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Volcanic forces inferred from EBSD and µXRD analyses of Yellowstone quartz

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The magnitude of forces at play in active magmatic systems is poorly constrained because direct observation is difficult. Additional complications include short time scales and the likelihood of overprinting signatures of deeper processes by the catastrophic nature of eruption. Deformation of crystal lattices is one signature of magmatic force common to all crystals that survive eruption. Quartz crystals have documented residual elastic stresses in the hundreds of MPa measured using synchrotron µXRD. These stresses may be caused by several processes: crystal-crystal impingement in a crystal mush, explosive fragmentation, or shear in flowing lavas. To better unravel when these stresses were imparted relative to the ultimate eruption, we combine µXRD with new EBSD measurements. EBSD helps constrain subgrain and twin boundary relationships, geometrically-necessary dislocation density (GND), and plastic deformation.

We target quartz grains from a violent Yellowstone super-eruption and from a large-volume rhyolitic obsidian lava flow (Huckleberry Ridge Tuff and Summit Lake lava, respectively). We use ‘Herkimer diamonds’ as a comparative baseline for deformation. Herkimer diamonds are quartz crystals, famous in the mineral specimen community, that grew into vugs and have experienced no tectonic or volcanic stresses. Samples from both Yellowstone eruptions preserve roughly the indistinguishable amounts of elastic residual stresses, ranging from 100 to 150 MPa. EBSD indicates a GND density of ca. 4E12, with slightly higher values in the Summit Lake Lava. Diffraction peak broadening provides a record of plastic deformation using µXRD. Diffraction peaks are significantly more smeared in Summit Lake lava (0 to 0.15 degrees) than in Huckleberry Ridge Tuff (~0.06 degrees). Subgrain formation in both samples is documented by both µXRD and EBSD. By isolating processes we conclude that elastic residual stresses record pre-eruptive magmatic environment. Viscous shear during lava emplacement generates the majority of plastic deformation, which swamps the signal of lesser amounts of plastic deformation produced in the reservoir or conduit. Pre-eruption processes are likely the source of elevated elastic residual stresses, and we favor an interpretation where the stresses arise from force-chain impingements within crystal mushes prior to eruption.

Finally, EBSD and µXRD provide complementary and overlapping results. Because µXRD peak smearing is sampling both geometrically-necessary and statistically-stored dislocations (SSD;

dislocations which contribute no net lattice bending but do contribute to strain hardening), and EBSD only GNDs via relative lattice curvature, the relative proportion of both types of dislocation may be calculated. Huckleberry Ridge Tuff grains preserve up to 20% GNDs, and Summit Lake lavas less than 10%, potentially reflecting the greater total stresses of the Summit Lake samples.