Testing a model of crystal accumulation for the Turkey Creek caldera, Arizona
Rachel Haynes, 2015

Twenty-seven million years ago violent super-eruptions in Turkey Creek, Arizona extruded 500-1000 km$^3$ of volcanic material (Du Bray & Pallister 1991) – enough to bury the state of Maine in at least 6m of hot ash and pumice. After the massive eruption, the emptied magma chamber collapsed to form a caldera. There have been even larger eruptions like this in Yellowstone and Colorado, but none so destructive in thousands of years. The processes in the shallow crust that lead up to such an eruption are still a mystery. In order to predict when the next super-eruption will occur, it is necessary to study how these caldera systems form. We are able to study calderas by looking at volcanic deposits from past eruptions and cooled underground magma chambers (plutons) which have been exposed by erosion. This summer I used rock samples I collected from the Turkey Creek caldera to test competing models for caldera systems. The first model predicts that eruptible magma resides in the shallow crust in large, melt-rich magma reservoirs for a long enough time that mineral crystals (phenocrysts) settle into a pile (cumulate) at the bottom (Bachmann & Bergantz 2004). The magma that erupts forms volcanic rocks and magma that cools underground becomes a pluton. In the second model small injections of magma into the shallow crust remain liquid for a short time and either erupt directly or cool into plutonic systems (Glazner et al. 2004). In this model magmas do not reside long enough for crystal settling.

Previous research by Beane and Wiebe (2012) on granite and porphyry rocks from Vinalhaven, Maine, suggests that many crystals settling to the magma chamber floor come into contact on dominant crystal faces, resulting in quartz crystals bound together with strong lattice bonds in parallel or Esterel twin orientations (Figure 1). In rocks resulting from erupted magma, the explosive force is expected to have blown apart clusters weakly bound in random orientations, potentially resulting in a higher proportion of parallel and Esterel twins in extrusive rocks than their plutonic equivalents. If the Turkey Creek eruptions were the result of processes described by the first model, then we may find evidence of a cumulate by analyzing the relative orientations of crystals in clusters.

Data on crystal orientations were collected by electron backscatter diffractometry (EBSD) analysis on thin sections. Samples are of rhyolite tuff deposited by the first eruptions, dacite lava extruded in a second set of eruptions, and monzonite porphyry that was part of the magma chamber that cooled to a pluton. Quartz and feldspar phenocrysts from the Turkey Creek rocks are plentiful in the rhyolite (20-30%) and rare in the dacite and monzonite (<5%). Orientation data that we collected from 51 quartz and 14 plagioclase clusters revealed no systematic orientations of phenocrysts in clusters, meaning that the rhyolite is probably not an erupted cumulate (Figure 2). We did not have enough data to draw conclusions for the dacite and monzonite. Using EBSD analysis we also tested the thin sections for intragrain deformation that would be caused by compaction of a cumulate. There was no intragrain deformation, supporting our conclusion that the rhyolite is not an erupted cumulate.

Our data does not prove Turkey Creek behaved according to the first or second model; instead it is unique compared to similar studies of caldera eruptions in Colorado and New Zealand. Our working hypothesis is that these crystals did not settle as a cumulate at the base of a large melt-rich magma chamber, but instead may have formed as part of a carapace at the top. In the coming year I will continue my research to test this hypothesis. This research has been a great opportunity to become familiar with the pace of a developing project. It has also given me the chance to practice revising and adapting hypotheses when results are not as expected. I have gained experience with analytical techniques used in geology that have introduced me to different fields of geology. These experiences will be helpful as I continue geologic research in graduate school and a career in geology in the future.
Figure 1. Diagram illustrating parallel and Esterel twin orientations in dipyramidal quartz crystals (adapted from Beane & Wiebe 2012).

Figure 2. a Relative orientations of quartz crystals in clusters in Vinalhaven porphyry show that almost all clustered crystals are in parallel or Esterel twin orientations. Regions shaded in gray show crystals that are parallel (left) and Esterel (right). Adapted from Beane & Wiebe 2012. b Quartz clusters in Turkey Creek rhyolite show a wide distribution of orientations compared to Vinalhaven porphyry, which almost only showed parallel and Esterel twin orientations. This is interpreted to mean that the Vinalhaven porphyry originated as a cumulate whereas the Turkey Creek rhyolite did not.

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References