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Tracer-based prediction of thermal reservoir lifetime: scope, limitations, and the role of thermosensitive tracers

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Thermal-lifetime prediction is a traditional endeavour of inter-well tracer tests conducted in geothermal reservoirs. Early tracer test signals (detectable within the first few years of operation) are expected to correlate with late-time production temperature evolutions (‘thermal breakthrough’, supposed to not occur before some decades of operation) of a geothermal reservoir.

Whenever a geothermal reservoir can be described as a single-fracture system, its thermal lifetime will, ideally, be determined by two parameters (say, fracture aperture and porosity), whose inversion from conservative-tracer test signals is straightforward and non-ambiguous (provided that the tracer tests, and their interpretation, are performed in accordance to the rules of the art). However, as soon as only ‘few more’ fractures are considered, this clear-cut correlation is broken. A given geothermal reservoir can simultaneously feature a single-fracture behaviour, in terms of heat transport, and a multiple-fracture behaviour, in terms of solute tracer transport (or vice-versa), whose effective values of fracture apertures, spacings, and porosities are essentially uncorrelated between heat and solute tracers. Solute transport parameters derived from conservative-tracer tests will no longer characterize the heat transport processes (and thus temperature evolutions) taking place in the same reservoir. Parameters determining its thermal lifetime will remain ‘invisible’ to conservative tracers in inter-well tests.

We demonstrate this issue at the example of a five-fracture system, representing a deep-geothermal reservoir, with well-doublet placement inducing fluid flow ‘obliquely’ to the fractures. Thermal breakthrough in this system is found to strongly depend on fracture apertures, whereas conservative-solute tracer signals from inter-well tests in the same system do not show a clear-cut correlation with fracture apertures. Only by using thermosensitive substances as tracers, a reliable correlation between (early) tracer signals and (later) thermal breakthrough can be re-established.

Thus, thermosensitive tracers are indispensable for predicting thermal breakthrough, in such geothermal reservoirs whose ‘hydrogeological personality’ is given by a finite set of fractures, with flow occurring both across and along the fractures. In terms of the ‘gebo benchmark-model’ typology investigated by Hördt et al. (2011) [http://eposters.agu.org/abstracts/models-of-geothermal-reservoirs-as-a-basis-for-interdisciplinary-cooperation/] , such systems combine flow and transport patterns of the ‘petrothermal’ type and of the so-called ‘deep-aquifer’ type:

- across the fractures, heat is travelling faster than conservative-solute tracers;
- along the fractures, conservative-solute tracers experience much less retardation by transversal exchange (matrix diffusion), than heat;
- fluid (and tracer) flow is not limited to the fractures; matrix flow yields essential contribution to prolonging the fluid (and tracer) residence time.

Thermal lifetime results from the opposite effects of fracture aperture as an:

- advection-related parameter: fluid travel time increases with increasing fracture aperture
- advection-unrelated parameter: fracture – matrix exchange rate increases with decreasing fracture aperture, which accelerates transport across the fracture, but retards transport along the fracture.

In conservative-solute tracer signals, all these fracture aperture effects on tracer transport are masked by the very long residence time associated with the matrix *flow* component. Thermosensitive tracers are able to ‘magnify’ the visibility of fracture aperture effects against matrix flow effects.

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