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CO_2-deposits at Vorderrhön area (Thuringia) – gas migration from a deep reservoir to surface?

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Abstract. In the EU-project NASCENT a group of international research institutions investigate natural accumulations of carbon dioxide, in order to assess processes associated with the geological storage of anthropogenic carbon dioxide. Geological sequestration offers the potential to store most of Europe's CO_2 emissions for geological timescales. NASCENT will address key issues of geological CO_2 sequestration by using natural occurrences as analogues for geological repositories of anthropogenic CO_2. These issues include the long-term safety and stability of underground storage and the potential environmental effects of leakage from an underground reservoir (Pearce et al., 2002).

1 The Vorderrhön deposits, a fractured reservoir

Natural CO_2 occurrences in the Werra potassic salt district (Vorderrhön), located in the western part of Thuringia, have been known since the end of the 19th century. Despite industrial demand for pure CO_2, systematic exploration only started in 1960, when CO_2 was found by chance during potash exploration drilling. Four small deposits are known in this area: Bernardshall, Schorngraben-Wölferbutt, Gehaus-Hohenwart and Oechsen. The carbon dioxide is accumulated in liquid or supercritical phase depending on the depth. The Oechsen deposit is in a depth of about 1000 m, and here the CO_2 is accumulated in a supercritical phase. Deposits in the Vorderrhön area were under production for more than 100 years but were definitely shut down in 1994.

The CO_2 deposits in the Vorderrhön region are accumulated below the Werra salt beds in the Rotliegendes and lower Werra cycle (Zechstein). These strata are nearly impermeable, except in fractured zones. All deposits occur along north-south trends since the CO_2 is confined to Rhenian fractures of this orientation in relatively low permeability (mean porosity 6% and permeability < 0.01 mD) Rotliegend siltstones. The subsequent tectonic events created ascent pathways for the CO_2 and the late Tertiary basalts from the basement rocks, as well as the fractures of the reservoir rocks. The overlying Kupferschiefer mudstone, Zechstein Limestone, and Lower Werra Anhydrite are also fractured reservoir rocks. The Werra Rock Salt and the intercalated potash seams "Thüringen" and "Hessen" form the seal to the CO_2 deposits. During Nascent project the sealing capacity of these rocks is being investigated in laboratory gas migration experiments. The potash salt has been extensively mined in the Werra district. Late Tertiary basalts form caps to hills, exploiting the Rhenian and Eggian fault zones and typically located at the intersections of these with Hercynian-trending fault zones that were repeatedly utilised by successive eruptions. A direct relationship between north-south-trending faults, volcanic rocks and CO_2 is demonstrated by exposures in the Werra potash mines. Although geochemical analysis has yet to establish a definitive origin for the CO_2, this relationship would suggest that it is of volcanic origin (see Fig. 1).

The raw gas at the Oechsen deposit has a mean composition of 97–99.5% CO_2, $\sim$ 1% N_2, $<$ 7% CH_4, with traces of H_2 and He and higher hydrocarbons. The CO_2 from the Zechstein Limestone (Schorngraben deposit) sometimes also contains traces of higher hydrocarbons. CO_2 was produced from 1958 to 1994 and transported to a production plant at Leimbach via a high-pressure steel pipeline about 3 km in length with an inner diameter of 60 mm. When the Schorngraben 1/58 well went into production in 1959, a new, ca. 10 km long pipeline was built via Stadtlengsfeld. In 1963, the pipeline was extended from Schorngraben 1 through the Oechse valley to the new Oechsen 1/61 well. Total production amounted to about 528 million kg CO_2. In the southwestern and southeastern parts of the study area, leaching has reduced the thickness of the Werra Rock Salt, which is locally removed where Hercynian fault zones intersect other trend directions, especially the Rhenian. Rock bursts, caused by CO_2 and undersized stilts (Carnallitit) occurred in the local potash mines in 1975 and 1989. The rock burst (local magnitude $M1$ of 5.6) on 13 March 1989, caused damage

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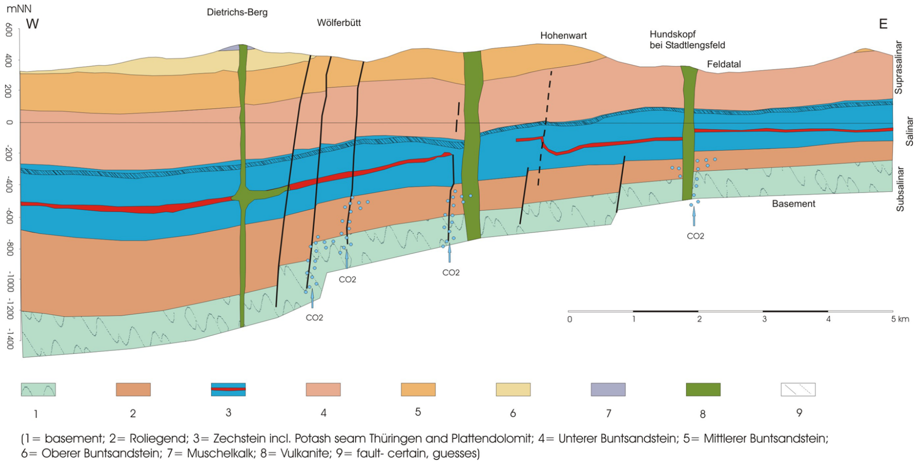

Fig. 1. Geological environment at Vorderrhön area (after Kästner, 1994).

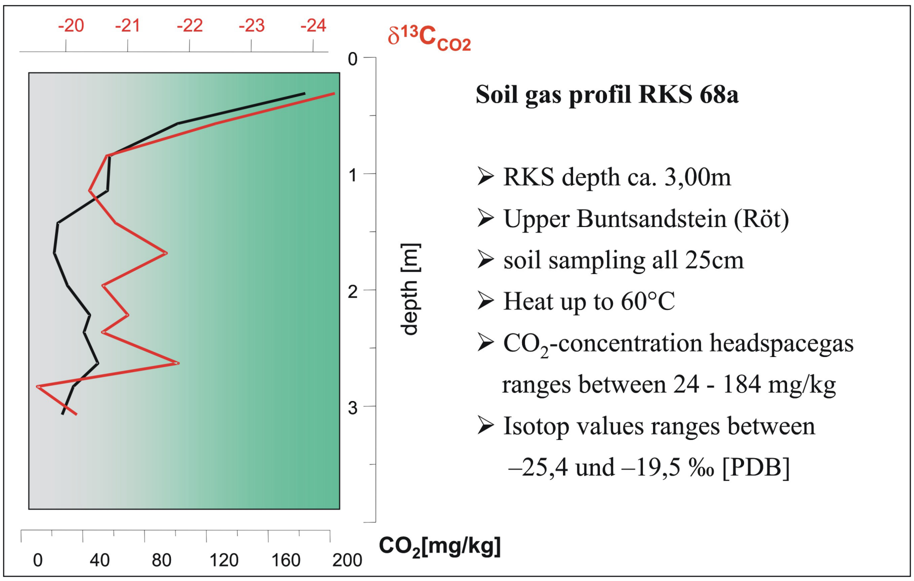

Fig. 2. Soil gas profile RKS 68a.

to local buildings in Völkershausen. The rock burst in the Merkers mine below Sünna had a magnitude $M1 = 5.2$. These blow-outs provide graphic evidence for CO_2 migration where salt is extensively leached.

soil gas analyses were used to select suitable locations for permanent stations to monitor variations in carbon dioxide concentration in soil gas.

2 Investigations

Several soil gas surveys have been completed above the Oechsen deposit for CO_2, Rn and He to detect anomalies in soil gas. A fault is believed to extend from the deposit to the near surface, although no surface expression is present. Increased concentrations of He and Rn and, less conclusively, CO_2 indicate that this fault is acting as a migration route for deep gases. However, $\delta^{13}C_{CO_2}$ analyses indicate that, although higher CO_2 concentrations are observed above the fault, much of this is of biogenic origin. The results of the

A shallow profile of soil gases to a depth of 3 m indicates that with increasing depth the concentration of CO_2 decreases and isotopic values ($\delta^{13}C_{CO_2}$) become heavier (see Fig. 2). This suggests that an isotopically heavier CO_2 of deeper origin is mixing with isotopically lighter biogenic CO_2 derived in the upper soil (Sheppard and Lloyd, 2002). It is not clear at this stage if this CO_2 is derived from increased biological activity in the soil as a result of increased CO_2 "fertilisation" from the deep source.

3 Results

Soil gas and groundwater analyses were performed in order to detect possible CO_2 leakages from the deep reservoir to the surface. The results of these investigations support the assumption that the CO_2 deposits in the Vorderrhön region can be considered as a closed systems. The long-term stability of the salt beds seems to be confirmed by the analytical results. The elevated CO_2, radon, and helium concentrations found at the surface across a fault zone may be explained by the morphology (varying moisture), hydrogeological conditions and last but not least by biogenic activity.

Based on the results of the field campaigns an automatic and remotely controlled station for monitoring gas components in the soil gas was established. This station monitor continuously CO_2, radon, temperature, air pressure, moisture and system voltage in one minute intervals and provide a useful tool for observing long-term stability and tightness of CO_2 deposits.

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