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The control of strain rate, temperature and strain on the symmetry, shape and magnitude of anisotropy developed during ice deformation

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Deformed polycrystalline ice has a strong crystallographic preferred orientation (CPO) with associated elastic and viscous anisotropy. We will present new data that help constrain the controls on the symmetry, shape (cone, cluster, planar etc) and magnitude of the CPO and its implications for elastic (seismic) anisotropy.

We have conducted ice deformation experiments across a wide range of temperatures (-2 to -70C) and strain rates (1E-7 to 1E-4). Most experiments are carried out in axial compression and a much smaller number in direct shear (∼ simple shear). Cryo-EBSD data from deformed samples demonstrate that microstructures of deformed ice change as a function of both temperature and differential stress/strain rate.

We have interpreted the microstructures in terms of key deformation, recovery and recrystallisation mechanisms. At high T or low strain rate (stress), strain induced grain boundary migration (SIGBM) is the dominant mechanism that influences the microstructure. The formation of the CPO is dominated by grains with high resolved stresses on the basal (easy slip) plane consuming other grains. In axial compression, c axes (poles to the basal plane) are arranged in a hollow cone (small circle distribution) around the compression axis. At lower T or higher strain rate (stress), deformation is dominated by lattice rotation, polygonization and grain rotation. In low-T axial compression experiments, c axes cluster parallel to the compression axis. The transition from hollow cone to cluster, with decreasing T or increasing strain rate, occurs by a reduction in the cone opening-angle. High temperature (∼-5C) experiments reproduce published observations that the cone angle also decreases as axial strain increases.

In axial compression the crystallographic orientations of grains with high resolved shear stress on the basal plane (c axis 45 degrees to compression) and the "ultimate" crystallographic orientations of grains rotated by slip on the basal plane (c axis parallel to compression) are distinct. In simple shear one of the orientations of grains with high resolved shear stress (c axis normal to shear plane) is coincident with the "ultimate" orientation of grains rotated by slip on the basal plane. This provides a simple explanation for why all sheared samples, (ours and from literature) have a dominant c axis maximum perpendicular to the shear plane. In high-temperature shear experiments, a secondary maximum lies in the plane containing the shear plane normal and the movement vector (profile plane) at an angle of up to 80 from the shear plane normal. This angle reduces as T decreases and also reduces as strain increases.

The cone angle in axial compression and the angle between the two maxima in simple shear relates to a balance of the rates of nucleation and SIGBM and the rate of lattice rotation. Understanding this balance is key to understanding CPO forming mechanisms. Polar terrestrial ice sheets deform at rates at least two orders of magnitude slower than any lab experiment, so CPO and anisotropy prediction in nature requires scaling of laboratory relationships.