We sincerely thank the reviewer for the careful reading of our preprint and for the constructive and insightful comments. We greatly appreciate the positive evaluation of our research. Following the reviewer's suggestions, we have revised the manuscript to improve its clarity, rigor, and presentation. Our detailed responses are provided below:

Comment 1

Lines 30-31: "Structural trapping is when CO_2 moves upwards below a low-permeability caprock because of buoyancy". Sentence not backed up by references. Please, insert literature on low-permeability sedimentary layers that affect the vertical movement of fluids:

- Medici, G., Munn, J. D., Parker, B.L. 2024. Delineating aquitard characteristics within a Silurian dolostone aquifer using high-density hydraulic head and fracture datasets. Hydrogeology Journal, 32(6), 1663-1691.

-Rutqvist, J. 2012. The geomechanics of CO_2 storage in deep sedimentary formations. Geotechnical and Geological Engineering, 30(3), 525-551.

Response: Thank you for this important suggestion. We agree that the statement required stronger literature support. In the revised manuscript, we will add references you mentioned to support the description.

Comment 2 and 3

Line 70: Summarize the overall goal of your research on geological carbon storage. Describe the three to four objectives of your research by using numbers (e.g., i, ii, and iii).

Response: Thank you for this suggestion. We agree that the overall research goal should be stated more explicitly. In the revised manuscript, we have added a concise statement in the Introduction in lines 64-69 to clarify the central aim of this work.

"Accordingly, the objectives of this study are to: (i) develop an integrated numerical framework for geological carbon storage that couples multiphase flow, dissolution-driven convection, geochemical reaction, and gravity-induced ripening; (ii) elucidate the spatiotemporal evolution and interactions of major trapping mechanisms governing the long-term migration and phase transition of injected CO_2 in saline aquifers; (iii) quantify how reactive transport and associated porosity–permeability changes influence plume migration and dissolution behaviour; and (iv) evaluate the effects of calcite content and reservoir heterogeneity on the long-term fate of CO_2."

Comment 4 and 5

Line 130: Specify the type of porosity, total or effective/kinematic? You mention "pore structure connectivity" just five lines above. I assume you're dealing with effective porosity.

Response: Thank you for pointing out this ambiguity. We agree that the type of porosity should be explicitly defined. As our model is unable to capture the microscopic evolution of pore structure, the above discussion on changes in the pore-space structure was intended only to emphasize the effect of geochemical reactions on porosity. In fact, it is the average porosity of REV that updates in real time based on the reaction.

Comment 6

Line 132: Two different equations. Is it ok using "a and b"?

Response: Thank you for this careful observation. We agree that using the same notation style for different equations may create confusion. In the revised manuscript, we have adjusted the equation number to avoid ambiguity and to ensure that each equation is clearly distinguished.

"$\phi = \phi_0 + x_{CaCO_3}\left(\frac{c_{CaCO_3,r}}{c_{CaCO_3,0}}\right)$, (9)

$k = k_0\left(\frac{\phi}{\phi_0}\right)^3\left(\frac{1-\phi_0}{1-\phi}\right)^2$, (10)"

Comment 7

Line 148: Lots of equations in the manuscript. Are all of them necessary?

Response: We understand the reviewer's concern that an excessive number of equations may affect readability. We carefully re-examined all of the mathematical expressions and confirmed that each equation is necessary for the completeness and clarity of the model formulation. This is because the present model simultaneously considers multiphase flow, dissolution and phase transition, geochemical reactions, gravity-driven ripening, and the coupling among these processes. Each group of equations describes a specific physical or physicochemical process or its interaction with the others. Removing any of them would make the model description incomplete.

Comment 8

Table 1: Specify the type of porosity.

Response: The reported porosity is **average total porosity** of REV. The influence of pore connectivity was not taken into account here.

Comment 9 and 10

Figure 1 and 2: Do you need an approximate spatial scale for this conceptual model?

Response: We thank the reviewer for this suggestion. Because Figure 1 is a conceptual schematic rather than a direct representation of a measured physical domain, it was originally prepared without a scale. The model was established based on the finite

element method, and thus is suitable for macroscopic characterization. In Figure 2, we present the length and width of the model (the detailed parameters are given in Table 1).

Comment 11 and 12

Figure 10 and 12: Increase the graphic resolution. Contours are not clear.

Response: We appreciate this comment and fully agree. The compression of images by PDF reduces the readability of the images. Figure 10 and 12 have also been replaced with a higher-resolution version in the revised manuscript so that the contour patterns can be more clearly distinguished. High-definition images will be added in the supplements.

Comment 13

Figure 13: Make this graph much larger.

Response: Thank you for this suggestion. We agree that the original size of Figure 13 limited its readability. In the revised manuscript, we enlarged the figure and adjusted its layout to improve the visibility of the curves, labels, and overall graphical presentation.