

La Palma Earthquakes

Steve Purves¹, Rowan Cockett¹

¹Curvenote,

Key Points:

- You may specify 1 to 3 keypoints for this PDF template
- These keypoints are complete sentences and less than or equal to 140 characters
- They are specific to this PDF template, so they will not appear in other exports

Corresponding author: Steve Purves, steve@curvenote.com

Abstract

The notebook should begin with a single markdown cell which contains document front matter (such as the title, author data, license, abstract, and more).

The abstract should begin with a short description of the problem addressed, briefly describe the new data or analyses, then briefly state the main conclusion(s) and how they are supported, and address any uncertainty.

In September 2021, a significant jump in seismic activity on the island of La Palma (Canary Islands, Spain) signaled the start of a volcanic crisis that still continues at the time of writing. Earthquake data is continually collected and published by the Instituto Geográfico Nacional (IGN). We have created an accessible dataset from this and completed preliminary data analysis which shows seismicity originating at two distinct depths, consistent with the model of a two reservoir system feeding the currently very active volcano.

0.1 Introduction

The content of your notebook may be broken into any number of markdown or code cells. Markdown cells use Quarto markdown. Quarto markdown supports an extended version of the basic Markdown syntax originally created by John Gruber, which adds support for many common document elements including citations, figures, tables, admonitions, and more. Quarto markdown also supports the use of LaTeX for mathematical equations, advanced layout control, as well as other advanced formatting.

La Palma is one of the west most islands in the Volcanic Archipelago of the Canary Islands, a Spanish territory situated in the Atlantic Ocean where at their closest point are 100km from the African coast Figure 1. The island is one of the youngest, remains active and is still in the island forming stage.

Figures may be added to your notebook using [markdown images or special markdown elements](#) (‘fenced divs’). They may refer to images saved in your `images/` folder (or other folders), images from the web, or generated directly using code cells. You may embed figures produced in other notebooks using the [embed shortcode](#) (this embed figures, tables, or any other content from Jupyter Notebooks). Refer to figures by their label (e.g. `@fig-map`).

La Palma has been constructed by various phases of volcanism, the most recent and currently active being the *Cumbre Vieja* volcano, a north-south volcanic ridge that constitutes the southern half of the island.

0.1.1 Eruption History

A number of eruptions were recorded since the colonization of the islands by Europeans in the late 1400s, these are summarised in Table 1.

Quarto supports a number of ways to create tables using both standard markdown tables (pipe tables) and more complex markdown tables using a grid style syntax (grid tables). In addition, Quarto provides the ability to control column width, caption position, create subtables, and more. See [Quarto’s table document](#) to learn more. Refer to tables in the text by their label (e.g. `@tbl-history`).



Figure 1: Map of La Palma in the Canary Islands. Image credit [NordNordWest](#)

Table 1: Recent historic eruptions on La Palma

Name	Year
Current	2021
Teneguía	1971
Nambroque	1949
El Charco	1712
Volcán San Antonio	1677
Volcán San Martín	1646
Tajuya near El Paso	1585
Montaña Quemada	1492

This equates to an eruption on average every 79 years up until the 1971 event. The probability of a future eruption can be modeled by a Poisson distribution Equation 1.

Numbered equations may be defined using ‘dollar math’ by placing equations between matching pairs of dollar signs. Learn more about Quarto’s equation here: <https://quarto.org/docs/authoring/cross-references.html#equations>. Refer to equations in the text by their label (e.g. @eq-poisson).

$$p(x) = \frac{e^{-\lambda} \lambda^x}{x!} \quad (1)$$

Where λ is the number of eruptions per year, $\lambda = \frac{1}{79}$ in this case. The probability of a future eruption in the next t years can be calculated by:

$$p_e = 1 - e^{-t\lambda} \quad (2)$$

So following the 1971 eruption the probability of an eruption in the following 50 years — the period ending this year — was 0.469. After the event, the number of eruptions per year moves to $\lambda = \frac{1}{75}$ and the probability of a further eruption within

the next 50 years (2022-2071) rises to 0.487 and in the next 100 years, this rises again to 0.736.

0.1.2 Magma Reservoirs

You may provide the bibliography directly as a bibtex, biblatex, CSL JSON, or CSL YAML file (defined in the document front matter or `_quarto.yml` project file) then embed the citation by citation key in your text using the `[@cite]` or `@cite` for parenthetical or textual citations, respectively. The following paragraph provides an example of this. Quarto's [documentation on citations](#) provides more details on working with bibliographies and citations.

Studies of the magma systems feeding the volcano, such as Marrero et al. (2019) has proposed that there are two main magma reservoirs feeding the Cumbre Vieja volcano; one in the mantle (30-40km depth) which charges and in turn feeds a shallower crustal reservoir (10-20km depth).

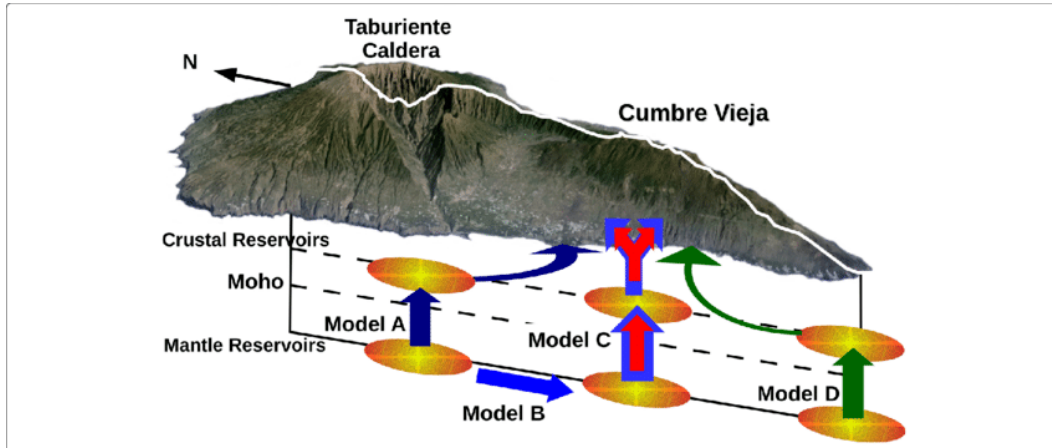


Figure 2: Proposed model from Marrero et al

In this paper, we look at recent seismicity data to see if we can see evidence of such a system action, see Figure 2.

0.2 Dataset

All data used in the notebook should be present in the `data/` folder so notebooks may be executed in place with no additional input.

The earthquake dataset used in our analysis was generated from the [IGN web portal](#) this is public data released under a permissive license. Data recorded using the network of [Seismic Monitoring Stations](#) on the island. A web scraping script was developed to pull data into a machine-readable form for analysis. That code tool is [available on GitHub](#) along with a copy of recently updated data.

0.3 Results

The dataset was loaded into a Jupyter notebook [visualization](#) and filtered down to La Palma events only. This results in 5465 data points which we then visualized to understand their distributions spatially, by depth, by magnitude and in time.

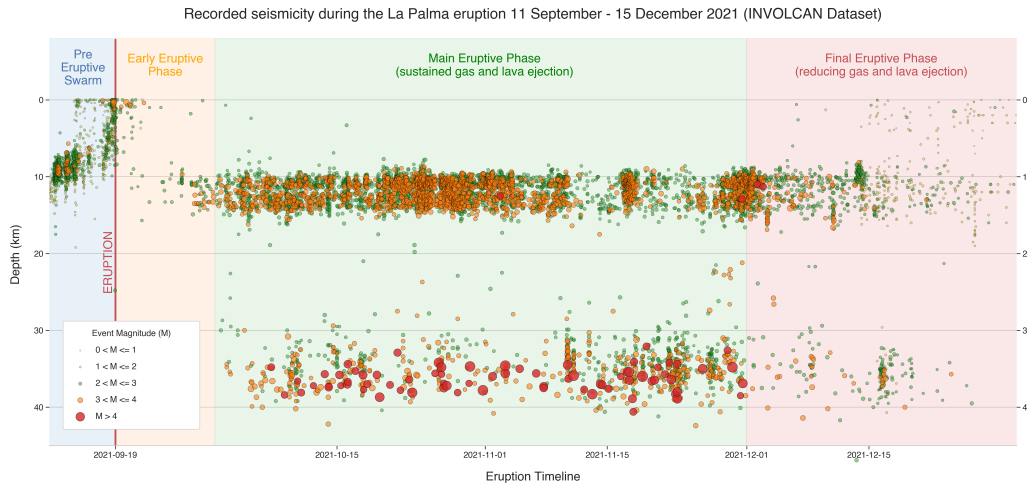


Figure 3: Earthquake data over time ($n=5465$) to understand their distributions spatially, by depth, by magnitude and in time.

This figure uses cell output from the Visualization notebook. That cell uses syntax at the top of the code to define a label and caption for the figure. Referencing the label pulls in the output of the cell in this document, and automatically creates links to the source document. You can read more about using the `embed` shortcode and customizing embedded content in the [Quarto documentation](#).

From our analysis in Figure 3, we can see 3 different systems in play.

Firstly, the shallow earthquake swarm leading up to the eruption on 19th September, related to significant surface deformation and shallow magma intrusion.

After the eruption, continuous shallow seismicity started at 10-15km corresponding to magma movement in the crustal reservoir.

Subsequently, high magnitude events begin occurring at 30-40km depths corresponding to changes in the mantle reservoir. These are also continuous but occur with a lower frequency than in the crustal reservoir.

0.4 Conclusions

From the analysis of the earthquake data collected and published by IGN for the period of 11 September through to 9 November 2021. Visualization of the earthquake events at different depths appears to confirm the presence of both mantle and crustal reservoirs as proposed by [marrero2019](#).

Availability

Data availability statement should be specified in a separate block with metadata `"part": "availability"`, similar to the abstract.

AGU requires an Availability Statement for the underlying data needed to understand, evaluate, and build upon the reported research at the time of peer review and publication.

118 A web scraping script was developed to pull data into a machine-readable form
119 for analysis. That code tool [is available on GitHub](#) along with a copy of recently
120 updated data.
121 Marrero, J., García, A., Berrocoso, M., Llinares, Á., Rodríguez-Losada, A., & Ortiz,
122 R. (2019). Strategies for the development of volcanic hazard maps in mono-
123 genetic volcanic fields: The example of La Palma (Canary Islands). *Journal of*
124 *Applied Volcanology*, 8. <https://doi.org/10.1186/s13617-019-0085-5>