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Noble gas signatures of fluids at Santorini and Milos (Greece).

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Introduction

The measurement of the chemical and isotopic content of leaking gases in volcanic arc enable to investigate magmatic and geodynamic processes and noble gases are one of the most powerful geochemical tracers (Porcelli et al. 2002). In this study we used helium concentration and isotopic ratio, coupled with majors gas concentration (CO_2 , N_2 , H_2 , CH_4), as well as carbon and nitrogen isotopy ($\delta^{13}\text{C}-\text{CO}_2$, $\delta^{15}\text{N}-\text{N}_2$) to investigate Milos and Santorini volatile sources (Aegean sea, Greece). We also continue the monitoring of Santorini fumarolic gases over the period 2015-2023, as it is one of the most dangerous volcano of the area. We performed a model of CO_2 dissolution in water to explain some recent helium anomalies.

Geological context

Santorini and Milos are located in the central part of the Hellenic volcanic arc (HVA), a 500 km long curved chain of active volcanoes, which extends in the South Aegean Sea from Greece to Turkey (cf. Fig. 1). This Upper Pliocene-Quaternary volcanic arc, and a large part of the Aegean tectonic result from the northward Meso-Cenozoic subduction of the remnant oceanic crust of the African plate beneath the continental Aegean microplate (southern margin of Eurasia). The slab is bounded to the east, and west by slab tears, and recent studies have shown that toroidal flows associated to these tears have an impact on the source of the volcanism of the Aegean arc.

Results / Discussion

I. Origin of CO_2 , N_2 and He

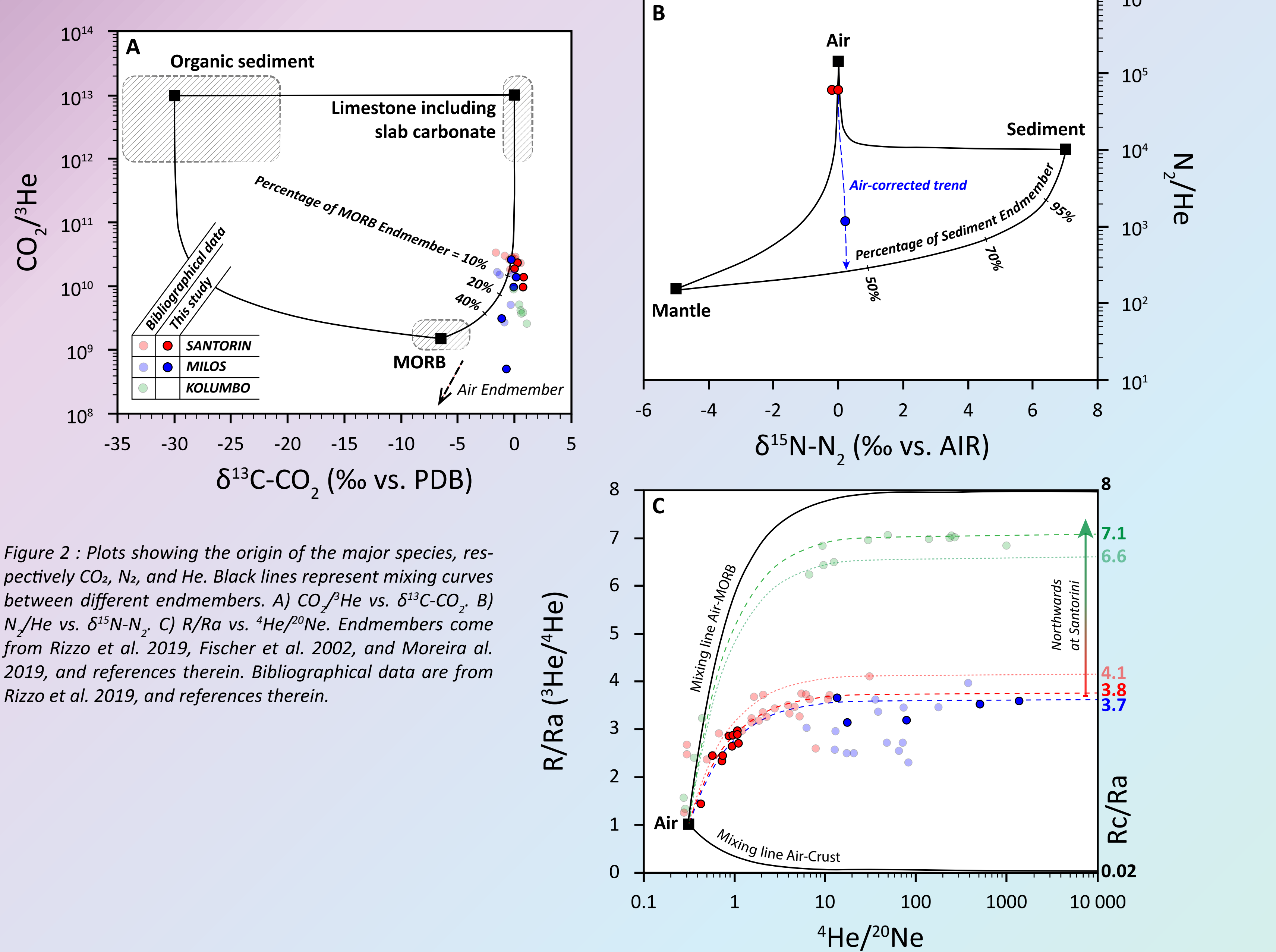


Figure 2 : Plots showing the origin of the major species, respectively CO_2 , N_2 , and He. Black lines represent mixing curves between different endmembers. A) $\text{CO}_2/{}^3\text{He}$ vs. $\delta^{13}\text{C}-\text{CO}_2$. B) $\text{N}_2/{}^4\text{He}$ vs. $\delta^{15}\text{N}-\text{N}_2$. C) R/Ra vs. ${}^4\text{He}/{}^{20}\text{Ne}$. Endmembers come from Rizzo et al. 2019, Fischer et al. 2002, and Moreira et al. 2019, and references therein. Bibliographical data are from Rizzo et al. 2019, and references therein.

We used the plot presented in Fig. 2.A to examine the origin of the CO_2 in our samples (cf. Rizzo et al. 2019). All data are aligned on the curve representing a mixture between a limestone source and a MORB-type endmember. The mantelic contribution appears to be relatively similar for the three volcanic systems, with proportions of about 10% of MORB-type endmember. The plot shown in Fig. 2.B has been used to study the origin of the N_2 (cf. Fischer et al. 2002). At Santorini, our samples are highly affected by atmospheric contamination as shown by the huge proportion of the Air endmember. Milos sample looks less contaminated by air, and the plot highlights a mixture between three endmembers (Air, Sediment, and Mantle). We can calculate a contribution of about 12% for both the Sediment-type, and the Mantle endmembers. The plot in Fig. 2.C shows that helium in Milos gases has a deep origin similar to Santorini rather than Kolumbo which is only 7km northeast of Santorini. Samples from Milos are less contaminated by air and show much more helium radiogenic contribution than those from Santorini. The helium isotopic ratio generally increases northwards along the Christiana-Santorini-Kolumbo volcanic field, with a sharp increase near the Kolumbo volcanic system (cf. Rizzo et al. 2019).

Compared to the last volcanic unrest of 2011-2012 at Santorini (cf. Rizzo et al. 2015, and references therein), the CO_2/CH_4 ratio, and the H_2 concentration measured between 2015 and 2023 do not show any significant variations, whereas the $\text{CO}_2/{}^3\text{He}$ ratio decreases and the helium concentration increases continuously (cf. Fig. 3.A, and 3.B). In the plot of Fig. 3.C we used a model of selective dissolution of gases in water, using boundary conditions close to those measured at the surface. We simulate an open-system condensation process under equilibrium conditions (cf. Rizzo et al. 2019, and references therein). Results show that the previously detected anomalies of the $\text{CO}_2/{}^3\text{He}$ ratio could be explain by a less important fraction of residual gas, after the preferential dissolution of the CO_2 . The reasons for this increase of CO_2 dissolution will be investigated in more details through more advanced thermodynamic modelling, in which parameters such as temperature, pressure, pH and salinity can be varied.

Conclusion

- I. This study led to the identification of several origins of CO_2 , N_2 and helium, as well as geographical variations in the geochemical signatures.
- II. During the period 2015-2022, helium anomalies were explained by variations in surface parameters, such as gas-water equilibrium conditions.

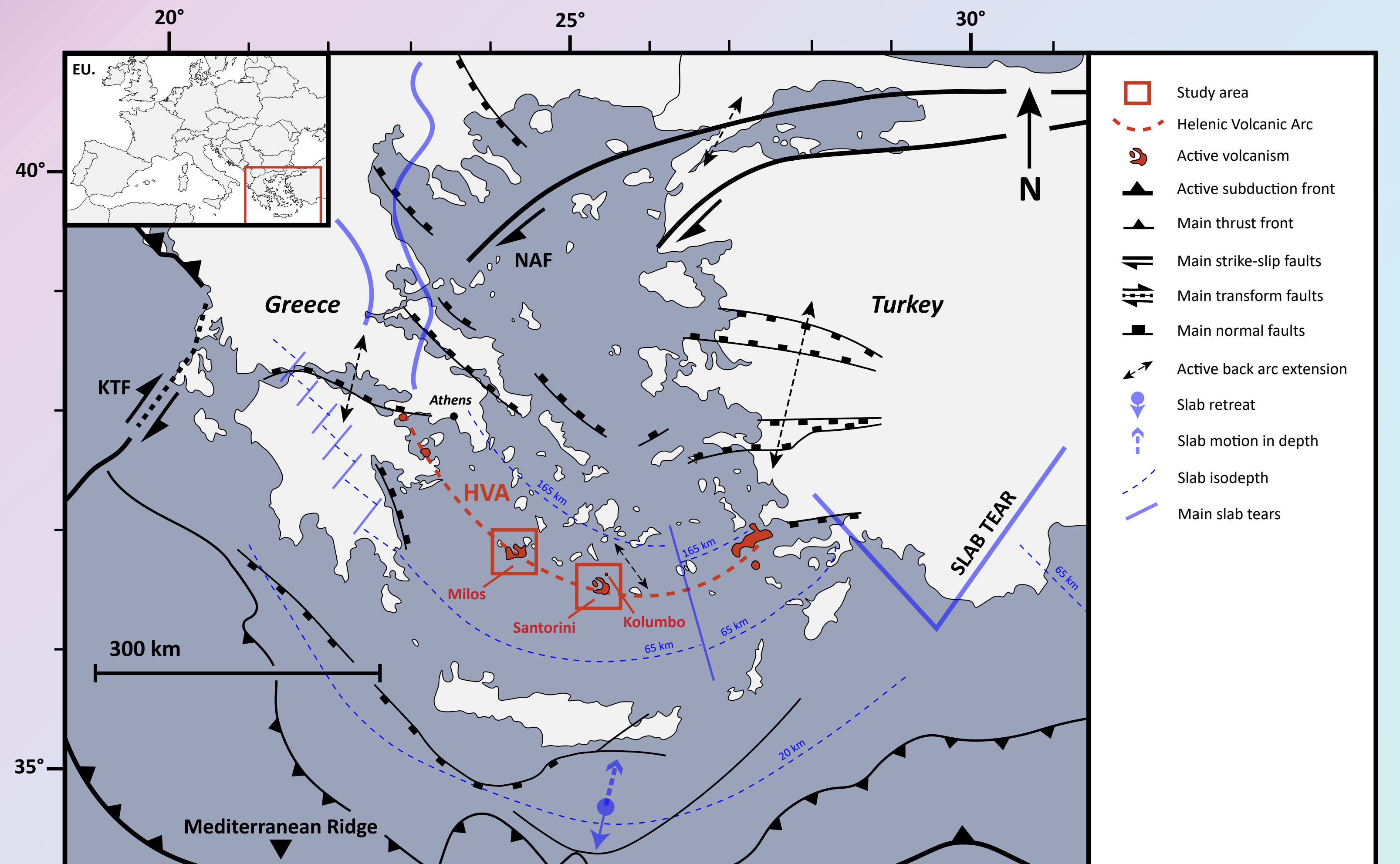


Figure 1 : Tectonic map of the Aegean sea showing the location of Santorini and Milos volcanoes. Slab features are also reported. Modified from Jolivet et al. 2013; Sachpazi et al. 2016; Bocchini et al. 2018; Hansen et al. 2019.

II. Geochemical monitoring of Santorini's fumaroles

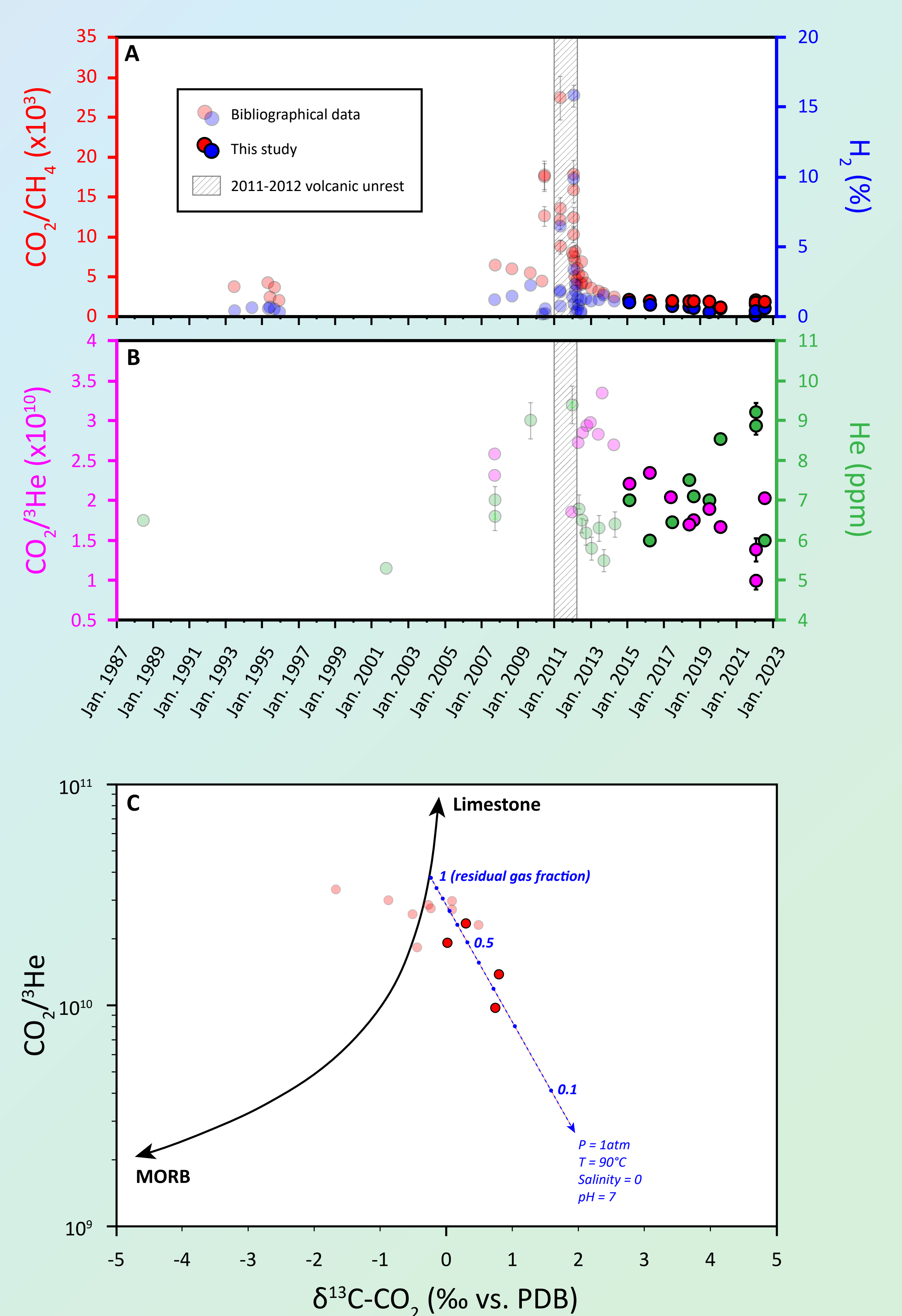


Figure 3 : A) Temporal evolution of CO_2/CH_4 ratio, and H_2 concentration. B) Temporal evolution of $\text{CO}_2/{}^3\text{He}$ ratio, and He concentration. C) $\text{CO}_2/{}^3\text{He}$ vs. $\delta^{13}\text{C}-\text{CO}_2$. Data from January 2022 are personal data, the other come from the INGV (Italy). Blue line represent the path of selective dissolution of gases in water modeled by an open-system condensation process under equilibrium conditions. (cf. Rizzo et al. 2015; 2019, and references therein).

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