The CO2FieldLab project: how to adapt a geochemical monitoring strategy to complex geological environments

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ABSTRACT

Under the auspices of the CO2FieldLab project, a shallow CO_2 leakage experiment was conducted during the summer in 2011 in Norway. This experiment was designed to describe the CO_2 behaviour during an induced leakage, and consisted of an injection in saturated horizons followed by physical/chemical monitoring in both saturated and unsaturated horizons. The leakage site, the Svelvik ridge, is located in the Drammen Fjord, 50 km south-west of Oslo. The injection was performed at a *c.a.* 20 m depth in heterogeneous glacio-fluviatile formations. We are here focusing on the results obtained from the geochemical monitoring.

The point monitoring of gas species present in the unsaturated zone allowed recording strong CO_2 enrichments (up to 15% vol.) in environments naturally poor in CO_2 (concentrations often lower than 0.5%) together with flushing of other gaseous species, mainly O_2. This was concomitant with a strong imprint of the injected CO_2 on the carbon isotope composition ($\delta^{13}C$) of the gas. Monitoring points with low CO_2 concentrations had natural $\delta^{13}C_{CO2}$ ratios ranging between -16 to -21‰ VPDB, with values as low as -27‰ at the leakage paroxysm, clearly highlighting the isotope influence of the injected CO_2 (heavily depleted in ^{13}C with $\delta^{13}C$=-30.4‰). Upon results obtained during this point monitoring, we were able to adapt the monitoring strategy during the leakage experiment. Indeed, the heterogeneity of the Svelvik geological formations induced shifts in the plume upwelling trajectory that were not expected by pre-injection scenarios. Consequently, less mobile monitoring methods, such as continuous ones operated in boreholes, sometimes failed to record concentrations changes. Nevertheless, successful results were obtained by the continuous $\delta^{13}C_{CO2}$ monitoring, showed significant variations of the $\delta^{13}C$ without correlated changes in corresponding CO_2 concentrations. This may highlight the role of fast equilibration processes between the injected CO_2 and the surrounding water that modify the isotope equilibrium between gas and water.

The water monitoring also allowed to register chemical/physical changes but only restricted to the northeast corner of the monitoring area, as a consequence of channelled leakage. Striking changes concerned the pH (decrease of 2 units), the electrical conductivity (rise by factor of up to 3) and the alkalinity (rise by factor of up to 6), together with changes in the redox parameters (Gal *et al.*, 2012).
Changes observed by these *in-situ* parameters have an influence on the geochemical equilibrium prevailing in the system prior to the leakage. Consequently there are some direct indicators

suggesting the presence of CO_2, such as the carbon and oxygen isotopes of CO_2 that were strongly affected by the CO_2 intrusion. The subsequent enrichment in HCO_3 and the related p_{CO2} rise were linked to 1) a depletion of ^{13}C, 2) an increase in ^{18}O, and a decrease from -6‰ to -11‰ VPDB for the Dissolved Inorganic Carbon.
Changes in the geochemical equilibrium may also be evaluated using indirect indicators. Dissolution/precipitation phenomena as well as ionic exchanges phenomena can be highlighted using 1) major or trace elements systematics (*e.g.* Mn, Zn …) or 2) isotopes of dissolved elements (*e.g.* Li, Sr…). Selected isotope systematics demonstrated that mixing of freshwaters and saline waters occurred following CO_2 injection (Humez *et al.*, submitted), perturbing the signals that may have been registered in less complex environments. Strong changes were also observed for dissolved elements, especially trace metal elements. It is one of the main concerns when referring to CO_2 leakage at CCS sites. In the present case, elements like Mn, Zn, Ba, Ni, Co or Fe were released in the surrounding water body with enrichment's factors often greater than 10. These enrichments were not perennial and decreases in concentrations were observed once the injection stopped, confirming the controlling CO_2 role in these processes. Nevertheless, it may be a concern for deeper-seated aquifers if a leakage occurs, as the corresponding remediation may be challenging.
The coupling of all of these geochemical indicators then help to detect the presence of the CO_2 plume, that is the main goal of the CO2FieldLab project, but not only. This kind of study helps in discriminating the influence of "natural" geochemical processes, linked to saline intrusion of salt water in the present case, and the influence of processes inducing by the CO_2 injection in a complex system. Referring to isotopes is especially interesting in that case since isotopes are very sensitive tools that can reveal different mechanisms depending on the element.

Such statements are of primary importance if we want to consider CCS sites at industrial scale. It is well established that leakage, if occurring, will impact water formations overlying the storage complex and may, in case of poorly constrained well completions, cause gas seepages at surface in narrow areas. The CO2FieldLab project shows that the heterogeneity of geological formations may cause leakage at locations that were not primarily suspected to be affected during site dimensioning. It also shows that the monitoring of gas concentrations is not the sole parameter to consider, as isotope changes occur in the absence of detectable concentrations changes. Last, the monitoring of the aquifers appears to be the most sensitive as it allows not only to monitor changes induced by a CO_2 intrusion but also to monitor changes that can occur following the mixing of different end-members. Such a situation may occur at CCS sites if upward brine movements occur during the injection.

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