Helium isotope characteristics of Andean Convergent Margin geothermal fluids

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Abstract

Subduction zones are the interface between Earth's interior (crust and mantle) and exterior (atmosphere and oceans), where carbon and other volatiles are actively cycled between Earth reservoirs by plate tectonics. Helium is highly sensitive to mantle inputs and can be used to deconvolute mantle and crustal volatile pathways in arcs. We report He isotope and abundance data for 18 deeply-sourced gas seep samples in the Central Volcanic Zone (CVZ) of Argentina and the Southern Volcanic Zone (SVZ) of Chile. We use 4He/20Ne values to assess the extent of air contributions, as well as He concentrations. Air-corrected He isotopes from the CVZ range from 0.21 to 2.58 RA (n=7), with the highest value in the Puna and the lowest in the Sub-Andean foreland fold-and-thrust belt. 4He/20Ne values range from 1.7 to 546 and He contents range from 1.0 to 31 x 106 cm3STP/cm3. Air-corrected He isotopes from the SVZ range from 1.27 to 5.03 RA (n=7), 4He/20Ne values range from 0.3 to 69 and He contents range from 0.5 to 175 x 106 cm3STP/cm3). Taken together, these data reveal a clear southeastward increase in 3He/4He, with the highest values (in the SVZ) plotting below the nominal range of values associated with pure upper mantle He (8 ± 1 RA1), but approaching the mean He isotope value for arc gases of ˜5.4 RA2. Notably, the lowest values are found in the CVZ, suggesting more significant crustal contributions to the He budget. The crustal thickness in the CVZ is up to 70 km, significantly more than in the SVZ, where it is just 35-45 km3. It thus appears that crustal thickness exerts a primary control on the extent of fluid-crust interaction, as helium and other volatiles rise through the upper plate in the Andean Convergent Margin. These data agree well with the findings of several previous studies4-14 conducted on the volatile geochemistry along the Andean Convergent Margin, which suggest a much smaller mantle influence, presumably associated with thicker crust masking the signal in the CVZ. [1] Graham, 2002 [2] Hilton et al., 2002 [3] Tassara and Echaurren, 2012 [4] Hilton et al., 1993 [5] Varekamp et al., 2006 [6] Ray et al., 2009 [7] Aguilera et al., 2012 [8] Tardani et al., 2016 [9] Tassi et al., 2016 [10] Tassi et al., 2017 [11] Peralta-Arnold et al., 2017 [12] Chiodi et al., 2019 [13] Inostroza et al., 2020 [14] Robidoux et al., 2020

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Background:
Subduction zones are the interface between Earth’s interior (crust and mantle) and exterior (atmosphere and oceans), where carbon and other volatiles are actively cycled between terrestrial reservoirs by plate tectonics (e.g., Bekaert et al., 2021).

Why helium and carbon?
Helium is a sensitive tracer of mantle inputs and can be used to deconvolute mantle and crustal volatile pathways in arc settings. Carbon is highly reactive and isotope fractionation patterns can be used to understand the dominant processes in the arc system (e.g., Barry et al., 2019).

Driving Research Question:
How do tectonic scale features (i.e., sediment thickness of incoming slab, slab dip, crustal thickness) affect volcanic outputs and the overall volatile budget?

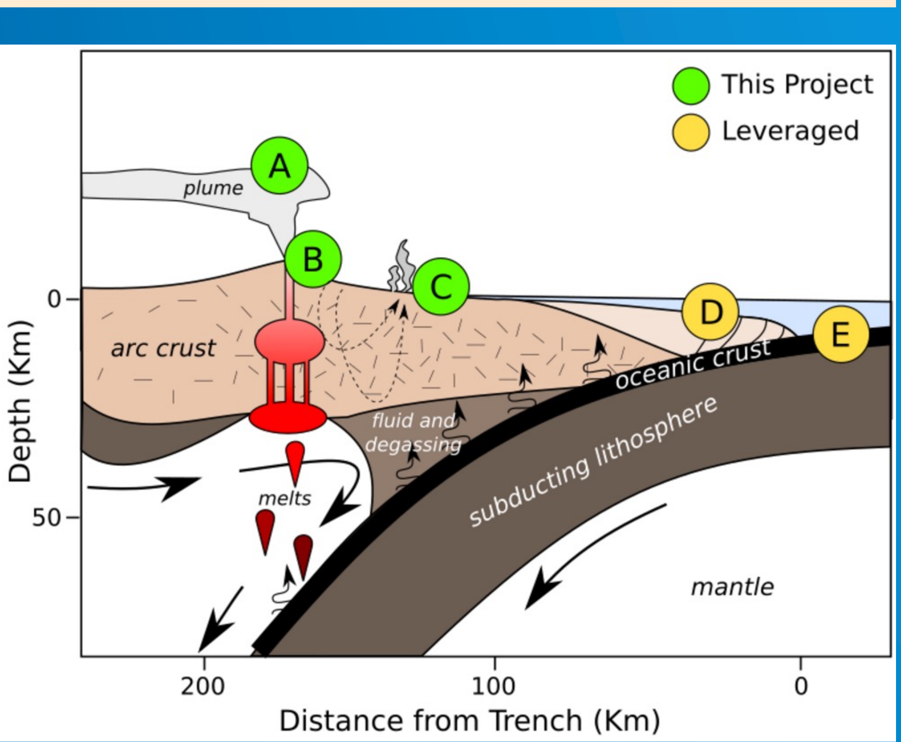


Fig. 1 - Schematic of a convergent margin showing the types of samples to be collected: A) plume fluxes, B) volcanic gases, C) forearc fluids, and leveraged IODP data: D) submarine forearc and E) downgoing slab.

Geological Context

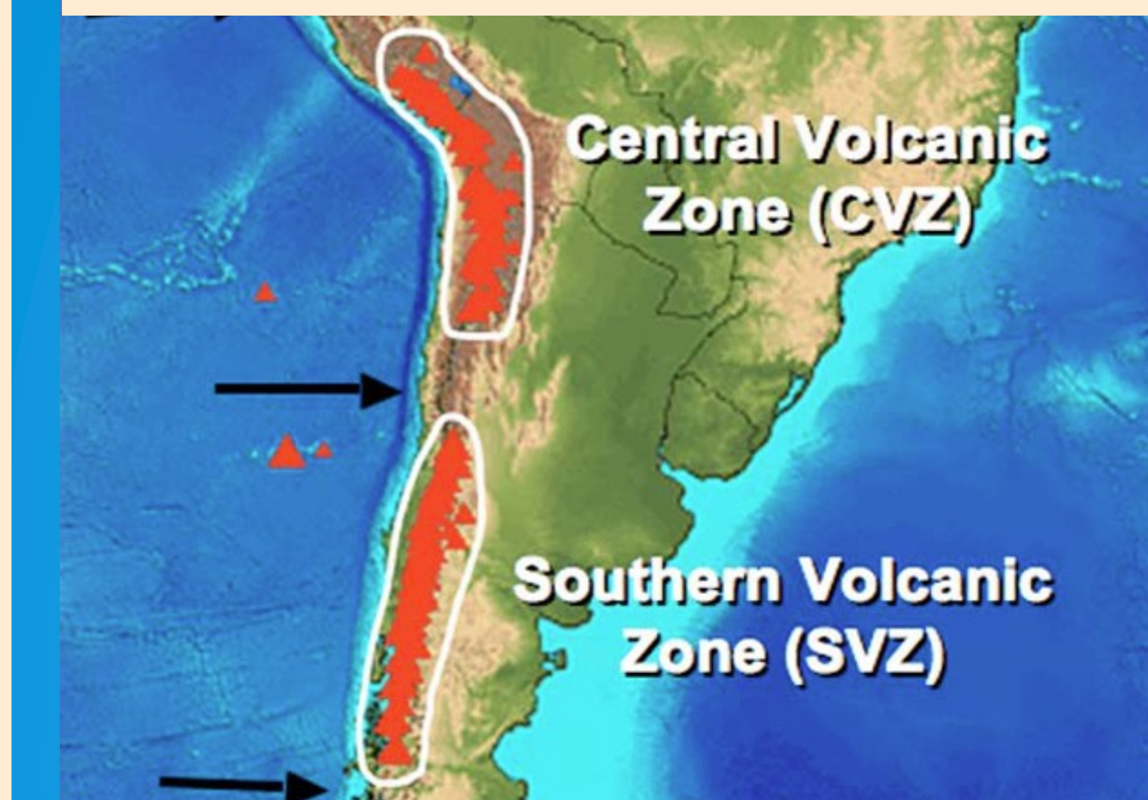


Fig. 2 - The Andean Convergent Margin (ACM). Red circle = volcanoes. Map is from Tilling et al., 2009.

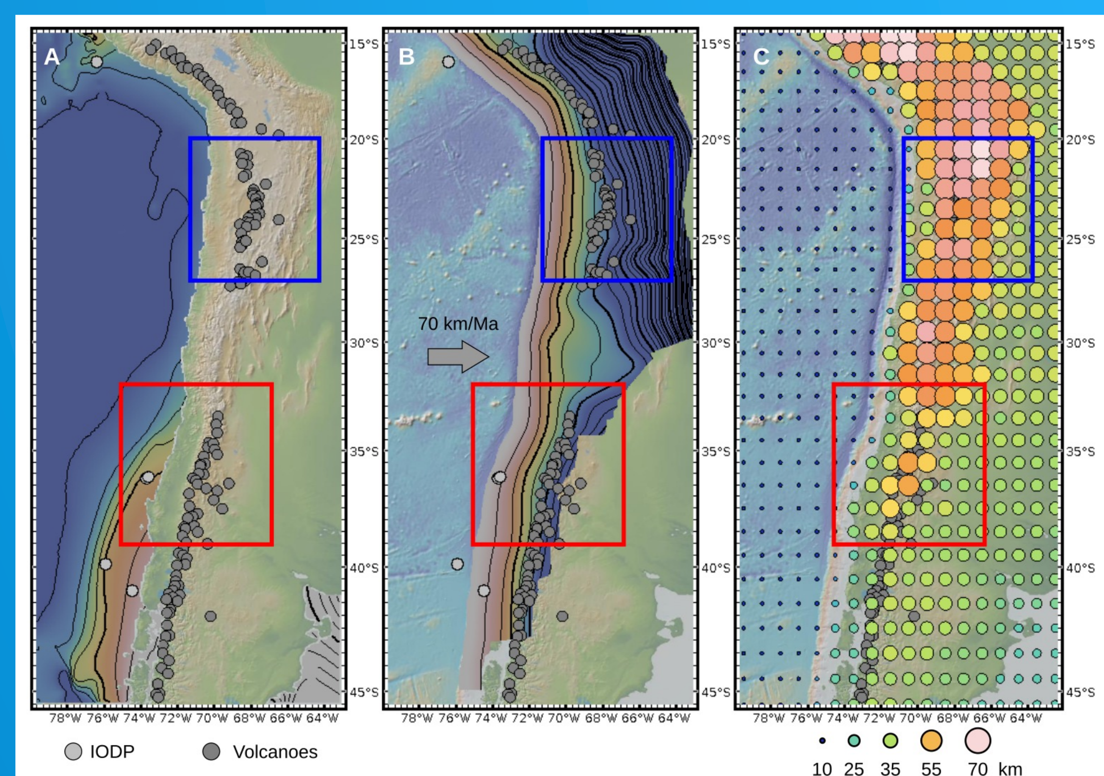


Fig. 3 - Along-arc variations in tectonic-scale phenomena. Volcanoes = grey dots. Blue box is our CVZ study area and red box is our SVZ study area.

Panel A) Offshore sediment thickness, with contour lines every 100 m and bold contour lines every 500 m.
Panel B) Depth of the slab with contour lines every 20 km and bold contour lines every 50 km. Convergence rate (70km/Ma) is also shown.
Panel C) Crustal thickness along the ACM, whereby dot size indicates crustal thickness.

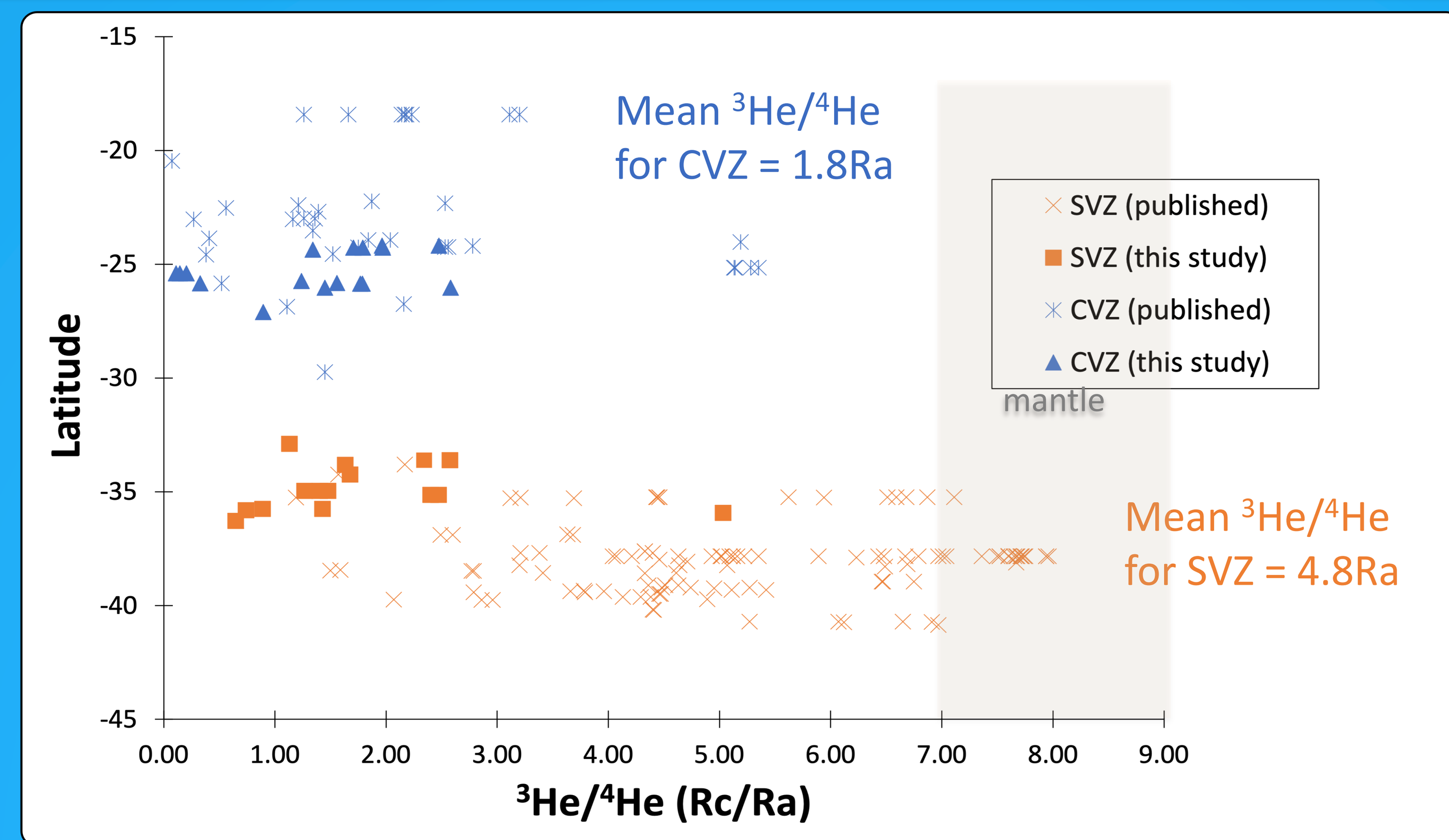


Fig. 4 - Latitudinal variations in He-isotopes in fluids and gases. The CVZ has significantly lower He isotopes, interpreted to reflect interaction with thicker (i.e., more radiogenic) overriding crust vs. the SVZ, which retains a more pristine mantle signal. Solid symbols are data from this study and crosses are published data.

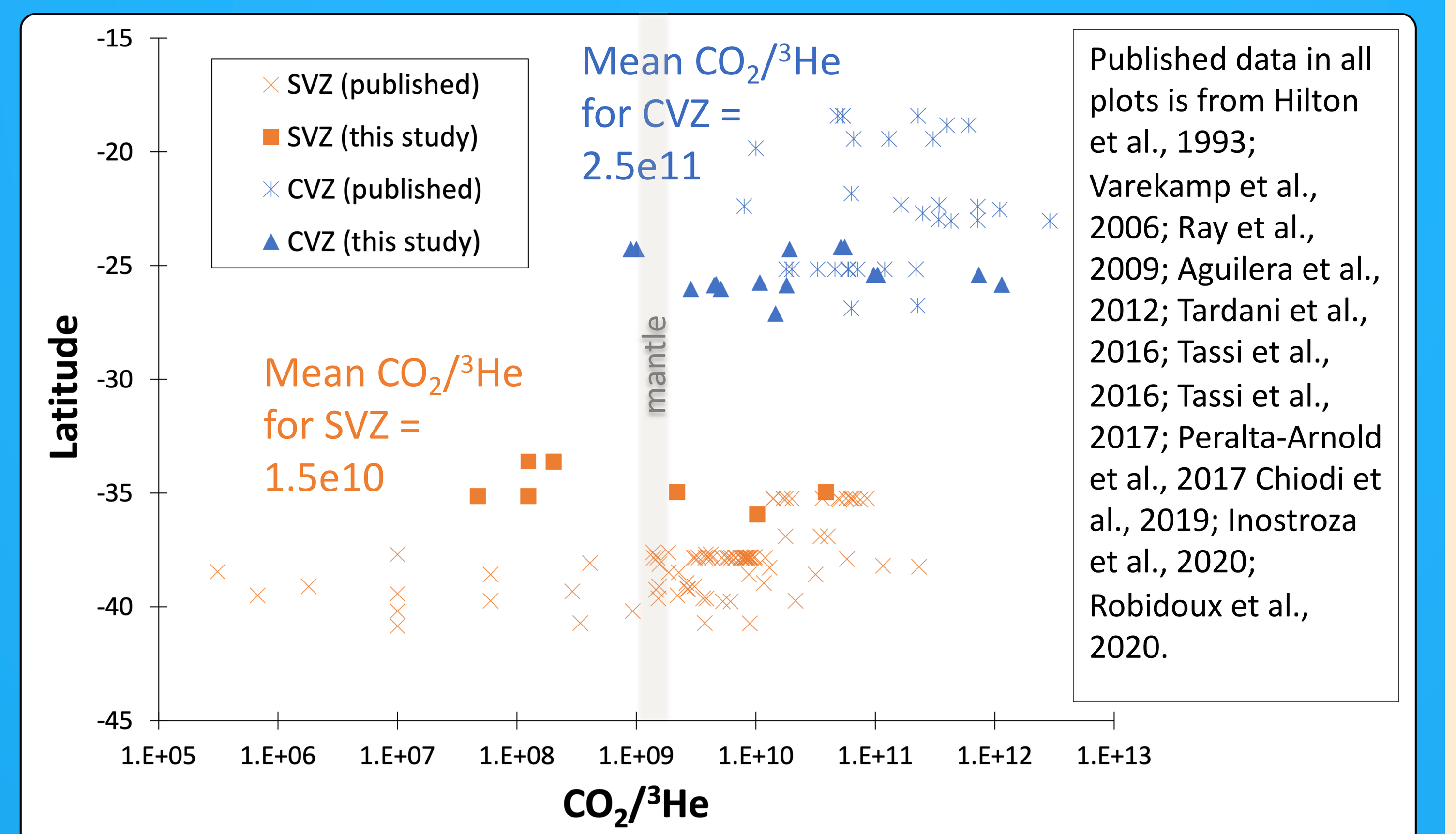
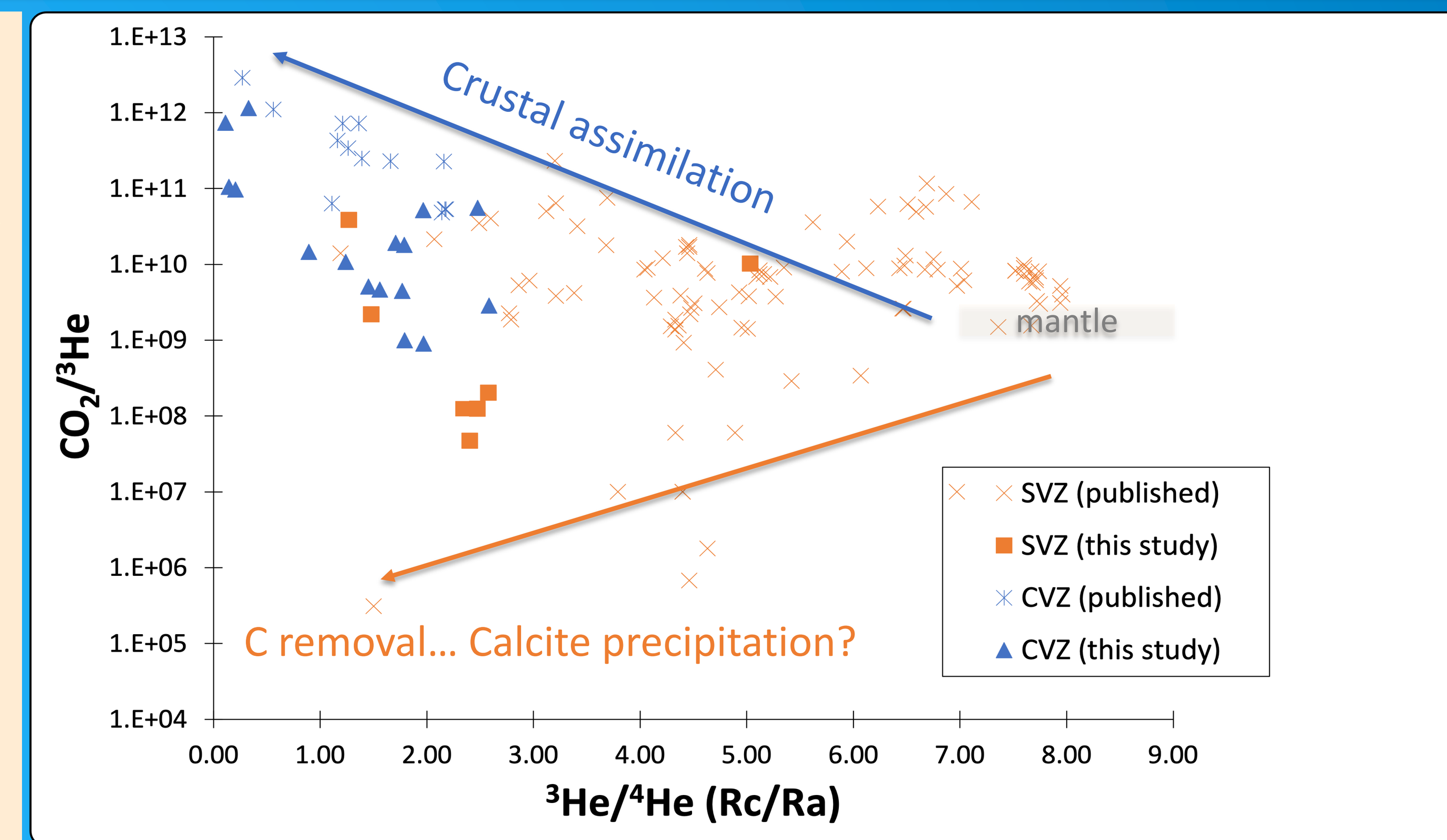
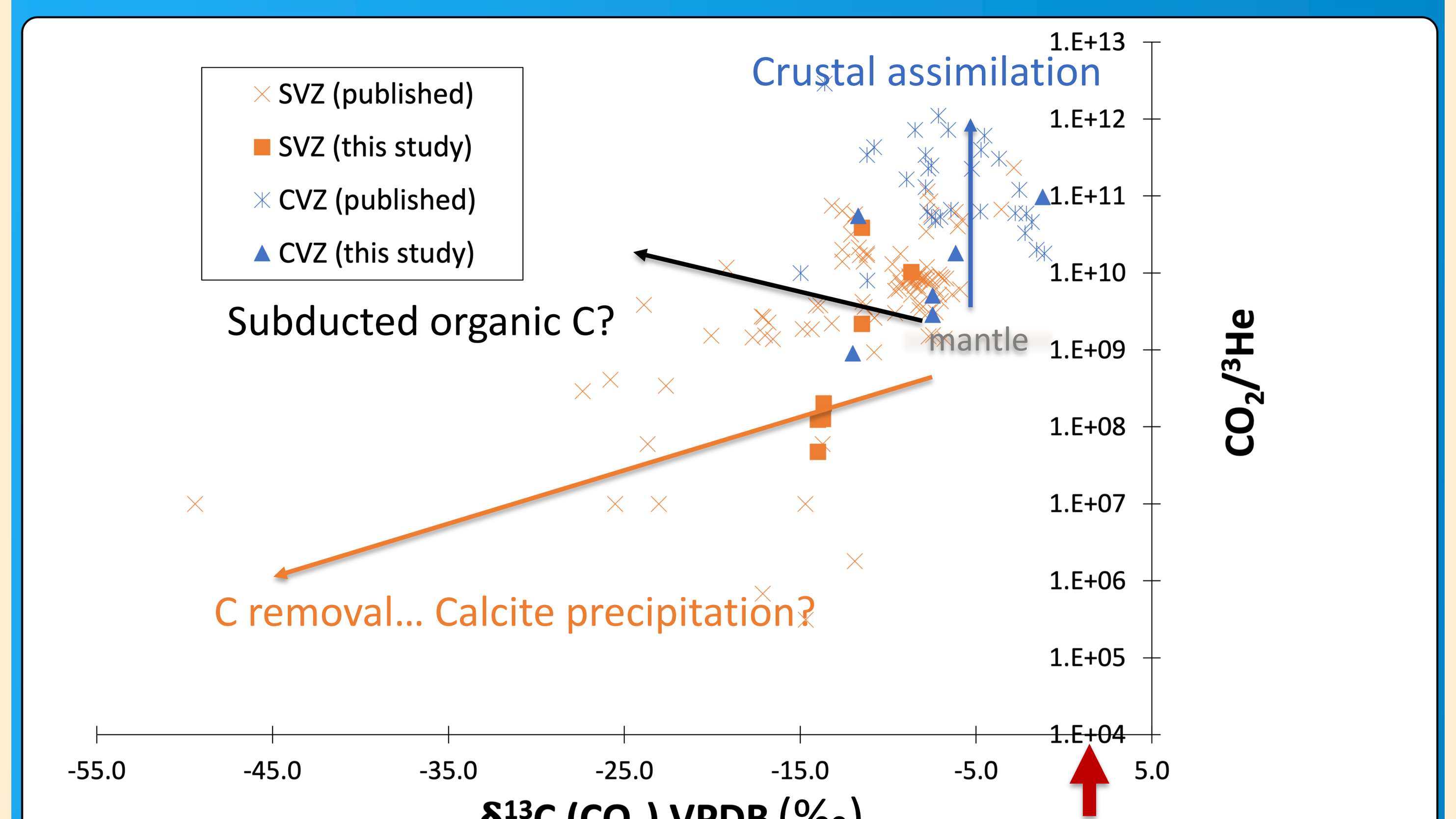


Fig. 5 - Latitudinal variations in $CO_2/^3He$. All CVZ samples have gained excess CO_2 relative to mantle ^3He, whereas SVZ values are typically lower and more variable.





Mean CVZ Calcite = 1.1 ‰

Fig. 6 - $CO_2/^3He$ vs. $^3He/^4He$. Higher $CO_2/^3He$ and lower $^3He/^4He$ in the CVZ are attributed to crustal assimilation, whereas SVZ are more mantle like.

Fig. 7 - $CO_2/^3He$ vs. C isotopes. Almost all CVZ samples are above mantle values, suggesting crustal assimilation. SVZ values are more disparate, potentially suggesting C removal (due to calcite ppt or biological processes?; Barry et al., 2019) or a light subduction signature associated with organic sediments in the slab.

Summary:

1) We report new He and C isotope and abundance data for 33 deeply-sourced fluid and gas samples in the CVZ of Argentina and the SVZ of Chile.
2) Air-corrected He isotopes from the CVZ range from 0.11 to 2.58 R_A (n=17), SVZ range from 0.65 to 5.03 R_A (n=16). New data are plotted alongside published data in figs.
3) Lowest He isotopes are in the CVZ = more significant crustal (radiogenic) contributions. The crustal thickness in the CVZ is up to 70 km, significantly more than in the SVZ (35-45 km). Overriding crustal thickness exerts a primary control on the extent of fluid-crust interaction.
4) Carbon isotopes vary between -12.0 to -1.2‰ (vs. PDVB) in the CVZ and $CO_2/^3He$ values vary over 3 orders of magnitude (9.0×10^8 to 1.1×10^{12}). In the SVZ, carbon isotopes ($\delta^{13}CO_2$) vary between -14.0 to -8.7‰ (vs. PDVB) and $CO_2/^3He$ values vary by nearly 3 orders of magnitude (4.7×10^7 to 3.9×10^{10}). Lower $\delta^{13}CO_2$ and $CO_2/^3He$ values in the SVZ are consistent with calcite precipitation in shallow-level (upper 5 km) hydrothermal systems (e.g., Ray et al., 2009).
5) Offshore sediment thickness, and thus delivery of isotopically light C is higher in the SVZ and could explain some of the lighter C isotopes. No correlations is detected with slab angle.

Open Questions:
1) Why is SVZ seemingly more affected by removal of carbon? 2) What is the role of biology in the SVZ? 3) What is the role of organic soil carbon in the SVZ? Adding fluid residence time information (tritium and ^{14}C) to future studies will help differentiate between deep and surface processes and enable flux calculations.