Pb-Sr isotopic temporal variations on juvenile ash samples from the last eruptive period of Tungurahua volcano (1999-2016)

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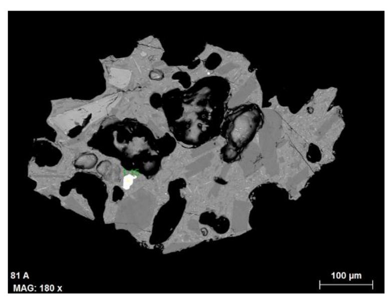
Introduction

- **Biphasic activity** of andesitic stratovolcanoes, irregularly alternating quiescence periods and highly explosive eruptions, is of great risk as important cities lie on their flank.

OBJECTIVE : Understand the rapid evolution of magmatic systems during reactivation phases

- Last **17-years period** of activity of Tungurahua volcano (1999-2016) offers a precious and rare overview on a **complete** and very well-constrained eruption phase
- The dense **monitoring network** on the flank of Tungurahua volcano allows the access to a huge database of gas measurements, seismo-acoustic records, ashes sampling, and quasi-continuous observations of the surface activity.

Samples and methods



- No regular lava emissions : No access to the magma composition and evolution

APPROACH: Focalization on quasi-continuously emitted products : **Ash**

- 85 ash samples temporally constrained and chemically preserved over the 1999-2016 period of activity
- Selection of 5mg of 300 µm **juvenile fragments** of each ash samples
- **Chemical separation** of Sr and Pb on chromatographic columns
- Measurement of **Sr-** (TIMS), **Pb isotopes** compositions (MC-ICP-MS) and **trace element** content (ICP-MS) on the same aliquot

Ash samples

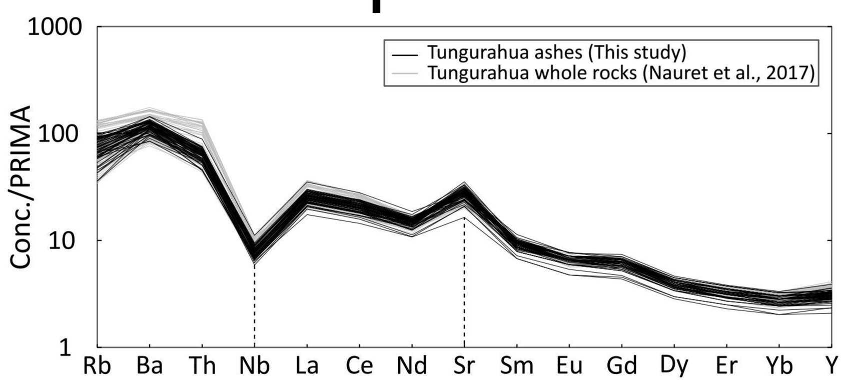


Figure 1 : Trace elements concentrations in ashes and whole rocks normalized to the primitive mantle

Major and trace elements

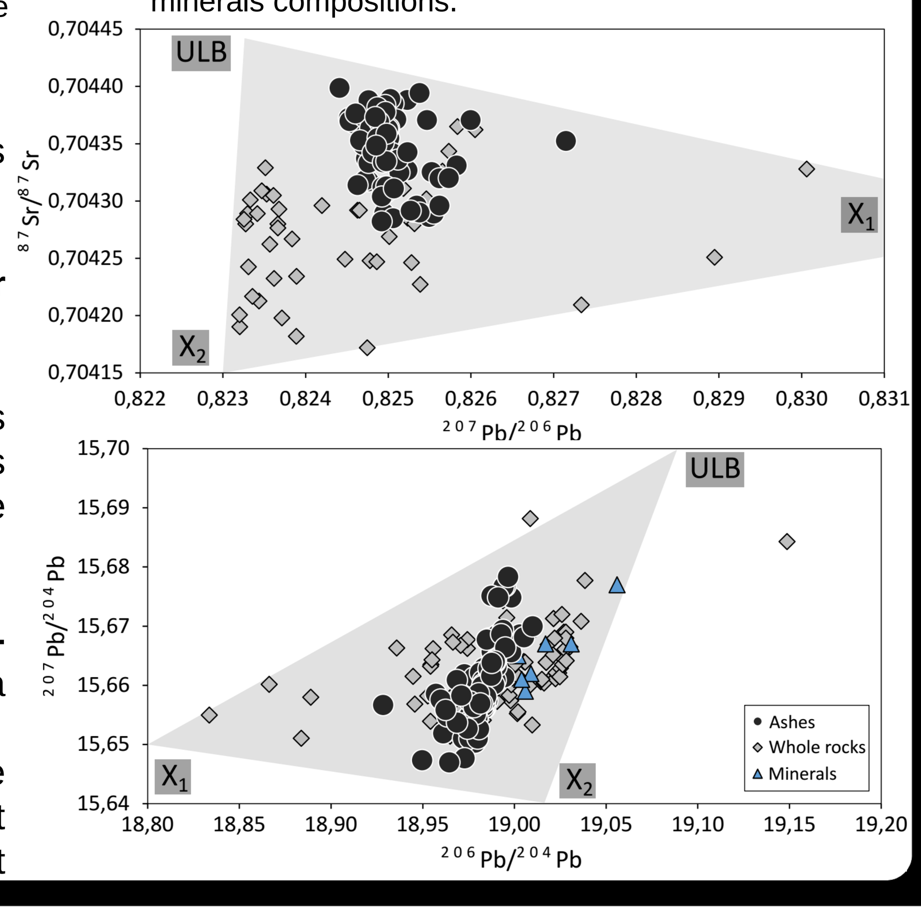
- Ash samples display typical Tungurahua **andesitic compositions.**
- Typical arcs magmas signatures
- Positive anomaly in Sr: Plagioclase accumulation

Pb-Sr isotopes

- Pb isotopic compositions of ash samples and whole rock are **equivalent**
- Ash samples are **more radiogenic in Sr** than whole rocks
- Identification of both plagioclases phenocrysts and quenched plagioclases microliths (MEB) : Strongly controls the Sr-isotopic composition of juvenile ashes.
- Triangular distribution : at least **3 end-members** at the source of Tungurahua magmas (Nauret et al., 2017)

X1 : Mantle wedge
X2 : Slab component or lower crust
ULB : Upper local basement

Figure 2 & 3 : $^{87}Sr/^{86}Sr$ vs. $^{207}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram reporting ashes, rocks and minerals compositions.



Pb-Sr isotopic evolution from 1999 to 2016

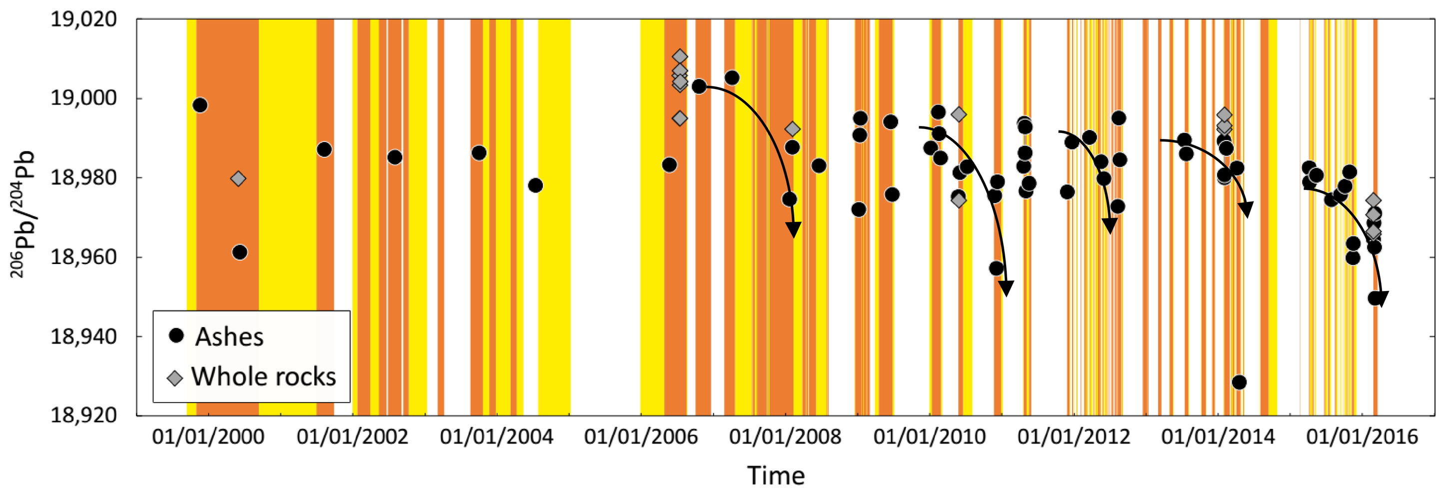
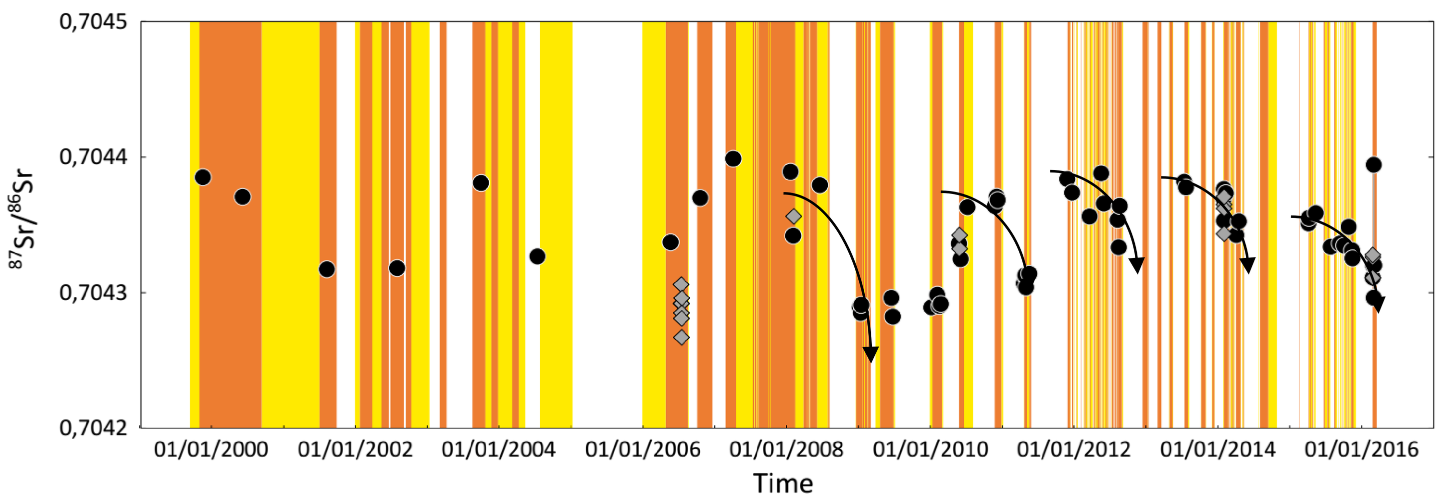


Figure 4 & 5 : $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ time series (1999-2016) of juvenile ash samples from Tungurahua volcano. Orange zones corresponds to High Explosive Activity (HEA). Yellow zones corresponds to Low Explosive Activity (LEA) (Hidalgo et al., 2015)

1) During the 1999-2008 period : absence of distinct pattern of Pb-Sr isotopic compositions because of the lack of samples

2) Since 2008 :

- **Pb isotopic ratio** continuously decreases until the end of activity in 2016.



- **Sr isotopic ratio** reaches its lowest value after 2008 paroxysm, increases until 2012 and decreases until the end of activity

3) At shorter scale, observation of repeated decreasing trends of Pb-Sr isotopic ratios during each phase of activity (black arrows).

1. Effect of crystals on trace elements

- 2 groups of juvenile ash are identified based on La/Ba and Nb/Zr trace elements ratios
- These 2 groups are regularly sampled during the whole eruptive sequence.
- Sr, Cr, Eu/Eu* are not discriminant for the 2 identified groups.

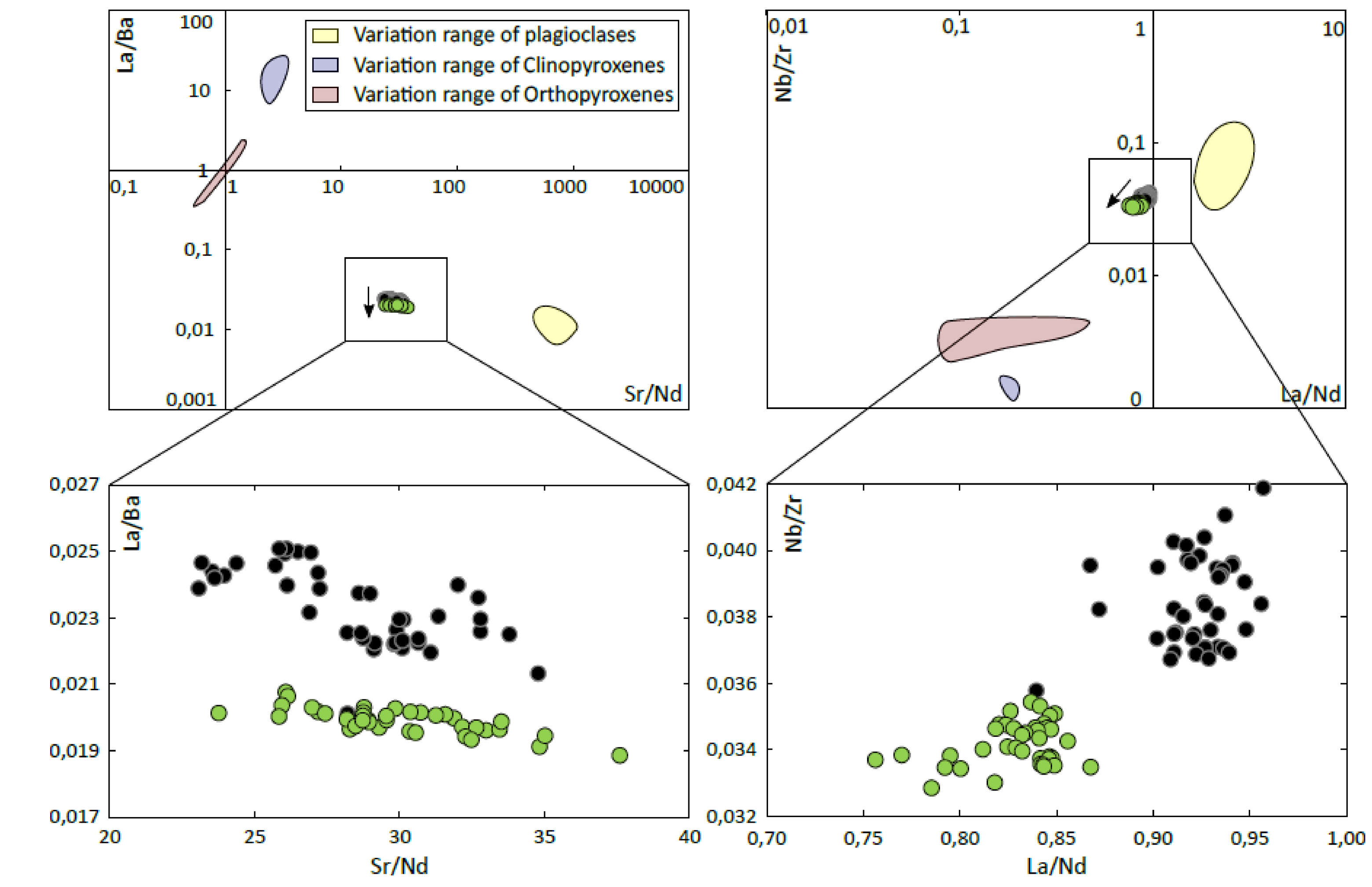


Figure 6 : Occurrence of 2 populations of juvenile ash samples based on trace elements contents. Plots of plagioclases, CPX and OPX compositions reveal that plagioclase and CPX crystals have a specific influence on Ba and Zr content of juvenile ash samples, respectively.

- Based on Th content and assuming that a typical andesitic melt exhibits 7.5 ppm of Th, ashes from the 2 groups display similar crystal contents ranged between 0-50% (black) and 15-49% (green) : differences are thought to be caused by 1) **different phases proportions in the mineralogical assemblage** and/or 2) **different phases compositions.**
- 2 magmatic reservoirs are identified to be seats of crystal nucleation and growth at Tungurahua (15-16km ; 8-10km, Samaniego et al., 2011; Andujar et al., 2017) and might bring an explanation to the occurrence of 2 distinct population of minerals.

2. Two distinct eruption phases

- Getting rid of the effect of crystals on juvenile ash samples geochemistry (<30% crystals), **2 eruption phases** with distinct **trace elements** and **Pb-Sr isotopes evolutions** are observable.

- **The transition occurred in 2011**.

This in good agreement with a change in eruption dynamics at Tungurahua from passive degassing in an open magmatic system to a partially closed system with occasional plugging of the conduit, overpressure and vulcanian eruptions (Hidalgo et al., 2015).

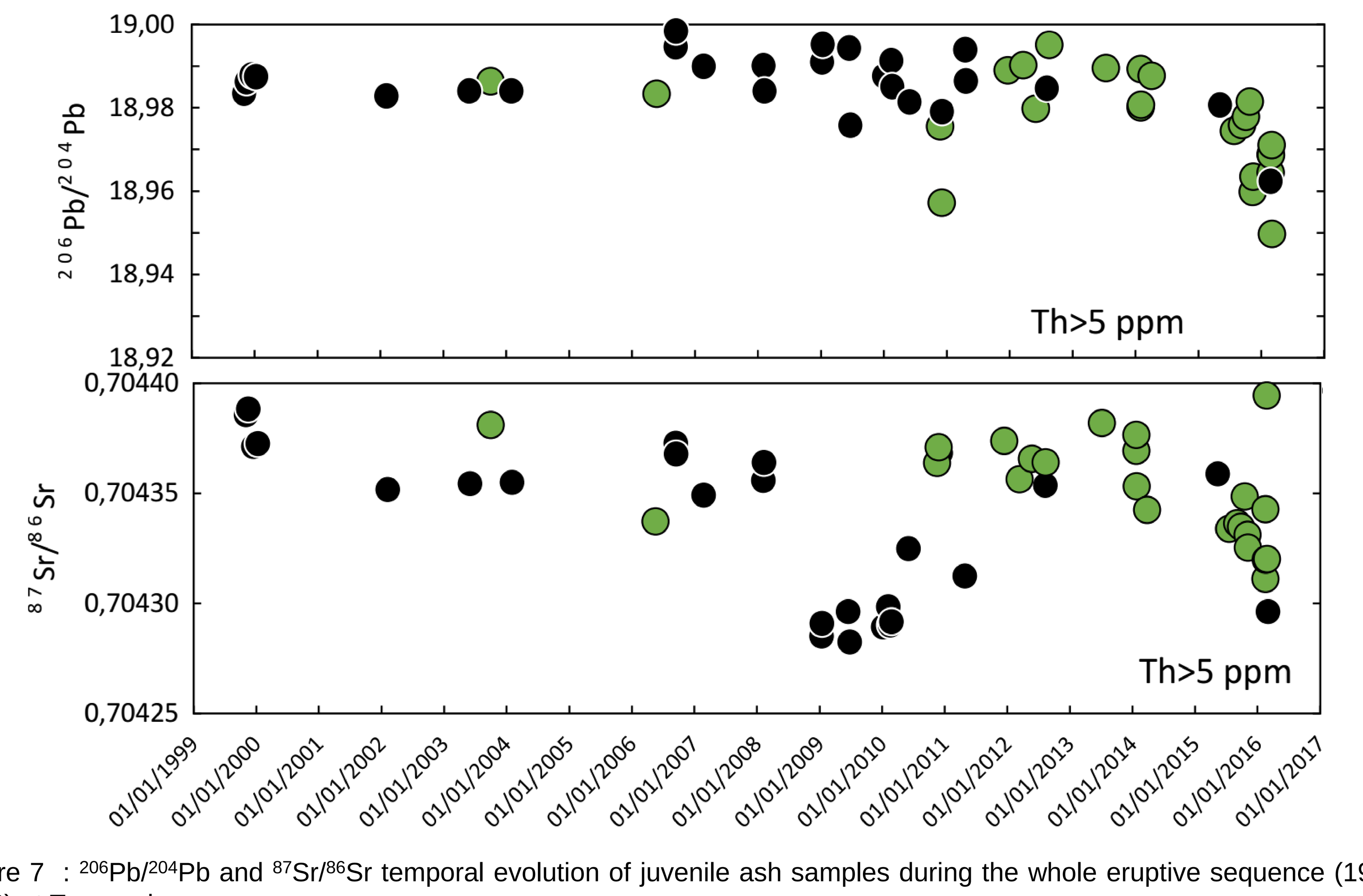


Figure 7 : $^{206}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ temporal evolution of juvenile ash samples during the whole eruptive sequence (1999-2016) at Tungurahua.

We observe that :

1) Pb isotopic evolution are **smoothed** when looking at juvenile ash with low crystal contents.
2) The evolution of $^{206}Pb/^{204}Pb$ is nearly **flat** from 1999 to 2011.
3) $^{06}Pb/^{204}Pb$ ratio **decreases** from 2011 until the end of the eruptive sequence in 2016.
4) Temporal evolution are similar for $^{87}Sr/^{86}Sr$ ratio.
5) The Sr-unradiogenic anomaly remains between 2008 an 2011

After filtering crystal noise, **two eruption phases** are observable at Tungurahua. ➡

1) The first eruption phase emits **radiogenic** and **homogeneous** samples in good agreement with (Samaniego, 2011)
2) The second phase emits samples **enriched in incompatible elements** (Ba), Sr, Zr and **less radiogenic** in Pb and Sr

Conclusions

- Accessing Pb-Sr isotopic composition of juvenile ash samples over the entire period of Tungurahua's activity (1999-2016) is allowed thanks to a **meticulous sampling work** and is useful to **understand the rapid processes occurring in the magma reservoir of active stratovolcanoes**.
- We observe a **high frequency variation** of Pb-Sr isotopic composition from the beginning until the end the eruptive sequence. This pattern can be explained by the occurrence of **two groups** of juvenile ash samples.
- The geochemical composition of juvenile ash appears to be sensitive to the composition of **trapped phenocrysts.**
- Correcting the phenocryst signal, **two eruption phases** appear. The end of the eruptive sequence is characterized by the emission of a more primitive and unradiogenic magma batch emptying the reservoir at depth.

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