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Rheology of deformed Carrara marble: Insights from torsion experiments

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Rock deformation experiments are essential for understanding lithosphere dynamics, strain localization processes and deformation mechanisms in polymineral aggregates, as they provide rheological parameters and record fabric development of rock-forming minerals, aiding the geological interpretation of naturally deformed rocks. Carrara marble received significant attention in the rock deformation community due to its homogeneous fabric and low impurities content, making it a laboratory standard. When the torsion actuator was developed for the Paterson-type gas-medium apparatus, it became possible to perform high strain experiments and reach true steady state flow conditions in Carrara marble. At the center of these ground breakings developments stood Luigi Burlini and his students. Their work showed for the first time, the importance of fabric development on steady state flow stress in response to high strain deformation and recrystallization. In the last years of Luigi‘s life, he and his students took rock deformation studies to a different direction by investigating the effect of initial strain and quantifying the coupling between fabric and flow stress.

We present here an overview of the four types of torsion experiment that were performed on Carrara marble with varied pre-existing strain. Earlier torsion experiments on homogeneous Carrara marble provided the framework in which these newer experiments were evaluated. In type I experiments samples were subjected to a torsion deformation leading to a maximum shear strain of 1 to 5, immediately followed by a reversed straining of equal magnitude. In type II and III experiments, a composite sample consisting of a segment of undeformed and one (type II) or two (type III) segment(s) of previously twisted Carrara marble, were deformed. In type IV experiments, a cylindrical segment of dynamically recrystallized Carrara marble was annealed 727 °C for up to five hours at to recover the original grain size without removing the developed texture. Subsequent deformation by torsion revealed the effect of initial texture on peak flow stress. Experimental conditions were designed to activate dislocation creep. Confining pressure was set at 300 MPa, temperature varied from 600 to 800 °C and the applied constant shear strain rate ranged from 3×10-4 to 1×10-3 s-1.

Type I to III experiments revealed that reversed deformation recovers sheared grains, with the recovery of shape preferred orientation (SPO) requiring less strain than the recovery of crystallographic preferred orientation (CPO). They also showed that recrystallization is controlled by absolute strain rather than total strain. In terms of rheology, the first three types of experiments highlighted that strain reversal is easier than continued forward deformation (Bauschinger effect), provided sheared relict grains dominate in the fabric. Additionally, bulk sample flow behavior was shown to be dominated by the weakest segment in the composite sample. Type IV experiments quantified the weakening effect of texture at 33-67%, depending on temperature and the degree of initial CPO. All experiments showed that deformed rocks are weaker than their protolith equivalents. Therefore, despite possible alteration of shear direction, or prior grain growth, mylonites will localize strain during the next deformation event.