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The Benefits of Maximum Likelihood Estimators in Predicting Bulk Permeability and Upscaling Fracture Networks

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The success of any predictive model is largely dependent on the accuracy with which its parameters are known. When characterising fracture networks in fractured rock, one of the main issues is accurately scaling the parameters governing the distribution of fracture attributes. Optimal characterisation and analysis of fracture attributes (lengths, apertures, orientations and densities) is fundamental to the estimation of permeability and fluid flow, which are of primary importance in a number of contexts including: hydrocarbon production from fractured reservoirs; geothermal energy extraction; and deeper Earth systems, such as earthquakes and ocean floor hydrothermal venting.

Our work links outcrop fracture data to modelled fracture networks in order to numerically predict bulk permeability. We collected outcrop data from a highly fractured upper Miocene biosiliceous mudstone formation, cropping out along the coastline north of Santa Cruz (California, USA). Using outcrop fracture networks as analogues for subsurface fracture systems has several advantages, because key fracture attributes such as spatial arrangements and lengths can be effectively measured only on outcrops [1]. However, a limitation when dealing with outcrop data is the relative sparseness of natural data due to the intrinsic finite size of the outcrops. We make use of a statistical approach for the overall workflow, starting from data collection with the Circular Windows Method [2]. Then we analyse the data statistically using Maximum Likelihood Estimators, which provide greater accuracy compared to the more commonly used Least Squares linear regression when investigating distribution of fracture attributes. Finally, we estimate the bulk permeability of the fractured rock mass using Oda's tensorial approach [3]. The higher quality of this statistical analysis is fundamental: better statistics of the fracture attributes means more accurate permeability estimation, since the fracture attributes feed directly into the permeability calculations.

The application of Maximum Likelihood Estimators can have important consequences, especially when we aim to predict the tendency of fracture attributes towards smaller and larger scales than those observed, in order to build consistent, useable models from outcrop observations. The procedures presented here aim to understand whether the average permeability of a fracture network can be predicted, reducing its uncertainties; and if outcrop measurements of fracture attributes can be used directly to generate statistically identical fracture network models, which can then be easily up-scaled into larger areas or volumes.

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