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# La Palma Seismicity 2021

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## **Key Points:**

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- You may specify 1 to 3 key points for AGU
- These key points 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

9      **Abstract**

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

17      **Plain Language Summary**

18     We show a model of a two reservoir system feeding the Canary Islands, Spain vol-  
 19    cano in September 2021.

20      **1 Introduction**

21     The content of your article is written in MyST markdown and supports standard  
 22    markdown typography and many directives and roles for figures, tables, equations,  
 23    etc.

24     La Palma is one of the west most islands in the Volcanic Archipelago of the Ca-  
 25    nary Islands, a Spanish territory situated in the Atlantic Ocean where at their closest  
 26    point are 100km from the African coast Figure 1 The island is one of the youngest, re-  
 27    mains active and is still in the island forming stage.

28     Figures may be added to your article using the figure directive. They may refer  
 29    to images saved in your `images/` folder, images from the web, or notebook cell  
 30    outputs referenced by label. The `:name:` is used to reference the figure in your  
 31    text; a reference to the following figure is found in the paragraph above. The fig-  
 32    ure caption is given as the body of this directive.



**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

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.

## 2 Eruption History

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

Simple tables may be created using the list-table directive. Similar to figures, tables may be referenced in the text by their `name`. The caption for this table is the first line of the directive.

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 (1).

Numbered equations may be defined using the `math` directive or in line. Equations defined with the `math` directive may be reference in the text by label.

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

Where  $\lambda$  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:

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

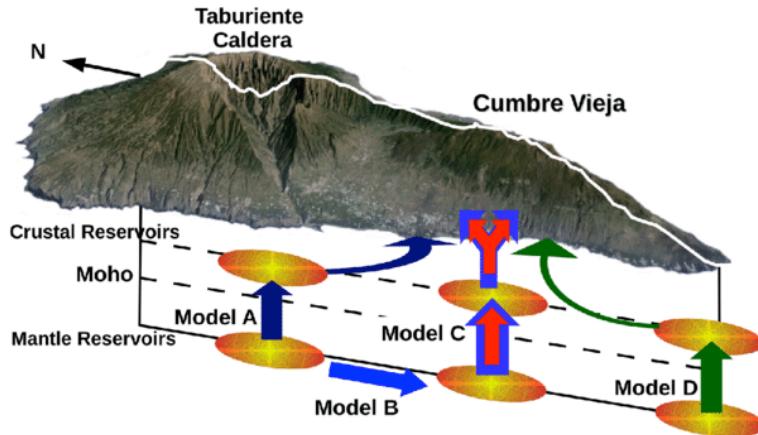
So following the 1971 eruption the probability of an eruption in the following 50 years — the period ending this year — was 0.469. After the event, the number of eruptions per year moves to  $\lambda = \frac{1}{75}$  and the probability of a further eruption within the next 50 years (2022-2071) rises to 0.487 and in the next 100 years, this rises again to 0.736.

### 2.1 Magma Reservoirs

You may add citations two ways. First, you may simply insert a markdown link to a DOI like so: Thompson et al. (1994). No additional bibliographic information is required for this approach; the reference will be looked up by DOI and added

implicitly to the references. Alternatively, you may provide the bibliography directly as `references.bib` BibTeX file, then embed the citation by BibTeX key in your text using the `cite:p` or `cite:t` for parenthetical or textual citations, respectively. The following paragraph provides an example of this. A single paper may combine both DOI and BibTeX 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. (2019).

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

### 3 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.

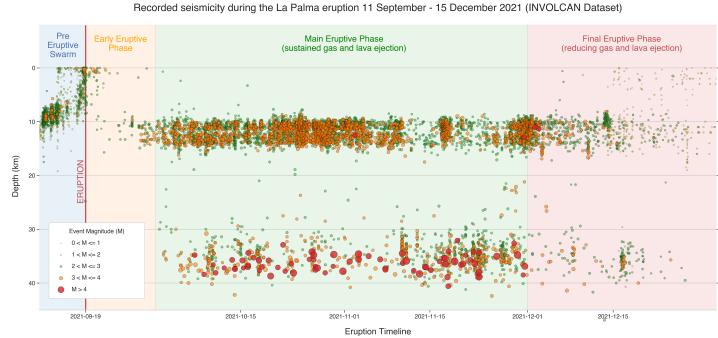
The earthquake dataset used in our analysis was generated from the IGN web portal this is public data released under a permissive license. Data recorded using the network of Seismic Monitoring Stations on the island. A web scraping script was developed to pull data into a machine-readable form for analysis.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

### 4 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.

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.



**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. The first line of the cell is `#| label: eq-timeline`. Referencing that label pulls in the output of the cell as a figure.

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

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

## 87 5 Conclusions

88 From the analysis of the earthquake data collected and published by IGN for the  
89 period of 11 September through to 9 November 2021. Visualization of the earthquake  
90 events at different depths appears to confirm the presence of both mantle and crustal  
91 reservoirs as proposed by Marrero et al. (2019).

92 The authors would like to thank the Notebooks Now working groups for their help  
93 on creating these templates and advising on metadata.

## 94 Open Research

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

97 AGU requires an Availability Statement for the underlying data needed to un-  
98 derstand, evaluate, and build upon the reported research at the time of peer re-  
99 view and publication.

100 A web scraping script was developed to pull data into a machine-readable form for  
101 analysis. That code tool is available on GitHub along with a copy of recently updated  
102 data.

## 103 References

- 104 Marrero, J., García, A., Berrocoso, M., Llinares, Á., Rodríguez-Losada, A., & Ortiz,  
105 R. (2019, 7). Strategies for the development of volcanic hazard maps in mono-

- 106 genetic volcanic fields: the example of La Palma (Canary Islands). *Journal of*  
107 *Applied Volcanology*, 8. doi: 10.1186/s13617-019-0085-5
- 108 Thompson, J. D., Higgins, D. G., & Gibson, T. J. (1994). CLUSTAL w: im-  
109 proving the sensitivity of progressive multiple sequence alignment through se-  
110 quence weighting, position-specific gap penalties and weight matrix choice. *Nu-*  
111 *cleic Acids Research*, 22(22), 4673–4680. Retrieved from <https://doi.org/10.1093/nar%2F22.22.4673>  
112 doi: 10.1093/nar/22.22.4673