Chemical Controls on Volcanic Ash Morphology: Magmatic Heterogeneities or Evolving Energetics at Turrialba, Costa Rica

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Abstract

Explosive, ash-producing volcanic eruptions are a significant natural hazard with the potential for loss of life, economy, and infrastructure. Turrialba is an active stratovolcano located in the Central Cordillera of Costa Rica. The edifice is located only 35 km east-northeast of Costa Rica's capital city and poses a threat to its central valley, the social and economic hub where more than half of the population resides. The most recent eruption took place in 2016-2017, consisting of four eruption phases. Preliminary observations using SEM show significant morphological differences between the various eruption phases, including the amount of dust and crystals that are present. The morphology of volcanic ash is fundamental to our understanding of magma fragmentation, and in transport modeling of volcanic plumes and clouds. The chemistry of the ash particles produced by fragmenting magmatic foams may affect their evolving morphology throughout the various stages of eruption. In addition, eruption energetics may play a role in ash morphology. Separating the roles of chemical heterogeneity and evolving energetics requires careful examination of ash morphology and its relation to composition. In this way, we take some initial steps in closing the knowledge gap between eruption mechanisms and how and why these mechanisms are exhibited in the morphology of ash during explosive eruptions.

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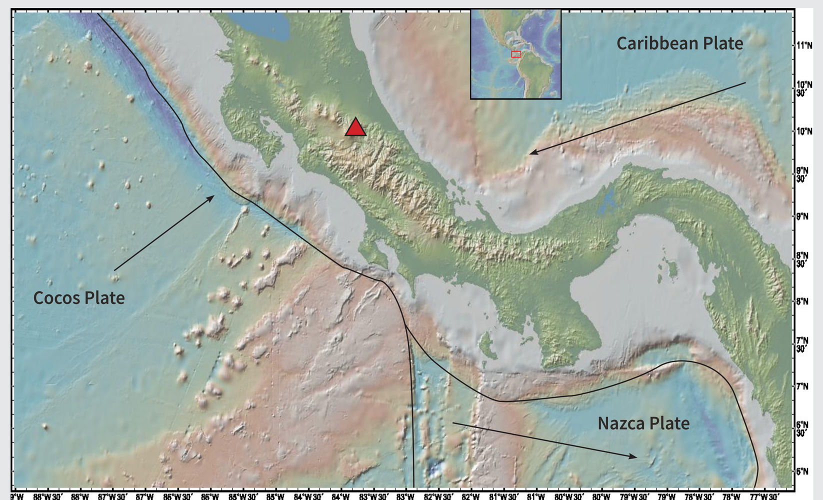
Background



Tectonic setting and topography of Costa Rica. Turrialba volcano indicated by triangle. Important geologic features indicated.

- Costa Rica is located in the southern extreme of Central America to the west of the Caribbean plate.
- To the west the Cocos plate is being subducted under the Caribbean plate: generating the volcanic front of Costa Rica (Ramírez-Leiva et al 2017).
- These lavas are known for their OIB signature (tholeiitic to undersaturated), due to the interaction of the mantle wedge with the Galapagos Hotspot tracks (Di Piazza, 2015).
- Two mantle sources: MORB source and veins of enriched mantle source cutting across the MORB (Feigenson and Carr 1993).
- This atypical OIB signature, similar to the Galapagos OIB lavas, contrast with the signatures usually observed in the CAVF, which are typical of convergent margins (Di Piazza et al., 2015).
- The basement of Turrialba is comprised of andesitic (2.15Ma) and basaltic (5.1Ma) lavas (Di Piazza et al., 2015; Soto, 1998).

View of the main crater of Turrialba.

- Turrialba is an active basaltic to dacitic strato-volcano located in the Central Cordillera of Costa Rica with an elevation of 3340 m.
- The edifice is located upwind only 35 km east-northeast from the highly populated central valley, including its capital city San José.
- Poses a threat to Costa Rica's social and economic hub of the country where more than half of the population resides.
- Eruption of this volcano has the potential to pose a huge threat to not only the majority of the population but also the economy of Costa Rica.

View of Turrialba during the first eruption phase (May 2016) of the most recent eruption.

- Volcanic ash is formed by fragmentation, a process which involves the magma and surrounding rock material of volcanic vents in which dissolved gases expand and escape violently.
- Morphology of ash particles can inform us of the eruption energetics, fragmentation processes, and particle behavior.

Google Earth image of Turrialba volcano. Yellow pin on the image is where the ash samples were collected, from the 2016-2017 volcanic eruption.

Methods

SEM

- Desktop Phenom XL: to acquire detailed images of the ash particles
- Hitachi 4300 used to image the four eruption phases

SEM-EDS

- Elemental composition of the erupted volcanic ash

Epoxy Mounts

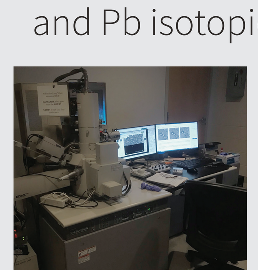
- Study petrology, mineralogy, and chemistry of ash particles after removing dust

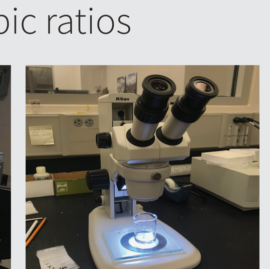
ICP-MS

- Flux samples with lithium borate for bulk and trace element data

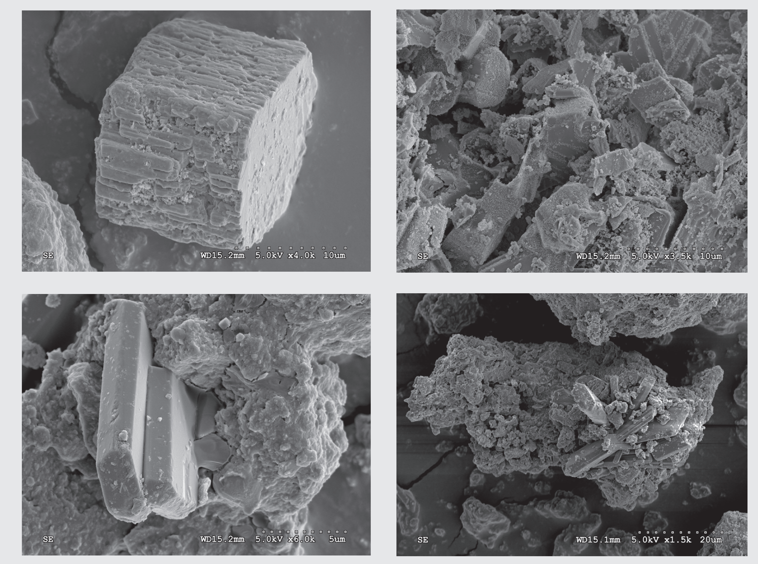
MC ICP-MS

- Use for isotopic composition of ash samples to distinguish origin
- Focus on Sr, Nd, and Pb isotopic ratios



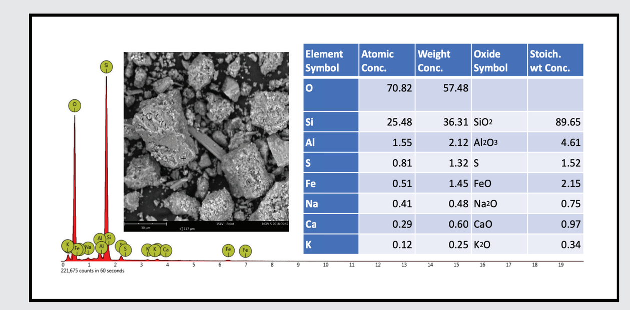


Interpretations



Eruption Phase I

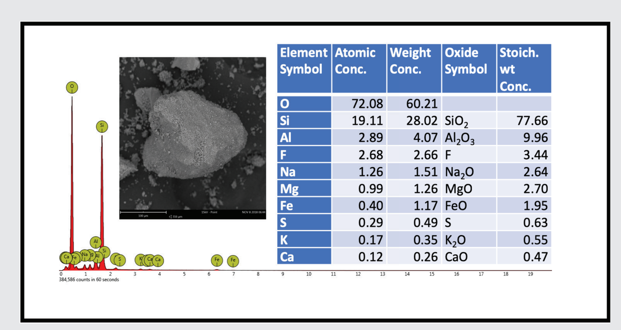
- *Morphology*: Abundant elongated prismatic gypsum crystals, ash particles covered in dusty material, small sub-rounded particles.
- *Chemistry*: Aluminosilicates, gypsum crystals (CaSO4), hard to distinguish chemistry of ash particles due to the outer dust layer.



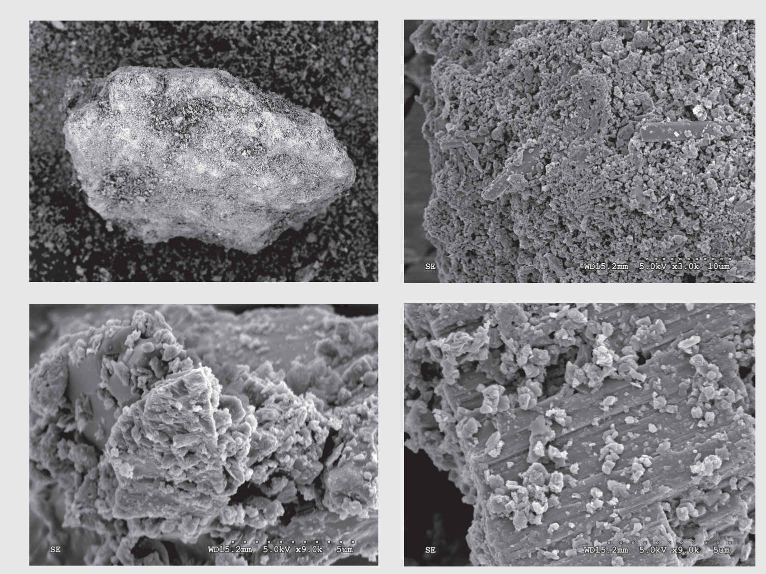
Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
O	70.82	57.48		
Si	25.48	36.31	SiO_2	89.65
Al	1.55	2.12	Al_2O_3	4.61
S	0.81	1.32	S	1.52
Fe	0.51	1.45	FeO	2.15
Na	0.41	0.48	Na_2O	0.75
Ca	0.29	0.60	CaO	0.97
K	0.12	0.25	K_2O	0.34

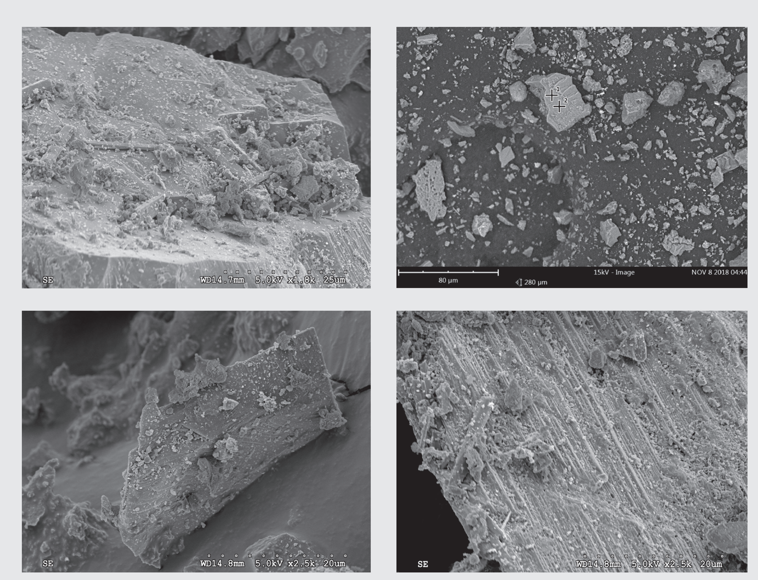
Eruption Phase II

- *Morphology*: Less volume of dust compared to first phase, but still very dusty sample. There are no elongated crystals only small fragments.
- *Chemistry*: Alumniosilicates with addition of Na and S and Mg, still difficult to distinguish chemistry of ash particles due to the dusty exterior.



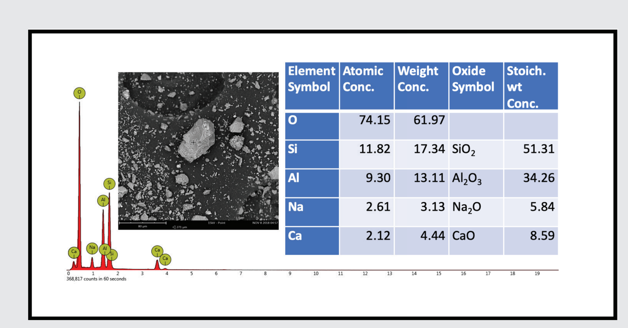
Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
O	72.08	60.21		
Si	19.11	28.02	SiO_2	77.66
Al	2.89	4.07	Al_2O_3	9.96
F	2.68	2.66	F	3.44
Na	1.26	1.51	Na_2O	2.64
Mg	0.99	1.26	MgO	2.70
Fe	0.40	1.17	FeO	1.95
S	0.29	0.49	S	0.63
K	0.17	0.35	K_2O	0.55
Ca	0.12	0.26	CaO	0.47





Eruption Phase III

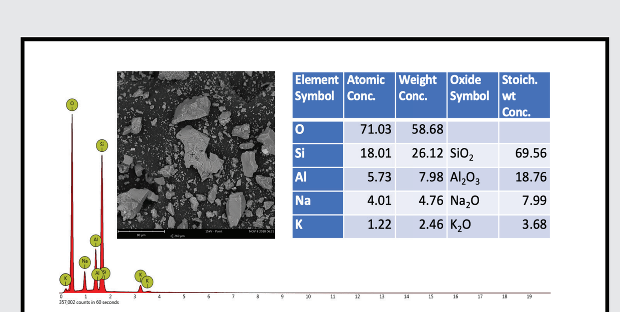
- *Morphology*: Angular ash particles with smooth surfaces that are exposed, due to lack of dust. No large crystals observed, but there are small shards of crystals still attached to surface at high magnification.
- *Chemistry*: Aluminosilicates dominate this sample with Na and Ca in their structure: Na, Ca rich plagioclase.



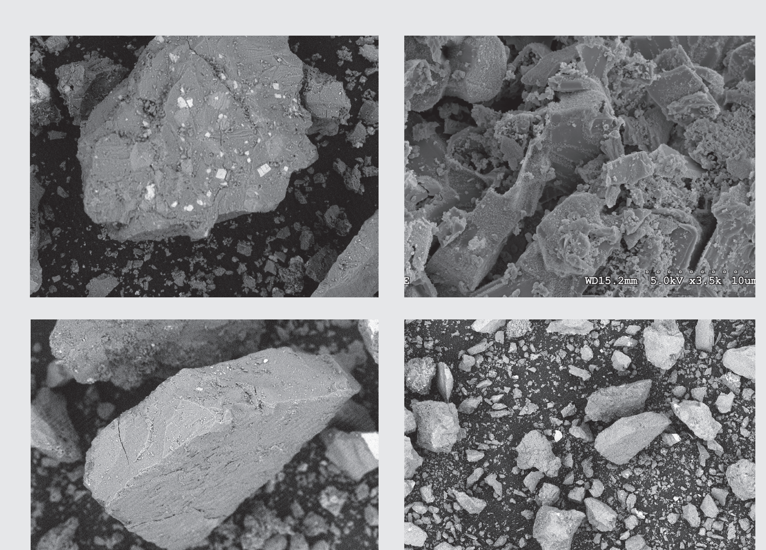
Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
O	74.15	61.97		
Si	11.82	17.34	SiO_2	51.31
Al	9.30	13.11	Al_2O_3	34.26
Na	2.61	3.13	Na_2O	5.84
Ca	2.12	4.44	CaO	8.59

Eruption Phase IV

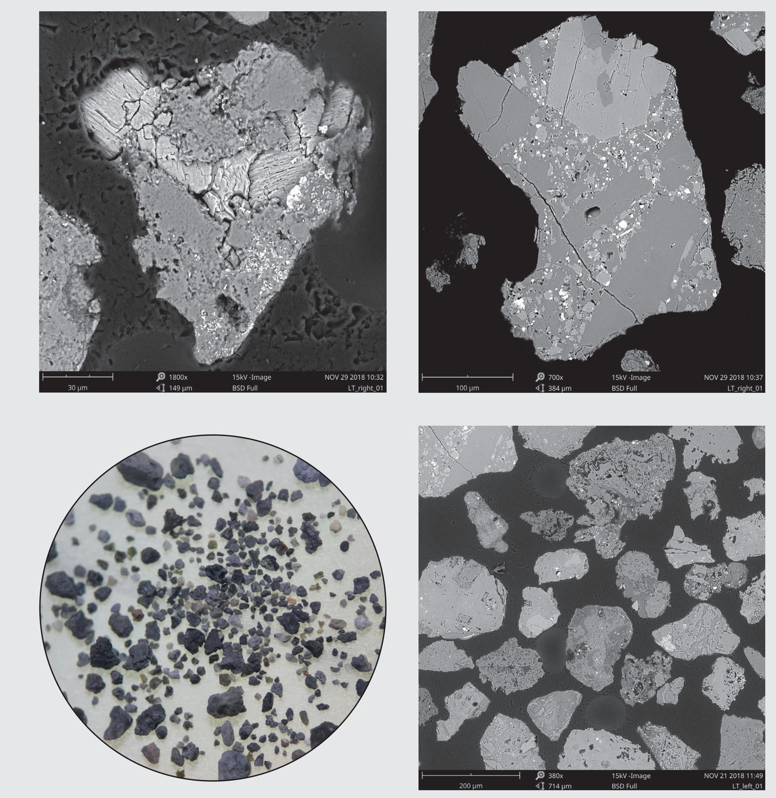
- *Morphology*: Sample has entirely no dust attached to the ash particles and there are no crystals, surfaces are exposed and smooth.
- *Chemistry*: Primarily composed of aluminosilicates with the addition of Na and K such as feldspars and pyroxene, and olivine. Bright colored specs are iron oxides.



Element Symbol	Atomic Conc.	Weight Conc.	Oxide Symbol	Stoich. wt Conc.
O	71.03	58.68		
Si	18.01	26.12	SiO_2	69.56
Al	5.73	7.98	Al_2O_3	18.76
Na	4.01	4.76	Na_2O	7.99
K	1.22	2.46	K_2O	3.68



Discussion

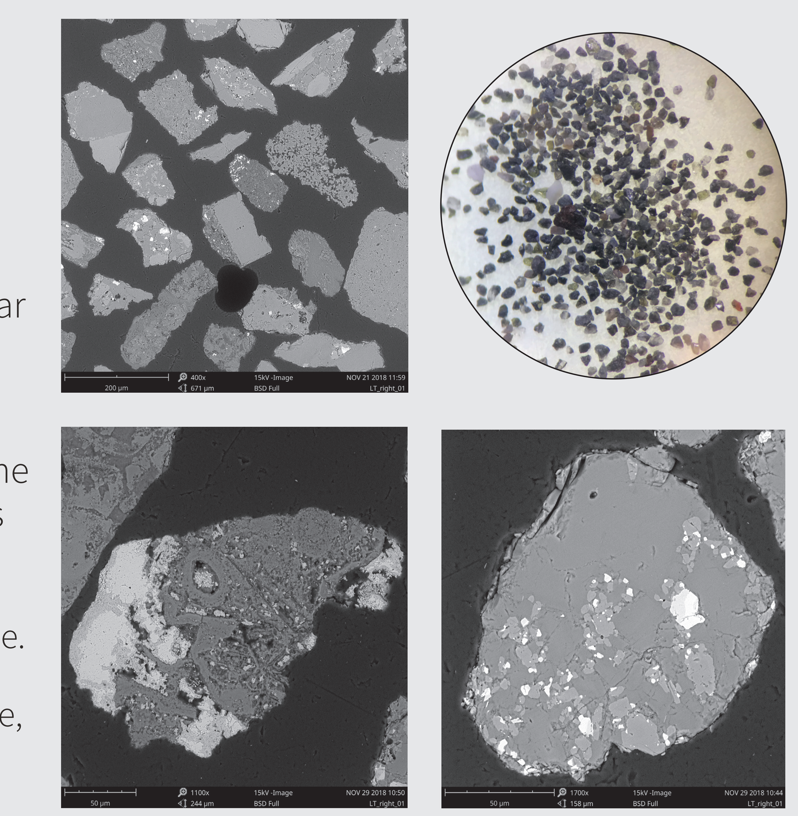


Beginning Eruption Phase

- Ash particles in this phase are sub-rounded in appearance and are larger in size.
- Particles have a dull luster, majority are dark to light charcoal gray in color. Small portion of sample, the smaller grains, are yellow-ish green and opaque white.
- Highly altered pumice and lithic grains.
- Identifiable minerals present from EDS: gypsum, iron oxide, olivine, plagioclase feldspar.

Final Eruption Phase

- Ash particles are much smaller and sub-angular in this, final eruption phase.
- They have a glassy appearance and are primarily charcoal gray to black. There are some white, clear, and yellow-ish green ash particles dispersed throughout.
- No lithic or pumice grains are present in this sample.
- Identifiable minerals present from EDX: amphibole, iron oxide, olivine, pyroxene.



- Ash morphology co-evolved with eruption style. As the energy of an eruption increases so does the column height and amount of syn-eruptive bubbles; at the same time the size of the ash particles and the amount of crystals and dust decrease.
- The dust is a different composition than the ash particles, it is a sulfate. It may have formed as a result of early exposed volatiles (sulfur) into the eruption cloud or assimilation of the wall rock.
- The reason the dust is only present in the early phases could be attributed to different energetics of the eruptions, material around the vent that was blasted off in the beginning phases, or precipitation of gypsum from sulfur aerosol source mixing with ash material.

Future Work

- Measure bulk chemistry of the ash particles, such as Si, Fe, Mg, and major oxides content using ICP-MS or XRF. Measure isotopic ratios of the ash particles in order to determine it's geochemical signature using MC ICP-MS.
- Prepare and make thin sections of ash particles to further look into chemistry and petrographic characteristics inside particles.
- Develop a simple model for the evolution of the magma chamber and conduit under Turrialba.

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