Phenocryst fragmentation in crystalline silicic magma during explosive and effusive eruptions

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Fragmented phenocrysts in volcanic rocks have been linked with rapid decompression and/or shear-induced breakage during magma ascent (e.g. Best and Christiansen, 1997; Allen and McPhie, 2003). Because broken phenocrysts in lavas are generally less abundant than those in pyroclasts (e.g. Best and Christiansen, 1997), rapid decompression and melt inclusion foaming (Bindeman, 2005) are thought to be the dominant process. However, experimental studies (e.g. Cordonnier et al., 2009) demonstrate that shear stress yielding on crystals during shear flow may also induce crystal fragmentation. This process is probably controlled by magma crystallinity because shear stress concentrates on the contact between crystals. To investigate the relative roles of these different mechanisms of phenocryst fragmentation we conducted microstructural studies from crystal-rich pumices and lavas (crystallinity of 35-55 vol %) from seven voluminous eruptions in Central Andes (Chile, Bolivia, and Argentina). All samples were high-K dacites to rhyolites with pumices coming from voluminous ignimbrites and the lavas from individual such as the Chao dacite in Chile and post-caldera lavas.

Three dimensional (3D) images were obtained using X-ray CT (ScanXmate-D180RSS270, Comscantecno Co, Ltd). In pumices, the felsic minerals (plagioclase and quartz) are highly fragmented to varying degrees. The broken crystals show a jigsaw pattern, with no or only minimal movement after breakage. This indicates that crystals and hence, magma, experienced limited flow after the fragmentation of phenocrysts. This is in contrast to the lava samples, where this type of crystal fragmentation is not found. Instead some mafic minerals show sliding along prominent cleavage planes. Crystal size distributions (CSDs) constructed from the 3D and 2D CT images display steeper slopes on log-log plots of the CSD´s for pumices than in lavas. No clear variation is seen with respect to changing the crystallinity. The steep slopes of CSDs in the pumices correspond to the phenocryst fragmentation, i.e. the formation of small fragments from large phenocrysts. These results indicate that the rapid decompression upon magma ascent and fragmentation during the pyroclastic eruptions was the main cause for phenocryst fragmentation and that during the effusive eruptions magmas ascended without significant phenocryst fragmentation despite their crystal-rich and silicic composition. Evidence from both explosive and effusive samples suggests that shear-induced breakage of crystal during magma ascent is not important in these natural samples. Our observations on these natural samples may indicate that unknown mechanisms, e.g., gas bubbles formed in magma, suppress the shear-induced breakage of crystal in crystal-rich magma and control its rheology in natural system.