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Formation of fault breccias and cataclastic shear zones within layered carbonates: examples from the Eastern Alps

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In this study, we focus on fractures that formed in carbonates prior to the full development of cataclasites, fault breccias, and gouges in order to get information on the evolution of fault zones in time and space. In particular, we want to draw the attention on the remarkable importance of high-angle fractures in certain rock types with a particular pre-existing structure and deformation-related geometry. Moreover, we focus on the assumed role of these structures in the development of brittle shear zones and brecciation. This study provides a kinematic concept based on field and lab observations and an evolutionary scheme from initial high-angle fracture formation toward the development of fault rocks, in particular fault breccias. For a case study study, we have chosen two major strike-slip faults in the Eastern Alps: the Thalhof fault being a segment of the Salzach-Ennstal fault system, and the Lavanttal Fault. The Thalhof fault shows predominant left-lateral displacement, the Lavanttal fault shows right-lateral displacement. These faults are in parts crosscutting layered carbonates (Triassic limestones and dolomites) of the Upper and Lower Austroalpine Unit, respectively. The development of brittle fault zones in the observed rock types starts with the generation of broad bands of concentrated shear-imposed deformation by the development of fracture zones with an internal lamellae structure. These fracture zones probably combine R‘, T and mixed-mode fracture components and may be assumed to evolve initially from transfer zones between parallel pre-formed large-scale shears of higher order. The consequent synthetic rotation of lamellae results in the first place in the development of a pervasive bending or kink zone with an axial plane subparallel to the pre- existing planar discontinuities (the shear zone boundary). Kinking results from the longitudinal constraint of lamellae associated by reduced lateral confinement as well. The kinking and overturning of lamellae, their breakdown due to the assumed impeded shear zone widening (required initially in a bookshelf-mode rotation) and their cracking along the pre-formed shear zone boundary (e. g, a foliation plane) altogether will co-operate in the formation of distinct zones of shear accommodation. Rupturing along kink bands developing within the lamellae array and breaking-up to smaller fragments with independent rotational and translational displacement may mark the transition to the formation of cataclastic fault rocks. Subsequent shear is assumed to be localized along these brecciated zones, eventually ending up with the formation of bands of fine-grained fault gouges, and the evolution of a fault core with slip planes of local influence. With the overturning of broken lamellae, bringing the fabric elements into the extensional quadrant of the incremental strain ellipsoid, and with breakup and kinking of lamellae, the evolution of cataclastic zones is triggered off. Only remnants and increasingly isolated rotated clusters of initial lamellae (torn apart, partially interacting in a domino-style kinematic) may survive during advancing stages of cataclastic deformation, thereby documenting the preceding stages of structural evolution. We assume that the structures described above represent common initial states in the development of brittle shear zones in rocks with spaced bedding or foliation, and the imposed shear deformation being roughly parallel to these primary structures. Additionally, this may be forced by a stress vector orientation at very high angles to theshear zone boundary. The obviously simultaneous development of different deformation styles and intensities along the shear zone extent is interpreted as being in the first place the consequence of variations in shear zone width (layer thickness, as in the marble samples) and hence differing stress- and strain conditions to be accommodated. These processes including the development of associated structures may proceed repeatedly in the case that earlier- formed breccias get cemented and subsequently undergo continuous brittle shear deformation - a cylic process of cementation healing and refracturing that might be termed “fault rock recycling”. Thus, fluids play a fundamental role in the evolution of these fault rocks. Stable isotope data have been obtained from host rock fragments, cement, and veins from these fault rocks. Approximately 50 host rock and cement samples have carbon (delta13C) and oxygen (delta18O) isotope values ranging from +2,7 to 0 and -8,5 to -6, respectively. This may indicate, that the stable isotope composition of the host rock fragments was completely equilibrated during faulting due to a high fluid/rock- ratio. Samples of fibrous carbonate veins have delta13C and oxygen delta18O isotope values -8,2 to -8,6 and -10,1 to -8,4; these may indicate a lower fluid/rock ratio at the final stages of the fault zone evolution.