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Deformation structures resulting from anisotropy during high-strain deformation of ice 1h with initial CPO

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Ice 1h shows a strong viscoplastic anisotropy, as the resistance to activate dislocation glide on basal planes is at least one order of magnitude smaller than on the other slip planes. During flow the viscoplastic anisotropy leads to the development of a crystallographic preferred orientation (CPO). The anisotropic behaviour of flowing ice can lead to strain localisation. Only when the ice is layered (e.g. due to cloudy bands) it may be possible to identify localisation structures, as ice otherwise has no readily recognisable strain markers.

We use the Viscoplastic Full-Field Transform (VPFFT; Lebensohn and Rollett, 2020) crystal plasticity code coupled with the modelling platform ELLE (http://www.elle.ws; Piazolo et al., 2019) to simulate the deformation of intrinsically anisotropic ice 1h with an initial single maximum CPO in dextral simple shear up to very high strains. The VPFFT-approach simulates deformation by dislocation glide, taking into account the different available slip systems and their critical resolved shear stresses. We use an anisotropy similar to that of ice 1h, systematically vary the orientation of the initial CPO, and use passive markers/layers to visualise deformation structures.

The localisation behaviour strongly depends on the initial CPO, but reaches a consistent steady state after very high shear strains of about 30. The fabric and stress evolution reach a steady-state situation as well. The orientation of the CPO controls the style of deformation, which varies from (1) synthetic shear zones with a stable shear-direction parallel orientation and that widen with ongoing strain to unstable, (2) rotating antithetic shear bands, (3) initial formation of antithetic shear bands and subsequent development of synthetic shear bands and (4) distributed localisation. Furthermore, evolving visual structures depend on the presence and orientation of a visual layering in the material. However, at very high strains, the material is almost always strongly mixed and any original layering would be destroyed.

Our results highlight the challenge to identify strain localisation in ice, yet they can help the ice community to identify and interpret deformation structures in large ice masses (e.g. the Greenland ice sheet). As strain localisation in anisotropic materials behaves scale independent (de Riese et al., 2019), large-scale equivalents may occur of the observed small-scale structures (Jansen et al., 2016).

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