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Determining pre-eruptive processes in Galápagos volcanoes: novel insights from petrologic analysis of the 2015 Volcán Wolf eruption

Post-fieldtrip report

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Introduction

The Galápagos Archipelago is one of the world's most volcanically active regions, with eruptions occurring every 3 to 5 years. The islands are famous for their unique ecosystem, which is largely unaffected by anthropogenic influence. They host a high proportion of endemic species, many of which live in geographically restricted areas – such as volcanic craters – and are therefore at significant risk during eruptions. Additionally, the human population of Galápagos is growing rapidly, with >30,000 current residents (cf. ~2,000 in the 1960's) and 225,000 tourist visitors per annum (cf. <20,000 in the 1970's). Eruptions from Galápagos volcanoes therefore represent, not only a major ecological and environmental threat, but a significant concern for civil protection, both in the archipelago and on the adjacent South American continent.

The risks associated with volcanic eruptions can be greatly reduced through detailed monitoring and understanding of pre-eruptive processes. Galápagos volcanoes are currently monitored for seismic activity, gas emissions and surface deformation. However, our knowledge of the magma chamber processes that precede eruptions in the archipelago is extremely limited relative to regions with similar volcanic activity, such as Iceland and Hawaii. These magmatic processes control the timing and magnitude of eruptions but a lack of constraint on Galápagos volcanoes severely limits the interpretation of monitoring data, reducing the potential for recognition of critical pre-eruptive 'warning' signs.

Volcán Wolf is one of seven shield volcanoes that comprise the persistently active western subprovince of the Galápagos Archipelago (Fig. 1). It is ecologically significant, as it is the only habitat of the Galápagos pink land iguana and a subspecies of giant tortoise. Volcán Wolf is <100,000 yrs old and has produced at least nine eruptions within the last 100 yrs, most recently between 25 May – 11 July 2015. The 2015 eruption expelled basaltic lava, which covered an area of ~21.6 km^2, and produced a 15 km high ash cloud that travelled >1,400 km, reaching the Ecuadorian capital of Quito on the South American mainland.

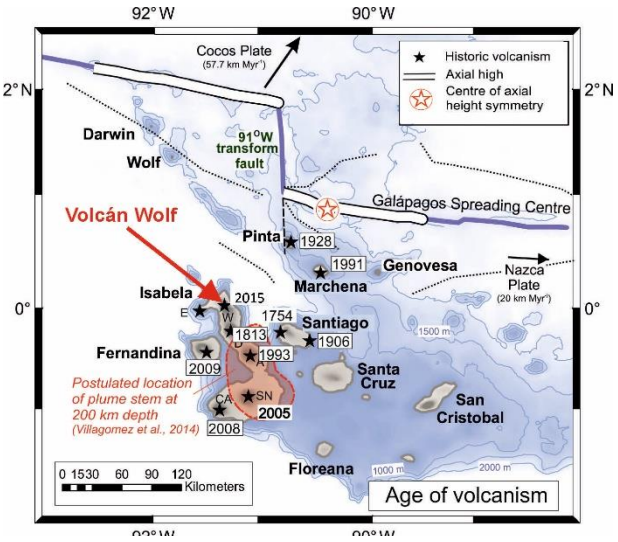

Fig 1. Map of the Galápagos Archipelago showing the dates of historic eruptions. Volcán Wolf is highlighted with a red arrow. From Gibson et al. (2015, G^3).

The overarching aim of my research project is to constrain the magma chamber processes that occurred during the build-up to the 2015 eruption of Volcán Wolf. This eruption was monitored in detail at the Earth's surface with: (i) better measurements of gas emissions and deformation than any previous Galápagos eruption, which were collected by recently-launched satellites; (ii) a newly-emplaced seismic network; (iii) overflight observations. It therefore offers a unique opportunity to correlate petrologic information with pre-eruptive monitoring data, providing retrospective constraints on surface observations.

Prior to this project, no geologic fieldwork had been conducted on Volcán Wolf since the 2015 eruption. A major field campaign was therefore required to sample the compositional diversity of the erupted lavas. The Jeremy Willson Charitable Trust (through the administration of the Geological Society of London) generously provided funding for this trip.

Planning and logistics

Fieldwork on Volcán Wolf was carried out in June 2017. The expedition team included international researchers, with wide-ranging academic interests (Fig. 2). In addition to myself (a volcanologist and igneous petrologist), the UK contingent included Dr Sally Gibson and Mr Matthew Gleeson from the University of Cambridge. Dr Gibson and Mr Gleeson are mantle geochemists, specialising in the Galápagos hot spot plume. We were joined by Dr Benjamin Bernard and Mr Antonio Proaño Altamirano from Escuela Politécnica Nacional in Quito (Ecuador), who are directly involved in monitoring Galápagos volcanoes to detect signals that might precede future eruptions. The final team member was Mr Wilson Villamar, a Galápagos National Park ranger. Fieldwork logistics were organised in collaboration with the Charles Darwin Foundation, a not-for-profit organisation that provides assistance to scientists working in the Galápagos Archipelago.

The Galápagos Islands are located ~1,000 km off the west coast of Ecuador and, although there are several small towns on the islands, Volcán Wolf is in a remote part of the archipelago, away from these population centres. Carrying out fieldwork in such a remote location is logistically challenging and required careful preparation; any injuries would risk prematurely ending the trip and could cause a serious evacuation challenge. To mitigate this, we hired *M/V Pirata* – a retrofitted schooner, manned by a highly experienced crew. The *Pirata* is used routinely for scientific expeditions and the crew are adept at transport visiting scientists to obscure parts of the archipelago. One of the most challenging aspects of undertaking fieldwork in Galápagos is finding safe places to disembark the boat and land on the shore. With rough tides and a rocky shoreline, landing on Volcán Wolf would have been almost impossible without the detailed local knowledge of the *Pirata* crew.

The fieldwork expedition

Before leaving the main towns on Galápagos, all scientists go through thorough quarantine. Material items and food are sterilised and put in a freezer for at least 48 hours, to remove seeds, insects and other organisms. This is a necessary precaution to prevent the transfer of biological material between islands and ensure the preservation of the Galápagos Islands UNESCO world heritage.

Volcán Wolf is in the north of Isabella Island (Fig. 1), directly on the equator. It takes ~1 day to reach the volcano from the main town of Puerto Ayora. The edifice is breathtakingly large, rising steeply up to a height of ~1,700 m, directly from sea level. Unlike the fertile older islands in the Galápagos Archipelago, the eastern flank of Volcán Wolf is almost entirely void of life. It is covered by hundreds of young basaltic lava flows, which have been emplaced within the last few thousand years. Saving a flock of flightless cormorants, we saw almost no wildlife during our time on the volcano and the vegetation exclusively comprised cacti and low-lying shrubs, which had been variably burned by nearby lava flows.

In total, we completed seven days of fieldwork on Volcán Wolf (with an additional two days spent travelling to and from the field site). This involved traversing a ~25 km stretch of coastline on the east flank of the volcano. The fresh lava is razor sharp and constantly shifts as you walk on it. Hence, samples were collected as close to the coast as possible, using the boat to move between sampling localities, thus minimising walking on the dangerous terrain. In some cases, it was necessary to hike further inland to target specific sampling sites, but this was time consuming and arduous; the samples collected furthest inland were taken ~5 km from the coast and took an entire day of trekking to reach.

Collecting material from 2015 eruption was the main objective of the expedition and samples were successfully taken from all the main lava flow lobes emplaced on the flank of the volcano between 25 May and 2 June. The final phase of the 2015 eruption (11 June – 11 July) occurred within the caldera at the summit of the volcano. Before departure, we had hoped to access the summit caldera and sample these flows. However, in the field it became clear that this would not be possible, due to the time required to reach the summit walking over the difficult terrain. In addition to material from the most recent eruption of Volcán Wolf, samples were collected from several older lava flows on the east flank of the volcano for a comparative study.

In total, over 50 samples were collected during the field campaign on Volcán Wolf. These were successfully shipped back to the UK, after being thoroughly checked for biological material by the Ecuadorian Biosecurity Agency and Galápagos National Park. Because they are so young, the rocks are almost completely unaltered and comprise fresh crystal and glass, which are ideal for geochemical microanalysis.

Future work

Many of the samples collected in Galápagos have already been thin sectioned and work is underway to prepare them for geochemical analysis. This will include both bulk-rock techniques and high-resolution micro-analysis of crystals and glass, using state-of-the-art equipment in the Department of Earth Sciences, University of Cambridge. Through comparison with thermodynamic models and experimental data, measured compositions will be interpreted to establish changes in conditions and melt composition during magma chamber development. Additionally, diffusion chronometry will be used to quantify the timing of changes in magmatic conditions and the onset of processes that triggered the 2015 Volcán Wolf eruption.

The records produced in this study will improve our understanding of pre-eruptive magmatic processes and the structure of sub-volcanic systems in the Galápagos Archipelago. It is hoped that geochemical analysis of the Volcán Wolf sample set will reveal generic processes responsible for triggering eruptions throughout the archipelago. Petrologic information will be compared with monitoring data measured at the Earth's surface in the build-up to the 2015 Wolf eruption, providing a retrospective recognition and understanding of pre-eruptive 'warning' signs. This will assist hazard assessment, inform contingency plans and facilitate better interpretation of monitoring data in the future, which will greatly improve wildlife and civil protection.

Fig 2. The expedition team, taken on the equator with Volcán Wolf in the background. From left to right: M. Stock, B. Bernard, W. Villamar, M. Gleeson, A. Proaño, S. Gibson.