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Insights into processes of fault reactivation in the brittle regime from the structural analysis of fracture-saturated crystalline basements: an example from Namaqualand, South Africa

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Unravelling the brittle history of old crystalline basements is a challenging task due to the long and complex nature of their geological evolution and to the common lack of clear time markers. Pre-existing ductile fabrics often play an important role in the localization of younger brittle features, which invariably reflect and result from multiple structural reactivations during the numerous orogenic events that controlled the growth and evolution of the crustal blocks. In spite of these complexities, the careful and systematic study of outcrops containing predominantly brittle structures (i.e. brittle deformation zones, faults, fractures and associated fault rocks) with the aim to document their character and kinematics may become a valuable tool towards the unravelling of these structural histories and can help refine our understanding of reactivation processes in the brittle field. The exceptionally well exposed crystalline basement of the ca. 1.03 Ga Namaqua Metamorphic Complex (NMC) in western South Africa is used as an example. Remote sensing analysis highlighted several sets of kilometric conjugate shear fractures. Their geometric arrangement and kinematics are constrained by the offset of lithological markers and by detailed field investigations that allowed gathering a significant dataset of fault-slip data. Striated fault planes were observed throughout the NMC and were documented by paying great attention to their geometry, kinematics, mineral coating and to the rock type they deform. Paleo-stress tensors were computed on internally homogeneous fault-slip datasets and a tentative relative geochronological succession of brittle deformation events was established. This was aided by separating in time faulting events through the usage of Cretaceous weathering horizons, silicified fluvial deposits, paleosols and 77–54 Ma olivine melilitite plugs as time markers. The oldest features recognized formed during four compressional episodes assigned to the Neoproterozoic Pan African evolution. This history is expressed by sub-vertical conjugate fracture sets and fits well the inferences derived from remote sensing. The greatest compressive direction rotated from NW-SE to NNE-SSW and finally to almost E–W. A subsequent ENE-WSW-oriented extensional episode is associated with the local effects of the opening of the Atlantic Ocean and was followed by a second, ca. E–W extensional episode, linked to the well-acknowledged Mid-Cretaceous (115–90 Ma) event of margin uplift. A late Santonian (85–83 Ma) NWSE compressive paleostress deformed the Late Cretaceous sequences and was in turn followed firstly by a renewed episode of NE-SW extension and later by ca. NNE-SSW Late Maastrichtian (69–65 Ma) shortening. The latter is broadly coeval with the emplacement of the Gamoep magmatic suite. A phase of WNW-ESE Cenozoic extension is assigned to the extensional phase recorded in the Okawango delta, interpreted as reflecting propagation of the East African Rift System into southern Africa. No stress tensor was computed for the present day "Wegener anomaly" stress field, oriented NW-SE. However, the available in situ stress measurements from the region were used to perform slip tendency analysis, which indicates that, under the currently existing stress conditions, WNW-ESE- and NNW-SSE-striking faults are critically stressed and are the most likely reactivated, in agreement with the present seismicity.