

Module 3: Paired Volcanoes



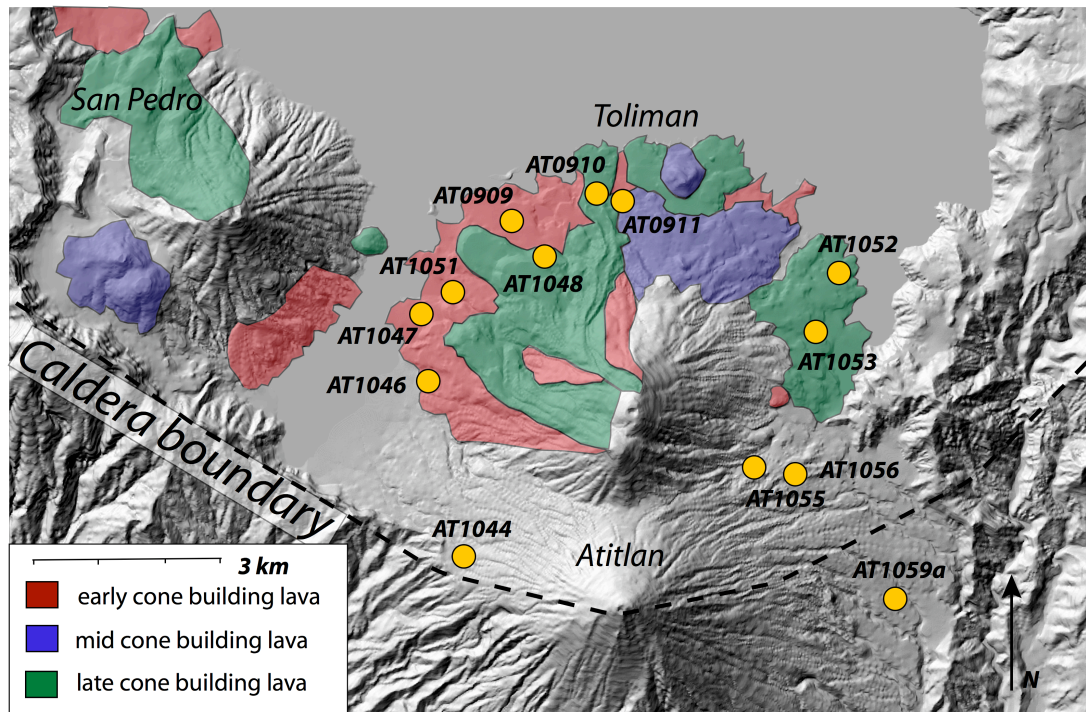
Figure 1. Photo of Tolimán (near) and Atitlán (far) looking southward.

Volcanoes along the Central American Volcanic Front are spaced 25 km apart (Halsor and Rose, 1988). However, in the Atitlán Volcanic System there are three individual volcanoes within a 10 km² area. The aim of this module is to compare the lavas erupted from two adjacent volcanoes, Tolimán and Atitlán, where vents are <5 km apart. The eruptive volume of the stratocones is roughly equal (42 km³ vs. 46 km³ respectively). Yet the eruptive style between the two cones is drastically different. Tolimán is characterized by small volume lavas flows while the Atitlán erupts volcanic blocks and ash (see DEM below). In addition, there are several geochemical and mineralogic features that differ between the two volcanoes. In this activity, you will investigate the processes causing variability in magmas between Atitlán and Tolimán, which we can assume have the same source magma due to the close vent spacing.

For this project you will test the hypotheses: 1. The Tolimán lavas are the product of fractional crystallization of Atitlán lavas and 2. The Tolimán lavas are the product of assimilation-fractional crystallization (AFC) between the crystallizing Atitlán basalts and granitic plutonic rock in the upper crust. Use the mineralogic and geochemical data provided in the Excel spreadsheet Atitlán Module 3.xls to compare and contrast the processes modifying the magmas erupting from Toliman and Atitlán.

1. Name several characteristics that you would look for to determine if the magmas evolve via fractional crystallization. And how would AFC differ?

Figure 2. Map of sample localities with corresponding geochemical data. The A series Atitlan lavas were collected by Halsor (1989) and do not have GPS coordinates to map sample locality. Cone lavas are broken into early, middle and late cone building phases based on relative stratigraphy published by Penfield et al (1986). Since Atitlán is blanketed by pyroclastic deposits, it is difficult to determine eruptive stratigraphy.



Part 1: Mineral Data

During fractional crystallization of plagioclase the An (Ca) content decreases while the Ab (Na) content increases. Similarly, when olivine crystallizes, the Fo (Mg) content decreases as the Fa (Fe) increases.

1. Using mineral chemistries provided in the mineralogic data tab, which volcano displays the greater range of mineral chemistries (An, Fo)?
2. Are olivine and plagioclase normally zoned or reversely zone at Tolimán? Atitlán?
3. Does this suggest open system (assimilation) or closed system (fractional crystallization) processes?

Part 2: Geochemical data

1. Using the data on the geochemical page, plot major elements and K_2O/Na_2O vs. MgO for Atitlán and Tolimán. Are there any notable differences between the volcanoes?

2. Tholeiitic (Fe enriched)-calc-alkaline (non-Fe enriched) classifications are used to characterize the fractionating phases of a magma. Calculate the FeO^* ($= \text{Fe}_2\text{O}_3 * 0.8998$ – note that the red italic Atitlán lavas are measured FeO) and FeO^*/MgO for the Atitlán and Tolimán lavas. Plot the data on the thol-calc page. How do the Atitlán lavas differ from the Tolimán lavas?
3. Calculate and plot several trace element ratios (including by not limited to Sr/Th, U/Th, La/Yb, Th/Nd, Ce/Y, Ba/La) vs SiO_2 . Are there any notable differences between the volcanoes?
4. Which volcano displays a greater range of major and trace element concentrations?
5. Atitlán sits on the caldera rim while Tolimán sits in the caldera basin (Figure 2). How might the location of the vent affect magma composition?
6. Use the provided EC-AFC spreadsheet from Bohrson and Spera (1999) to test these models. Use the partition coefficients (D) and magma parameters provided in the following data tables. Plot the Tolimán and Atitlán data with the modeled trends to turn in. Do either FC or AFC models replicate the geochemical data? How does this fit with the mineralogic data?

Table 2. Partition Coefficients for EC-AFC models

	Sr	Rb	Th	La	Yb	Ba	Nd
rhyolite	0.57	0.05	0.04	0.21	0.82	0.35	0.45
basalt	0.4	0.03	0.05	0.05	0.13	0.09	0.15

Using EC-AFC

Fractional crystallization (FC) and assimilation of crustal material (A) are two processes that are commonly inferred in igneous systems based on mineralogic, geochemical and isotopic data. EC-AFC is an Excel Macro program that uses differential equations describing thermodynamic processes to constrain the physical and chemical evolution of magma bodies. The thermal conditions of each magma body are important during AFC. For instance, two liquids with similar temperatures and viscosities will readily mix while, two liquids with different viscosities (oil and vinegar) may mix if stirred but otherwise will separate out. To complicate matters, the rock that the magma is rising through is a solid and in order to chemically mix with the magma body, the melting temperature of the rock has to be surpassed. Sometimes, xenoliths, or rock fragments, are found in volcanic rocks and illustrate incomplete melting of the bedrock. From these examples, it is apparent that not only does the chemical composition of the magma body matter, but also the thermal condition.

The first steps of using EC-AFC require the user to define several thermal parameters including:

- The temperature of the magma (T_m) and the assimilant (T_a)
- Enthalpy (heat content) of fusion (Δh_{fus}) and crystallization (Δh_{cry})
- Heat capacity (heat required to raise 1 mole of substance 1°C) of the magma (C_{pm}) and assimilant (C_{pa})

- Liquidii for the magma (T_{lm}) and the bedrock (T_{la}), the solidus temperature (T_s) and the temperature of equilibration (T_{eq})

The following table provides values for “standard” upper crustal conditions

Magma liquidus temperature (T_{lm})	1280°C
Magma initial temperature (T_m)	1280°C
Assimilant liquidus temperature (T_{la})	1000°C
Assimilant initial temperature (T_a)	300°C
Solidus temperature (T_s)	900°C
Equilibration temperature (T_{eq})	980°C
Crystallization enthalpy (Δh_{cry})	396000 J/kg
Specific heat of magma (C_{pm})	1484 J/kgK
Fusion enthalpy (Δh_{fus})	270000 J/kg
Specific heat of assimilant (C_{pa})	1370 J/kgK

To run EC-AFC

1. Click on the thermal parameters button and input the correct values from the above table
2. Click on the home button
3. Run the equilibration series
4. Set the equilibration temperature to correct value from the above table
5. Click on the trace element parameters and input the element, concentration and bulk D from the Table 2 and the Atitlán Module 3 spreadsheet. For FC the assimilant cells can be left blank
6. Click on the isotope parameters and input the elemental concentrations (C), bulk D and isotopic (ϵ) ratios from Table 2 and Atitlán Module 3 spreadsheet
7. Run the path dependent series. If you do not want the results to be overwritten, rename the output tab prior to running the next path dependent series model