Preparing for eruptions in subduction zones: Insights from the petrological study of both monogenetic and polygenetic volcanic systems.

This project aims to improve our understanding on fundamental processes occurring in subduction zones, adopting the original approach of studying a large-volume silicic monogenetic and polygenetic volcanoes present in the same volcanic area, together with the most primitive magmas, using innovative petro-geochemical tools. We aim in particular to constrain the architecture of the magma plumbing system and its dynamics, with special emphasis on the timescales involved in the magmatic processes driving the remarkable magma diversity, to improve the forecast of future eruptions and its impacts on the environment, human society and climate.

Context of the PhD

Volcanoes represent the visible part of a feeding system that not long ago, was thought to consist in a large pool of magma called "magma chamber", but, over the past decades, petrological studies have shown that this feeding system is made of interconnected conduits and reservoirs, developed at the scale of the crust, and where the magma evolves into a crystal mush *(Cashman et al., 2017; Sparks et al., 2019*). This discovery has revolutionized our understanding of, and afforded exciting new insights into, the dynamic of entire magma plumbing systems, in particular under pre-eruptive conditions.

The development of diffusive timing based on the interpretation of the compositional zoning of crystals has made it possible not only to identify the processes responsible for mobilizing the magma mush stored in the system and triggering an eruption, but also to date this process *(Costa, 2021)*. Indeed, the eruption freezes the disequilibrium conditions by a thermal quenching effect that stops any diffusion of elements in the crystals, which then act as an archive of the space-time history in pre-eruptive conditions *(Petrone et al., 2022)*. Nevertheless, this technique has been widely applied to basaltic systems with an abundant literature *(Hartley et al., 2016; Couperthwaite et al., 2020; Kahl et al., 2022)*, but more rarely to differentiated systems *(Allan et al., 2013; Druitt et al., 2012; Flaherty et al., 2018; Weber et al., 2019)*, hence providing limited insights on subduction volcanism that mostly involves differentiated calc-alkaline magmas.

The main objective of this PhD is **to advance in the understanding of volcanism at subduction zones**. Continental subduction zones concentrate the most devastating volcanoes in the world, with highly explosive eruptions having local and global impact on the environment, human society and climate. They also show a wide diversity in volcano types and eruptive behavior, which is controlled by poorly understood complex magmatic processes taking place within the crust. The Trans-Mexican Volcanic Belt is an active continental arc, which is dominated by monogenetic volcanoes forming large fields but also punctuated by large polygenetic volcanoes. Monogenetic volcano size, type, and chemical composition vary greatly across the belt. In the Serdán Oriental basin located in the eastern part of the belt, this activity formed recent large rhyolitic domes surrounded by tuff rings, scoria cones and lava flows of similar ages and basaltic to rhyolitic compositions *(Siebe and Verma 1988)*. In particular, the Las Derrumbadas twin rhyolitic domes are the youngest and best preserved domes of the Serdán Oriental basin (AD20: *Chedeville et al. 2020*). They are 1000-m high corresponding to 11 km^3: they represent « one of the most voluminous silicic effusive eruptions during the Holocene wordwide » *(Chedeville et al. 2020)*. A major stratovolcano, Los Humeros, is also present in the north of the basin, responsible of significant magma volume emission, from differentiated composition to mafic one in the late stage of activity. The Serdán Oriental basin is typically representative of **both monogenetic and polygenetic volcanic activity, spanning a large range of magma composition and eruptive style, present in subduction zones, but rarely investigated together**.

Objectives and questions

Our study aims to better constrain the dynamics and timescales of magma evolution prior and during eruptions at subduction zones. Recent work at active polygenetic volcanoes have shown that the petrological records preserved by the crystals, and in particular the time elapsed between the process responsible for the destabilization of the reservoir at depth leading to the eruption, may be correlated to the seismic reactivation signals picked up by the monitoring networks *(Ostorero, Balcone- Boissard et al., 2022).* **Thus, magma crystals from past eruptions can tell us how much time is available before an eruption if a volcanic system reactivates, making it a pre-eruptive early-warning clock.**

Polygenetic volcanoes have a feeding system that is stable over time, but reactivated differently during eruptions *(Mangler et al., 2019; Solaro, Balcone-Boissard et al., 2020; Ostorero et al., 2021).* In comparison, monogenetic volcanoes have a short-lived magmatic system that is believed to form during the event and to rapidly freeze afterwards, thus impeding its re-activation. This system is generally assumed to be extremely simple (dike-like) but advanced petrological studies of historic eruptions have shown that these events may be characterized by complex magmatic processes that take place months to years before as well as during the eruption, coinciding with reported seismic activity (Albert et al., 2016, 2020; Larrea et al., 2021; Kahl et al., 2022). Thus, monogenetic eruptions may have more complex feeding systems than previously known. Polygenetic volcanoes dominate the eruptive record of continental arcs, but **monogenetic volcanoes may hold crucial information, yet they are underrepresented in geochemical and petrological studies. The questions to be addressed during the PhD are: (1) To what extent the feeding system of polygenetic and monogenetic volcanoes are connected? in terms of magma source(s), magma storage zone(s) and (2) What are the timescales of reactivating processes for both systems?**

Here we propose to study jointly the two volcanic systems to unravel magma sources, linked to the subduction zone, then the associated magma plumbing architecture (magma transfer through the crust, and stable magma ponding zones), which is a prerequisite to understand magma pre-eruptive storage and ascent (magma degassing and eruptive style). Results of this work will have implications about the processes of large-volume silicic magma generation in subduction zones and their potential precursors. The accumulation of magma at crustal levels for a long period of time, which would hence suppose long-lasting precursory signals, or if the magma ascent is rapid, fed directly from a deep magma source, which would then led to little warning.

The case-study area is still active (seism’s, passive degassing), as highlighted by the geothermal factory within Los Homeros caldera. The Los Humeros volcanic complex constitutes one of the most important exploited geothermal fields in Mexico with ca. 90 MW of produced electricity. Thus a new rhyolitic volcanic activity may take place in this same site or nearby.

→ PhDs’s results may thus be used in the future to elucidate the pre-eruptive behavior of magmas emitted in subduction zones and improve risk mitigation (forecast), but also to infer about geothermal potential in the future.