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Progressive evolution of bedrock fracture patterns: A case study from coastal western Norway

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Complex fault and fracture patterns are common features, especially in geologically old basement terranes. They are the cumulative expression of repeated episodes of brittle deformation. The progressive spatial evolution of brittle features and their interaction, as well as the temporal sequence of deformation, remain often obscure due to the general lack of systematic overprinting relationships and absolute geochronological constraints.

In an approach to unravel the complex geological history stored in fault and fracture patterns, we combined a number of methods to study the pervasively-fractured Early to Mid-Ordovician intrusive rocks in the northern Bømlo islands, SW Norway. The fracture pattern was analyzed by careful manual extraction of lineaments from high-resolution LiDAR-derived hillshade models. Ground truthing of the obtained results was done by the systematic collection of structural field data, including information about lithology, fracture mineralogy, and additional fault characteristics such as fault rock type, kinematics and displacement. Petrographic microscopy of coated fracture planes and damage zone samples combined with XRD analysis of fault gouge and cataclasite of selected representative faults allowed us to further refine the field mineralogical classification of the structural data. 40Ar/39Ar mica and K-Ar fault gouge geochronology provided absolute age constraints for the activity of the various fault sets. Finally, paleostress inversion was applied to fault sets, which were carefully sorted according to the observed relative age relationships in addition to the knowledge derived from the different styles of mineral coating associated with different faults, the structural trend, and absolute age constraints.

The local brittle structural record is interpreted as reflecting a sequence of seven deformation stages, three ascribable to the Caledonian orogenic cycle and four to the rift evolution of the North Sea. The Caledonian structures are assigned to (1) Late Ordovician NNW-SSE transpression, (2) Silurian WNW-ESE compression and (3) Devonian NW-SE transtension. Rifting initiated under (4) NE-SW extension in the Carboniferous ($\sim$ 330 Ma), enhanced during (5) Permian to Mid Triassic ENE-WSW extension ($\sim$ 290-245 Ma), and resumed during (6) Late Triassic to Late Jurassic E-W extension ($\sim$ 210-160 Ma) and (7) Early Cretaceous WNW-ESE extension ($\sim$ 125 Ma). In our model, all the structural elements defining the currently exposed fracture pattern were largely established by the Middle Triassic, and existing faults and fractures were mainly reactivated during later deformation episodes. By that time the basement was saturated of fractures and faults, which inhibited the nucleation and growth of new brittle structures. Permian faulting was seismic in nature, as demonstrated by the presence of pseudotachylyte along discrete fault planes and Late Triassic to Jurassic extension was associated with extensive formation of incohesive fault rock; Early Cretaceous deformation was characterized by fluid-induced alteration and lower accommodated strain. This change in deformation intensity accompanied a gradual clockwise rotation of the extensional stress field, which can be related to the northward rift propagation from the North Sea to the Mid-Norwegian Margin.