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Mixed brittle-plastic deformation behaviour in a slate belt. Examples from the High-Ardenne slate belt (Belgium, Germany)

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In the High-Ardenne slate belt, part of the Rhenohercynian external fold-and-thrust belt at the northern extremity of the Late Palaeozoic Variscan orogen (Belgium, Germany, France), particular quartz vein occurrences can be observed in predominantly fine-grained siliciclastic metasediments. Detailed structural, petrographical and geochemical studies has revealed that these vein occurrences can be related to a mixed brittle-plastic deformation behaviour in a low-grade metamorphic mid-crustal environment.

The first type of quartz veins are bedding-perpendicular, lens-shaped extension veins that are confined to the sandstone layers within the multilayer sequence. Fluid inclusion studies demonstrate high fluid pressures suggesting that the individual sandstone bodies acted as isolated high-pressure compartments in an overpressured basin. Hydraulic fracturing occurred during the tectonic inversion (from extension to compression) in the earliest stages of the Variscan orogeny. The vein fill shows a blocky character indicating crystal growth in open cavities. Both the typical lens shape of the veins and the subsequent cuspate-lobate folding of the bed interfaces in between the quartz veins suggest plastic deformation of cohesionless fluid-filled fissures. Metamorphic grade of the host rock and fluid temperature and pressure clearly indicates mid-crustal conditions below the brittle-plastic transition. This first type of quartz veins exemplifies mixed brittle-plastic deformation behaviour, possibly related to a transient deepening of the brittle-plastic transition. This is in contrast with contemporaneous bedding-perpendicular crack-seal veins observed in higher – upper-crustal – structural levels in the slate belt, reflecting pure brittle deformation behaviour.

The second type are discordant quartz veins confined to extensional low-angle detachment shear zones. These very irregular veins transect a pre-existing pervasive cleavage fabric. They show no matching walls and again a blocky infill. The detachments reflect the late orogenic destabilisation of the slate belt, again suggesting vein development related to a tectonic inversion (from compression to extension). A kinematic model is developed in which brittle parental cracks are affected by a steady-state solid-state deformation within a creeping shear zone and evolve as plastically deforming fluid-filled cavities. Also this type of quartz veins reflects mixed brittle-plastic deformation behaviour in mid-crustal conditions.

Both types of quartz vein demonstrate that fluid-assisted, mixed brittle-plastic deformation in a developing slate belt is strongly related to major changes in the overall stress regime. Both during the tectonic inversion in the earliest and late stages of the Variscan orogeny extensive veining occurred. This is in contrast to the main compression stage of the orogeny, during which vein development seems rather occasional. While the late orogenic vein occurrence can be linked directly to a mid-crustal detachment root of an upper-crustal fault system, the regional aspect of the early orogenic veins remains enigmatic.

In both cases a transient strain-rate dependent deepening of the brittle-plastic transition is proposed to explain the formation of the brittle parental cracks. The plastic deformation of the fluid-filled cavities may be related to a recovery of the long-term brittle-plastic transition. The former deepening may thus be related to coseismic loading of the middle crust, while the latter recovery may reflect the postseismic relaxation. In this respect the different types of mixed brittle-plastic vein structures observed in the High-Ardenne slate belt may be seen as a reflection of earthquake-related deformation and fluid redistribution in the middle crust.