Alteration of Venus Surface Materials: Experimental Perspectives

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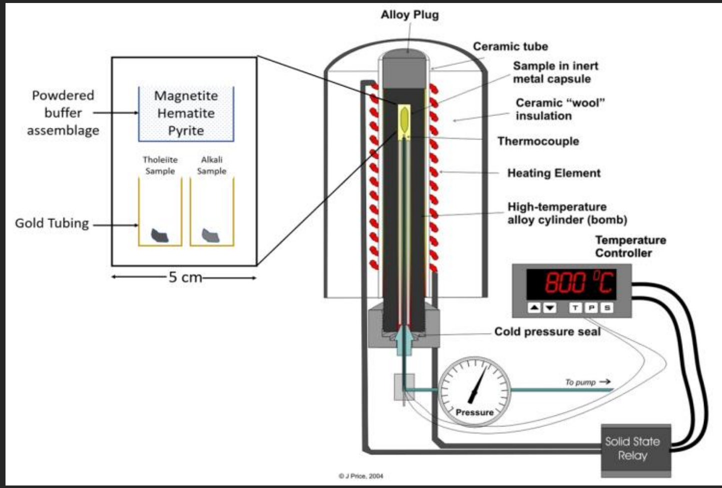
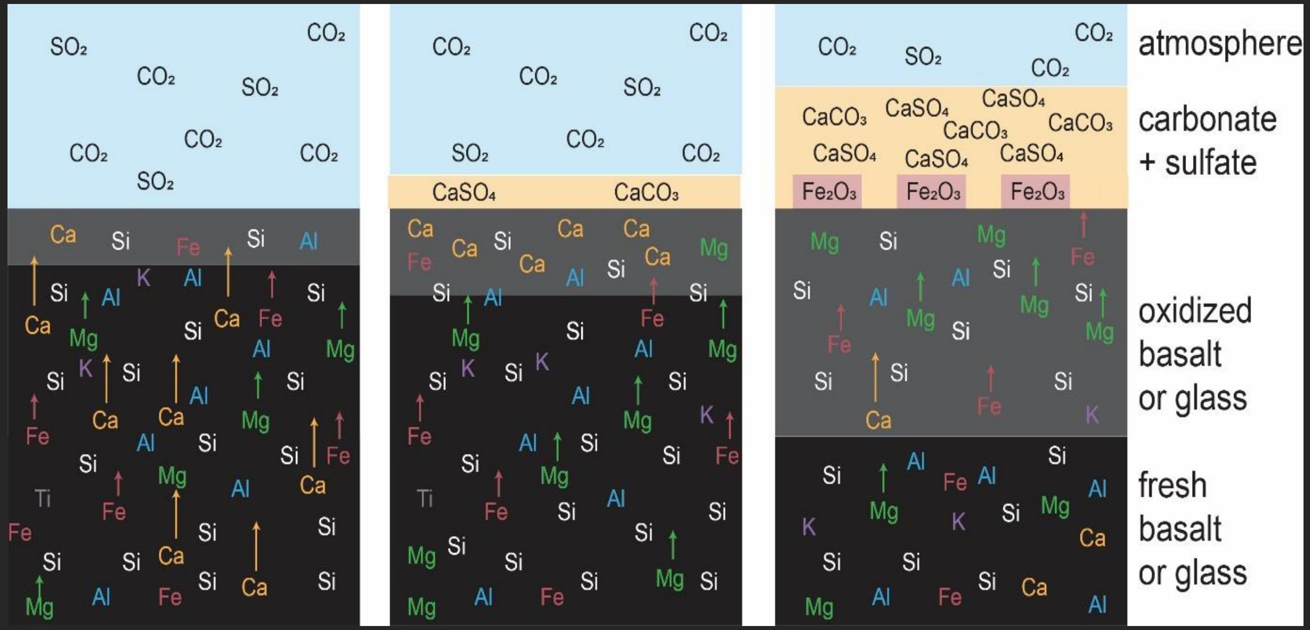


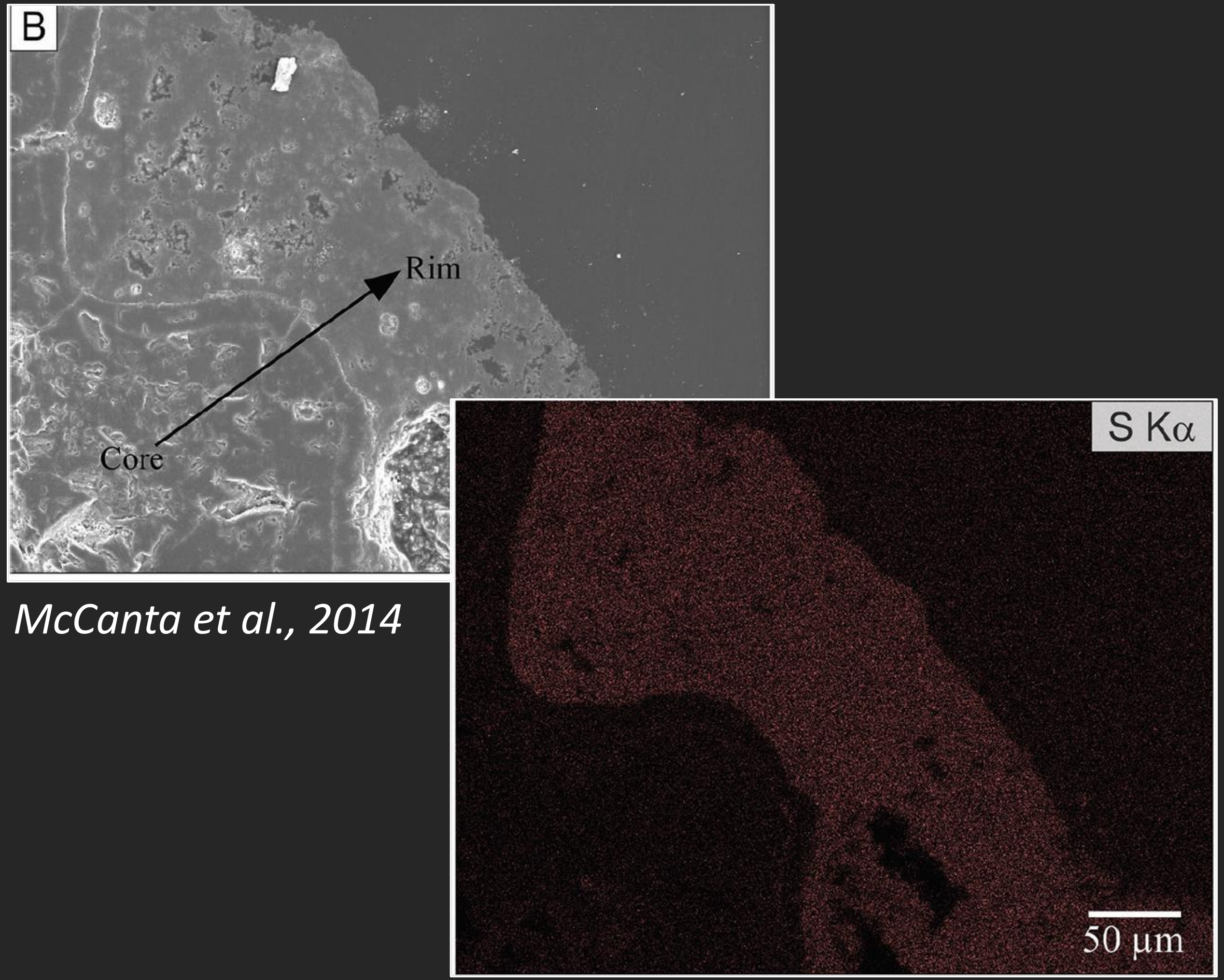
Laboratory experiments are crucial

- Venus surface-atmosphere conditions & composition unlike any terrestrial analogues, difficult to model
  - Low T oxidation may be inconsistent with equilibrium thermodynamics
- Formation of altered surface species dominated by diffusion of divalent cations to surface to react with atmosphere
- At depth oxidation occurs due to removal of cations (increasing oxygen/cation ratio)



Laboratory experiments are crucial

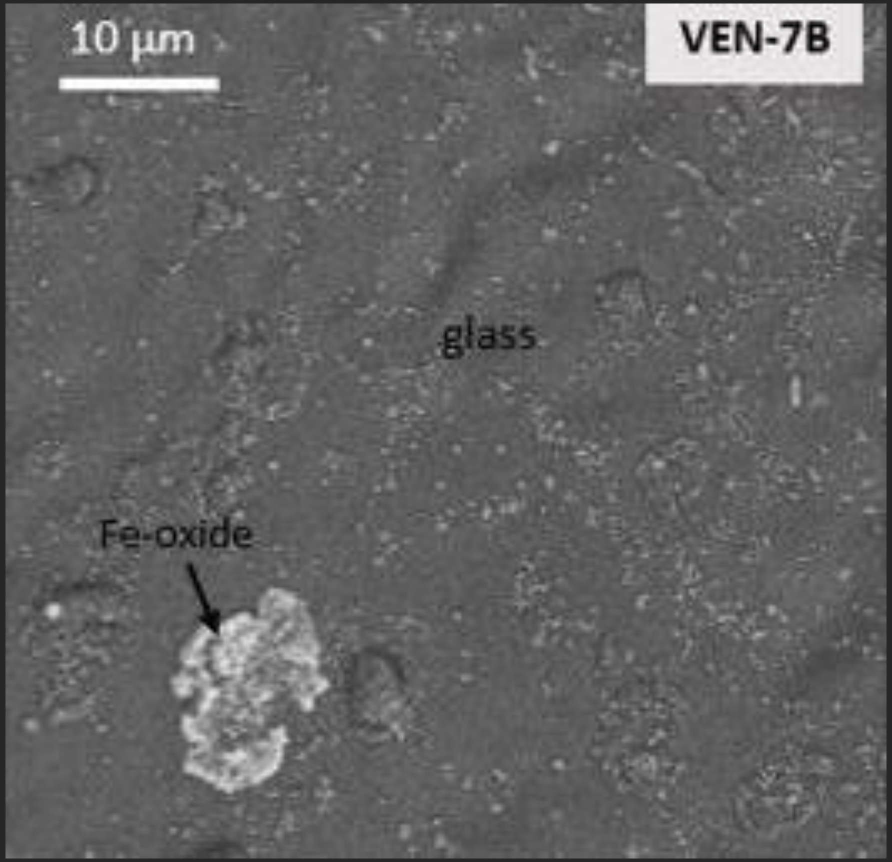
- Reactions will determine surface compositions returned by spacecraft
- Alteration may obscure spacecraft analysis
- Alteration presence/absence may determine rock unit age



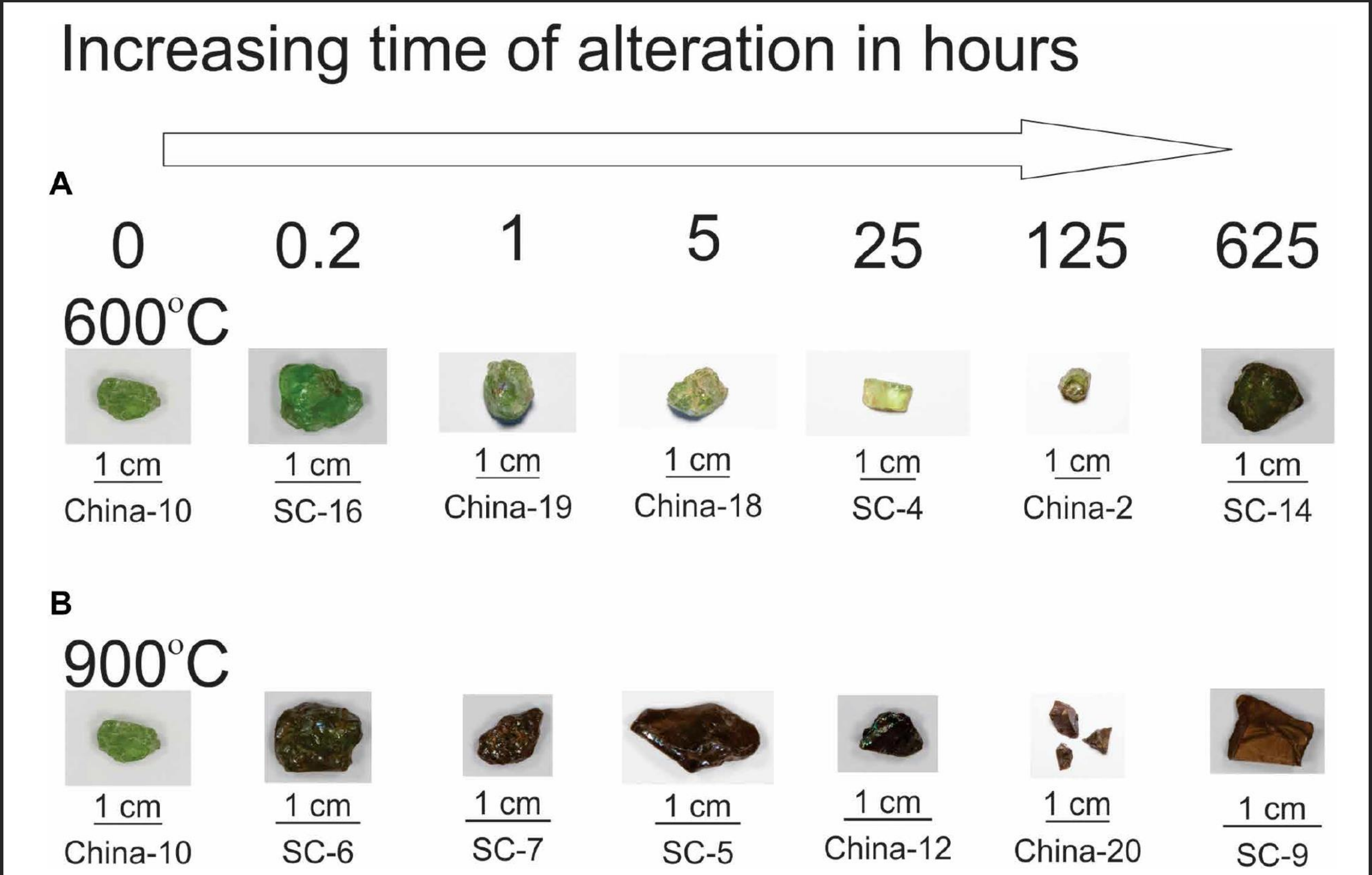
McCanta et al., 2014

Experimental parameters: Oxidation

- Reaction of basalt/basaltic minerals at Venus (or Earth) atmosphere-temperature conditions
  - Results: Fe-oxide coatings, mineral changes to include Fe^{3+} (*Teffeteller et al., 2019*; *Cutler et al., 2020; Filiberto et al., 2020*)
- Rapid oxidation rates (days-months): coat surfaces with NIR-opaque Fe-oxide coating
  - Hematite, magnetite, maghemite, magnesioferrite

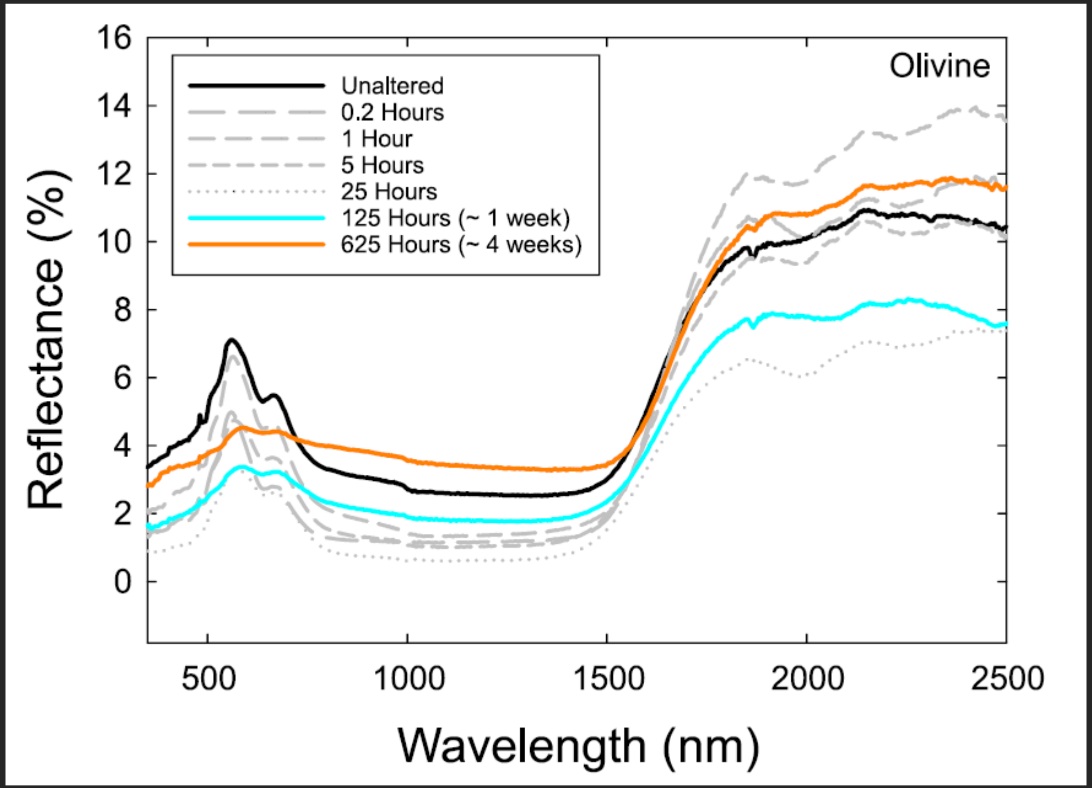


Teffeteller et al., 2019

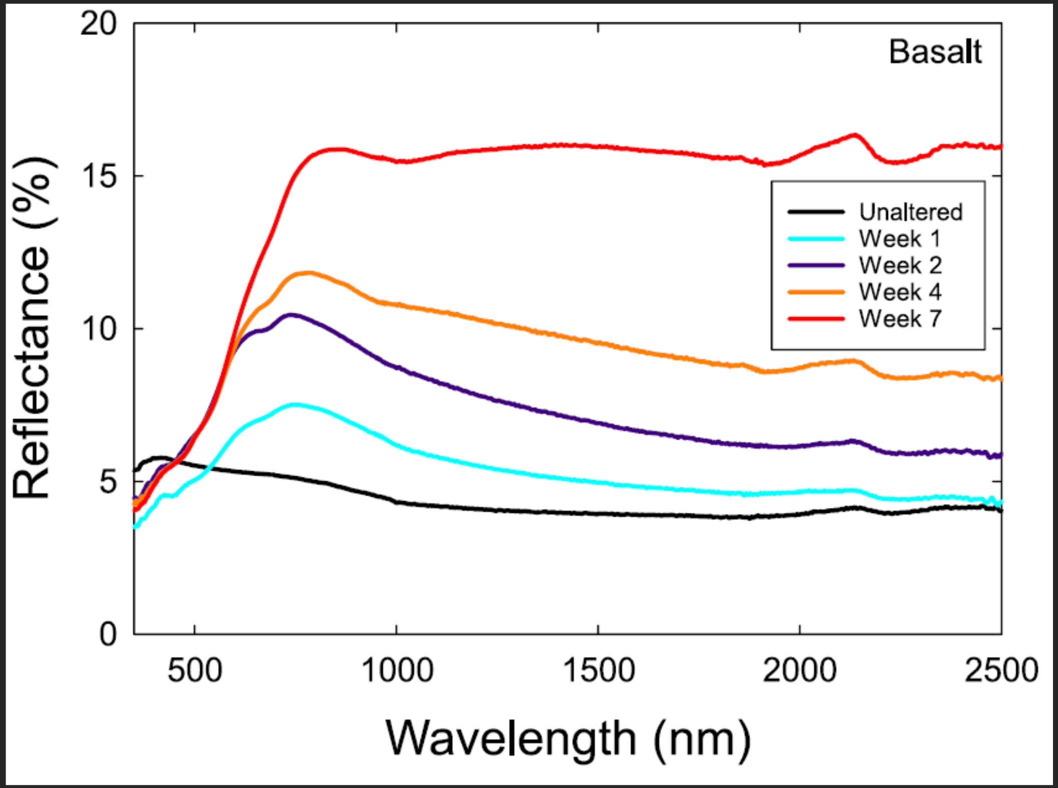


Filiberto et al., 2020

Experiments: Earth atmosphere, 1 atm, 600-900°C, duration ≤ 4 weeks

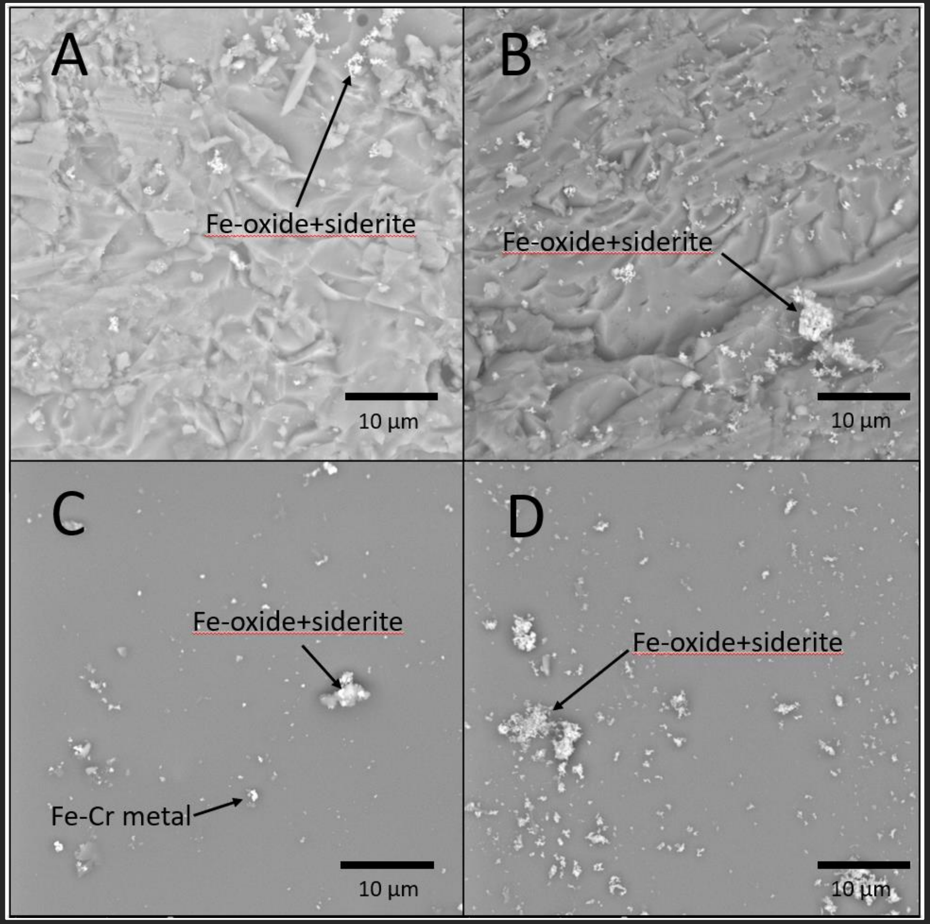


Filiberto et al., 2020

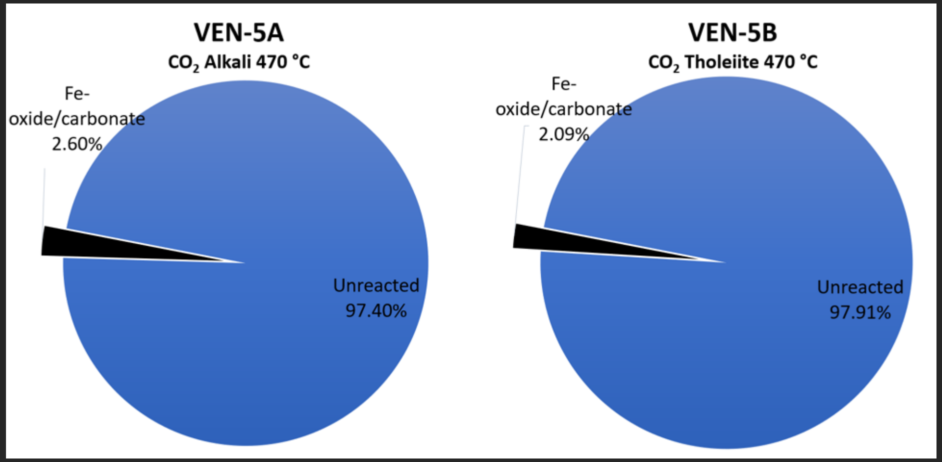


Cutler et al., 2020

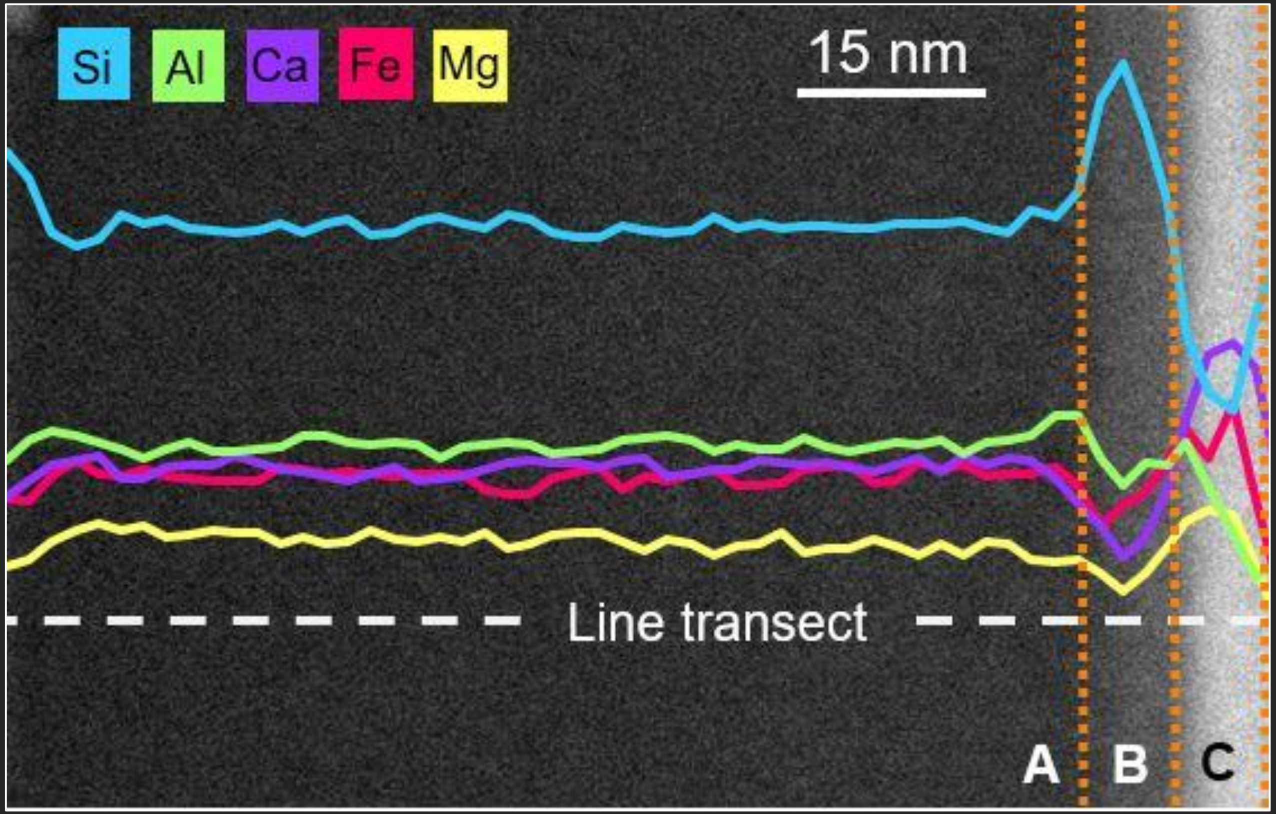
Experiments: all CO_2 atmosphere, 90 bars, 470°C, duration ≤ 3 weeks



Composition matters as related to surface layer development– alkaline vs. tholeiitc basalt

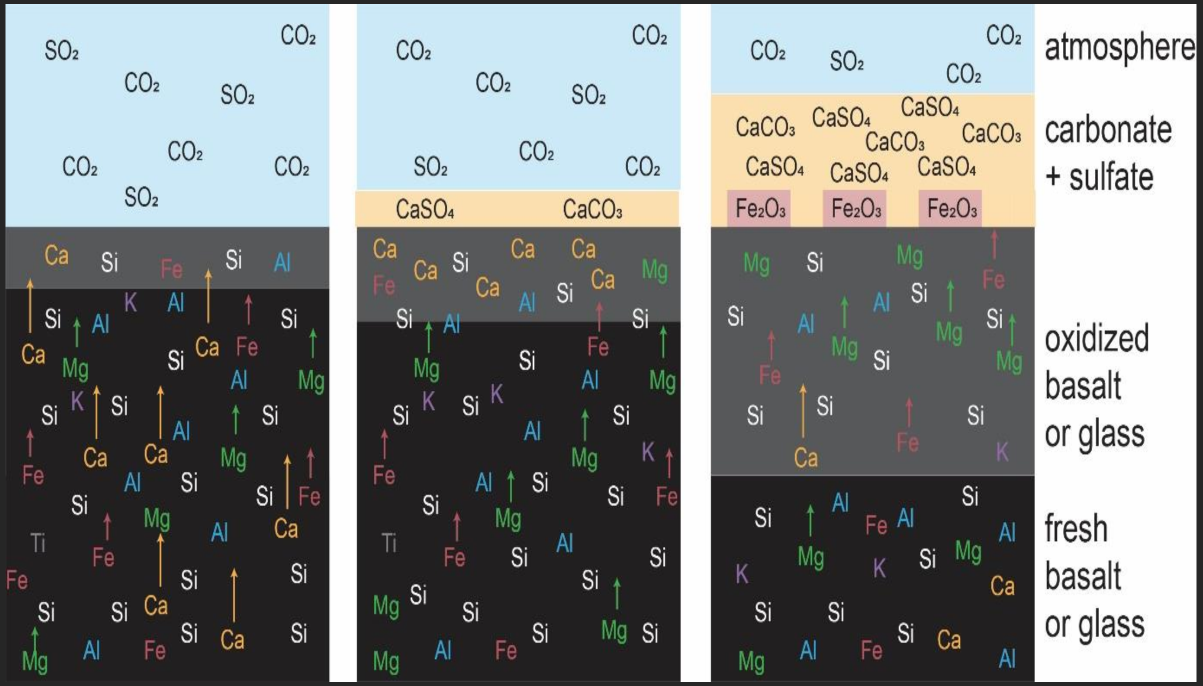


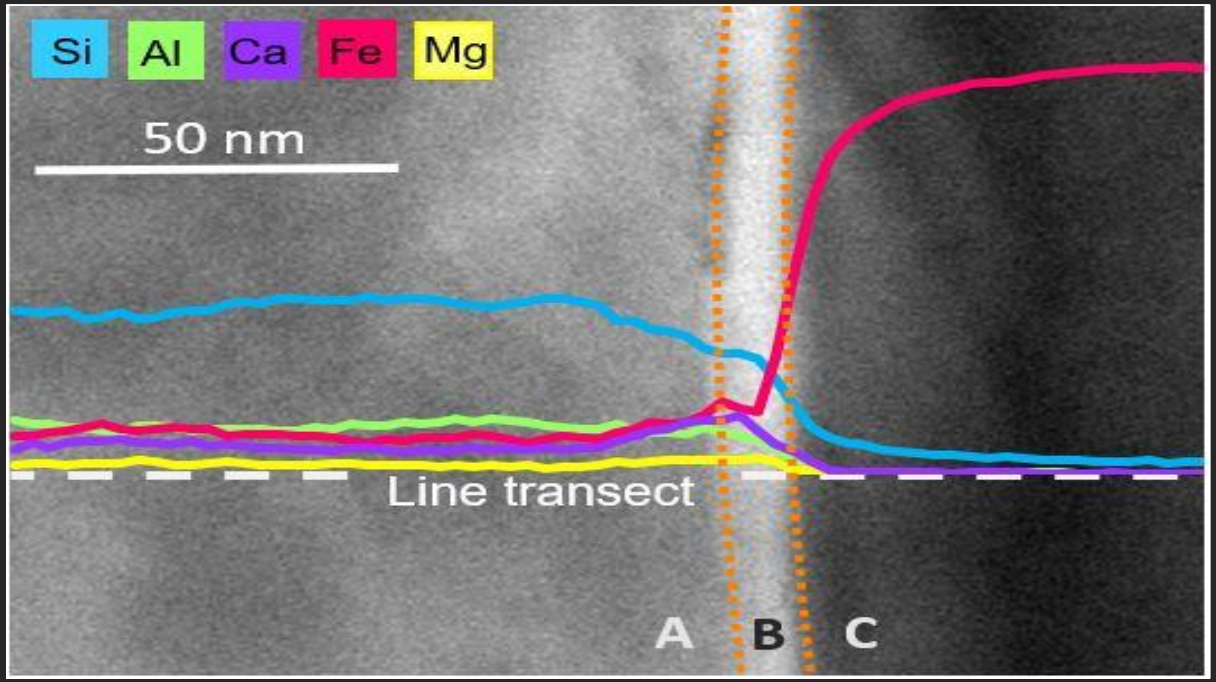
Reid et al., 2021



Ven-5B: tholeiite, T = 470°C, P = 90 bars, f_{O2} = MH, duration = 15 days

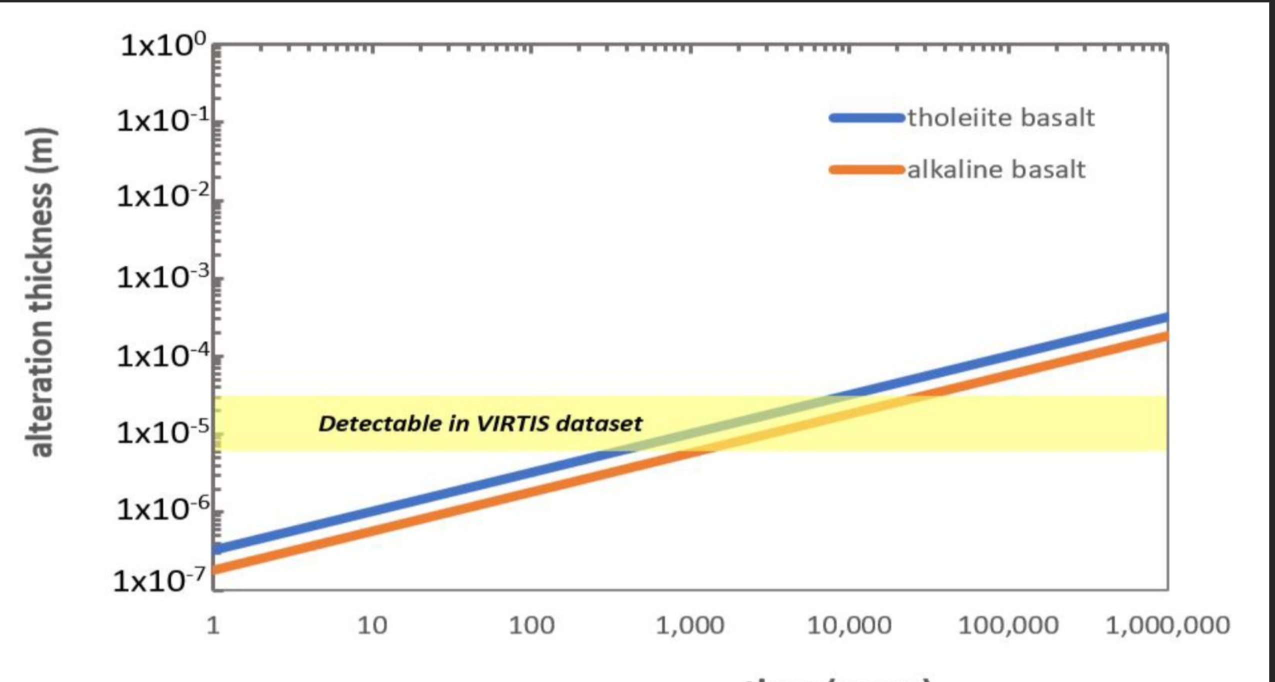
- Oxidation effects propagate into sample due to element mobility
- Elemental flux to surface followed by development of rate-limiting passivation layer





Ven-5A: alkaline, T = 470°C, P = 90 bars, f_{O2} = MH, duration = 15 days

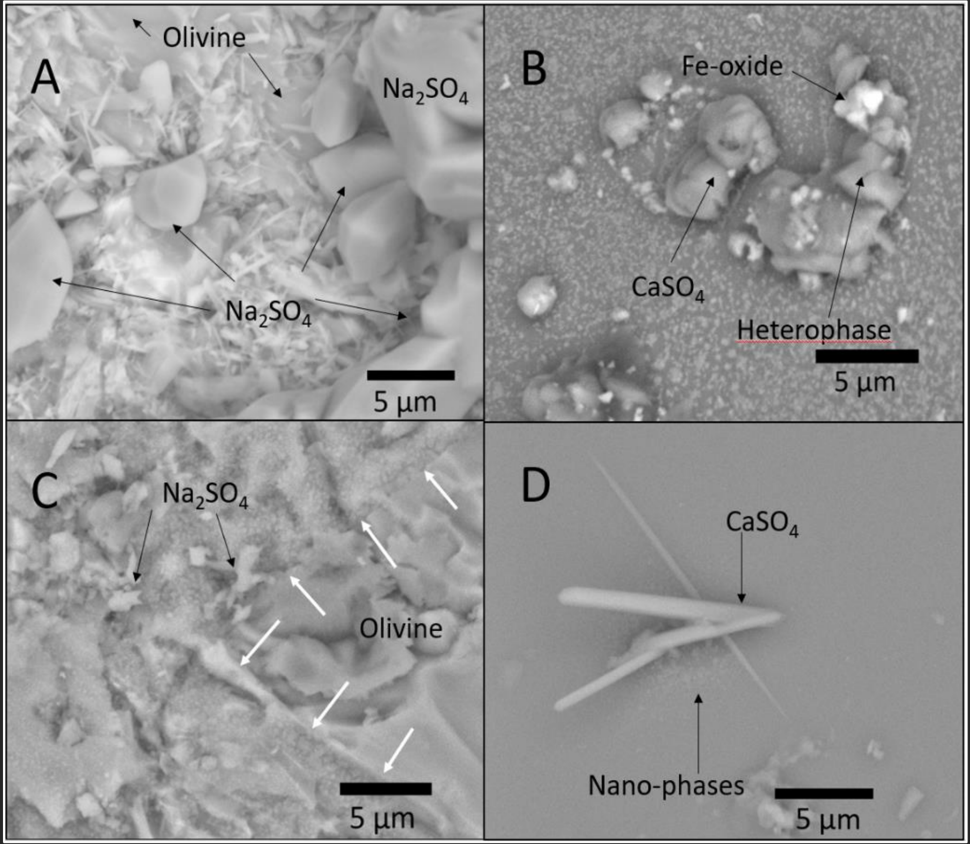
- Slow reaction rates below surface (100's – 1000's years to obscure spectral signal)



Teffeteller et al., 2021

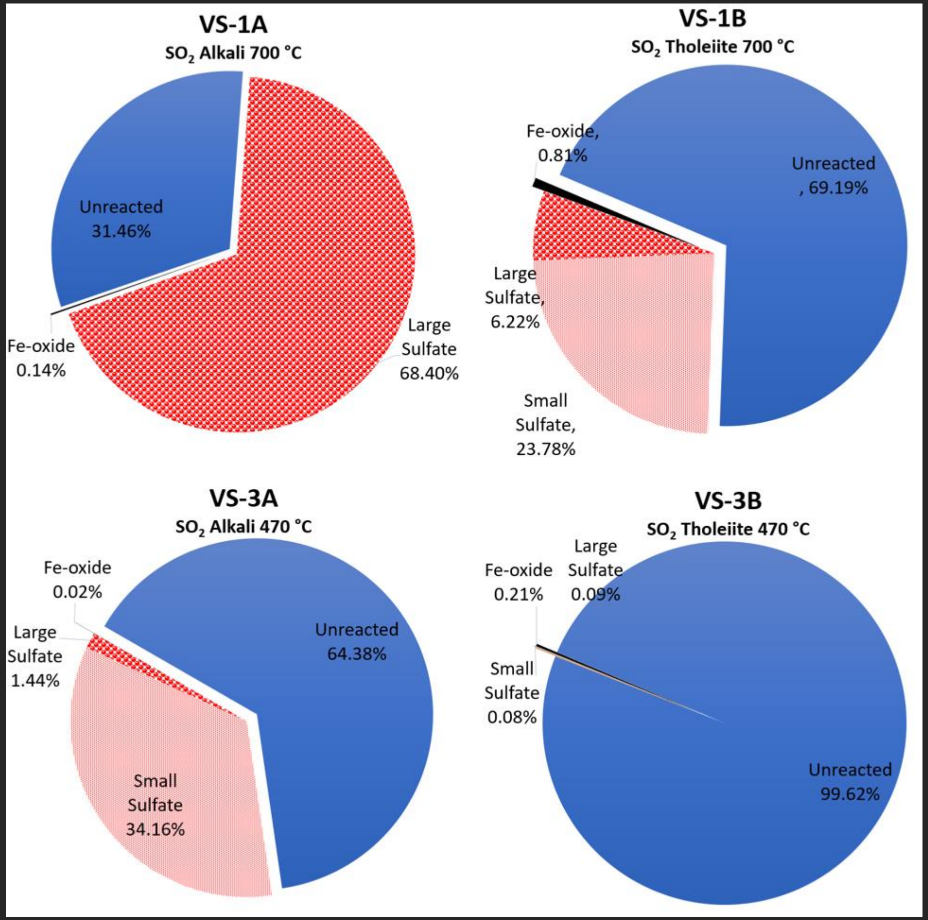
Experimental parameters: Sulfate formation

- Atmospheric S varies significantly over time
  - Related to S-rich volcanic eruptions, followed by chemical sequestration to the surface
- Surface coating of anhydrite ($CaSO_4$), alkali sulfates & carbonates (*Renggli & King, 2018; Berger et al., 2019; Reid et al., 2021*)



Reid et al., 2021

Experiments: CO_2 + SO_2, 90 bars, 470-700°C, duration ≤ 3 weeks

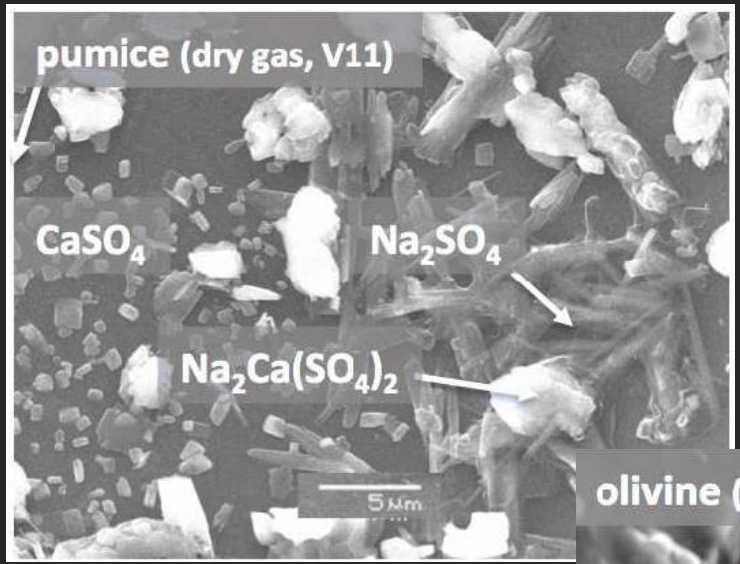


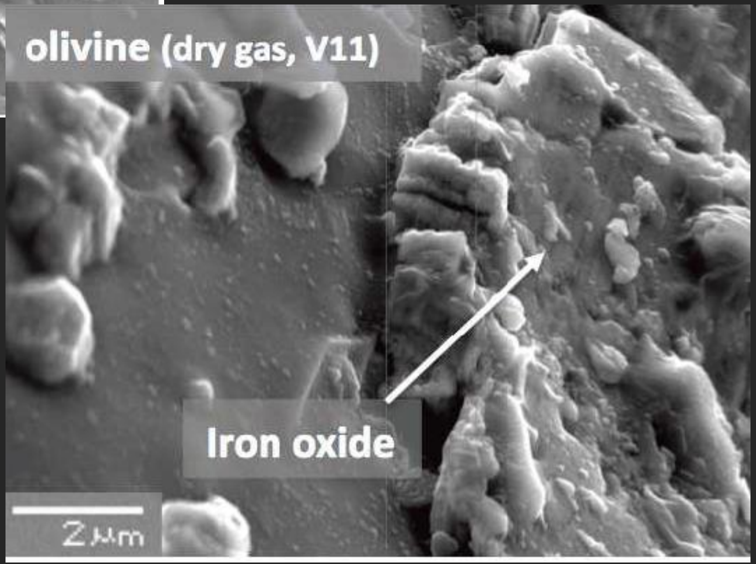
Reid et al., 2021

- Surfaces are covered with extensive reaction products in weeks
  - Alkaline samples: Na, Ca-sulfates & Fe-oxides
  - Tholeiitic samples: Ca-sulfates, Fe-oxides
- More extensive alteration at higher T
- More alteration of alkaline samples

Experiments: Hydrous (early) vs dry (current) alteration

- Dry atmosphere: surface oxidation of glasses, Fe-oxide coating of olivine, surface deposition of sulfates
- Glass, olivine alter faster than plagioclase, pyroxene
    - Oxidative formation of magnesioferrite under glass surface
- Slow reaction rates below surface (months to 1000's years to obscure spectral signal)

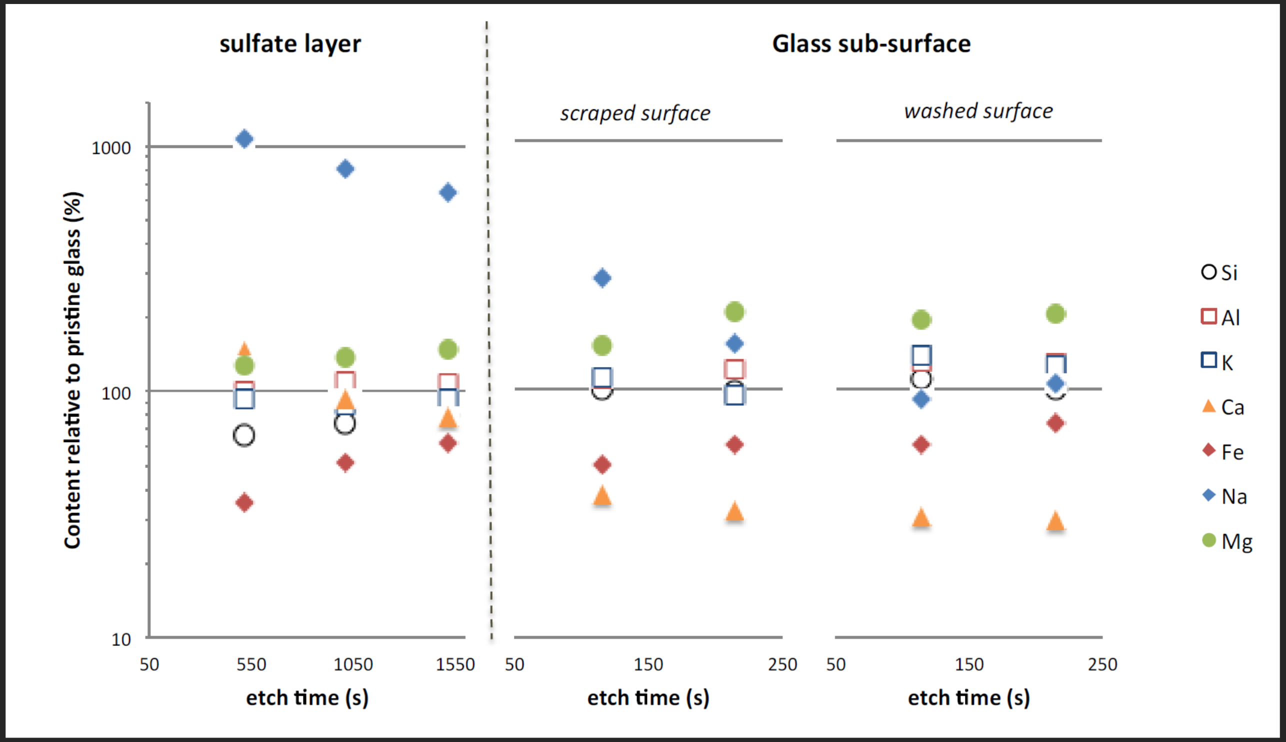




(Berger et al., 2019)

Experiments: Hydrous (early) vs dry (current) alteration

- Wet atmosphere: surface deposition of sulfates, clays, micas, amphiboles; olivine coated with fibrous phase
- Deep alteration layer forms in few days = significantly faster reaction rates



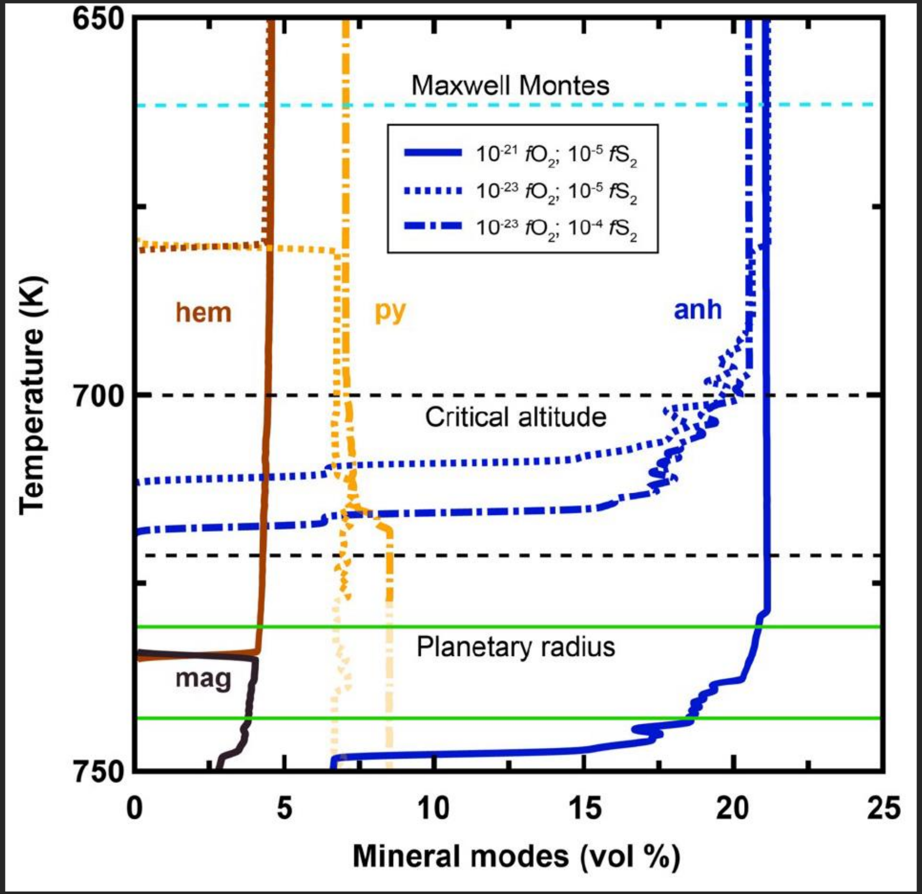
(Berger et al., 2019)

Experimental parameters: Halogenation

- Atmospheric HF (~500 ppb) & HCl (5 ppb)
- React with surface rocks to produce fluorite (CaF_2), halite (NaCl), chlorapatite [$Ca_5(PO_4)_3Cl$]
- Rates and reaction products fairly unconstrained

Experimental parameters: Radar-bright "snow"

- Radar-bright surfaces all begin at same elevation = "snow line"
- Causes: atmosphere-rock reaction (pyrite, Fe-rich phases: *Semprich et al., 2020*), deposition of metals, semi-metals, chalcogenide or sulfosalt compounds transported as vapor from hotter low elevations (*Schaefer & Fegley, 2004; Port et al., 2020*)
- Stability & reaction rates unconstrained



(Semprich et al., 2020)

What is still needed experimentally

- Need spectroscopic data on experimentally altered samples to provide links to orbital data, specifically emissivity
- Constrain the rate of atmospheric sulfur reacting out of the atmosphere into the crust producing sulfates
- Explore the effects of halogens on crustal mineralogy, and radar and NIR emissivity
- Experiments to constrain both the mineralogy and timing for the formation of the ‘snow-line’ on Venus mountain tops