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PyVOLCANS: A Python package to flexibly explore similarities and differences between volcanic systems

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Summary

There are over 1,400 volcanoes on Earth that have either erupted or shown signs of volcanic activity (e.g. fumaroles or hot springs) in, approximately, the last 12,000 years. Of these, around 40-50 are erupting at any given time (Global Volcanism Program, 2013; Siebert et al., 2010). Volcanoes provide a range of economic benefits, such as fertile soils, geothermal energy or valuable mineralisations, create a strong sense of belonging among local populations, and fascinate visitors. However, volcanic systems can also generate hazardous phenomena, which may threaten local inhabitants, tourists and infrastructure at distances of up to tens or hundreds of kilometres.

In order to understand and quantify volcanic hazard, volcano scientists are faced with many questions. How often do eruptions occur? How big are they? What style of eruption is possible (e.g. mainly explosive or effusive)? From where on the volcano is eruptive activity sourced? What areas around the volcanic system may be impacted? Will there be any early warning signals?

Quantitative data to address these questions are scarce (Loughlin et al., 2015). While a handful of volcanoes (e.g. Etna, Italy; Kīlauea, USA; Merapi, Indonesia) have been extensively studied, hundreds of volcanic systems around the world remain poorly-understood. One possible mitigation to the issue of data scarcity in volcanology and volcanic hazard assessment is the use of *analogue volcanoes* (Newhall et al., 2017; Newhall & Hoblitt, 2002). These are volcanoes with similar characteristics to a data-scarce volcano of interest. Data and insights from the well-studied volcano(es) can be used to provide estimates for important variables, such as the number of eruptions during specific time windows or the size of those eruptions. Such methods have been used for many years, here we present the first tool enabling a structured and harmonised approach that can be applied worldwide.

Statement of need

`PyVOLCANS` (Python VOLCano ANalogues Search) is an open-source tool that addresses the need for an objective, data-driven method for selection of analogue volcanoes. It is based on the results of VOLCANS (Tierz et al., 2019), a first-of-its-kind method to quantify the analogy (or similarity) between volcanic systems, based on a structured combination of five volcanological criteria: tectonic setting, rock geochemistry, volcano morphology, eruption size, and eruption style. `PyVOLCANS` provides a command-line interface to make the results from the VOLCANS study easily accessible to a wide audience. `PyVOLCANS` is a versatile tool

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for volcano scientists, with potential applications ranging from investigating commonalities between volcanic systems (Cashman & Biggs, 2014) to supporting probabilistic volcanic hazard assessment at local, regional and global scales. Exploring similarities and differences between volcanic systems using `PyVOLCANS` can also be useful for teaching and scientific outreach purposes.

Users can easily derive data-driven sets of *top* analogue volcanoes (i.e. those with highest analogy) to any volcanic system listed in the reference database for recent global volcanism: the Volcanoes of the World Database, hosted by the Global Volcanism Program of the Smithsonian Institution (Global Volcanism Program, 2013). Users can also choose the number of *top* analogue volcanoes to investigate and can customise the importance (i.e. weight) that is given to each of the five aforementioned volcanological criteria. Additionally, users can select a number of *a priori* analogue volcanoes (i.e. volcanoes deemed as analogues by other means, such as expert knowledge) and assess their values of analogy with the target volcano to see how well they match on different criteria and if other volcanoes could be a better choice (Figure 1).

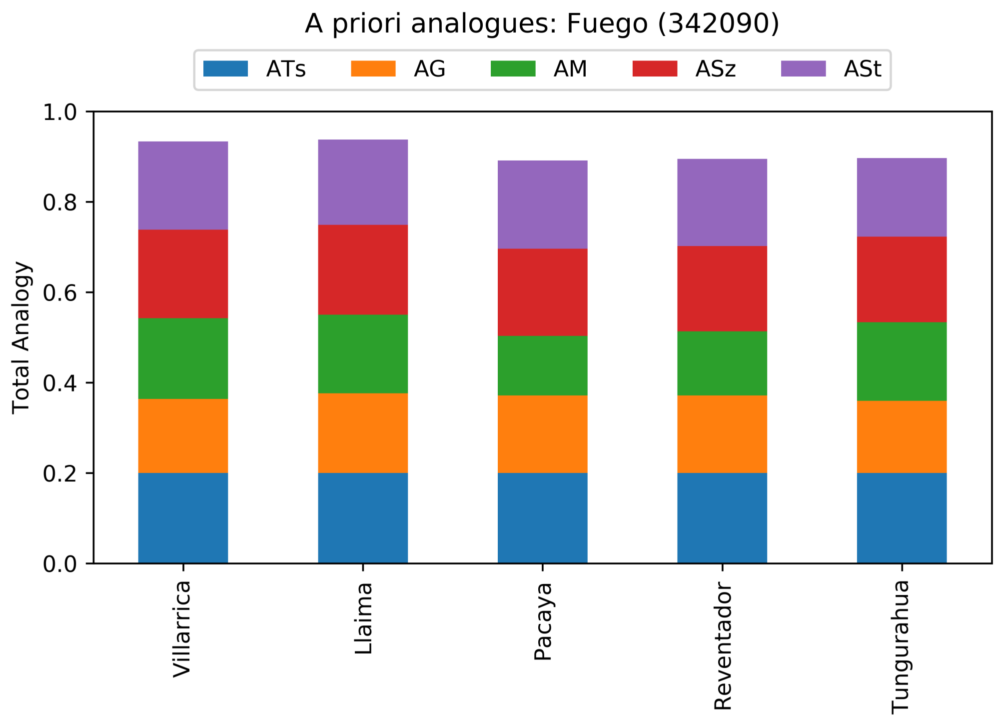

Figure 1: Values of single-criterion (colours) and total analogy (bar heights) between an example target volcano, Fuego (Guatemala)*, and five *a priori* analogues (please see Tierz et al., 2019, for more details). ATs: Analogy in Tectonic setting; AG: Analogy in rock Geochemistry; AM: Analogy in volcano Morphology; ASz: Analogy in eruption Size; ASt: Analogy in eruption Style. *Number between brackets denotes the unique volcano identifier used by the GVP database.

The results from the VOLCANS study have been used in research to explore the volcanological factors that influence the development of particular volcano morphologies (Philippa White, unpublished thesis); to constrain potential hazardous phenomena and hazard scenarios at a given target volcano, based on its analogue volcanoes (Simmons, 2021); to quantify probability distributions of eruption sizes and probabilities of occurrence of diverse hazardous phenomena (Tierz et al., 2020); or even to explore volcano analogies at regional scales, by generating sets of analogue volcanoes for tens of volcanic systems. The last two example applications have played a key role in developing quantitative hazard analyses for Ethiopian volcanoes, within the RiftVolc project (please see `PyVOLCANS` documentation for further details on these analyses). Moreover, the future potential of VOLCANS/`PyVOLCANS`, particularly in the field of volcanic hazard assessment, has also been recognised in recent relevant publications in the area (Marzocchi et al., 2021; Papale, 2021)

We hope that the release of `PyVOLCANS` will encourage further studies based on data-driven selection of analogue volcanoes and that such analyses will continue to grow in number and diversity of their scientific purposes.

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