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Control of compositional and structural heterogeneity on shear zone nucleation and strain accumulation in granitoids of the Tauern window, Eastern Alps

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In spectacular glacier-polished outcrops of the Mesule area (South Tyrol, Eastern Alps), granitoids forming part of the Tauern window preserve different stages of development of Alpine amphibolite facies ductile deformation, from incipient localized shear zones to pervasive mylonitic foliation. The pre-Alpine intrusive protolith consists of a dominant medium-grained granodiorite, leucocratic fine-grained granites, and different generations of basic dikes (lamprophyres) and aplites. The oldest set of lamprophyres ($lamp_1$) displays magma mingling relationships with granodiorites, whereas late lamprophyres ($lamp_2$) cut all the other intrusive bodies. Joints within granitoids were filled with epidote and surrounded by alteration haloes before the onset of the main Alpine deformation. The protolith shows widespread structural and compositional heterogeneity, either primary (i.e. different intrusives) or secondary (i.e. related to fluid–rock interaction along joints). This heterogeneity played a major role in shear zone nucleation and strain localization and all shear zones within the granitoids appear to be directly related to precursor structures or lithological boundaries. Single shear zones nucleated and localized along weak layers or discontinuities (lamprophyres and joints). Paired shear zones invariably developed at the boundaries of relatively strong layers (aplites or bleached haloes around joints). The kinematics

within the (strike-slip) shear zone network was determined by the orientation of the initial discontinuities with respect to the inferred principal axis of bulk shortening ($\sim$340˚). The main set of $lamp_1$, mostly striking NNE-SSW and steeply dipping, were sheared sinistrally, as was typically observed for all structures striking in the range 340˚-070˚. Most aplites, $lamp_2$and joints are oriented E-W to ESE and were exploited as dextral shear zones, as typically observed for structures striking in the range 250˚-340˚. Intersecting dextral and sinistral shear zones may be active at the same time, giving rise to a characteristic flattening zone at their intersection, perpendicular to the bulk shortening direction. Ductile deformation was accompanied by extensional opening of quartz-calcite-biotite-plagioclase veins, up to a few meters wide and tens of meters long, which were also involved in localized shearing after their formation. Most of these veins are oriented ca. N-S and show opening geometries (pull aparts, wing cracks) and ductile deformation features indicative of a component of sinistral shear. Veins are interpreted to have most commonly filled pre-existing joints with orientations favourable for such reactivation, but some also occur along newly created fractures developed orthogonal to the instantaneous stretching axes. The overall kinematics of the shear zone network at the kilometre scale is very consistent and shows no evidence for significant local refraction of stress trajectories due to structural and rheological heterogeneities. With increasing deformation, the structural network of localized shear deformation becomes more and more inefficient in accommodating the bulk strain and deformation progressively involves the intervening country rocks, which develop a pervasive foliation. This process is accompanied by the progressive rotation of early-formed discrete shear bands and veins.