# Geophysical and soil gas monitoring methods for the characterization of $CO_2$ degassing sites – What can we learn from natural analogues?

CLAUDIA SCHÜTZE[1], UTA SAUER[1], HENDRIK LAMERT[1] and PETER DIETRICH[1]

[1] UFZ – Helmholtz Center for Environmental Research, Dept. Monitoring and Exploration Technologies.

claudia.schuetze@ufz.de

Several research and development projects on **Carbon Dioxide Capture and Storage** (CCS) have been initiated in the last few years, and demonstration projects are currently being implemented all over the world (FISCHEDIK et al., 2007). Furthermore, governments in different countries are stimulating the commercial deployment of CCS (e.g. USA, UK and Australia). However, uncertainties still exist concerning large-scale implementation of this emergent technology. Until now, both the assessment of environmental & safety risks and the validation of available monitoring technologies to monitor leakage paths are still missing. A main issue when attempting to gain public acceptance of this new method is ensuring provision of appropriate monitoring practices, aimed at delivering health, safety and environmental risk assessment, so that potential risks that may arise from $CO_2$ storage are minimized.

The goal of the MONACO project (**Mon**itoring **a**pproach for geological **$CO_2$** storage sites using a hierarchic observation concept; funded by GEOTECHNOLOGIEN Program), which was initiated in September 2011, is the development of reliable tools to work on different usable scales at geological $CO_2$ storage sites, both during and after operational phases. The project aims to develop monitoring technologies, especially to identify $CO_2$ migration paths and leakages from the shallow subsurface into the atmosphere.

Successful monitoring depends on the tools selected and requires the identification of appropriate methods to provide necessary information in real time. Within the frame of this project, an integrative hierarchic monitoring concept is proposed, with the aim of reliably detecting and assessing possible leakages from storage formations into the shallow subsurface (including aquifers and unsaturated zones, plus degassing of $CO_2$ into the atmosphere). As part of this concept, several methods and technologies from different disciplines (such as chemistry, hydrogeology, and geophysics) will be either combined or used complementary to one another. This hierarchical approach – with method developments and applications ranging from remote sensing, to regional measurements, to local insitu measurements (Fig. 1) – will allow large spatial areas to be consistently covered, and for efficient increase in spatial and temporal resolution to occur e.g. as required for the investigation of suspected or critical $CO_2$ degassing zones.

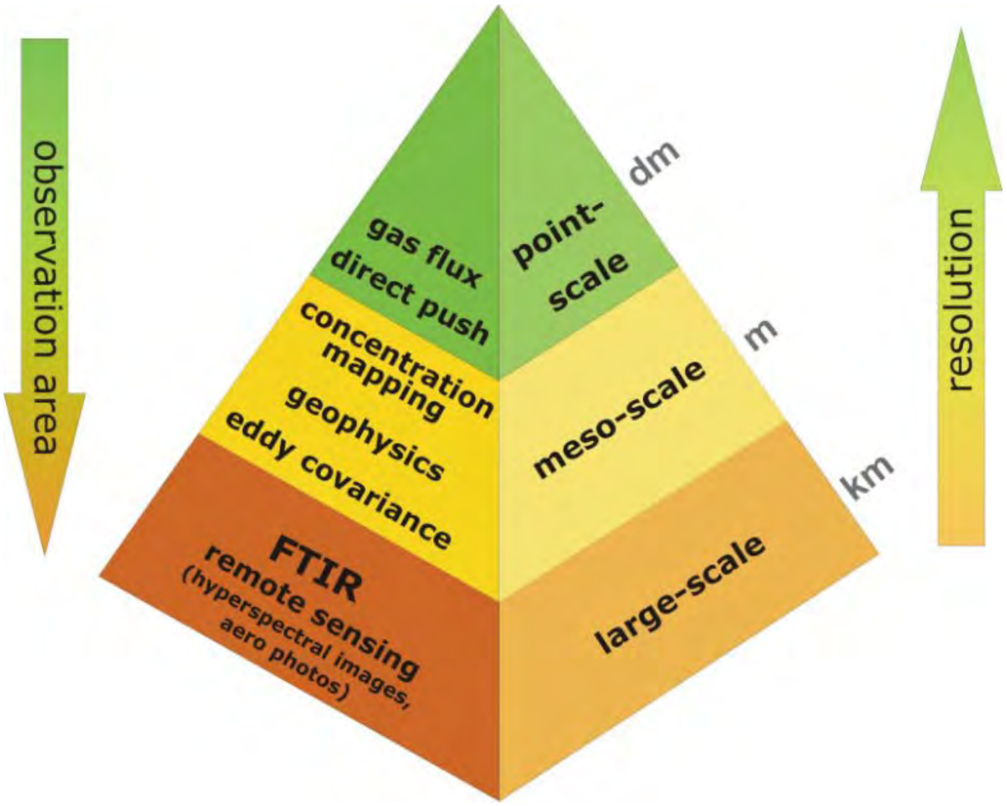

**Fig. 1:** Hierarchic monitoring concept

There are two main processes which should be monitored. Firstly, dissolved volatile $CO_2$ in the pore space has an impact on resistivity, which could be measured with Electrical Resistivity Tomography (ERT) and Electromagnetic Induction (EMI) methods. Secondly, fluid movements may lead to the occurrence of electro-kinetic effects (streaming potentials), measurable with self-potential (SP) mapping or monitoring. BYRDINA et al., 2009 showed that measured SP and electrical resistivity tomography results are related to the permeable fracture zone serving as a preferential pathway for soil gases and water. The combination of various kinds of geophysical information (such as resistivity, self-potential with surface-based measurements of $CO_2$ concentration and $CO_2$ flux) will provide more reliable insights, in order to constrain the extent of potential leakage systems and to understand patterns of fluid flow (FINIZOLA et al., 2009).

Naturally occurring $CO_2$ deposits provide unique natural analogues for evaluating and validating methods used for the detection and monitoring of $CO_2$ spreading and degassing into the atmosphere.

The investigation of natural $CO_2$ release sites can facilitate the attainment of valuable information that helps improve our understanding of the chemical and physical processes taking place and thus provide significant information for the development of new monitoring and assessment tools.

Furthermore, natural analogues are useful for providing dependable insights into processes related to $CO_2$ migration, trapping and leakage. Geological and hydrological structures of the Cheb Basin (NW Bohemia, Czech Republic), situated in the western part of the tectonically active Eger Rift, represent such a natural analogue for $CO_2$ leakage and offer a perfect location for the verification of monitoring tools, concerning the direct investigation of processes along preferential migration paths (Figure 2).

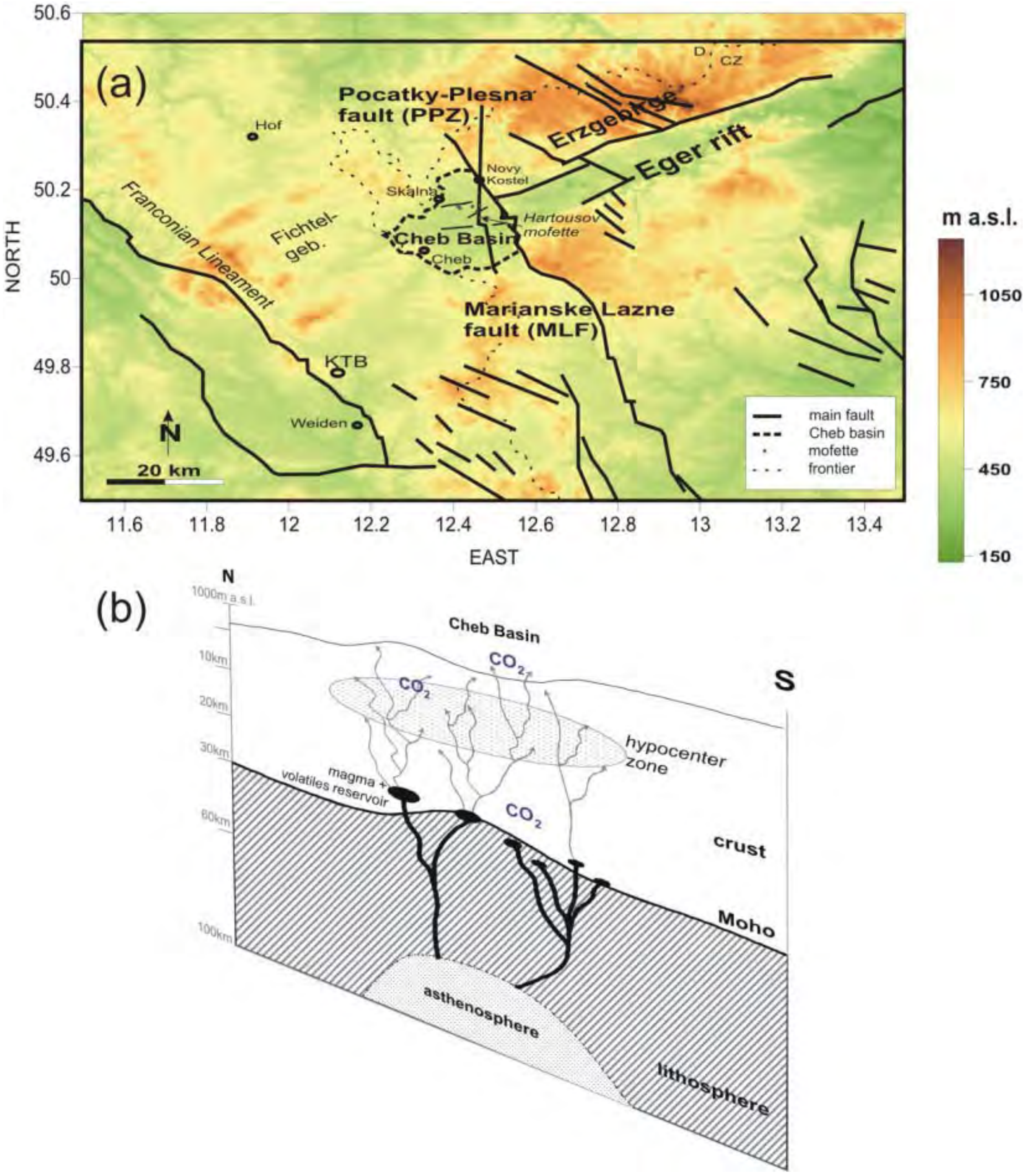

**Fig. 2** (a): The border region Vogtland/NW Bohemia is one of the most tectonically active regions in Central Europe. The Cheb Basin is situated in the western Eger rift. The most important deepreaching N-S trending faults regarding the Cheb Basin are the Mariánské Lázně fault (MLF) and the Počatky-Plesná fault zone (PPZ) (after BANKWITZ et al., 2003). The elevation map is derived from STRM 90m Digital Elevation Data Base (JARVIS et al., 2008).
(b): Deep processes are responsible for the occurrence of $CO_2$ in the Cheb Basin (simplified according to GEISSLER et al., 2005). The $CO_2$-rich mineral springs and mofettes along the PPZ and MLF are an indication of preferential CO2 migration pathways.

This shallow basin of Tertiary age is characterized by up to 300 m thick Neogene sediment fillings and several tectonic active faults. The $CO_2$-rich mineral springs and mofettes along the major faults are an indication of preferential $CO_2$ migration pathways. They are supplied by fluids from a deep magmatic reservoir in the lithospheric mantle. The gas (up to 99,99 % $CO_2$) ascends via tectonic fault zones directly from the upper mantle to the surface (BRÄUER et al., 2008, 2011). In this area, both focused small-scale $CO_2$ degassing sites (so-called mofettes) and larger areas with diffuse degassing behavior (see Figure 3b) are present.

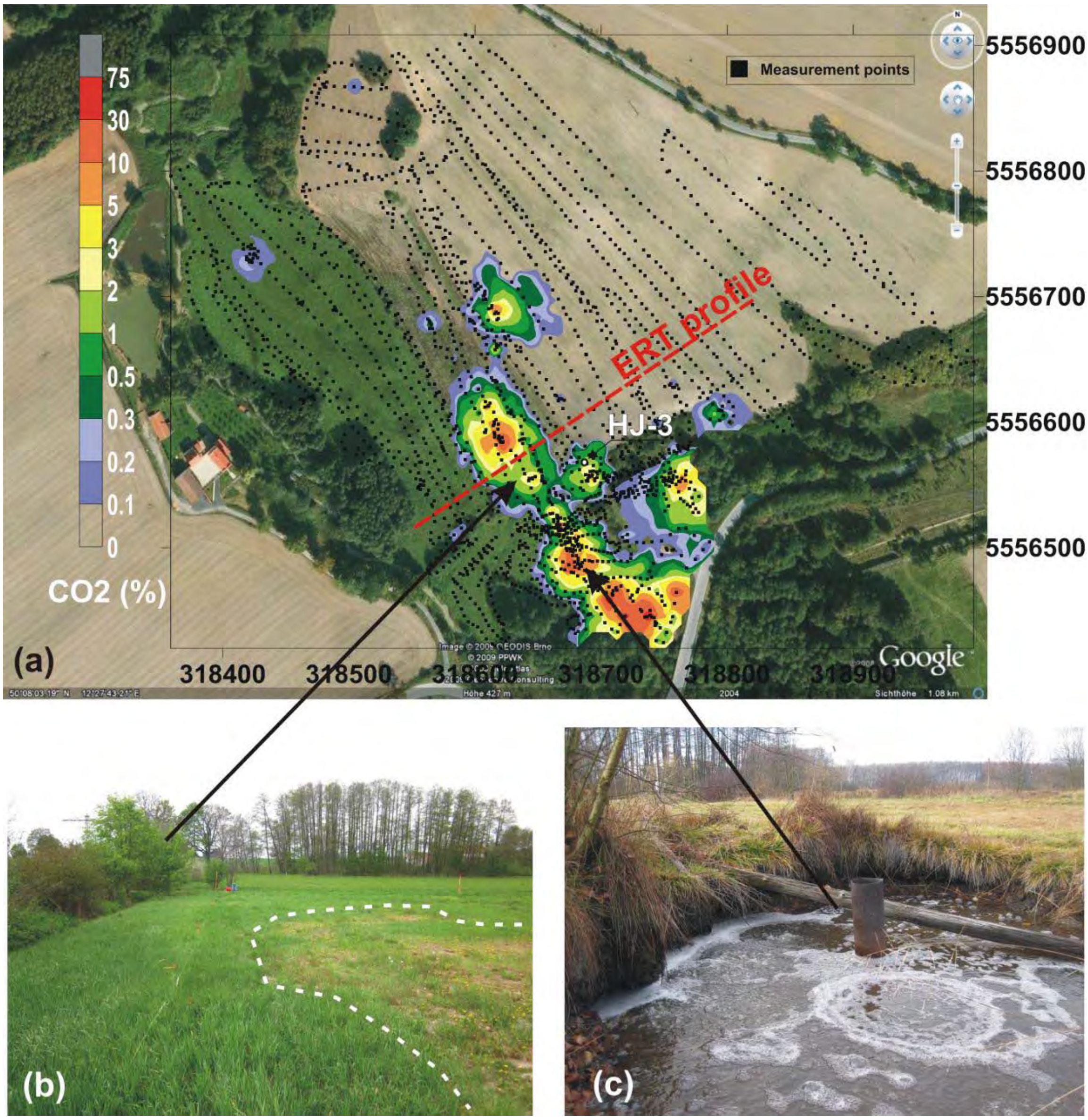

**Fig. 3** (a)**:** Surface CO2 concentration patterns near the village Hartousov. Maximum CO2 concentrations of up to 75 % are observable in shallow soil horizons. The degassing area is supposed to be aligned along the trace of the Počatky-Plesná fault zone segment. The geoelectrical line (ERT profile) crosses the diffuse degassing anomaly in the northern region of the test site. (Source aerial photo: Google Earth).
(b): Diffuse CO2 degassing structure is often traceable due to anomalies in vegetation vitality.
(c): Focused degassing can be observed at the main mofette, seasonally filled with groundwater (SCHÜTZE et al., 2012).

At the test site in Hartouchov, we consider two anomaly zones – anomaly zone 1 with focused release and anomaly zone 2 with diffuse release. At both anomaly zones, $CO_2$ concentration measurements with a mobile gas analyzer ANSYCO GA94, $CO_2$ flux measurements with the Automated Soil $CO_2$ Flux System LI-8100A (LI-COR Biosciences), SP and ERT measurements were performed. Table 1 gives an overview of the first results of the measurements.

The SP measurements show a strong correlation between $CO_2$ degassing zones and SP anomalies. However, there are negative anomalies in the zone with focused release and positive anomalies in the zone with diffuse release, which poses a significant challenge for interpretation. SP signal can be influenced by a combination of electrokinetic and junction potentials (MAINEULT et al., 2006), due to the presence of flow and concentration gradients, dissolution of volatile $CO_2$ in groundwater and movements of fluids ($CO_2$ and water). In further investigations, the main question relating to the basic self-potential driving processes must be solved.

| | **Anomaly zone 1 – focused release** | **Anomaly zone 2 – diffuse release** |
|---|---|---|
| $CO_2$ concentration measurements | soil gas concentration up to 100%, | soil gas concentration up to 80% |
| $CO_2$ flux rates | flux rates up to 5000 g $m^{-2}$ $d^{-1}$ | flux rates up to 3800 g $m^{-2}d^{-1}$ |
| SP measurement | negative SP anomaly minima of -30 mV | large positive SP anomaly up to 15 mV |
| ERT | ERT - anomaly with decreased resistivities | ERT – resistivity variations especially in near surface horizon |

**Tab. 1:** General outcomes at the two degassing zones considered in our study.

Site-specific near surface geological features seem to exert great influence upon the degassing pattern. In this current study, the distribution and thickness of lowly permeable sediments at surface level are able to impede $CO_2$ discharge into the atmosphere. ERT data shows two distinct locations where the upper clay layer is only a few decimeters thin or nearly non-existent. Highest soil $CO_2$ concentrations and flux rates were observed at these locations. Furthermore, a correlation between the thickness of the upper clay layer and the flux rates needs to be discussed. It should be noted that agricultural usage can possibly create migration paths in the surface layer and therefore higher $CO_2$ concentrations can be observed.

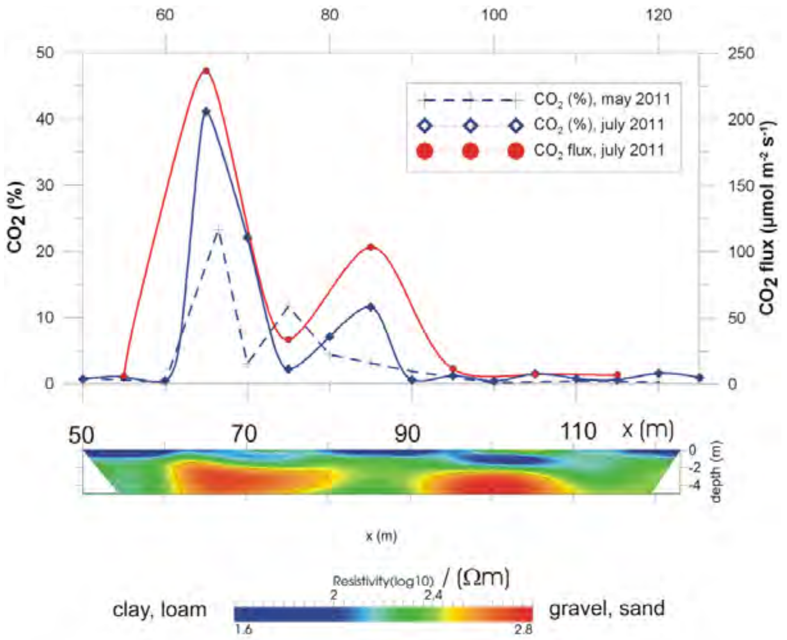

**Fig. 4**: Detailed soil gas and geoelectrical investigations characterizing a distinct degassing anomaly. Variations are observable in the $CO_2$ concentration values. This may be caused by the features of the upper soil horizons, in particular the pore water content, due to different meteorological situations in May and July. The structural features of the shallow subsurface (down to a depth of 5 m) can be described by a clay layer (lower resistivities) with variable thickness, followed by a gravel and sand layer (higher resistivities) (SCHÜTZE et al., 2012).

The first measurements indicate that the hierarchic monitoring approach represents a multidisciplinary modular concept working in different scales and resolutions. Soil gas surveys in combination with geoelectrical investigations have been proven to be a valuable tool for the characterization of structural near surface features controlling the degassing process. It is a non-destructive technique, which is relatively inexpensive to perform. Depending on the required spatial and temporal resolution, method combination is recommended for the characterization and observation of medium-scale to small-scale areas.

Natural analogues provide different geological and hydrological situations to test, adapt and validate appropriate monitoring technologies. Results of geoelectric and soil gas measurements clearly indicate subsurface structures and dynamic behavior of degassing areas. However, comprehensive investigations (including those on site-specific and temporal environmental conditions) will be necessary, so that a better understanding of leakage processes can be gained.

## Acknowledgements

This research was carried out within the frame of the joint research projects “CO2 leakage test within a near surface aquifer” – support code 03G0785A and “MONACO – Monitoring approach for geological CO2 storage sites using a hierarchic observation concept” – support code 03G0785A. Financial support given by the GEOTECHNOLOGIEN Programm and the German Federal Ministry of Education and Research (BMBF) is gratefully acknowledged. We thank the native speaker Christopher Higgins for proof reading.

## References

BANKWITZ, P., SCHNEIDER, G., KÄMPF, H. and BANKWITZ, E., 2003: Structural characteristics of epicentral areas in Central Europe: study case Cheb Basin (Czech Republic). – Journal of Geodynamics, **35**, 5-32.

BRÄUER, K., KÄMPF, H., NIEDERMANN, S., STRAUCH, G. and TESAR, J., 2008: Natural laboratory NW Bohemia: Comprehensive fluid studies between 1992 and 2005 used to trace geodynamic processes. – Geochemistry Geophysics Geosystems, **9**, Q04018, doi: 10.1029/2007GC001921.

BRÄUER, K., KÄMPF, H., KOCH, U. and STRAUCH, G., 2011: Monthly monitoring of gas and isotope compositions in the free gas phase at degassing locations close to the Nový Kostel focal zone in the western Eger Rift, Czech Republic. – Chemical Geology, **290**, 163-176.

BYRDINA, S., REVIL, A., PANT, S.R., KOIRALA, B.P., SHRESTHA, P.L., TIWARI, D.R., GAUTAM, U.P., SHRESTHA, K., SAPKOTA, S.N., CONTRAIRES, S. and PERRIER, F., 2009: Dipolar self-potential anomaly associated with carbon dioxide and radon flux at Syabru-Bensi hot springs in central Nepal. – Journal of Geophysical Research, Solid Earth, **114**, B10101, doi: 10.1029/2008JB006154.

FINIZOLA, A., AUBERT, M., REVIL, A., SCHÜTZE, C. and SORTINO, F., 2009: Importance of structural history in the summit area of Stromboli during the 2002-2003 eruptive crisis inferred from temperature, soil $CO_2$, self-potential, and electrical resistivity tomography. – Journal of Volcanology and Geothermal Research, **183**, 213-227.

FISCHEDIK, M., ESKEN, A., LUHMAN, H., SCHÜWER, D. and SUPERSBERGER, N., 2007: $CO_2$-Capture and Geological Storage as a Climate Policy Option. Technologies, Concepts, Perspectives. – Wuppertal Spezial 35 e, 32 S., Wuppertal Institute for Climate, Environment and Energy.

GEISSLER, W.H., KÄMPF, H., KIND, R., BRÄUER, K., KLINGE, K., PLENEFISCH, T., HORÁLEK, J., ZEDNÍK, J. and NEHYBKA, V., 2005: Seismic structure and location of a $CO_2$ source in the upper mantle of the western Eger (Ohře) Rift, central Europe. – Tectonics*,* **24**, TC5001, doi: 10.1029/2004TC001672.

JARVIS, A., REUTER, H.I., NELSON, A. and GUEVARA, E., 2008: Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org).

MAINEULT, A., BERNABÉ, Y. and ACKERER, P., 2006: Detection of advected, reacting redox fronts fromselfpotential measurements. – Journal of Contaminant Hydrology, **86**, 32-52.

SCHÜTZE, C., SAUER, U., BEYER, K., LAMERT, H., BRÄUER, K., STRAUCH, G., FLECHSIG, CH., KÄMPF, H. and DIETRICH, P., 2012: Natural analogues – a potential approach for developing reliable monitoring methods to understand subsurface $CO_2$ migration processes. – Environmental Earth Sciences, DOI: 10.1007/s12665-012-1701-4.

Zeitschrift/Journal: Berichte der Geologischen Bundesanstalt

Jahr/Year: 2012

Band/Volume: 93

Autor(en)/Author(s): Schütze Claudia, Sauer Uta, Lamert Hendrik, Dietrich Peter

Artikel/Article: Geophysical and soil gas monitoring methods for the characterization of CO2 degassing sites - What can we learn from natural analogues?. 82-88