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Tracer-assisted characterization of deep geothermal reservoirs: some German experiences

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Tracer tests (artificial spikings) are indispensable in characterizing fluid-based geothermal reservoirs, in that they provide the only means for determining fluid residence times and fluid-rock contact-surface (i.e., heat exchange) areas; hydraulic and geophysical methods are largely insensitive w.r. to these parameters.

A report is given on two simple and three complex spiking sequences – comprising single-well intra-layer push-pull, dual-scale push-pull, single-well inter-layer and inter-well flow-path tracings – conducted in about 4 km deep crystalline or sedimentary formations (candidate or actual geothermal systems) in Germany since 2003.

The main results of these experiments, namely

- for the Urach-3 hole (HDR system in SW-German crystalline): *superposition* of tracer push-pull signals from at least two fractures with ambiguously-determined transport properties
- for the Landau site (hydrothermal system in mainly Buntsandstone layers, Upper Rhine Graben): improved estimation of *least reservoir size* (and thus of earliest thermal breakthrough) from lowered detection limits in tracer analytics
- for the pilot KTB hole (intersecting permeable fault system in Mid-German crystalline basement): estimation of near-field and far-field *fracture densities* and of their increase/decrease during depletion/stimulation
- for the Horstberg site (water-induced frac in tight clay/sandstone layers in N-German sedimentary basin): estimation of inter-layer *flow capture angle* based

on extrapolated tracer recovery; computing the *flow-storage distribution* of the induced hydrofrac based on a statistical time-moment analysis of the measured tracer breakthrough [*]

- for the ongoing tests at the GroßSchönebeck site (induced water- and gel-proppant fracs in volcanic and sandstone layers in N-German sedimentary basin): provisional estimation of frac *volume* and of *fluid exchange* with adjacent regions,

are discussed w. r. to their degree of ambiguity in transport parameter determination (as apparent from sensitivity analyses) and their direct or indirect relevance to predictions of long-term reservoir behaviour under various heat extraction schemes.

Time-rate design options of continued fluid sampling and of new spiking operations are proposed and analysed for the KTB, Horstberg/Hannover, GroßSchönebeck, Landau, as well as for the Bruchsal site (a further hydrothermal system in the Upper Rhine Graben).

[*] the rather early peak combined with a unusually high tailing of the tracer breakthrough curve measured in the Horstberg flow-path tracing (from which signal background contributions could be excluded with certainty), which appeared as irritating from the point of view of local geothermal modeling, is explained in terms of
(a) high dispersion of flow trajectories within the divergent-convergent flow field, and
(b) pronounced fluid exchange between macroscopic regions of different fluid mobility (including matrix diffusion in the narrower sense, but to a rather limited extent; attempting to explain the tailing by matrix diffusion alone, of which the tracer BTC indeed presents the typical shape, would require the assumption of unrealistically high diffusion coefficients or of unusually high fracturing density – given the short duration of the spiking)

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