Assessing Volcanic Hazard and Exposure at Obscure Volcanic Fields: A Case Study from the Bolaven Volcanic Field, Laos

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Abstract

South-east Asia is one of the most volcanically active places on Earth, with the majority of the volcanoes located in Indonesia and in the Philippines. Indochina (Myanmar, Cambodia, Laos, Thailand and Vietnam) also hosts a certain number of volcanoes that for several reasons (post-World War II conflicts, little accessibility due to dense vegetation, no significant historical activity recorded), have been little studied so far. Some of these volcanoes show evidence of recent (Quaternary) activity, therefore, a systematic assessment of the threat these volcanoes may pose to resident populations is needed in the region. A recent study on the inferred location of the Australasian meteorite impact (the largest known young meteorite on Earth) provided an unprecedented amount of data for the Bolaven Volcanic Field in Laos, in terms of geological mapping, location of vents, and over 30 absolute ages of lava flows and vents. On this basis, besides additional data obtained for this work, we used the Bolaven Volcanic Field as a case study, to assess the potential exposure of populations and infrastructure to lava flows in case of an eruption in the field. Key results suggest that an overall area of ~5500 km2 is potentially exposed to lava flows in case of eruption, including over 2000 km of roads, 400 km of power lines, two power stations and two dams, and over 500 km2 of agricultural lands, with the potential to affect about 300,000 people living in this area, and their main businesses (hydropower and coffee production). In addition, the abundance of water in this region may lead to life-threatening explosions from phreatomagmatic eruptions. Finally, based on the data available we provide a maximum estimate of the past eruption frequency of the field, which is approximately 10,400 years. Our study provides a number of techniques and approaches (remote sensing of potential sources and past flows, lava flow simulations and open-access exposure data) that can be used to assess hazards and exposure at other understudied volcanoes.

Assessing volcanic hazard and exposure at obscure volcanic fields: a case study from the Bolaven Volcanic Field, Laos

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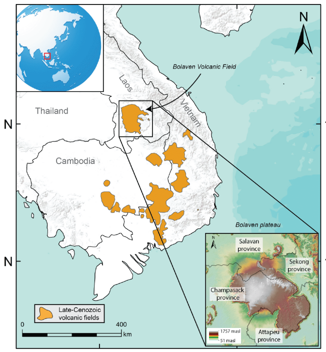
1. Background

Volcanic eruptions play a crucial role in human activities. Predicting them has always been challenging for geoscientists. One way to reduce this gap is through statistical numerical modelling. For this study, we conducted a long-term volcanic hazard assessment for the Bolaven Volcanic Field (BVF), southern Laos, through the use of the freely available code MOLASSES (Modular Lava Simulation Software for Earth Sciences; Gallant et al., 2018). We used this software to simulate 10,000 lava flows on and around the Bolaven plateau (based on the distribution of scoria cones that produced lava flows in the last ~790 ka). The result is a probabilistic inundation map, which was then combined with population, infrastructure and landcover data, to evaluate their exposure to future eruptions.

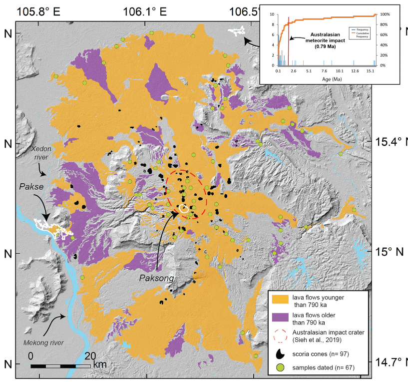
Rationale

- Sieh et al. (2019) presented several lines of evidence that the BVF buries the 790 ka Australasian impact crater.
- A volcanic hazard assessment has never been carried out for any volcanic field in Indochina
- Sieh et al. (2019) provided a uniquely large volume of data, to use in conducting a first-time volcanic hazard assessment of the BVF in Indochina
- The unique climatic and geographic conditions of the Bolaven plateau, make this area an important economic asset for the rest of the country, in terms of power production (hydropower), coffee production and export, and tourism



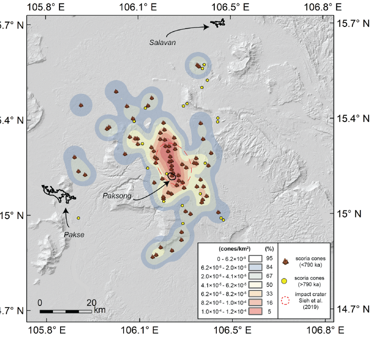
2. Geology of the BVF

The basaltic BVF has been active for the last ~16 Ma (Sieh et al., 2019). The basalts erupted through thick flat-lying Mesozoic non-marine clastic sedimentary rocks, and cover mostly the western portion of the plateau, with flows spilling out to its north, west and south, for an overall extent of about 5000 km². The field includes over 300 individual flows, and about 100 scoria cones. Flows vary in length from a few hundred meters to ~50 km. Thickness of the BVF ranges from a few meters (where only one flow lies directly upon non-volcanic sediment or bedrock) to ~300 m near the summit region, where numerous flows have accumulated. A key moment of the BVF history is the Australasian meteorite impact, about 790 ka ago. Because post-impact flows are better exposed than older ones, we used the post-impact ones for our hazard calculations.

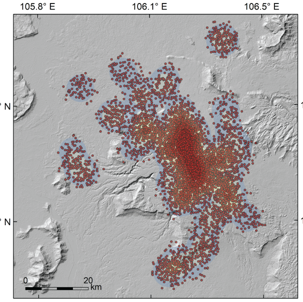


3. Vent spatial density

The spatial distribution of vents on the BVF was obtained through a kernel density estimation (KDE). A KDE is a non-parametric statistical method by which each point is transformed into a density through spatial smoothing, and all the densities are then averaged to represent the entire point distribution, based on the distance between them. The KDE was performed through ArcMap 10.7.1, and 7 density classes were defined (5th to 95th percentiles), representing the number of cones per km² (for example, a vent for a future volcanic eruption has a 33% chance of opening within the perimeter of the 8.2x10^{-5} density field). The map shows a broad N-S trend of vents with a higher density (1.0x10^{-4} - 1.2x10^{-4} cones/km²) in the centre of the plateau, and encompassing the city of Paksong. Other major cities are Pakse, the most populated, and Salavan.



4. Vent-opening map



The MOLASSES code was designed to open the specified number of vents (n= 10,000) within the spatial density map, based on the different density fields. Hence, the number of new vents is directly related to the density values, as one can see on the map above.

Eruption Source Parameters

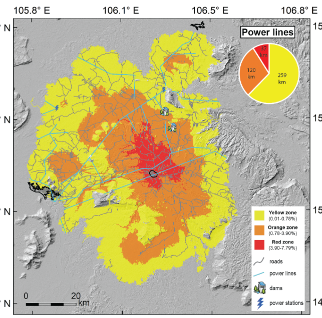
	min	max	log mean	log SD
Thickness (m)	3.63	22.06	1.10	0.64
Volume (m³)	4.12E+07	3.01E+09	8.46	8.47
Pulse volume (m³)	6.80E+04	4.59E+05	n/a	n/a

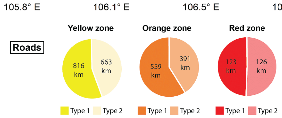
The input parameters for MOLASSES are lava flow thickness, its total volume and pulse volume, and a Digital Elevation Model (DEM). For the ranges of thickness and volumes we used averaged values from the BVF (where measurable) and from analogue volcanic fields, namely the Shamiaram plateau (Armenia), the Eastern Snak River Plain (Idaho, USA), the Northern Harrat Rahat volcanic field (Saudi Arabia) and the Auckland volcanic field (New Zealand). As a DEM we used the Shuttle Radar Topography Mission (SRTM) at 30-m resolution.

5. Hazard & Exposure

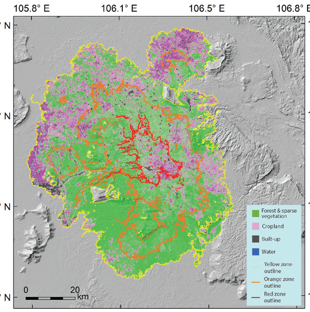
We simulated one lava flow for each of the 10,000 vents. The parameters were sampled within the range considered (see Eruption Source parameters table) following a log-normal mathematical law. By using a log-normal law, we allowed occasional high-volume/high-thickness flows to erupt. The MOLASSES output is a probabilistic hazard map (basemaps in the images below), where the different colours (yellow, orange, red) represent the probability of inundation, in case an eruption occurs. For example, the centre of the plateau (red zone) is the one with the highest probability of inundation (3.90-7.79%), whereas the yellow zone (0.01-0.78%) has the lowest probabilities. In case of an eruption, the assets exposed are numerous, including 2 dams, 2 power stations, over 2500 km of roads and over 400 km of power lines. In terms of landcover, the highest impact would be on croplands, with coffee representing the major business in Laos. Not shown here is the population, over 300,000 people will be potentially exposed in case of an eruption, with the majority living in the city of Pakse, followed by Paksong and a relevant number of villages and more rural areas.

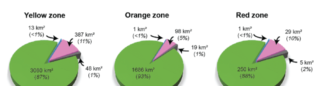
Infrastructures exposure



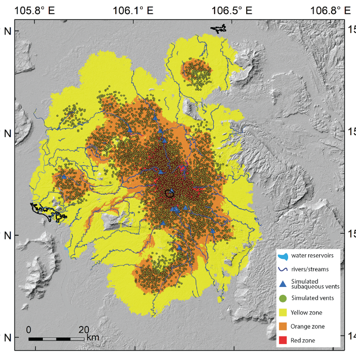


Land cover exposure

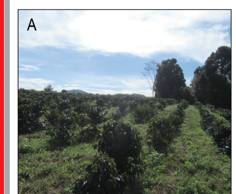




Phreatomagmatic hazard



Besides lava flows, also explosive magma-water interactions are a potential hazard in this area. These explosions are broadly called phreatomagmatic eruptions and occur when rising magma encounters either groundwater or standing water of a river or lake, if some physical conditions are met. The large availability of water of the Bolaven plateau, both surface and groundwater, makes it a likely candidate for phreatomagmatic activity. In the image above there is just an example from our simulations, where some of the simulated vents opened within a surface water reservoir. However, if we consider the groundwater, the probability (not quantified here) of phreatomagmatic activity occurring is much higher, given the larger surface area involved. Typical hazards associated with this activity include the formation of phreatomagmatic surges, formation of an eruptive column, with delivery of hot ash, lapilli and bombs in the atmosphere, and formation of tsunamis (if the eruption initiates in large water reservoirs).



Shown here are two of the major businesses in southern Laos. On the left (A) there is a coffee plantation on the Bolaven plateau. On the right (B) is a view of the Houay Lamphan dam (E-SE side of the Bolaven plateau). Both photos were taken during a field campaign in late 2016, by Kerry Sieh and his collaborators.

6. Average Recurrance Interval (ARI)

$$\text{Eruption frequency} = \frac{\#\, eruptions}{time\ interval}$$

? (# eruptions) ✓ (time interval) (790 ka)

<u>What do we need to answer this question?</u>

- Good level of exposure/preservation of lava flows and their sources (to understand the stratigraphic relationships)
- Absolute age for all the lava flows and their sources
- Geochemical data for all lava flows and their sources (to see if they match or not)

<u>Assumption</u>:
1 scoria cone = 1 eruption

$$EF = \frac{76}{790\ ka} = 9.6 \times 10^{-5}\ \text{(\# eruptions/year)}$$

$$ARI = \frac{1}{EF}$$ ⇨ **1 eruption every 10,396 years (Maximum estimate)**

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<u>Fields of interest:</u> Volcanic Risk, Physical Volcanology, Hydrovolcanism, Geochemistry, Sedimentology

Paper reference

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