Development of an integrated monitoring concept to detect possible brine migration

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Introduction

Carbon dioxide is considered to be one cause of climate changing. Therefore, the preferential objective is to reduce the greenhouse gas, produced by industrial production. The long term storage in underground reservoirs represents one possible way to this aim. The most important research focus of the multidisciplinary integrated project BRINE is to ensure the safe storage operation (KEMPKA et al., 2010). That means an adequate monitoring of possible brine migration into freshwater aquifers from lower saline aquifers by gas displacement. For both the qualitative and quantitative investigation, a combination of several geophysical methods is needed. The electrical resistivity tomography (ERT) is a measurement method with a comparatively high spatial resolution on small scales. Therefore, it will be generally used for borehole and near subsurface investigations.

Geological setting

This research work refers to an area in eastern Brandenburg (Germany). However, the analysis can be applied to regions with comparable geological characteristics. The area is part of the North German Basin. The relevant reservoir horizon is located within a classic anticlinal structure, generated by salt tectonic processes. The Rupelian clay formation with an average thickness of 100 m is a natural liner between the deep brine aquifers and the freshwater zone. The layer is located at depths of 100 up to 300 m below the surface. Glaciogenically formed channels have partially deleted the formation structure implicating a potential upward migration of the underlying saltwater. Finally, the anticlinal structure is easterly flanked by a large fault-zone (STACKEBRANDT and MANHENKE, 2004).

Monitoring concept

Geological characteristics and technical limitations make high demands on an integrated monitoring system. The concentration of total dissolved solids (TDS) in the region of investigation is comparatively high, even at shallow depths. It ranges from 1 to 10 g/l above and 10 to 50 g/l below the Rupelian clay and from 50 to 350 g/l below the tertiary base (GRUBE et al., 2002). Therefore, only a small change in resistivity is expected due to a brine migration. The volume of investigation strongly depends on the electrode distance, which should be practicable in field surveys. Otherwise a depth of the storage horizon of about 1000 m makes it difficult to deploy ERT. Typically, the number of installed borehole electrodes is limited. In order to achieve an adequate resolution in critical depths and at the same time get an overview over the entire length of the borehole, a division of the profile should be performed. The adapted electrode array should consist of segments of short electrode distances near the reservoir and near the aquifer zone as well as long distances in between.

The presented monitoring concept focusses on three potential pathways. One cause of the upward brine migration could be a pressure build-up within the reservoir horizon. The injected CO_2 neither dissolves immediately, nor completely in the pore fluid. Hence, if the pressure is not regulated in time, the saline fluid could spread along zones of weakness. The most probable pathways are permeable fault-zones, wellbores with leakages along their annuli and formation defects within impermeable layers. The concept of a comprehensive monitoring system must take into account these critical points (Figure 1).

The fault-zones can extend over several kilometres. In addition to other monitoring methods, ERT provides a locally limited but high resolution. Using parallel profiles, the infiltration zone can be narrowed down by geoelectrical measurements. The most important application of ERT, however, is the monitoring of the near region of injection and observation wells. In addition, it offers the only possibility to detect small changes already at the storage horizon. A combination of shallow boreholes and surface measurements is particularly suitable for the monitoring of the Rupelian defects. They are circular to channel-like shaped with an extension of 100 m up to several hundred metres.

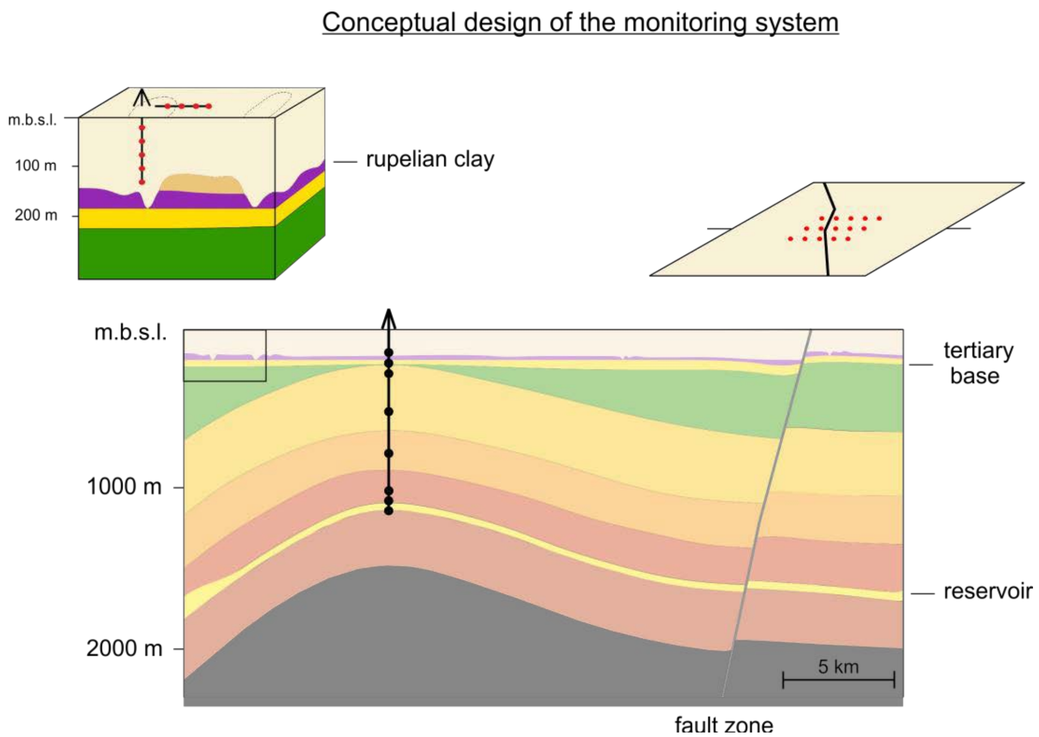

Fig. 1: Concept of a monitoring system including combined surface-downhole measurements near the formation defects, an adapted electrode array in the wellbore and parallel profiles along the fault zone (f.l.t.r.).

Model and experiment

The main objective is to find an optimal combination of several electrode arrays to detect time-lapse effects of the subsurface resistivity distribution. The presented study is divided into two work packages. In the first part, real-scale resistivity models of the described critical areas are created. For this purpose a simplified geological model of three layers (reservoir, consolidated sediments and unconsolidated deposits) is used. The increasing salinity is realised by decreasing electrical resistivity values. For different electrode geometries (e.g. inhole, crosshole, surface-downhole, etc.) and various electrode configurations (e.g. pole-pole, pole-dipole and dipole-dipole), a forward modelling study is performed. Subsequently, we invert the synthetic electrical resistances with an additional noise of 5 %. A well-established method to detect even small changes in resistivity is the ratio inversion technique (e.g. HAYLEY et al., 2011). For this analysis, however, a common difference method is used, which shows more distinct results. An example, calculated for the injection well, is demonstrated in Figure 2.

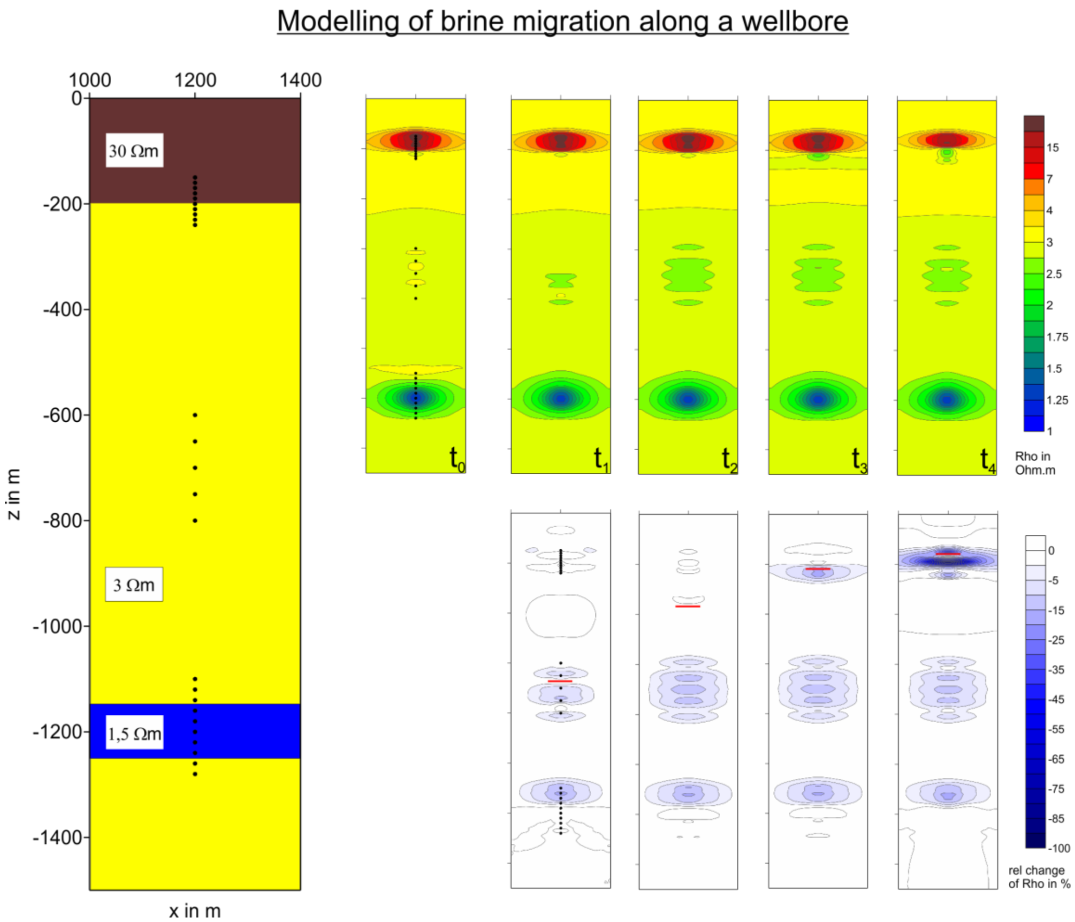

Fig. 2: Modelling of a brine upward migration in four steps. For modelling and inversion a bipole-bipole (cp-cp) configuration with an adapted geometry was used. The upper line shows the inversion results with t0 for the undisturbed model, the bottom line shows the differences (tn-t0) of inverted results. The red line marks width and height of the saltwater column.

In the second part of this study, the results are validated under controlled and well-defined laboratory conditions. In a cylindrical sandbox with a diameter and a height of 0.6 m, various combinations of borehole and surface electrodes can be installed in order to test certain configurations. For the filling, materials with different hydraulic characteristics can be used.

In a first experiment, homogeneous *Fontainebleau* sand with a porosity of 45 per cent and a permeability of 23 Darcy was used. The material was fully saturated with tap water at the beginning of the experiment. Synthetic brine with a concentration of 200g/l NaCl was injected at the bottom of the tank over a period of 6 days. With a combination of 50 surface- and 25 borehole electrodes the standard configurations (Wenner, Schlumberger and dipole-dipole) were measured.

Conclusions

First results of the modelling study compared with laboratory measurements demonstrate the potential of ERT for leakage detection, especially in the near subsurface and the surrounding of the wellbores. Obviously the adapted arrangement of electrodes both gives an adequate overview and limits the number of electrodes and subsequently the costs of a monitoring system. Next we will focus on the formation defects and fault-zones with more complex models. Other points of interest are the limit of spatial resolution and the limit of brine detection.

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