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Abstract

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 Geográphico 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.

1 Introduction

> The content of your notebook may be broken into any number of markdown or code cells. Markdown cells use MyST markdown and support standard markdown typography and many directives and roles for figures, tables, equations, etc.

La Palma is one of the west most islands in the Volcanic Archipelago of the Canary Islands, a Spanish territory situated is 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.

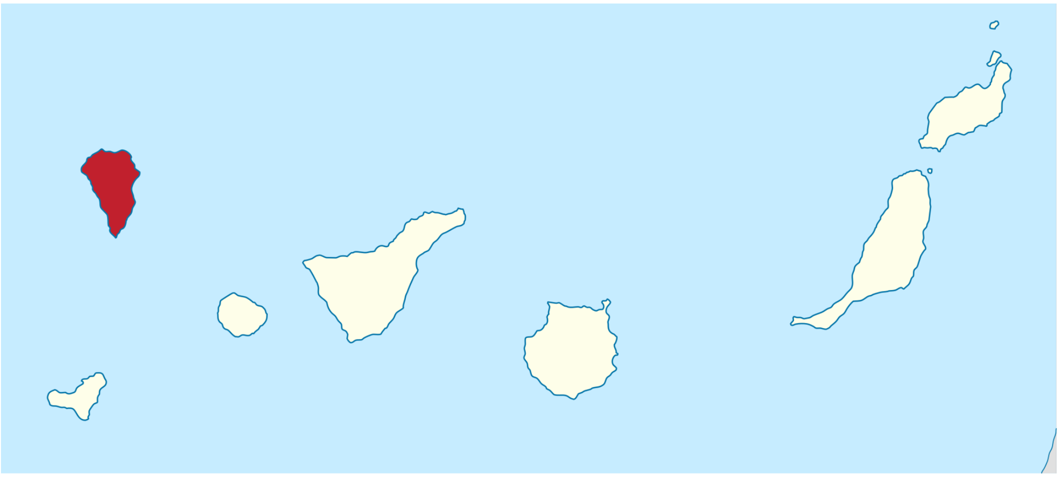

Figure 1: Map of La Palma in the Canary Islands. Image credit NordNordWest

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.

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.

> 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.

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 Martin	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 the math directive or in line. Equations defined with the math directive may be reference in the text by label.

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

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:

$$p_e = 1 - \mathrm{e}^{-t\lambda} \tag{2}$$

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.

1.2 Magma Reservoirs

> You may add citations two ways. First, you may simply insert a markdown link link to a DOI like so: . 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).

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

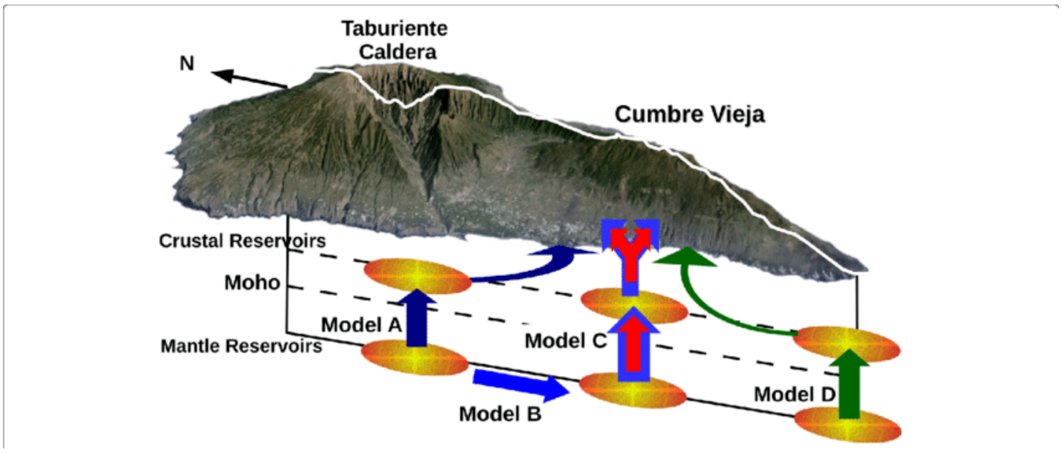

Figure 2: Proposed model from Marrero et al. (2019)

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.

2.1 Main Timeline Figure

Code cells may be seamlessly interleaved with markdown cells. Currently, with a single-article submission, code cannot be hidden in the output document.

Table 2: A preview of ra

	Event	Date	UTC time	Local time(*)	Latitude	Longitude	Depth(km)	Magnitude	M
0	es2022cibon	2022-02-02	20:46:39	21:46:39	40.7805	3.4874	2.0	2.0	m
1	es2022cibcw	2022-02-02	20:33:08	21:33:08	35.4494	-3.6606	13.0	2.3	m
2	es2022ciaxl	2022-02-02	20:26:45	21:26:45	35.4879	-3.6302	27.0	2.0	m
3	es2022ciavv	2022-02-02	20:24:52	21:24:52	35.4216	-3.6531	17.0	2.3	m
4	es2022chvdg	2022-02-02	17:31:41	17:31:41	28.6224	-17.9208	0.0	1.7	m

```
df_ign['DateTime'] = pd.to_datetime(df_ign['Date'] + ' ' + df_ign['Local time(*)'])
df_ign['DateTime']
```

```
0       2022-02-02 21:46:39
1       2022-02-02 21:33:08
2       2022-02-02 21:26:45
3       2022-02-02 21:24:52
4       2022-02-02 17:31:41
                ...
12465   2021-08-31 02:30:13
12466   2021-08-31 02:28:39
12467   2021-08-31 02:27:43
12468   2021-08-31 02:25:20
12469   2021-08-31 02:02:21
Name: DateTime, Length: 12470, dtype: datetime64[ns]
```

```
tab10_colors = (
    (0.12156862745098039, 0.4666666666666667,  0.7058823529411765  ), # 1f77b4
    (1.0,                 0.4980392156862745,  0.054901960784313725), # ff7f0e
    (0.17254901960784313, 0.6274509803921569,  0.17254901960784313 ), # 2ca02c
    (0.8392156862745098,  0.15294117647058825, 0.1568627450980392  ), # d62728
    (0.5803921568627451,  0.403921568627451,   0.7411764705882353  ), # 9467bd
    (0.5490196078431373,  0.33725490196078434, 0.29411764705882354 ), # 8c564b
    (0.8901960784313725,  0.4666666666666667,  0.7607843137254902  ), # e377c2
    (0.4980392156862745,  0.4980392156862745,  0.4980392156862745  ), # 7f7f7f
    (0.7372549019607844,  0.7411764705882353,  0.13333333333333333 ), # bcbd22
    (0.09019607843137255, 0.7450980392156863,  0.8117647058823529),   # 17becf
)

tab20_colors = (
    (0.12156862745098039, 0.4666666666666667,  0.7058823529411765  ), # 1f77b4
    (0.6823529411764706,  0.7803921568627451,  0.9098039215686274  ), # aec7e8
    (1.0,                 0.4980392156862745,  0.054901960784313725), # ff7f0e
    (1.0,                 0.7333333333333333,  0.47058823529411764 ), # ffbb78
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    (0.596078431372549,   0.8745098039215686,  0.5411764705882353  ), # 98df8a
    (0.8392156862745098,  0.15294117647058825, 0.1568627450980392  ), # d62728
    (1.0,                 0.596078431372549,   0.5882352941176471  ), # ff9896
    (0.5803921568627451,  0.403921568627451,   0.7411764705882353  ), # 9467bd
    (0.7725490196078432,  0.6901960784313725,  0.8352941176470589  ), # c5b0d5
    (0.5490196078431373,  0.33725490196078434, 0.29411764705882354 ), # 8c564b
    (0.7686274509803922,  0.611764705882353,   0.5803921568627451  ), # c49c94
    (0.8901960784313725,  0.4666666666666667,  0.7607843137254902  ), # e377c2
    (0.9686274509803922,  0.7137254901960784,  0.8235294117647058  ), # f7b6d2
    (0.4980392156862745,  0.4980392156862745,  0.4980392156862745  ), # 7f7f7f
    (0.7803921568627451,  0.7803921568627451,  0.7803921568627451  ), # c7c7c7
    (0.7372549019607844,  0.7411764705882353,  0.13333333333333333 ), # bcbd22
    (0.8588235294117647,  0.8588235294117647,  0.5529411764705883  ), # dbdb8d
    (0.09019607843137255, 0.7450980392156863,  0.8117647058823529  ), # 17becf
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)

tab20c_colors = (
    (0.19215686274509805, 0.5098039215686274,  0.7411764705882353  ), # 3182bd
    (0.4196078431372549,  0.6823529411764706,  0.8392156862745098  ), # 6baed6
    (0.6196078431372549,  0.792156862745098,   0.8823529411764706  ), # 9ecae1
    (0.7764705882352941,  0.8588235294117647,  0.9372549019607843  ), # c6dbef
    (0.9019607843137255,  0.3333333333333333,  0.050980392156862744), # e6550d
    (0.9921568627450981,  0.5529411764705883,  0.23529411764705882 ), # fd8d3c
    (0.9921568627450981,  0.6823529411764706,  0.4196078431372549  ), # fdae6b
    (0.9921568627450981,  0.8156862745098039,  0.6352941176470588  ), # fdd0a2
    (0.19215686274509805, 0.6392156862745098,  0.32941176470588235 ), # 31a354
    (0.4549019607843137,  0.7686274509803922,  0.4627450980392157  ), # 74c476
    (0.6313725490196078,  0.8509803921568627,  0.6078431372549019  ), # a1d99b
    (0.7803921568627451,  0.9137254901960784,  0.7529411764705882  ), # c7e9c0
    (0.4588235294117647,  0.4196078431372549,  0.6941176470588235  ), # 756bb1
    (0.6196078431372549,  0.6039215686274509,  0.7843137254901961  ), # 9e9ac8
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    (0.8549019607843137,  0.8549019607843137,  0.9215686274509803  ), # dadaeb
    (0.38823529411764707, 0.38823529411764707, 0.38823529411764707 ), # 636363
    (0.5882352941176471,  0.5882352941176471,  0.5882352941176471  ), # 969696
    (0.7411764705882353,  0.7411764705882353,  0.7411764705882353  ), # bdbdbd
    (0.8509803921568627,  0.8509803921568627,  0.8509803921568627  ), # d9d9d9
)
```

The PostScript backend does not support transparency; partially transparent artists will be ren

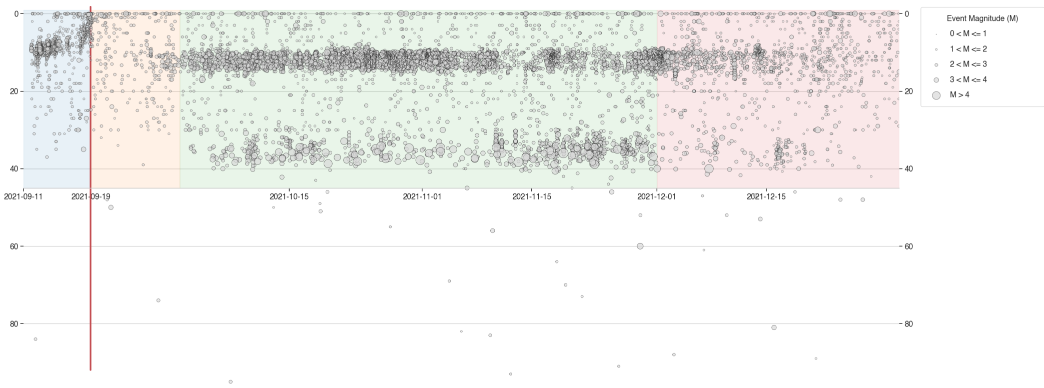

Figure 3: A timeline of volcanic activity through the years.

2.3 Cumulative Distrubtion Plots

```
def cumulative_events_mag_depth(df, hue='Depth', kind='scatter', ax=None, dpi=300, palette=No
    matplotlib.rcParams['ytick.labelright'] = False
    g = sns.jointplot(x="Magnitude", y="Depth(km)", data=df,
                      kind=kind, hue=hue, height=10, space=0.1, marginal_ticks=False, ratio=8
                      hue_order=['Shallow (<18km)', 'Interchange (18km>x>28km)', 'Deep (>28km
                      ax=ax, palette=palette, ylim=(-2,50), xlim=(0.3,5.6), edgecolor=".2", m
    if kde:
        g.plot_joint(sns.kdeplot, color="b", zorder=1, levels=15, ax=ax)
    g.fig.axes[0].invert_yaxis();
    g.fig.set_dpi(dpi)


def cumulative_events_spatial(df, hue='Depth', kind='scatter', ax=None, dpi=300, palette=None
    g = sns.jointplot(x="Longitude", y="Depth(km)", data=df,
                      kind=kind, hue=hue, color="m", height=10, palette=palette,
                      hue_order=['Shallow (<18km)', 'Interchange (18km>x>28km)',  'Deep (>28k
    g.plot_joint(sns.kdeplot, color="b", zorder=1, levels=15, ax=ax)
    g.fig.axes[0].invert_yaxis();
```

Applied Volcanology, *8*. https://doi.org/10.1186/s13617-019-0085-5