Dear Editor,

Enclosed is our manuscript titled “**Depths in a day - A new era of rapid-response Raman-based barometry using fluid inclusions**” to be considered for publication as Science Advances *Letter*.

Rapid-response response petrology monitoring is increasingly being used by volcanic observatories to obtain information about the magmatic plumbing system to help inform decision making during crises. The depth of the storage reservoir supplying melt to the surface has been identified as one of the most valuable pieces of information to obtain through petrological monitoring (Re et al. 2021, JVGR). Magma storage depths are essential to be able to build and validate models of the plumbing system, to help predict changes in eruptive style and vigour, and to interpret geophysical signs of unrest. However, it is generally accepted that it is not possible to determine magma storage depths on the day-week timescales required to inform decision making during eruptions. One of the most popular methods, melt inclusion barometry, typically takes 1yr+ to complete. Mineral barometry can be faster and has been completed on week-month timescales. However, calculated pressures (and therefore depths) are extremely imprecise, with errors spanning the entire crustal column in many tectonic settings. Small pockets of CO2-rich fluids trapped in crystals, termed fluid inclusions, offer an exciting alternative. Recent developments in Raman spectroscopy means the density of these fluids to be measured extremely quickly – these densities are closely linked to the pressure of fluid inclusion entrapment, and thus the depth of magma storage. Recent studies by DeVitre and Wieser (2024, GPL) and Lerner et al. (2024, EPSL) have underscored the method's reliability in comparison to established methods such as melt inclusion barometry and geophysical estimations. Moreover, investigations by Dayton et al. (2022, Sc. Advances) and Zanon et al. (2024, Sc. Advances) have speculated that this method has the potential for near real-time assessment of magma storage depths using either Raman spectroscopy- or microthermometry-based fluid inclusion barometry during eruptive crises. However, none of these studies performed measurements in near-real time to rigorously quantify the temporal needs of all the sample preparation and analysis steps. Such stress testing of methodologies is vital for fluid inclusion barometry to move from a hypothetical monitoring method to a tool that observatories can trust to yield results during the next volcanic crisis.

Here, we present a rapid response simulation conducted in collaboration with the Hawaiian Volcano Observatory (HVO) to assess whether fluid inclusion depths can be obtained fast enough to provide useful information during volcanic eruptions. We used samples erupted during the September 10-16th 2023 eruption of Kilauea volcano. We received samples on Sept 19th, beginning the exercise on the 20th with a modestly sized research group composed of two undergraduate students, a postdoc, an assistant professor, and a graduate student who was trained during the simulation! By 4:13pm HST on Day 1, we were able to report 16 magma storage depths to our HVO colleagues clearly indicating that magma was being supplied from the shallower Halemaʻumaʻu (HMM) reservoir at 1-2 km identified by previous geophysical studies. In a real crisis, this would allow enough time for our colleagues to digest our results when making decisions the following day. This timeline is unprecedented in petrological monitoring and demonstrates that the interpretation of magma storage depths can become part of crisis-response during volcanic eruptions. At the end of day 2, we reported 46 depths to HVO by 5:24 pm HST, confirming the dominant role of the HMM reservoir. On day 4, we utilized rapid energy-dispersive spectroscopy measurements (EDS) to measure the crystal chemistry close to each fluid inclusion, providing additional context to the reported depths. It is notable that results reported in day 1 identified the same magma storage region as the more detailed results obtained in day 4. The significant delay between this simulation and the submission of this paper reflects substantial delays in the peer-review process (a detailed chronology is presented in the supplement (S4).

The results presented in this letter are the first rigorous demonstration that petrologically derived magma storage depths can become part of an observatory’s toolbox, with implications extending well beyond the academic sphere and bearing a direct impact on people's lives. Observatories having more information upon which to make informed operational decisions will directly impact the lives and livelihoods of individuals residing near active volcanoes, such as those surrounding Kīlauea volcano in Hawai‘i. Information can also bring comfort during volcanic events – for instance, during the devastating 2018 Lower East Rift eruption, Hawai‘i Island residents routinely asked questions related to the source of the erupting magmas and were expecting answers from the Hawaiian Volcano Observatory (HVO). Now that we have demonstrated the feasibility of this method, it will be deployed in future eruptions in concert with HVO’s current bulk rock XRF chemical monitoring routines. This will allow information about melt properties such as viscosity and temperature to be specifically tied to the reservoir supplying the melt. Time-series analyses of fluid inclusions would be particularly powerful for identifying a switch to a different magma supply.

So far, fluid inclusion studies have focused on applying the method to single volcanoes. However, given that our simulation has demonstrated this method can be used as a rapid response monitoring technique, we evaluate the global applicability of this method. Fluid inclusions are most accurate in systems where the exsolved vapour phase is CO2-rich and relatively H2O-poor. We compile a comprehensive database of >4000 melt inclusions from 122 locations in different tectonic settings around the world and calculate the molar fraction of H2O in exsolved fluids in a magma (XH2O). This compilation demonstrates that many volcanic systems are characterized by CO2-rich fluids (<20% H2O), providing the first global assessment of the utility of this method. Importantly, this compilation demonstrates that fluid inclusion barometry could be applied during volcanic crises at many hazardous and frequently erupting volcanoes worldwide, including the Galápagos, Réunion, Azores, Canary Islands, Iceland, Cabo Verde and perhaps even in dryer subduction zones such as the Cascades for the most mafic, CO2-rich magmas. It could also be used to better constrain magma storage depths along Mid-Ocean Ridges around the world.

Thank you for your consideration of what we believe is a technique that will truly revolutionize the way volcano observatories make decisions during volcanic crises.

Dr. Charlotte LJ Devitre and Dr. Penny Wieser