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Non-Intersected Nearby Faults: 'Dazzling Blind' Spot for Artificial Tracers in Inter-Well Tests (Scoping Simulations, 3)

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ABSTRACT

This is a just a brief note, updating a small-study series (2017, 2019) concerning the ability of conservative artificial tracers, in inter-well forced-gradient flow, to 'detect' and quantify the properties of 'nearby' fractures or faults (non-intersected by the wells involved in the test). In an earlier short note (2015), we criticized the 'bad habit' of predicating '*tracer test failure!*' from the objective datum of a very long residence time (a property intrinsic to fluid turnover in the georeservoir subject to the given forced-gradient flow). We now revisit a particular reservoir setting in the Upper Rhine Rift Valley, to find that a long residence time for circulating fluids may indeed be associated with 'tracer test failure', but in a different sense than previously incriminated. Again, this is not a test design issue, but a more general problem posed by a georeservoir class we may deem 'very large' in terms of fluid turnover volume under the typical conditions of a geothermal heat extraction project. With ever increasing georeservoir dimensions, the usefulness of artificial tracers in inter-well circulation may indeed become questionable, especially in the presence of large-scale faults.

1. LONG RESIDENCE TIMES – BAD TRACER TESTS?

In an earlier short note (Ghergut et al. 2015), we criticized the 'malpractice' of equating the objective datum of a *long residence time* (for fluid in a georeservoir subject to forced-gradient inter-well flow) to a so-called 'tracer-test failure'; we argued that fluid residence times are intrinsic to the flow field (whether natural or forced-gradient), not steerable by the design and sizing of a tracer test; what can be influenced by the latter is just the ability to detect and meter (and accurately quantify) a tracer signal at a particular (passive or active) monitoring well, sooner or later (or maybe 'never') after having added a well-defined tracer slug (in a well-defined manner) into the given flow field.

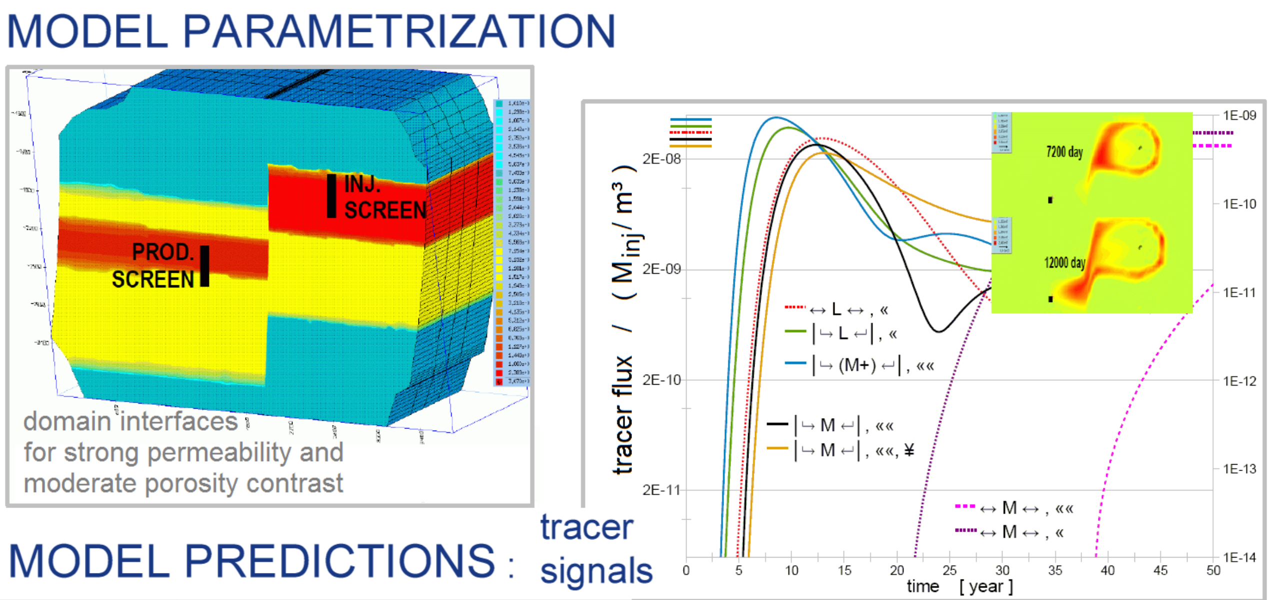
We now revisit the particular reservoir setting described by Meixner (2009), to find that a 'long residence time may indeed be associated with 'tracer test failure', but in a different sense than previously 'incriminated'. Again, this is not a test *design* issue, but a more general problem posed by a georeservoir class we may deem '*very large*' in terms of fluid turnover volume under the typical conditions of a geothermal heat extraction project. The 'operational size' of the project is limited by the maximum pressure buildup and drawdown which can be sustained at injection and production wells, respectively. In practice, for real-world reservoirs in the Upper Rhine Rift Valley on its 'German' side (Meixner 2009; Herzberger et al. 2009, 2010; Eggeling et al. 2013; Meixner et al 2016), this amounts to inter-well distances in the range of 1 – 3 kilometres. Lithostratigraphy of target formations (in particular, layer thickness and porosity values for native rocks) is something we can choose, but not influence. Swept reservoir volumes depend on chosen flow regimes – with flow rates more or less dictated by economical considerations or constraints, again beyond the reach of tracer test design considerations. Simulations discussed below update a small-study series (Ghergut et al. 2017, 2019) concerning the ability of conservative artificial tracers, in inter-well forced-gradient flow, to 'detect' and quantify the properties of neighboring (non-intersecting) fractures or faults.

2. TRACER SIGNALS IN THE (INCREASINGLY AMBIGUOUS) 'PRESENCE' OF LARGE-SCALE FAULTS

Relying on the structural-hydrogeological model proposed by Meixner (2009) for a particular hydrothermal system in South-West Germany (on the East side of the Upper Rhine Rift, this reservoir being used to demonstrate electricity production by means of a well doublet), we set up a distributed-parameter model (using Feflow5.4) enabling to numerically simulate fluid ages, temperature evolutions and tracer test signals for a number of contrasting assumptions w. r. to

- the nature of boundary conditions and hydrogeological characteristics of neighboring, large-scale natural faults,
- the degree of permeability contrast between different system compartments,
- anisotropy of permeability for selected reservoir layers,
- the hydrogeological characteristics of a naturally-occurring fault, located between injection and production wells.

It appears that a tracer slug sizing allowing for tracer signals to become detectable during the first three years after tracer injection in all scenarios considered here (as specified in fig. 1) is not feasible in practice. In some of the scenarios considered, the system will act like a 'very large' reservoir, with fluid residence times in the order of decades, and extreme dilution of injected tracers. Even using preparative-scale cleaning of samples, brine separation, sample enrichment by solid phase extraction, evaporative concentrating etc., followed by state-of-the-art chromatography techniques to separate between tracer and natural background, it will not be possible to lower tracer detection limits below a certain threshold (the latter being controlled, primarily, by the amount of certain naturally-occurring aromatics in the reservoir fluids). On practical reasons, the tracer slug sizing will be limited to some hundred kilogram of one or two organic tracers. This means that part of the scenarios illustrated in fig. 1 will remain indistinguishable during the first three years after tracer injection.



L / M+ / M	very large / large / moderate hydraulic transmissivity of large-scale fault situated between inj. and prod. wells
|↕ (…) ↲|	remotely-situated faults act either as flow barriers, or like vertical drains (Kv » Kh)
↔	remote faults act like drains horizontally (Kh » Kv)
«« / «	very high / high permeability contrast between adjacent aquifer layers (in yellow and red)
¥	increased anisotropy of permeability (ratio between horizontal and vertical permeability components within aquifer layers)

Figure 1: Outline of model parametrization, and tracer signal predictions for selected fault-zone scenarios

3. LONG RESIDENCE TIMES: DECREASING SENSITIVITY

On the other hand, for this reservoir structure, there is no clear-cut correspondence between early-vs.-late ‘appearance’ of tracer and small-vs.-large reservoir. How much information will actually be lost, and what degree of uncertainty will affect temperature predictions, as a consequence of the chosen practical ceiling on injected tracer quantities?

As long as the ‘middle’ fault (M) acts as a vertical drain, irrespective of lateral fault (L) behavior, tracer signals recorded (provided they were detectable and meterable) within one decade from tracer injection would allow to roughly tell the existence and large-scale properties of these fault zones, the signals being separated by at least one year in terms of ‘arrival time’, and by ~two orders of magnitude per year, in terms of increase rate (for the scenarios illustrated in fig. 1, the l.-h.s. range of BTCs). In other words, tracer signals would be worth being metered (‘whatever it takes’ in terms of laboratory-instrumental power) at their ascending stage during this ‘early’ first decade. However, following peak passage, they soon become insensitive to fault characteristics, with signal differences spanning less then 1/3 magnitude order, for the entire second decade. During the third decade, sensitivity to fault characteristics would be regained to a certain extent, spanning approximately one magnitude order – but, after having ‘waited’ for two decades, the accumulated effects of further uncertainty sources (like flow-rate variability, etc.) are likely to override this magnitude order of fault-zone sensitivity.

If the ‘middle’ fault (M) does not act as a vertical drain, fluid residence times become so large that tracer signals would stay undetectable for at least two decades. – The accelerating effect of a vertically-draining ‘middle’ fault seems counter-intuitive at first sight, but can be explained by the flow cross section 'shrinking' effect of vertical drainage (cf. small inserts at the upper r.-h.s. corner of fig. 1, showing tracer 'plume' shapes after two and three decades), independently of the transport-effective porosity of adjacent rock.

Such large residence times, and the associated limitations to fault-zone sensitivity, of artificial tracers are not a test design issue, but a more general problem posed by a georeservoir class we may deem 'very large' in terms of fluid turnover volume under the typical conditions of a geothermal heat extraction project. Beyond certain georeservoir sizes, the usefulness of artificial tracers in inter-well circulation may indeed become questionable (or redeemable only at very high costs), especially in the presence of large-scale fractures or faults (even when not intersected by any of the wells involved in forced-gradient flow). The transport-effective size of a georeservoir is determined not only by lithostratigraphy, but also by barrier and drainage characteristics of fault zones, especially when these are found 'inside' the reservoir.

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