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Constraining geometrical, hydrodynamical and mechanical properties of a fault zone at hourly time scales from ground surface tilt data

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Flow through reservoirs such as fractured media is powered by pressure gradients which also generate measurable poroelastic deformation of the rock body. The combined analysis of ground surface deformation and sub-surface fluid pressure provides valuable insights of a reservoir's structure and hydromechanical properties, which are of interest for deep-seated CO_2 or nuclear waste storage for instance. Amongst all surveying tools, surface tiltmeters offer the possibility to grasp hydraulically-induced deformation over a broad range of time scales with a remarkable precision (1 nanoradian). Here, we investigate the information content of transient surface tilt generated by flow in a kilometer scale sub-vertical fault zone and its surrounding fractured rock matrix. Our approach involves the combined analysis of field data and results of a fully coupled poroelastic model, where fault and matrix are represented as equivalent homogeneous domains. The signature of pressure changes in the fault zone due to pumping cycles is clearly recognizable in field tilt data and we aim to explain the peculiar features that appear in: 1) tilt time series alone from a set of 4 instruments; 2) the ratio of tilt over pressure. With the model, we evidence that the shape of tilt measurements on both sides of a fault zone is sensitive to its diffusivity and its elastic modulus. In particular, we show a few well placed tiltmeters (on each side of a fault) give more information on the medium's properties than well spatialized surface displacement maps. Furthermore, the ratio of tilt over pressure predominantly encompasses information about the system's dynamic behavior and extent of the fault zone, and allows separating contributions of flow in the different compartments. Hence, tiltmeters are well suited to characterize hydromechanical processes associated to fault zone hydrogeology at short time scales, where space-borne surveying methods fail to seize any deformation signal.