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## CO<sub>2</sub> pressurisation of a storage reservoir does not lead to salinization of shallower aquifers through intact caprocks

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### Abstract

Current world-wide scientific activities addressing geological CO<sub>2</sub> storage highlight one question of utmost importance for the general feasibility of CO<sub>2</sub> storage in saline aquifers: What is the risk for freshwater reservoirs by potential upward brine migration as a result of pressure elevation in the storage formations? A vertical 1D model from reservoir depth to the surface was applied of a prospective storage site in the North German Basin to study the sealing capacity of a multi barrier system. Results emphasize that saltwater does not reach into the groundwater resources through intact caprocks.

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*Keywords:* numerical modelling; CO<sub>2</sub> storage; saline aquifer; brine migration; freshwater salinisation

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### 1. Introduction

Anthropogenic emissions of carbon dioxide (CO<sub>2</sub>) into the atmosphere have had a significant impact on the Earth's carbon cycle. As part of the global effort to reduce climate change, the geological storage of CO<sub>2</sub> has been accepted as a method that may provide up to 25 % of the total reduction of emissions, although this figure is still subject to change [1]. In most scenario studies for climate mitigation, the role of Carbon Capture and Storage (CCS)

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in the portfolios increases over the course of the century. It is found that CCS could reduce the costs of stabilizing CO<sub>2</sub> concentrations in the atmosphere by 30 % or more [1]. Therefore, geologic carbon sequestration in deep saline aquifers or depleted oil and gas fields is considered to be a promising method to mitigate the adverse impacts of climate change [2].

However, there are risks involved with this technology, which need to be assessed before deployment [3] and harm for the environment has to be excluded. But with an appropriate site selection based on standards of science and technology, the risks can be as little as with current activities in natural gas storage or deep underground disposal [1]. Potential problems comprise over-pressurisation, which could lead to either caprock failure and leakage of CO<sub>2</sub> or the displacement of brine. Both have a major impact on the viability and implementation of large scale CO<sub>2</sub> storage [2]. Pressurisation is governed by the rate at which brines in the storage formation can migrate away from the injection site. Important to note is the fact that the compressibility of the formation rock and the pore fluids as well as the dissolution of CO<sub>2</sub> in the formation water are not expected to play a significant role to the alleviation of pressurisation [2].

The study of Birkholzer et al. [4] underlines with numerical modelling of idealized subsurface formations the possible impact of industrial-scale CO<sub>2</sub> injection on regional multi-layered groundwater systems. It is shown that considerable pressure build-up in the storage formation is supposed to occur more than 100 km away from the injection zone. However, the lateral brine transport velocity and migration distance is less significant, meaning no changes in water quality. Within that work it is concluded that brine migration through a sequence of layers into shallow groundwater is extremely unlikely [4].

Current world-wide scientific activities addressing geological CO<sub>2</sub> storage highlight the question: What is the risk for freshwater reservoirs by potential upward brine migration from saline aquifers as a result of pressure elevation in CO<sub>2</sub> storage formations? Within this study we investigate the potential for salinisation of shallow drinking water aquifers based on a simplified 1D model in the region Beeskow-Birkholz in Brandenburg, Germany.

## **2. Site geology, applied simulation code and calculated scenarios**

### *2.1. Site geology*

The site Beeskow-Birkholz is located in the Southern part of the Northeast German Basin (NEGB) and is dominated by an anticline structure. The structure describes a NW-SE oriented asymmetric anticline of approximately 15 km length, which was formed by salt tectonic processes in Upper Permian evaporites. The trend of the anticline is sub-parallel to the major regional fault zones as the Lausitz fault zone (LFZ) and the Guben-Fürstenwalde fault zone (GFFZ). Stackebrandt and Manhenke [5] suggest the GFFZ as major influence on local salt mobilization and tectonics at Beeskow-Birkholz. The top of the Upper Permian salt is located at a depth of approximately 1,550 m. Due to the salt movement, the Mesozoic cap rocks are uplifted and partially eroded. In the centre of the structure, the Cretaceous and Jurassic cap rocks are missing, and the Upper Triassic (Keuper) is in direct contact with unconsolidated Cenozoic rocks. At the margins of the anticline, the Jurassic sediments are still present. Cretaceous formations do not exist area-wide and are partly incomplete, especially in the Upper Cretaceous. The potential reservoir rocks are in Lower Triassic successions (Middle Buntsandstein depth approximately 1,075 m - 1,255 m at top of anticline). It is covered by the caprocks of the Upper Buntsandstein, the Muschelkalk (Middle Triassic) and the Keuper, and at the flanks of the anticline by Jurassic sediments.

The stratigraphic layers of the geological model comprise eight different geological units, ranging from the Carboniferous to the Quarternary. Special focus has been directed to the Buntsandstein sandstones, and in particular the Middle Buntsandstein (Lower Triassic) with the target formations Volpriehausen, Detfurth and Hardegsen. The total thickness of the three formations of the Middle Buntsandstein is about 200 m, in which Volpriehausen marks 80 m, Detfurth 60 m and Hardegsen 40 m. Top Hardegsen varies in depth from 1,075 m (top of anticline) to 1,370 m (flank of anticline). The base of Volpriehausen shows the same pattern as Hardegsen and is encountered from 1,255 m (top of anticline) to 1,550 m (flank of anticline). Well data of four deep wells with a maximum depth of 2,666 m below ground surface assisted in defining the lithological boundaries.

2.2. Applied simulation code

The applied simulation code was the TOUGH2-MP simulator [6] involving different modifications for efficient processing of simulation models. The TOUGH2/ECO2N module [7] allows for simulating non-isothermal multi-phase flow of CO<sub>2</sub> and brine taking into account NaCl precipitation and dissolution.

2.3. Simulation of water migration across the multi-barrier system

The geological model as described above was applied to investigate an injection scenario in which CO<sub>2</sub> was injected over a time period of 20 years directly at the top of the anticline with a rate of 1.7 million tonnes per year corresponding to around one third of the CO<sub>2</sub> emissions of a large power plant of 1 GW [8-9]. The overpressure, determined was used in our 1D models as driving force for saltwater to migrate across the caprocks and secondary reservoirs in the multi barrier system towards shallow drinking water aquifers.

The 1D model represents a “worst case” scenario, since lateral water migration into intermediate high-permeable sandstone layers is not taken into account. Total model height comprises 900 m and ranges from the base of the Hardeggen sandstone at the top of the anticline (-1,115 m) to the base of the Rupelian clay (-215 m, Fig. 1).

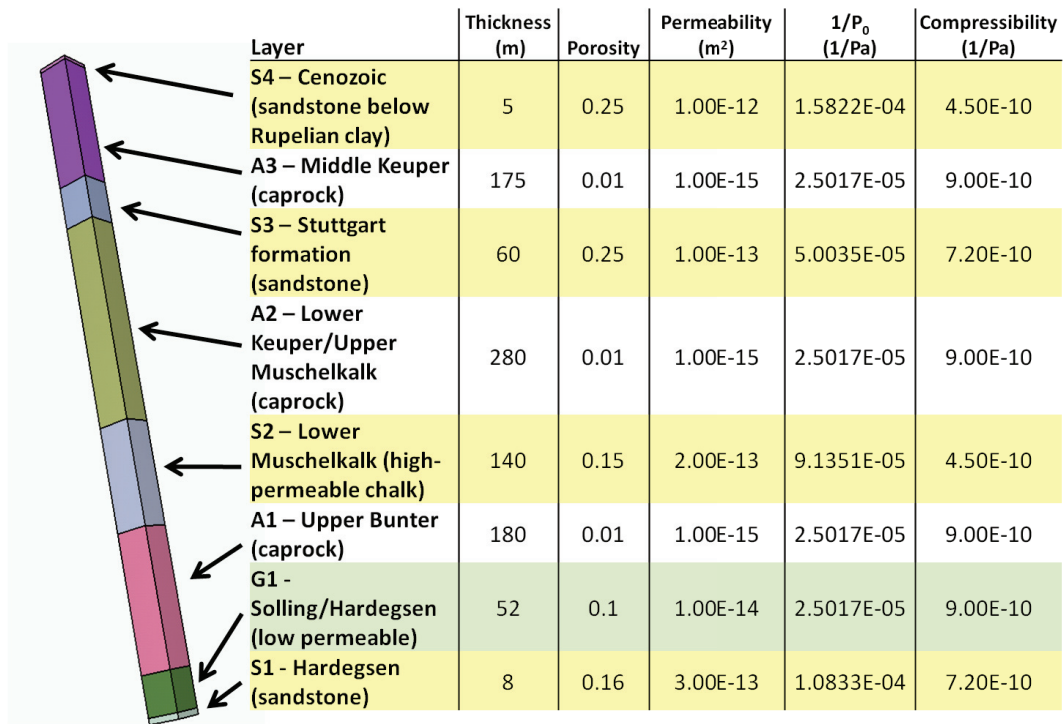


Fig. 1. The 1D model (1,785 elements) of the overburden up to the Rupelian clay (main regional barrier) with parameters applied.

The model discretization in vertical direction was 0.5 m for all formations. The Hardeggen sandstone was assigned one element of 8 m height and it was the location for the brine injection, which was performed with varying rates in accordance to the resulting pressure to coincide with the overpressure observed by Tillner et al. [8-9]. The pore volume of the topmost cell of the model was increased by a factor of 10<sup>4</sup> to represent an open boundary. The model was studied under a constant geothermal gradient of 0.03 °C per metre and an initial gradient of salinity from zero (top of the model) to 0.25 kg NaCl per kg brine (bottom of the model, injection) over the model height of 900 m.

Varying caprock permeabilities, including scaled capillary pressures according to Leverett [10], were investigated with regard to the resulting pressure elevation in the formations above the storage reservoir and the resulting increase of salinity in the vertical profile. Simulations were performed for a time period of 20 years (10 years of injection and 10 years after stop of injection), since the pressure build-up within the Hardeggen Formation requires a few years to establish depending on the chosen permeabilities.

### 3. Results and discussion

The overpressure of 30 bar determined in the 3D model due to injection of CO<sub>2</sub> into the storage reservoir [8-9] was applied to the 1D model. This overpressure acts as driver to potentially force saltwater to rise across caprocks and secondary reservoirs towards shallow drinking water aquifers. As mentioned, the 1D model represents a “worst case” scenario, because lateral flow is not taken into account. Varying caprock permeabilities were investigated with regard to resulting pressure elevation in the formations above the storage reservoir and the resulting increase of salinity in the vertical profile.

It can be seen that with decreasing permeability assigned to the caprocks the affected height of the model decreases as well (Figs. 2-5). While pressure increase is determined up to the top of the model with caprocks of  $10^{-15} \text{ m}^2$  permeability (Fig. 2), the influence is only recorded in the first caprock above the storage reservoir for a permeability of  $10^{-18} \text{ m}^2$  (Fig. 5). However, it can be assumed that caprocks consisting of shale comprise a permeability range from  $10^{-16} \text{ m}^2$  to as low as  $10^{-20} \text{ m}^2$  [11].

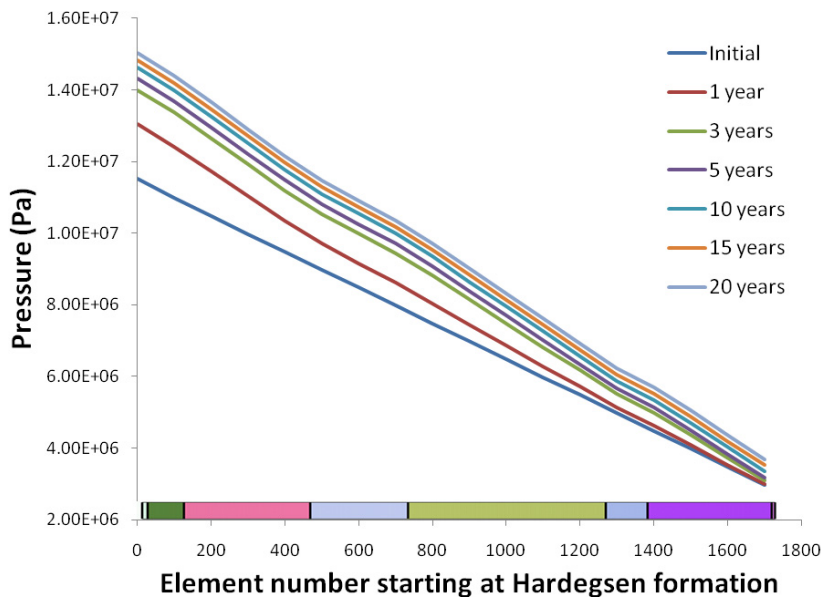


Fig. 2. Pressure increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-15} \text{ m}^2$ .

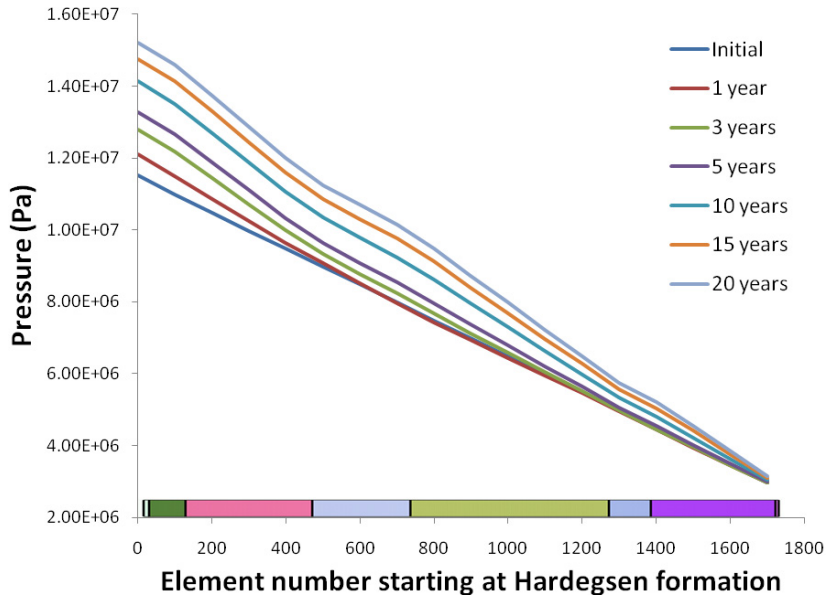


Fig. 3. Pressure increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-16} \text{ m}^2$ .

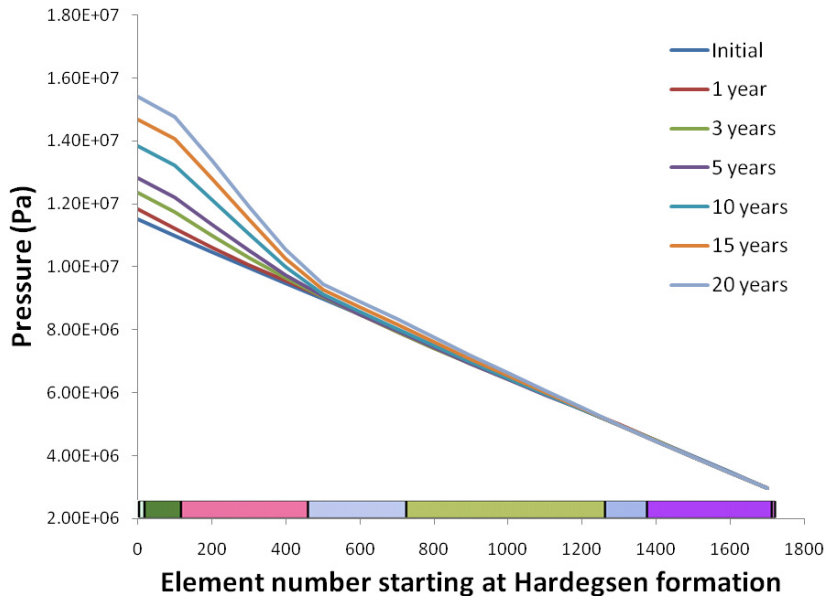


Fig. 4. Pressure increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-17} \text{ m}^2$ .

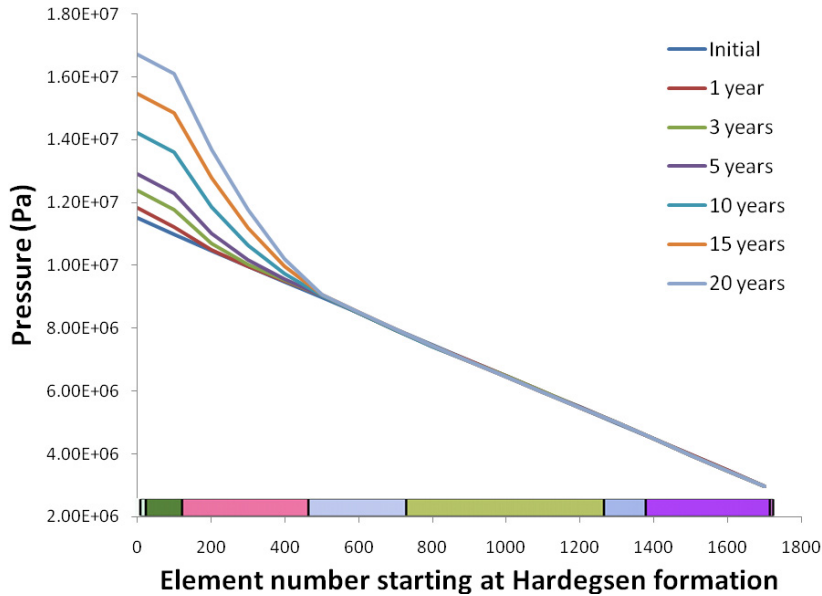


Fig. 5. Pressure increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-18} \text{ m}^2$ .

Salt concentration, due to pressurisation and resulting brine migration, was mainly increased in the caprocks (Figs. 6-9). This is in accordance with findings from literature [4]. In the present study, caprock permeabilities higher or equal to  $10^{-17} \text{ m}^2$  (Figs. 8 and 9) did not lead to any increase of salt concentration in formations above the reservoir. Significant salinisation, even within shallower levels of the model, was only observed in the case where caprocks were assigned a permeability of  $10^{-15} \text{ m}^2$  (Fig. 6). The main increase is about 0.03 kg NaCl per kg brine in this scenario.

The results emphasize that salinisation does mainly occur in formations of greater depth within the model. It can be concluded that with regard to the investigated overpressure due to injection of  $\text{CO}_2$ , saltwater from depth cannot reach the shallow drinking water aquifers through intact caprocks.

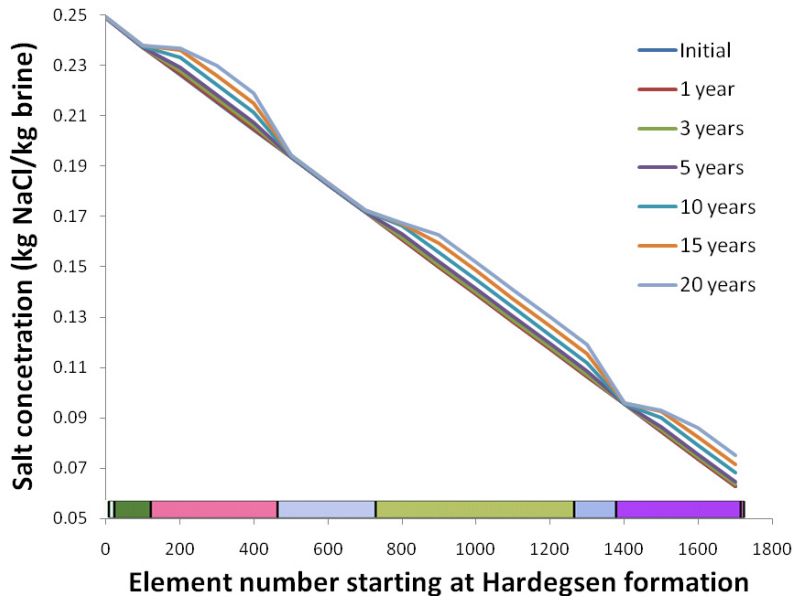


Fig. 6. Salinity increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-15} \text{ m}^2$ .

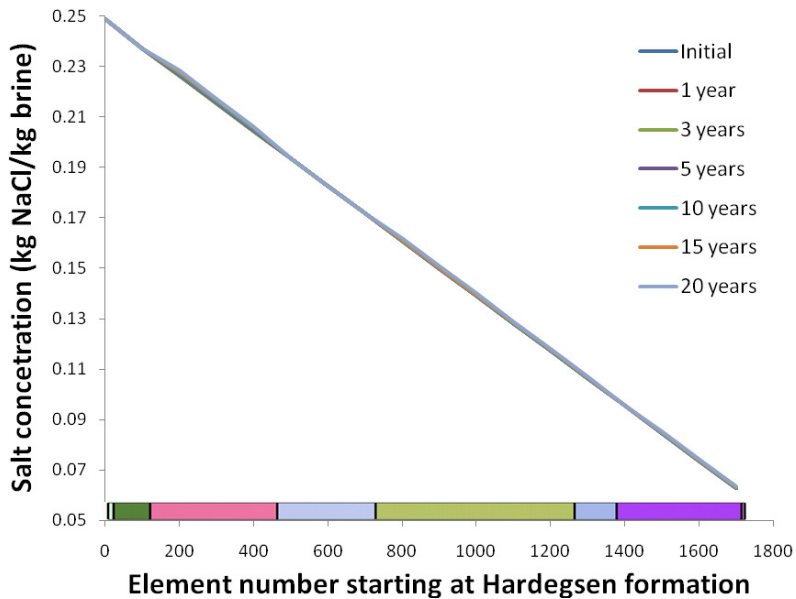


Fig. 7. Salinity increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-16} \text{ m}^2$ .

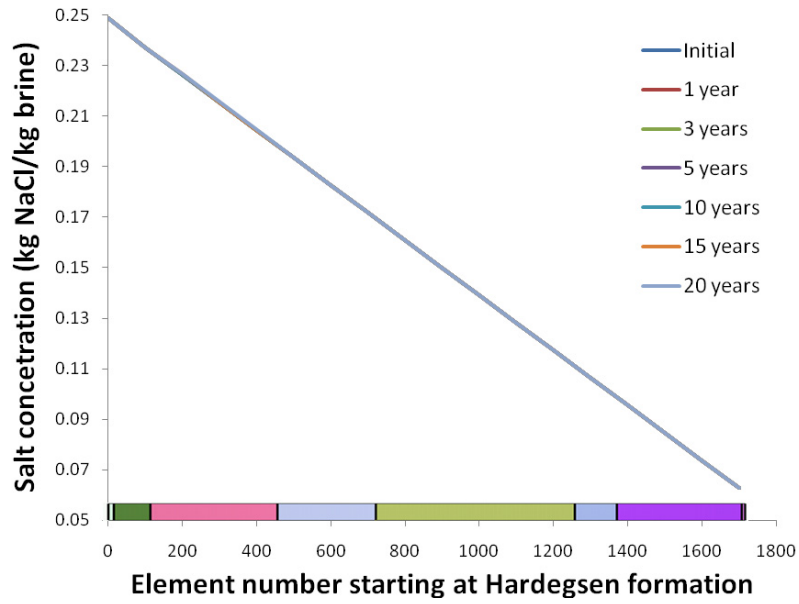


Fig. 8. Salinity increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-17} \text{ m}^2$ .

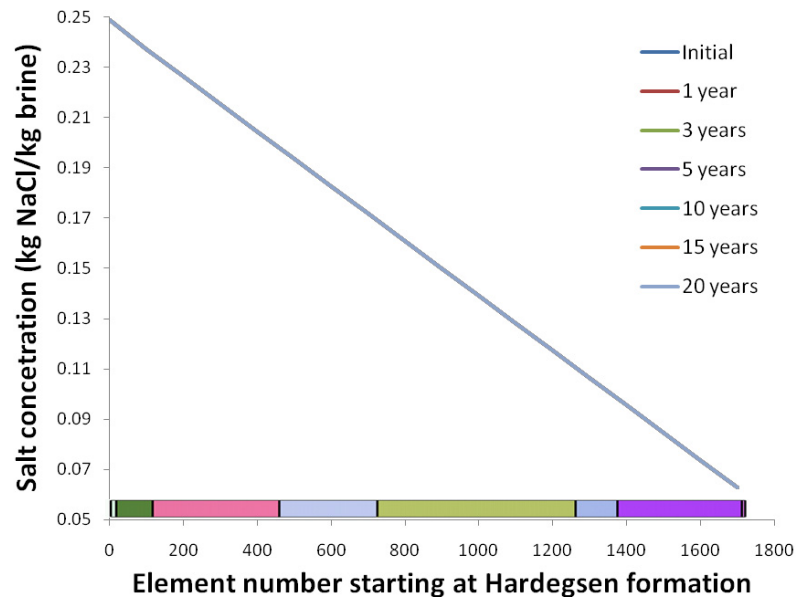


Fig. 9. Salinity increase over the vertical 1D profile for reservoirs (S1, S2, S3, S4; Fig. 1) and caprocks (A1, A2, A3; Fig. 1). For the simulation all caprocks were assigned the same permeability of  $10^{-18} \text{ m}^2$ .



#### 4. Conclusions

The storage of CO<sub>2</sub> in deep saline aquifers involves risks [3], which need to be assessed for any specific location before deployment. The aim is to exclude harm for the environment. Major problems with regard to the implementation of large-scale CO<sub>2</sub> storage comprise over-pressurisation and displacement of brine. Within the presented study, we investigated the potential storage region Beeskow-Birkholz in Brandenburg, Germany.

A simplified vertical 1D model from reservoir depth to the surface was applied to study the sealing capacity of the multi barrier system with the initial over-pressure determined from a 3D model [8-9] to assess potential salinisation of groundwater aquifers in various depths. The results emphasize that saltwater does not migrate into the freshwater resources through the existing caprock formations.

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#### References

- [1] IPCC. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change (Metz B, Davidson O, de Coninck HC, Loos M, Meyer LA, editors) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA; 2005.
- [2] IEAGHG. Pressurisation and brine displacement issues for deep saline formation CO<sub>2</sub> storage; 2010.
- [3] Kühn M. CO<sub>2</sub>-Speicherung - Chancen und Risiken. *Chemie unserer Zeit* 2011; 45:126-138.
- [4] Birkholzer JT, Zhou Q, Tsang C-F. Large-scale impact of CO<sub>2</sub> storage in deep saline aquifers: A sensitivity study on pressure response in stratified systems. *International Journal of Greenhouse Gas Control* 2009; 3:181-194.
- [5] Stackebrandt W, Manhenke V. Atlas zur Geologie von Brandenburg. Landesamt für Bergbau, Geologie und Rohstoffe (LBGR); 2004.
- [6] Zhang K, Wu Y-S, Pruess K. User's Guide for TOUGH2-MP - A Massively Parallel Version of the TOUGH2 Code, Report LBNL-315E, Earth Sciences Division, Lawrence Berkeley National Laboratory; 2008.
- [7] Pruess K. ECO2N. A TOUGH2 Fluid Property Module for Mixtures of Water, NaCl, and CO<sub>2</sub>, Report LBNL-57952, Lawrence Berkeley National Laboratory, Berkeley, California; 2005.
- [8] Tillner E, Kempka T, Nakaten B, Kühn M. Brine migration through fault zones: 3D numerical simulations for a prospective CO<sub>2</sub> storage site in Northeast Germany. *International Journal of Greenhouse Gas Control* 2013; 19:689-703. doi: 10.1016/j.ijggc.2013.03.012
- [9] Tillner E, Kempka T, Nakaten B, Kühn M. Geological CO<sub>2</sub> Storage Supports Geothermal Energy Exploitation: 3D Numerical Models Emphasize Feasibility of Synergetic Use. *Energy Procedia* 2013; 37:6604-6616. doi: 10.1016/j.egypro.2013.06.593.
- [10] Leverett MC Capillary behaviour in porous solids. *Transactions of the AIME* 1941; 142:159–172.
- [11] Kühn M, Gessner K. Coupled Process Models of Fluid Flow and Heat Transfer in Hydrothermal Systems in Three Dimensions. *Surveys in Geophysics* 2009; 30:193–210. doi: 10.1007/s10712-009-9060-8.