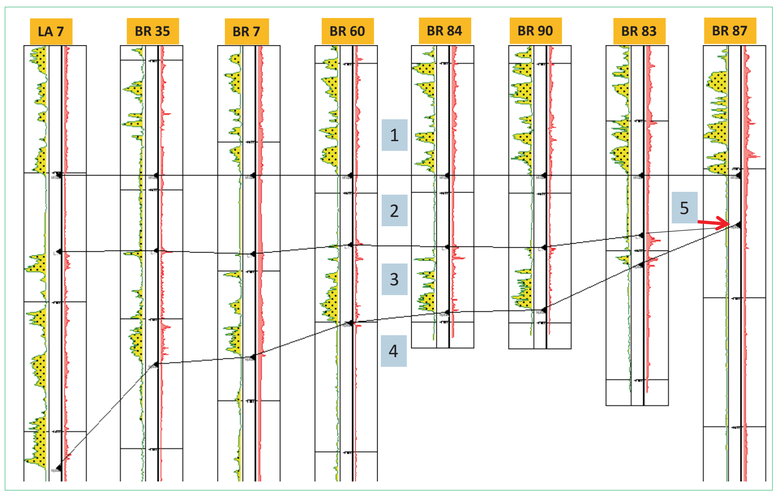
4. The geological structure itself does not contain any high risks associated with future injection of fluids while the abandoned wells and quality of their completion require more attention.

5. The updated reserves estimation comprise about 290 thous. sm^3 initial oil in place and 97 mil. sm^3 of initial gas in place, 73 thous. sm^3 recoverable oil and 78 mil. sm^3 of recoverable gas. These values are in fairly good agreement with the total produced oil and gas from the LBr-1 field.

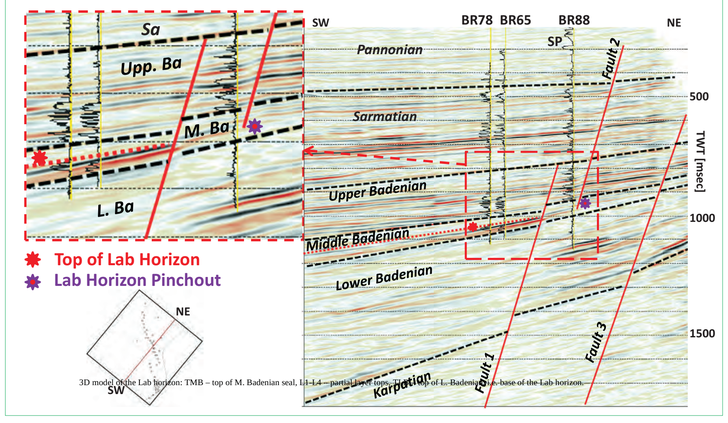
INTERPRETATION OF WELL AND SEISMIC DATA – MAPPING HORIZONS



Detailed well log correlation: 1 - U. Badenian, 2 - M. Badenian seal (top - TMB), L1-L4 partial layers of the major reservoir - Lab horizon intercalated by thin shale layers, and 3 - L. Badenian shales (top - TLB).



WSW-ENE cross section with SP and RAG2 (resistivity) well logs: 1 - Upper Badenian overburden, (2) - Middle Badenian shale seal, 3 - Lab horizon, the major reservoir, 4 - Lower Badenian shale and 5 - pinch-out of the sands.



Integration of seismic and well log data in time domain (ms). The seismic data show the areal shape of sandstone pinchout and are used in maps of the reservoir bodies. Faults and their shapes are visible in the seismic lines as abrupt termination and change in the dip of the reflections. Clear N-S fault system was identified with through of 10 - 20 m, which fades towards N and S.

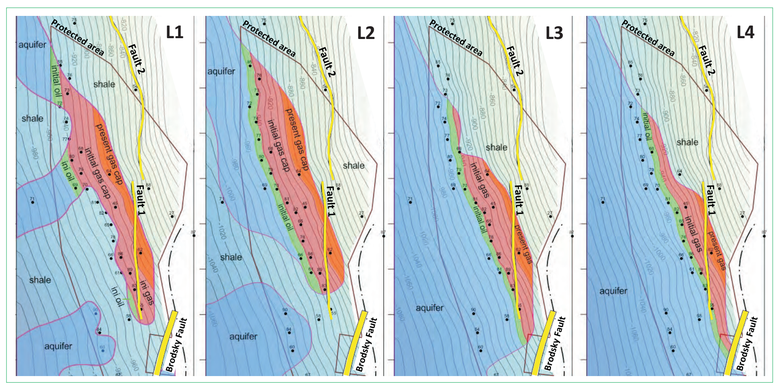
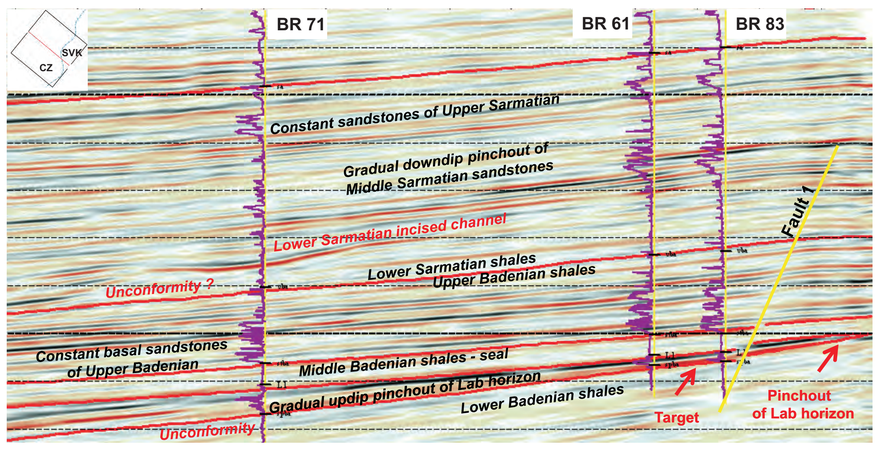


Fig. 12 Tops of the partial layers of the Lab horizon L1, L2, L3 and L4 with areal extent of initial and present gas cap (red), initial oil zone (green), and aquifer (dark blue).

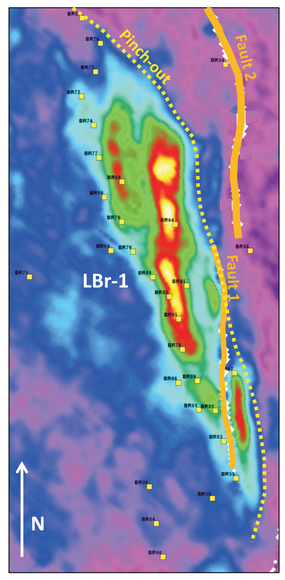
LITHO-FACIAL ANALYSIS AND ANALYSIS OF SEISMIC ATTRIBUTES



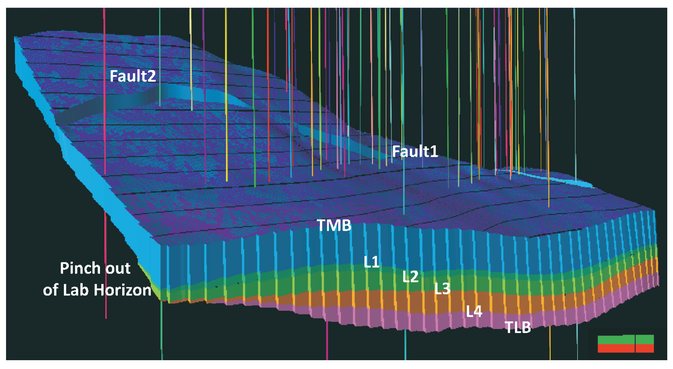
Several additional sedimentological phenomena were identified in the seismic lines, e.g. regional stability of the shale seal, constant sand dominated Upper Badenian, potential unconformity at the Sarmatian/Badenian boundary, and an incised channel in the Lower Sarmatian. Gradual downdip pinchout occurs in the Middle Sarmatian, i.e. oposit direction to the middle Badenian sand bodies. It suggests the change in the basin geometry at the Badenian\Sarmatian phase of

Average absolute amplitude of the Lab horizon.

Application of seismic attribute analysis made it possible to visualize more details in the architecture of the storage complex. The major reflectors and the faults are picked more precisely in this way. The average absolute amplitude shows the residual hydrocarbon saturation of the reservoir, probably close to the initial extent of the oil and gas field.



3D BASIN MODEL OF THE STORAGE COMPLEX



3D model of the Lab horizon: TMB – top of M. Badenian seal, L1-L4 – partial reservoir layer tops, TLB – top of L. Badenian, i.e. base of the Lab horizon. Each color represents a volume, properties, such as lithology.

An updated reserves estimation according to the 3D model of the LBr-1 storage complex provides the following values [a]. For comparison the archival estimated values [b] are shown with the really recovered oil and gas [c].

Oil in place Gas in place

a

STOIIP	GIIP	Recoverable oil	Recoverable gas
[*10^3 sm3]	[*10^3 sm3]	[*10^3 sm3]	[*10^3 sm3]
290	96970	73	77576

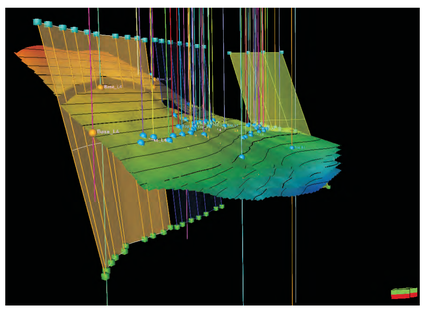
b

STOIIP	GIIP	Recoverable oil	Recoverable gas
[*10^3 sm3]	[*10^3 sm3]	[*10^3 sm3]	[*10^3 sm3]
305	83778	61.1	75400

c

Recovered oil	Recovered gas
[*10^3 sm3]	[*10^3 sm3]
61.9	68200

Recoverable / Recovered



3D model of the LBr-1 Co_2 storage complex: Four above one another sands are identified as partial reservoir bodies. The tops are cut by faults, which act as seals.

ACKNOWLEDGEMENTS

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REPP-CO_2: EQUILIBRIUM MODELLING OF CO_2-ROCK-BRINE SYSTEMS

Martin Klajmon[a,b], Václava Havlová[a], Angela Mendoza[a,b], Radek Červinka[a], Juraj Franců[c], Roman Berenblyum[d], Øystein Arild[d]

[a)] ÚJV Řež, a. s., Czech Republic; [b)] University of Chemistry and Technology, Prague, Czech Republic, [c)] Czech Geological Survey, branch Brno, Czech Republic; [d)] International Research Institute of Stavanger (IRIS), Norway; ✉ martin.klajmon@ujv.cz, vaclava.havlova@ujv.cz

INTRODUCTION

REPP-CO_2 is a Czech-Norwegian research project focusing primarily on the development of the CO_2 geological storage technology in the Czech Republic. This poster aims to present and summarize experimental and geochemical modelling activities covered by the company ÚJV Řež, a. s. within the project. These activities were focused on long-term laboratory experiments and both equilibrium and kinetic geochemical modelling studies on CO_2-water-rock interaction.

ROCK SAMPLES AND GROUNDWATER COMPOSITION

The LBr-1 site, a depleted Miocene oil field situated in the Czech part of the Vienna Basin, was chosen as the prepared CO_2 storage pilot. The rock samples used in our experiments originated from the reservoir itself or were analogous to rocks being present at the site. Four representative rock samples used for the study are described in Tab. 1. The composition and properties of synthetic saline water Br-45 (Tab. 2) used in experiments were statistically derived from chemical analyses of deep groundwater samples relevant to the storage site.

Parameter	Conc. (mg l^{-1})
Ca^{2+}	142.9
Mg^{2+}	55.2
Na^{+}	3777.0
Cl^{-}	4826.2
HCO_3^{-}	1410.9
SO_4^{2-}	785.9
TDS	10998.1
pH	8,1

Tab. 2: The composition of brine Br-45.

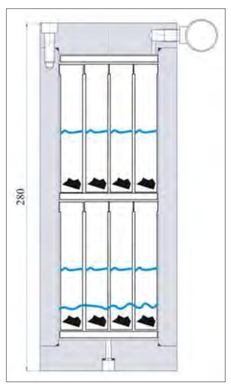

Fig. 1: Pressure steel chamber for long-term static experiment with vial layout and samples.

Fig. 2: Photo of the double chamber apparatus used for long-term static experiments.

LONG-TERM STATIC EXPERIMENTS

The static batch experiments were based on long-term interactions of rock samples with supercritical CO_2 and brine Br-45 at temperature 40 °C and pressure 75 atm. The rock samples were inserted into the glass vials and the synthetic brine was added. All the vials were inserted into the high pressure steel chamber (Fig. 1). The chamber was closed and filled with supercritical CO_2 under 40 °C and 75 atm (Fig. 2). The samples were kept under these conditions for 60 days. After the experiment the vials were taken out of the chamber and pH and conductivity were consequently measured in each vial. All rock samples were characterized using XRD and mercury porosimetry measurements.

GEOCHEMICAL MODELLING

The both equilibrium and kinetic modelling studies on CO_2-water-rock interaction were performed in the geochemical program PHREEQC version 3 [1] applying the LLNL.DAT thermodynamic database. We have modified the database by some additional data in order to make it capable to capture the CO_2 dissolution in water correctly (see Fig. 3 depicting prediction of CO_2 solubility in brine Br-45).

Fig. 3: CO_2 solubility in brine Br-45 predicted with PHREEQC using the modified LLNL.DAT database.

In equilibrium modeling of CO_2-rock-brine systems, mineral assemblages representing the rock samples were equilibrated with the brine Br-45 and CO_2 at temperature 43 °C and pressure 115 atm. The following secondary minerals were allowed do precipitate (if thermodynamically possible): ankerite, magnesite, siderite, kaolinite, gibbsite, anhydrite, boehmite, pyrite, goethite, Na-montmorillonite, and carbonate mineral dawsonite, despite the fact that the role and stability of dawsonite in CO_2 flooded reservoirs is still under scientific debate [2]. Kinetic simulations were consequently conducted to investigate also the time scale of the occuring geochemical processes. For the rate of precipitation and dissloution of minerals, a simple formalism of Lasaga was applied [3]. Kinetic parameters for minerals were taken from the literature [3].

EXPERIMENTAL RESULTS

The presented results are focused on the rock samples, representing the main constituents of the injection system, that were exposed to supercritical CO_2. Comparing the rock samples composition prior and after the experiments (Tab. 1), it is clear that mineralogical changes are relatively small and do not exceed several %. No general trends can therefore be formulated.

Sample	Description (stratigraphy)		Quartz	Muscovite	Microcline	Albite	Kaolinite	Chlorite	Calcite	Siderite	Dolomite	Ankerite	Porosity
Br-52	**Reservoir horizon** Fine grained sandstone (Middle Badenian, 1150-1155 m)	Prior	60.23	9.83	3.85	7.66	-	6.42	6.97	-	3.12	-	24.51
		After	62.75	11.03	1.35	6.86	-	4.62	8.18	-	4.58	-	32.13
Br-60	**Cap rock** Calcareous siltstone up to claystone (Middle Badenian, 1150-1155 m)	Prior	29.88	35.14		7.92	-	6.63	11.53	-	8.90	-	9.54
		After	29.33	36.35	3.62	7.90	-	4.83	10.53	-	7.43	-	22.59
Hr-197	**Underlying rock layer** Calcareous sandstone (Lower Badenian, 1075-1079 m)	Prior	48.57	13.35	2.25	16.13	4.61	4.30	4.57	-	5.32	-	24.87
		After	52.79	10.30	2.43	10.70	-	6.70	6.93	-	3.36	6.69	45.43
Br-54	**Higher overburden rock** Clayey siltstone/silty claystone (Sarmatian, 800-806 m)	Prior	39.41	20.74	3.88	7.00	6.16	5.49	13.13	2.49	1.70	-	18.72
		After	50.72	15.01	1.85	6.24	6.22	7.44	10.42	-	2.09	-	41.80

Tab. 1: Description and composition (prior and after the static experiment) of representative rock samples used in our work. Mineralogical compositions are in weight % based on X-ray diffraction (XRD) analyses. Porosities are in %.

MODELLING RESULTS

Equilibrium modelling of CO_2-water-rock systems revealed that all systems undergo almost identical geochemical evolution in terms of equilibrium (see Fig. 4) mainly because of similar mineralogies and the same aqueous phase considered. The predicted geochemical changes are: dissolution of primary carbonates, chlorite, albite and microcline, and precipitation of quartz, kaolinite and secondary carbonates (ankerite and dawsonite).

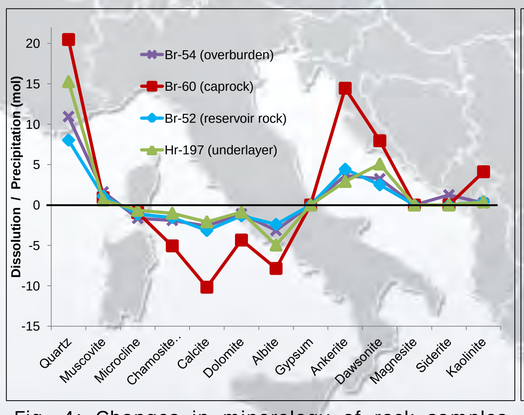

Fig. 4: Changes in mineralogy of rock samples predicted by equilibrium modeling.

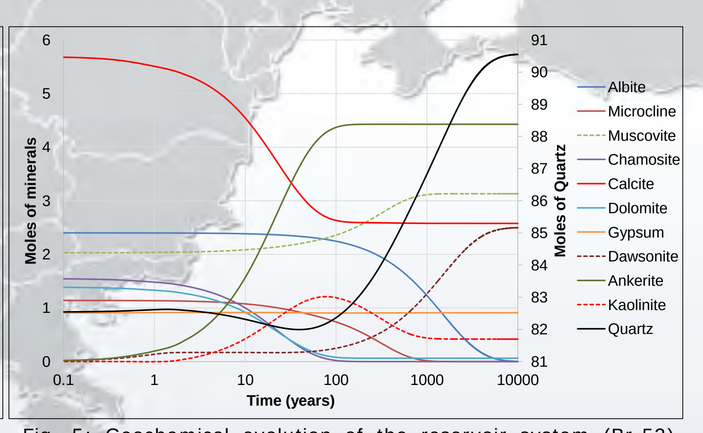

Fig. 5: Geochemical evolution of the reservoir system (Br-52) over 10,000 years.

Kinetic geochemical evolution of the reservoir system (Br-52) in time up to 10,000 years is illustrated in Fig. 5. The fastest reaction is the conversion of primary carbonates and chlorite into ankerite and kaolinite, while the slowest one is albite/dawsonite conversion.

MAIN CONCLUSIONS

No significant changes in mineralogy of rock samples were observed after two-month-long **static experiments**.

Equilibrium modelling in PHREEQC predicted that all rock samples react almost identically with CO_2 and water. The predicted geochemical changes are: dissolution of primary carbonates, feldspars and chlorite, and precipitation of quartz, kaolinite, ankerite and dawsonite.

Kinetic modelling revealed that the fastest process is dissolution of primary carbonates, while the slowest one is the albite/dawsonite conversion. Equilibrium state will be achieved after *ca.* 6,000 years.

ACKNOWLEDGEMENT

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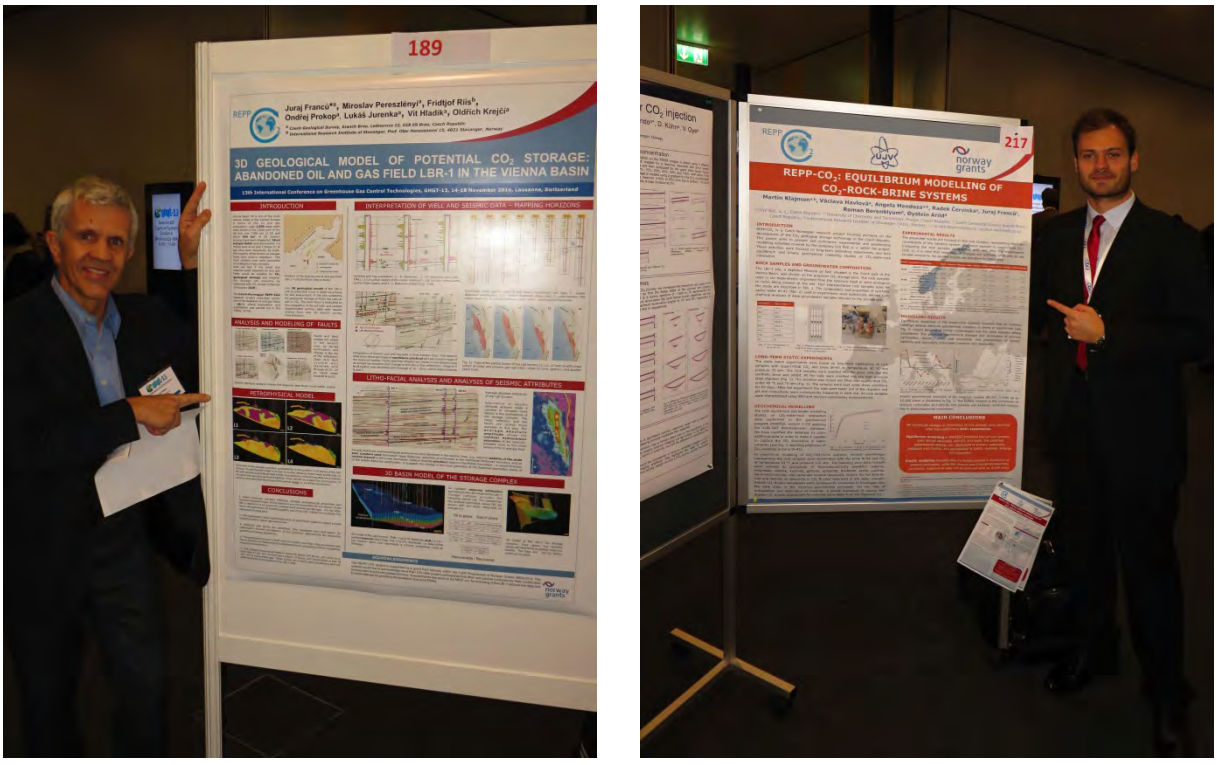
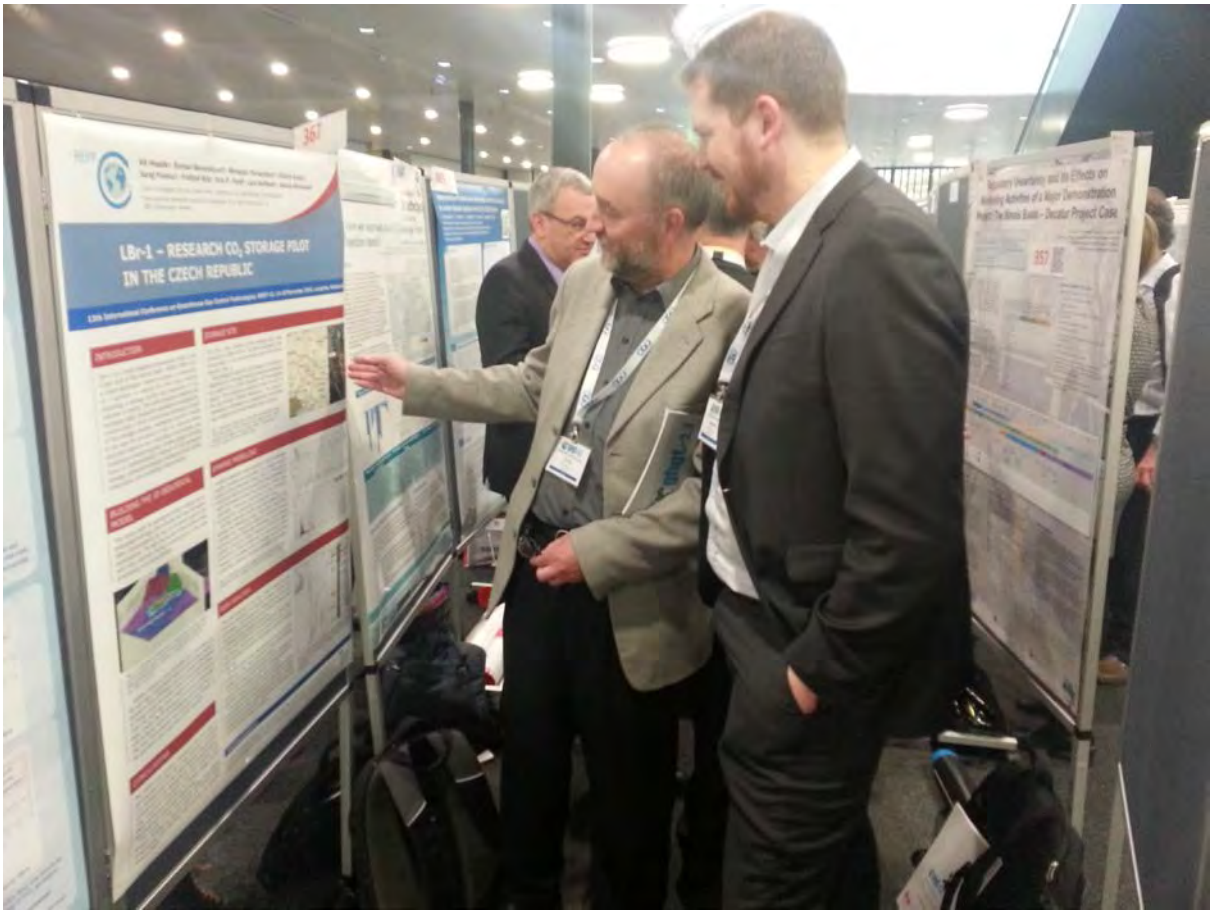
1.4

M. Mansouri (IRIS) prezentuje výsledky analýzy rizik z projektu REPP-CO2 na konferenci GHGT-13



J. Franců (ČGS) a M. Klajmon (ÚJV Řež) se svými postery na konferenci GHGT-13



V. Hladík (ČGS) představuje poster projektu REPP-CO2 B. Beckovi ze Světové banky