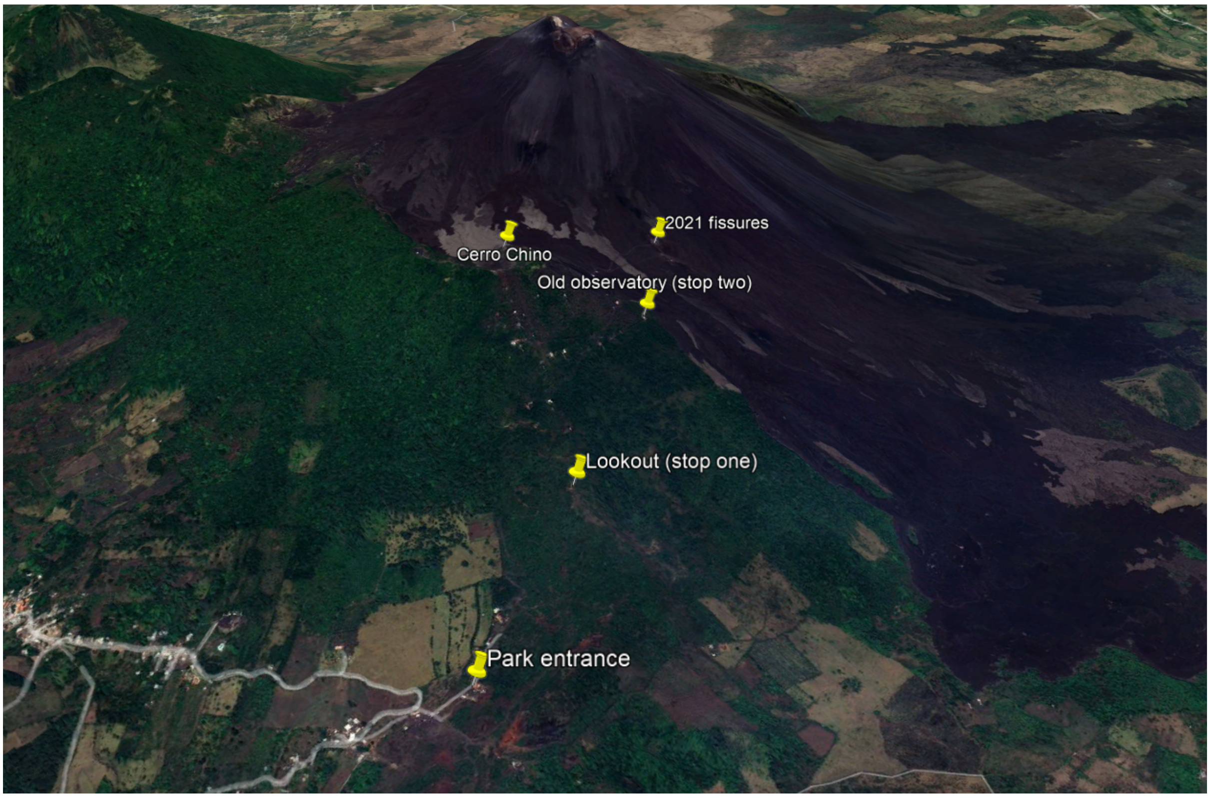
Pacaya field trip: Pacaya volcano and basaltic volcanism

This trip sees us travel to Pacaya volcano, an example of basaltic volcanism. We will visit recent and older lava flows before heading towards the summit. It is a long day, although not hugely physically challenging. You will need a good deal of water (provided, but feel free to bring extra), lunch (provided) and a snack or two if you get hungry to keep you going until we get back to Antigua (it may be quite late for the later buses).

Activity	**Time**
Drive to Park Entrance	1 hr 15 minutes
Hike up	1 hour 30 minutes
Lunch and lava	2 hours
Hike down	1 hour 30 minutes
Drive back to Antigua	1 hour 15 minutes
Total:	**~7 hours**

All timings are approximate.



Last eruption	**Ongoing**
Elevation	2552 metres (8371 feet)
Location	14.38°N / -90.6°W (31 km from Guatemala City, 35 km from Antigua)
Maximum recorded VEI	3
Type of activity	Strombolian, Sub-Plinian

Background

Pacaya is a complex basaltic volcano south of the Pleistocene Amatitlán caldera; the majority of the complex has formed in the last 23,000 years. The volcano is composed of basaltic lava flows interbedded with scoria fall units, pyroclastic surge beds, and welded tuffs. The complex consists of Pacaya Viejo stratovolcano and three large secondary cones (Cerro Chino, Cerro Chiquito, and Cerro Grande) as well as numerous flows and tephra. The domes have been inactive since the 19th century, but activity continues at the main crater, the Mackenney cone. Strombolian eruptions often produce a'a lava flows and eject incandescent bombs, while less common sub Plinian eruptions cover the nearby areas with ash. Eruptions at Pacaya are often visible from Guatemala City. The current and ongoing activity began in 1961. Activity is mainly Strombolian, but there are also intermittent lava flow extrusions on the flanks of the Mackenney cone ~300-500 m below the summit (Dalton *et al*., 2010).

Figure 1. Location map of Pacaya, relative to Guatemala City, Antigua and the Amatitlán Caldera (blue).

Pacaya is one of Guatemala's most frequently active volcanoes, and has been erupting almost continuously since 1961. Its eruptions are typically VEI 1-3. Paleomagnetic studies of exposed lava flows indicate that activity at Pacaya is generally episodic, with short eruptive periods followed by longer repose periods. Pacaya's eruptive activity can transition quickly between effusive and explosive. There is a lack of written records concerning pre-16th century eruptions, but this is when the majority of cone-building activity occurred. Collapse of the Pacaya Viejo stratovolcano between 600 and 1500 years ago created a 25 km-long debris avalanche deposit. From the 16th century to 1860, activity was confined to the Pacaya Viejo collapse crater and the Cerro Chino cinder cone. The collapse has been partially filled with the Mackenney cone, a small composite cone which is now the locus of activity on Pacaya. The Global Volcanism Network documents 15 confirmed and 4 uncertain eruptions during this time, ranging from VEI 2-3. A particularly noteworthy eruption is that of July 1775, which produced a widespread blanket of tephra extending to Antigua and a basalt lava flow which travelled 6 km from its vent on Cerro Chino.

An arcuate collapse scarp surrounding the northern and eastern flanks marks the of Pacaya confined the effusive activity during eruptions between 1961 and 2009. However, this topographic barrier has since been breached and a large lava flow eruption has caused lava to extend into nearby populated areas, highlighting the need for the assessment and monitoring of lava flow hazards. This led to a study being conducted by Morgan *et al* (2013) who used thermal infrared satellite data to estimate lava discharge rates from Pacaya volcano during the 2004-2010 eruptive phase. Two types of effusive activity in the subset of flows analysed were identified: a short-duration, relatively high effusion rate activity (1-10m^3s^{-1}), and a long-duration, relatively low-effusion rate activity (0.1-1m^3s^{-1}). The former type of activity is the more dangerous as this type of flow will move more quickly and will cover larger areas and distances. In the future, if satellite data can distinguish between the two types of activity in real-time, then evacuation plans can be put in place downhill of the summit vent in anticipation of a lava flow (given that it is the former type).

However, larger events are still frequent, and these can pose significant hazards. In 1987, eruptions destroyed 63 houses and forced 3000 people to evacuate from nearby villages due to the threat of ash falls and lava flows. In 1991, pyroclastic flows caused further evacuations and left 2000 people homeless. Pacaya was intermittently active between July 2004 and October 2010. May 2010 saw a particularly active period where explosions occurred on the 27th and 28th, and the months leading up to these explosions saw the venting of lava flows on the E and SE flanks of the volcano. This eruptive activity caused a blanket of tephra to spread 1000 km^2. It eventually reached Guatemala City, where the international airport, La Aurora, had to close for five days. Incandescent material rose 1.5 km above the crater and villages north of the Mackenney cone, such as El Cedro, San Francisco de Sales and Calderas, were affected by the high density of ballistics erupted, which consequently injured 59 people and led to ~2000 people being evacuated (Rose et al., 2013). Ash emissions were also a widespread problem: they fell on many of Pacaya's surrounding villages and could be detected as far away as the Caribbean coast. Secondary effects came in the way of debris flows due to rainfall from tropical storm Agatha, causing 0.9m of rain in some places. Strombolian activity continued into June but with diminishing intensity, and emissions became more effusive, closer to typical behaviour of Pacaya. Fortunately, the explosive activity only caused one fatality and two people died from cleaning tephra from their roofs. However, 179 deaths were caused by the tropical storm.

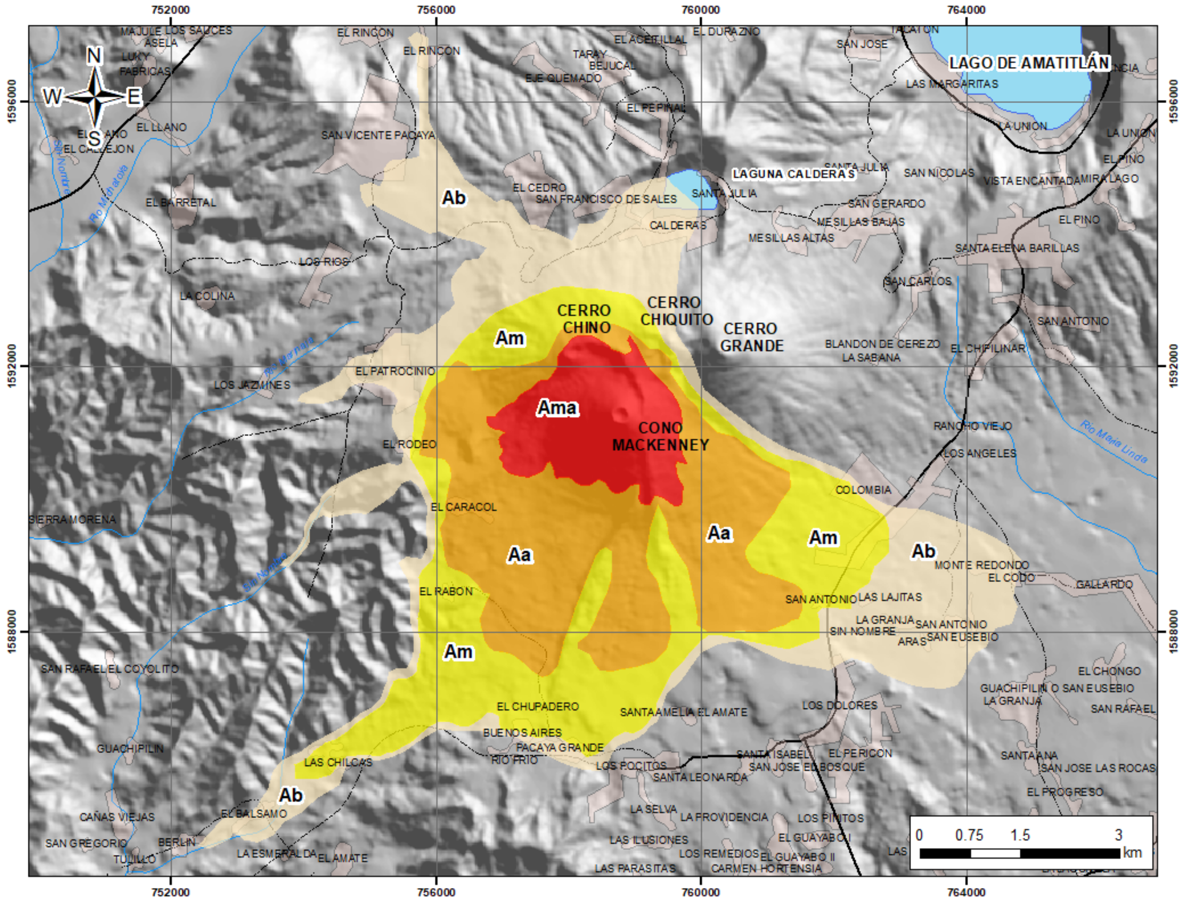


Figure 2. Hazard map for Pacaya by Carla Chun (UMG)
(Ama = very high risk, Aa = high risk, Am = medium risk, Ab = lower risk)

A Plinian eruption in March 2014 created ash clouds 4 km high and caused flights to be diverted from the area. In 2021, as you will see, there were a series of lava flows produced from the western flanks during a fissure eruption and an emptying of the crater in a series of what were, for Pacaya, large explosions. Lava erupted at Pacaya is generally porphyritic olivine basalt, with phenocrysts of up to 45% plagioclase plus olivine, clinopyroxene, and Fe-Ti oxides. The groundmass is composed of these same minerals in addition to glass. The basalts are generally 47-52 wt% SiO_2 and 18-21 wt% Al_2O_3. They are enriched in large-ion lithophile elements (LILE) and depleted in high field strength elements (HFSE). The lavas have a very high FeO/MgO ratio compared to mafic rocks from different tectonic settings, and this is typical of the Central American arc, where primitive basalts are generally scarce. The most likely explanation is that magnesian lavas rising through the continental crust are trapped at the Moho due to its sharp density gradient. The magmas pool at the Moho depth, meaning they fractionate before rising to the surface.

Older lava flows at Pacaya (>0.5Ma) are basalts and basaltic andesites. From the basalts to the andesites, there is an increase in SiO_2, K_2O, Rb, Zr, Ba and Th, and a decrease in MgO, CaO, TiO_2 and Sr, suggesting fractional crystallisation in a high-level magma chamber. Slightly later lava domes, including Cerro Chiquito, are andesitic to dacitic with 20-30% basaltic andesite enclaves. These enclaves are not related to the dacite of the domes by simple fractional crystallisation, so the association of the two rock types must be the result of mixing prior to extrusion. There are two plausible subsurface configurations which could explain this: either two connected shallow magma chambers exist under the dome, or magma in a single shallow chamber is altered by the addition and re-melting of amphibole cumulates from greater depths.

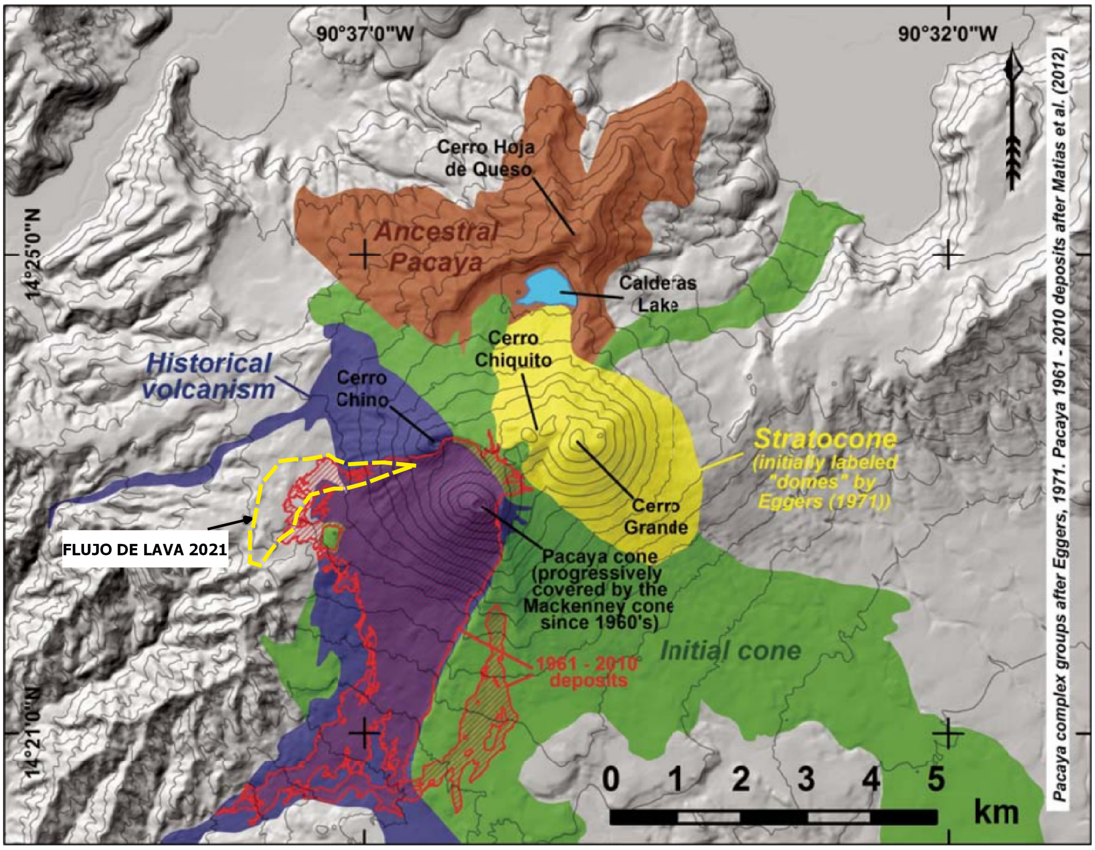


Figure 2. Mao of recent lava flows at Pacaya from Carla Chun (UMG)

The most recent lava flows from the active Pacaya cone show a return to the basalts and basaltic andesites of earlier phases: the two groups of flows have almost the same major and trace element composition. Plume compositional data (Battaglia et al., 2019) suggest Pacaya exhibits a H_2O-poor (for an arc volcano) composition (80.5 mol. %), with a characteristic magmatic CO_2/St ratio of ~1.0 to 1.5. Both the H_2O-poor and low CO_2/St ratio composition concur to suggest a limited slab-fluid and a dominant mantle-wedge derivation of the emitted volatiles. The $^3He/^4He$ ratios measured in fluid inclusions hosted in olivines (Ra) are within the MORB range (8 ± 1Ra) and among the highest values in the Central American Arc. This strongly supports that the mantle source beneath Pacaya lacks of any contamination of radiogenic ^4He from the slab or the crust. This mantle affinity for He (and C) is consistent with independent petrological/geochemical evidence for magmas underneath Pacaya forming by decompressional melting rather than by slab-fluid addition, and also points to rapid magma transit in the crust, favoured by local extensional regime.

Stop one: The 2021 flows overlook

Once at the start of the climb you will head to the first stop, an overlook from where you can see the extent of the Westernmost flows. This is the site of the most recent activity at Pacaya, in 2021. Between February and May 2021 a series of explosions emptied the crater and a series of lava flows emanated from the western flank (highlighted in yellow in figure 1) and flowed towards the town of El Patrocinio.

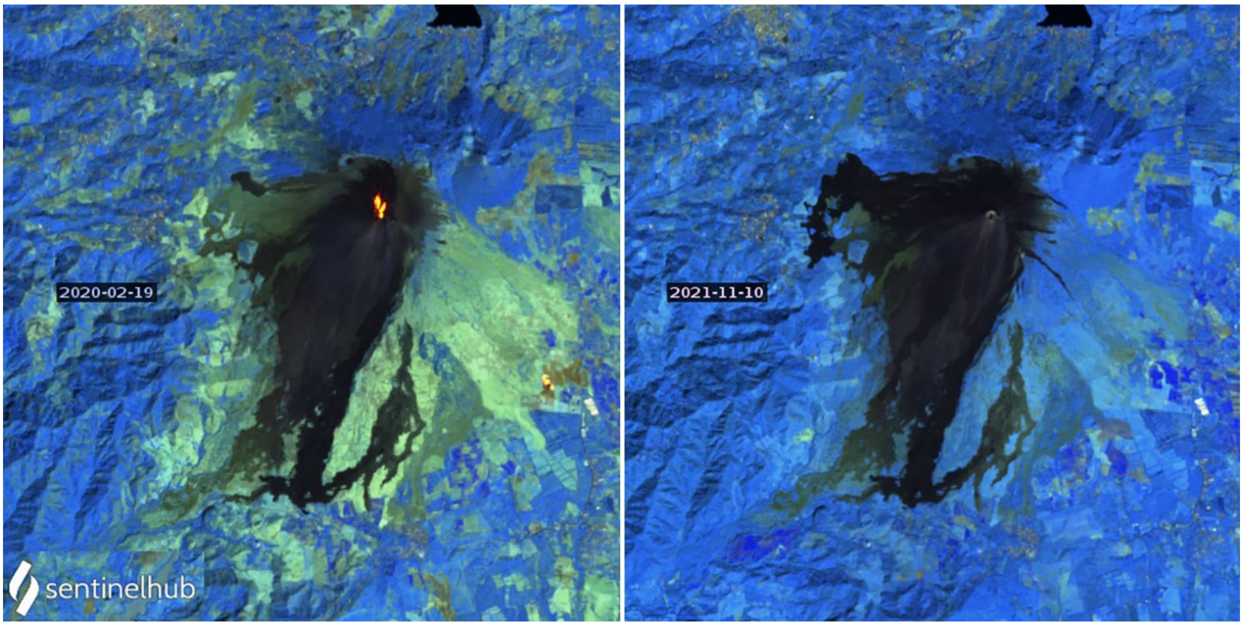


Figure 3. From GVP. Pre and post emplacement satellite imagery of Pacaya's 2021 lava flows.

Stop two: The old observatory and the summit flows

After a further hike from the overlook you will arrive at the old (abandoned) observatory and your first view of the summit crater system. You will learn about the Mackenney cone - an impressive edifice given it is only 63 years old! There are a number of sequences of flows overlaying one another and some beautiful flow textures. You'll see the 2021 fissures (the source of the flows) and Cerro Chino, an ancestral cone from an eruption in 1775.

References

Battaglia, A., Bitetto, M., Aiuppa, A., Rizzo, A.L., Chigna, G., Watson, I.M., D'Aleo, R., Juárez Cacao, F.J. and de Moor, M.J., 2018. The Magmatic gas Signature of Pacaya Volcano, with implications for the volcanic CO_2 flux from Guatemala. Geochemistry, Geophysics, Geosystems, 19(3), pp.667-692.

Dalton, M.P., Waite, G.P., Watson, I.M. and Nadeau, P.A., 2010. Multiparameter quantification of gas release during weak Strombolian eruptions at Pacaya Volcano, Guatemala. Geophysical Research Letters, 37(9).

Morgan, H.A., Harris, A.J. and Gurioli, L., 2013. Lava discharge rate estimates from thermal infrared satellite data for Pacaya Volcano during 2004–2010. Journal of volcanology and geothermal research, 264, pp.1-11.

Rose, W.I., Palma, J.L., Escobar Wolf, R., and Matías Gomez, R.O., 2013, A 50 yr eruption of a basaltic composite cone: Pacaya, Guatemala, in Rose, W.I., Palma, J.L., Delgado Granados, H., and Varley, N., eds., Understanding Open-Vent Volcanism and Related Hazards: Geological Society of America Special Paper 498, p. 1–21, doi:10.1130/2013.2498(01)