# Self-limiting atmospheric lifetime of environmentally reactive elements in volcanic plumes

Evgenia Ilyinskaya<sup>1\*</sup>, Emily Mason<sup>2</sup>, Penny Wieser<sup>2</sup>, Lacey Holland<sup>3</sup>, Emma J. Liu<sup>2,4</sup>, Tamsin A. Mather<sup>5</sup>, Marie Edmonds<sup>2</sup>, Rachel C. W. Whitty<sup>1</sup>, Tamar Elias<sup>6</sup>, Patricia A. Nadeau<sup>6</sup>, David Schneider<sup>7</sup>, Jim McQuaid<sup>1</sup>, Sarah Allen<sup>8</sup>, Clive Oppenheimer<sup>9</sup>, Christoph Kern<sup>10</sup>, David Damby<sup>11</sup>

The 2018 eruption of Kilauea, Hawai'i, produced exceptionally high discharge of metal pollutant elements, and an unprecedented opportunity to track them from vent to exposed communities over 200 km downwind. We discovered that magmatic volatility is an important control on the atmospheric behavior of elements, with [volatile elements] decreasing up to 100 times faster after emission than [refractory elements]. The differential deposition disproportionately impacts populated areas closest to the active vents, as the rapidlydeposited volatile elements generally have the highest environmental lability and potential toxicity.

<sup>1</sup>School of Earth and Environment, University of Leeds, Leeds, United <sup>7</sup>Alaska Volcano Observatory, United States Geological Survey, AK, USA. Kingdom. <sup>2</sup>Department of Earth Sciences, University of Cambridge, UK.

<sup>3</sup>Department of Atmospheric Sciences, University of Hawai'i at Mānoa, HI, USA.

<sup>4</sup>Department of Earth Sciences, University College London, UK. <sup>5</sup>Department of Earth Sciences, University of Oxford, UK.

USA.

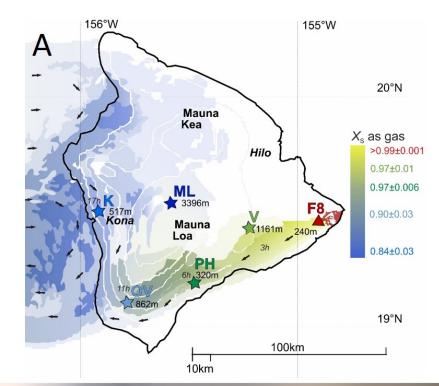
**f** 

6Hawaiian Volcano Observatory, United States Geological Survey, HI,

8University of Bern, Switzerland

<sup>9</sup>Department of Geography, University of Cambridge, UK.

<sup>10</sup>Cascades Volcano Observatory, United States Geological Survey, WA, <sup>11</sup>California Volcano Observatory, United States Geological Survey, CA,





#### EGU Sharing Geoscience online 2020

## Related presentations at EGU this year

Emily Mason *et al.* 

eruption

EGU2020-162

*Trace element emissions during the* 

ITS2.13/AS4.29/CL4.43/GMPV10.2

Wed, 06 May, 10:45–12:30 | D2234

2018 Kilauea Lower East Rift Zone

#### Tracking Sulfur and its Chalcophile Allies at Kilauea Volcano, Hawai`i Penny E. Wieser<sup>1\*</sup>, Frances E. Jenner<sup>2</sup>, Marie Edmonds<sup>1</sup>, John Maclennan<sup>1</sup>, and Barbara Kunz<sup>2</sup> <sup>1</sup>University of Cambridge, UK <sup>2</sup>Open University, UK

#### Motivation:

Understand the processes controlling the emission of S and other (often toxic) chalcophile elements at Kīlauea Volcano, Hawai'i.

- Findings:
- Sulfides saturate early at Kilauea (~ 12 wt% MgO). · Element volatility, rather than sulfide resorption, predominantly controls the chemical composition
- of the volcanic plume. For more info, flick through the slides, or read the paper (in press; GCA) https://eartharxiv.org/u6j79

NERC

**J** 

UNIVERSITY OF CAMBRIDGE pew26@cam.ac.uk

Penny Wiese

#### Penny Wieser et al. Tracking sulfur and its allies at Kīlauea volcano Hawai'i EGU2020-355 | GMPV8.3/NH2.7 Tue, 05 May, 14:00–15:45 | D1553

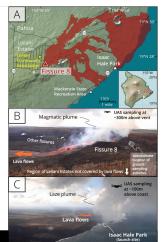


**Emily Mason**\*<sup>1</sup>, Penny Wieser<sup>1</sup>, Emma Liu<sup>2</sup>, Marie Edmonds<sup>1</sup>, Evgenia Ilyinskaya<sup>3</sup>, Rachel C W Whitty<sup>3</sup>, Tamsin Mather<sup>4</sup>, Tamar Elias<sup>5</sup>, Patricia Amanda Nadeau<sup>5</sup>, Christoph Kern<sup>6,7</sup>, David I Schneider<sup>8</sup> and Clive

This study presents the trace element composition and speciation of emissions from the **magmatic plume** (B, right and **lava-seawater interaction plume** ('laze', C, left) associated with the 2018 eruption of Kīlauea volcano, with a particular focus on the **trace metal and metalloid** degassing

<sup>4</sup>University of Oxford, Department of Earth Sciences University of Cambridge, Department of Earth USGS Hawaiian Volcano Observatory, United States <sup>2</sup>University of Leeds, School of Earth and 6USGS, Baltimore, MD, United States USGS Cascades Volcano Observatory, United States Environmen <sup>3</sup>University College London, Dep <sup>8</sup>USGS Alaska Volcano Observatory, United States University of Cambridge, Department of Geograph

EGU Sharing Geoscience online 2020



#### Spatial and temporal variations in SO<sub>2</sub> and PM<sub>25</sub> levels around Kīlauea Volcano, Hawai'i during 2007–2018 Whitty et al - D2223 | EGU2020-405 Journal DOI: https://doi.org/10.3389/feart.2020 Volcanic emissions Schematic overview of Kilauea 2018 LERZ eruption Not drawn to scale Graphic credit: Emily Mase SW -Prevailing wind direction (NE Trade Winds) Oxidation of SO<sub>2</sub> (gas) to SO<sub>4</sub><sup>2-</sup> (particulate) issure

Rachel Whitty et al. Spatial and temporal variations in ambient SO2 and PM2.5 levels influenced by Kīlauea Volcano, Hawai'i, 2007 - 2018 EGU2020-405 ITS2.13/AS4.29/CL4.43/GMPV10.2 Wed, 06 May, 08:30–10:15 | D2223

EGU Sharing Geoscience online 2020



## Related presentations at EGU this year

Much of the fundamental information on emanation coefficients and how they work, sampling methods and analysis can be found in this presentation, which describes the source composition.

We would advise checking that presentation first as this one follows on from it.

#### Emily Mason *et al.*

*Trace element emissions during the 2018 Kilauea Lower* East Rift Zone eruption EGU2020-162 | ITS2.13/AS4.29/CL4.43/GMPV10.2 Wed, 06 May, 10:45–12:30 | D2234

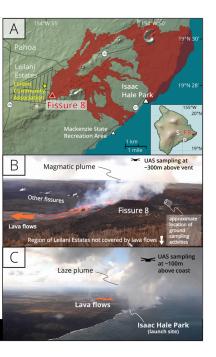
#### Trace element emissions during the 2018 Kilauea Lower East Rift Zone eruption

**Emily Mason**\*<sup>1</sup>, Penny Wieser<sup>1</sup>, Emma Liu<sup>2</sup>, Marie Edmonds<sup>1</sup>, Evgenia Ilyinskaya<sup>3</sup>, Rachel C W Whitty<sup>3</sup>, Tamsin Mather<sup>4</sup>, Tamar Elias<sup>5</sup>, Patricia Amanda Nadeau<sup>5</sup>, Christoph Kern<sup>6,7</sup>, David J Schneider<sup>8</sup> and Clive Oppenheimer<sup>9</sup>

This study presents the trace element composition and speciation of emissions from the **magmatic plume** (B, right) and lava-seawater interaction plume ('laze', C, left) associated with the 2018 eruption of Kilauea volcano, with a particular focus on the trace metal and metalloid degassing.

<sup>1</sup>University of Cambridge, Department of Earth Sciences <sup>2</sup>University of Leeds, School of Earth and Fnvironmen <sup>3</sup>University College London, Department of Earth Sciences

<sup>4</sup>University of Oxford, Department of Earth Sciences <sup>5</sup>USGS Hawaiian Volcano Observatory, United States <sup>6</sup>USGS, Baltimore, MD, United States <sup>7</sup>USGS Cascades Volcano Observatory, United States <sup>8</sup>USGS Alaska Volcano Observatory, United States <sup>9</sup>University of Cambridge, Department of Geography EGU Sharing Geoscience online 2020

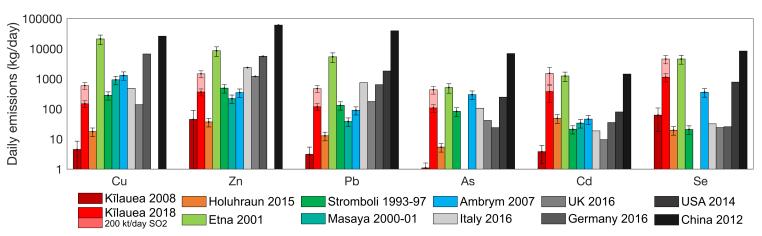






## Why study volatile trace element emissions from volcanoes?

1. Volcanoes can emit significant fluxes of trace metals, comparable to some anthropogenic sources: daily emissions from individual **volcanoes** = daily anthropogenic emissions from entire countries



Data sources: Volcanoes - Edmonds et al. 2018 and references therein; National emissions (based on fuel sold) - European Environment Agency, Tian et al. (2015) and United States Environmental Protection Agency. Figure from Ilyinskaya, Mason et al. (in revision)

2. Volatile trace elements sourced from volcanoes can acts as nutrients, pollutants and biological catalysts. For example **selenium**, present in selenoproteins, is an essential component of major metabolic pathways (Brown and Arthur, 2001) and has been implicated in processes affecting cancer risk (Rayman, 2005). However, at high levels selenium toxicosis (selenosis) causes symptoms such as hair loss and reductions in livestock productivity (Aitken, 2001).

...however, the data needed to develop guidelines for exposure to and hazard from metal pollutants during volcanic eruptions are currently lacking.





# Why study volcanic emissions and their evolution downwind?

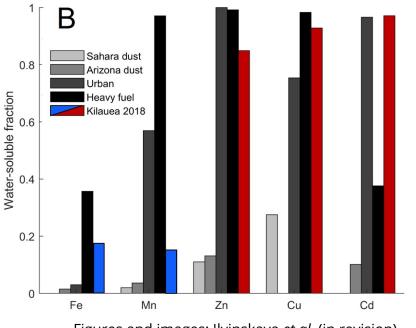
Volcanic emissions can have serious impacts on **air quality**, and subsequently **health** 

### Volatile metals in volcanic plumes are **water-soluble** and therefore **environmentallyreactive**

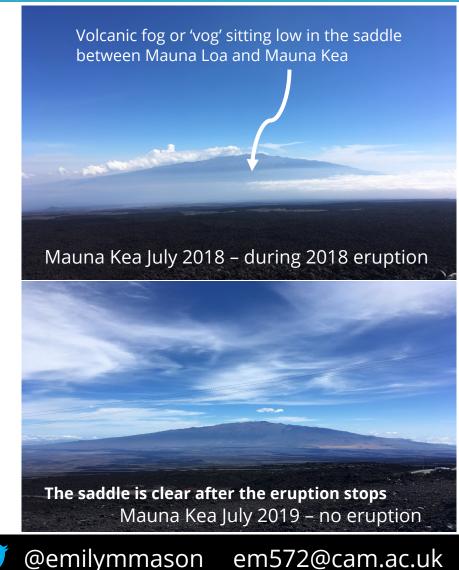
Volatile metals such as Cd, and moderately volatile elements such as Cu and Zn emitted from volcanoes are similar in solubility to anthropogenic pollution emissions of these elements (such as those produced from heavy fuels, i.e. from power plants)

 $(\mathbf{i})$ 

**For more detail see:** Rachel Whitty *et al.* Spatial and temporal variations in ambient SO2 and PM2.5 levels influenced by Kīlauea Volcano, Hawai'i, 2007 - 2018 EGU2020-405 | ITS2.13/AS4.29/CL4.43/GMPV10.2 Wed, 06 May, 08:30–10:15 | D2223



Figures and images: Ilyinskaya *et al.* (in revision)





How do the concentrations of volatile trace elements measured on <sup>Summary slide 3</sup> Hawai'l during the eruption compare to 1) background levels and 2) urban areas in the USA?

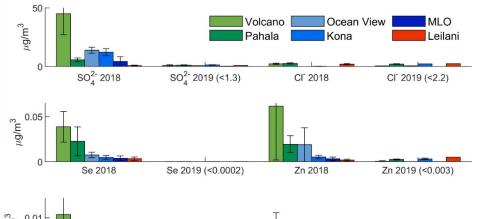
155°W 20°N Mauna Kea  $X_{\rm s}$  as gas >0.99 0.97 0.90 Mauna Loa 100km 10km In 2018, Kīlauea volcano was a big source of air pollution for the residents of the Island of Hawai'i

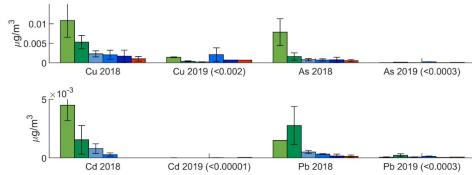
 $(\mathbf{i})$ 

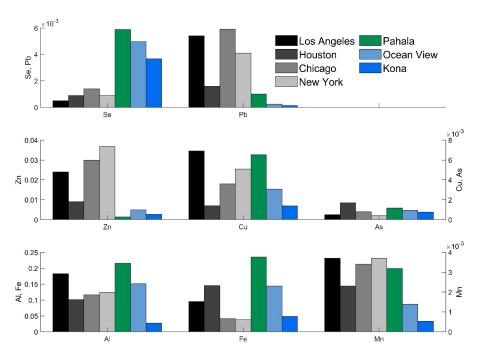
BY

CC)

1) Concentrations during the eruption in 2018 are generally significantly above background concentrations, measured during no activity in 2019





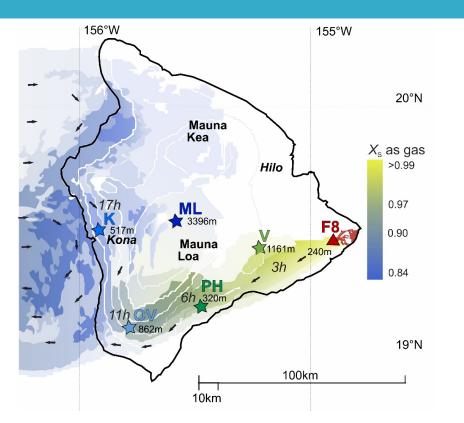


2) Concentrations during the eruption in 2018 are comparable to concentrations measured in urban areas of the USA



em572@cam.ac.uk

# Volatile elements are depleted faster than refractory/lithophile elements



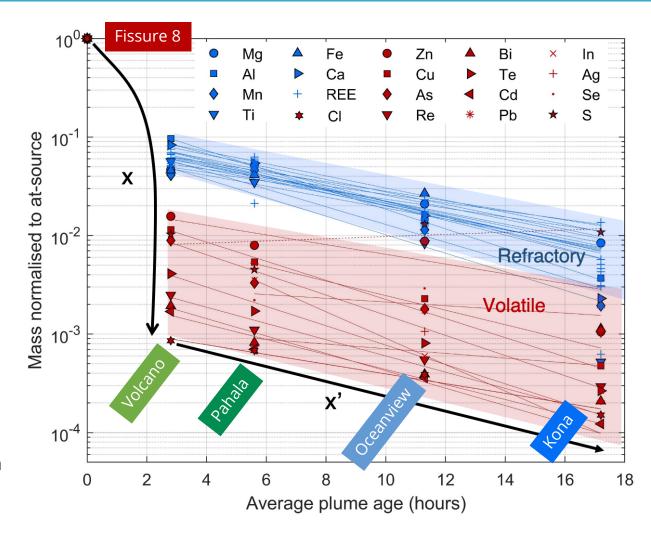
There is a rapid decrease and large fractionation in element concentration between the source at Fissure 8 and Volcano (x on figure, right).

 $(\mathbf{i})$ 

BY

(cc)

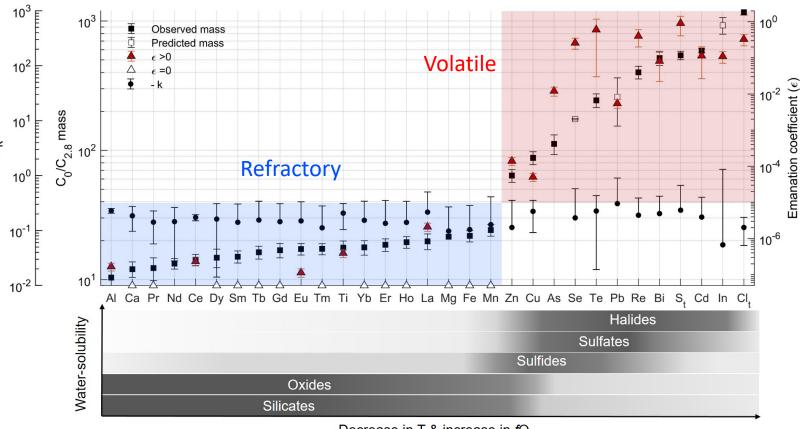
There is a slower decrease in element concentration and negligible fractionation between Volcano and Kona (x' on figure, right)



@emilymmason



### Can we explain variable loss rate of volatile elements using their speciation?



Decrease in T & increase in fO<sub>2</sub>



The most volatile elements are removed very early on in the lifetime of the plume. This puts disproportionate pressure on the communities living closest to the volcano - these elements are not behaving like sulfate.

Some volatile elements are lost at an order of magnitude greater rate than others. Are these elements speciating as the most soluble complexes, thereby allowing them to be scrubbed from the plume the fastest?

 $(\mathbf{i})$ 

BY

CC)



## Conclusions

- Preferential deposition of volatiles places disproportionate environmental burdens on the populated areas in the immediate vicinity of the active vent and, in turn, reduces the impacts on far-field communities.
- 8 of the 12 volatile, rapidly-deposited elements (Zn, Cu, As, Pb, Se, Cl, Cd, S) are classified by environmental agencies as metal pollutants. The high solubility of volatile-bearing particles in water makes them environmentally labile, increasing their potential impacts and toxicity.
- The atmospheric depletion rate of sulfur, and thereby the associated hazard distribution, does not represent an accurate guide to the atmospheric lifetime and potential impacts of all other species 40 in volcanic emissions.

- There are tens, and potentially hundreds of actively degassing volcanoes worldwide, some with communities living very close to their degassing vents. The potential environmental and health impacts of rapid near-vent deposition of metal pollutants **should be investigated further**, particularly in communities that rely on rain catchment systems for household water supplies.
- We can use our results to work towards creating firstorder dispersion maps and population exposure assessments for different pollutants even in the absence of direct measurements.
- The transport and deposition of environmentallyimportant elements from volcanoes has also implications for interpreting interactions between volcanic activity and the biosphere throughout Earth history, in particular for volcanic events with global impacts such as flood basalt eruptions.





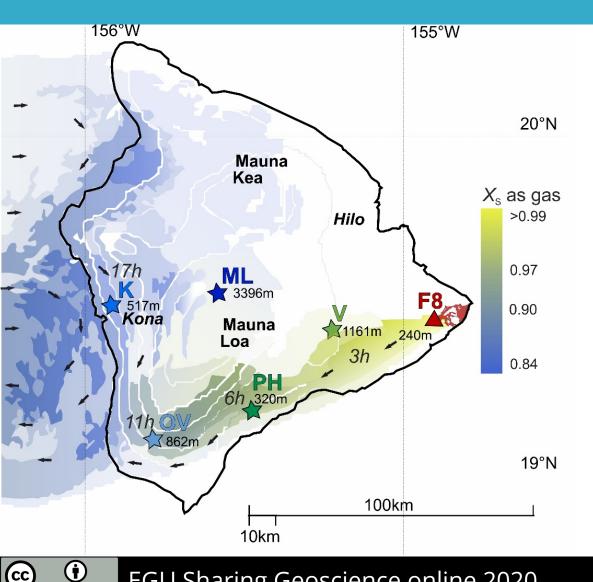
## Extra slides





@emilymmason em572@cam.ac.uk

### The network of downwind stations during the eruption in 2018 and the background sampling in 2019



#### Island of Hawai'i with volcanic plume dispersion pattern and average plume age (h).

- Fraction of sulfur in the gas phase 5 (XS) is shown here as a proxy for the plume's chemical maturity at variable distances from source (supplementary text S6).
- The plume dispersion pattern and the map's spatial domain are based on the operational volcanic air pollution forecast in Hawaii (VMAP) for 23 July 2018 and is representative of typical trade wind conditions which dominated during the eruption.
- **Sampling sites:** F8 Fissure 8, main eruptive vent within Leilani Estates; V – Volcano village; PH – Pahala; OV – Ocean View; K – Kailua-Kona; ML – Mauna Loa Observatory. Elevation of each sampling site is in m above sea level. Lava flows from Fissure 8 are shown in red.

BY

