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Microscale investigations of the evolution of deformation mechanisms in a low-temperature marble mylonite, NE Attica, Greece

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Carbonate rocks compose 15% of Earth's ice-free continental surface and commonly consist of kilometer thick sequences that host complex crustal-scale fault zones, accommodating displacements on the order of tens of kilometers. These intricate fault networks significantly influence fluid migration, further controlling crustal mechanics. Understanding the deformation mechanisms of calcite and dolomite, two of the dominant carbonate forming minerals, is therefore essential for predicting the rheological properties of carbonate rocks. Herein, we conduct a microstructural analysis to investigate the interactions between brittle-ductile structures under greenschist facies conditions in a naturally occurring biphasic marble mylonite. The framework of the mylonite, which is exposed in a tectonic window north of the Greek Cyclades on the Attica peninsula, indicates deformation occurred at 300-350°C and 7-8 kbar during the late Oligocene. The mylonitization is overprinted by a weak, but pervasive axial plane cleavage. A second strong, and densely spaced axial plane cleavage, oriented perpendicular to and truncating the first set, creates a 'pseudo-boudinage' of the dolomite layers. Localized shear bands cross-cutt the second axial plane cleavage set, suggesting a fourth phase of deformation. Electron backscatter diffraction analysis of the mylonite reveals coarse (30-200 μm) calcite with evidence of crystal-plasticity in the form of low-angle (<15°) grain boundary development (LAGB) and linear to heterogeneous misorientation patterns. LAGB density and misorientation angles increase towards the clast rims, to maximum misorientations reaching 44° relative to the mean orientation of the grain. The coarse grains are surrounded by fine (<25 μm) calcite revealing little to no intracrystalline misorientation. Fine calcite is similar in size to subgrains defined by LAGBs within high misorientation domains of coarser grains, which is consistent with subgrain rotation recrystallization and lower greenschist facies conditions. Calcite in the mylonite record a grain-shape preferred orientation that is parallel to the main foliation and oblique to that of the cross-cutting ductile shear bands. These shear bands are characterized by fine grained (2-10 μm) inequigranular calcite with no internal misorientation and sparse, 20-30 μm anhedral calcite with weak heterogeneous misorientation patterns and a maximum misorientation of 8° in the panhandles of grains. Contrastingly, deformation in the dolomite bands is dominantly brittle as evinced from the brecciation of these layers. Clasts commonly display primary growth twinning

characterized by a rotation of 180° around one of the $[11\bar{2}0]$ axes, 12-120 µm in diameter and show minor evidence for crystal-plasticity in the form of intragranular lattice distortions (maximum misorientation of 22° relative to the grain average orientation). Calcite infilling the space between dolomite fragments exhibits no grain-shape preferred orientation and consists of 5-25 µm diameter grains with minimal intracrystalline lattice distortion (0°-8°) and e-twins characterized by an 80° rotation about the $[0\bar{2}21]$ axes. The same twinning is observed in the coarse calcite with twin density increasing with proximity to dolomite 'boudins'. Our study identifies the active deformation mechanisms in calcite and dolomite during four successive phases of deformation to clarify the feedback between brittle-ductile microstructures on strain localization, yielding insight into rheological evolution of carbonates.