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Darcy flow in heterogeneous porous media: relevance at sedimentary basin scale

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Understanding heat transfer mechanisms in sedimentary rocks is important for recovering thermal history of sedimentary basins. Fluid flow may play a significant role by advecting heat within porous rocks of the basin. In extensional continental setting associated with stretching and thinning of the lithosphere, geothermal gradient below sedimentary basins may rise and contribute to the onset of thermal convection. Such process can be approximated by Darcy flow through porous media where thermal expansion introduces a gravitational instability between lighter hot fluids at the bottom and denser cold fluids at the top of the basin. However, the convection in such setting is inhibited by closing of the porosity with depth, which leads to limited amount of heat carrying fluids and a reduced permeability.
We address this problem numerically by modeling Darcy's equations. To assess the accuracy of the pressure and velocity field in media with strongly varying permeability we compared two different numerical methods, 1) the standard finite element formulation with different order of elements (quadratic-pressure and linear-temperature) and 2) the mixed finite element formulation. An additional challenge in this study is to treat carefully the advection by choosing an appropriate numerical scheme. We used the method of characteristics with different flow integration, the Euler's and the 4th order Runge-Kutta's scheme, to avoid artificial diffusion that may significantly pollute the numerical solution. Results obtained for a homogeneous porous medium correspond to the analytical solution of the scaling between the Nusselt and Rayleigh numbers. We apply the tested model to investigate numerically the pattern of convection in heterogeneous porous rocks. We analyze the first-order characteristics and the limits of the convection in sedimentary basins under such conditions.