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USING GIS TO CREATE HAZARD MAPS AND ASSESS EVACUATION ROUTES AROUND "THE GATE TO HELL"; MASAYA VOLCANO, NICARAGUA

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ABSTRACT

Volcán Masaya in Nicaragua is made of a series of calderas and craters that lies 7 km from the city of Masaya with a population of over 100,000. Masaya is part of the Central American Volcanic Arc (CAVA) which contains hundreds of volcanoes. While many of the volcanoes of the arc produce small, quiescent eruptions, some are capable of large explosive events. The recent cycle of volcanism at Masaya began 7000 years ago. Initial eruptions were primarily lava, small ash flows, ashfalls, and degassing events which eventually gave way to climactic Vulcanian eruptions. The hazards presented from this system affect not only larger cities, but many underdeveloped communities surrounding Volcán Masaya. These communities require a simple map and action plan to use during an evacuation. While government-issued routes are in place, there are no known secondary options. The communities surrounding Masaya lack the education they need for having such a fierce geologic feature right in their backyard to base their own opinions on when and if to evacuate the area on their own accord. We visited the study area to gather data for the creation of an evacuation route and hazard map to help prepare the surrounding communities. By consolidating our research and field data, the maps we created give the

communities surrounding Masaya more insight as to the behavior of the eruptions. This research gives the local population options for evacuation and more knowledge about their environment.

Key Words: Volcano, Geographic Information Systems, Geologic Hazards

Introduction

The Central American Volcanic Arc (CAVA) system has produced the volcanoes found in Guatemala, El Salvador, Honduras, Nicaragua, and Costa Rica (Williams-Jones, 2009). Masaya has produced several voluminous lavas, though Vulcanian eruptions and ignimbrites that have been recorded in the stratigraphy surrounding the volcano. An eruption in 4550 BC is estimated to be one of the largest of the last 10,000 years. Calderas, craters, and steam vents are visible at Volcan Masaya today (Figure 1). The summit caldera has produced at least three Plinian events, though much of the surrounding stratigraphy is capped by lava flows making differentiation of ash flows difficult (Williams-Jones, 2009; Zurek, 2016). Currently, Volcan Masaya is exhibiting consistent seismic activity and degassing, suggesting that it is still quite active. The volcanic record and the ongoing activity should be of concern for the approximately 140,000 people who live in the communities surrounding Masaya.

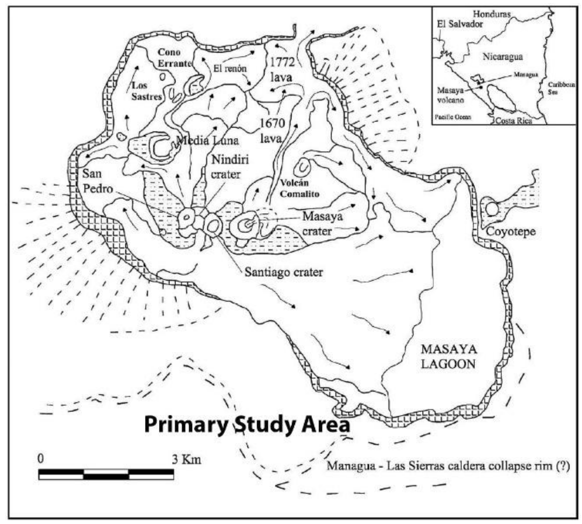

Figure 1. Modified from Viramonte, J., & Incer-Barquero, J, 2008. This map shows the inner Masaya Volcanic Complex. Each of the vents are shown in the western portion of the complex with calculated flow directions shown from prominent deposits. It is worth noting that the town of Masaya is located directly to the East of the Lagoon. The town of Nindiri is located to the North of the Lagoon. The primary study area is labeled to the South of the complex.

Nicaragua is rich with cultural significance surrounding their volcanic abundance. Figure 2 depicts ancient peoples experiencing a lava flow at Masaya. For them, all of the local volcanoes are honored and worshiped. Ancient people believed Masaya housed a god and to appease this god they performed human sacrifices into the volcano. This served as an offering to warn off catastrophes such as droughts, tropical storms, and especially eruptions of any kind. The last documented sacrifice was in 1771. During this time, the catholic church was established in the area and Pope Granada condemned the sacrifices, demanding that no more be done. Shortly after that in 1772, Masaya produced the last lava flow on record (Nevala, 2007). Since then, the local communities have not experienced a significant eruption from Masaya and much of the ancient knowledge has been lost. While at the field site our translator Kathy Matthews said "the people who live here are not afraid of the volcano erupting, they don't know and understand what it can do. If an event takes place, they will only leave their homes if the government physically makes them go". This spells for devastating consequences of the local population.

Figure 2. A painting in the Visitor's Center in the Volcan Masaya National Park. This painting highlights the long relationship that the local indigenous people have had with Volcan Masaya.

Nicaragua is the poorest country in Central America and the second poorest country in the western hemisphere (CIA, 2018). Obtaining potable water can be difficult let alone having the means of getting on a computer in their homes to view the monitoring sites of their volcanos or do research on their own. The income distribution is scattered and things such as health care services are scarce.

As of 2014, the roadways in Nicaragua totaled around 23,897 km of which only 3,346 km of them are paved (CIA, 2018). Figure 3 shows a major intersection while we were visiting the study area. Many of the roads surrounding Masaya are unpaved or poorly maintained. Many had standing pools of water or were located in areas that showed evidence of frequent flooding.

Figure 3: Examples of poor road conditions surrounding Volcan Masaya. Photos A & B highlight the threat of flooding that may hinder evacuation. Photo B is an example

of an often-used intersection in the town of Masaya. Note the low-lying road as it passes through a channel that could not only be at risk for flooding, but also lahars in the event of widespread ash dispersal. Photos C & D highlight the narrow passages that will make it difficult for these roads to handle large traffic volume.

Geologic Setting

The CAVA is a result of the Cocos plate moving to the northeast and subducting beneath the western margin of the Caribbean plate (Figure 4). The Cocos plate is a relatively young oceanic plate that was created when the Farallon Plate broke into pieces approximately 23 million years ago. The Caribbean Plate is thought to be the result of an Atlantic hotspot which no longer exists (Nevala, 2007). This theory explains that the motion of the Caribbean Plate was headed in a westerly direction 80 million years ago (Ma) during the Cretaceous, and this migration leads to the convergence of the Cocos plate subducting beneath the Caribbean plate about 5 million years ago. The subduction created the CAVA (Central American Volcanic Arc) and eventually, the Masaya volcano (Nevala, 2007). On the southern end of the CAVA, there are approximately 12 active volcanic structures, including Masaya which has an open lava pit. Some of these structures are less active than Masaya but are still considered active volcanoes.

Figure 4. Volcan Masaya is shown in the context of the Central American Volcanic Arc (CAVA) and the plate boundary. Crust of the overlying plate is not as thick as many other prominent arcs and thus hosts more mafic eruptions. Explosive events are still possible, as shown in the record at Masaya. Though the Caribbean plate is predominantly oceanic crust, the

western margin is composed of thin continental crust.

With this type of convergence and age we expect Masaya to behave like a stratovolcano with the composition being felsic yet, Masaya has produced basaltic eruptions and behaves more like a shield volcano (Bice, 1983; Bice, 1985). This is likely due to it being a younger arc. The continental crust within the study area is 25 to 44 km that is relatively thin compared to other volcanic arcs such as the Cascadian arc in the United States (Mackenzie et al., 2008). The thinner crust is the key contributor to the mafic composition in this section of the arc.

Masaya is one of many examples of a shield volcano emitting mafic materials in the CAVA rather than a stratovolcano that we expect to see with this type of convergence. Masaya as we see it today was created 2,500 years ago from an 8-km³ basaltic ignimbrite erupt eruption. There have been 19 minor debris type eruptions within the past 400 years (volcanodiscovery.com/masaya.html, 2017).

Methods

Maps were created using a combination of data collected via GIS software, field work, and literature reviews. By studying published data of previous eruptions and prominent weather patterns, we were able to create hazard zones. These hazard zones (labeled in gradients of red & orange, for decreasing risk) rely on the pattern of previous eruption deposits and dominant wind patterns. It is our assumption that a modern-day climactic, explosive eruption would have similar characteristics to recent explosive events from Masaya, though effusive events are more likely and still pose a threat to the local communities. Preliminary maps were created using GIS software. Data were gathered from the Smithsonian which provided typical wind directions showing potential atmospheric currents for ashfall hazard areas. These data were then added to the GIS data to highlight potential areas of risk and common transportation routes. These maps were then used to guide the field work. GPS units were used to gather specific data points as we travelled each of the main roads in the area. We made note of road conditions and possible evacuation issues like low-lying roads, bridges, or poorly maintained roads that would slow traffic. With this information, we confirmed possible alternative routes and hazardous areas. Thematic maps were compiled with three options. Option A is the preferred route. Given proper forecasting and warning, we would suggest that residents use Option A assuming that the conditions allow for such an evacuation. Option B is the secondary route containing sections of caution. This is the option that we would suggest as the best possible backup, or the option to use as traffic leads to congestion in Option A. Option C is not a recommended route. Roads along this route are in poor condition and could not be used to evacuate residents in a safe and timely manner.

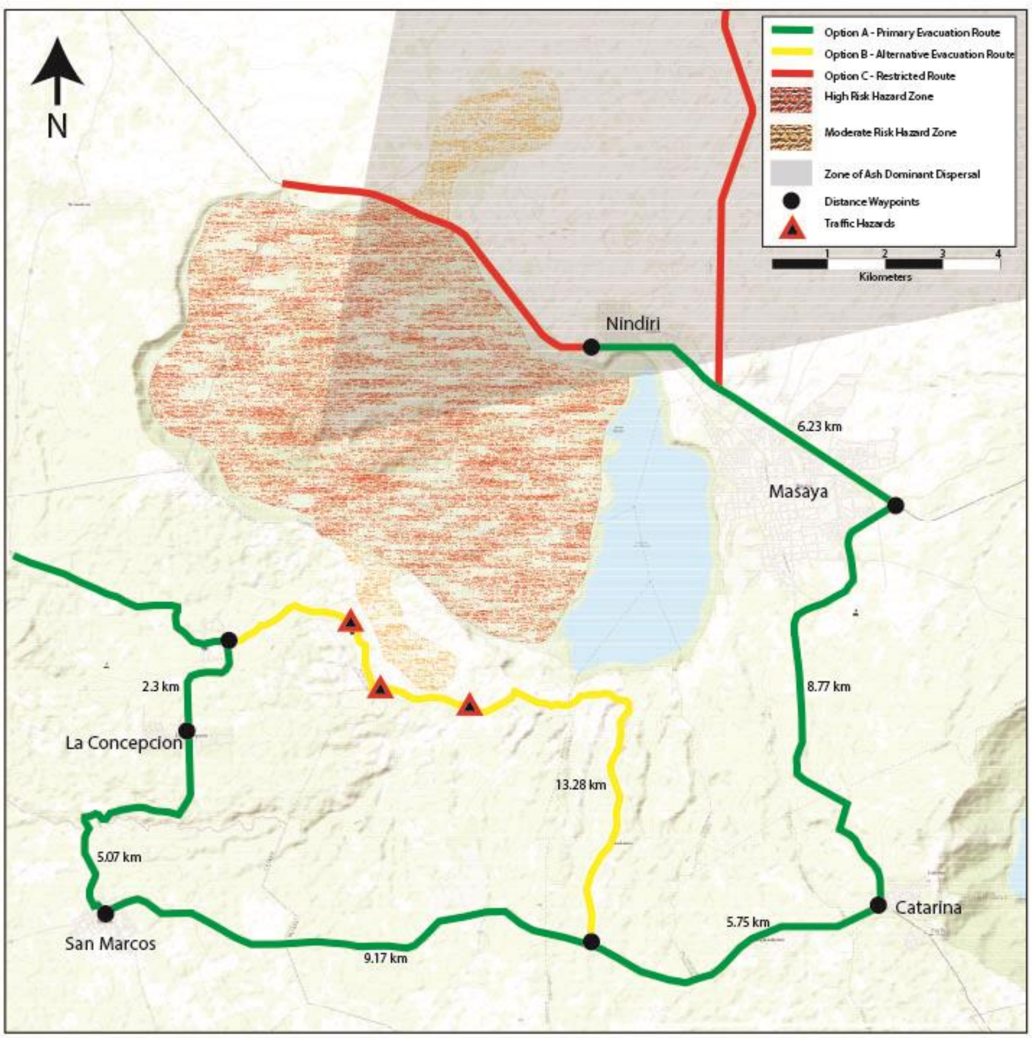

Figure 5. Our hazard map highlights high-risk areas shown in red and orange. These are primarily the result of potential wind-blown ash from an explosive eruption. The evacuation routes are color coded. Green (Option A) is our preferred route given its ability to move residents away from the volcano and the improved road conditions. Yellow (Option B) is the alternative route. This route contains roads of lesser quality that may hinder large amounts of traffic. We have also noted potential hazards along the Alternative Route. Red (Option C) should be avoided. While these are generally good roads, the routes lie directly in the path of potential ash fall deposits that would make evacuation quite dangerous and difficult. We have also placed measured distances along the routes for residents to better estimate travel times.

Discussion

The communities surrounding Volcan Masaya are some of the most densely populated areas in Nicaragua. These communities need access to evacuation routes that provide them some level of safety and efficiency in a disaster. Given the potential risk of ongoing explosive activity from Volcan Masaya, we propose risk areas and evacuation routes based on data collected on previous eruption extents, prominent weather patterns, and current road conditions. Figure 5 highlights the risk areas (color coded regions) and ranked evacuation routes. We suggest an evacuation route that leads directly away from the volcano as efficiently as possible (shown as the green path on Figure 5). These roads were also deemed to be the best option to accommodate large amounts of traffic given their quality and width. The alternative route (Option B) is designated in yellow and lies primarily to the South of the volcano. We suggest the use of this path only when Option A is not ideal or is too congested with traffic. This alternative designation was made based on the fact that the route does not take residents away from the volcano in an efficient manner, and the road quality was less than ideal for accommodating large amounts of traffic all at once. Option C is shown as the red route on the map. This designation was made primarily based on the proximity of the roads to expected ash deposits. Based on predominant wind directions (Figure 6), we determined that travel on roads to the northeast of the volcano is not advisable unless residents are already in those locations and can travel safely away from the volcano. These options are based on the assumption that a new climactic eruption would have similar characteristics to previous eruptions, and would thus create large, wind-blown ash deposits to the northeast of the volcano. These ash deposits would make travel dangerous or impossible and could set the stage for ongoing lahar hazards. For these reasons, we suggest that residents travel South or North to escape the primary and secondary eruption risks.

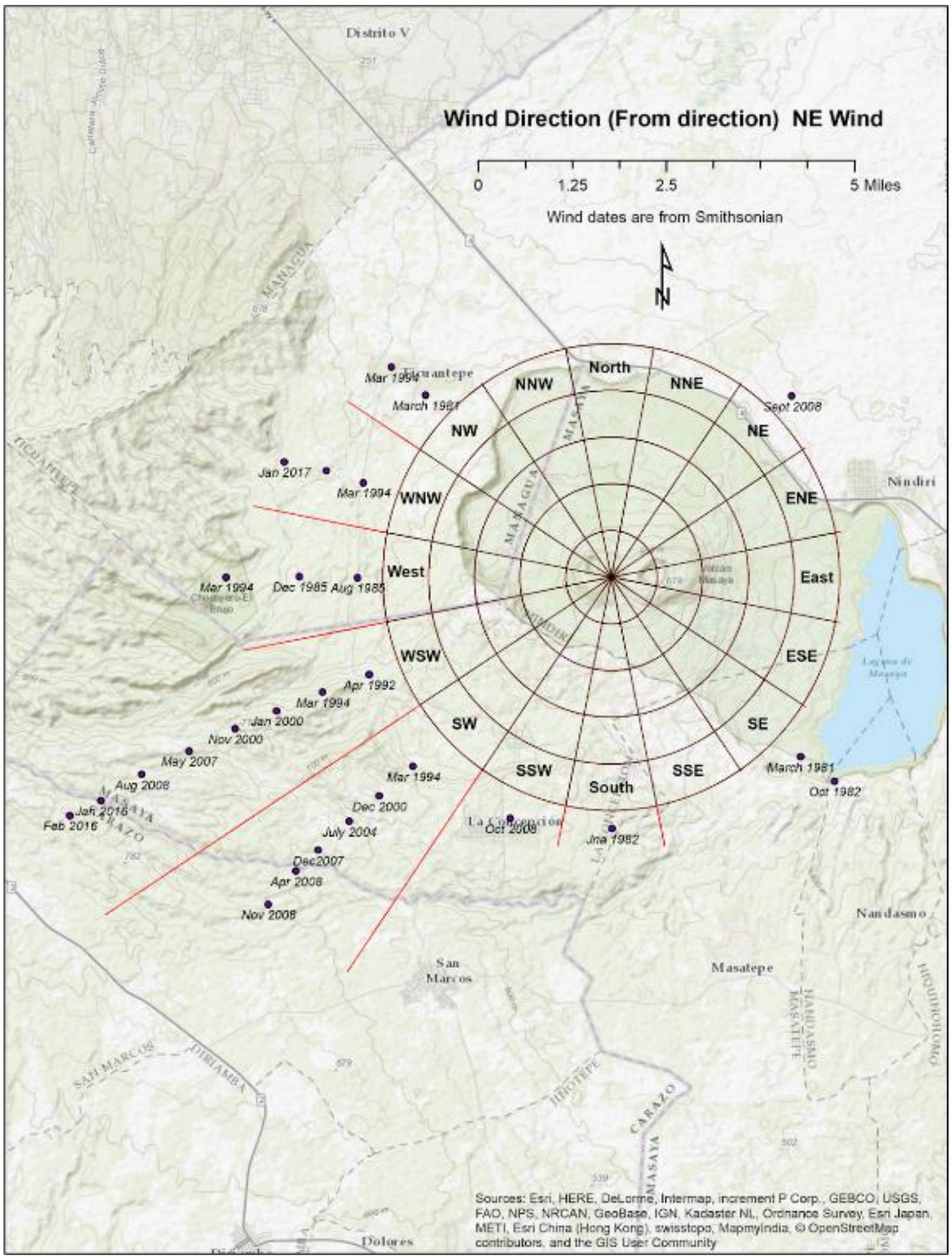

Figure 6. A map of predominant wind directions compiled from Smithsonian data. These wind directions suggest that ash would blanket much of the region to the northeast of the volcano and thus must be factored into the evacuation route criteria.

The quiescent nature of Masaya is considered a stable or metastable system because it does not erupt material over a large area; however, it should not be taken lightly. It still holds the power to produce violent eruptions. This type of system provides challenges when creating accurate forecasts. Though ongoing monitoring is happening at the volcano, there is a lack of resources to provide proper community education. Even a moderate eruption of debris can and will threaten the surrounding communities' way of life (Stix, 2007). Providing a hazard map and evacuation routes can provide the local population with knowledge of more dangerous locations to avoid if an evacuation were ever needed, but this is only a small portion of the effort needed to keep the community safe. Further research is needed on the extent of specific hazards like pyroclastic flows and lahars as well as earthquake potential. These data would need to be added to a hazard map with updated evacuation routes. As Volcan Masaya lies in a National Park, we would like to advocate for opportunities for the park officials to host community education events. These events would include short lectures on the hazards of another eruption and what to do in the case of a damaging event. The hazard maps and evacuation routes would also need to be displayed to the public at these events. Eventually, these events could be hosted by local schools. A pamphlet that would be available todisperse to the population in the area could be a great benefit to them for education and preparation.

Summary

Based on published data and our own field work, we have created a hazard map that highlights dangerous areas and evacuation routes surrounding Volcan Masaya in Nicaragua. By combining data from past eruptions with current weather patterns and road conditions, we present ranked evacuation routes that provide access to safety in the event of an explosive eruption from Volcan Masaya. Further research on the extent of past eruptions and how these types of systems can become unstable should be completed for a better understanding of Volcan Masaya in its entirety. Ongoing research and monitoring of the volcano will provide more accurate forecasts, while community education initiatives led by the national park and schools would help implement safe practices for the local population.

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