Image processing for quantifying fracture orientation and length scale transitions during brittle deformation

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Image processing for quantifying fracture orientation and length scale transitions during brittle deformation (Invited)

Roberto Emanuele Rizzo[1], David Healy[1], Natalie J. Farrell[1]

[1]Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom

We have implemented a novel image processing tool, namely two-dimensional (2D) Morlet wavelet analysis, capable of detecting changes occurring in fracture patterns at different scales of observation, and able of recognising the dominant fracture orientations and the spatial configurations for progressively larger (or smaller) scale of analysis. Because of its inherited anisotropy, the Morlet wavelet is proved to be an excellent choice for detecting directional linear features, i.e. regions where the amplitude of the signal is regular along one direction and has sharp variation along the perpendicular direction. Performances of the Morlet wavelet are tested against the 'classic' Mexican hat wavelet, deploying a complex synthetic fracture network.

When applied to a natural fracture network, formed triaxially ($\sigma_1>\sigma_2=\sigma_3$) deforming a core sample of the Hopeman sandstone, the combination of 2D Morlet wavelet and wavelet coefficient maps allows for the detection of characteristic scale orientation and length transitions, associated with the shifts from distributed damage to the growth of localised macroscopic shear fracture. A complementary outcome arises from the wavelet coefficient maps produced by increasing the wavelet scale parameter. These maps can be used to chart the variations in the spatial distribution of the analysed entities, meaning that it is possible to retrieve information on the density of fracture patterns at specific length scales during deformation.

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Detecting the transition to failure: wavelet analysis of multi-scale crack patterns at different confining pressures

Roberto Emanuele Rizzo[1], David Healy[1], Natalie J. Farrell[1]

[1]Geology and Petroleum Geology, University of Aberdeen, Aberdeen, United Kingdom

Numerous laboratory brittle deformation experiments have shown that a rapid transition exists in the behaviour of porous materials under stress: at a certain point, early formed tensile cracks interact and coalesce into a 'single' narrow zone, the shear plane, rather than remaining distributed throughout the material. In this work, we present and apply a novel image processing tool which is able to quantify this transition between distributed ('stable') damage accumulation and localised ('unstable') deformation, in terms of size, density, and orientation of cracks at the point of failure. Our technique, based on a two-dimensional (2D) continuous Morlet wavelet analysis, can recognise, extract and visually separate the multi-scale changes occurring in the fracture network during the deformation process.
We have analysed high-resolution SEM-BSE images of thin sections of Hopeman Sandstone (Scotland, UK) taken from core plugs deformed under triaxial conditions, with increasing confining pressure. Through this analysis, we can determine the relationship between the initial orientation of tensile microcracks and the final geometry of the through-going shear fault, exploiting the total areal coverage of the analysed image. In addition, by comparing patterns of fractures in thin sections derived from triaxial ($\sigma_1 > \sigma_2 = \sigma_3 = Pc$) laboratory experiments conducted at different confining pressures (P_c), we can quantitatively explore the relationship between the observed geometry and the inferred mechanical processes. The methodology presented here can have important implications for larger-scale mechanical problems related to major fault propagation. Just as a core plug scale fault localises through extension and coalescence of microcracks, larger faults also grow by extension and coalescence of segments in a multi-scale process by which microscopic cracks can ultimately lead to macroscopic faulting. Consequently, wavelet analysis represents a useful tool for fracture pattern recognition, applicable to the detection of the transitions occurring at the time of catastrophic rupture.