Hydrochemical Indicators for Sustainable and Optimized Geothermal Use of Deep Groundwater

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Hydrochemistry in deep geothermal

The hydrochemical fingerprint of deep groundwater affects

- the **technical safety and economic efficiency of** geothermal plants (corrosion and scaling)
- the **longevity** of geothermal use (thermal breakthrough through dissolution processes at the reinjection site)
- **medical applications in spas** (via changes in effective concentrations).

A well's hydrochemistry, in turn, is determined by and a good indicator of the water's **flow paths** and its contact with other aquifers or oil fields.

1. How can the hydrochemical signature of a well detect unsustainable well operation?
2. Are yearly analyses sufficient and capable of representing sub-seasonal hydrochemical fluctuations?
3. What are the pore-scale effects of dissolution processes at geothermal reinjection sites?

Conclusions

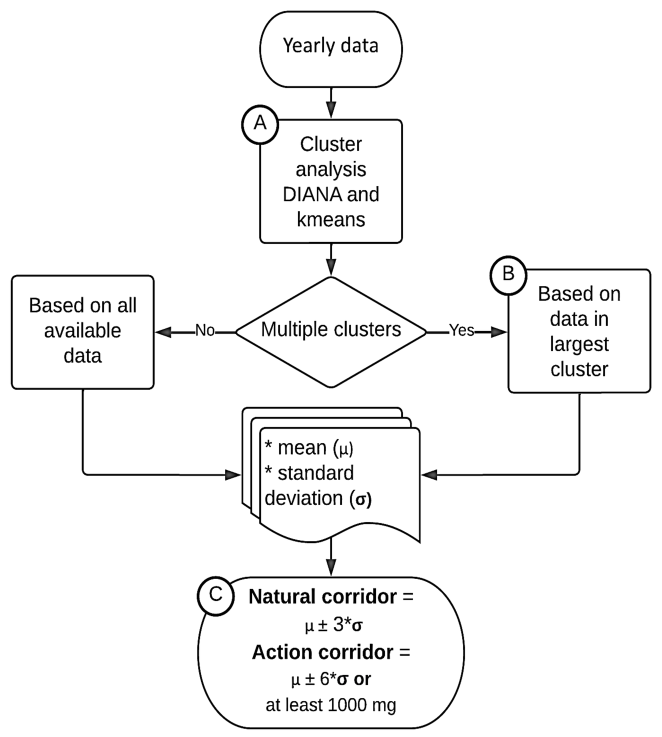
Pursuing the goals to safeguard deep groundwater aquifers and to promote sustainable water use, this study demonstrates the utility of hydrochemical properties to

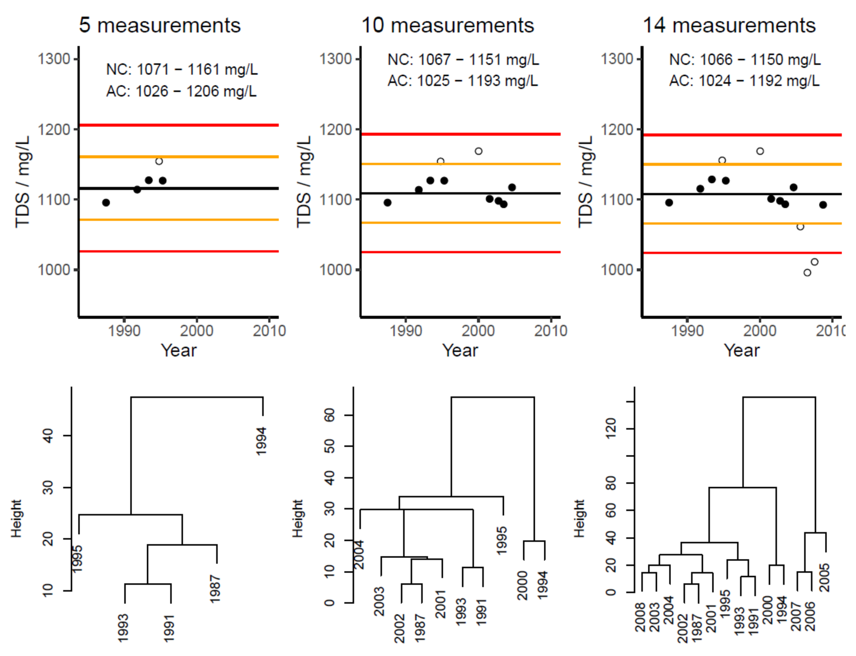
1) determine deep well usage sustainability via **cluster analysis**,
2) develop a novel **sampling protocol of > 3 samples/year** to capture sub-seasonal fluctuations overlooked by traditional yearly sampling procedures
3) quantify **dissolution processes at reinjection wells** and refine existing hydrochemical models.

1 An early warning system!

Deep groundwater is a crucial, last resort resource in cases of emergency when other water sources are no longer available or contaminated. These aquifers thus require protection from unsustainable exploitation practices, which the current EU water framework directive fails to provide.

We developed a robust, reproducible statistical method to describe natural fluctuations and assess sustainable use.





Clustering algorithm (bottom) and resulting natural and action corridors (top).

Based on clustering algorithm:

- Natural hydrochemical fluctuation range (min. 5 analyses)
- Warning and action corridors detect external effects on flow regime

BUT: yearly analyses reflect similar load.
Is this representative?

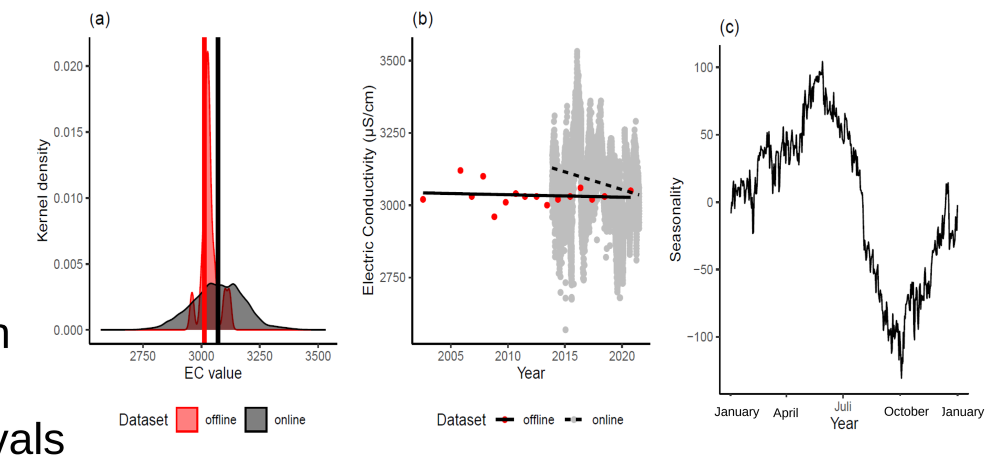
2 Is the data robust enough?

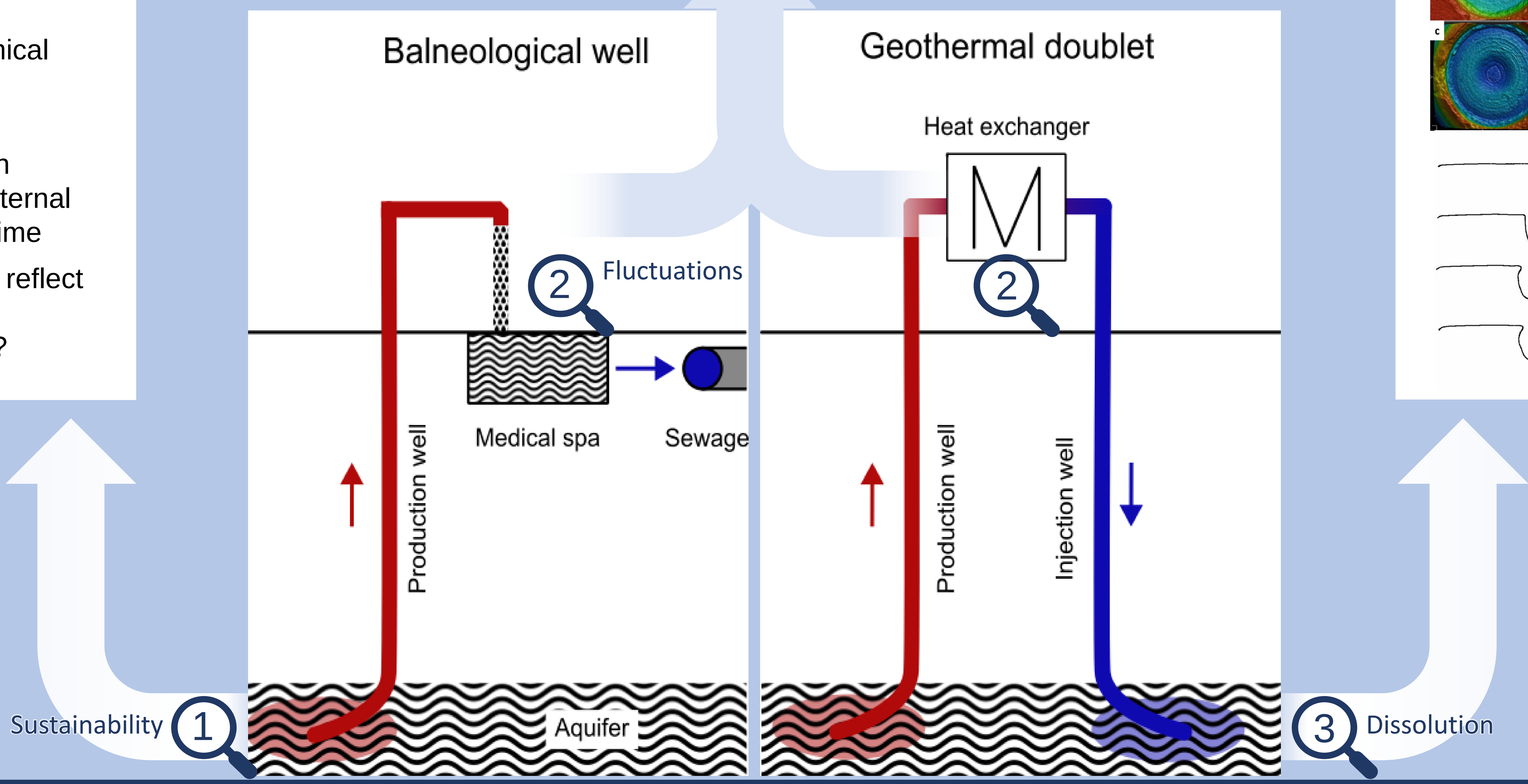
Deep groundwaters are difficult to access and thus plagued by a notorious data scarcity. State-of-the-art sampling protocols typically budget for one sample per year but there are seasonal fluctuations even in deep groundwater.

We assessed sub-seasonal hydrochemical fluctuations in deep aquifers to adjust sampling protocols.

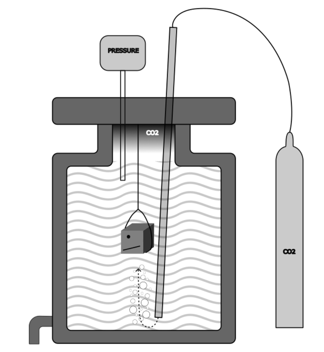
Results:

- Strong seasonal fluctuations due to changes in load states
- Strong recommendation of > 3 samples/year and/or at irregular intervals (potential for virtual sensors)





3 What about long term effects?

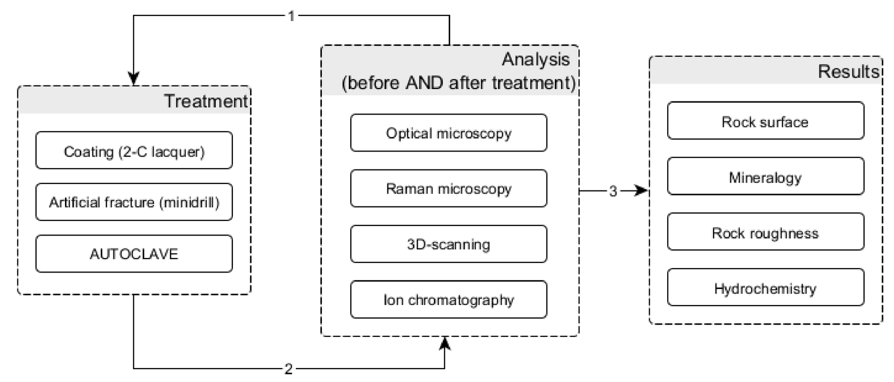


Reinjected, cooled waters in carbonate reservoirs become undersaturated

→ Hydrogeochemical imbalance in aquifer

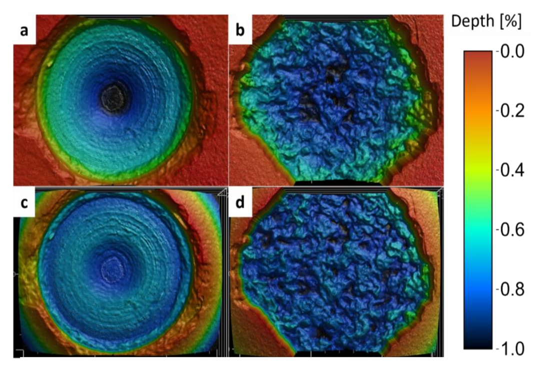
→ Rock matrix dissolution along flow paths

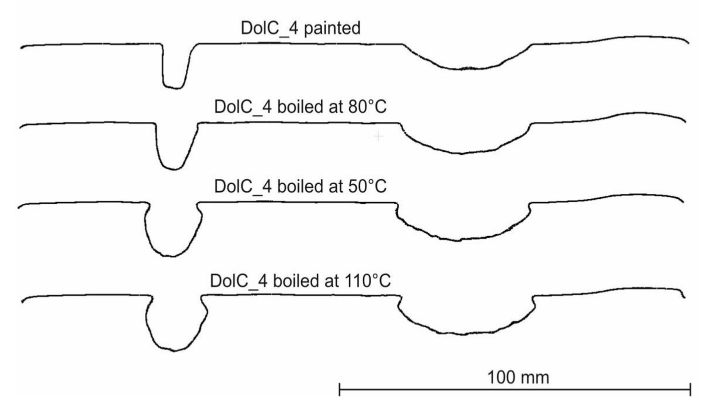
Autoclave with CO_2 simulates low saturation index and allows for time-lapse experiments on rock dissolution processes.

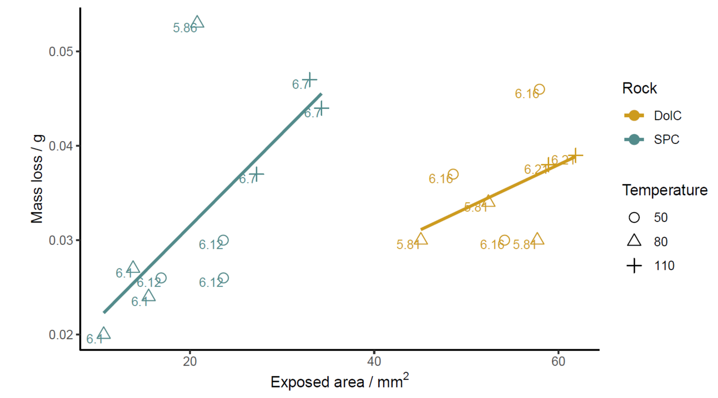


Preliminary results:

- Changes in surface depend on heterogeneity of rock matrix (preferred dissolution of smaller crystals)
- Hydrogeochemical model overpredicts dissolution (local equilibria in fractures?)
- Dolomite dissolution depends on initial solution (more when water in equilibrium with limestone)







Publications

- Dietmaier, A.; Baumann, T. Forecasting changes of the flow regime at deep geothermal wells based on high-resolution sensor data and low-resolution chemical analyses. AdGeo. 2023, 58. 189-197
- Dietmaier, A.; Baumann, T. Assessing sustainable development of deep aquifers. WatResM 2023, 37. 3857-3874

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