Spatial continuity of rock fracture surfaces

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Introduction

Fluid flow through some rocks may be predominantly through fractures. Coupled Thermo-Hydraulic-Mechanical-Chemical (THMC) numerical models rely on fractures' surfaces representations to construct a distribution model of the empty space (aperture) between the two. The generally used statistical representations of fracture surfaces often overlook directionality which may result in a poor representation of the aperture distribution and thus a poor model. The aim of this study is to investigate the possibility of characterising a fracture surface roughness using semi-variograms and an upscaled fracture surface. Comparing the kriging originated fracture surface to the original offers a measurement of methodological quality. A statistical analysis was performed in a greywacke in order to acquire the semi-variograms' parameters necessary to describe the spatial continuity of the fracture surface topography. The surface was then interpolated using Ordinary Kriging techniques.

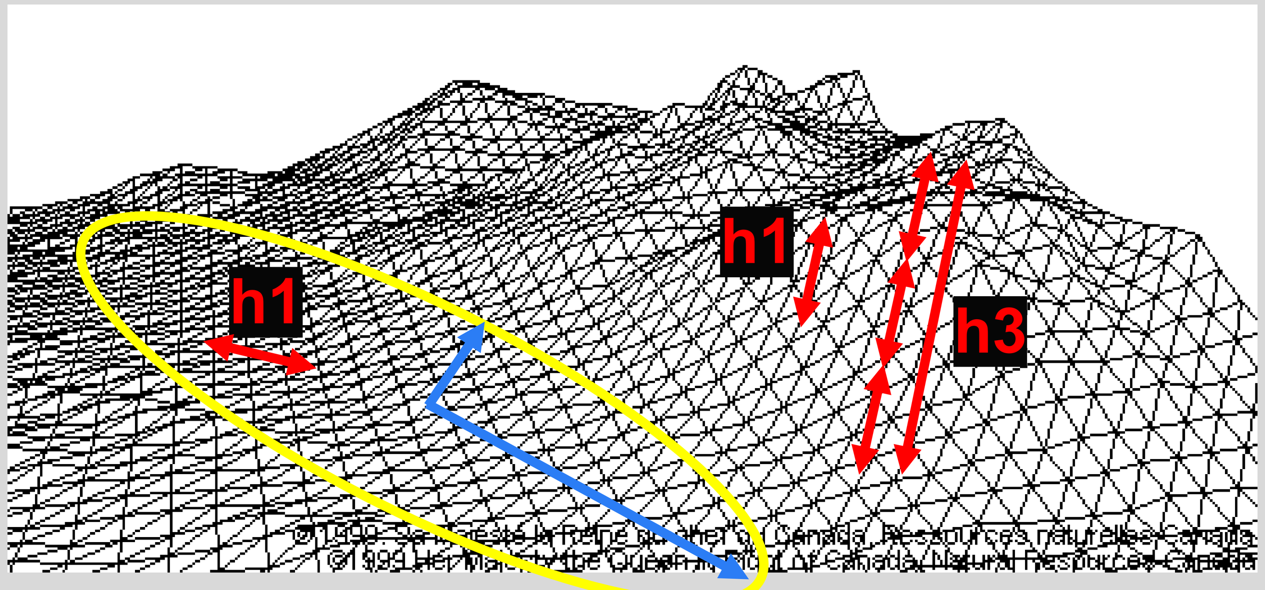

Fig.1 – Spatial Continuity on topographic surface
https://ethz.ch/content/dam/ethz/special-interest/baug/irl/plus-dam/documents/lehrveranstaltungen/msc/MCDA/Lecture3_KRIGING.pdf

Minor and major directions and respective ranges of correlation

Correlation limit area

Spatial Continuity

- **What is it?** It's the spatial dependency of a regional variable to itself. Points closer to each other are more similar than points farther apart.
- **How is it used?** In conjunction with kriging, it is used to predict a value at an unknown location
- **What is kriging?** Kriging is the **BLUE** (**B**est **L**inear **U**nbiased **E**stimator).
  - **Best** – aims to reduce global σ^2.
  - **Linear** – uses Inverse Distance Linear weights
  - **Unbiased** – aims at Mean Global Error=0 (i.e. $\sum_{i=1}^{n} \lambda_i=1$)
  - It uses the variograms' directions and distances to the data points to calculate the weights (λ) used to predict the value z at location x_0.

Data

The data used was taken from the 4th quadrant (red square Fig.2) of a Colburn greywacke fracture surface. A colour-scaled illustration is depicted in Fig.3, which shows a strong trend in the y-direction where most low values are at the bottom and systematically increase towards the top. This is also clear in Fig.4 in 3D. To model this trend, a first order plane is fit through the points and then subtracted from them to take the trend out. This results in the residuals (de-trended) dataset rendered in Fig.5.

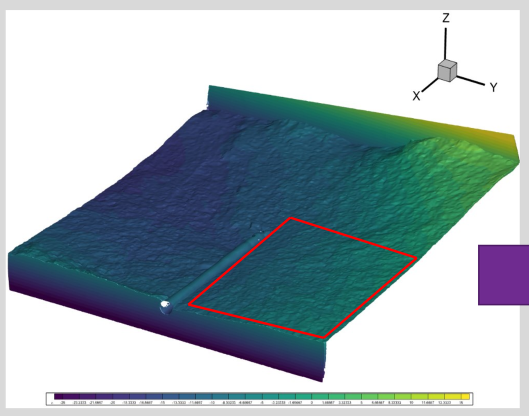

Fig.2 - Original Greywacke data. The red square represents the sub-dataset used in the study.

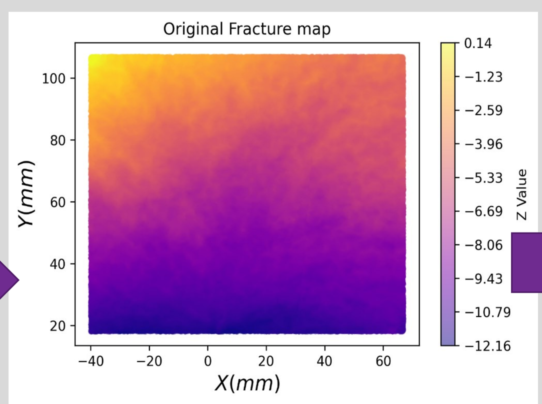

Fig.3 - Colour-scaled quadrant 4 greywacke top surface.

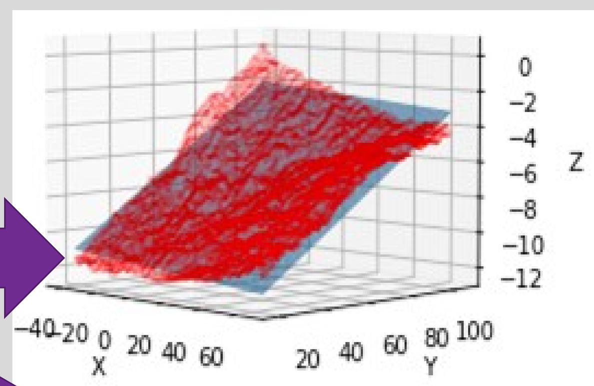

Fig.4 – De-trending process using a fitted plane through the data and subtracting that plane from the data.

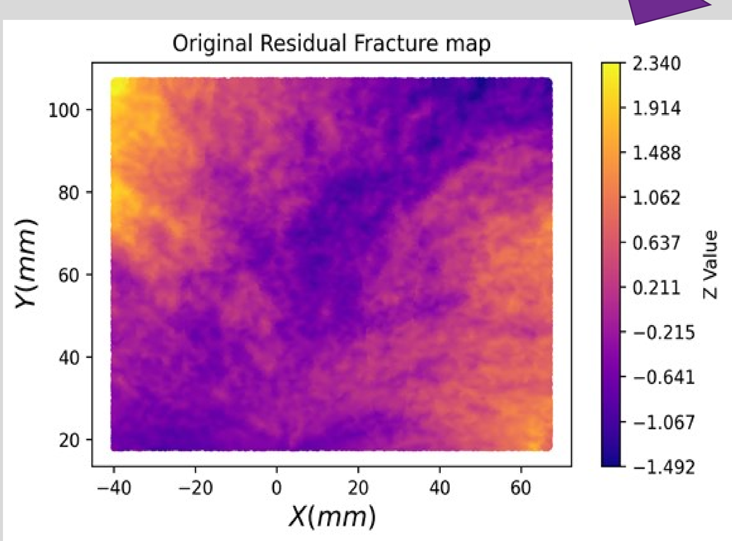

Fig.5 - residuals fracture map.

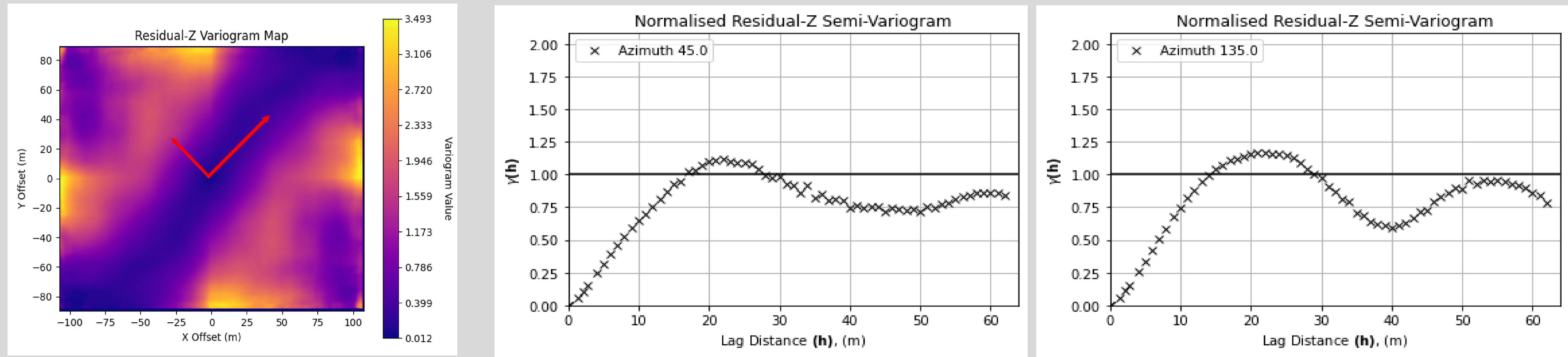

Fig.6 – Left: Residuals semi-variogram map. Red arrows represent the major and minor directions. Right: Semi-variograms for 45 and 135°.

The variogram map in Fig. 6 (Left) shows the directions of major and minor continuity vectors in red which correspond the variograms for the 45° (Middle) and 135° (Right). The lag values of each variogram that correspond to the function crossing the sill (maximum variance of 1) are called ranges. The ranges help characterising the spatial continuity in each direction since they limit the correlation and are used in the kriging algorithm.

Upscaling

In order to krig (interpolate between points), the algorithm requires a baseline which is given by some scattered base points which in turn come from the upscaling of the initial fracture residuals (Fig.7).

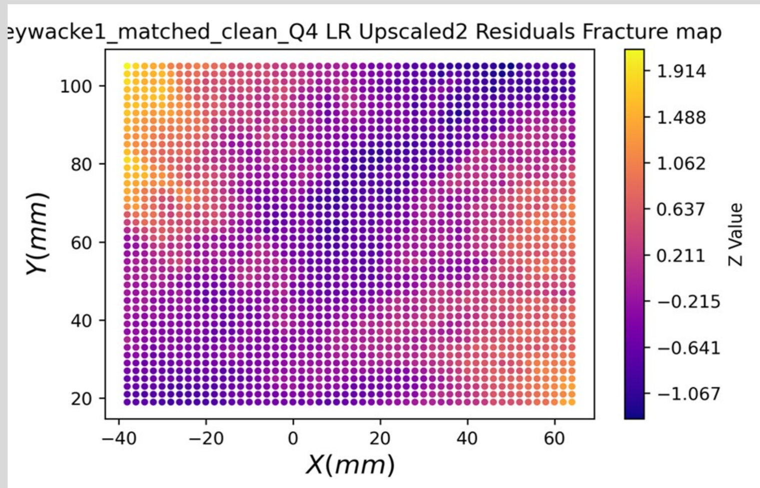

Fig.7 – Upscaled results of 2x minimum "cell" size.

Results

A reasonable match was achieved between the normalised residuals and the kriged surface.

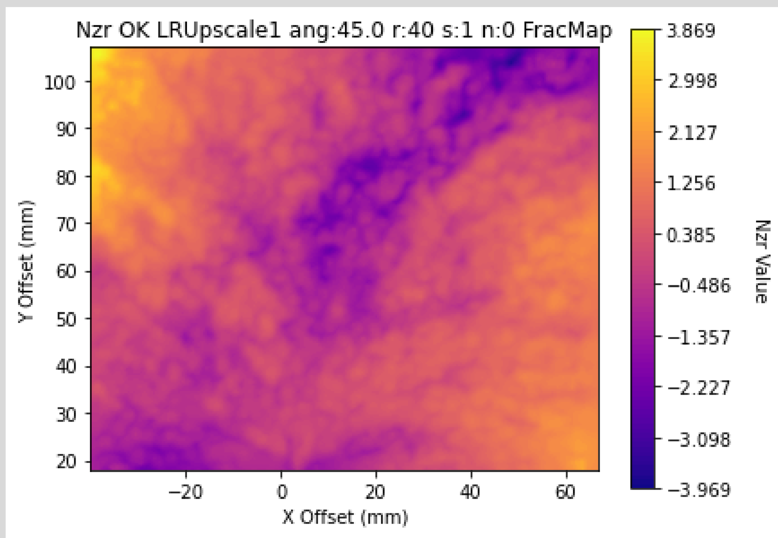

Fig.8 – Ordinary Kriging results

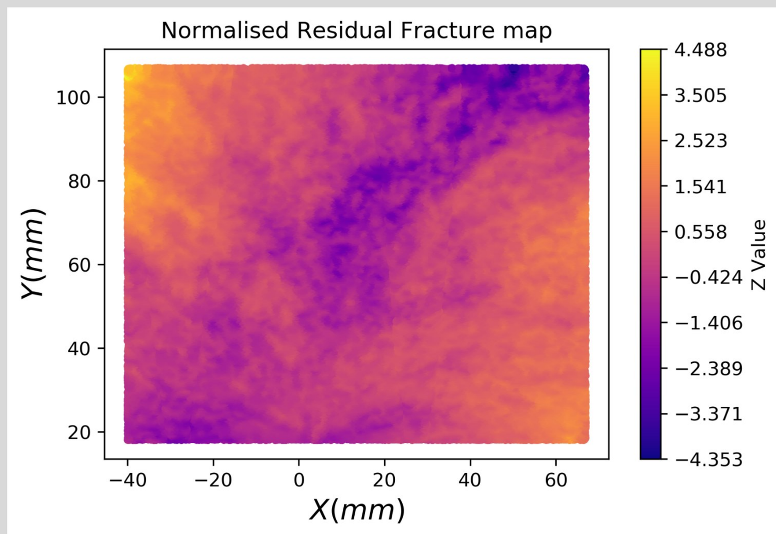

Fig.9 - Normalised residuals fracture map (Normalised Fig.7).

Next Steps

Aperture is the parameter that most influences the permeability of a fracture. It is well known that shear can cause fracture dilation, i.e. increase in aperture, but the direction in which shear occurs is often neglected. The next step is to shear the fracture surfaces in discrete steps and take the aperture at each one, hence building a shear vs aperture function, for each continuity direction. This would then be used to inform any mechanical Finite Element Method (FEM) model of the aperture differential as a function of shear displacement.

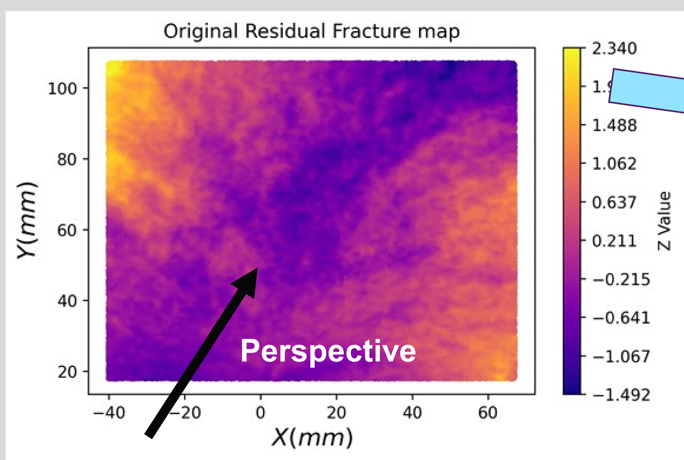

Fig.5 - Residuals fracture map.

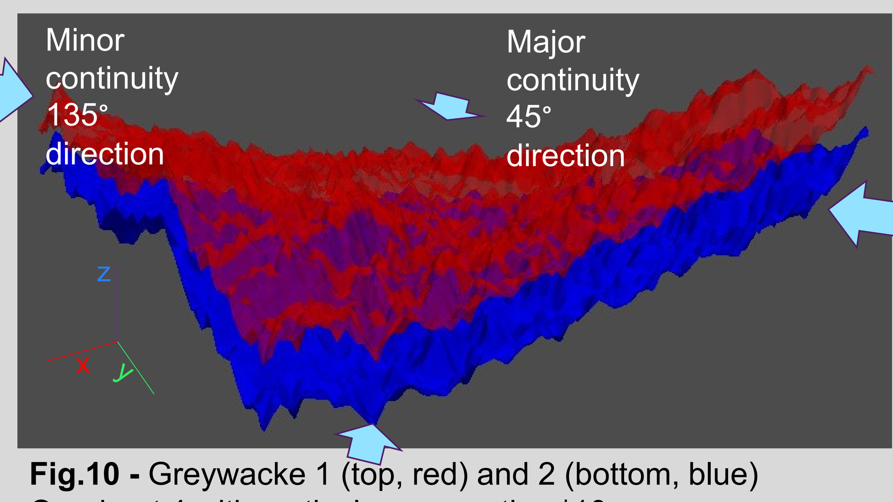

Fig.10 - Greywacke 1 (top, red) and 2 (bottom, blue) Quadrant 4 with vertical exaggeration *10

Conclusion

The random function of a rock rough fracture surface has been characterised. A reasonable match between the kriged and original surfaces confirms the method's accuracy. They can be useful to provide more control over and more realistic aperture distributions of THMC Finite Element Method models. These results may provide a new alternative to current storing and computing solutions for fracture representation.

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