Geophysical Research Abstracts
Vol. 20, EGU2018-4037, 2018
EGU General Assembly 2018

Evolution of fluid flow regimes in rough-walled rock fracture

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Understanding fluid flow through a rough-walled rock fracture is important in geological and environmental sciences, such as risk assessment of geologic storage of radioactive waste, the formation of hydrothermal ore deposits by magmatic fluids, and groundwater management and remediation. However, abruptly varying apertures make it difficult to interpret flow regime and quantify the onset of nonlinearity in rough-walled rock fractures. Numerical studies indicated that a weak inertial regime started at Re = 1 to 10 and nonlinear flow became considerable for Re > 20. But, another numerical study showed that the recirculation zones were generated even for Re < 1. The opposing results demand more direct observation (or measurement)-based-studies for a fundamental understanding of the non-linear flow regime in fluid flow and solute transport in rough-walled fractures. We conducted the first direct measurement of fluid flow velocity up to Re = 20 within a rough-walled fracture using micro Particle Image Velocimetry (micro-PIV) system to observe the evolution of fluid flow regimes and the onset of nonlinearity. A rough-walled fracture, 200-mm long and 1-mm wide, was prepared by scanning both surfaces of a rough-walled fracture and engraving them on acrylic using a numerically controlled computer modeling machine. The measured velocity vectors were measured in the range of Re from 0.1 to 20 and were used for magnitude analysis of inertial and viscous forces of Navier-Stokes equations. Preliminary results showed that the magnitude of the inertial forces increased rapidly at Re = 10 and at Re = 20, inertial forces were almost comparable to viscous forces. The result indicated that the onset of nonlinear flow occurs from Re = 10 at highly-varying aperture region, and fully identified at Re = 20.