Extremely fast fluid fluxes through metamorphic rocks on Syros, Greece

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I. Introduction

During mountain building, metamorphic reactions cause the breakdown of hydrous and carbonate minerals and liberate volatiles such as H_2O and CO_2. These fluids travel upwards in Earth's crust until they ultimately reach the surface. On their way the fluids interact with the surrounding rocks and can change their composition. How big is the influence of the released CO_2 on the global carbon cycle? To answer this question we have to study the reactions in metamorphic rocks and track fluid-rock interactions along ancient fluid flow pathways. The values obtained in these studies can be used to calculate carbon fluxes in Earth's crust. Here, we present field, petrological and geochemical evidence from Syros in the Greek Cyclades of high fluid fluxes during mountain building.

II. Study area

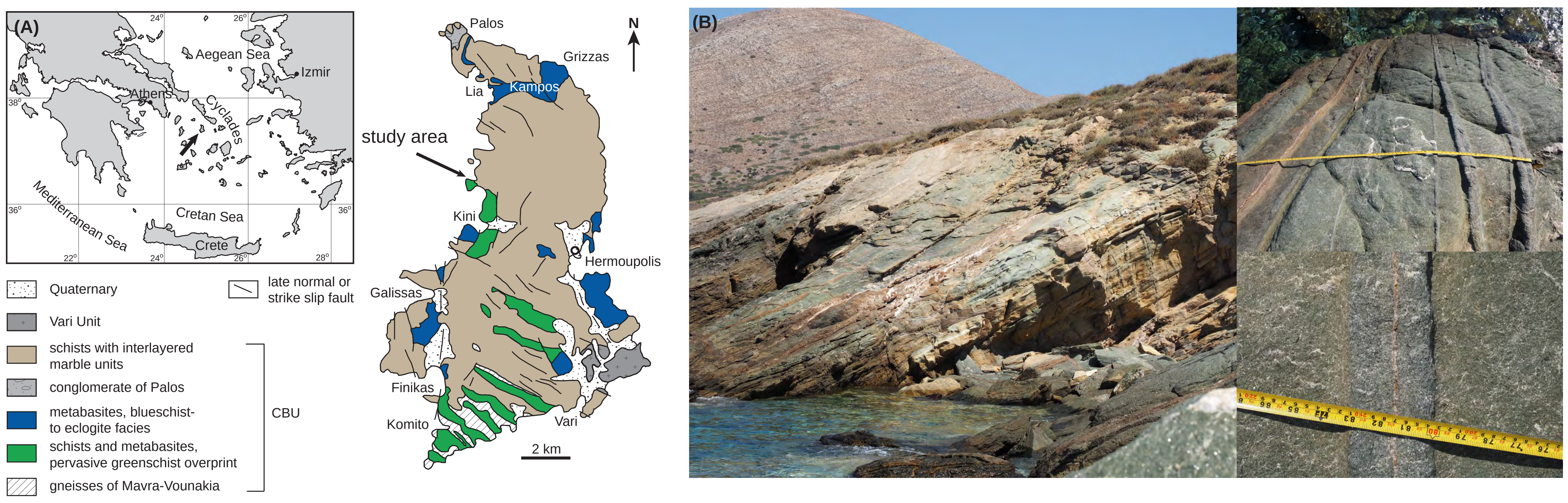

Fig. 1: (A) Geological map of Syros (modified after [1]). (B) The outcrop comprises a number of cross-cutting carbonate-quartz veins with variable widths (from 0.1 to 5 cm) which cut through the foliated schists. The veins are surrounded by symmetrical dark halos surrounding these veins. These halos can reach a width of up to 60 cm.

III. Petrography, geochemistry and mineral reactions

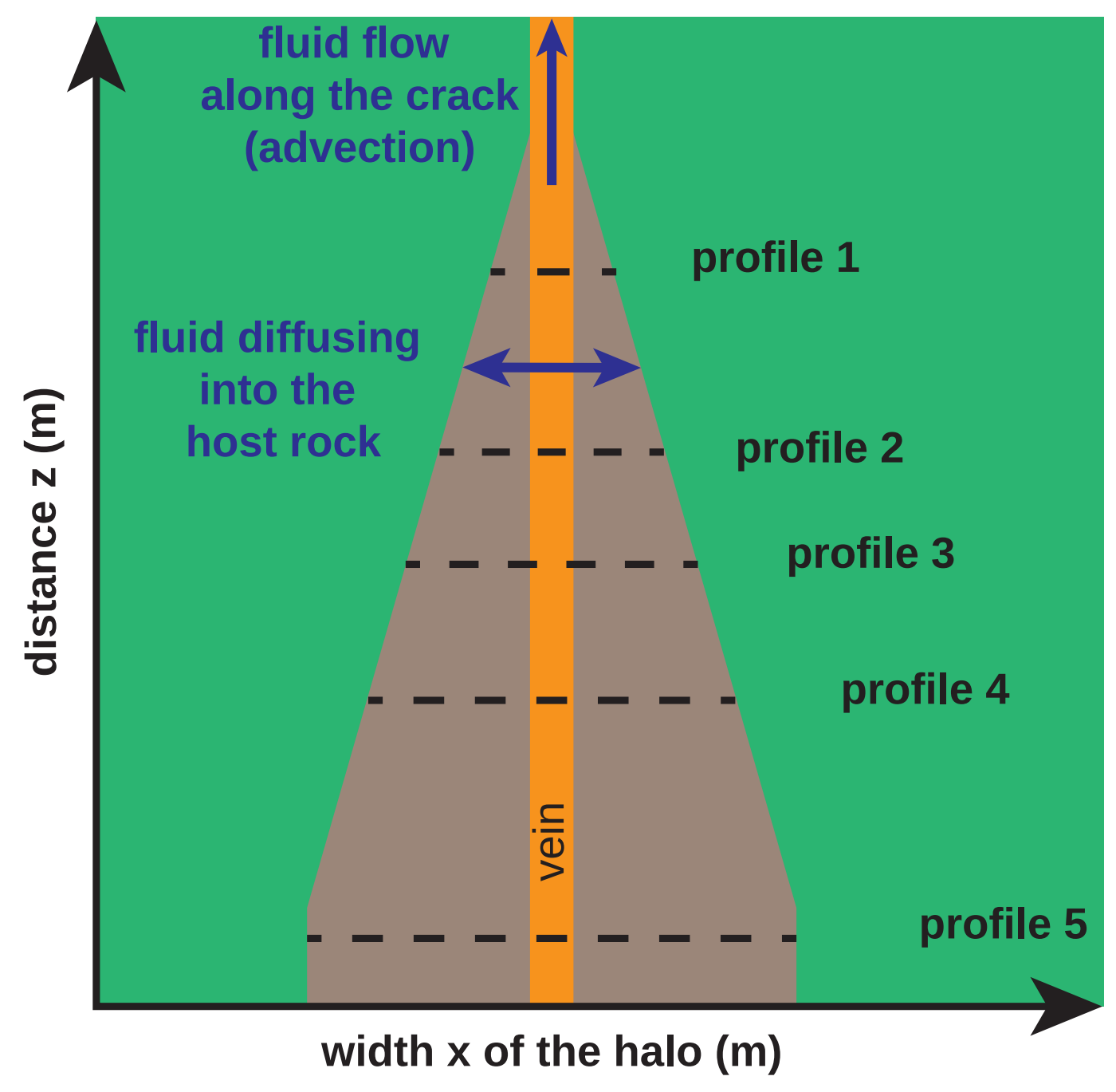

Fig. 2: Five profiles for mineralogical and geochemical analysis have been sampled across the halo along a vein.

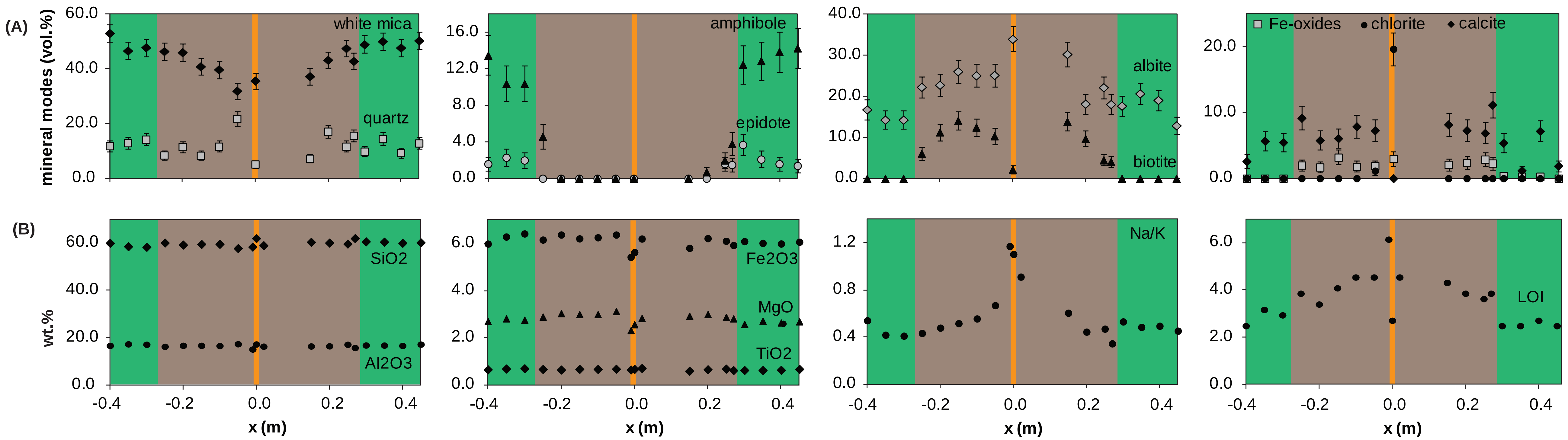

Fig. 3: (A) Changes in mineralogy along profile 5. (B) Reactions must have occurred largely isochemically with respect to volatiles and a few trace elements.

Based on modal data, reaction textures and geochemistry following carbonation reaction can be derived:

2 amphibole + 5 white mica + 4 CO_2 = 5 biotite + 21 quartz + 4 calcite + 2 H_2O

The fluid which caused the reaction halos around the fractures was most likely a CO_2-H_2O bearing fluid.

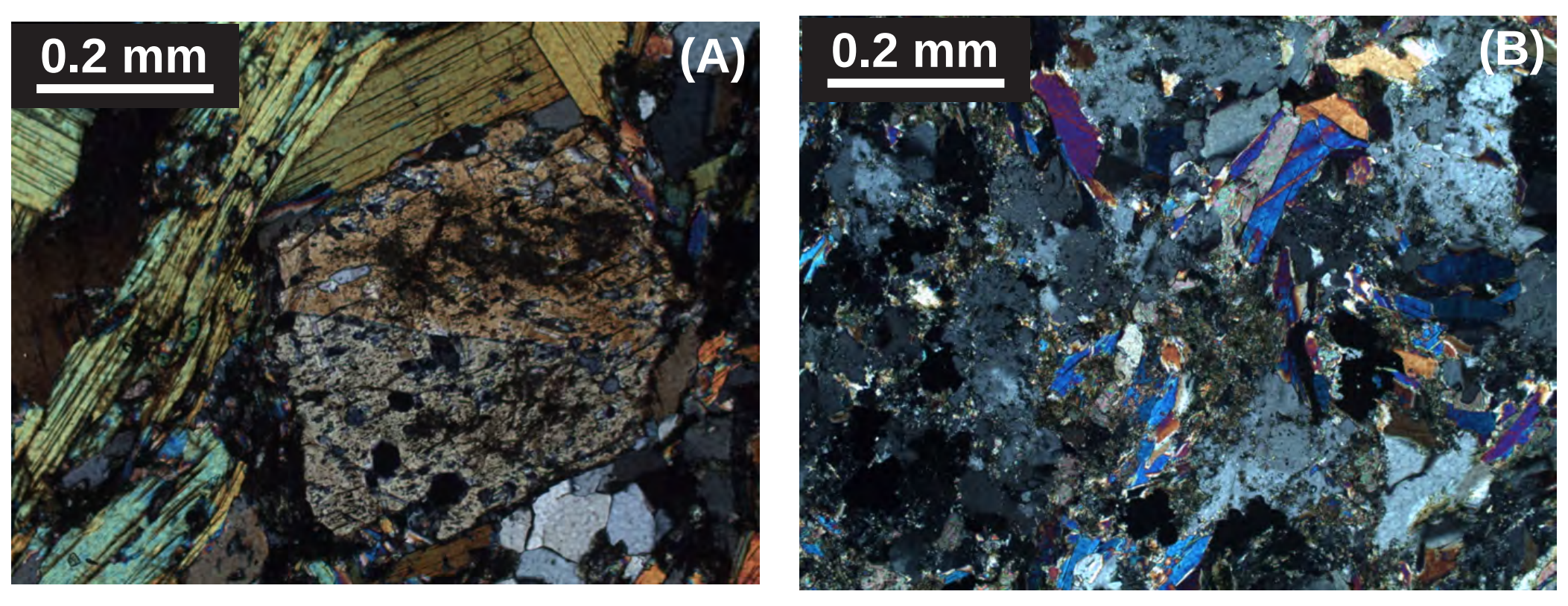

Fig.4: Amphibole and white mica before (A) and after (B) carbonation.

IV. Discussion

The perfect outline of the reaction halos and the concentration ratio Sr/Ca provide powerful tools to model the duration of fluid flow and fluid velocities along ancient fluid pathways (veins).

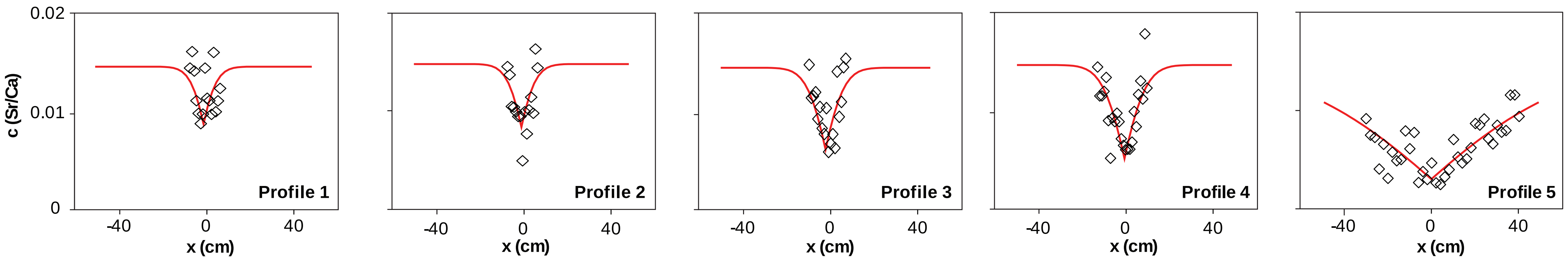

Fig.5: Profiles showing the concentration ratio Sr/Ca (open diamonds) and model fits (red lines).

Modeled concentration ratio Sr/Ca:

$$\frac{c_v}{c_0} = erfc\left(\frac{\frac{x\theta}{b^2}\left(\frac{Dh}{v}\right)^{0.5}}{2(t-x)^{0.5}}\right) \quad \text{vein}$$

$$\frac{c_h}{c_0} = erfc\left(\frac{\frac{x\theta}{b^2}\left(\frac{Dh}{v}\right)^{0.5} + \frac{(z-b)}{D^{0.5}}(vh)^{0.5}}{2(t-x)^{0.5}}\right) \quad \text{halo}$$

Velocity of fluid flow:

$$v = -\frac{b^2}{3\mu}\frac{dP}{dx}$$

velocities of the fluid in the vein: 10^{-5} - 10^{-2} m/s

duration of fluid flow: 0.008 - 5 years

Large vein widths give small estimates of flow velocity, but large estimates of timescales!

V. Conclusion

- Fluid flux along the veins ranged from 10^{-2} to 10^{-5} m/s. This is several orders of magnitude faster than typical groundwater fluxes.

- Fluid flow along each vein was active over a period of years. This is shorter than previous estimates of meatmorphic fluid duration.

- Metamorphic fluid flow might be a short term phenomena which is capable of influencing surface systems on societally-relevant timescales.

VI. Appendix

c_v = tracer concentration in the vein

c_h = tracer concentration in the halo
ν = fluid velocity in the fracture;
D = diffusion coefficient
b = half fracture aperture;
z = distance along the fracture
x = is the halo width
θ = rock porosity
t = time
h = arbitary lenght scale
μ = dynamic viscosity
dP/dx = hydraulic pressure gradient

VII. References

[1] Keiter et al. (2011) Geological Society of America Special Paper 481, 43pp.