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Ascent and Crystallization of Magma beneath Arc Volcanoes

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Study of samples erupted recently from Mount St. Helens, Mt. Pinatubo, Mt. Unzen, Etna, and Soufriere Hills on Montserrat have demonstrated that a series of reactions occurred during the decompression of these magmas, driven by the loss of dissolved water from the melt phase. Studies of these magmas combined with experimental data on reaction rates yields interesting insights into the dynamics of magma ascent processes provided we can determine the water content and P-T conditions in the pre-eruption magma storage reservoir. The reactions occur only after the magma is volatile saturated, which means that knowing the storage zone conditions is critical. Fortunately, the required data are often obtainable from the magmatic mineral assemblage. We have determined that once saturation is reached, water degassing from melt into bubbles occur rapidly in ascending silicic melts, i.e., equilibrium water distribution is achieved in ascents slower than 0.25 MPa/s, but Cl and S movement is much slower (1,2,3). Microlite nucleation and crystal growth occur in magmas ascending to surface conditions slower than 0.2 MPa/s (4), and hornblende decomposition occurs in ascents slower than 0.004 MPa/s (5). The 1991 Pinatubo eruption sequence is very interesting because the pre-eruption magma was clearly volatile saturated, and the same magma erupted in several ascent processes. Pre-climatic dacitic magmas erupted in a series of explosive events separated by different repose times and thus experienced different low pressure annealings during their ascent; the climatic eruption involved a single stage ascent which was too rapid for microlite nucleation or crystal growth, and for significant loss of S from the melt phase, although much of the water and some Cl was lost. Matrix glasses in poorly-vesiculated material produced during the pre-climatic events contain 1.3 to 1.7 wt. percent water, compared to ~0.4 in the climatic eruption. They also contain extensive groundmass crystallization in the form of high number-density feldspar microlites. An increase in bulk magma viscosity as a result of microlite crystallization seems to have prevented the final stages of water loss. Furthermore, the accumulation of degassed, crystal-rich material in the conduit near the end of each eruptive phase may have modulated the pulsatory nature of subsequent eruptive events. The behavior of S and Cl in these preclimatic magmas is still being studied. However, we have now experimentally determined the relative rates of crystal growth vs. nucleation for groundmass melt in the 1991 Pinatubo magma as a function of anneal pressure. We have also tested decompression rates which are non-linear as would be expected given the changes in magma composition, density, and viscosity that accompany degassing and various possible degrees of gas loss from a batch of magma (6). The plagioclase microlite textures produced by different decompression paths are consistent with our understanding of the relationship between nucleation and growth processes as functions of the degree of supersaturation (5).

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