

Response to the comments of reviewer #2

Manuscript se-2020-13, Linsel et al.

"High-Resolution Analysis of the Physicochemical Characteristics of Sandstone Media at the Lithofacies Scale"

Dear Reviewers and Editor,

we would like to express our sincerest thanks to the reviewers who both provided a very constructive feedback, which helped to significantly enhance the quality of our manuscript. Below please find a point-by-point response to the general and specific comments of Giacomo Medici (reviewer #2). The response is provided in blue color whereas replaced and new text in the manuscript is indicated by *italic blue* font.

General comments

The authors should consider literature on the physicochemical properties of sandstone media more widely in the introduction and discussion. I recognize that the paper is original, but the authors should clarify better the reason in the introduction. As expressed above, models that combine spatial representation of chemical and physical parameters contrasts large part of literature on sandstone that largely focuses on 3D representation of the physical properties in three dimensions. Other papers exclusively treat the chemical properties of sandstone aquifers. Although the paper is generally well written I can see problems in the organization of the conclusions. Please, refer to the comments below that aim to support resolution of problems and bring the impact out of your research.

We would like to thank Giacomo Medici for the thorough review and refer to the point-by-point response of the specific comments as the general comments are addressed there. Generally, we have added more literature to the Introduction, Discussion and Conclusion, revised some minor technical issues and rearranged the Conclusions as suggested by the reviewer.

Specific comments

1.0 Introduction

Lines 29-30 Add papers that treat upscaling and spatial properties of sandstone with regards to permeability issues related to nuclear waste repositories and hydrocarbon reservoirs.

- Kiryukhin, A.V., Kaymin, E.P. and Zakharova, E.V., 2008. Using TOUGHREACT to model laboratory tests on the interaction of NaNO₃-NaOH fluids with sandstone rock at a deep radionuclide repository site. Nuclear technology, 164(2), pp.196-206.

- Medici, G., West, L.J. and Mountney, N.P., 2016. Characterizing flow pathways in a sandstone aquifer: tectonic vs sedimentary heterogeneities. *Journal of contaminant hydrology*, 194, pp.36-58.

- Medici, G., West, L.J., Mountney, N.P. and Welch, M., 2019. Permeability of rock discontinuities and faults in the Triassic Sherwood Sandstone Group (UK): insights for management of fluvio-aeolian aquifers worldwide. *Hydrogeology Journal*, 27(8), pp.2835-2855.

We are grateful to the reviewer for providing us with these valuable references. We have placed them into our running text as you recommended.

Lines 32-34 Again, I suggest updated literature on the topic for low porosity layers that reduce flow at the scale of the pumping tests in sandstone.

- Hamdi, Hamidreza, Philippe Ruelland, Pierre Bergey, and Patrick WM Corbett. "Using geological well testing for improving the selection of appropriate reservoir models." *Petroleum Geoscience* 20, no. 4 (2014): 353-368.

- Medici, G., West, L.J. and Mountney, N.P., 2019. Sedimentary flow heterogeneities in the Triassic UK Sherwood Sandstone Group: Insights for hydrocarbon exploration. *Geological Journal*, 54(3), pp.1361-1378.

- Jackson, M.D., Muggeridge, A.H., Yoshida, S. and Johnson, H.D., 2003. Upscaling permeability measurements within complex heterolithic tidal sandstones. *Mathematical Geology*, 35(5), pp.499-520.

- Tellam, J.H. and Barker, R.D., 2006. Towards prediction of saturated-zone pollutant movement in groundwaters in fractured permeable-matrix aquifers: the case of the UK Permo-Triassic sandstones. *Geological Society, London, Special Publications*, 263(1), pp.1-48.

- Tidwell, V.C. and Wilson, J.L., 1997. Laboratory method for investigating permeability upscaling. *Water Resources Research*, 33(7), pp.1607-1616.

We have also incorporated these suggested references into our introduction. Thanks again!

Lines 25-68 Overall very good introduction. I suggest to add two or three sentences to explain not only which is your observation scale but also where it lies. Your outputs lie between the core plug and pumping test scale. Hence, your research contributes to bridge the gap between the two scales. See below relevant publications on the upscaling properties of sandstone aquifers/reservoirs.

- Corbett, P.W., Hamdi, H. and Gurav, H., 2012. Layered fluvial reservoirs with internal fluid cross flow: a well-connected family of well test pressure transient responses. *Petroleum Geoscience*, 18(2), pp.219-229.

- Medici, G., West, L.J. and Mountney, N.P., 2018. Characterization of a fluvial aquifer at a range of depths and scales: the Triassic St Bees Sandstone Formation, Cumbria, UK. *Hydrogeology journal*, 26(2), pp.565-591.

- Zheng, S.Y., Corbett, P.W., Ryseth, A. and Stewart, G., 2000. Uncertainty in well test and core permeability analysis: a case study in fluvial channel reservoirs, northern North Sea, Norway. AAPG bulletin, 84(12), pp.1929-1954.

Again, thank you very much for providing relevant literature references. We have added the references to the running text and provided a paragraph at the end of the introduction which aims at describing the scale of investigations and which role it plays in upscaling procedures.

“The research outputs of this study lie between the scale of a core plug measurement and a wireline log/pumping test (Medici et al., 2018). Hence, we aim to contribute towards estimating the uncertainty that must be accounted for when performing up- or down-scaling between those two scales of investigation (Zheng et al., 2000; Jackson et al., 2003; Corbett et al., 2012; Hamdi et al., 2014).”

2. Measurement campaign

Line 109 “Hassler cell permeameter”. I understand that you provide a reference. But, I think the manuscript would benefit of a sentence that explains the basic principal of your permeameter.

We have added a sentence on the basic principle of the permeameter as follows:

“The Hassler cell is a gas-driven permeameter which measures the permeability of a cylinder-shaped rock sample under steady-state gas flow.”

Lines 182-183 I leave to the authors the decision to state typical ranges of flow anisotropies (K_h/K_v) at the centimetre-meter scale in sandstones providing general references. Typical flow anisotropies are ~10-500 in sandstone aquifers with lower value in channelized sandstone of fluvial and deltaic origin.

We have inserted a sentence about the typical range of k_v to k_h :

“The intrinsic permeability, for example, provides typical ranges for the ratio between the vertical (k_v) and horizontal permeability (k_h) of 10^{-5} to 1 (Ringrose and Bentley, 2015).”

Also, we have added a comment on the observed anisotropy of the intrinsic permeability in line 277:

“Also, the intrinsic permeability does not show a significant anisotropy.”

3. Results

Lines 238-239 I suggest described by Fongngern et al. (2018).

Yes, thank you for the remark. We revised it in the text.

Lines 306-307 Possible adding a short explanation on the reason why inverse distance and kriging provide comparable results? I guess the geometry that needs to be interpolated is relatively simple.

Both interpolation procedures are so-called exact interpolators, which means that at each known point, the interpolation function takes the value of that exact point. Due to the high sampling density, the patterns are thus similar. Following that, we adapted the text here like: *"...provide comparable patterns, which is due to the high sampling density."*

Lines 316-323 Realistic values of intrinsic permeability but very low. Please, justify your outputs with reference to the rock-type/lithofacies. The reason of this low permeability should be the sheet-like sandstone nature of the geological material tested. It's well known that sheet like sandstone are not very conductive for the fluids. I'm inviting the author to make more evident in the paper the relation between sedimentology and intrinsic permeability.

This is an important comment, which we tried to resolve by adding two sentences in the discussion of the relationship between porosity and permeability as follows:

"... In addition, these observations are well reflected by the very low values of the intrinsic permeability in both rock cubes. Another reason for the very low intrinsic permeability is the high amount of primary clay and the low maturity of deltaic sheet-like distributary mouth bar deposits (Tye and Hickey, 2001)."

4. Discussion

Line 379 If the authors want to enlarge bibliography on sandstone mineralogy and diagenesis. I suggest the following papers:

- Ixer, R.A., Turner, P. and Waugh, B., 1979. Authigenic iron and titanium oxides in Triassic red beds:(St. Bees Sandstone), Cumbria, northern England. *Geological Journal*, 14(2), pp.179-192.
- Van Keer, I., Muchez, P.H. and Viaene, W., 1998. Clay mineralogical variations and evolutions in sandstone sequences near a coal seam and shales in the Westphalian of the Campine Basin (NE Belgium). *Clay Minerals*, 33(1), pp.159-169.

Thank you so much for these valuable references. We have considered them in our manuscript.

Line 380 I invite the authors to avoid the use of "because" in a scientific paper. Aside from minor issues the manuscript is very well written.

Thank you for the suggestion. We substituted this word throughout the manuscript.

5 Conclusions

Lines 400-401 I agree on the use of bulletin points. I suggest adding one or two sentences to introduce your four points. This passage from standard text to bulletin points sound chunky to the readers.

We have inserted an introductory sentence before the conclusions:

“All in all, the following conclusions can be drawn from this study:”

Lines 417-419 Future work is introduced here in an abrupt way. Also, better avoiding new topics in the conclusions. It's fine to introduce future research scenarios. But, in this case, the topic needs to be analysed in the discussion section.

We understand your comment and removed the outlook from the conclusions accordingly.

Figures and tables All figures and tables of publishable quality. I remind the authors to comment on the low intrinsic permeabilities (see Fig. 14) of the studied deposits.

We would like to mention that we commented on the low intrinsic permeabilities in the Discussion section as outlined for the comment on Lines 316-323.

Fig. 6 Make this image larger.

We increased the size of the image.

Fig. 7 Figures on axes larger.

The figures have been adapted.