Lava flow impacts on buildings and infrastructure: taking lessons from La Palma to New Zealand

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Executive Summary

The Auckland Volcanic Field (AVF) is a volcanic centre consisting of at least 53 volcanoes, spread across Auckland city. The geological record shows that many Auckland eruptions generated lava flows, extending several kilometres from the vent, highlighting the potential damage that could be sustained in a future eruption. Lava flow impacts on urban environments occur rarely yet they provide important lessons for preparedness at volcanic centres that are potentially vulnerable to these hazards. To gain the best knowledge of the potential damage, timescales, response, and recovery from lava flows, we turn to globally relevant examples for useful learning opportunities.

Here we describe the damage incurred by a near three-month long Tajogaite eruption at La Palma, Canary Island, Spain. The style of eruption with lava flows, ashfall, and a new scoria cone, is similar to what we could see in the next AVF eruption. The two locations also share the uncertainty around where the next vent will open. The 2021 Tajogaite eruption on La Palma provides a rare, well-documented case study of lava flow impacts on a modern urban environment. These lessons directly inform planning for a future AVF eruption, particularly the scale of damage, response timelines, and infrastructure vulnerabilities.

The Tajogaite eruption began in September 2021 with a short period of explosive eruptions that deposited ash downwind of the new vent area. Subsequent eruptive activity included prolonged effusive phases that generated extensive lava flows downslope and into the ocean, with continued ash emission. Lava flows destroyed several settlements and towns over the 85 days of the eruption, with damage around the margins being highly variable.

Once the eruption was over, the emplaced lava flows had covered an area of ~10 km^2, around 7,000 people had been displaced. Significant critical infrastructure was damaged and required rapid re-build, including immediately starting to re-establishing the main road network. This meant working in conditions with high temperatures and gases still emanating from the lava flow.

Our detailed examination of the damage at La Palma utilises satellite images, drone footage, and in-person damage assessments to develop new understanding of the

complexities of lava flow impacts. This was guided by local expertise of GeoTenerife, who were on site during the eruption and early recovery. We then use these data to assess the impact on Auckland city based on a scenario that illustrates the potential extent of a future eruption. Our work highlights the utility in learning from overseas case studies, that can be used to assess the possible impacts, and preparedness strategies that could feed into planning for a future eruption in Auckland. Lastly, we provide commentary on the lessons learned from the experiences recounted to us by infrastructure agencies and members of the public to aid in response and recovery operations in this complex event.

Abstract

The likelihood of an eruption within the Auckland Volcanic Field is ~ 10 % within the next 50 years and the dominant style of eruption begins with an explosive phase followed by the effusion of lava flows. Here, we make observations of an analogue eruption to assess the damage incurred by lava flows on an urban environment during the 2021 Tajogaite eruption, La Palma, Canary Islands. We observed key differences between the satellite-derived damage assessments and those conducted via drone- and ground-based measurements. We note that the detailed damage is highly complex on the margins of the lava flow field and that the damage state can vary over short distances. We use these observations to construct a damage state map of the region that could be utilised to support homeowner understanding of the damage incurred. Lessons learned from the Tajogaite eruption highlight the difficulties in modelling detailed flow paths, whereas simple modelling, even during the early stages of eruption, proved useful for managing the crisis as it unfolded. When compared to Auckland, the Tajogaite eruption is a useful analogue for understanding the timescales of protracted unrest, punctuated by a rapid rise in unrest intensity a week before the eruption, and the rate of lava flow emplacement, despite the relatively low viscosity of these La Palma lavas. Recovery from the Tajogaite eruption continues and the lessons learned there will help prepare Auckland for a future eruption, reducing unnecessary costs and the timescales of disruption.

Keywords

Volcanoes, Quantifying hazards and risk, Resilient buildings, Supporting people and decisions

Introduction

Lava flows are moving masses of molten rock that traverses downslope and upon cooling, solidifies into layers of rubbly and cohesive rock, depending on the flow type. Lava flows can contain multiple flow units, or individual flows that stack on top of each other, and multiple flows can stack and spread out across a landscape to form a lava flow field. There are two main lava flow types; pahoehoe, which is generally a relatively thin, ropy type and 'a'ā, which is generally relatively thick, rubbly flow that progresses faster.

The damaging nature of lava flows are a function of the high temperatures; reaching 800–1,200 °C depending on the chemical composition of the lava (rhyolite to basalt, respectively) and the cooling rates after emplacement; the thickness of the flows can reach metres to tens of metres; their dynamic pressures or the force that they apply to structures; and their velocity (Wilson et al., 2014). High temperatures can ignite fires and melt building and other construction materials. The temperatures associated with lava flows extend away from the flows as radiation of heat around the margins. Lava flows can take hours, days, or years to cool depending on their thickness, complicating recovery efforts in built environments.

The lengths of lava flows vary depending on complex factors, with lava flow fields like the one at Tajogaite often growing wider through an eruption. These factors are the viscosity (resistance to flow or 'stickiness'), the volume erupted, the rate of effusion (how fast lava erupts at the vent), the slope or steepness of the landscape it flows over, and the shape of the landscape (flat or depressions and valleys that might redirect or hinder movement) (Walker, 1973).

While the focus of this work is on lava flows and the damage that they impart, it should be noted that volcanoes often produce more than one hazard such as volcanic ashfall (fragmented rock less than 2 mm in diameter), ballistic ejecta (larger rocks thrown out of a vent), volcanic gases, and seismicity (ground shaking) either at the same time or at different stages of an eruption.

While many hazards such as flooding or earthquakes destroy buildings and infrastructure, usually structures can be rebuilt. Lava flows present a unique challenge where property is buried under solid rock, preventing the recovery of property and complicating rebuilding efforts on the new landscape. Entire communities are buried, family homes and businesses lost, and people displaced into temporary housing conditions or homelessness. Surfaces of lava flows have variable relief and steepness, are sharp, and the 'a'ā type flows have a layer of clasts centimetres to metres in size increasing the instability. Additionally, a network of hollow lava tubes is often present throughout the flow field.

From around 3491 BCE to 2022 there have been 155 recorded events at 51 volcanoes where lava flows have impacted communities (Meredith et al., 2024), as well as the ongoing eruption at Sundhnúksgígar in Iceland as of 2025. The top 12 events that have impacted the greatest number of buildings (maximum estimations) range from around 14,000 during the 2002 eruption of Nyiragongo volcano in the Democratic Republic of the Congo (DRC) to 293 during the 1977 eruption of Karthala, Comoros (Table 1). The focus of our work at La Palma during the 2021 eruption ranks fourth on this compilation list at 3,644 buildings. The events with impacts assessments are the 2014–2015 eruption of Fogo, Cape Verde (Jenkins et al., 2017), the 2002 Nyiragongo eruption, the 2018 Kīlauea lower East Rift Zone eruption (Meredith et al., 2024), and ongoing research on the 2021 La Palma eruption.

Table 1. The highest-ranking lava flow events in terms of impact to the number of buildings from Meredith et al. (2024). These are likely maximum numbers and excludes events that are inferred or are based on contradictory evidence.

Buildings			
Rank	**Start year**	**Volcano**	**Building number**
1	2002	Nyiragongo, DRC	14,000
2	1914	Sakurajima (Aira), Japan	4,500[a]
3	2021	Nyiragongo, DRC	3,644
4	2021	La Palma, Canary Islands, Spain	3,126
5	1977	Nyiragongo, DRC	800
6	1928	Etna, Italy	750
7	2018	Kīlauea, Hawai'i, USA	716[b]
8	1730	Lanzarote, Canary Islands, Spain	700[a]
9	1983	Miyakejima, Japan	423
10	1672	Fayal, Azores, Portugal	307[c]
11	1973	Eldfell (Vestmannaeyjar), Iceland	300[a]
12	1977	Karthala, Comoros	293

[a] includes tephra damage; [b] 1,929 including water tanks and other structures; [c] includes earthquake damage.

The 2021 Tajogaite eruption

La Palma is the northwestern of seven main Canary Islands (Figure 1), where at least 13 eruptions have occurred since 1500 CE on La Palma, Tenerife, Lanzarote, and El Hierro (Longpré and Felpeto, 2021). Eruptions have had variable unrest and eruption durations, with most forming scoria or spatter cones and producing lava flows and ashfall (Table 2; Carracedo et al., 2022).

Table 2. Dates of unrest and eruption duration of historical Canary Islands events, modified from Carracedo et al., 2022.

Year	Island	Eruption	Seismic precursors	Duration onset-end	Days
1492	Tenerife	Boca Cangrejo			
1585	La Palma	Jedey/Tajuya	~50 days	19 May–10 Aug	84
1646	La Palma	Martin/Tigalate	~1 day	1 Oct–21 Dec	82
1677–1678	La Palma	Fuencaliente	~4 days	17 Nov–21 Jan	66
1704–1705	Tenerife	Siete Fuentes	~1 month	31 Dec–5 Jan	66
		Fasnia		5–15 Jan	10
		Arafo		2 Feb–27 Mar	53
1706	Tenerife	Garachico	~1 year	5 May–13 Jun	39
1712	La Palma	El Charco	~5 days	9 Oct–3 Dec	56
1730–1736	Lanzarote	Timanfaya	~6 years	1 Sep 1730–2 Apr 1736	2041
1798	Tenerife	Chahorra	~3 years	9 Jun–15 Sep	99
1824	Lanzarote	Tao	~11 years	31 Jul–1 Aug	2
		Nuevo		29 Sep–5 Oct	7
		Tinguatón		16–24 Oct	9
1909	Tenerife	Chinyero	~2 years	18–27 Nov	9
1949	La Palma	San Juan	>2 years	24 Jun–30 Jul	37
1971	La Palma	Teneguía	>1 month	26 Oct–18 Nov	24
2011–2012	El Hierro	Tagoro	>4 years	10 Oct–15 Feb	129
2021	**La Palma**	**Tajogaite**	**~4 years**	**19 Sep–13 Dec**	**85**

All of the historical La Palma eruptions have been sourced from vents along the southern Cumbre Vieja ridge, or Cumbre Vieja, with most flows directed to the west, downslope and towards the coastline (Figure 1, Martí et al 2022). Previous impacts due to volcanic activity occurred during the 1949 eruption, where earthquakes caused building damage in two towns and one road was covered by lava (Klügel et al., 1999). That eruption produced two vents 3 km apart, with lava flows down the eastern and western island flanks.

Unrest leading up to the eruption was relatively complex and can be traced back to an initiation stage ~4 years earlier. The bulk of the early precursory (3-4 years prior) hypocentres were located ~ 5 to 10 km south of the eventual vent location, at a mean depth of ~21-26 km depth (Torres-Gonzalez et al., 2020). Through time, two seismic clusters formed, one between ~20 and 40 km and another at ~9-13 km, both located to the south of the vent. In the preceding 7 days, magma ascended from a depth of ~ 10km

(D’Auria et al., 2022) towards the western coastline, firstly, as a relatively constant progression that was subsequently punctuated by very rapid shallowing in the preceding 24 hours (Suarez et al., 2023).

Based on the many datasets published on the unrest phase, the unrest phase at La Palma began with the pressurisation of a relatively deep magma reservoir, located in the mantle, beneath the crust (Dayton et al., 2023). That deep magma reservoir continued to be fed from below, generating enough pressure to propagate dykes into a much shallower crustal reservoir. Further dyke propagation from these reservoirs transported magma shallower in the crust, before stalling for several weeks before the final dyke was able to successfully reach the eventual vent area (Fernández et al., 2022). This highlights the seemingly protracted unrest over several years that rapidly accelerated in the week to days before the eruption.

The Tajogaite eruption began at 14:11 local time on 19 September 2021 and continued for 85 days, ending on 13 December 2021. The hybrid eruption included mildly explosive activity and also effusive lava flow extrusion at the same time, leading to the growth of a scoria cone (Bonadonna et al., 2022). This generated substantial volcanic ash with 4 km of the vent, with homes buried by ashfall near the vent, and ash removal necessary to prevent more extensive roof collapse (Reyes-Hardy et al., 2024). Ballistic ejecta also impacted the cone area. The extensive lava flows travelled downslope, towards the coastline to the west of the vent. The damage from lava flows is the main focus of this work, however, we were able to make some assessments of ash damage that requires additional analysis. Nevertheless, the hybrid nature of this eruption highlights the complexity and multi-modal damage that can be imparted on communities near an eruption of this type.

By the end of the eruption, a new ~220-m-high Tajogaite cone had formed within the municipality of El Paso, with vents across ~560 m a lava flow field to the west, and ash deposits to the south. The flow field covers ~12.4 km^2 with a maximum thickness of over 70 m and includes a network of lava tubes and two lava deltas extending into the ocean (Carracedo et al., 2022; Civico et al., 2022; González-de-Vallej et al., 2024; Calvari et al., 2026). Away from the lava flow, gas emissions impacted the La Bombilla and Puerto Naos communities, resulting in evacuations over years after the eruption ended (white arrows, Figure 2).

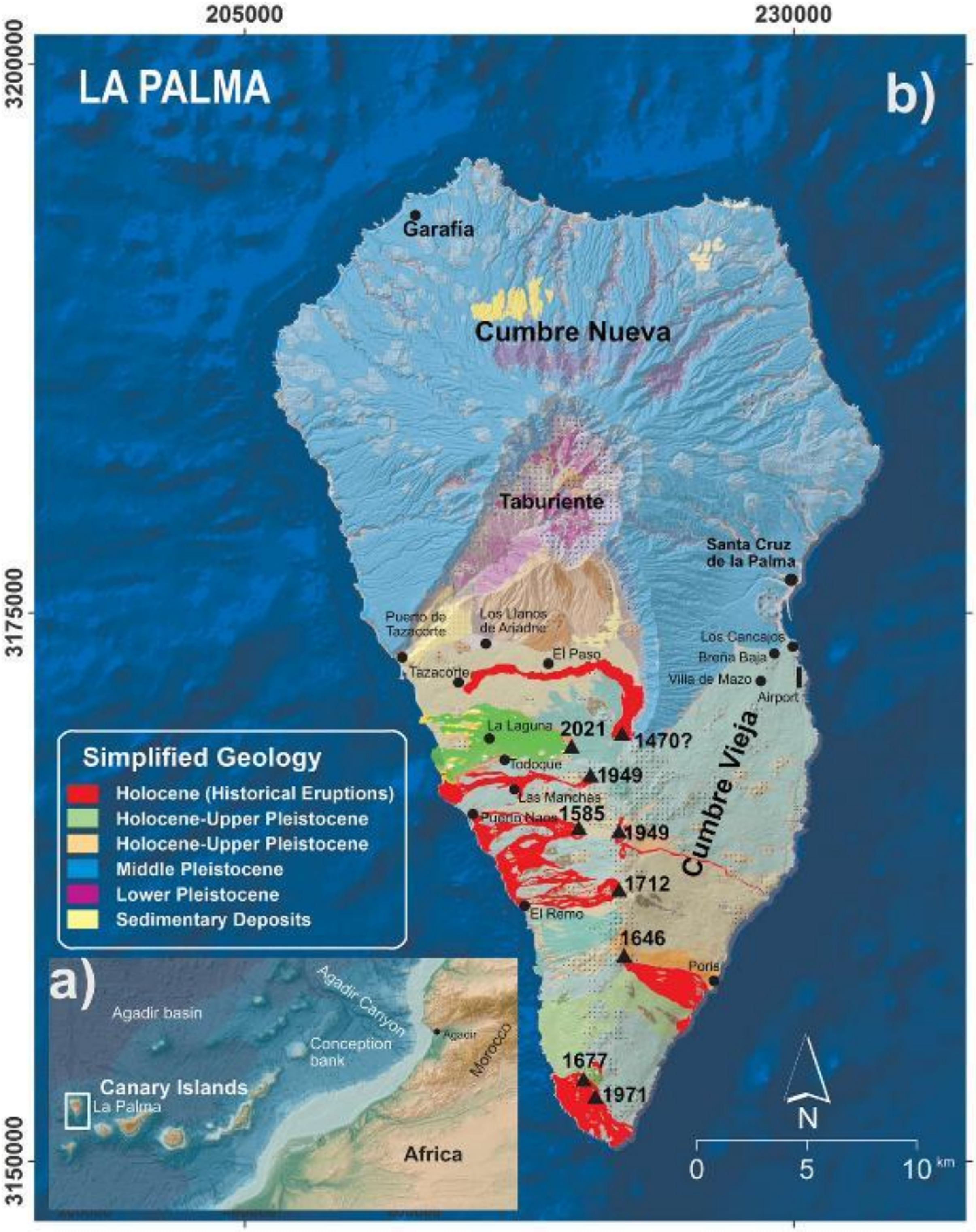

Figure 1. (a) Location of La Palma within the Canary Islands. (b) Geological map of La Palma with historical eruption lava flow fields sourced from vents of the Cumbre Vieja ridge (from Martí et al. (2022)).

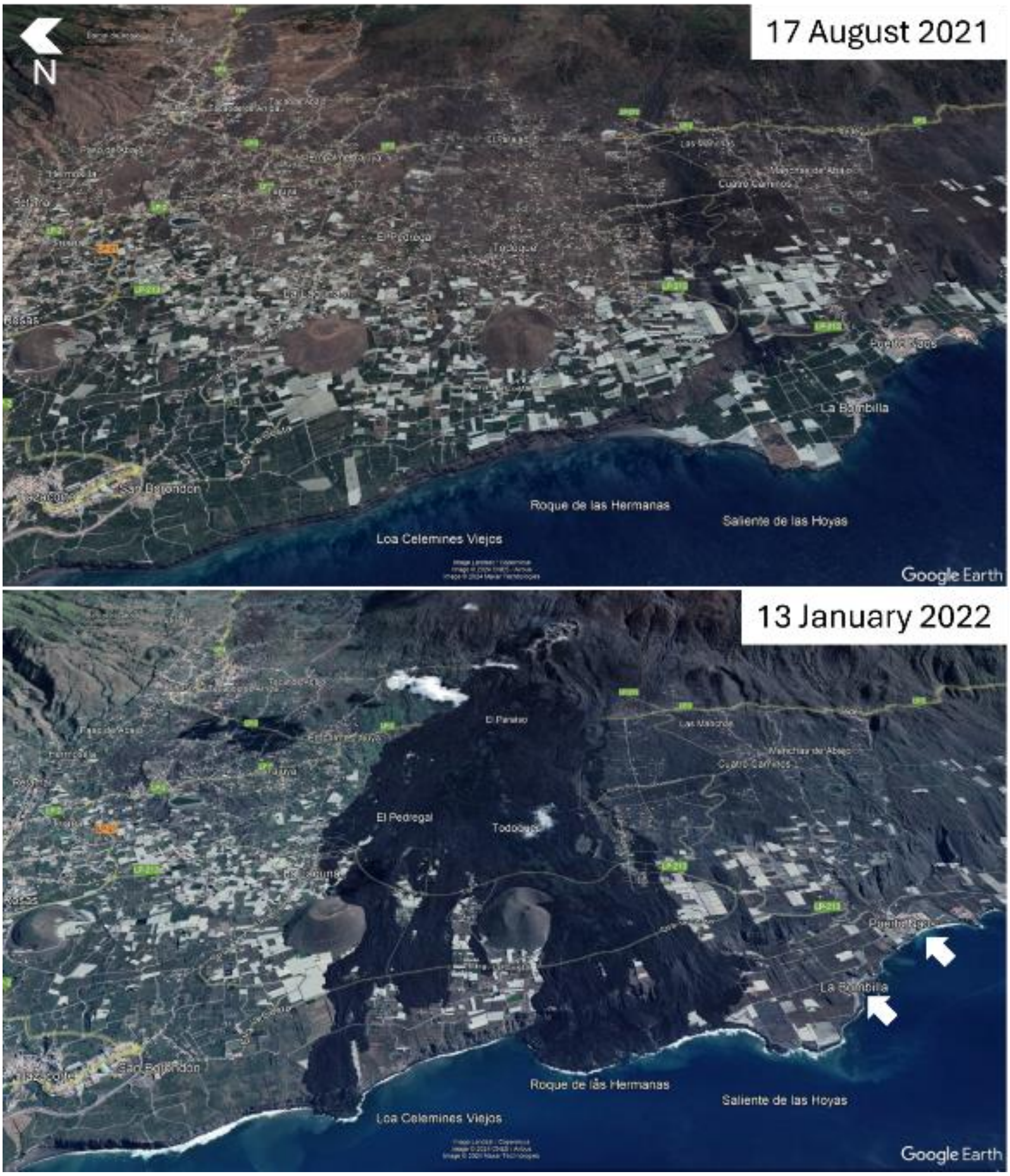

Figure 2. The area impacted by the 2021 Tajogaite eruption before (top) and after (bottom). Several roads had already begun construction in the lower image. White arrows indicate the La Bombilla and Puerto Naos communities impacted by gas emissions beyond the end of the eruption.

It is important to note that the complex loss that residents and business owners have suffered expands far beyond buildings and continues years after the eruption (e.g., Fourgassie et al., 2025), but the lived experience of the residents is often left out of research topics. Some residents had ~15 minutes to evacuate, and their experience was marked with uncertainty and trauma (Rice and Oppenheimer, 2025). Throughout the eruption timeline, residents were unsure about the state of their homes, some even told that their home was destroyed when it had not been. Four years after the eruption ended, reported disputes over compensation and uncertainty continue (El Time, 2025).

Methodology

Meredith et al. (2022) developed a six-point damage state (DS) schema (Table 3) that ranges from DS0 where there is no visible damage, to DS5 where there is complete destruction of the building, based on the 2018 Kīlauea lower East Rift Zone eruption. They assessed 3,165 structures and classified 1,839 as destroyed (58%) and 90 as damaged (3%). Building materials were wood, plastic, metal, and concrete, which differs from the case on La Palma where the dominant building material is *bloque*, which is a reinforced concrete block. This material clearly differs from the bulk of the building stock in New Zealand, the key reason for comparing the two situations, yet it still provides important information on the damage that could be done during the primary interaction between buildings and lava. Secondary impacts i.e., from fire following lava flow impact, forms part of ongoing research that is being completed by NZ-based researchers with overseas collaborators, specifically for application to the Auckland Volcanic Field.

Here we use the same system as Meredith et al. (2022) for assigning damage states on La Palma, due to its robust simplicity and enables comparison between events outlined in that work. Limitations of this study include the lack of pre-eruption information on the buildings, and the few conversations with homeowners to respect privacy and avoid inflicting harm in a still-stressful situation.

Damage assessments were conducted in three main ways, namely: 1) analysis of satellite-based data to account for the inundation of lava flows into the built environment; 2) drone-based aerial footage to assess the land damage and building-specific damage state; 3) ground-based assessments of damage based on close-in inspection of damaged walls, roofs, and in some cases, damage to the interior.

Modern high-resolution satellite data allow rapid, first-pass damage assessments as an eruption evolves. The Copernicus Damage Assessment program regularly released maps of the lava flow field extent along with destroyed and possibly damaged buildings. Damage assessments were made at regular intervals, usually between 5 and 12 days throughout the 85 days of the eruption. Additional satellite data included the Google Earth historical imagery function, and WorldView-3 data panchromatic band data with 0.31-0.34 m resolution, acquired on 13 January 2022. Information was collected throughout the eruption by the GeoTenerife Volcano Stories project, and was utilised through this study (Backhouse et al., 2023).

Table 3. The damage state schema by Meredith et al. (2022) that describes six levels of damage to buildings by lava flows from no visible damage (DS0) to complete destruction (DS5).

Damage State	Severity	Description	Schematic
DS0	No visible damage	No evidence of structural or non-structural damage.	
DS1	Negligible	Negligible structural damage, minor surface damage, such as melting of plastic exterior façade.	
DS2	Minor	Minor structural or non-structural damage, such as cracking and holes in wall, or <30% inundated.	
DS3	Moderate	Partial structural damage or roof destruction, partial destruction of non-structural wall, or 30-60% inundated.	
DS4	Major	Major structural and non-structural damage; wall, column, beam or roof collapse, or >60% inundated.	
DS5	Complete destruction	Complete structural destruction or burial.	

The final damage assessment was based on the analysis of satellite imagery within seven days of eruption cessation. This provided a useful, albeit broad, assessment of the damage incurred throughout the La Palma eruption. A key advantage of this method is the ability to make regular damage assessments over large areas, depending on satellite return intervals. Conversely, a clear disadvantage of this method is the lack of detail obtainable from satellite footage. This became clear when more detailed damage assessments were made possible after access to buildings was safe to do so. Assessments at the property level are crucial for residents and their ability to move forward.

Drone-based damage assessments – Drone footage was acquired in the field in June 2023 with GeoTenerife colleagues, funded by National Geographic. Additional aerial footage taken during the eruption from drone-based platforms were collected from online sources. This highly detailed dataset is extremely useful in assessing building damage from lava flow impacts and ash loading. Furthermore, drone-based footage provided a new observation tool of the lava flow path, areas impacted by lava tube formation, and the locations of fissures. Such observations were generally obscured in the satellite images yet are clearly delineated in the drone-based footage. It is important to note that the drone footage was not necessarily obtained for damage assessments and was instead used to track the evolution of the lava flows, the expansion of the flow field, and the dynamics of the eruption more generally. Nevertheless, the abundance of footage was used to forensically examine building damage and the impact to property.

The primary purpose of our ground visits was to supplement the satellite and drone-based footage. We were also able to explore infrastructure damage incurred by a range of providers, including water, roading, electricity, and communications. Each of these critical infrastructure providers explained the mitigating factors put in place before the eruption, and how they each responded after the eruption. All of these interactions were supported by in-country partners.

Results and discussion

Overview of damage states

The Copernicus Rapid Mapping Team produced an impressive 64 products over 90 days, reporting 2,988 buildings destroyed (Copernicus, 2022). Buildings were given a grade of destroyed, possibly damaged, or no visible damage (Figure 3). There is a range of damage states assigned in this study with each of the Copernicus damage grades (Table 4). While the Copernicus data gives a helpful overview of loss, especially during a rapidly evolving event, the data should be used with the understanding of the limitations. When used poorly, the damage grades were used to assign insurance payouts in haste. Where damage states were demonstrably inaccurate, this resulted in further distress to residents. These data were used in attempts to deny residents financial assistance for their lost homes (El Valle de Aridane, 2023).

The number of damaged buildings from this program were shared throughout the eruption as a proxy for damage but lacking the limitations of the data. Upon inspection, there are often multiple grades given on a property, including swimming pools, fields or yards, garages, or multiple sections of a house (Figure 4). There are also properties where no grade was assigned.

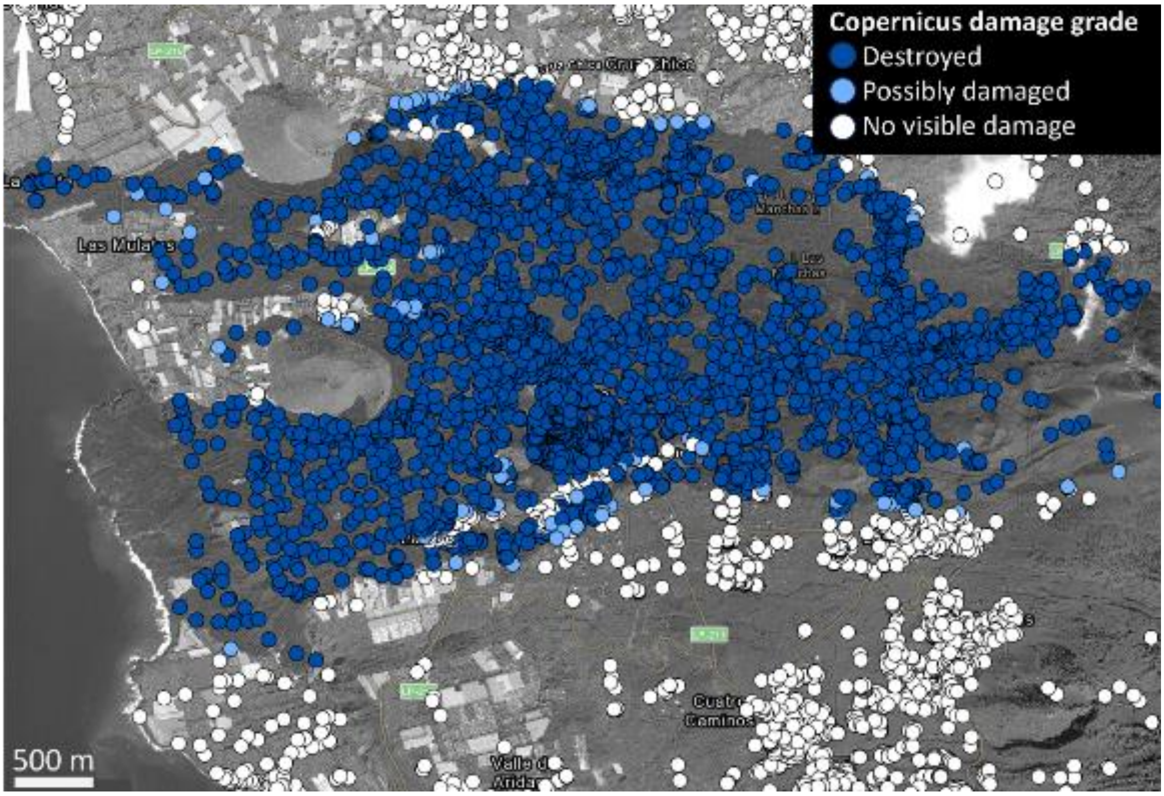

Figure 3. A map showing the Copernicus rapid mapping damage grades across the Tajogaite lava flow field.

Table 4. The damage states assigned in this study and the Copernicus damage grade for the same building or property.

Damage State	No visible damage	Possible damage	Destroyed	No grade	Multiple grades
0	5	11	1	1	6
1	0	8	2	0	3
2	1	14	11	1	11
3	2	21	28	3	14
4	0	6	37	1	16
5	1	1	48	2	14

In this study, 206 buildings around flow boundaries were assessed based on accessibility and availability of data. For these properties, satellite data, drone data, and in-person assessments as well as the Copernicus damage states. Of the 206 buildings, 18 of these were assigned DS0, 10 DS1, 27 DS2, 54 DS3, 44 DS4, and 53 DS5 (Figure 5). This does not include the majority of buried buildings below the lava flow field that would have an assigned DS5. For many structures, it was difficult to assign a DS as they were on the boundary of two. An additional aspect of undertaking this assessment two and three years after the eruption was the removal of lava from properties and from the inside of buildings.

Figure 4. An example of one property with five damage grades. Here, we assigned a damage state of 4 for this building. White arrows indicate flow direction.

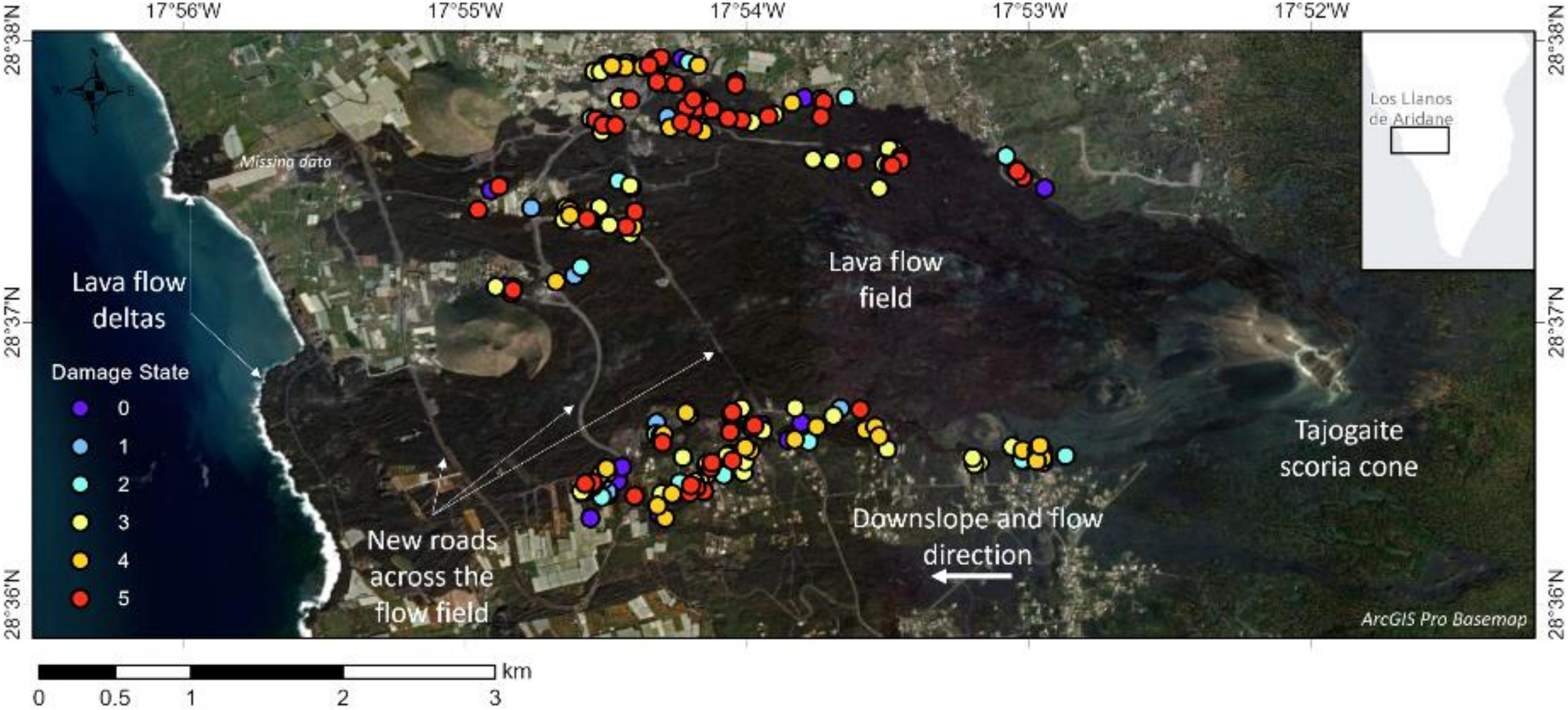

Figure 5. A map of the Tajogaite lava flow and cone with the damage states for the buildings assessed in this study.

Details of damage

The majority of observed buildings were reinforced concrete or masonry, with very few buildings of unidentifiable materials (i.e., large warehouse-style buildings). Damage included deterioration to paint (discolouration, chipping, bubbling), broken windows, cracking or pitting of the building exterior, cracking, roof collapse, wall collapse, inundation (variable levels of lava filling the buildings), bulldozing (pushing the building horizontally), and burial (Figure 6). Structural damage from lateral load varied from fractures through structural walls, the ground and building floors, and forming holes through structural walls (Figure 7).

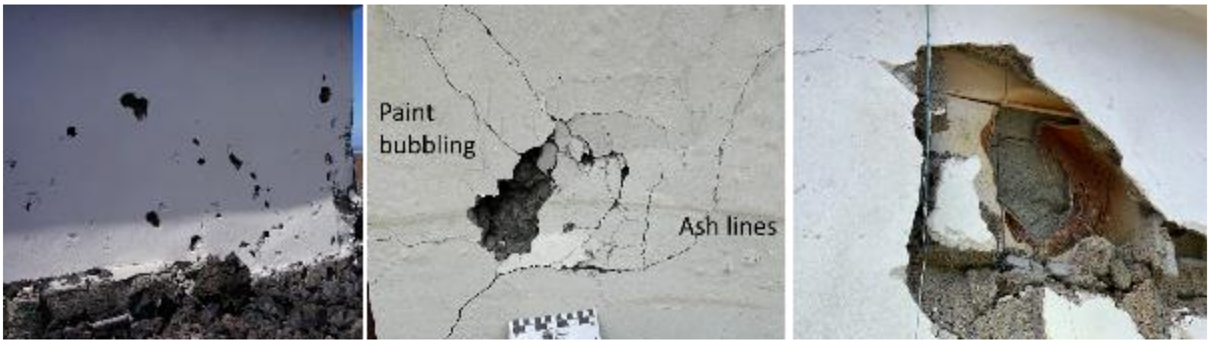

Figure 6. Examples of minor damage to exterior building walls.

Figure 7. Examples of damage caused by lateral load, or pushing by the lava flows.

Lava inundation was variable around the flow margins, from inundating part of a building, flowing through windows or other openings and inundating a single floor of a multi-storey building, lava flowing across properties and through boundary walls, and complete burial (Figure 8).

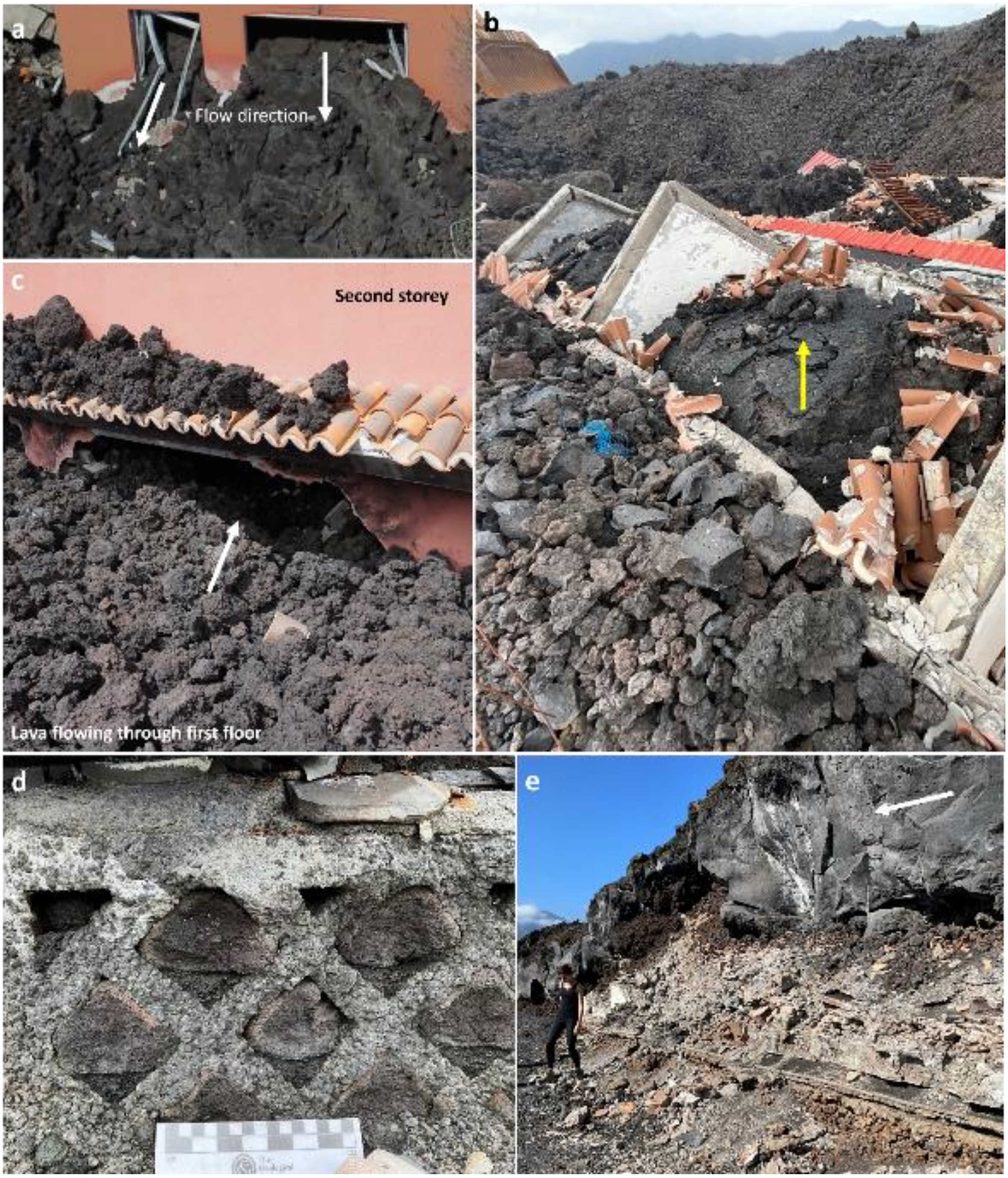

Figure 8. Variable lava flow inundation across structures: a) lava flowing through a building and out of the window and door with the structure still standing; b) lava flowed through the back wall then rose up into the structure (yellow arrow); c) lava flowing into the lower floor of a two storey building while the structure remains standing; d) lava flowing through gaps in a boundary wall, the upper marks on the scale are 1 cm; e) complete inundation and burial. The white arrows show lava flow direction.

Thermal damage caused by the radiative heat from the lava produced melting of building materials including glass, plastic, and metals, and discolouration and bubbling of paint (Figure 9). While evidence of fires was not widespread in the buildings we inspected, fire and smoke damage was present in some cases.

Figure 9. Thermal damage to different materials around the lava flow field boundary.

Notable examples were observed where the built environment influenced the lava flow direction, impacting buildings away from the main flow channel (not shown). There are also cases where lava was directed around a building because of flow diversion around the house immediately upslope. In these specific cases, the flow type caused disparate impacts i.e., 'a'ā flows caused bulldozing of the buildings whereas pahoehoe flows seemed to retain heat with less kinetic force, leading to distinct thermal damage (Figure 10).

Figure 10. An example of a roof that had been nearly overridden by two types of flows. ‘A’ā flows were relatively cool compared to pahoehoe. In this case, the roof sealant melted due to the pahoehoe heat.

Finally, due to the re-establishment of roads, other infrastructure, and in fortuitous regions of the lava flow field, we were able to make observations of completely destroyed buildings (Figure 11; Damage State 5). In these cases, lava flow bulldozing via 'a'ā cause flattening and fragment dispersal. In these cases, remnants of the buildings were limited, yet we were able to observe that buildings were clearly transported a short distance within the flows.

Figure 11. Complete damage to houses and other buildings as examples of Damage State 5 within the lava flow field.

Lava flow modelling

The Tajogaite eruption provides a useful example for how lava flows behave and impact an urban area. This modern eruption was very well monitored and observations of the lava flow field evolution through time were supported by ground-based monitoring, drone footage and satellite imagery. Together, these provide uniquely detailed data to assess the performance of existing lava flow models and how they could be used or modified for future scenario planning, or in the early phases of a response.

Several numerical flow models exist for the quantitative determination of flow paths, thickness, lengths and speeds. Some consider a more simplified approach that considers some aspects of the flow to be largely stable throughout (MAGFLOW, MOLASSESS, VolcFlow), others consider simplified 3D simulations (LavaSIM), whereas new models utilise 3D mesh to resolve the flow evolving through time (GPUSPH). It is important to note that lava flows are quite complex, consisting of an evolving three-phase mixture of melt, bubbles and crystals, all of which change in response to temperature, pressure, and oxidation state. Not only are they rheologically complex mixtures, but the key determinant for the flow speed and direction are the effusion rate, cooling rate, and the bulk viscosity. These are often poorly constrained and result in non-unique results that require data from analogue eruptions that are well monitored and recorded. As such, modelling lava flow behaviour is non-trivial and still an active area of research.

According to the vast literature on lava flow modelling, there is little consensus as to the most appropriate model to use for future, deterministic scenarios. Several different models have aimed to reproduce lava flows from well-studied eruptions, yet all fail to predict the generation of lava tubes, the pressurisation and subsequent overflow of their roofs causing secondary perpendicular flow, nor the transition between ‘a’ā and pahoehoe or vice versa. Failure to predict lava tube formation can lead to underestimates of the impact area as these self-insulating features facilitate enhanced flow speed, duration, and extent. As a result, the impact area can be much wider than the surficial flow field and can cause crustal foundering when the lava tube roof is too weak for subsequent loading.

During the Tajogaite eruption, attempts were made to model the lava flow field using the pre-existing digital elevation model (DEM). In particular, Martin-Raya et al. (2023) used Q-LavHa – a QGIS plug-in that simulates a non-Newtonian flow downslope. This provided a useful output for planning purposes, and in the early stages of the response, emergency management practitioners were able to access estimates of the aerial extent of inundation. As the eruption progressed, the model was updated with a DEM of the lava flow affected area, which helped to refine later flow paths, ultimately improving the accuracy of the subsequent simulations (Figure 12).

Simulations of the Tajogaite lava flow field have also been conducted using VolcFlow by Marquez et al. (2022). These authors showed that once the model was calibrated based on satellite imagery, and used to derive a discharge rate, the simulations could be used to forecast future impacted regions. This is an interesting outcome because the underlying physics are not entirely accounted for in this, nor any other, lava flow model. Because of this, caution must be applied when utilising any flow model simulation as the results could vary widely without a thorough understanding of the effusion rate, bulk flow viscosity, and the cooling rate.

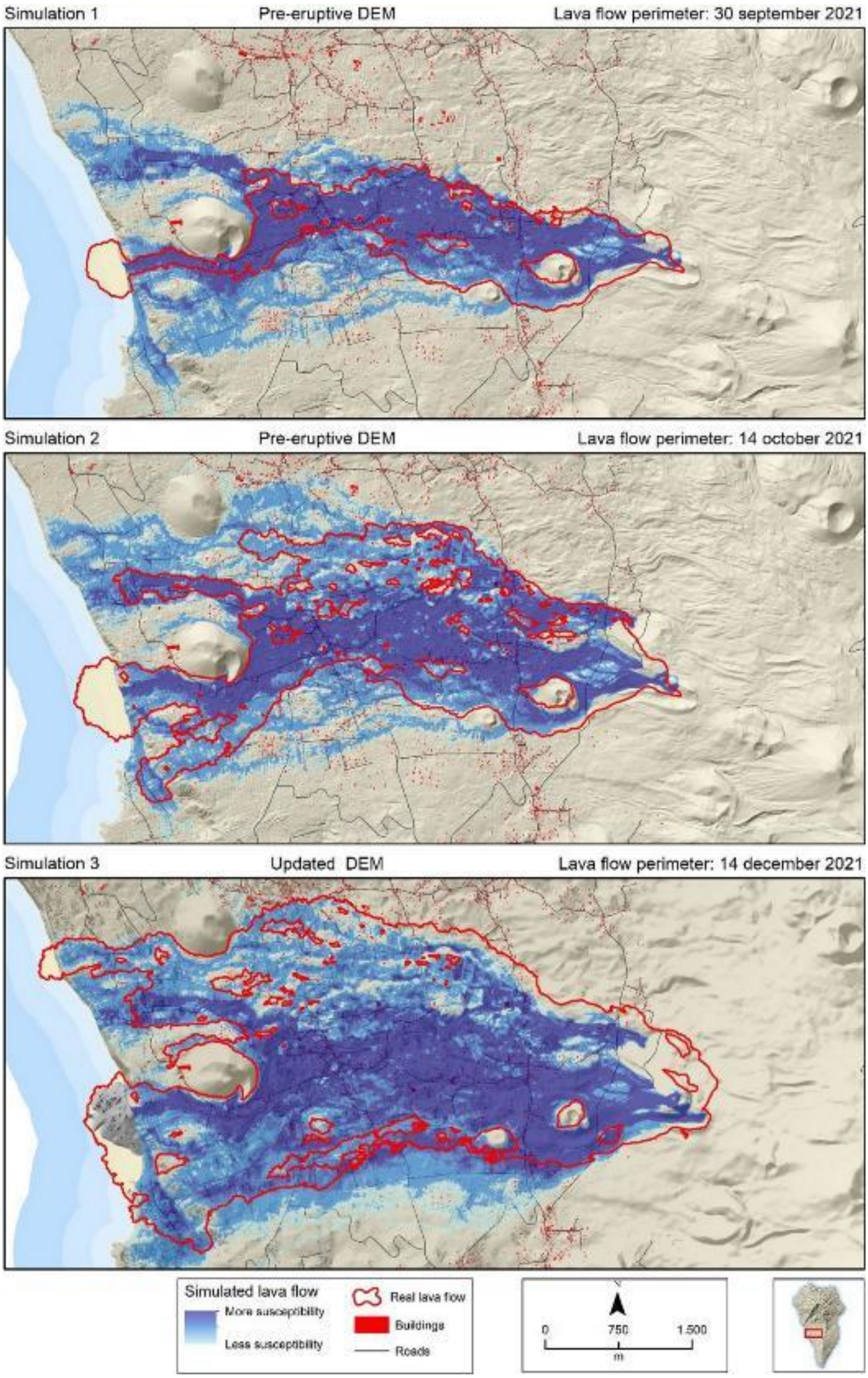

Figure 12. Lava flow susceptibility simulations in Q-LavHa against the eventual flow field (red outline) from Martin-Raya et al. (2023). The model replicates the flow field reasonably well, including the flow around elevated topography.

Application to Auckland

The Tajogaite eruption has similar characteristics to past event in Auckland, but aspects are not identical. In the following, we outline some of the key similarities and discrepancies that we identified throughout the project, namely:

- Basanite (a type of alkali-rich basalt) is the main magma type at both Tajogaite and Auckland, albeit with demonstrable chemical differences and inferred temperature of emplacement. This is important because the Tajogaite lava flows were very low viscosity (10 to 212 Pa s - a very low viscosity), due to their high eruption temperature and low crystal content (Castro and Feisel, 2022; Gisbert et al. 2023). In contrast, Auckland lavas are relatively crystal rich, causing them to be several orders of magnitude more viscous (Rhode 2017). As a result, the Auckland lavas would be emplaced as relatively thick lavas with short run-out distances.

- Building stock on the island of La Palma (masonry with reinforced concrete) is clearly different from those in Auckland (timber frame with relatively lightweight design) but the impact on property and houses will be similar. This is because ‘a’ā flows impart significant lateral forces on structures and much lighter construction would suffer similarly devastating bulldozing along the flow path. It is worth noting that timber-frame construction of the Auckland building stock would suffer additional fire following lava flow emplacement, which is outside the scope of this study. Nevertheless, observations from Tajogaite show that fire was also a significant factor in further damaging the internal components of buildings, which had otherwise been moderately impacted by the lava flow margins. Our assessment shows that buildings located on the margins of the flows can be variably damaged, and the width of the flow is the key determinant for damage scale. In line with the fragility functions derived by Meredith et al. (2022) for Hawaii, and based on the Auckland building stock, we would expect all buildings subject to a lava flow thickness of 6 m and above, to be completely destroyed.

- The Tajogaite eruption started with an explosive phase that soon transitioned to include the effusion of lava flows. This noted transition is to be expected at a future Auckland eruption, aligning with geological evidence of past eruptions. In particular, the Auckland region is known to host significant groundwater, hosted by fracture lava flows. Therefore, initial magma ascent will interact with groundwater reservoir/s flashing water to steam to cause an explosive phase. This will be followed by a more magmatic phase that generates weak explosive to effusive eruptions over weeks to months. This highlights the need to prepare for several weeks to months for a future eruption at Auckland, in line with the observations at La Palma.

- Fire following lava flow ignition (e.g., Kerr 2025) is an area of ongoing research, and based on the prevalence for timber framed buildings in Auckland, could be a significant contributor to the damage state. Our results from analysis of buildings impacted during the Tajogaite eruption, show that pahoehoe, which is common in Auckland, generated increased thermal damage, even for wooden window inserts. This is because the thermal diffusivity in these flows was much lower than the ‘a’ā flows. Therefore, the housing stock in Auckland is highly vulnerable to lava flow ignition in Auckland. This could be further exacerbated by restrictions to access for emergency services near active lava flows.

- Lastly, the unrest timescales leading up to the Tajogaite eruption were protracted (over four years) with increasing intensity toward the eruption, especially in the preceding week. Some estimates of magma ascent rates for past Auckland eruptions are fast (i.e., several days to weeks), based on elemental diffusion rates in crystals (Brenna et al. 2018; Didonna et al. 2024). However, it is useful to note that samples collected from the initial phase of the ~20 ka Waitomokia eruption, recorded a wide range in timescales from 3 to 135 days (Didonna et al. 2024). This highlights that some magma interactions were occurring at least four months prior to the eruption and could indicate that unrest occurs over months, not days before eruption. This is an important finding, similar to the experience of the Tajogaite unrest, and potentially indicates that the earliest signs of unrest need not result in mass evacuations of Auckland City as stated in the AVF Response Plan (Auckland Emergency Management 2025)

Conclusions

The Tajogaite eruption on the island of La Palma provides a modern example of an urban environment, severely impacted by lava flows. Over 85 days, this hybrid eruption included explosive activity that deposited volcanic ash several kilometres from the vent area, as well as effusive lava emission that emplaced thick flows throughout several settlements. Damage was incurred on households, critical infrastructure, and inhabitants suffered long-lasting mental health issues due to the damage caused, the uncertainty surrounding rebuilding efforts, and the ability to re-locate. Through in-country contacts, we were able to compare satellite-based damage assessments with drone- and ground-based observations to improve our understanding of lava flow impacts. We found that the complexity of the lava flows caused distinct building-scale damage, even over short distances. Our results are highly relevant to Auckland, despite specific differences in building stock and the flow behaviour of the lavas, and provides a useful case study for assessing the utility of response plans, unrest timescales, and how recovery can be enhanced with careful planning.

A notable outcome of the eruption was the need to work quickly to reinstate critical infrastructure to support the response and recovery of the island to the eruption. This was complicated by the persistently high ground temperatures due to the thick lavas that had been emplaced. In some regions, such high temperatures prevented underground services to be reinstalled. Based on our research, we recommend that critical infrastructure explore the interdependencies during potential response to a future AVF eruption e.g., roading, communications, water, sewerage. Such planning, supported by scientific understanding of the flow path, thicknesses and temperatures, will improve recovery efficiency for affected communities.

Our work continues to build on the lessons learned from La Palma, in particular how critical infrastructure and local governments have responded and recovered from the eruption. We will continue to monitor how recovery has progressed and where possible, use the example presented here, to prepare key agencies within New Zealand for an eventual eruption within the AVF.

Publications, communications and engagement

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