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Prediction of the low-velocity distribution from the pore structure in simple porous media

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The macroscopic properties of fluid flow and transport through porous media are a direct consequence of the underlying pore structure. However, precise relations that characterize flow and transport from the statistics of pore-scale disorder have remained elusive. Here we investigate the relationship between pore structure and the resulting fluid flow and asymptotic transport behavior in two-dimensional geometries of non-overlapping circular posts. We derive an analytical relationship between the pore throat size distribution $f_\lambda \sim \lambda^{-\beta}$ and the distribution of the low fluid velocities $f_u \sim u^{-\beta/2}$, based on a conceptual model of porelets (the flow established within each pore throat, here a Hagen-Poiseuille flow). Our model allows us to make predictions, within a continuous-time random-walk framework, for the asymptotic statistics of the spreading of fluid particles along their own trajectories. These predictions are confirmed by high-fidelity simulations of Stokes flow and advective transport. The proposed framework can be extended to other configurations which can be represented as a collection of known flow distributions.