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

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The 2018 eruption of Kīlauea, 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 rapidly-deposited volatile elements generally have the highest environmental lability and potential toxicity.

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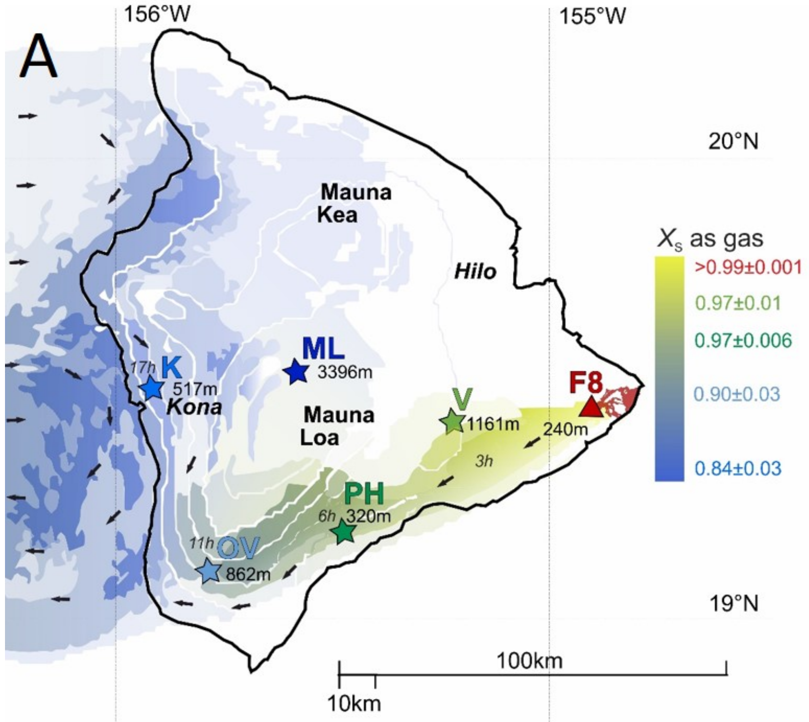

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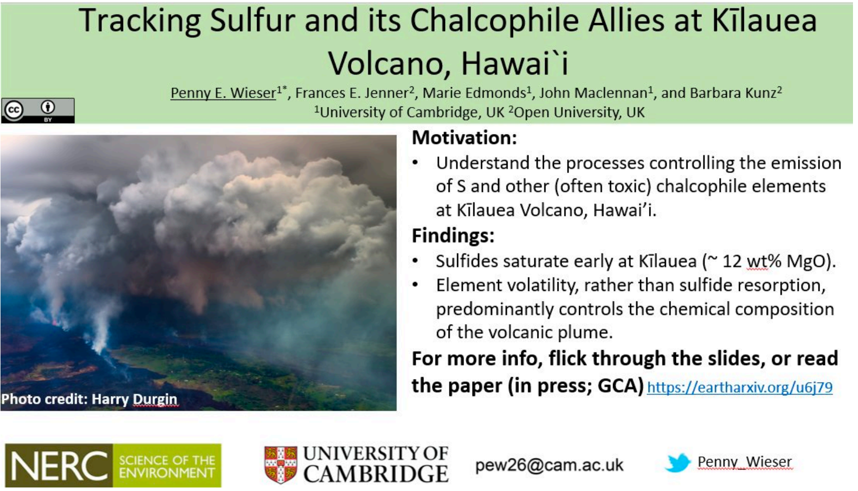
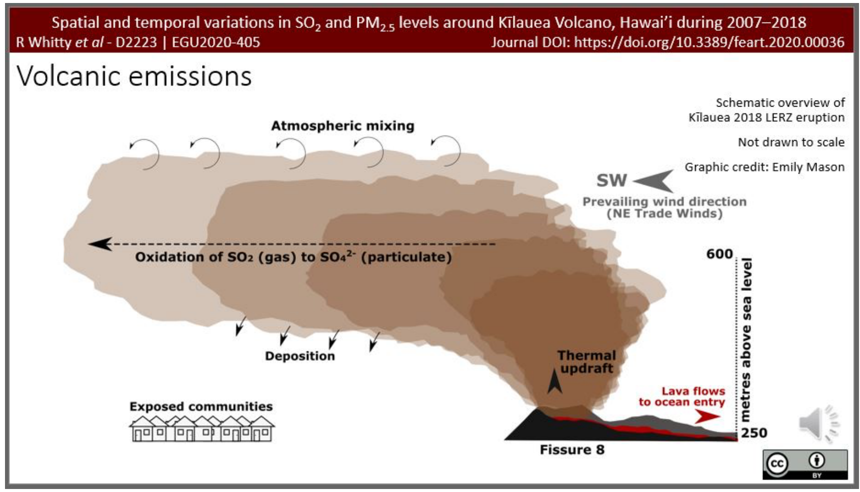


Emily Mason *et al.*

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

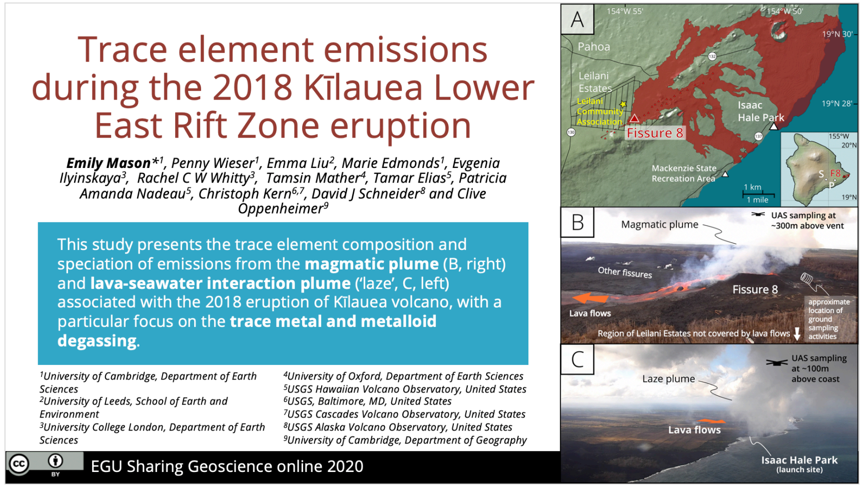


Penny Wieser *et al.*

Tracking sulfur and its allies at Kīlauea volcano Hawai'i

EGU2020-355 | GMPV8.3/NH2.7

Tue, 05 May, 14:00–15:45 | D1553



Rachel Whitty *et al.*

Spatial and temporal variations in ambient SO2 and PM2.5 levels influenced by Kīlauea Volcano, Hawai'i, 2007 - 2018

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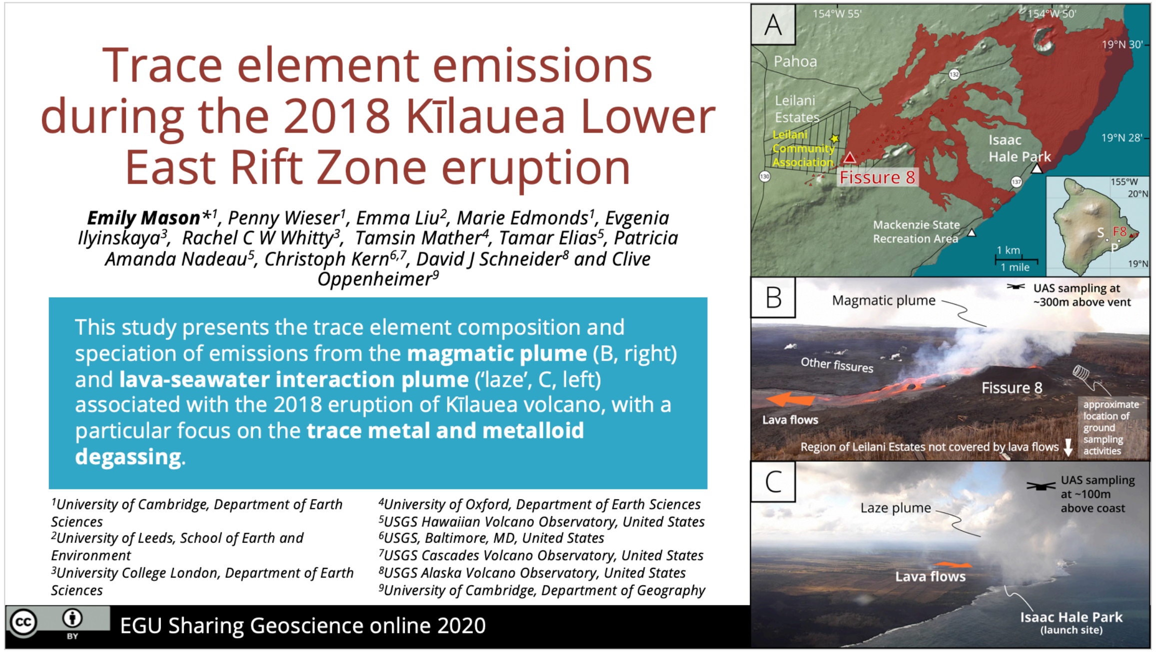
Much of the fundamental information on **emanation coefficients** and how they work, sampling methods and analysis can be found in this presentation, which describes the **source composition**.

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



Emily Mason *et al.*

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EGU2020-162 | ITS2.13/AS4.29/CL4.43/GMPV10.2

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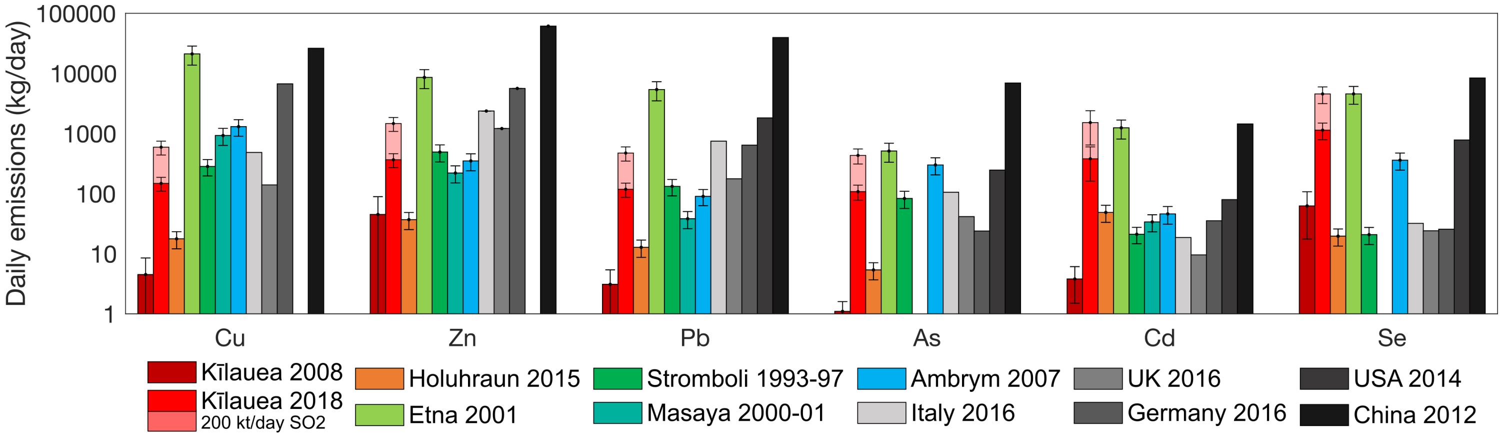
Why study volatile trace element emissions from volcanoes?

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 **environmentally-reactive**

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)

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
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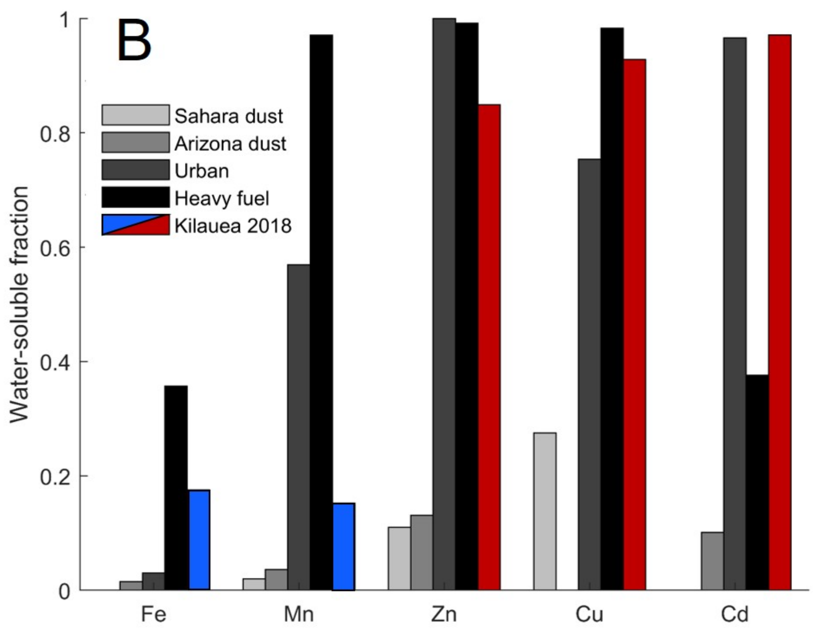
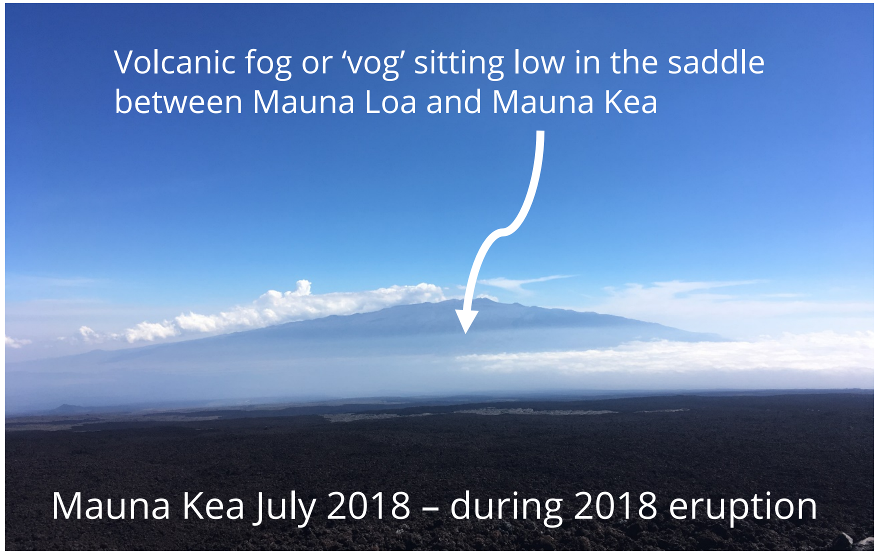
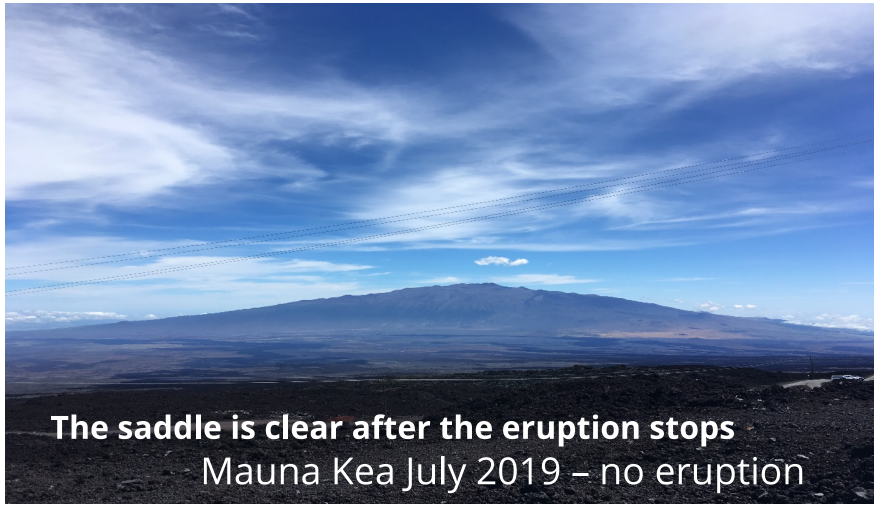


Figures and images: Ilyinskaya *et al.* (in revision)





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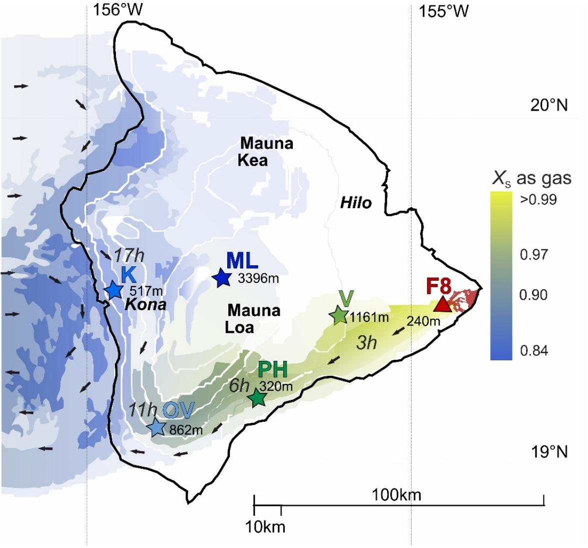
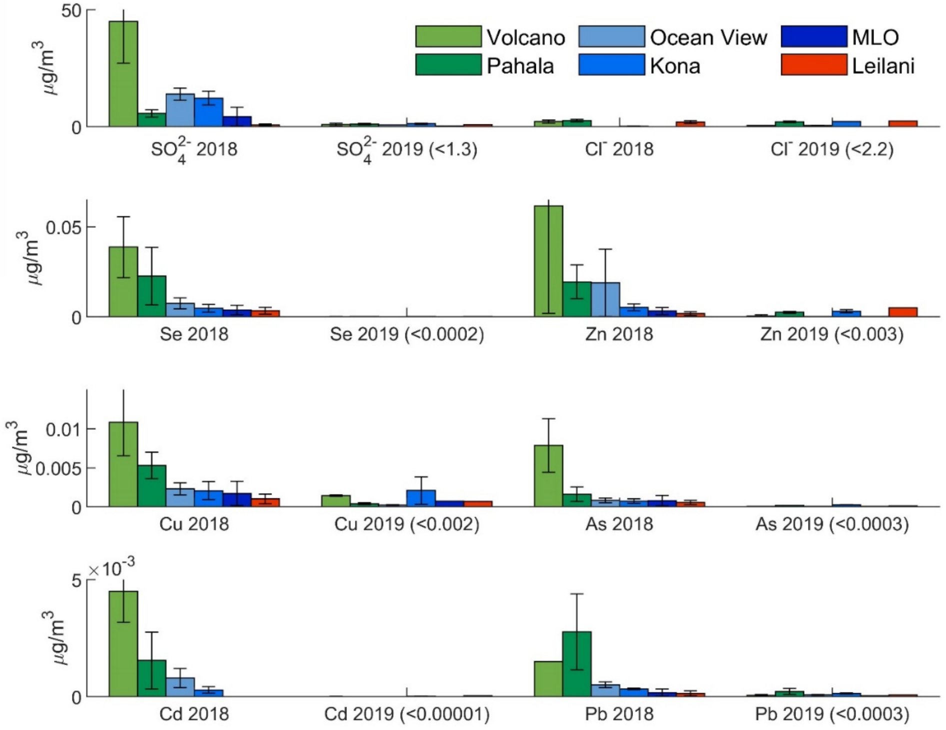
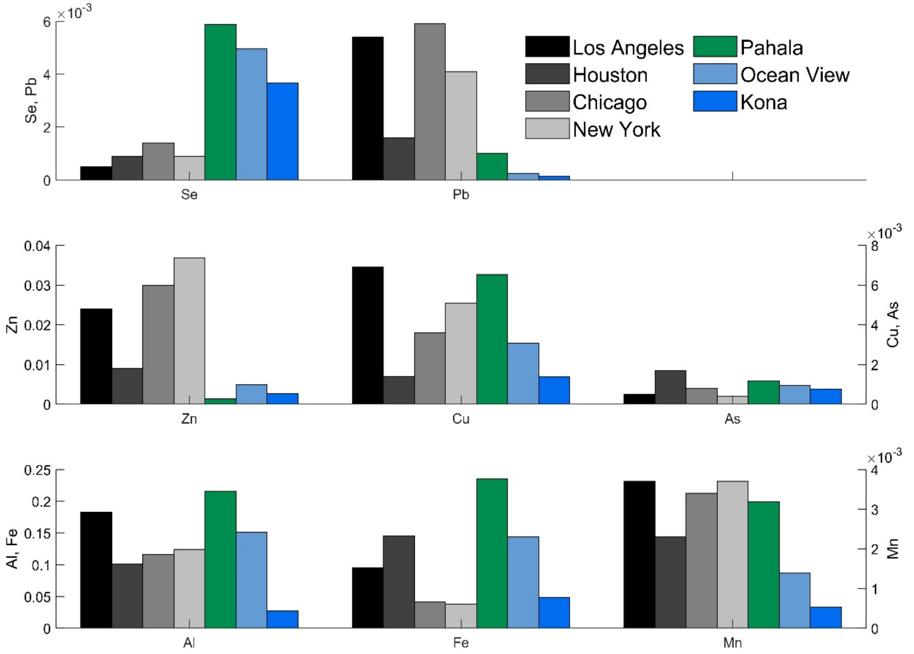
How do the concentrations of volatile trace elements measured on Hawai'I during the eruption compare to 1) background levels and 2) urban areas in the USA?



In 2018, Kīlauea volcano was a big source of air pollution for the residents of the Island of Hawai'i

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

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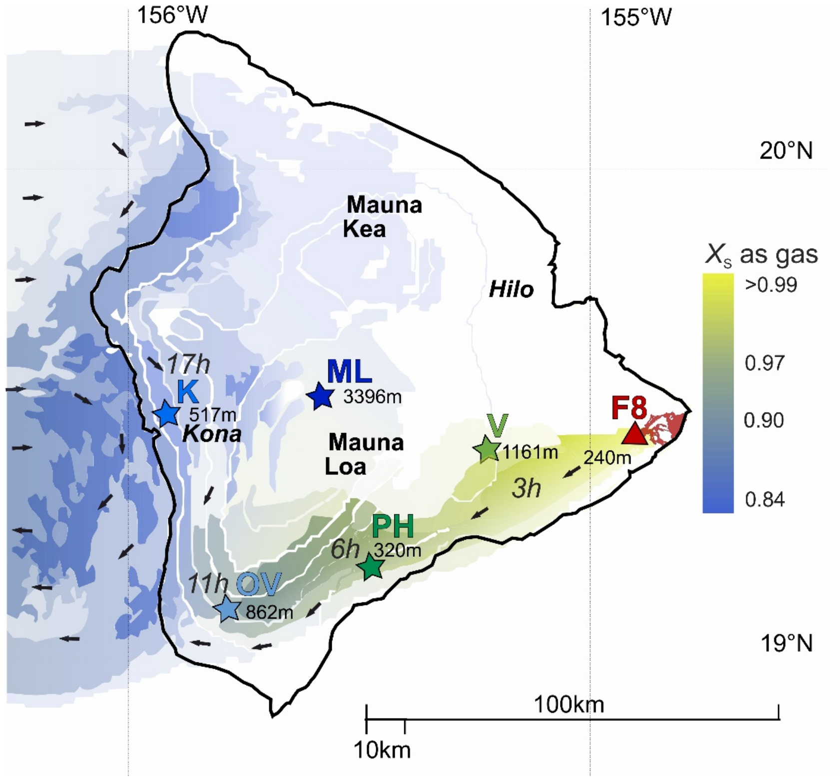
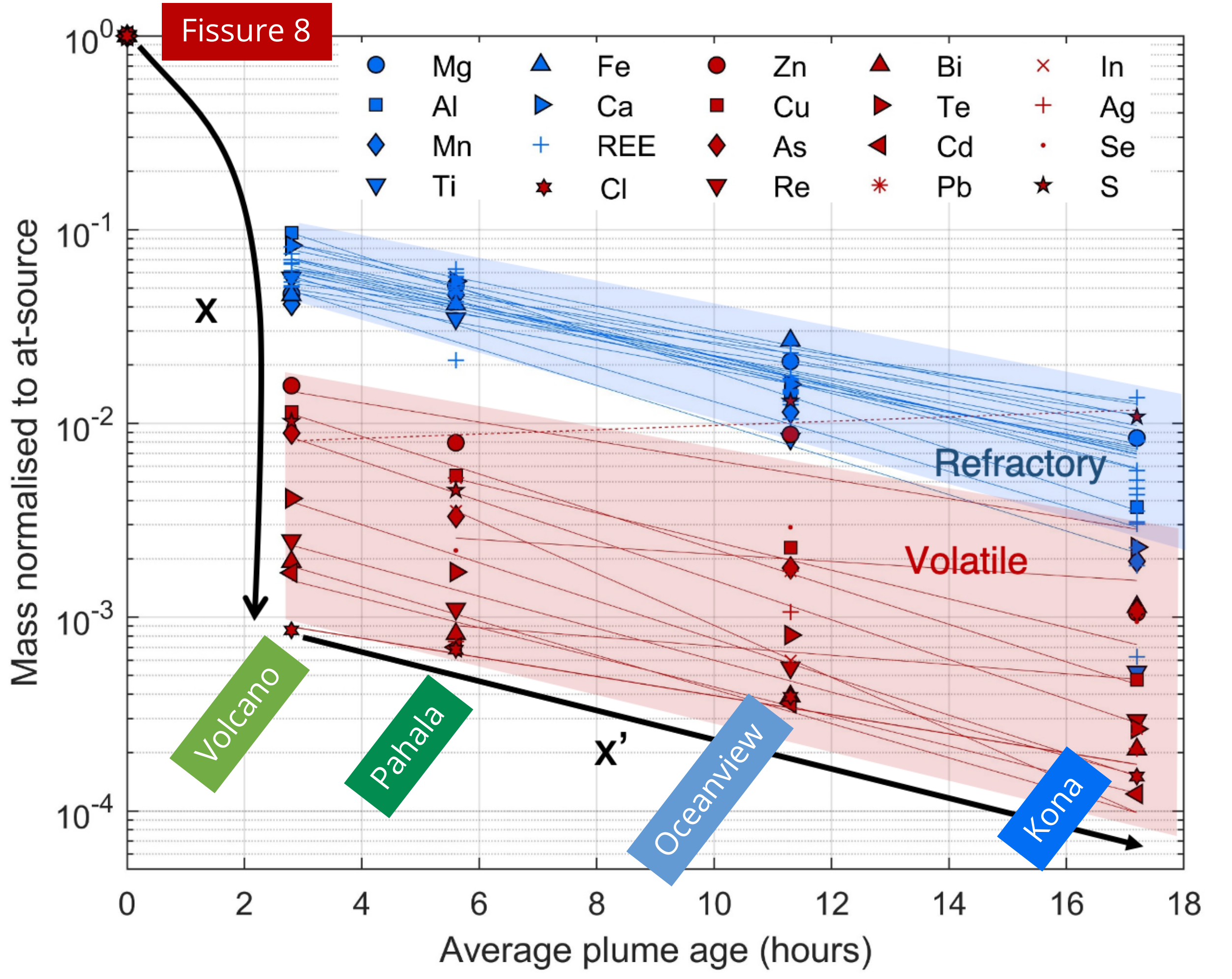
Volatile elements are depleted faster than refractory/lithophile elements

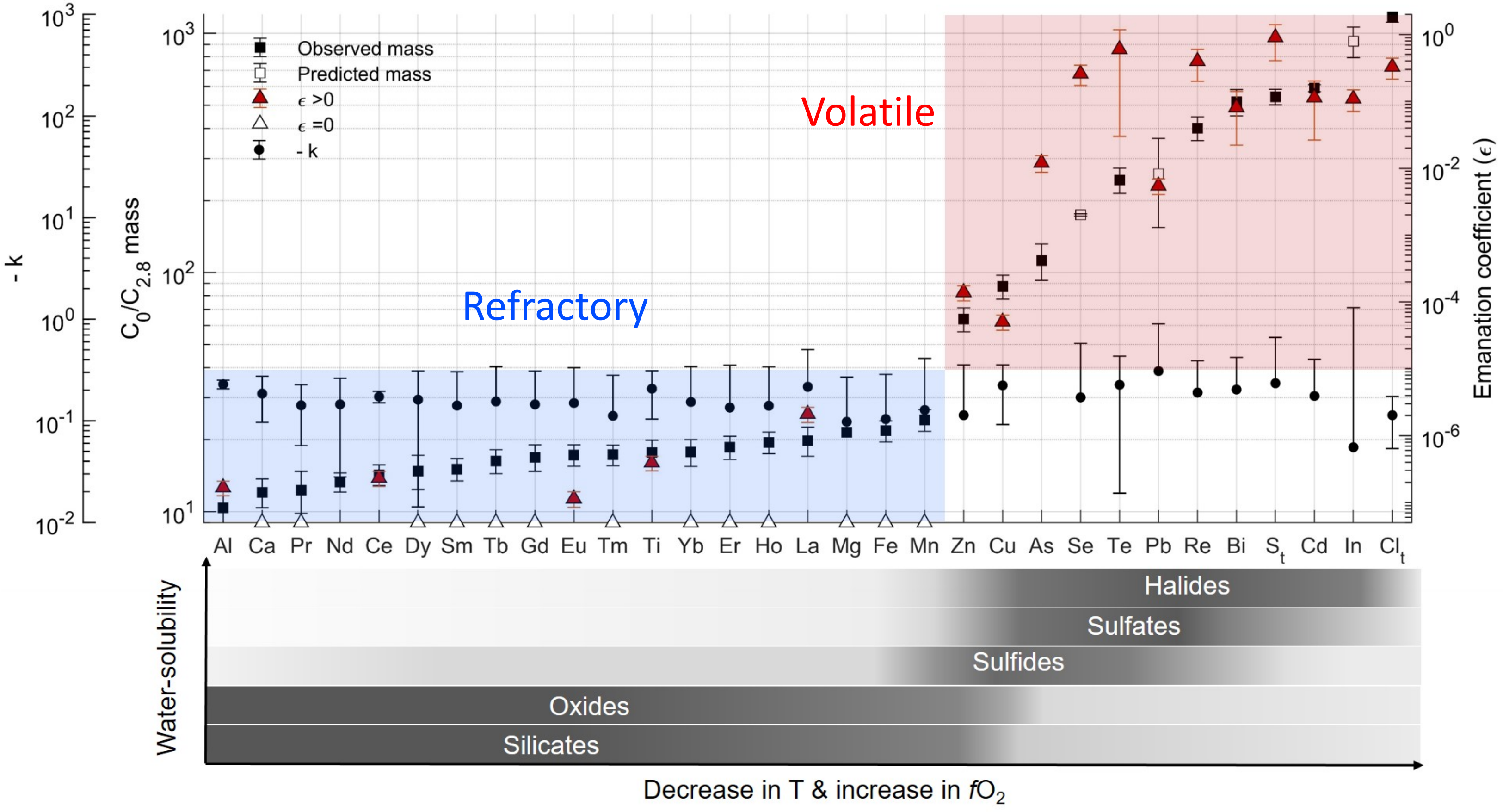




There is a rapid decrease and large fractionation in element concentration between the source at Fissure 8 and Volcano (x on figure, right).

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

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



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?

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 first-order dispersion maps and population exposure assessments for different pollutants even in the absence of direct measurements.

- The transport and deposition of environmentally-important 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.

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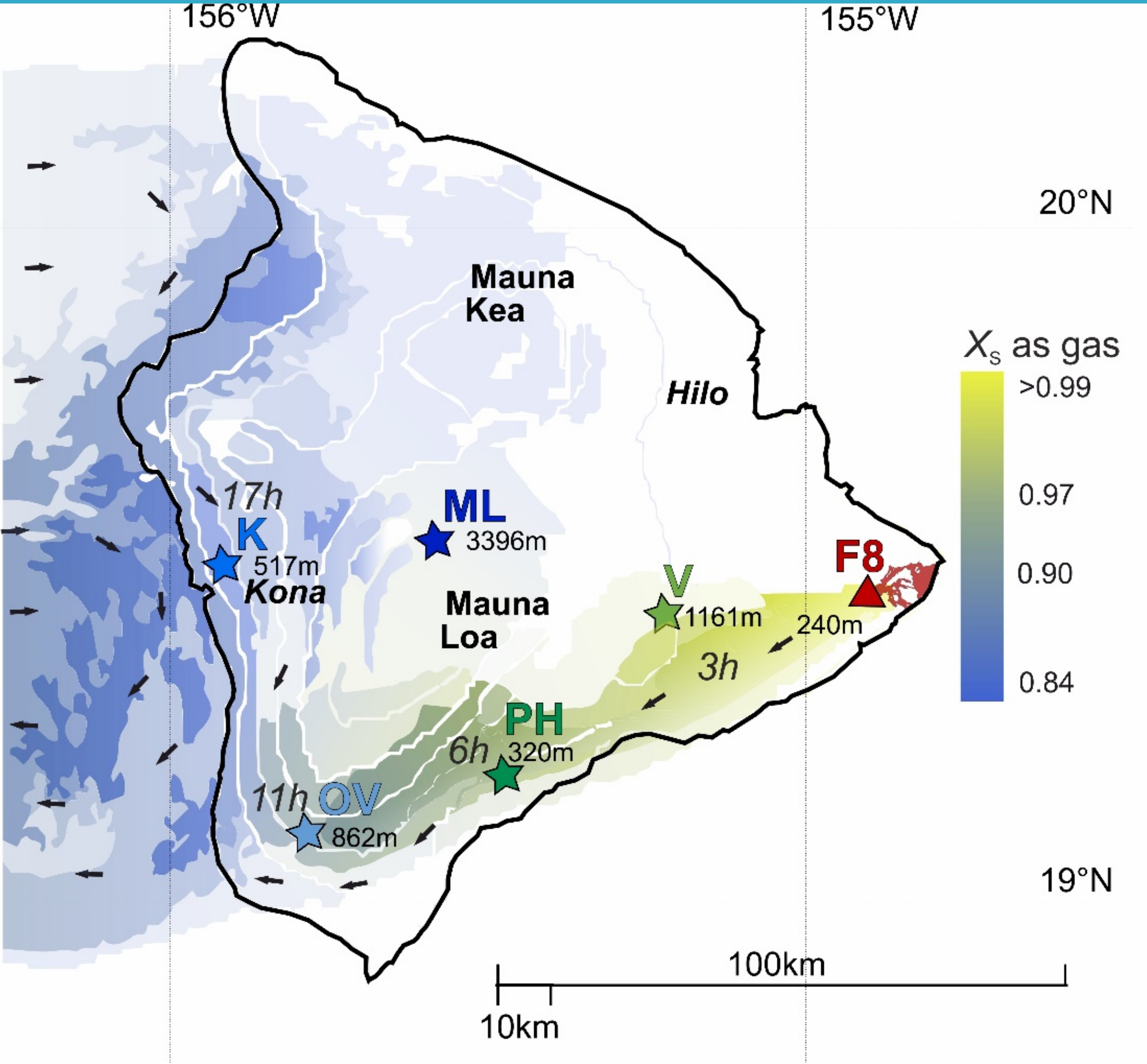
Extra slides

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 (*X*S) 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 – Pāhala; 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.