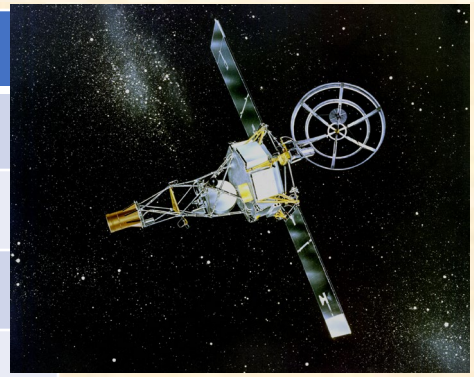
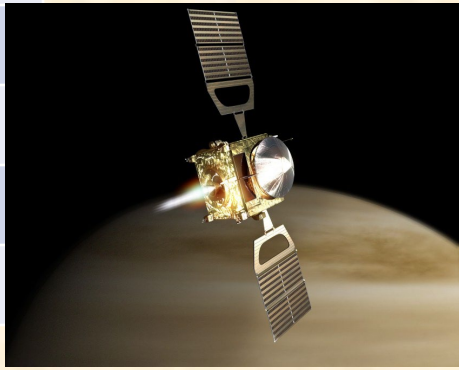
Present Day Volcanism on Venus: Evidence from Alteration Experiments

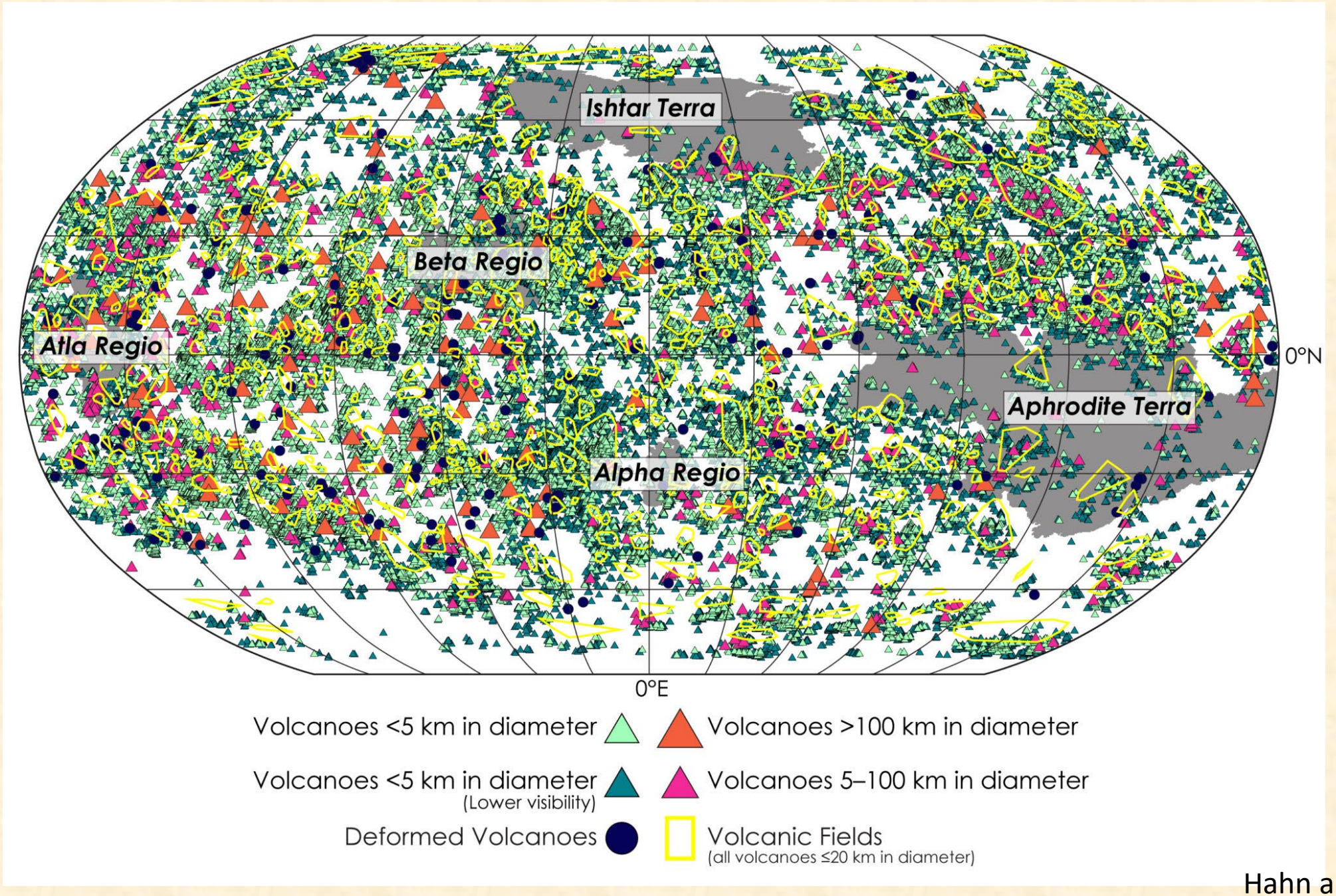
Justin Filiberto, NASA Johnson Space Center

Successful Missions to Venus

Mission	Agency	Year
Mariner 2	NASA	1962
Mariner 5	NASA	1967
Mariner 10	NASA	1973-1975
Venera	**Soviet**	**1961-1983**
Vega 1	**Soviet**	**1985**
Vega 2	**Soviet**	**1985**
Galileo	NASA	1990
Pioneer Venus	**NASA**	**1978-1992**
Magellan	**NASA**	**1989-1994**
MESSENGER	NASA	2004
Venus Express	**ESA**	**2005**
Akatsuki	**ISAS**	**2010**





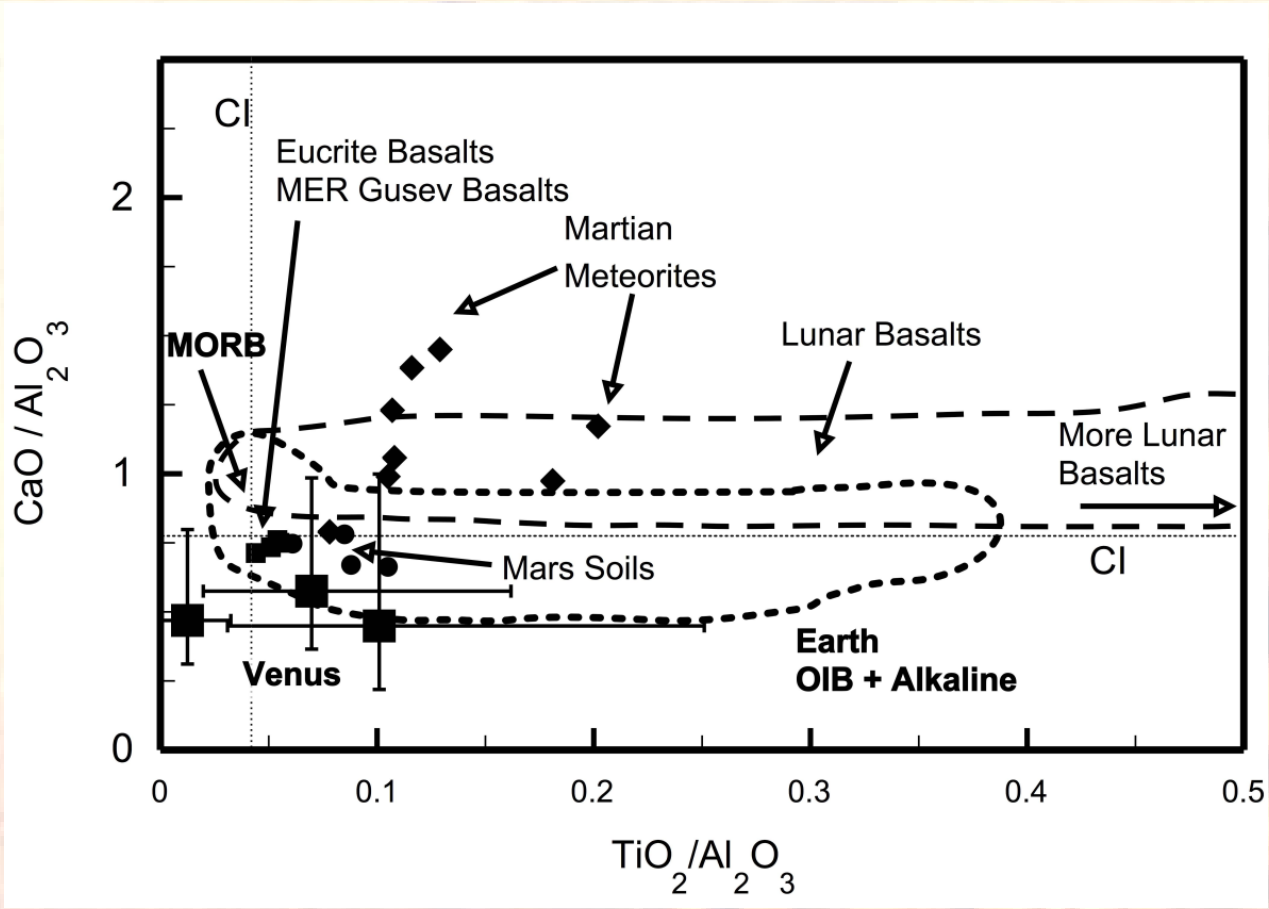


Hahn and Byrne 2023

Some Open Questions

- What types of Igneous Rocks do we have on Venus?
- How old is the Volcanism?

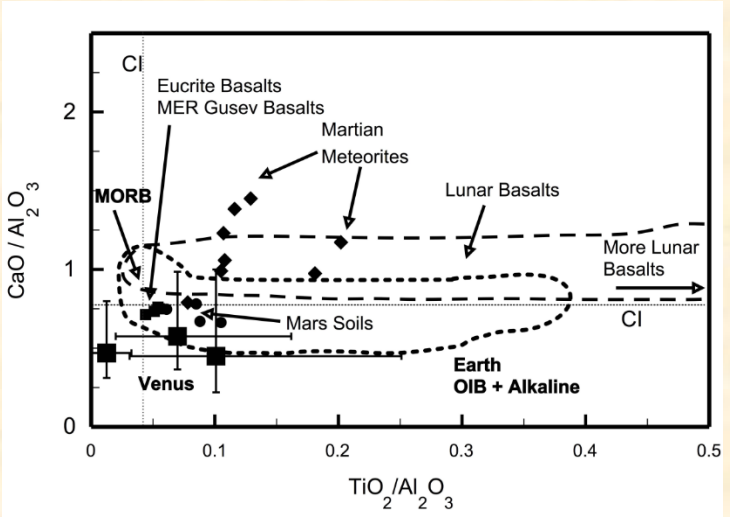
Venera and Vega Data



From Treiman 2007

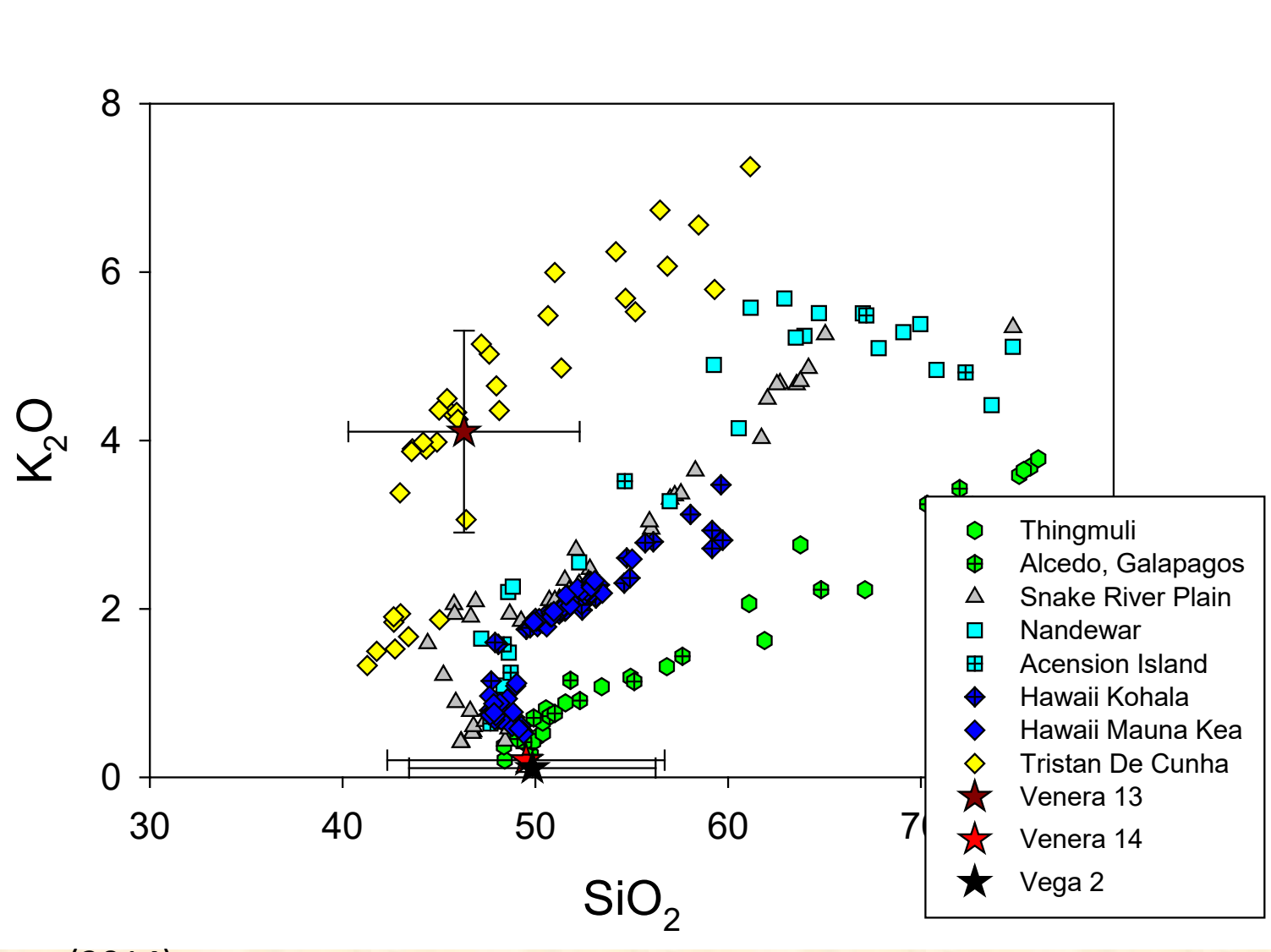
So what does this tell us about Venus?

- Compare with suites of rocks from the Earth
- Assumptions:
  - Earth-like basaltic chemistry
  - Earth-like magmatic processes
- Experimental crystallization studies can constrain formation conditions – P, T, XH2O



From Filiberto (2014)

Venera and Vega Data



From Filiberto (2014)

Experimental Constraints

Fractionation Pressure		Depth (km)	Volatile Content	Trend	Terrestrial Analog
Surface	0-2kb	0-10		Tholeiitic Trend	Galapagos Thingmuli
Base of the crust/Upper mantle	5-11kb	20-40	<0.3wt% water	Potassic Alkalic Series	Snake River Plain
	9-11kb	30-40	>0.3wt% water	Sodic Alkalic Series	Nandewar Ascension Island
	12-16kb	45-60	>0.3wt% water	Silica-undersaturated	Hawaii
Mantle	18-27kb	65-100	~0.2 wt% water	Phonolitic Series★	Tristan de Cunha

★ May require the presence of dissolved CO_2

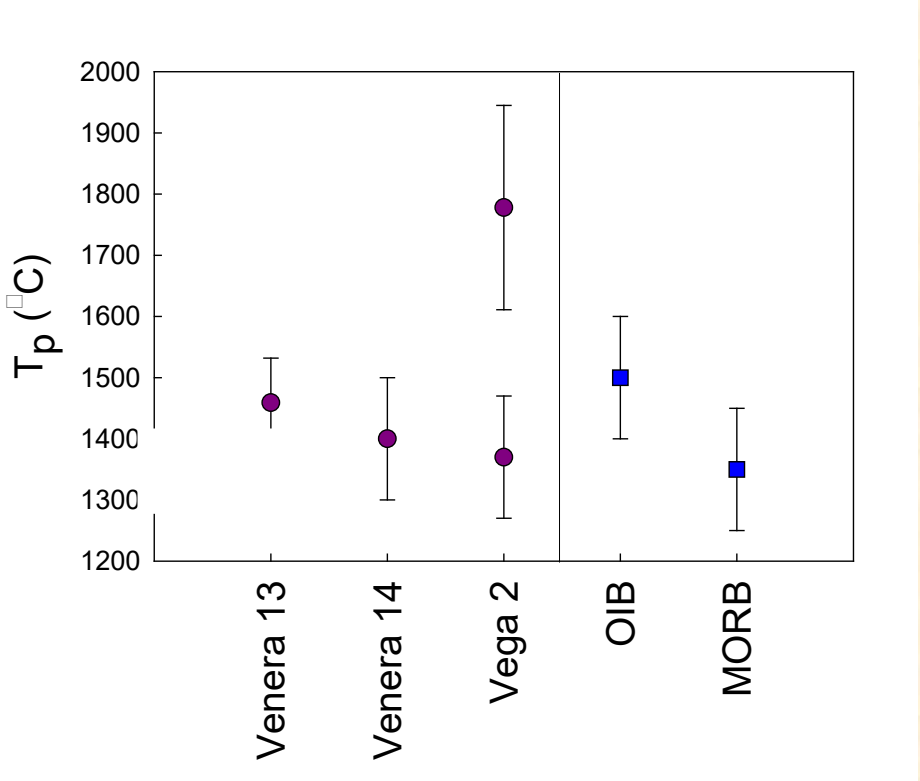
From Filiberto (2014)

Experimental data from: Spulber and Rutherford, 1983; Litvan 2005; Whitaker et al., 2007a,b; 2008; Rossier, 2006; Dasgupta et al. 2007; Botcharnikov et al., 2008; Nekvasil et al., 2004; Filiberto and Nekvasil, 2003; Green, 1970

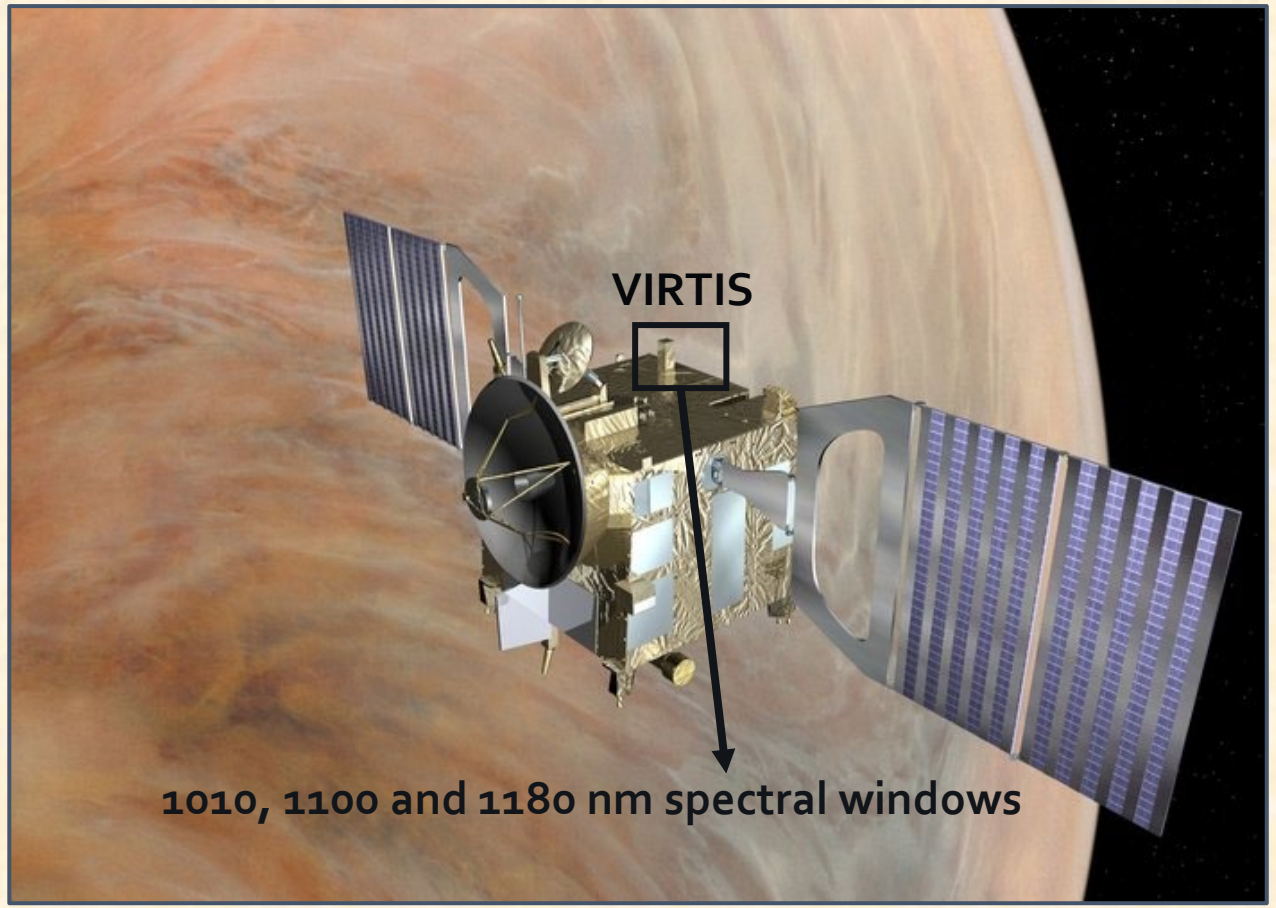
MORB or OIB-like?

- Vega 2 and Venera 14 analyses
  - Consistent with a terrestrial olivine tholeiite
    - Vega 2 MORB-like? – Ti only
    - Venera 14 OIB-like? – except Tp?

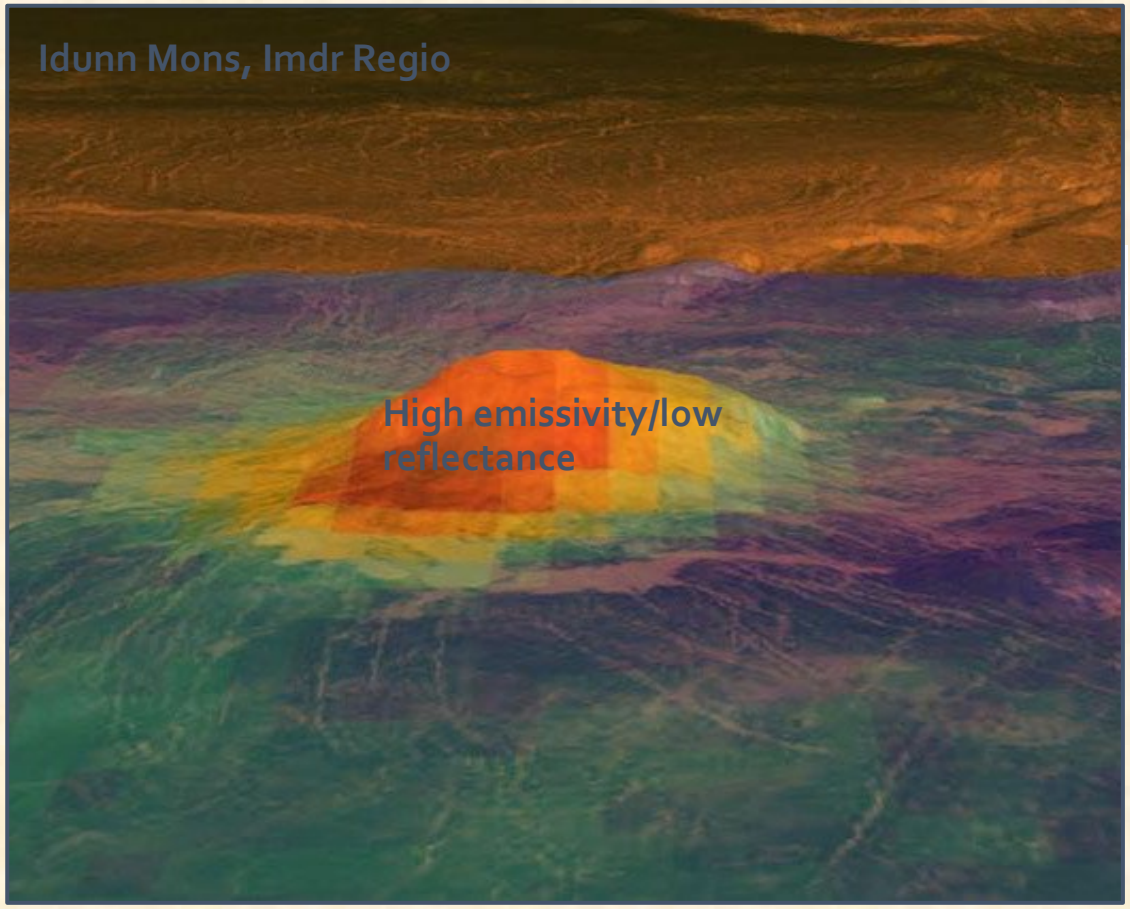
- Venera 13 analysis
  - Consistent with silica-undersaturated
  - Origin similar to rocks from Tristan de Cunha
  - Deeper origin than Vega 2/Venera 14
  - ~0.2 wt% bulk water in the basalt
  - Carbon-rich source region(?)



How old is the volcanism on Venus?

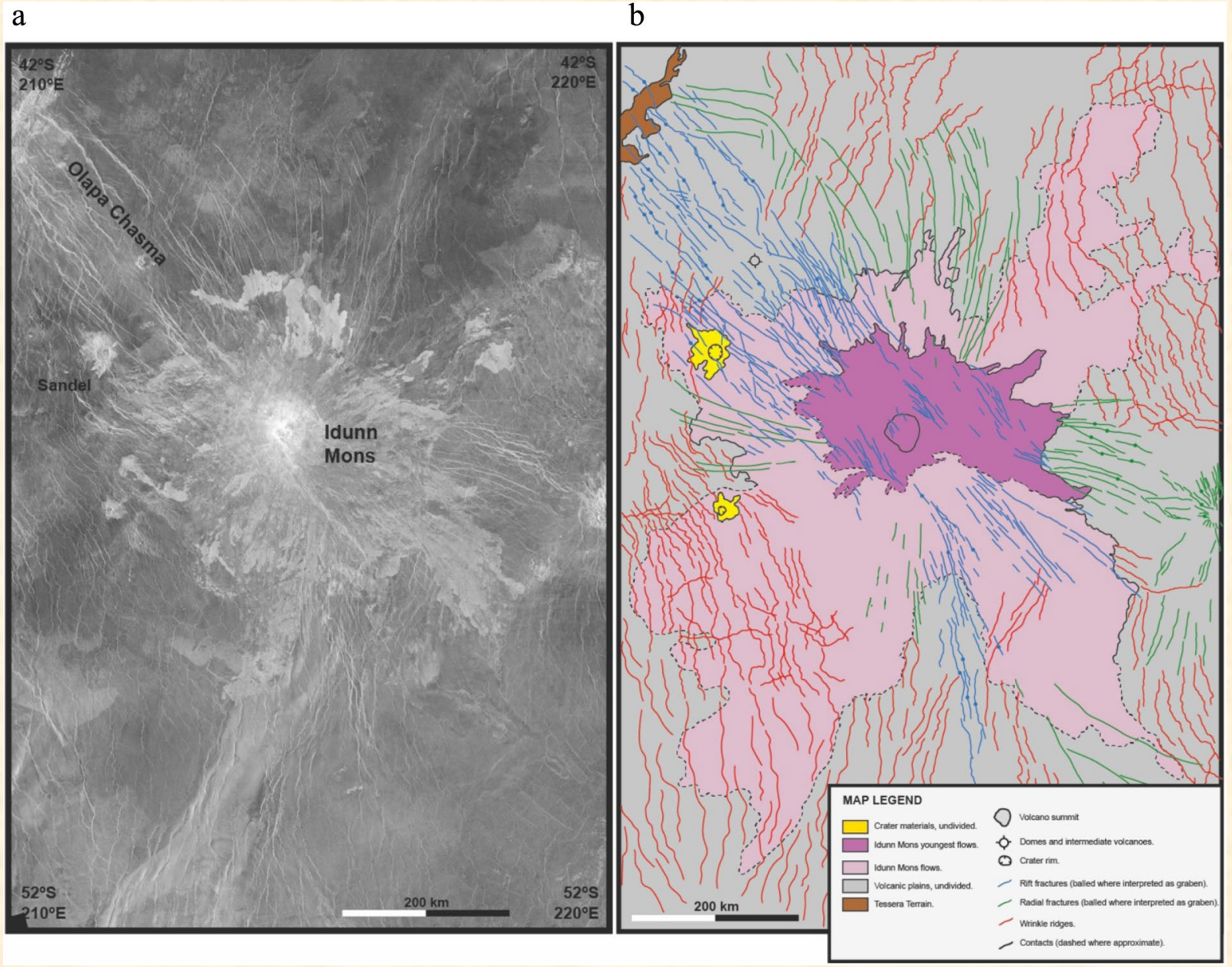


|Artistic impression of Venus Express orbiting Venus| image credit: ESA|



|Emissivity at Idunn Mons| image credit: NASA/JPL|

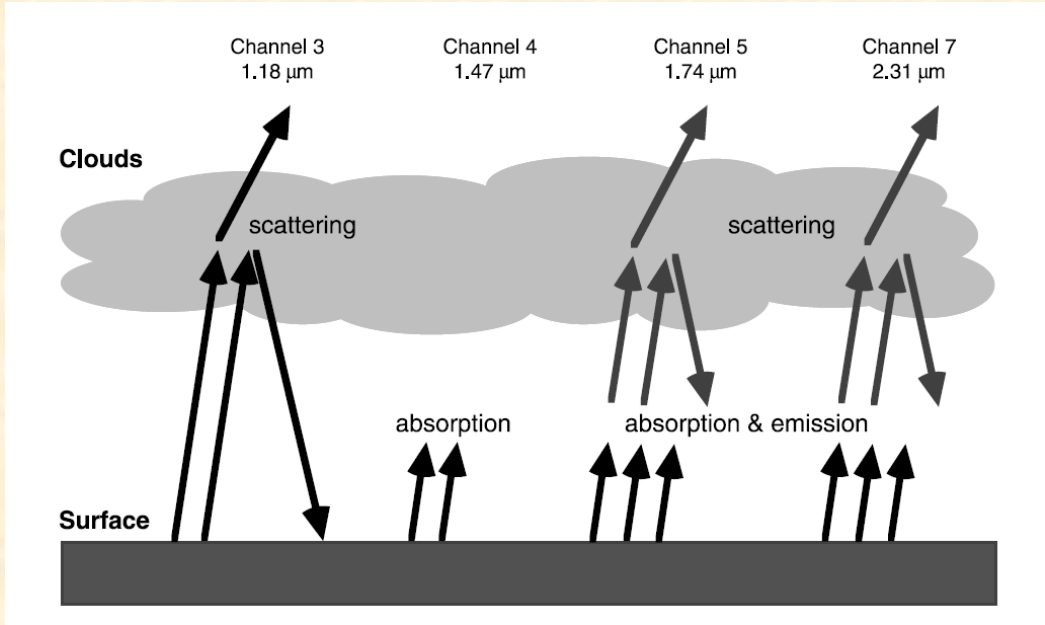
Idunn Mons



D'Incecco et al. (2021 a,b); Lopez et al. (2022)

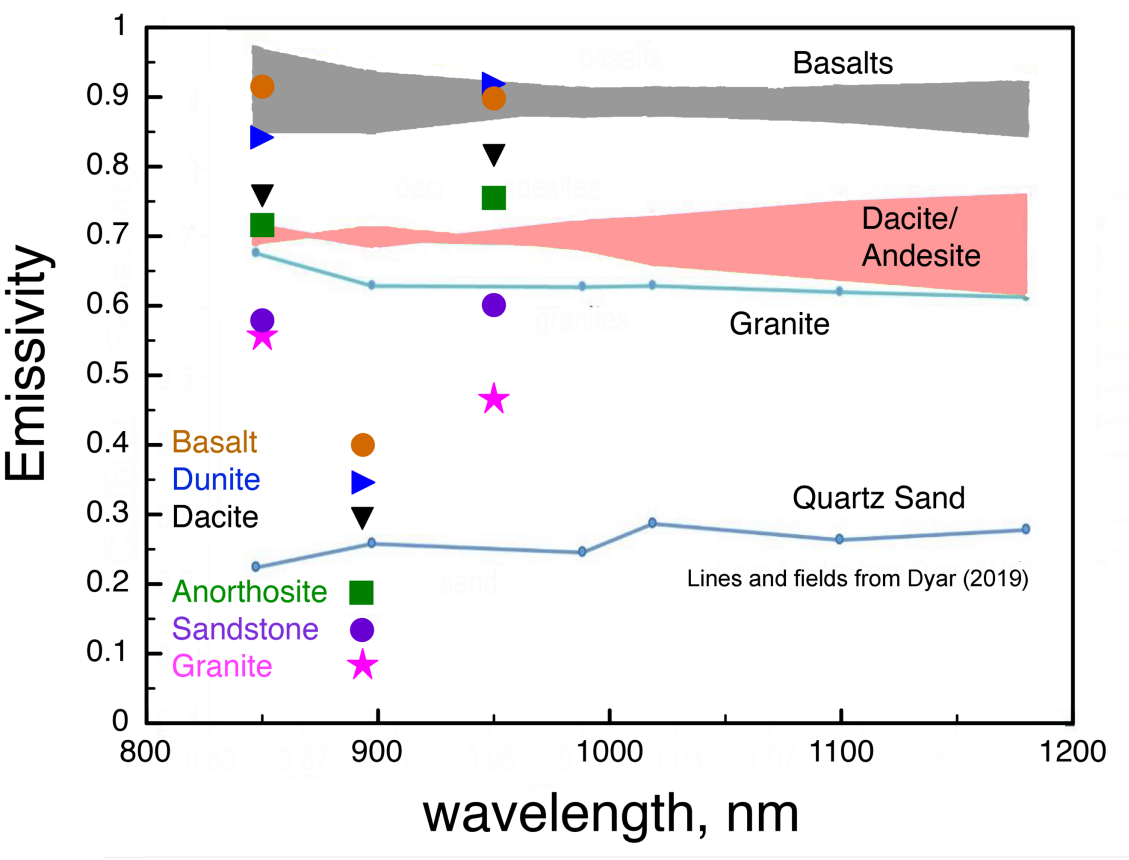
How can we use emissivity?

- Orbital measurements of the surface
- Provides information of mineralogy
- Felsic and Secondary minerals have low emissivity
- Mafic minerals have high emissivity

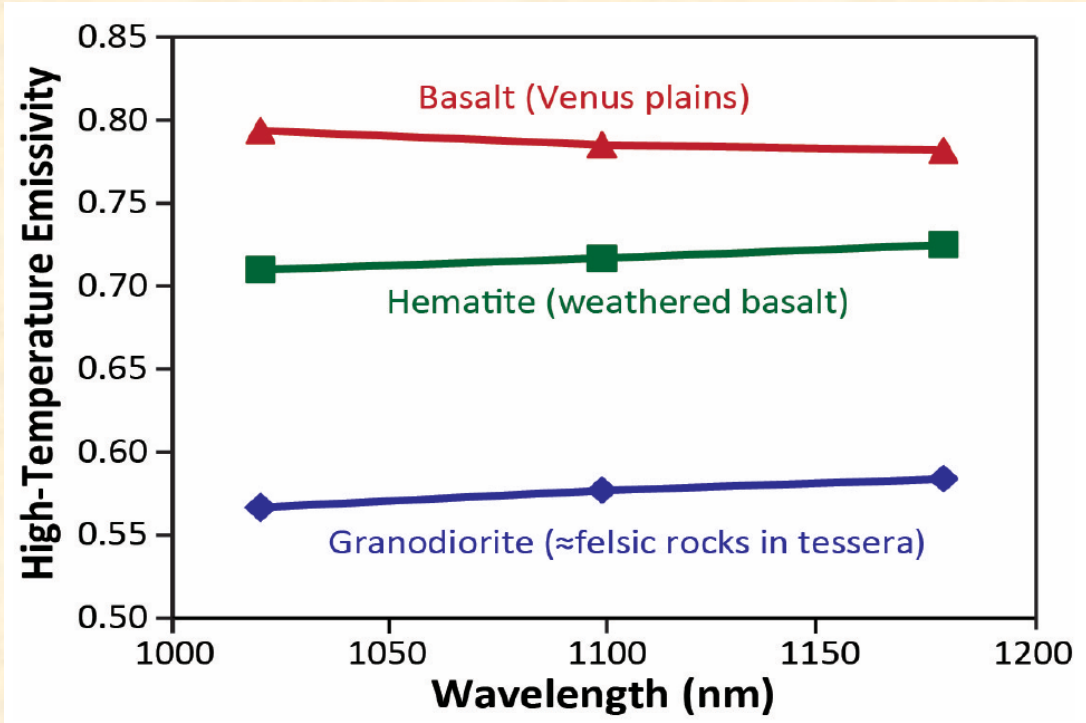


Hashimoto et al. 2008

How can we use emissivity?



Mafic minerals have high emissivity

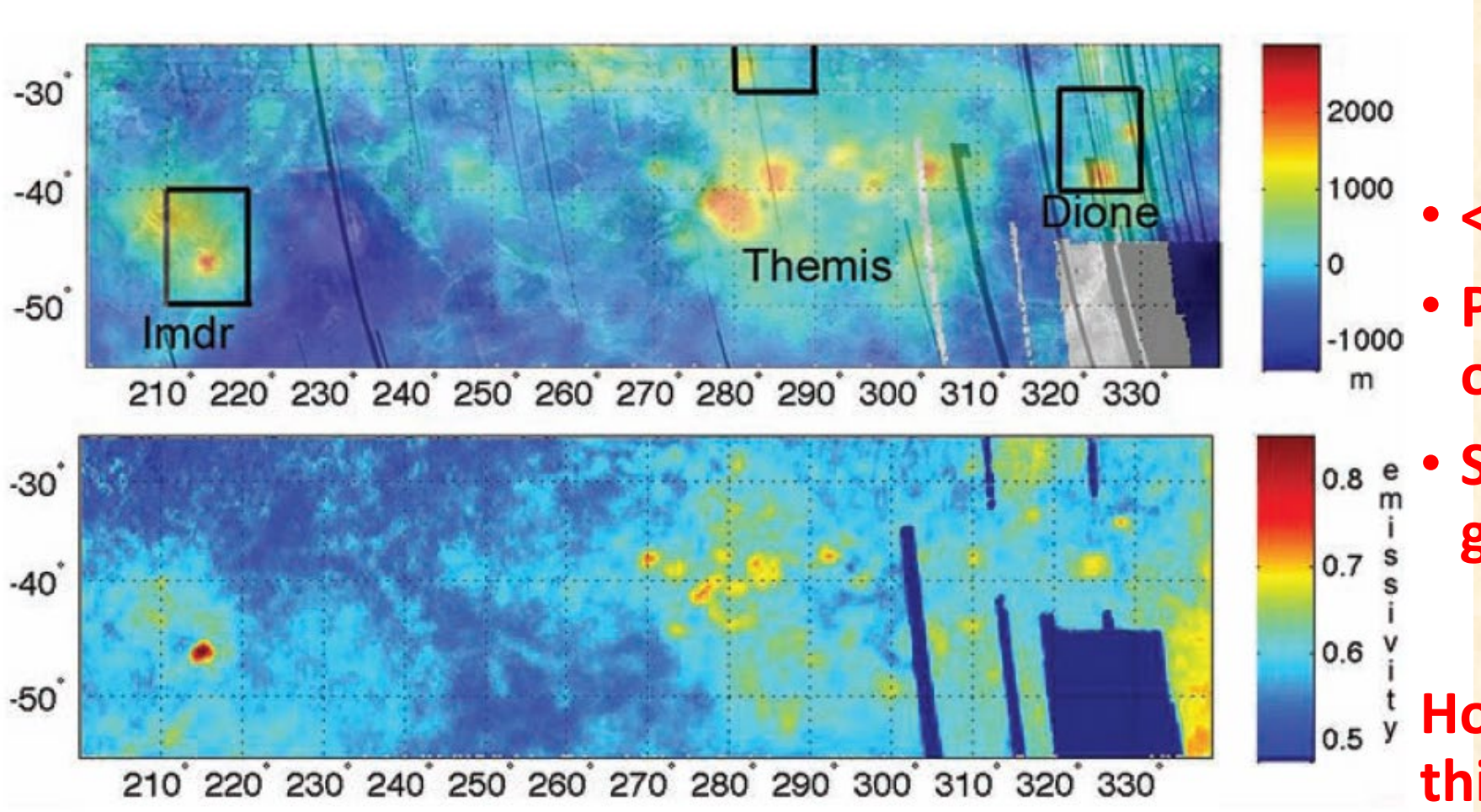


Felsic minerals have low emissivity
Alteration (Fe3+) lowers the emissivity

Dyar et al. (2021); Helbert et al. (2021); Treiman et al. (2021)

Recent Volcanism on Venus

- Warmer colors may be fresh lava



- **< 2.5 million years old**
- **Possibly < 250,000 years old**
- **Suggests Venus may be geologically active**

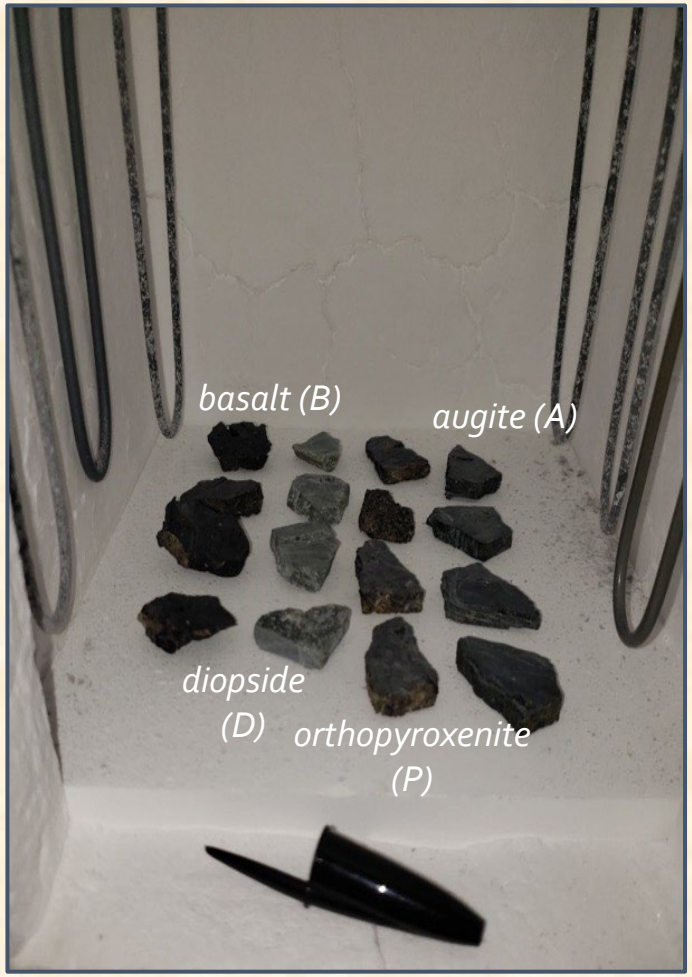
How do we constrain this?

ESA's Venus Express data of Southern Hemisphere

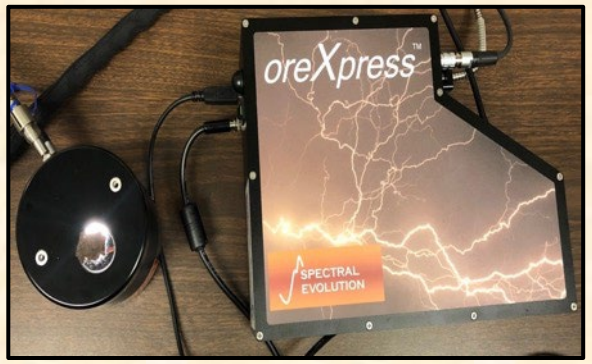
Smrekar et al. 2010

Methods

- Oxidation experiments
  - Olivine
  - Alkali Basalt
  - Augite
  - Diopside
  - Orthopyroxenite
- Open air box furnace
- Up to 7 weeks
  - Ol up to 1 month
- 600°C
  - 900°C – Ol only



|Box furnace set-up at JSC|

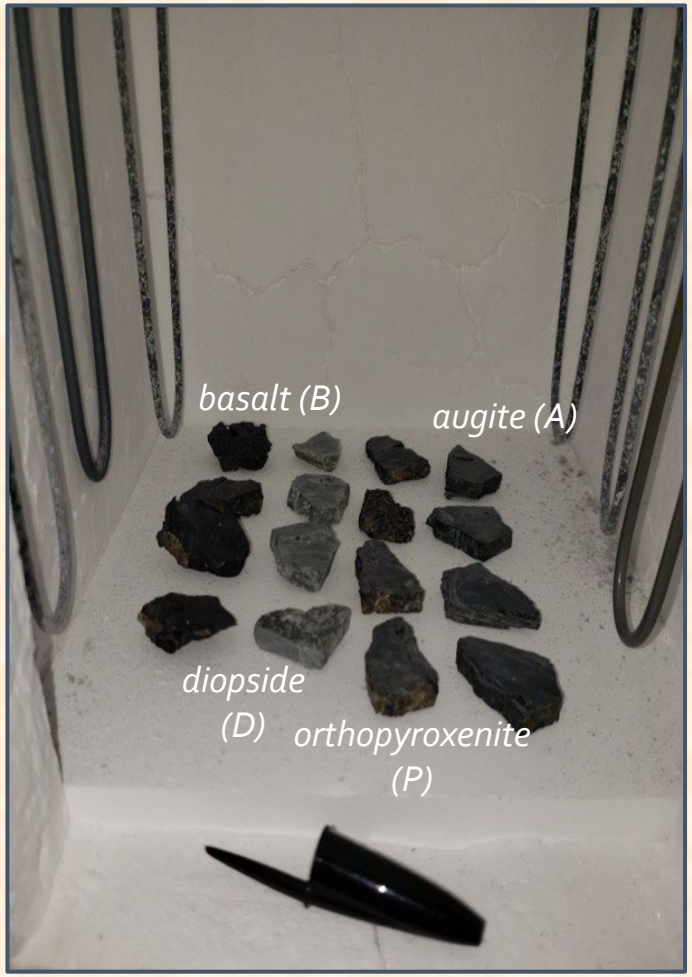


|VNIR spectroscopy|

See Knafelc et al. (2019); Filiberto et al. (2020); and Cutler et al. (2020) for more information

Methods

- Measured surfaces before/after
  - Mineralogy
    - Raman – Ol
    - SEM and EMPA – all others
  - Texture
    - SEM
  - Spectroscopy
    - Reflectance and not emission
    - E = 1- R
  - Magnetic properties (Ol only)



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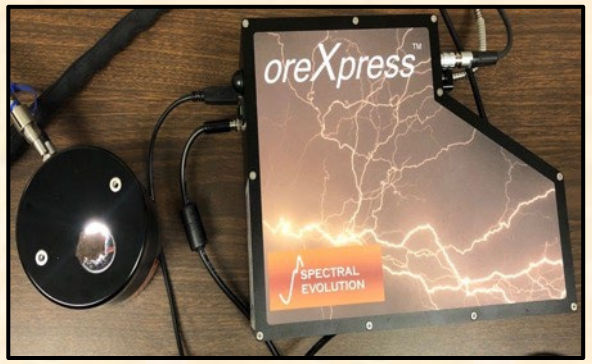


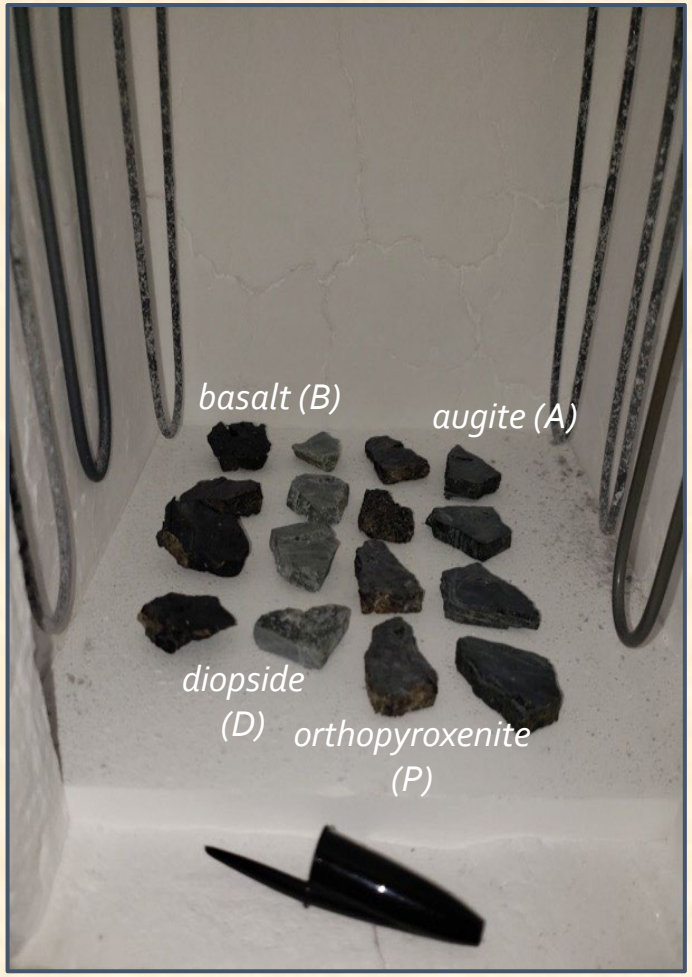
|VNIR spectroscopy|

See Knafelc et al. (2019); Filiberto et al. (2020); and Cutler et al. (2020) for more information

Methods

- **Experimental Approach:**
  - Olivine
  - Alkali Basalt
- Air
  - Oxidation state ~ FMQ +10
- 600°C (and 900°C)
- Measured surfaces before/after
  - Spectroscopy
    - Reflectance and not emission
    - E = 1- R

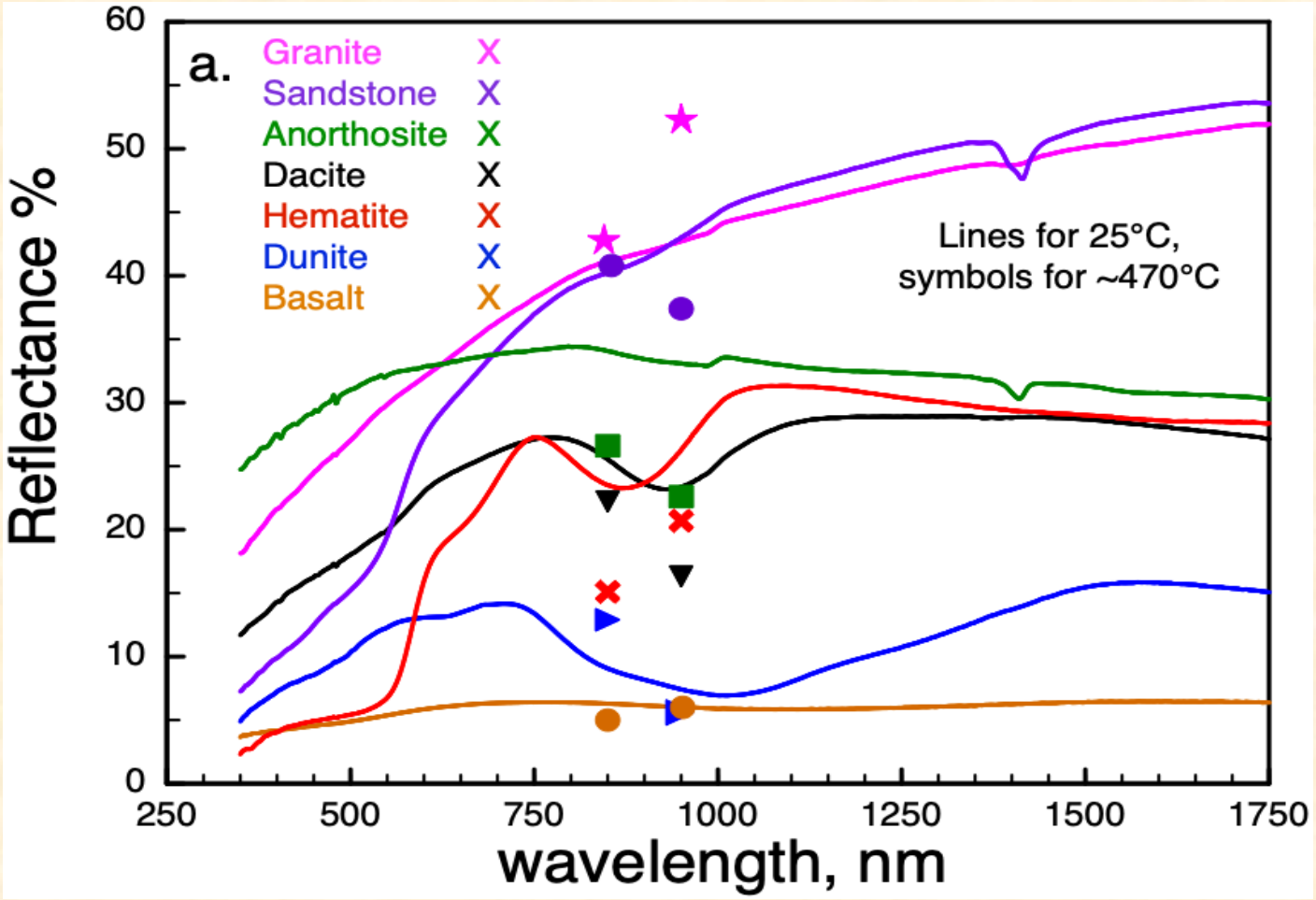
- **Venus Conditions:**
  - 'Basaltic crust'
  - Chemistry and mineralogy not well constrained
- CO_2-atmosphere with S
  - Oxidation state at or above hematite-magnetite buffer
- ~470 °C for basaltic plains
  - 92bar pressure
- Emissivity
  - 1µm feature only



|Box furnace set-up at JSC|

See Knafelc et al. (2019); Filiberto et al. (2020); and Cutler et al. (2020) for more information

Can room temperature spectra be applied at temperature?

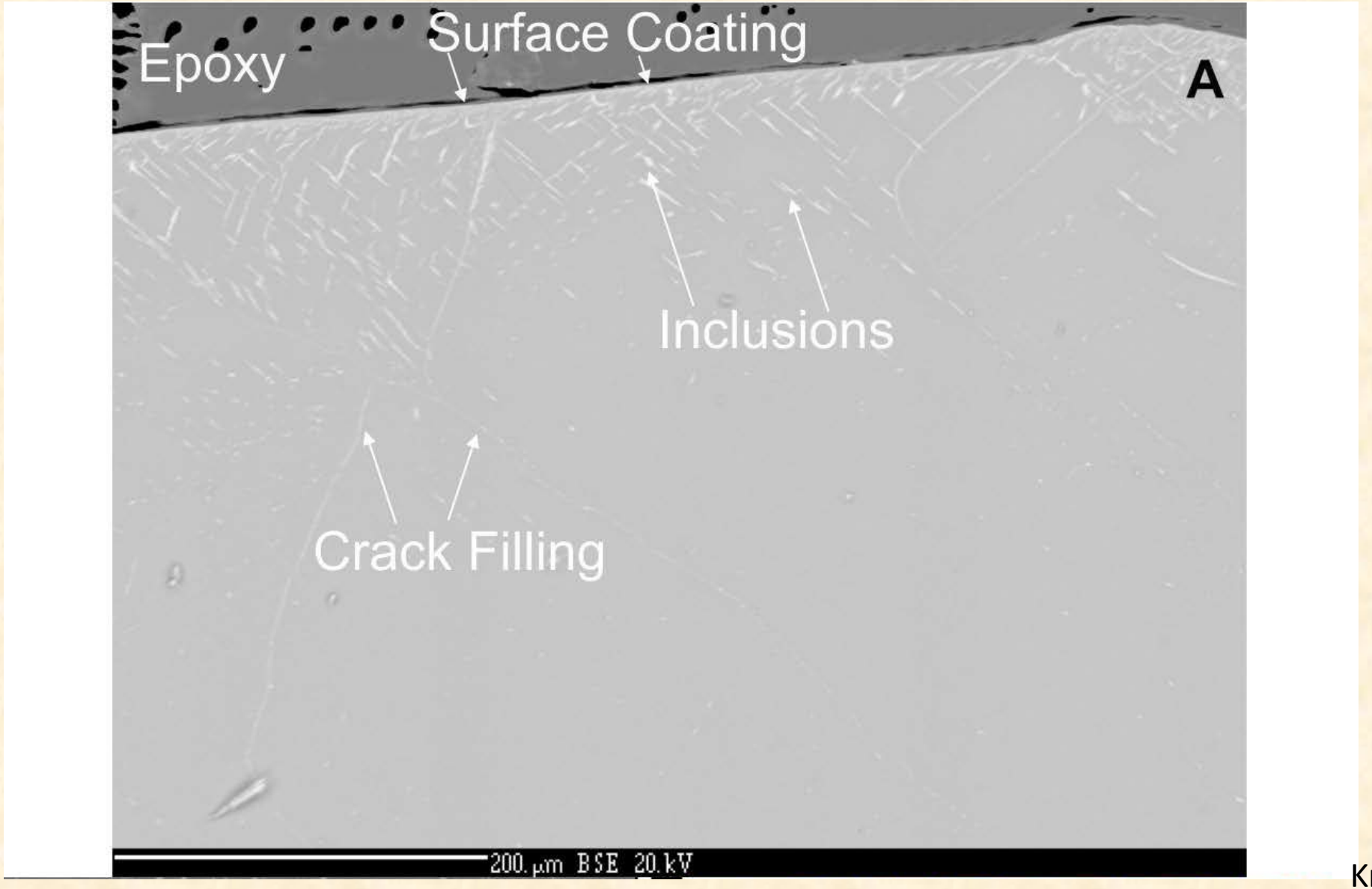


Treiman et al (2021)

Oxidation Experiments

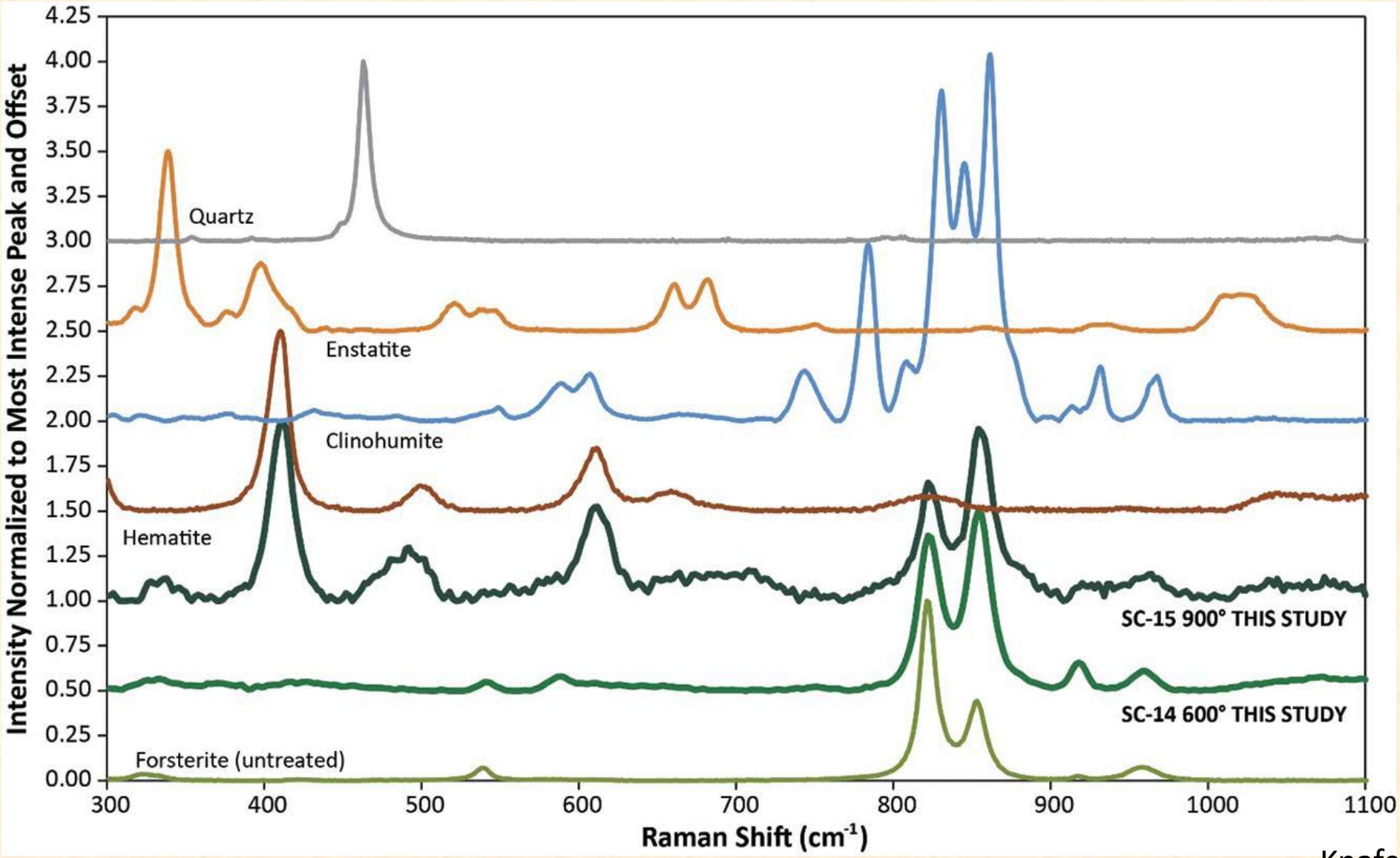
Original experiments from Knafelc et al. (2019); Filiberto et al. (2020)

Oxidation Experiments



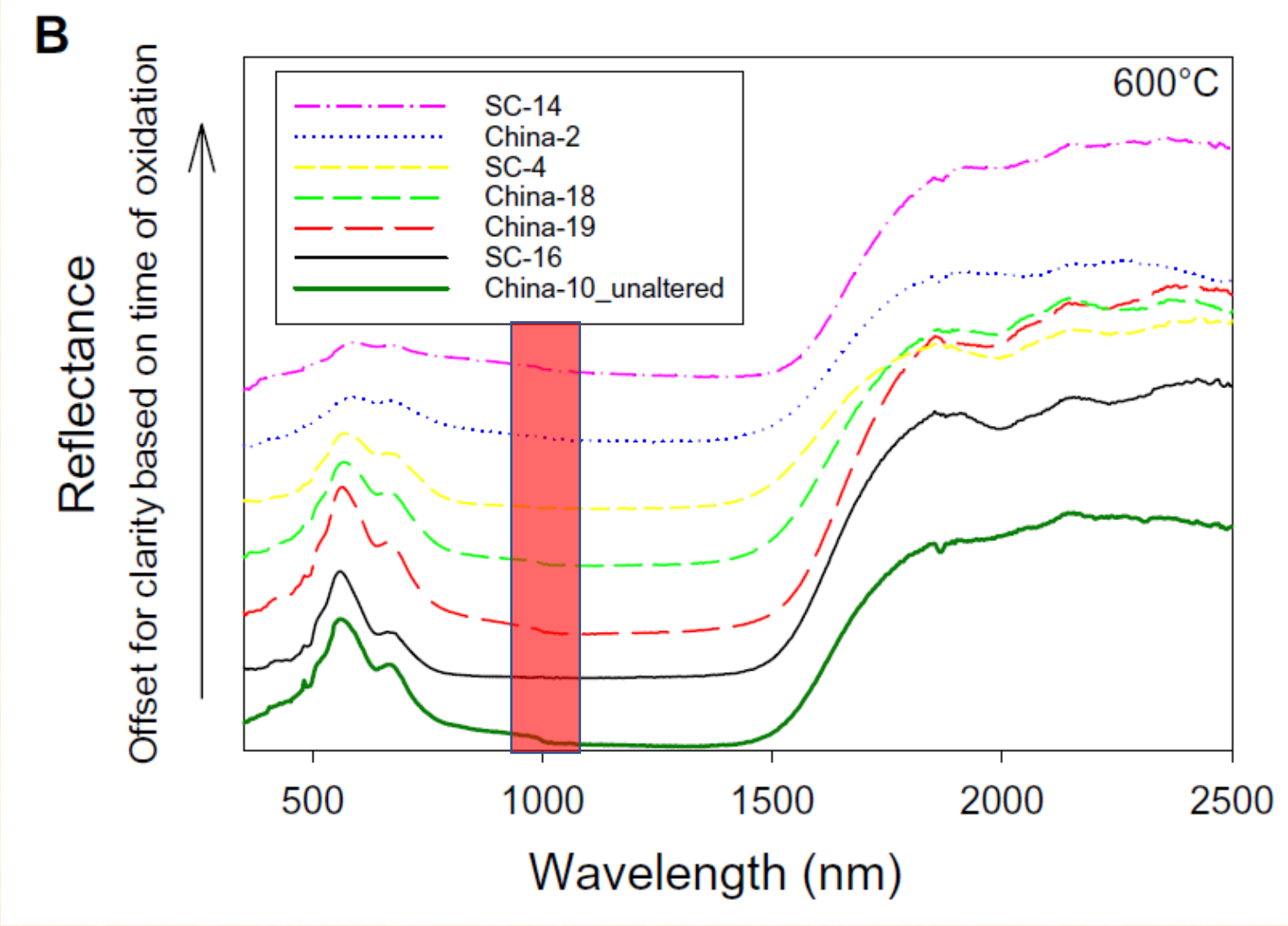
Knafelc et al. (2019)

Raman Data



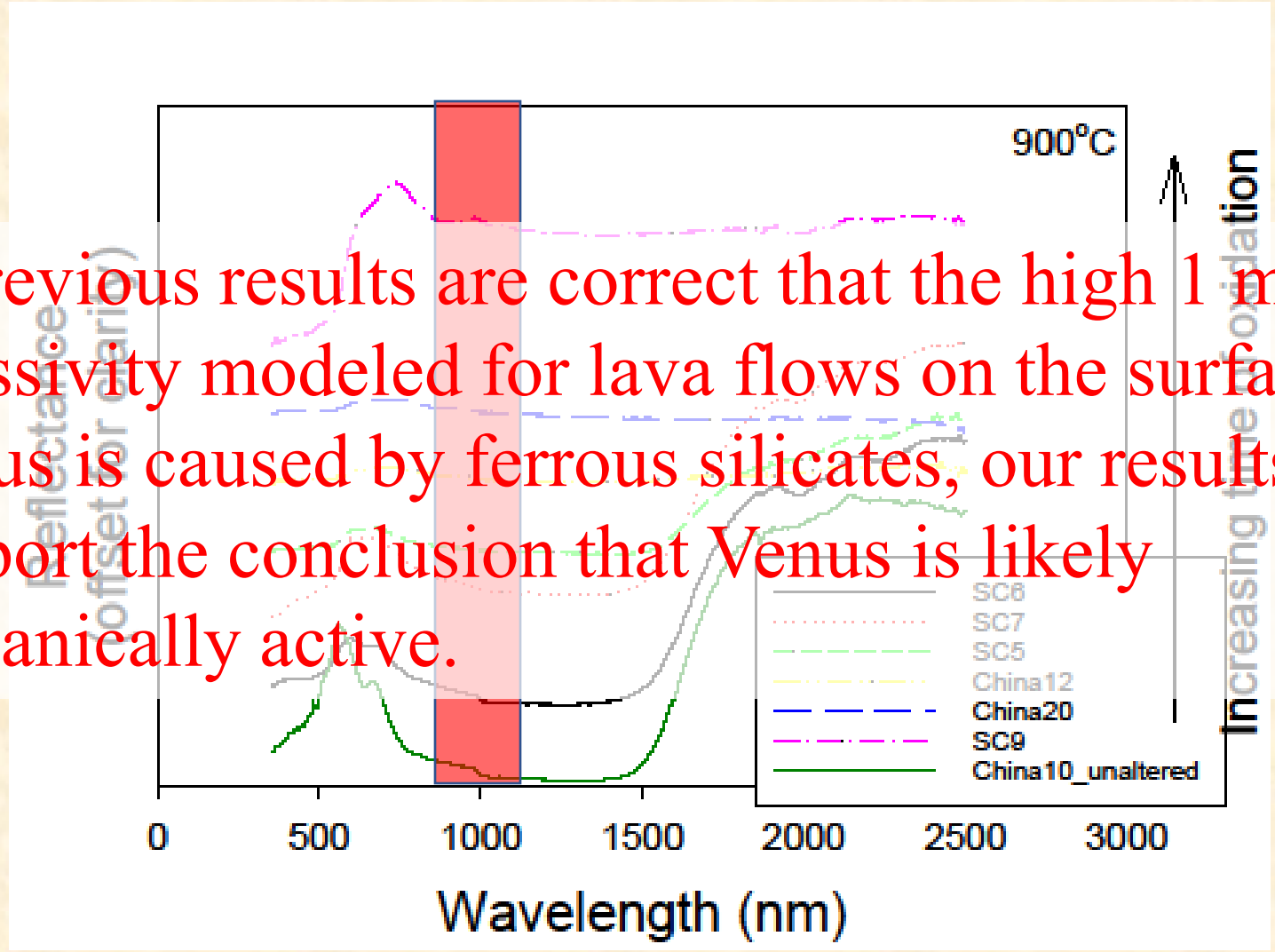
Knafelc et al. (2019)

VNIR Spectroscopy



Filiberto et al. (2020)

VNIR Spectroscopy

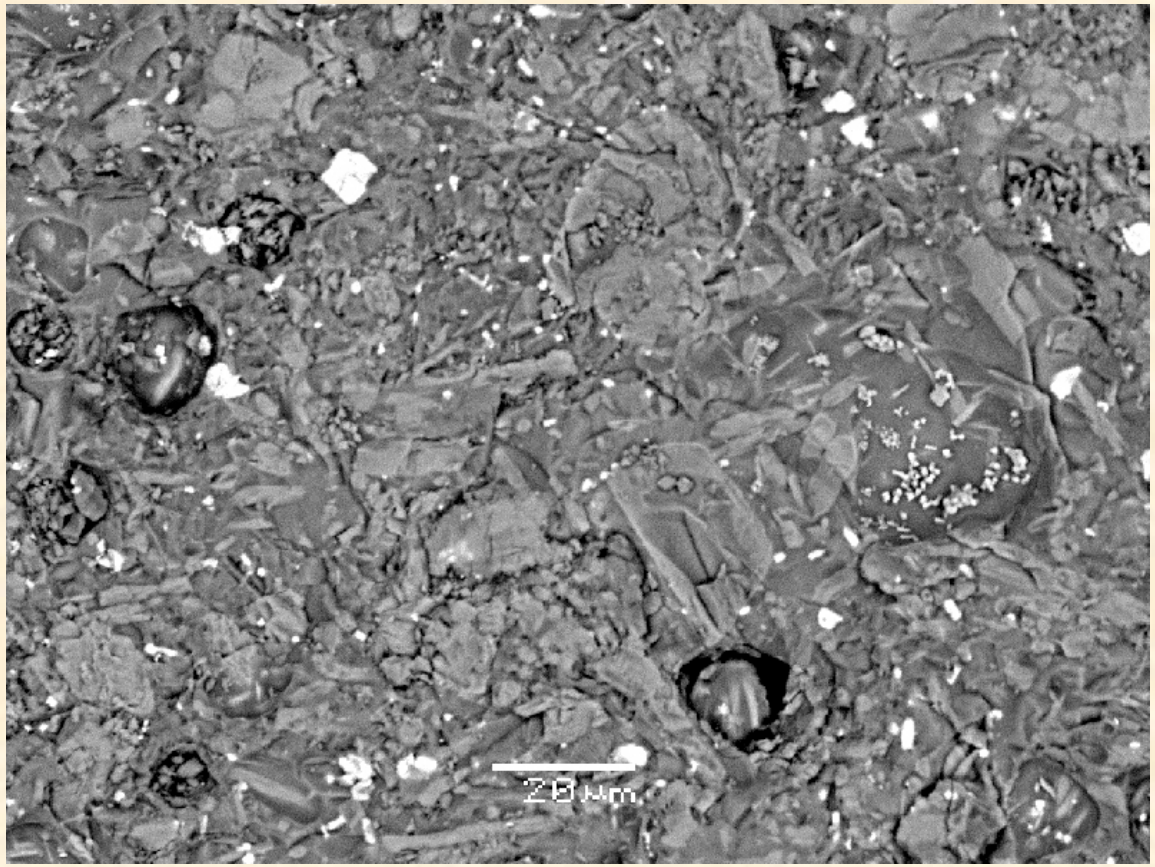


If previous results are correct that the high 1 micron emissivity modeled for lava flows on the surface of Venus is caused by ferrous silicates, our results support the conclusion that Venus is likely volcanically active.

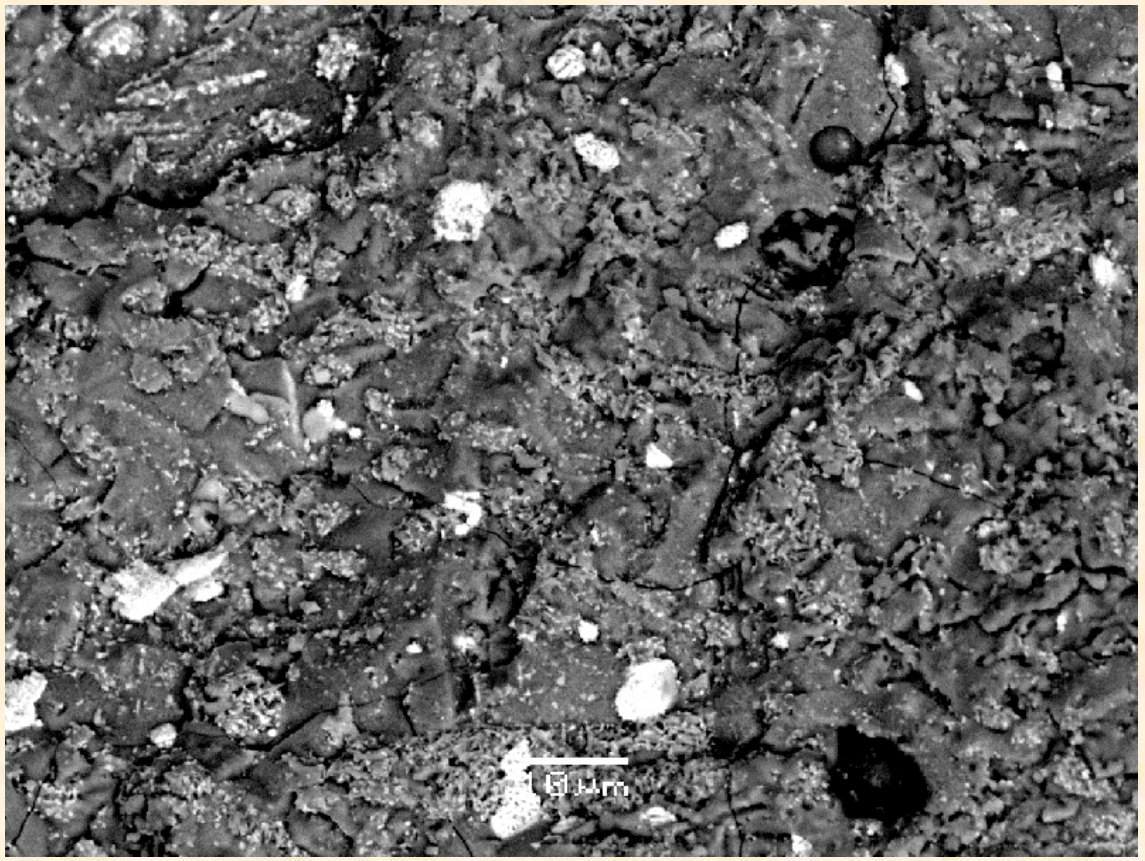
Filiberto et al. (2020)

Basalt Alteration in the Lab

Unaltered

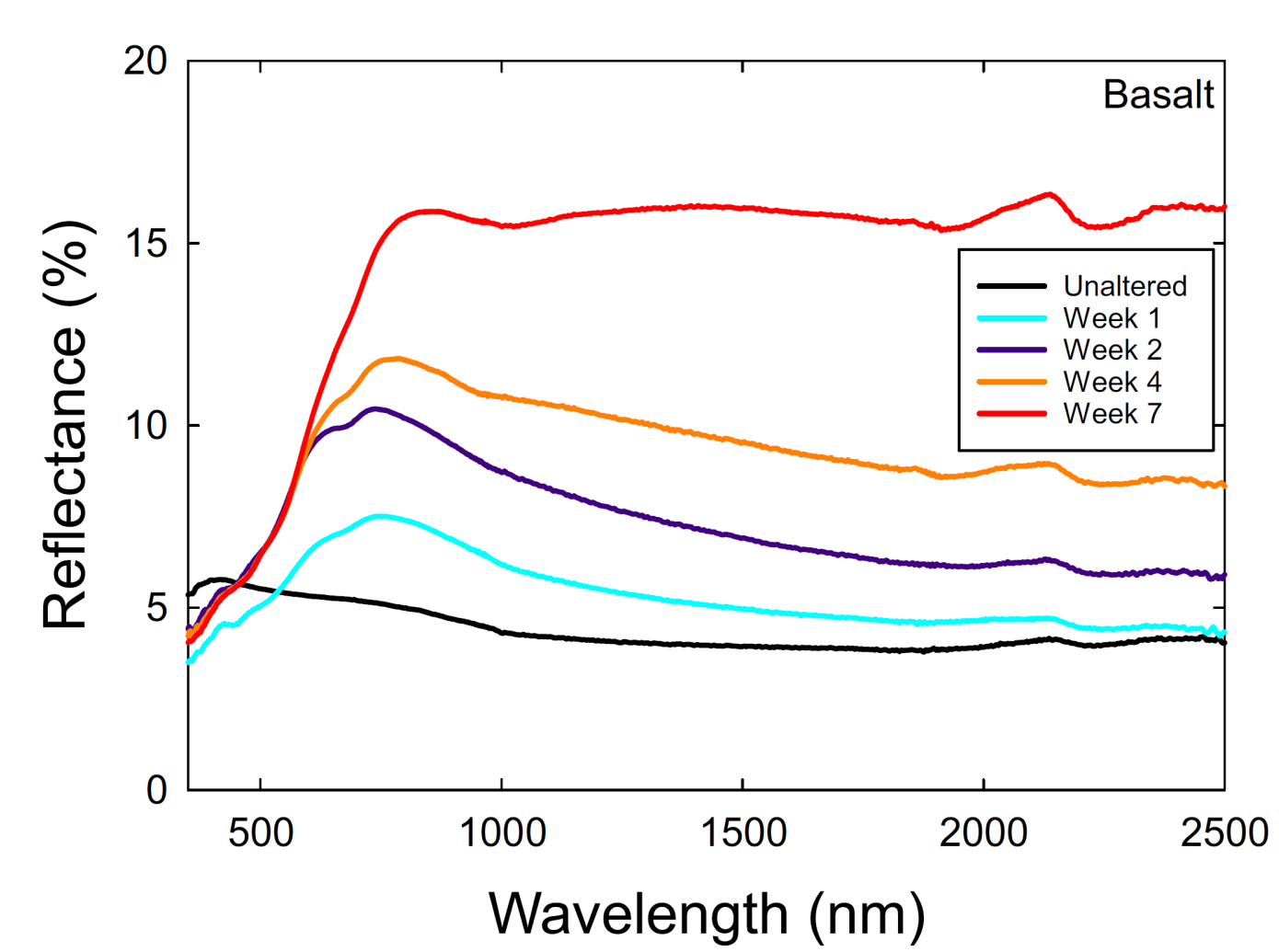


Altered for 7 weeks



Cutler et al. (2020)

Effect of Oxidation on Spectra



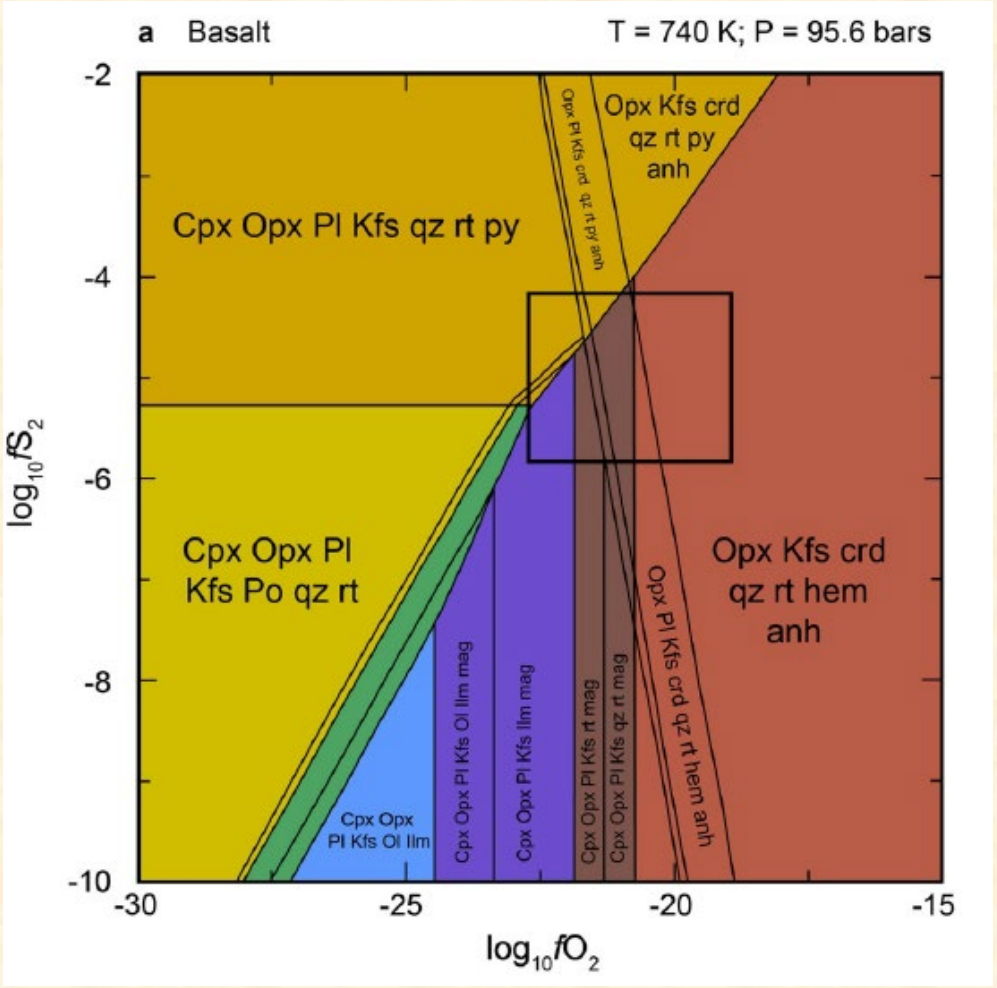
- Increasing time
  - Increases reflectance
  - Features shift towards higher wavelength
  - Features of olivine/pyroxene disappear
  - Form features of hematite

Cutler et al. (2020)

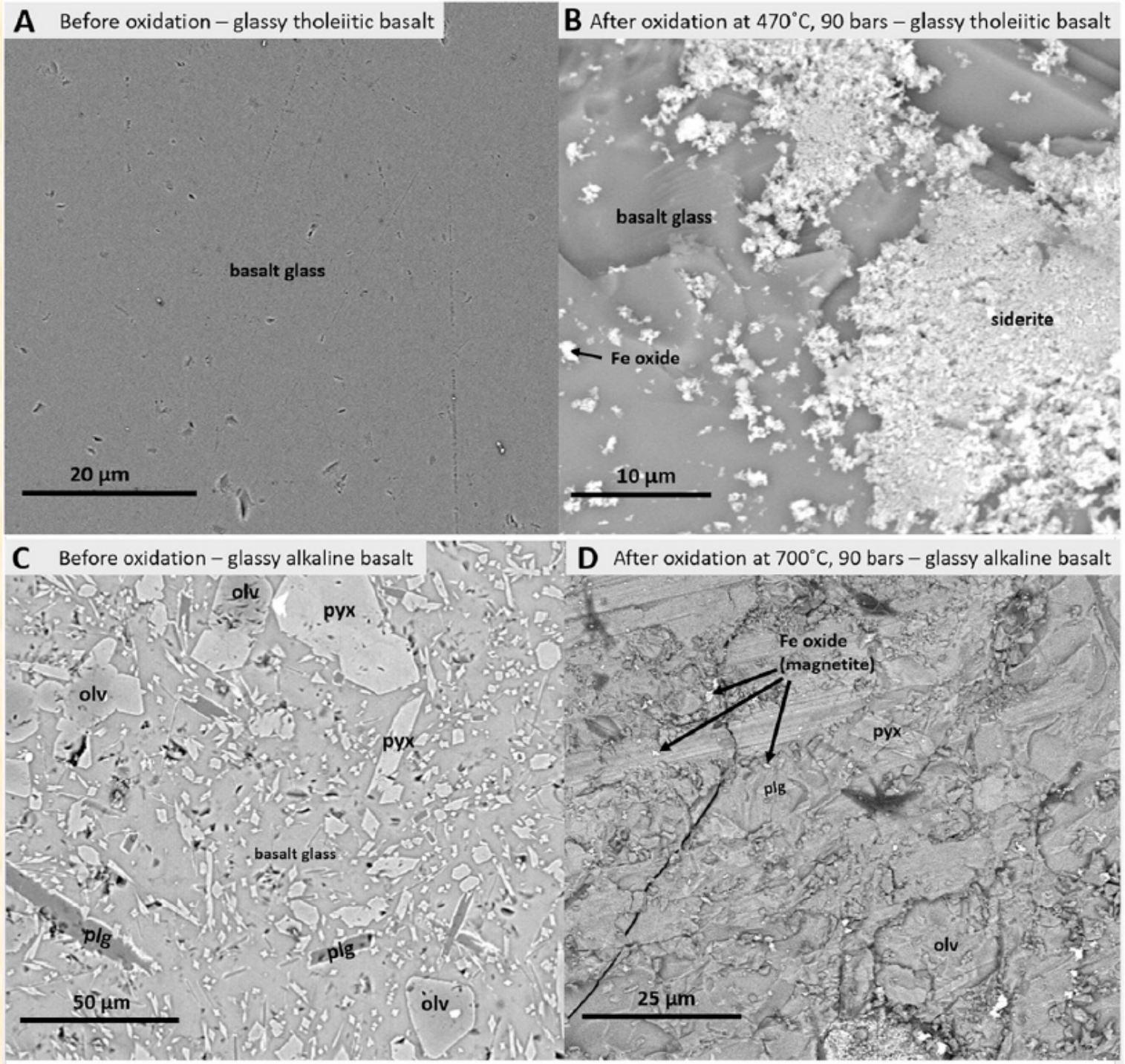
Do our experiments replicate Venus surface well enough?

- Oxidation only:
- Mineralogy
  - Iron oxidation
  - Hematite coatings
- Time scales
  - Olivine
    - Days to months
  - Basalts
    - Months to years
  - Pyroxene
    - Years to decades

- Directly applicable Exp and Models:
- Mineralogy
  - Iron oxidation
  - Hematite, Sulfides
  - Iron and Ca migration
- Time scales
  - Days to months

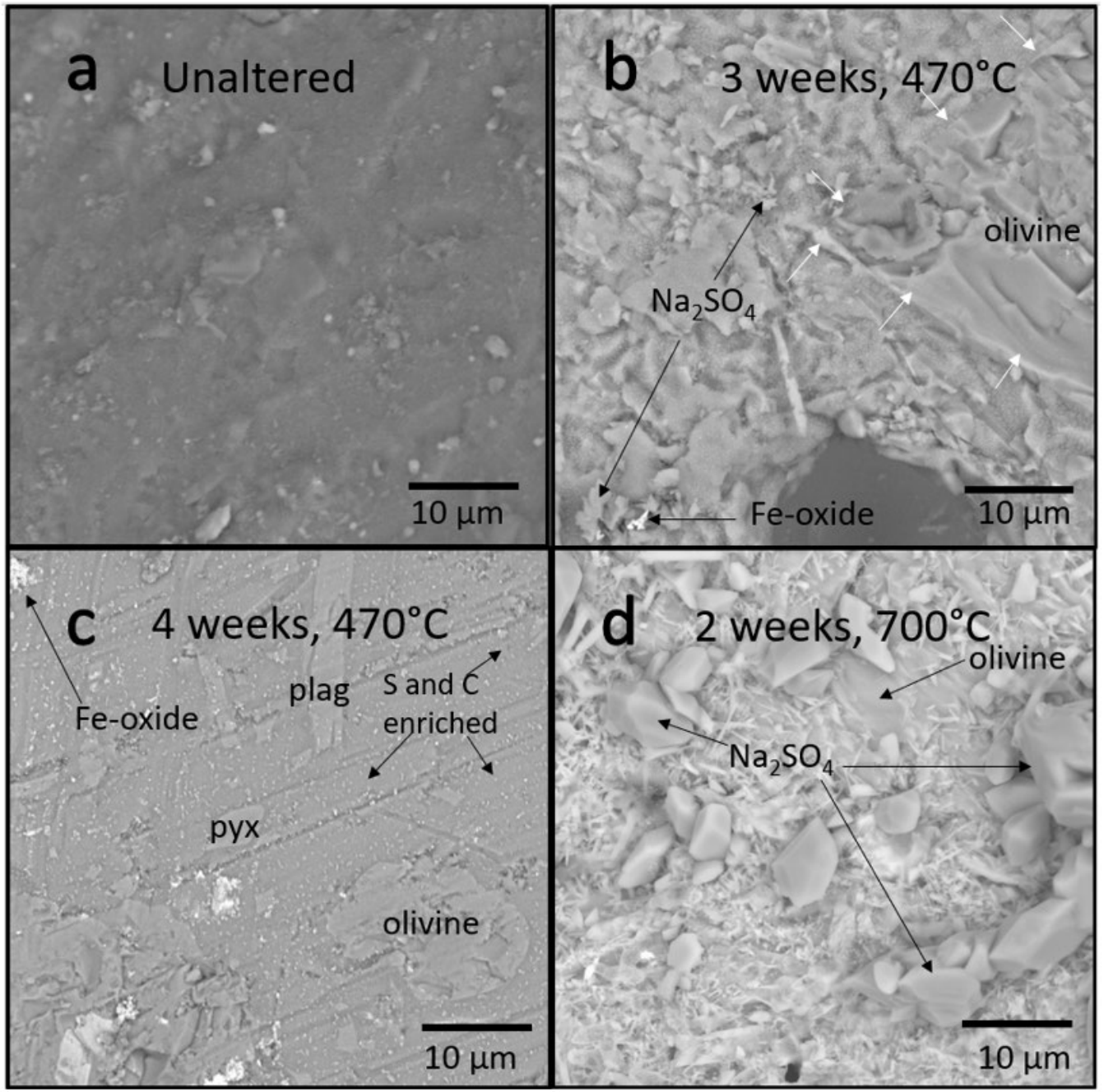


Berger et al. (2019); Semprich et al. (2020); Teffeteller et al. (2022)



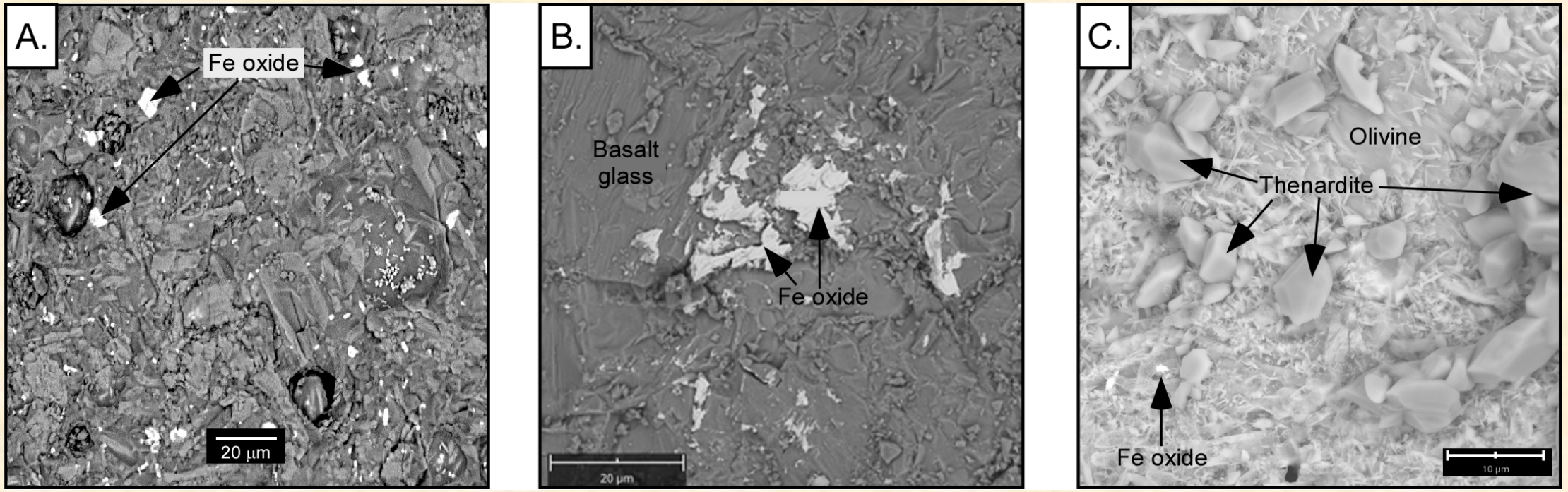
Teffeteller et al. (2022)

Alkali Basalt Experiments at 90 bars

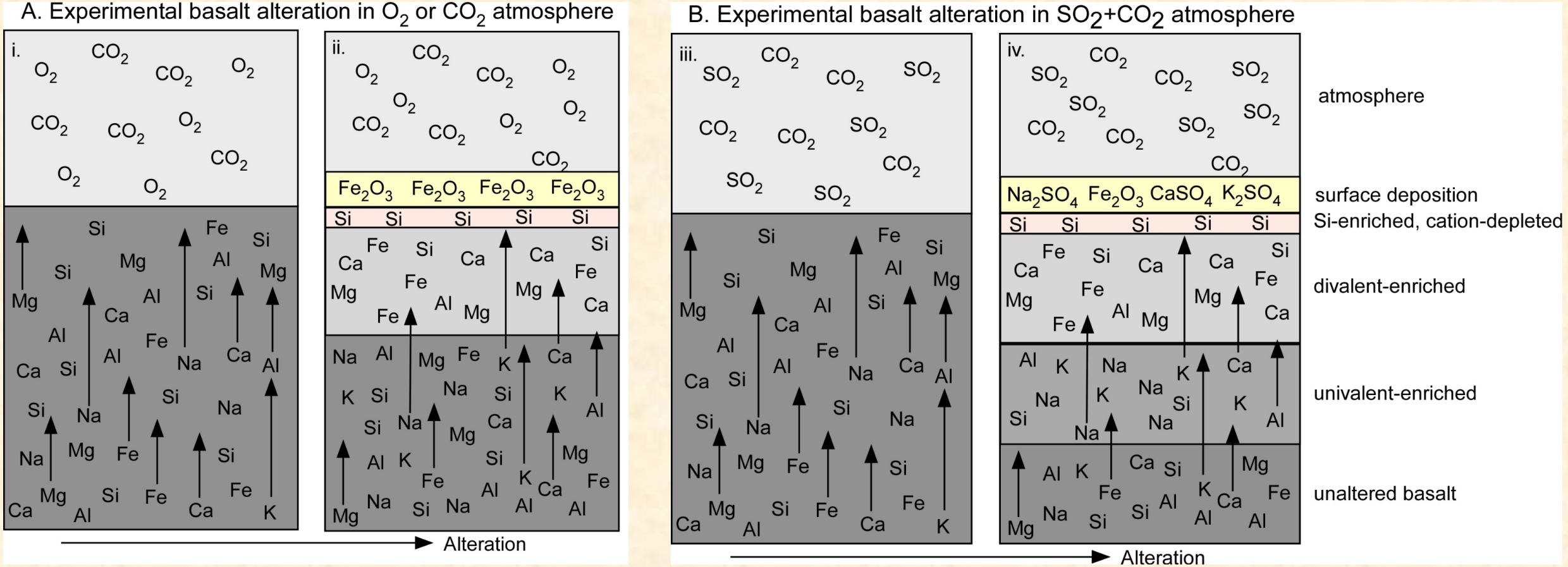


Reid et al. (Submitted)

Basalt Alteration on Venus



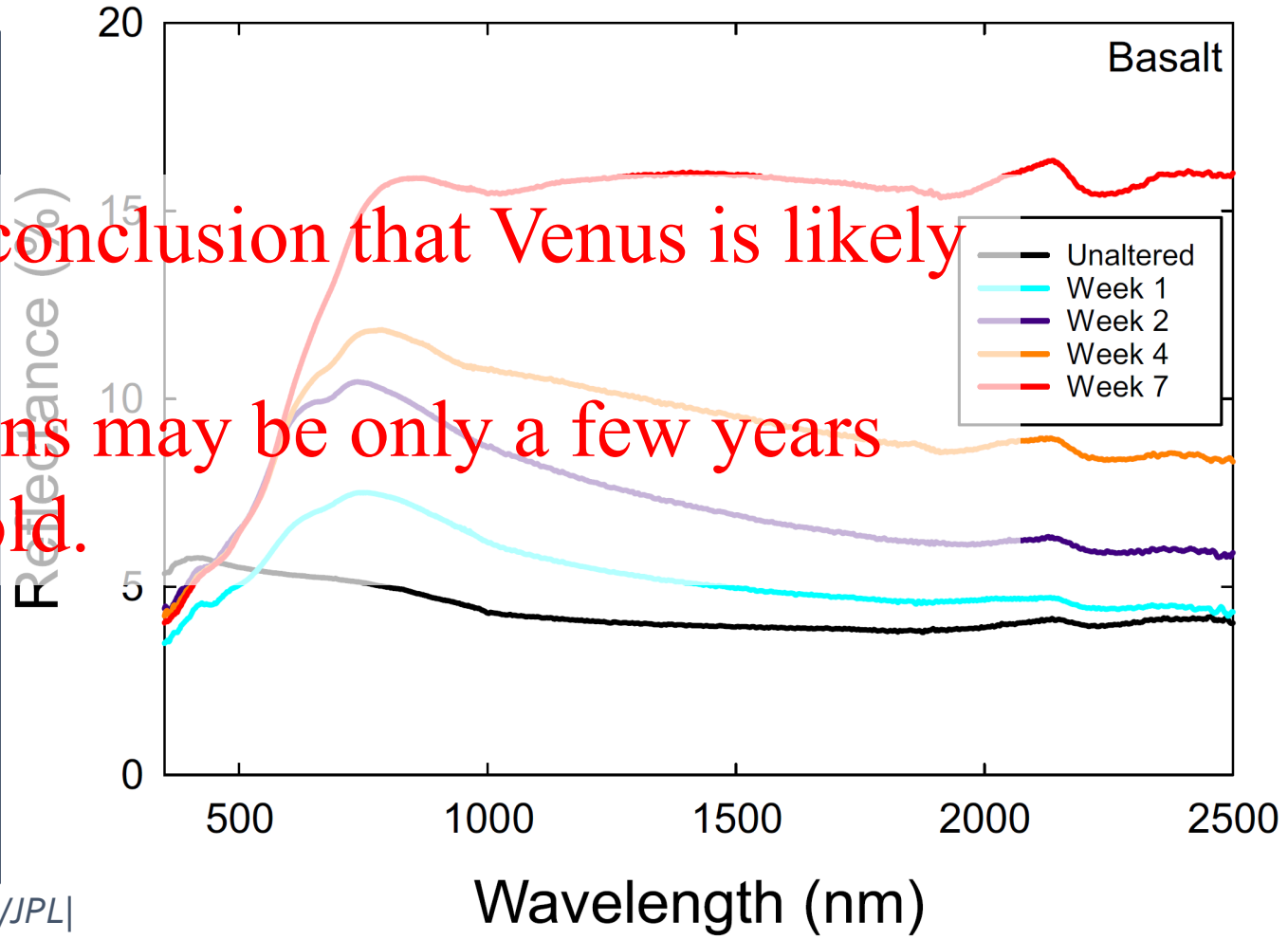
Filiberto and McCanta (2023/Accepted)



Recent Volcanism on Venus

- Emissivity = 1 – reflectance

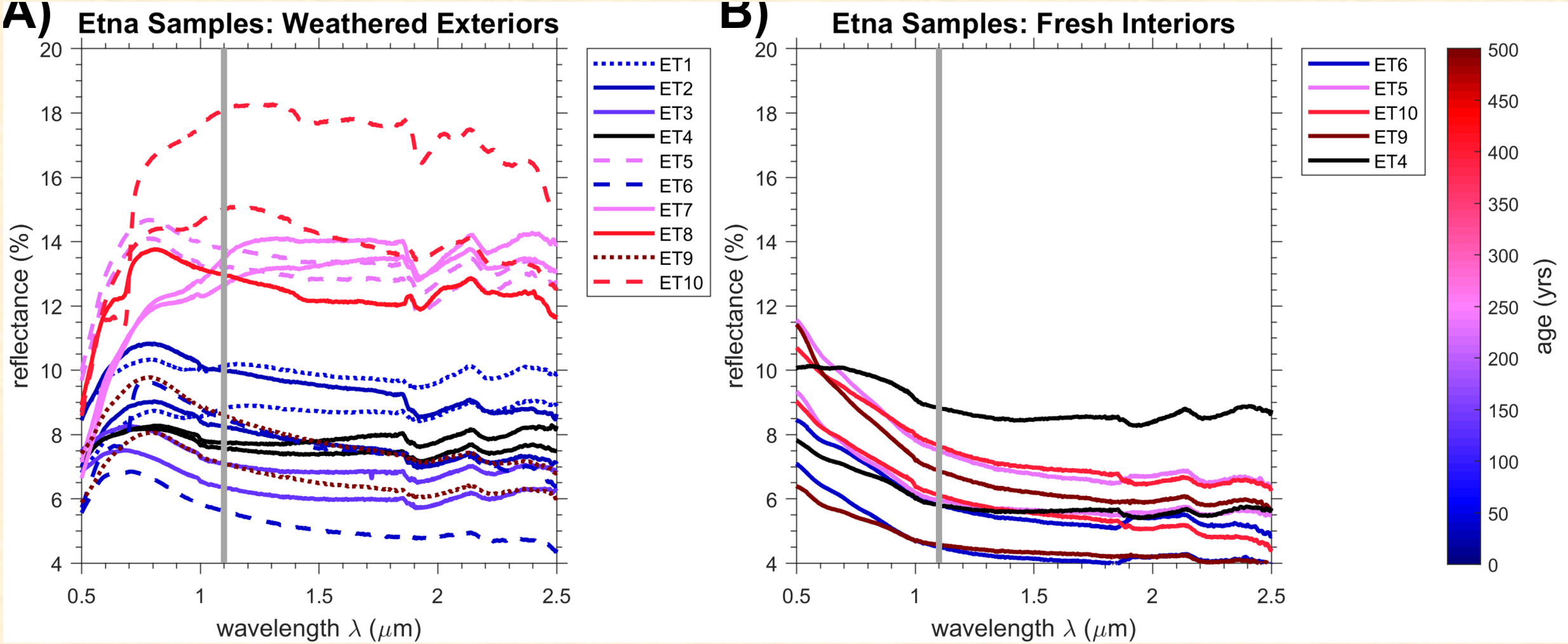
Our results support the conclusion that Venus is likely volcanically active.
Lava flows at Idunn Mons may be only a few years (up to a few thousand) old.



Smrekar et al. 2010 |*Emissivity at Idunn Mons*| *image credit: NASA/JPL*|
ESA's Venus Express data of Southern Hemisphere

Cutler et al. (2020)

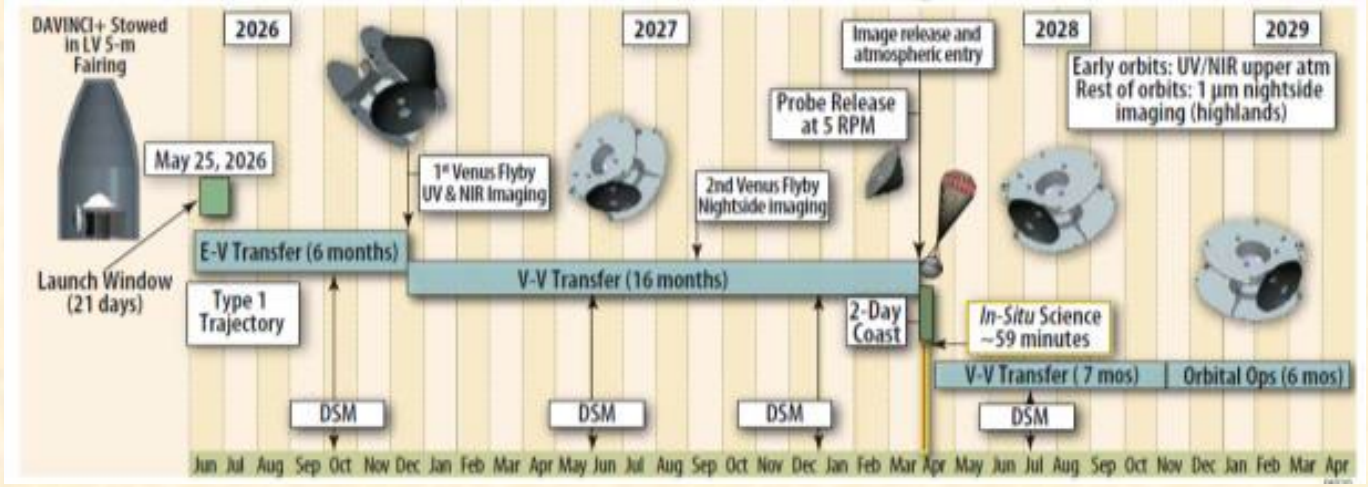
Testing this model on Earth at Mt Etna

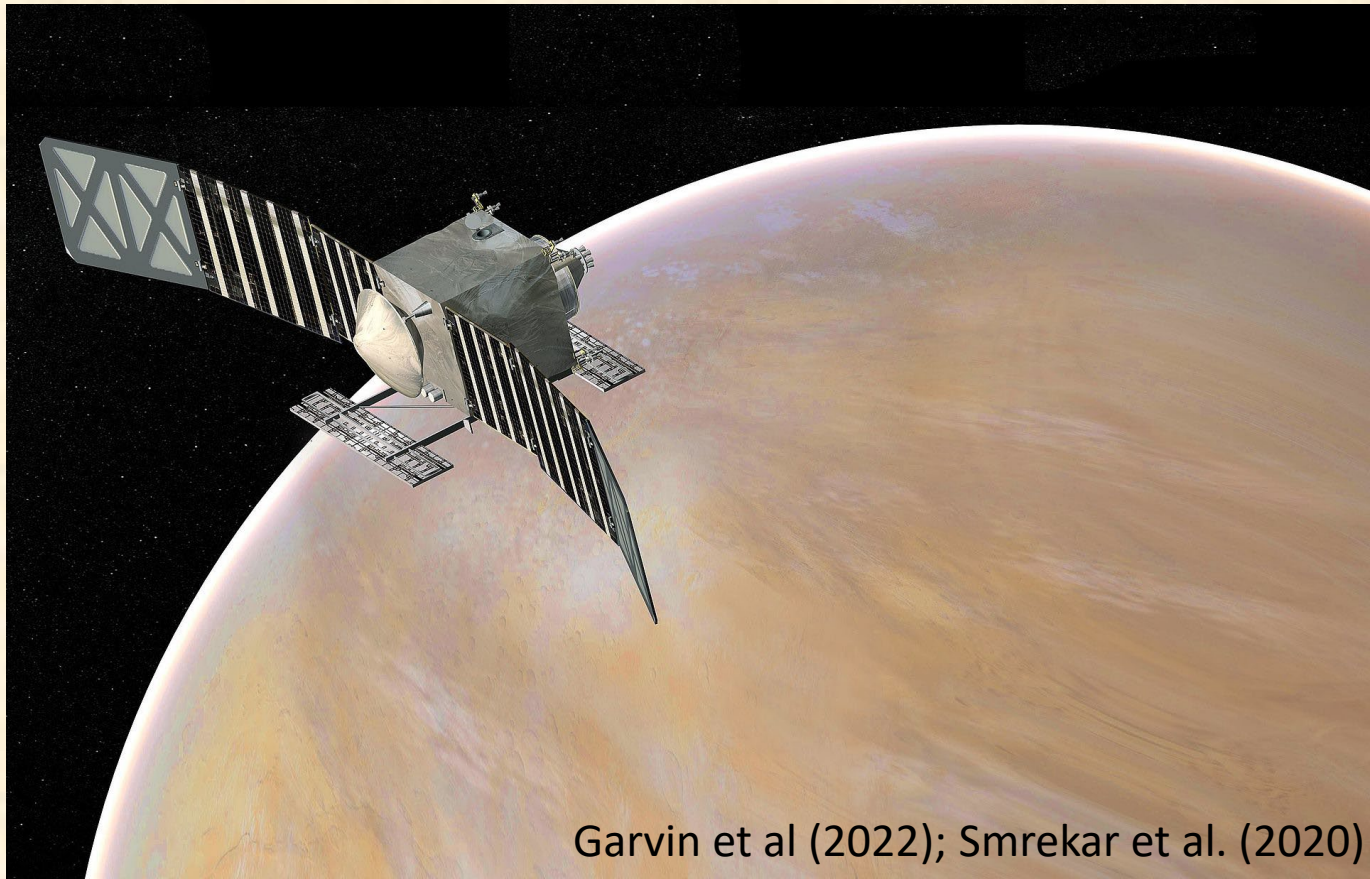


Eggers et al (2023) LPSC

New Missions!!!

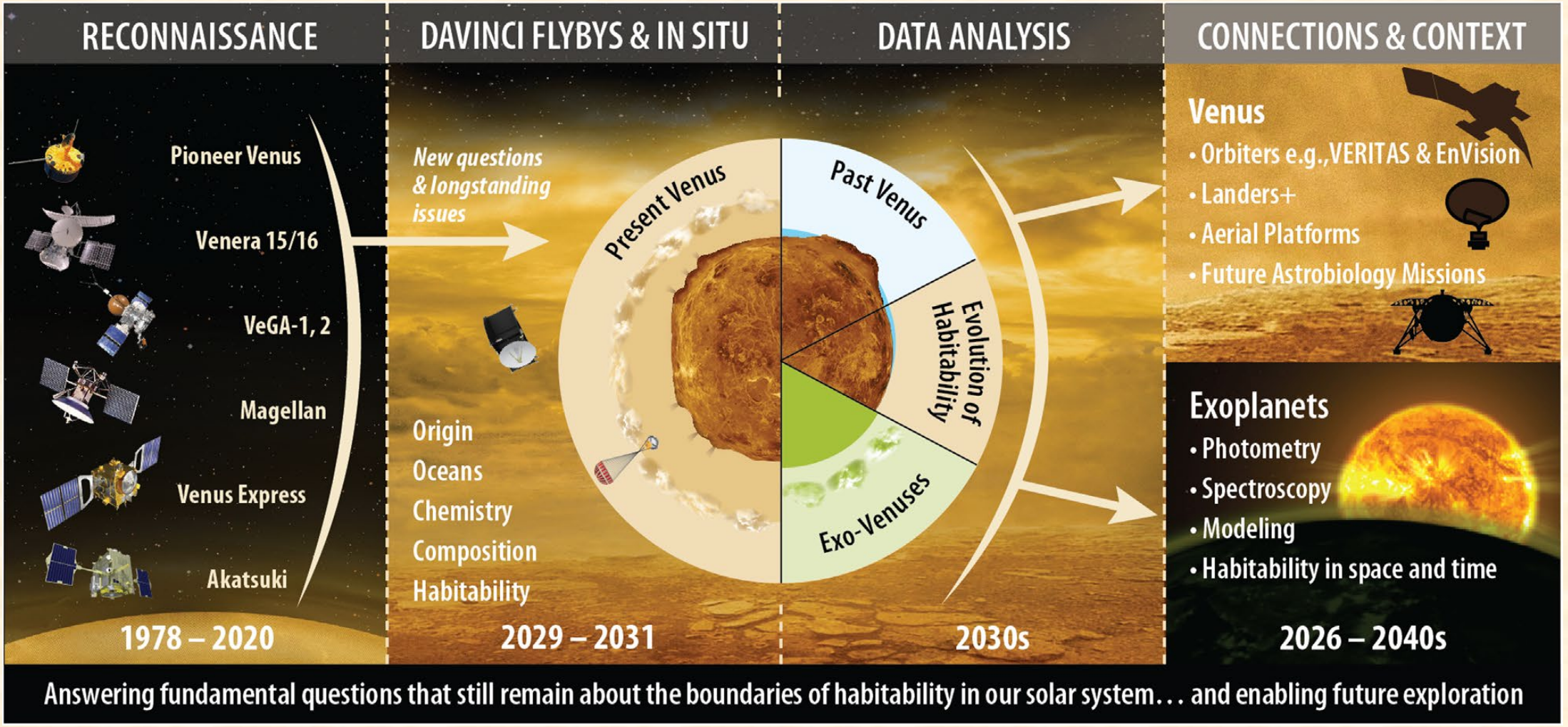
- NASA missions:
  - DAVINCI and Veritas
  - Phase-B
  - Launch 2028 and 2029 resp.
- Roscomos Venera-D mission
  - Launch date 2026-2031 - proposed
  - Includes an orbiter and lander
- ESA Envision Mission
  - Launch date 2032 - proposed
  - High resolution radar mission
- ISRO Shukrayaan-I
  - Launch date 2024 – planned
  - Orbiter
- China VOICE
  - Launch date 2026 – proposed
  - Orbiter imaging and climate
- Others…





Garvin et al (2022); Smrekar et al. (2020)

DAVINCI



Garvin et al (2022)

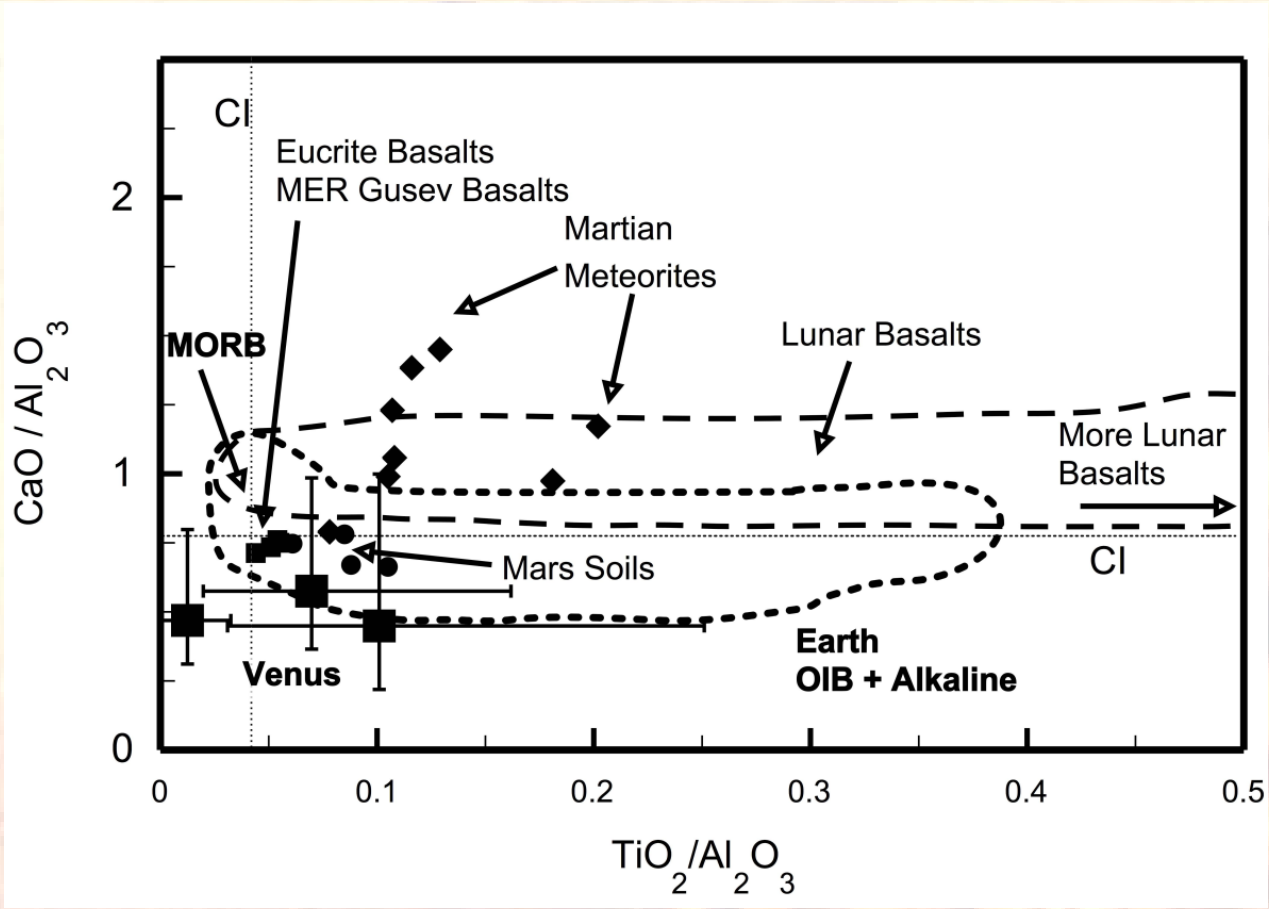
DAVINCI

Garvin et al (2022)

Conclusions

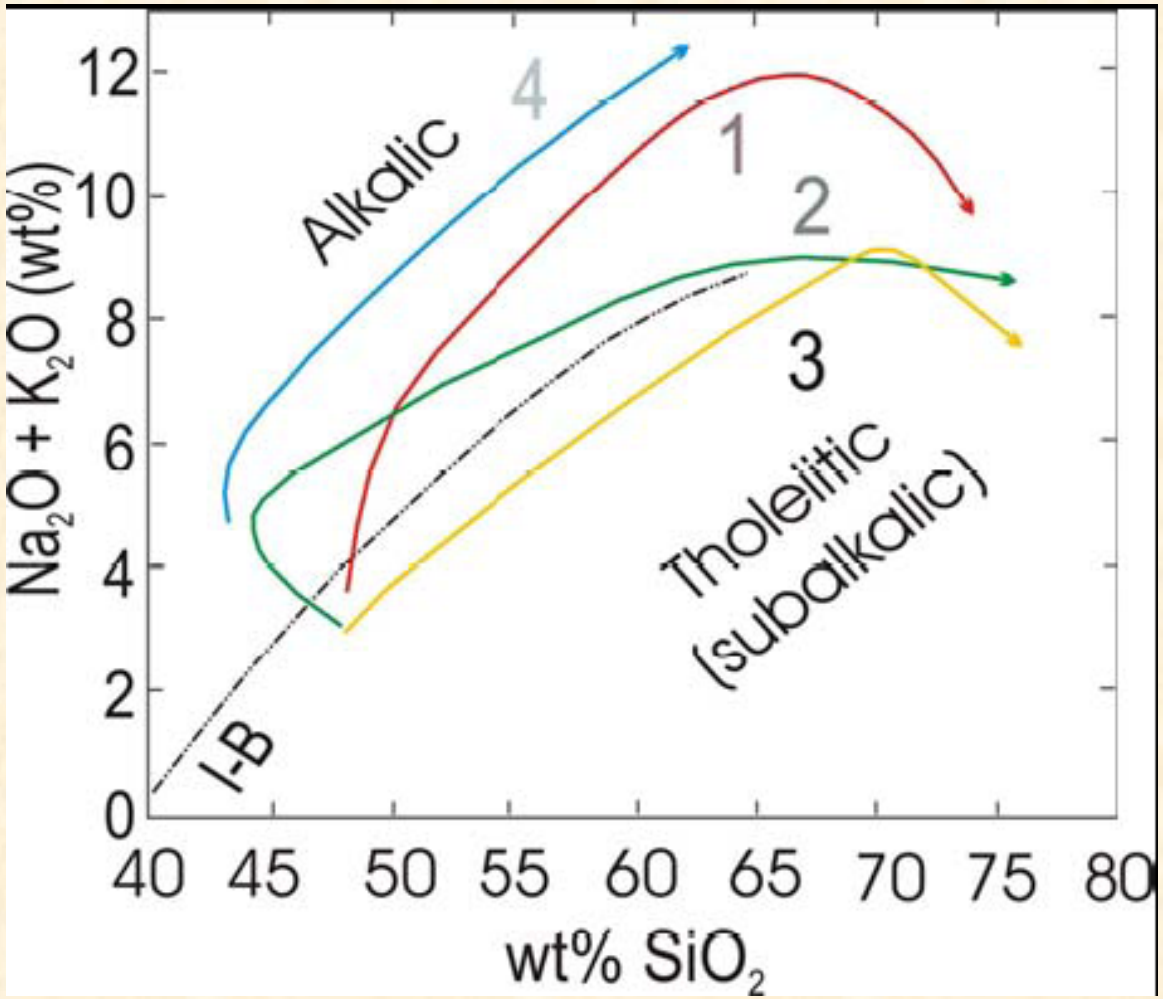
- Spectroscopy can be used to first order constrain age of surface features
  - However, it cannot be used for exact ages
- Surface of Venus should react quickly with the atmosphere
  - Iron oxides and Sulfates
  - Consistent with surface coloration – Pieters et al. (1986)
  - High S content of Vega 2 analysis
- Lava flows at Idunn Mons, and possibly other volcanoes are likely young
  - Years to decades old (oxidation only exp)
  - Decades to thousands of years (CO_2 only exp)
  - Possibly much younger (Experiments with S)
- Future missions should investigate young volcanic rises for changes
  - D'Incecco et al. (2021 SSR)

Venera and Vega Data



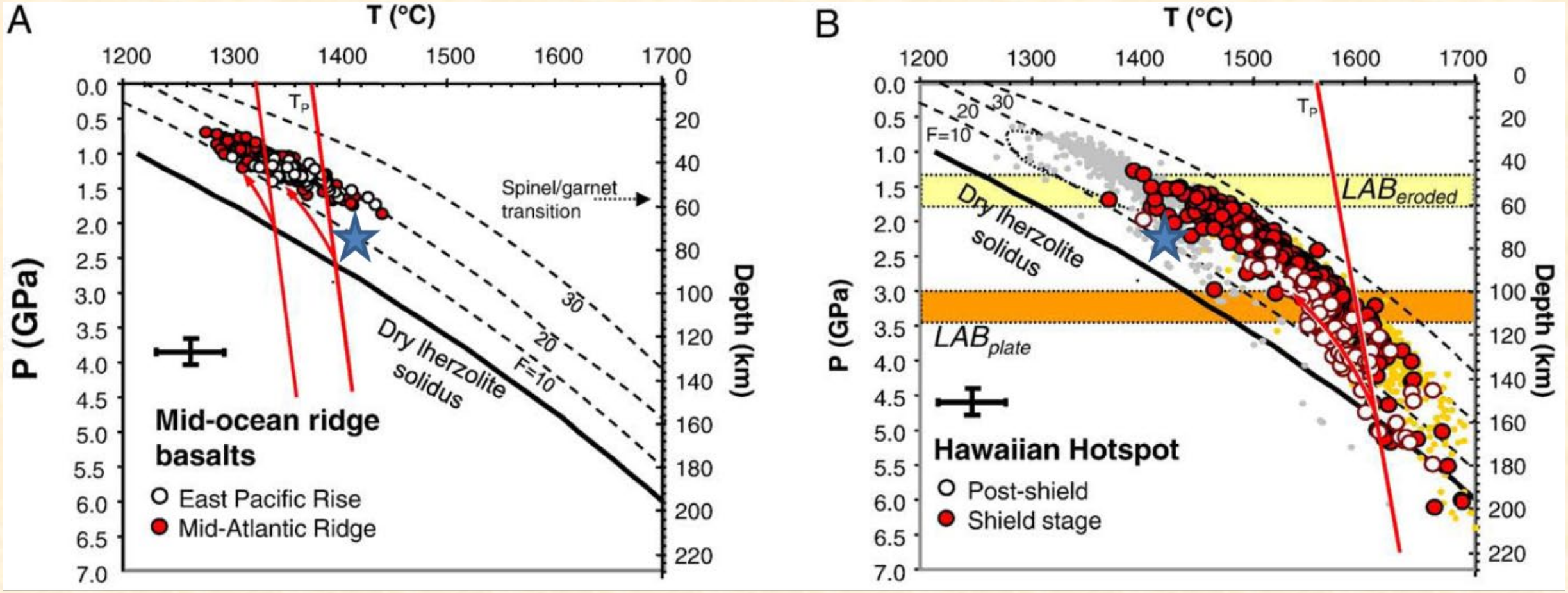
From Treiman 2007

The Earth as a Model



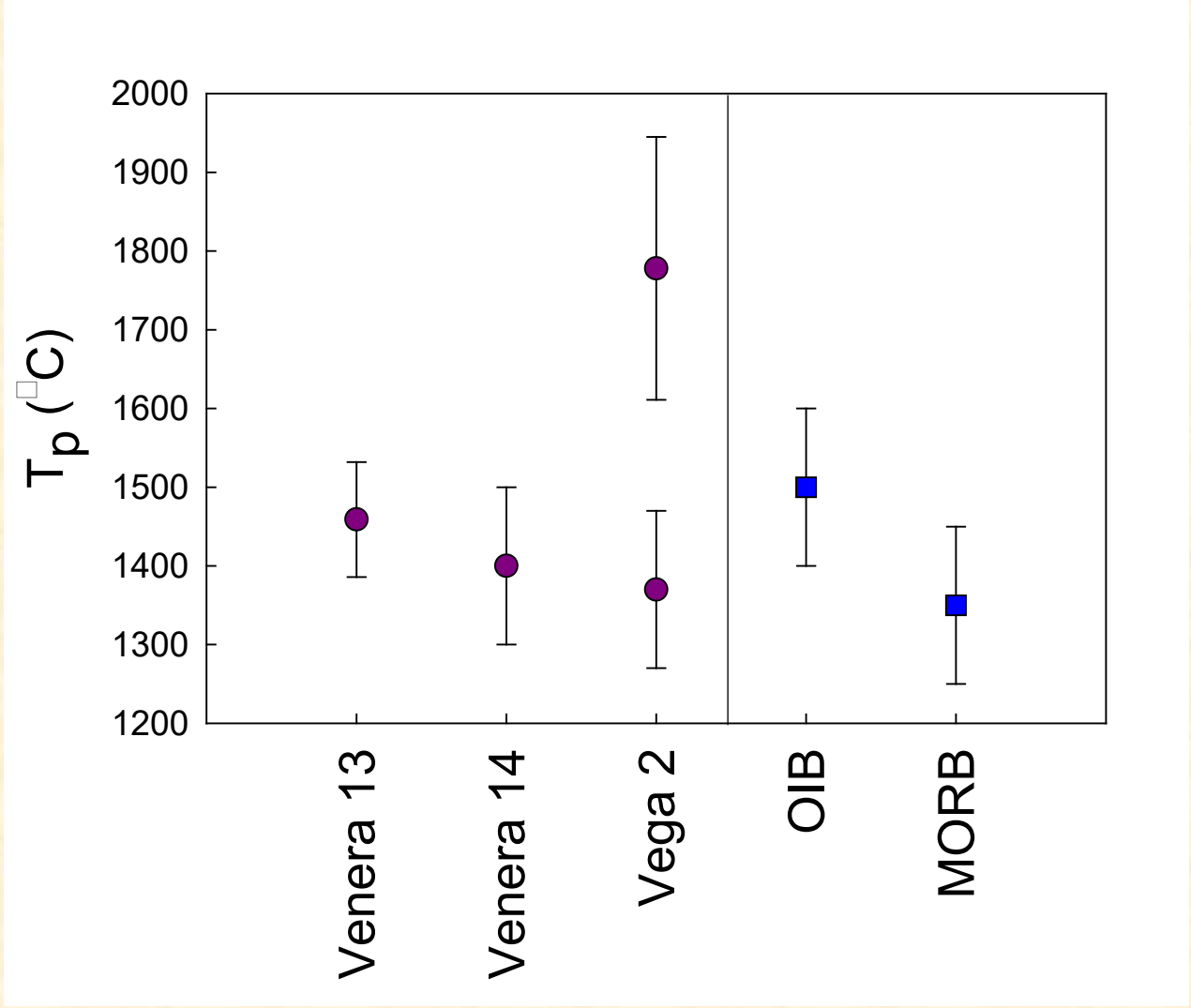
Nekvasil et al. (2000; 2004)

Magma Genesis Conditions



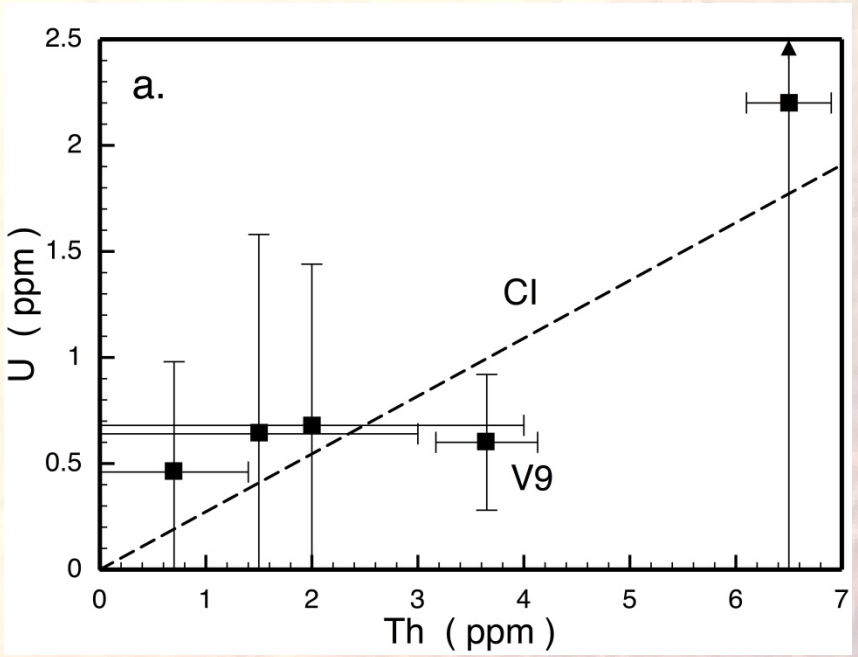
Terrestrial MORBs and Hawaii from Lee et al. (2009) with average data for Venus (blue star) from Lee et al. (2009); Weller and Duncan (2015); Shellnutt (2016)

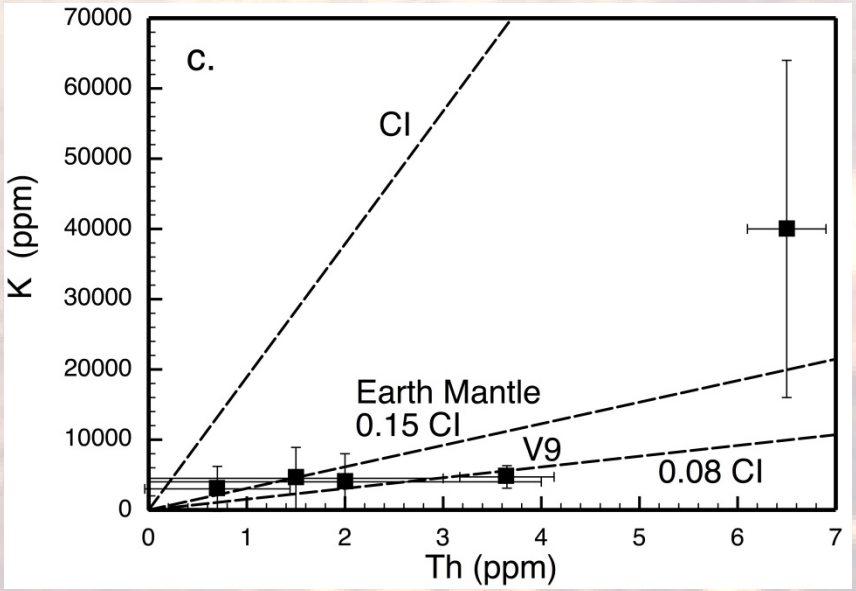
Mantle Potential Temperature



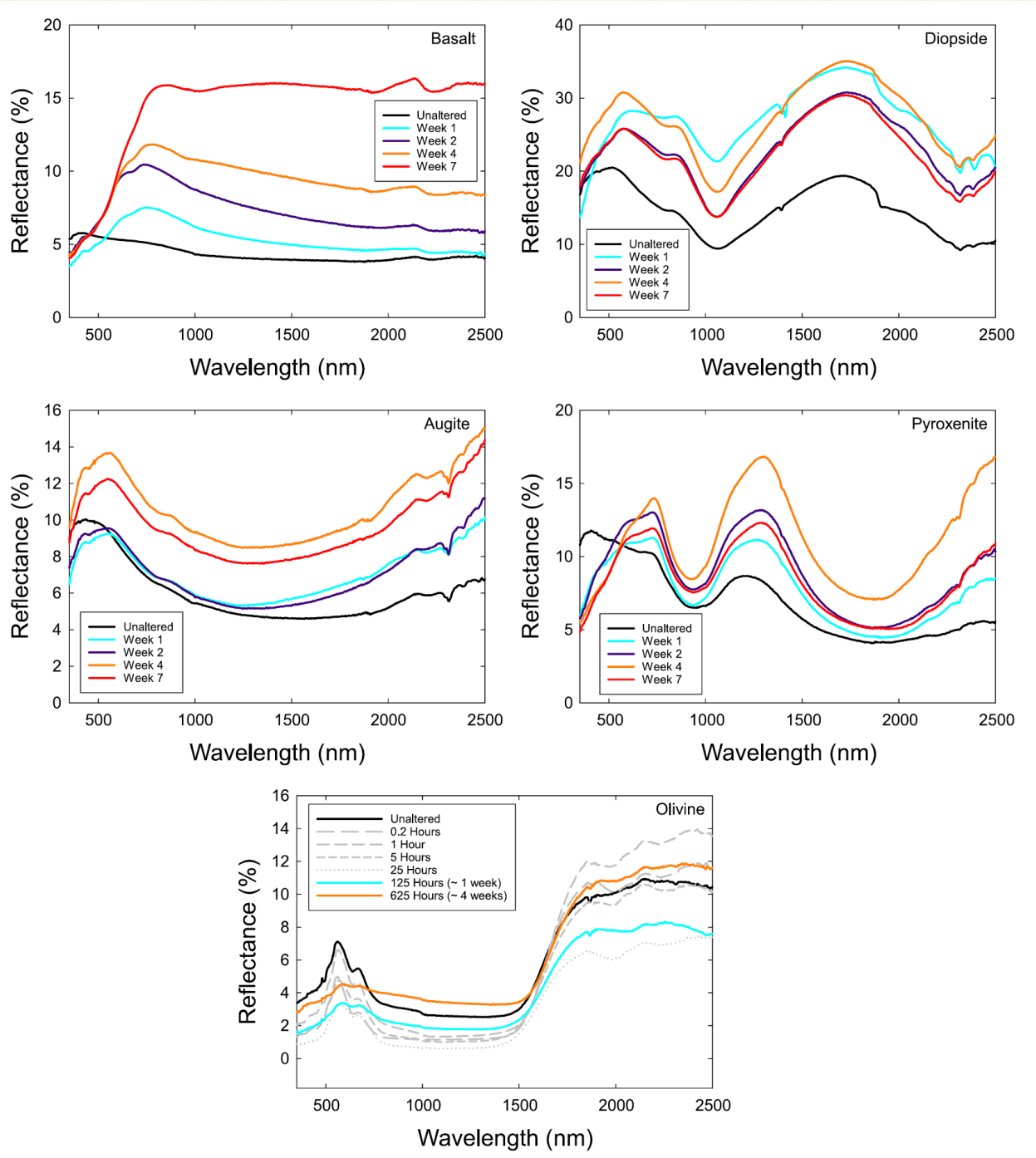
Terrestrial data as summarized in Lee et al. (2009) and Filiberto and Dasgupta 2015with average data for Venus (blue star) from Lee et al. (2009); Weller and Duncan (2015); Shellnutt (2016)

Venera and Vega Data

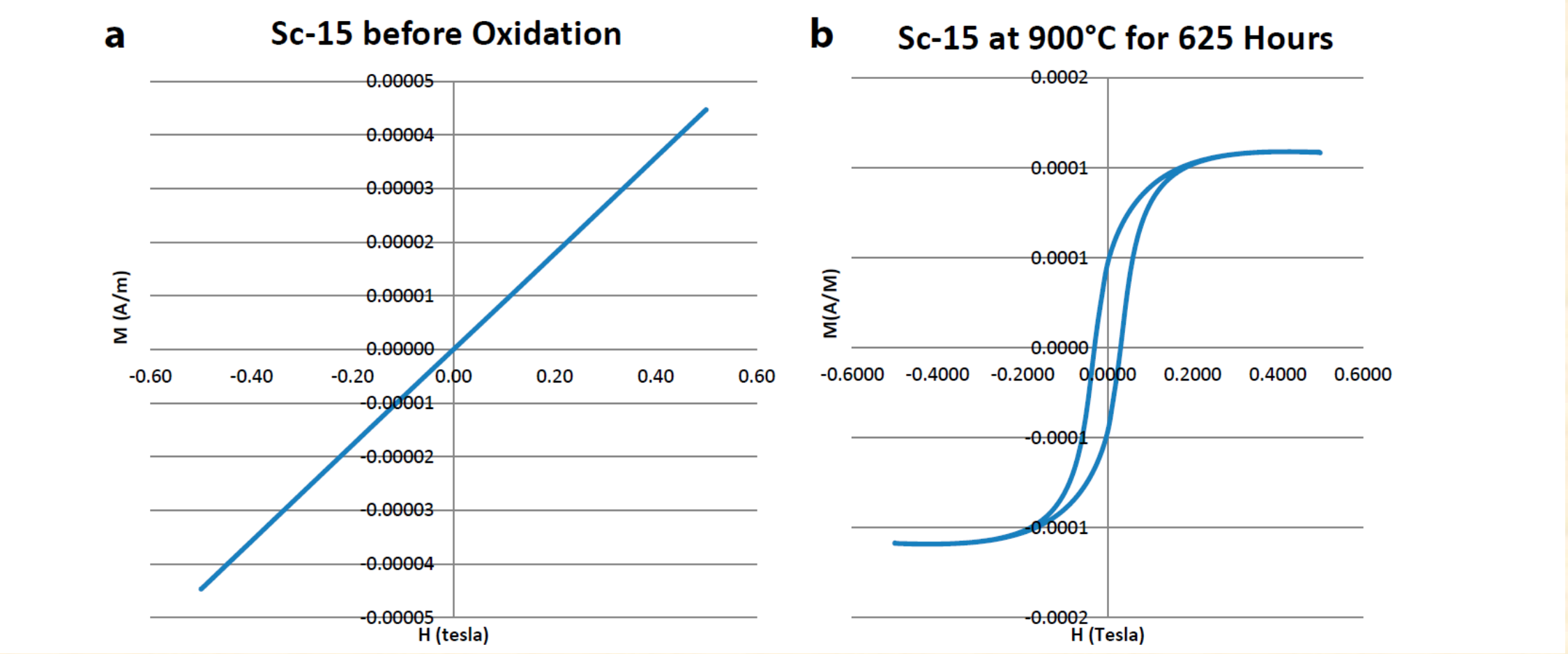




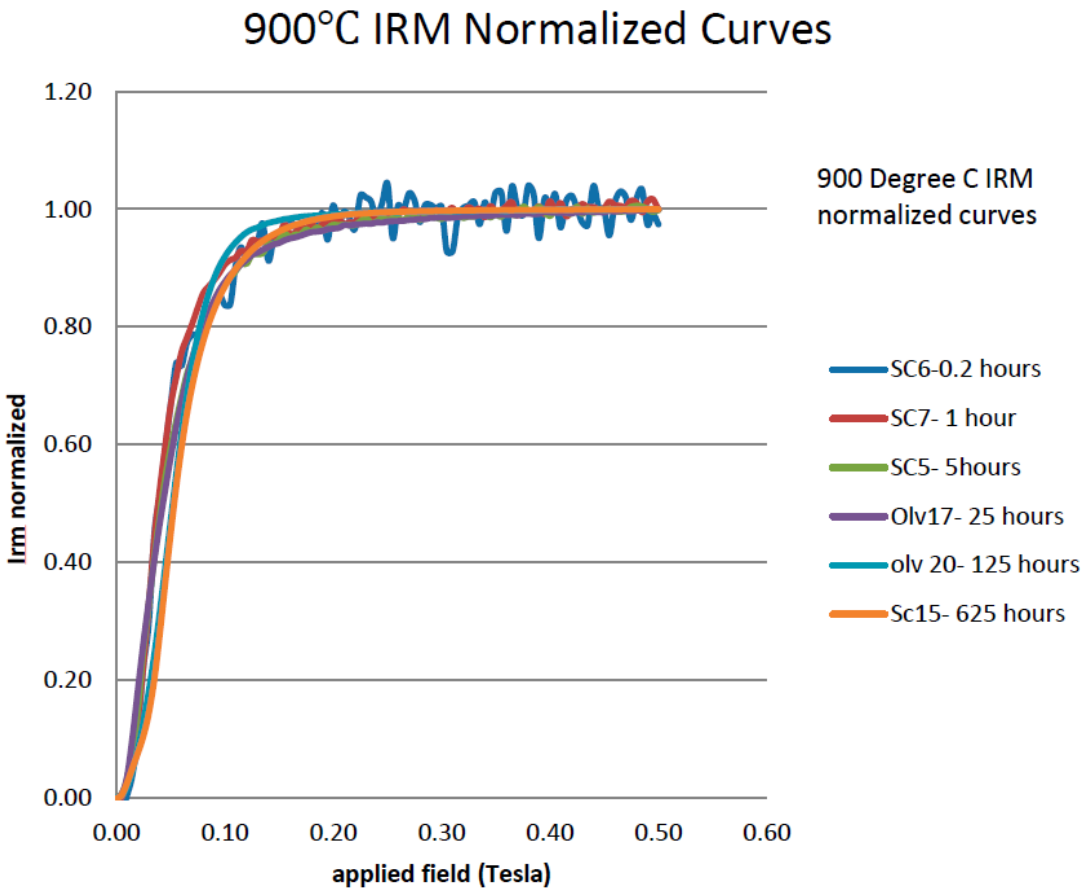
From Treiman 2007

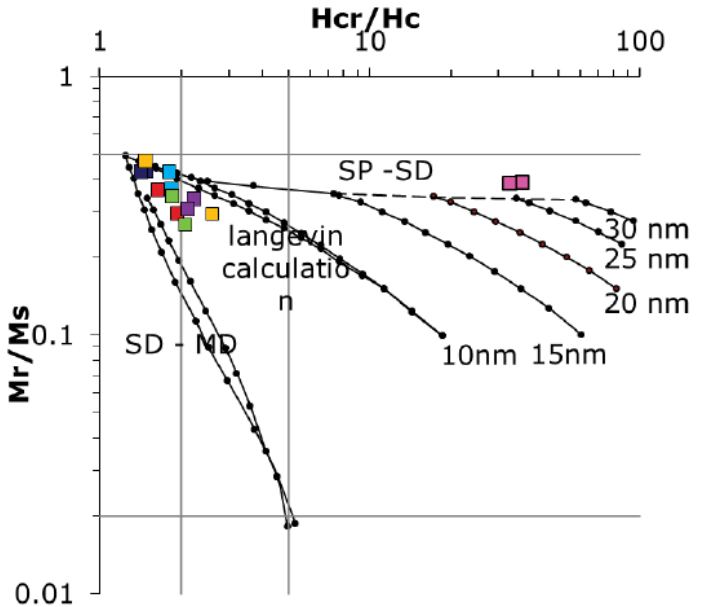


Cutler et al. (2020)



Knafelc et al. (2019)





Sample #	time (hours)	Temperature (C°)
Sc-9	625	900
Sc-15	625	900
China 20	125	900
China 21	125	900
China 12	25	900
China 17	25	900
Sc-5	5	900
Sc-23	5	900
China 1	1	900
Sc-7	1	900
China 22	0.2	900
SC-6	0.2	900
Sc-14	625	600
Sc-3	625	600

FIGURE 6. Dunlop (2002) plot for all experimental results showing magnetic grain size quantification. H_{cr}/H_c is the remanent coercity divided by coercive force. M_r/M_s is the isothermal remanent magnetization divided by the saturation magnetization. Most samples exhibit more

Knafelc et al. (2019)