Geochemical constraints on the source, flux, migration and seismic signatures of volcanic fluids, Katmai Volcanic Cluster, Alaska

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Fluid movement in the subsurface of active volcanoes is frequently thought to produce elevated seismicity; however the actual type of fluid (i.e. magma, volatiles, or hydrothermal waters) and the implications of the fluid movement are not well constrained. Knowledge of the type of fluid/s in the subsurface is critical for both forecasting and estimating the explosivity of the impending volcanic eruptions. In open-system volcanoes, low-solubility volatiles can be released from magma during ascent and outgassed at the surface of the volcano in advance of the source magma. This provides a useful tool to aid in eruption forecasting. The chemical and isotopic composition of these volatiles can provide insights into both the source (i.e. subducted slab, mantle wedge, or crust) and the type of volatiles at depth, which can help elucidate subduction and magma generation processes. Further, advanced knowledge of a hydrothermal and/or meteoric water system in a volcano's subsurface may help scientists to better interpret the monitoring data and evaluate potential hazards during periods of unrest. Finally, if magma movement can be directly identified from seismic data, then scientists could provide robust constraints on the likelihood and/or timing of impending eruptions.

In this project we aim to utilize these geochemical tools to address several fundamental science questions for three active volcanoes within the Katmai region of the Aleutian Arc, Alaska. Specifically, we will use geochemical and complementary seismic datasets to (1) identify volatile sources, (2) determine proportions of magmatic,

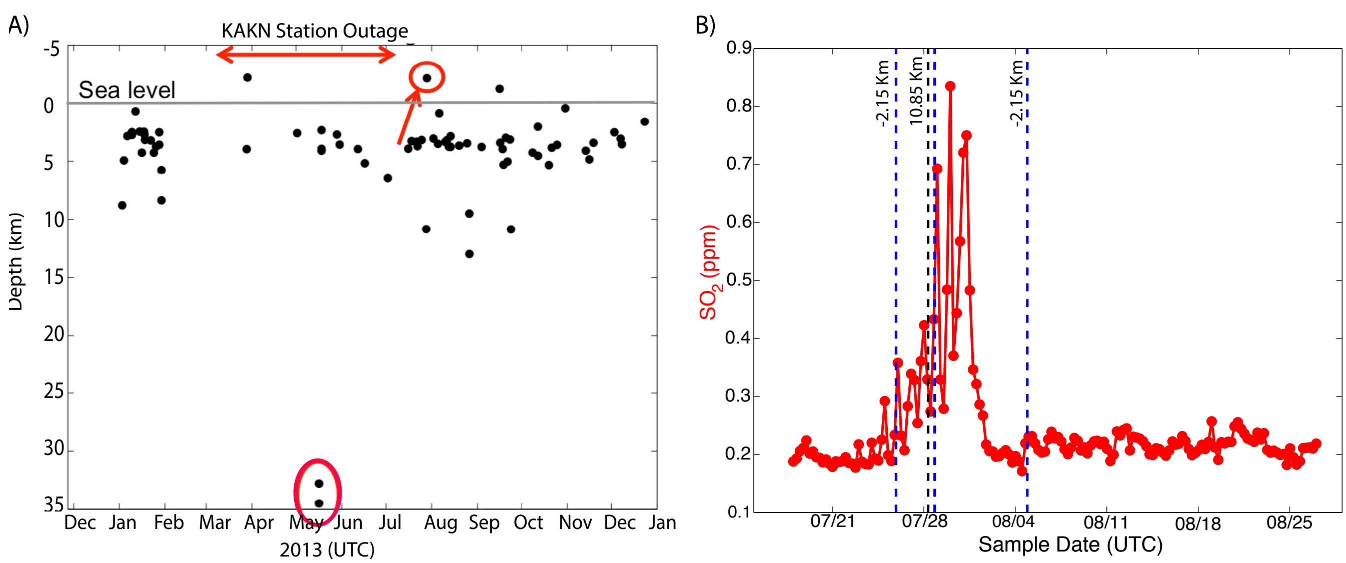

Figure 1. AVO located earthquakes within 5 km of Trident Volcano (A) and measured MultiGas SO_2 concentration from Trident's fumarole field and repeating earthquakes detected during the 2013 field campaign (B).

volatile and/or hydrothermal fluids within the subsurface, and (3) distinguish trends in gas composition that correlate with seismic signatures of fluid movement. Mt. Martin, Mt. Mageik, and Trident Volcanoes are selected as the targets of this study due to their continuous gas emissions, active hydrothermal systems, and abundant seismicity likely related to subsurface "fluid" movement. A two-week field campaign was conducted in July 2013 during which (1) fumarolic gases were sampled for chemical and isotopic analysis from Mt. Mageik and Trident Volcano, (2) MultiGas instruments where installed adjacent to the active fumarole fields for in situ sampling of plume CO_2, SO_2, and H_2S composition at all three target volcanoes, (3) and broadband seismometers were co-located with MultiGas instruments at Mt. Mageik and Mt. Martin to complement the existing Alaska Volcano Observatory (AVO) seismic network and measure local seismicity.

We use the chemical and isotopic compositions of the sampled volcanic fluids along with simple 2- and 3-component mixing models to distinguish mantle, crust, and sediment volatile sources at Mt. Mageik and Trident Volcano. Similar chemical and isotopic trends are observed at both volcanoes. Specifically, $^3He/^4He$ ratios of the fumarolic gases ($R/R_A \geq 7.3$) are similar to that of the upper mantle (~8±1 R_A) and are consistent with magma degassing in the subsurface. $\delta^{15}N$ values combined with N_2/He ratios indicate that sediment is the primary N_2 source, while $\delta^{13}C$ of CO_2 combined with $CO_2/^3He$ ratios indicate decreasing abundances of limestone, sediment and mantle C sources. Because the basement rock beneath the target volcanoes is comprised primarily of Jurassic limestone and sediments, we cannot conclusively distinguish subducted slab from crustal sedimentary volatile sources. Finally, $\delta^{18}O$ and δD isotopes from steam condensate within the fumarole samples reflect mixing of meteoric and subducted (i.e. andesitic) water, with meteoric water being the predominant water source at both volcanoes. Specifically, Trident's steam condensate is comprised of ~56% meteoric water and 43% andesitic water; while Mageik's steam condensate is comprised of ~71% meteoric water and 29% andesitic water.

Based on the gas composition from measured fumarole samples (Mageik and Trident only), the MultiGas measurements, and previous results in the literature, and through comparison with other well-studied volcanoes, we conclude that (1) preferential removal of (acidic) magmatic gases by hydrothermal waters (a process known as scrubbing) is occurring in the subsurfaces of both Mt. Mageik and Trident Volcano, and (2) shallow magma is degassing beneath Mt. Martin. Elevated CO_2 concentrations relative to SO_2 and HCl in the fumarolic samples from both Mt. Mageik and Trident Volcano are consistent with scrubbing of magmatic gases by hydrothermal waters, when combined with the strong meteoric signature of the steam condensate described above, suggest that both Mt. Mageik and Trident Volcano have well-developed hydrothermal systems. Additionally, changes in the relative composition of CO_2, HCl and S within gaseous emissions since the 1990's indicate that Mt. Mageik's hydrothermal system has increased in volume with respect to the magmatic system, while Trident's hydrothermal system has decreased in volume with respect to the magmatic system. A relatively low CO_2/SO_2 ratio (<1) at Mt. Martin observed in the MultiGas data is consistent with magma degassing at relatively shallow depths and a relatively dry pathway to the surface.

Changes in gas composition are also compared with seismicity to help constrain seismic signatures of subsurface fluid flow. Here we present preliminary results from Trident Volcano. Earthquakes located within ~5km of Trident by AVO are shown in Fig. 1A. Note that Trident seismicity tends to cluster at depths of ~3-7 km below sea level, which is consistent with proposed depths of magma storage in this region. Two deep (~32-35 km), low frequency earthquakes were located beneath Trident ~2 months prior to our field study. Such events are frequently seen at Alaska Volcanoes (e.g. Pavlof, Redoubt) and are often associated with the influx of magma from the mantle. Observations of ~1 month of MultiGas data from Trident Volcano find an ~6 day period from 7/25/13 – 8/1/13 during which emissions of SO_2, a magmatic gas, increase to detectable levels before returning to below detection limit levels for the remainder of the study period (Fig. 1B). The initial increase in SO_2 corresponds with the occurrence of a small and near-surface (+2.15 km) volcano-tectonic earthquake located within 2 km of the fumarole field that repeated twice more within the next week (marked by red arrow in Fig. 1A and by blue dashed lines in Fig. 1B). We speculate that this earthquake may have been related to the ascent and surface release of magmatic gas. Additionally, during this time period a swarm of 12 low-frequency repeating earthquakes occurred over a 14 minute period on 7/28/13 (black dashed line, Fig. 1B) at a depth of ~10.8 km. We propose that these earthquakes may be related to ascent of a small batch of magma within the crust and resulting volatile release. Additional data over a longer time period are required to more robustly constrain the relationship between subsurface fluid movement, seismicity and surface outgassing at Trident Volcano. Future work will involve similar data comparisons and analyses at Mt. Mageik and Mt. Martin volcanoes.