RESPONSE TO COMMUNITY COMMENTS 1

General comments

Very good research on the parallel between solute and heat transport in geological porous media. You can follow my suggestions to improve your manuscript.

We appreciate the insightful and constructive comments. We have carefully considered each comment and propose our revisions below.

Specific comments

Lines 30-76. The discussion is not very long. You can better highlight your novelties in contaminant hydrology, as well as in geothermal energy research.

Authors reply: We fully agree. The broader relevance of the present findings to contaminant hydrology and geothermal energy applications was not sufficiently highlighted in the original Introduction. We will expand this section to clarify how pore-scale heterogeneity and tracer-specific transport behavior may influence solute-based interpretations relevant to contaminant transport as well as heat-based characterization relevant to geothermal applications. We will also more clearly state the novelty of directly comparing these two tracer types under the same porous-medium framework.

Lines 30-31. You can insert recent reviews that combine discussion on solute, and heat transport:

- Kurylyk, B.L., Irvine, D.J., Bense, V.F., 2019. Theory, tools, and multidisciplinary applications for tracing groundwater fluxes from temperature profiles. Wiley Interdisciplinary Reviews: Water, 6(1), p.e1329.

- Lupi, F., Agbotui, P. Y., Medici, G. 2026. Hydraulic Conductivity in the Mesozoic units of the Umbria-Marche succession (Italy); insights towards a sustainable management of carbonate aquifers worldwide. Sustainability, 18, 9297; https://doi.org/10.3390/su18189297.

Authors reply: Thank you for suggesting these recent studies. We will incorporate the suggested references where relevant and use them to strengthen the discussion of the broader applications of solute and heat transport in hydrogeological and geothermal systems.

Line 38. “Small-scale heterogeneities”. How small? Can you disclose a range?

Authors reply: We agree that the term “small-scale heterogeneities” is ambiguous without a characteristic spatial scale. In the revised manuscript, we will clarify this expression by providing additional information on the relevant spatial scale and, where appropriate, by using more specific terminology such as sub-REV heterogeneity.

Line 38. “Small-scale heterogeneities”. Think about introducing sedimentological terms if you are in an alluvial environment. Point and alternate bars, and channel fills are appropriate here.

Authors reply: We agree that sedimentological structures such as point bars, alternate bars, and channel fills are important examples of heterogeneity controlling Darcy-scale flow and transport in alluvial aquifers. However, as clarified in response to the previous comment, the “small-scale heterogeneity” investigated in the present study refers specifically to sub-REV pore- to grain-scale variability. We therefore consider it out of scope to directly relate the present experimental results to larger-scale sedimentological architectures. In the revised manuscript, we will clarify this scale distinction.

Line 39. Be more specific on the intergranular porosity. Effective porosity with the Darcian flux?

Authors reply: We appreciate this comment and agree that the terminology should be clarified. The porosity values reported in Table 1 represent experimentally measured intergranular porosity. For the conversion between solute front velocity and Darcy flux, this measured porosity was assumed to approximate the effective porosity of the clean, fully saturated sand packs. This assumption is consistent with the micro-CT analysis, which indicated negligible closed porosity within the imaged samples. We will explicitly state this assumption and the supporting CT observation in the revised manuscript.

Line 190. I don’t think you need equation 10.

Reply to the comment) We agree. We will remove Eq. (10) and define the metric briefly in the text instead.

Line 283. 21 equations are too many for this manuscript. I would reduce the number.

Authors reply: We agree. We will streamline the Methods by removing or combining intermediate and standard expressions where possible, while retaining the equations that are directly required for parameter estimation, tracer-to-flux conversion, and interpretation of the results.

Line 390. Please, avoid the footnote. There is no need in this case.

Authors reply: We agree. We will remove the footnote and incorporate the necessary definition directly into the corresponding figure/table caption so that the information can be understood without referring to a separate note.

Line 614. “Research and industrial contexts” better?

Authors reply: Thank you for this suggestion. We agree that the applied relevance could be expressed more clearly. We will revise the wording to “research and practical applications,” which we believe encompasses both industrial and broader hydrogeological applications.

Figures and tables

Figures 1b, and c. Increase the graphic resolution.

Authors reply: We agree. We will replace Figs. 1b and 1c with higher-resolution versions and improve the readability of the labels and graphical elements.

Figure 5. Do you need regression lines on the graphs?

Authors reply: Thank you for this suggestion. The purpose of Fig. 5 is to highlight the contrasting linear and nonlinear tendencies observed for solute and heat transport, respectively, rather than to establish empirical predictive relationships. We therefore consider regression lines unnecessary but will clarify the purpose of the figure in the corresponding text and caption.

Figure 1A. This is a good conceptual figure. I would move in the main body of the manuscript.

Authors reply: We agree. Because this conceptual figure summarizes the workflow used to characterize microstructural complexity and provides useful context for the subsequent analyses, we will move Fig. A1 from the Appendix to the main Methods section and revise the figure numbering and corresponding references accordingly.

Table 1. Expand caption.

Authors reply: We agree. We will expand the caption of Table 1 so that the table is more self-contained. The revised caption will clarify the reported hydraulic, physical, and thermal properties, the meaning of the abbreviations, the statistical representation of the values, and the sources of the data where applicable.

Table 2. Same here. Expand the caption.

Authors reply: We agree. We will expand the caption of Table 2 to more clearly describe the experimental conditions summarized in the table, including the experiment types, Darcy-velocity ranges, tracer-input conditions, and data sources.