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New Insights into the Statistical Behavior of Middle Eastern Naturally Fractured Reservoirs Obtained Through Near Deterministic Discrete Fracture Network Modeling

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ABSTRACT

Outcrop studies have played a fundamental role in progressing our understanding of the structural architecture and fluid flow behavior of naturally fractured carbonate reservoirs, with rock exposures of lithologically and tectonically analogous rock units providing information about fracture size, termination style, intensity and connectivity, commonly not afforded by subsurface datasets. In this regard, the use of close range 3D remote sensing techniques (esp. terrestrial lidar and digital stereo photogrammetry) has recently risen to prominence within fracture characterization and modelling studies employing outcrop datasets. Photo-textured 3D mesh-based representations of naturally fractured rock exposures generated using the aforementioned techniques (i.e. digital outcrop models) may be interrogated interactively or using unsupervised classifiers, providing a wide suite of discontinuity attributes required for conditioning discrete fracture networks (DFN). The merits of these digital discontinuity analysis techniques is well-established, providing data acquisition rates and sampling domain coverage akin to (2D) photo-analysis of outcropping fracture networks (e.g. trace maps), whilst generating the comprehensive suite of fracture attributes commonly associated with manual surveys.

Whilst the value of digital outcrops for obtaining spatially averaged fracture data has received wide recognition, the utility of this data medium in the context of fractured rock mass characterization and modelling has developed little beyond initial metrological applications. With regards to the estimation of discontinuity properties from exposed rock masses, however, digital outcrop models have the potential to be harnessed in a more explicit manner than has previously been attempted. With this in mind, the author has developed a novel outcrop constrained DFN modelling framework which enables semi-deterministic estimates of fracture network properties to be obtained from rock exposures. The models generated provide reconstructions of discontinuity architecture exposed in outcrop using equivalent data structures to conventional DFNs, thus enabling numerical routines commonly applied to discrete fracture networks (e.g. porosity/permeability upscaling, direct flow simulation, coupled DFN-discrete element geomechanical modelling) to be appropriated towards the near deterministic case. In this work, this framework is utilized to estimate geometric and petrophysical fracture network properties, namely volumetric discontinuity intensity (P_{32}: discontinuity area per unit volume), porosity (P_{33}: discontinuity volume per unit volume), connectivity, and equivalent fractured rock mass permeability (Oda's method) from two outcropping analogues of major Middle Eastern naturally fractured reservoirs: the Cretaceous Mishrif Formation and the Triassic Ghail Formation (Khuff analogue) within Ras Al Khaimah of the United Arab Emirates (UAE).