COMBINED ANALYSIS OF FLUID AND MELT INCLUSIONS IN RECENT CEZALLIER VOLCANOES, FRENCH MASSIF CENTRAL: FROM MANTLE MELTING TO MAGMA STORAGE AND ASCENT

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INTRODUCTION

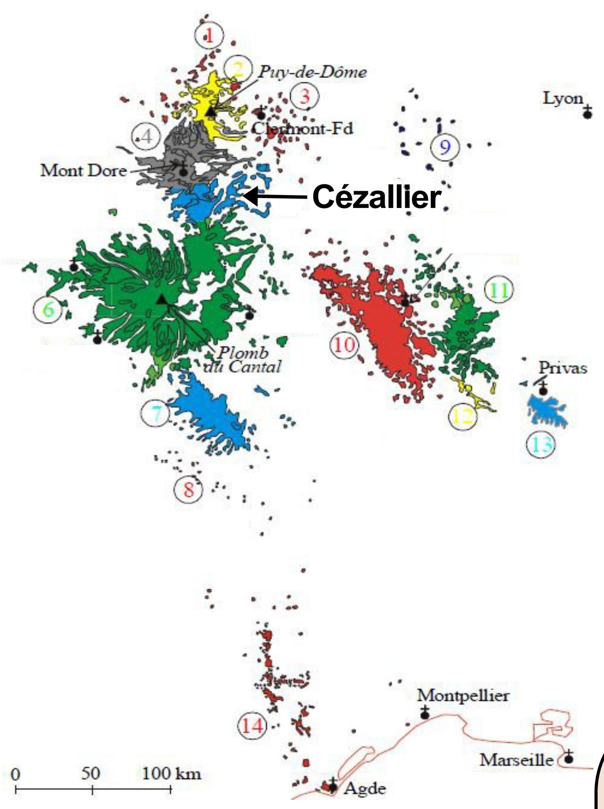


Figure 1: Map of the Cenozoic volcanic provinces of the French Massif Central. Modified from [1].

There is increasing evidence that the primary magmas at the origin of low-silica alkaline volcanism, such as basanites, are **very rich in CO_2** and that they can rise rapidly, directly from the mantle to the Earth's surface. Such volcanic systems are numerous in intraplate oceanic and continental settings, including the **French Massif Central**, and some are remarkable for the abundance of large mantle-derived xenoliths.

In this study, we focus on three volcanoes of the youngest period of activity of the **Cézallier volcanic province** that erupted less than 200 ka ago: Sarran, Mazoires and la Godivelle.

OBJECTIVES

(1) Determine the compositions of primary magmas through the study of melt inclusions (MIs)

(2) Characterize magma ascent and storage with fluid inclusions (FIs)

SAMPLES AND METHODS

FLUID INCLUSIONS

- FIs were analyzed in **phenocrysts** (olivines, clinopyroxenes, amphibole) and **xenocrysts** (olivines, clinopyroxenes, orthopyroxenes).
- The dominant type of FIs are **trails of secondary fluid inclusions** with rare occurence of primary FIs.

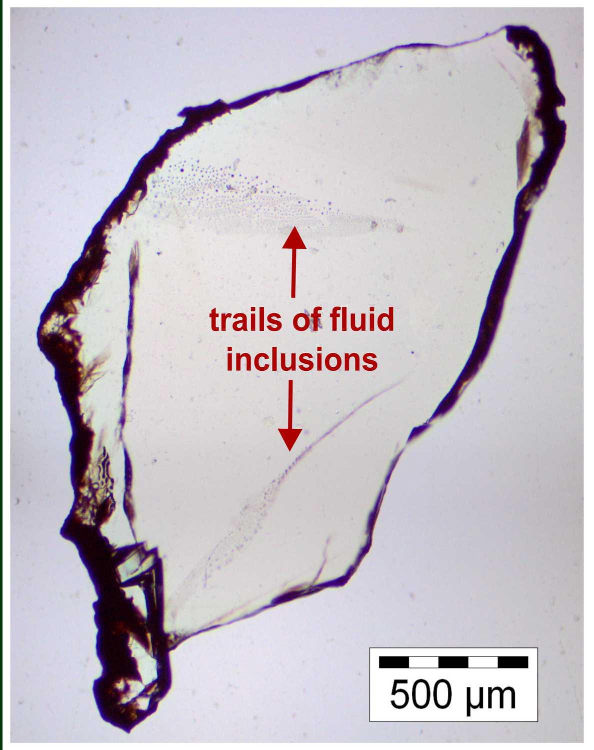


Figure 2: Olivine phenocryst from la Godivelle volcano.

FIs were analyzed by **microthermometry** (Fig. 3) which is based on the measurements of phase transitions within FIs upon cooling and heating.

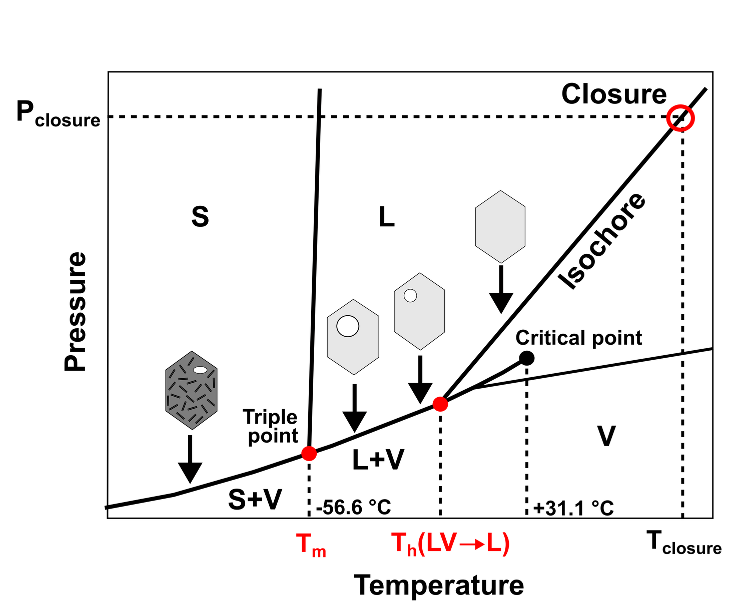


Figure 3: Principles of FI microthermometry. Modified from [2].

MELT INCLUSIONS

- MIs were analyzed in olivine phenocryts with **high forsterite content** ($Fo_{78-88.5}$).
- They are all composed of **silicate glass** and a **shrinkage bubble**. The bubbles are made of fluid CO_2 and the walls are covered by carbonates, sulfides and rare sulfates.

Raman spectroscopy: CO_2 and H_2O quantification in MI glasses and bubble characterization (CO_2 density, nature of microcrystals)

Electron microprobe: Determination of major element and volatile (Cl, F, S) compositions in glasses

LA-ICP-MS: Determination of trace element compositions of the glass

X-ray tomography: Characterization of the shape and volume of MIs and their shrinkage bubbles

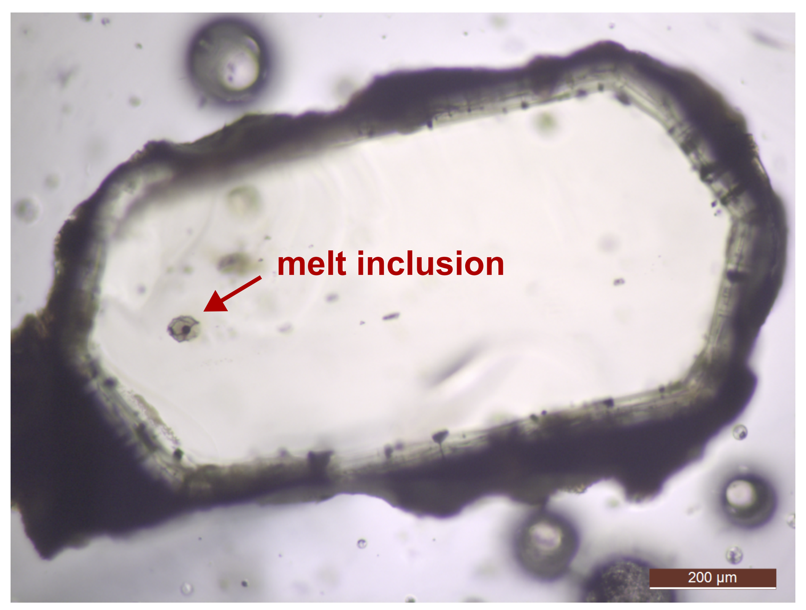


Figure 4: Olivine phenocryst from Sarran volcano.

FLUID INCLUSIONS: insight into magma ascent path

Fluid inclusions are all **re-equilibrated** at lower pressures by stretching or decrepitation. This is expressed by the presence of cracks, deformed and elongated FIs and a dark color.

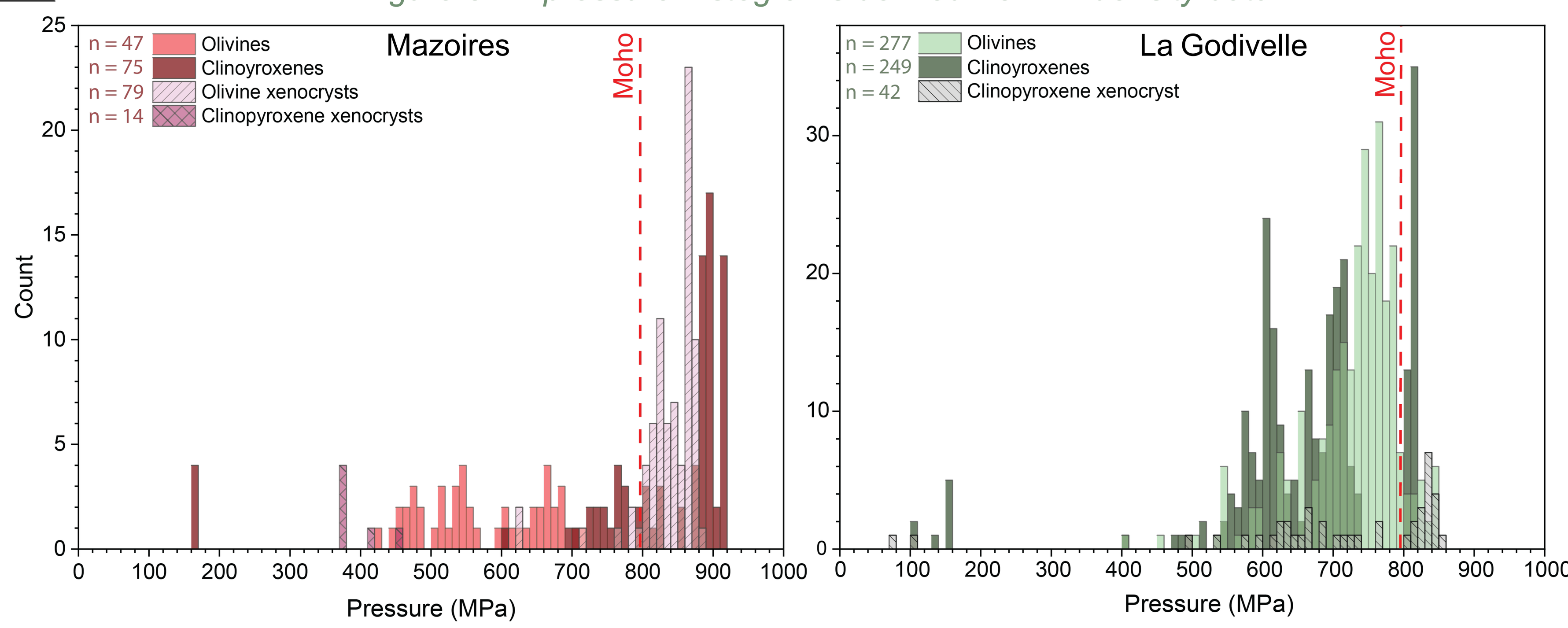
FI melting temperature = Fluid inclusion composition

- **Melting temperatures**: between **-56.5 and -56.6 °C** (T_m; Fig. 3) → almost pure CO_2 composition (+ H_2O)

FI homogenization temperature = Fluid inclusion density

- **Homogenization temperatures**: mostly between -18.2 and 5.5 °C (T_h; Fig. 3) which lead to densities of 1070 to 950 kg.m^{-3}
- FIs evolve along an **isochore** (constant volume) → conversion of densities into pressures considering a temperature of **1220 °C** ($T_{closure}$; Fig. 3; Fig. 5)
- Conversion of pressures into depth using a simplified **stratigraphic model** of the crust and lithospheric mantle (Fig. 9)

Figure 5: FI pressure histograms derived from FI density data.



The CO_2 pressure histograms show:

- At Mazoires: a major re-equilibration peak from 920 to 800 MPa (33.2 to 29.5 km) with a re-equilibration tail and an other re-equilibration peak at ~150 MPa (6 km).
- At La Godivelle: a major re-equilibration peak from 850 to 550 MPa (31 to 20 km) and an other re-equilibration peak at ~150 MPa (6 km).

(4) Magma stops near the Moho level, as indicated by the major re-equilibration peak of FIs at 800 ± 100 MPa, for a limited time.

(5) The long re-equilibration tail of FIs at Mazoires suggests a fast ascent to the surface associated with random FI re-equilibration. Ascent should be slower at la Godivelle in good agreement with the lack of mantle xenoliths.

(6) Part of the magma stops in shallow sill-like intrusions with short residence time, as indicated by the small re-equilibration peak at ~150 MPa.

MELT INCLUSIONS: insight into compositions of primary melts

X-RAY TOMOGRAPHY: Clues for homogeneous trapping

X-ray tomography is a powerfull tool to obtain **precise measurements of the volumes** of bubbles and melt inclusions.

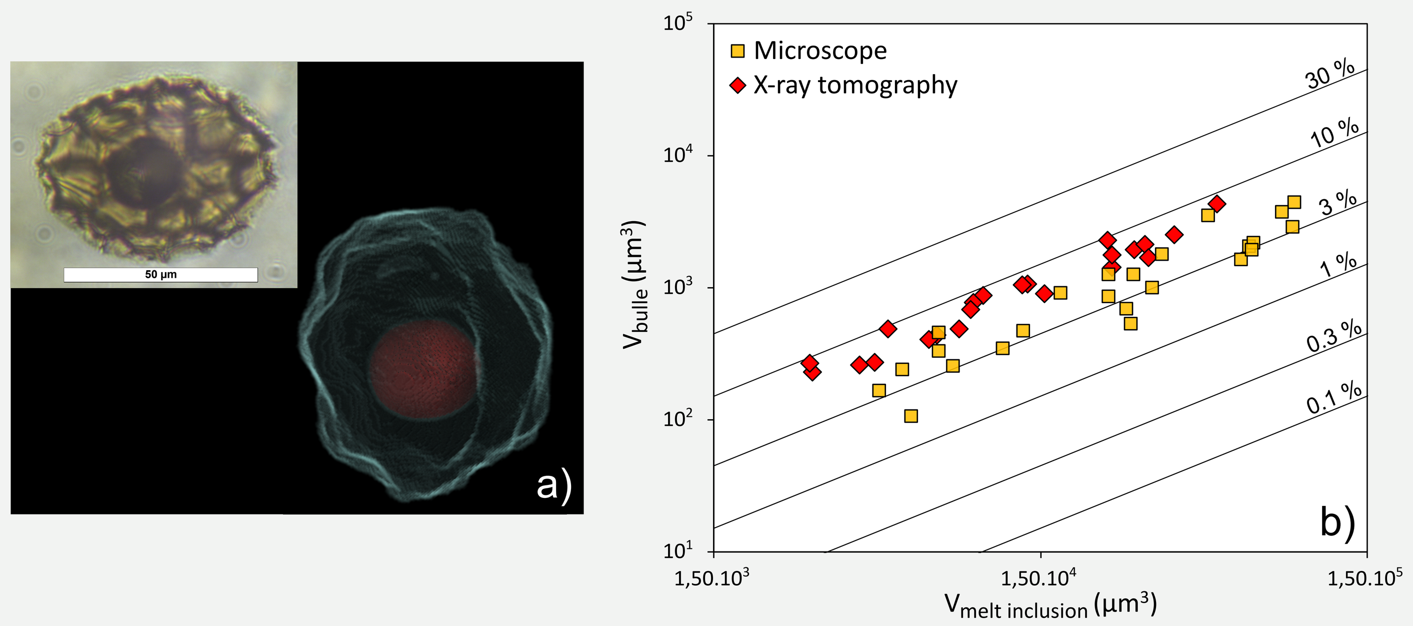
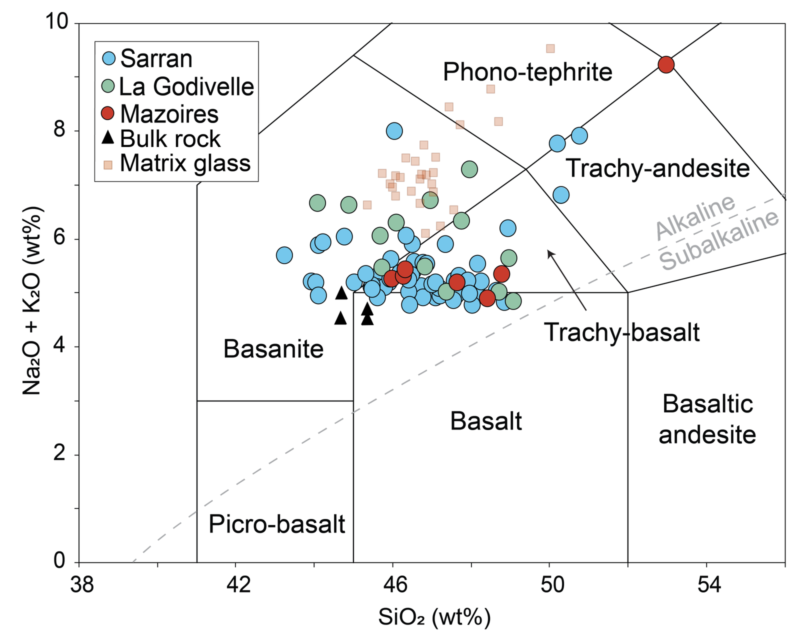


Figure 6: a) 3D X-ray tomography reconstruction of a MI from Sarran; b) Bubble volumes versus MI volumes obtained by optical microscopy and X-ray tomography

- V_{bubble}/V_{MI} obtained by X-ray tomography (Fig. 6b) are **homogeneous** within the dataset, ranging from 5.7 to 9.5 vol%.
- V_{bubble}/V_{MI} determined by optical microscopy (Fig. 6b) are more **scattered** and **lower**, ranging from 1.7 to 7.2 vol%.

From the determination of these volumes, we consider an **homogeneous trapping** of melt inclusions (= trapping of a single homogeneous phase).

MELT INCLUSION COMPOSITIONS



- MIs have compositions of **basanite to trachy-andesite** after post-entrapment crystallization corrections.
- MI compositions do not define a simple serie of differentiation by fractional crystallization → part of the chemical variability is inherited from the **mantle source**.

Figure 7: Total alkali-silica diagram [3] showing melt inclusion, matrix glass and bulk rock compositions of the Cézallier.

- MI glasses have high CO_2 content, up to **1.75 wt%**.
- To estimate the **total CO_2 content** of MIs, the CO_2 contained in the bubble (as fluid and carbonate microcrystals) must be added to the CO_2 dissolved in the glass.

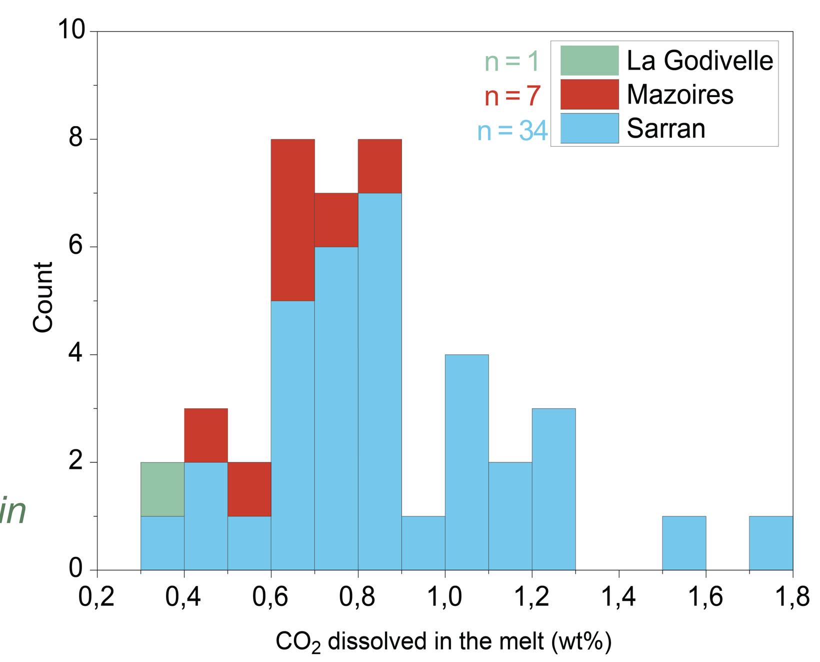


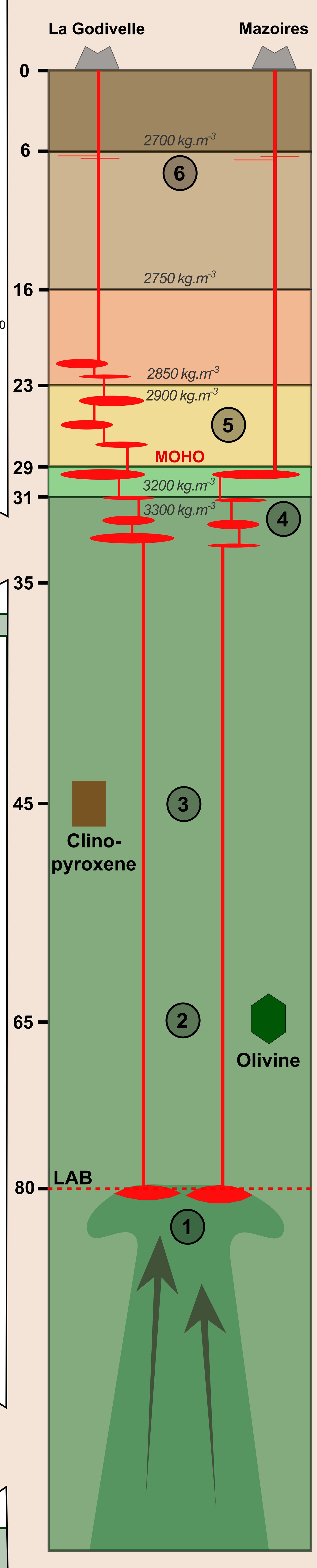
Figure 8: Histogram of the CO_2 dissolved in the MI glasses of the Cézallier.

(1) The melting of a mixed source of carbonated pyroxenites and peridotites produces magmas that accumulate towards the lithosphere-asthenosphere boundary (LAB).

(2) Olivines start crystallizing between 2 and 1.5 GPa (~65 km to 50 km) as evidenced by the high CO_2 concentrations of melt inclusions, and trap CO_2-dominated FIs during ascent.

(3) Pyroxenes start crystallizing at ~45 km (barometry; [4]) and trap secondary FIs during magma ascent.

Figure 9: Summary diagram



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