Surface-Atmosphere Interactions on Venus: A Review

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Outline

- overview of atmosphere-surface environment

- major processes
  - reactions with CO_2
  - reactions with S gases
  - surface redox conditions
  - low radar emissivity regions

- measurement requirements

Main Questions

- *to what extent is atmospheric chemistry controlled by surface mineralogy?*

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mineral A + gas (CO_2,SO_2,etc) ↔ mineral B ± mineral C

Overview: Atmosphere

- extreme near-surface conditions
  - 0 km: 740 K, 95 bar
  - 12 km: 650 K, 45 bar
  - reactive species

- ***composition below ~20 km is poorly known***

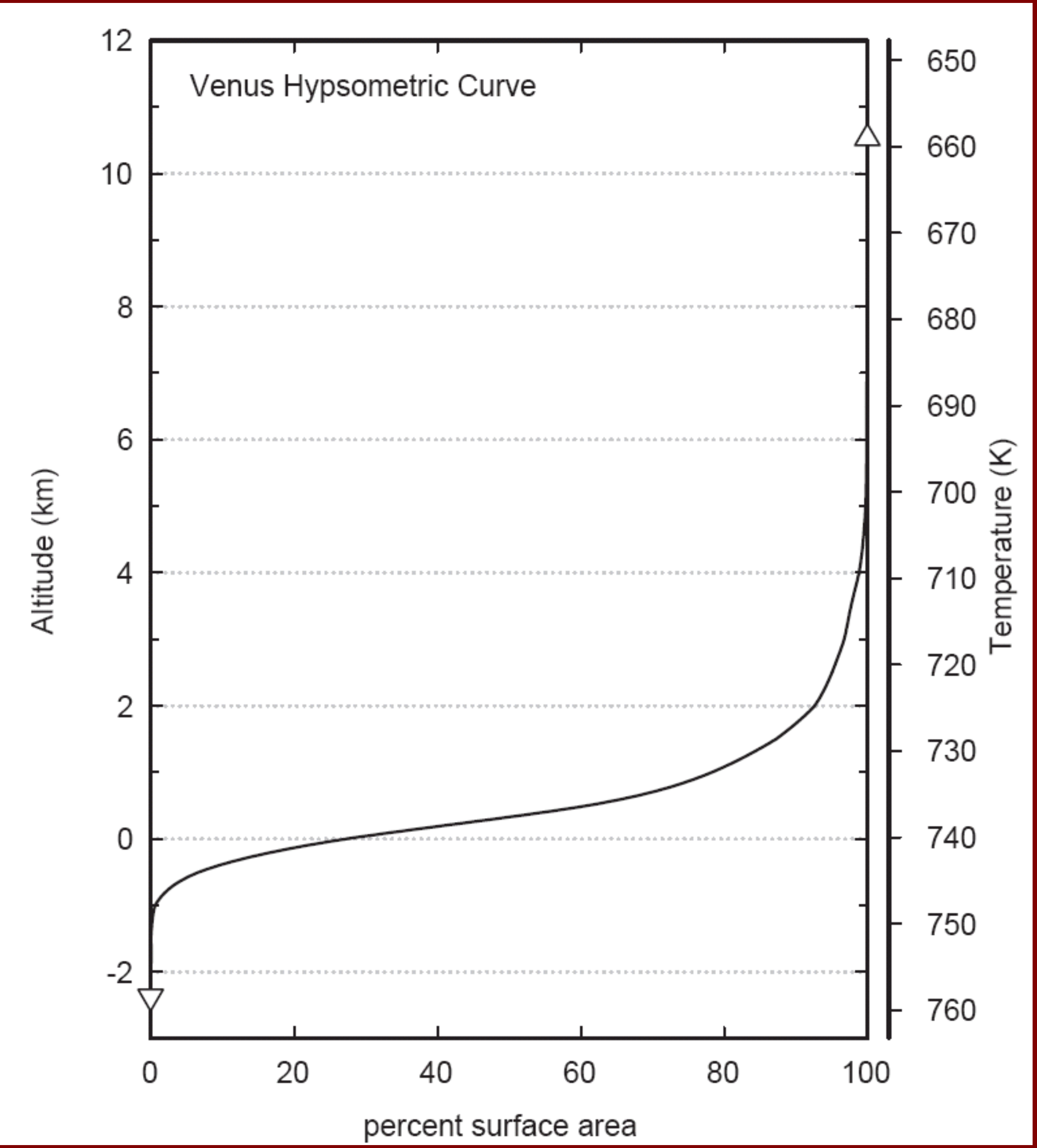
gas	abundance
CO_2	96.5%
N_2	3.5%
CO[a]	15 ± 10 ppm
SO_2[a]	130 ± 50 ppm
H_2O[a]	30 ± 15 ppm
H_2S[a]	3 ± 2 ppm
OCS[a]	4.4 ± 1 ppm
$S_{1\text{-}8}$[a]	20 ppb

[a] altitude dependent

Overview: Atmosphere

- ***composition below ~20 km is poorly known***

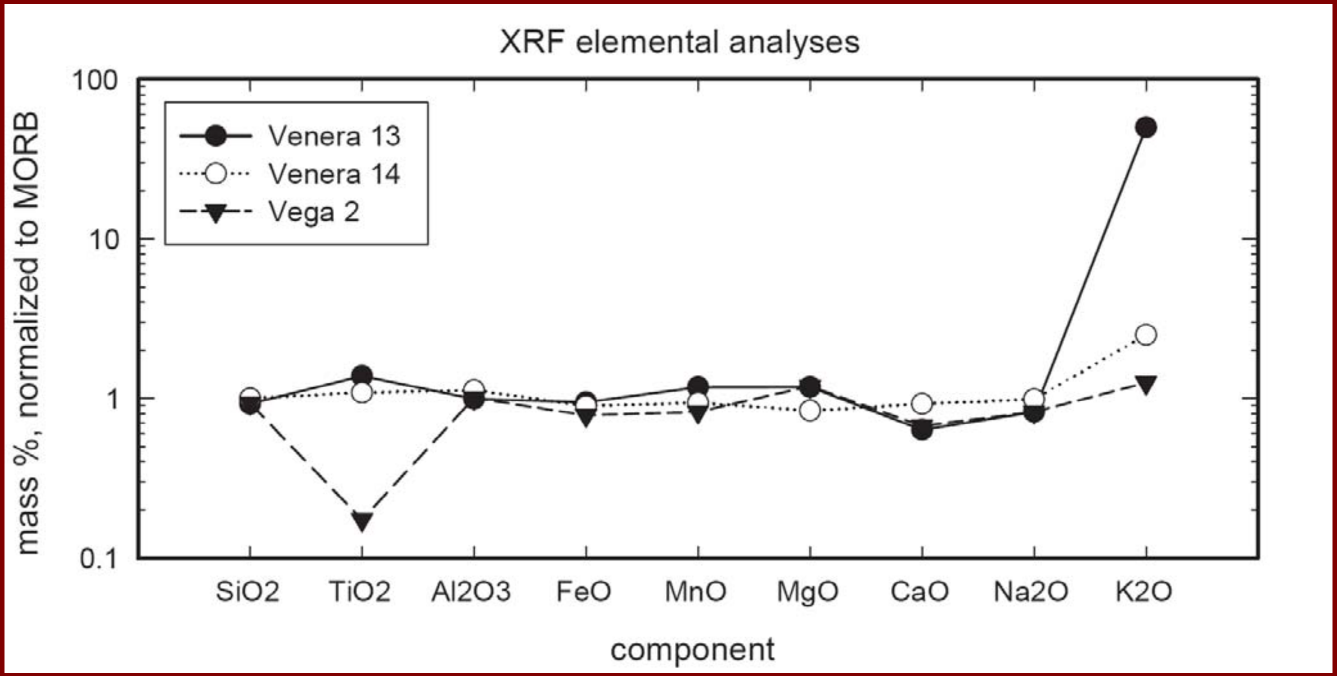
- 50% of atmospheric mass below Maxwell Montes



Overview: Surface

- XRF elemental analyses consistent with ~ basalt

- in contact with reactive species at high P, T
  - **<u>chemical weathering</u>** is dominant (low surface winds, dry)
  - mineral A + gas (CO_2,SO_2,etc) ↔ mineral B ± mineral C



XRF analyses of Venusian surface at ~ 1 km altitude

Reactions with CO_2: carbonate formation?

- "Urey reaction" as plausible buffer:

  $CaCO_3$(calcite) + SiO_2(quartz) = $CaSiO_3$(wollastonite) + CO_2

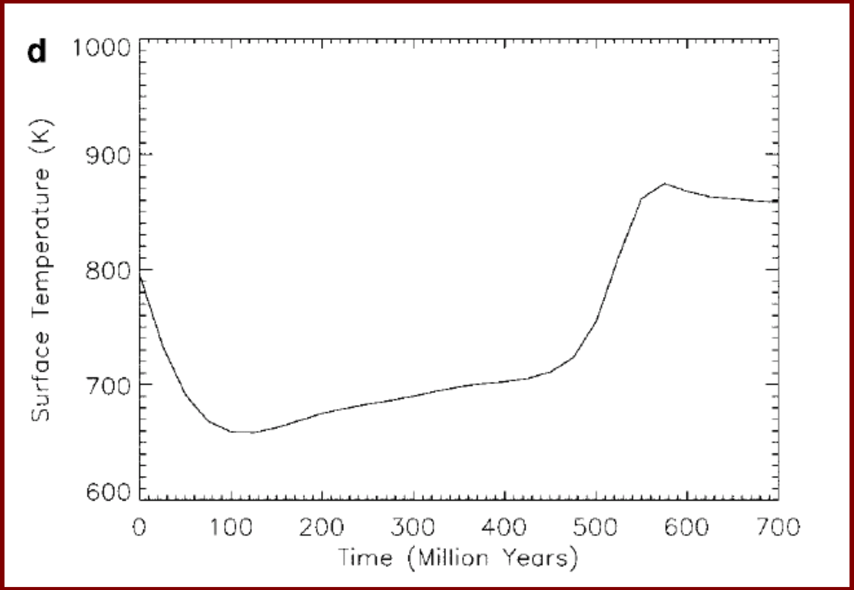
- at equilibrium: CO_2 ~ 90 bar at 740 K

- evidence for carbonates on Venus:
  - formation driven by high CO_2 pressure
    - $Mg_2SiO_4 + CO_2 = MgSiO_3 + MgCO_3$
  - flow features from carbonatite magmas →
  - responsible for 1-5% XRF mass deficits?

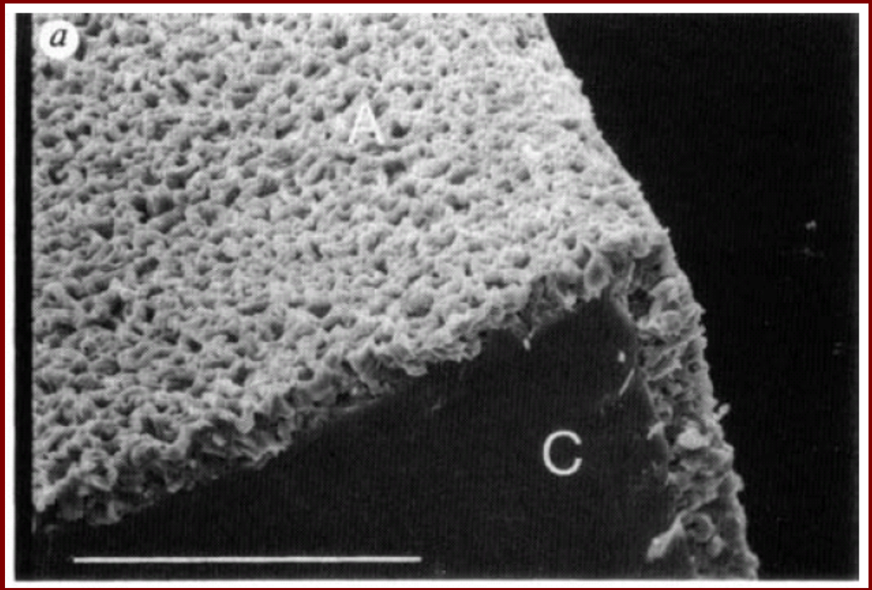
Treiman (2009)

Reactions with CO_2: carbonate formation?

- evidence against carbonates on Venus:
  - too dry
  - carbonate buffer results in climate instability
    - calcite + quartz = wollastonite + CO_2
  - *most* carbonates react with 130 ppm SO_2 to form sulfates



climate evolution since 0.5 Ga event

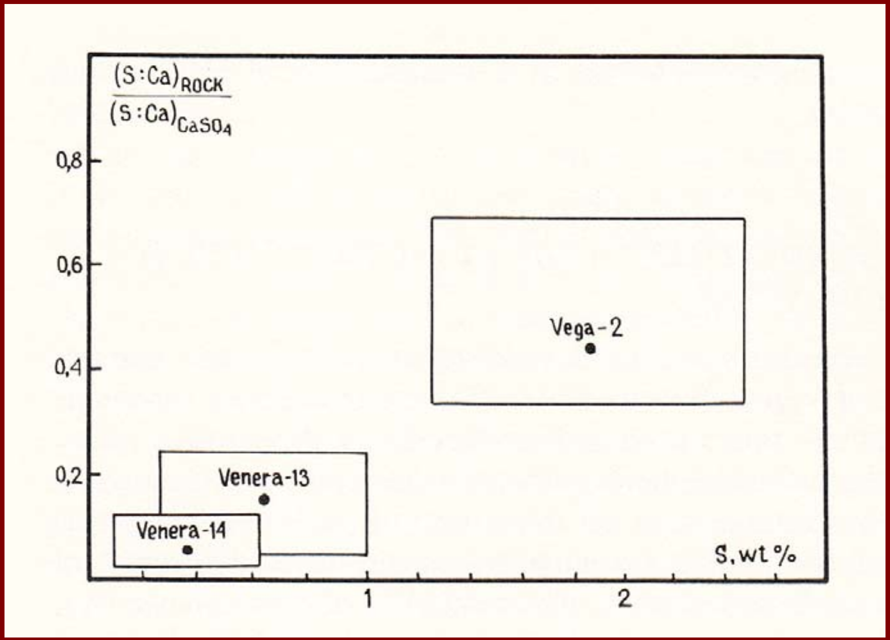


$CaSO_4$ on $CaCO_3$ crystal

Bullock & Grinspoon (2001); Fegley & Prinn (1989)

Reactions with S gases: Weathering

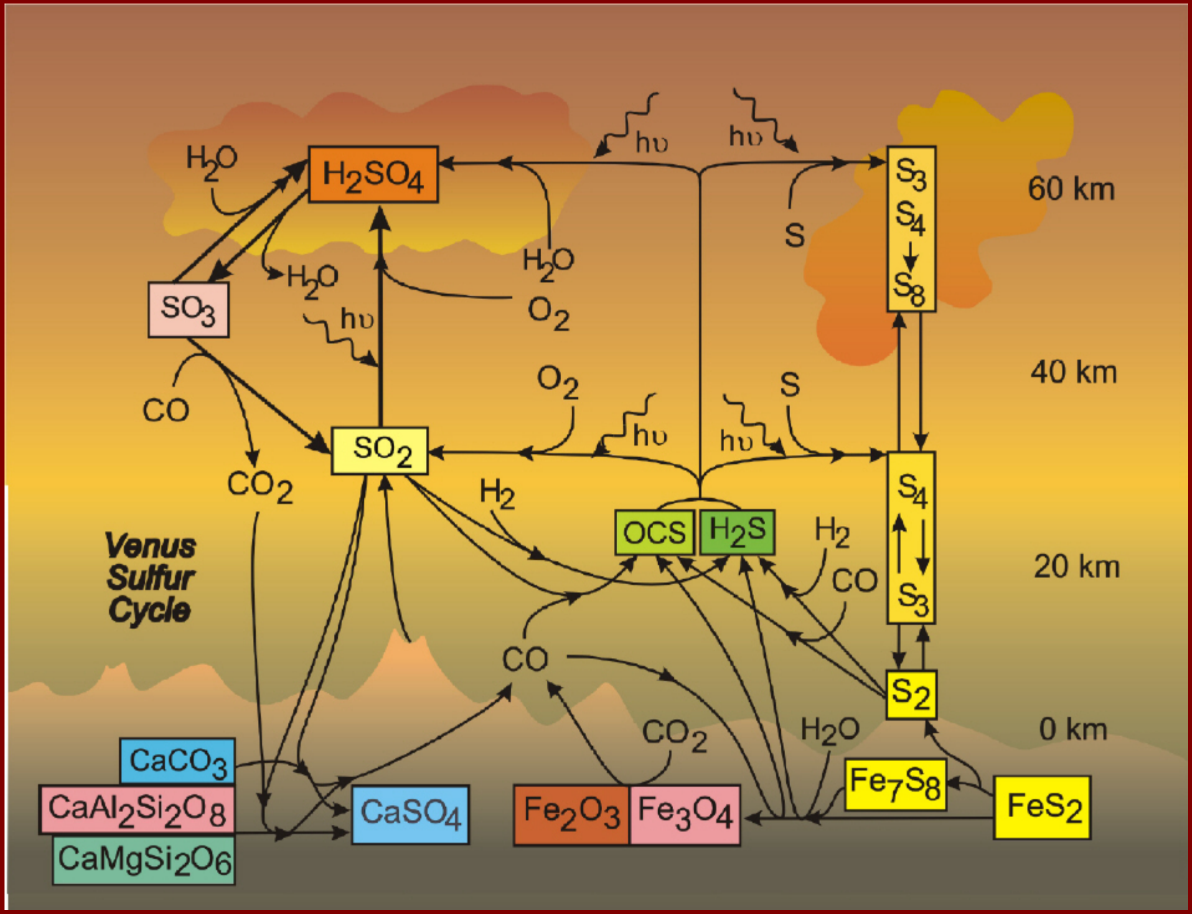
- SO_2 is important for chemical weathering
  - Ca-silicates + SO_2 → $CaSO_4$ (anhydrite)
  - surface basalts show high S content
    - incomplete sulfurization of Ca
    - S content correlates with physical weathering



Zolotov & Volkov (1992); Venera 13 and Venera 14 panoramas

Reactions with S gases: Sulfur Cycle

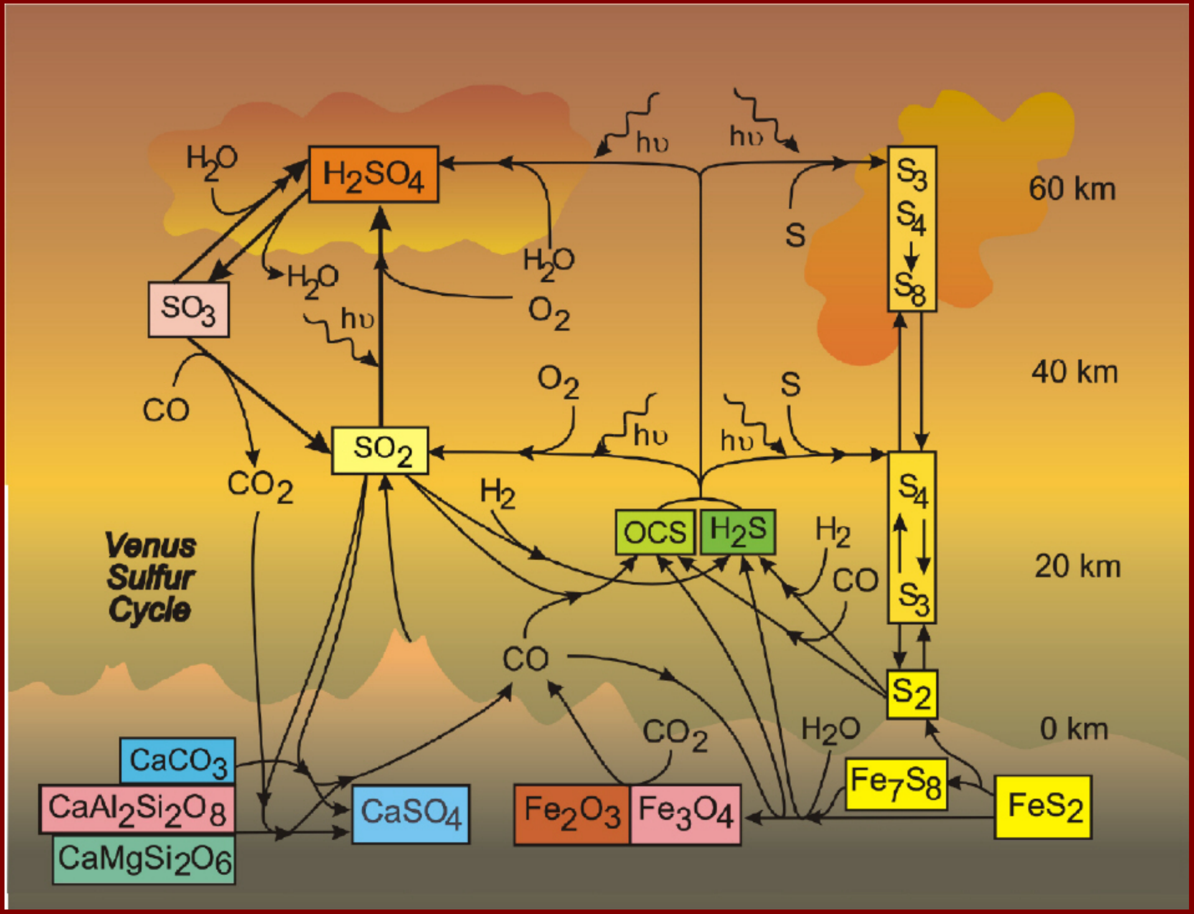
- SO_2 is removed from lower atmosphere by weathering
  - re-supplied from volcanic outgassing? (*cf. Esposito 1984, etc*)
  - what is the atmospheric sulfur abundance near the surface?



after Fegley et al (1995)

Reactions with S gases: Sulfur Cycle

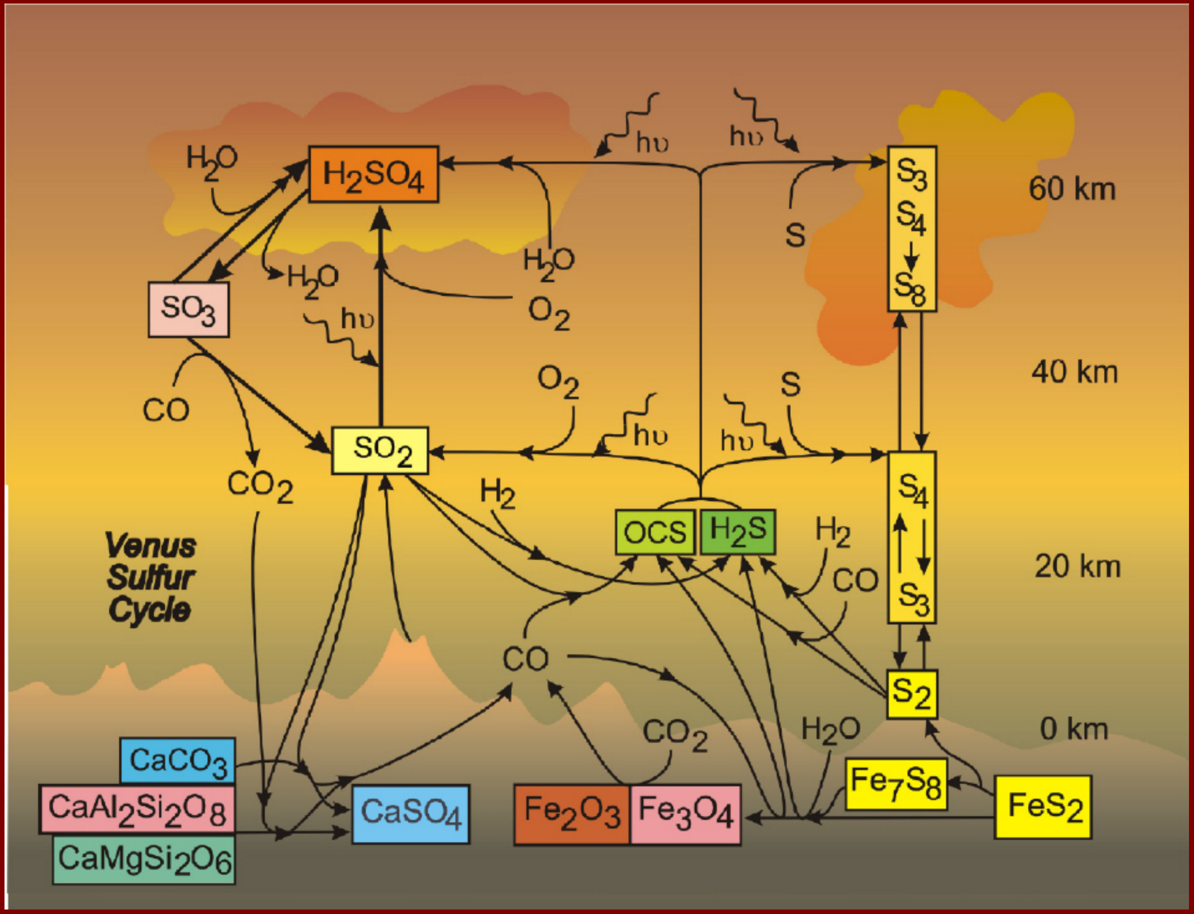
- OCS, H_2S abundances increase with depth
  - oxidation products of iron sulfides → iron oxides?



after Fegley et al (1995)

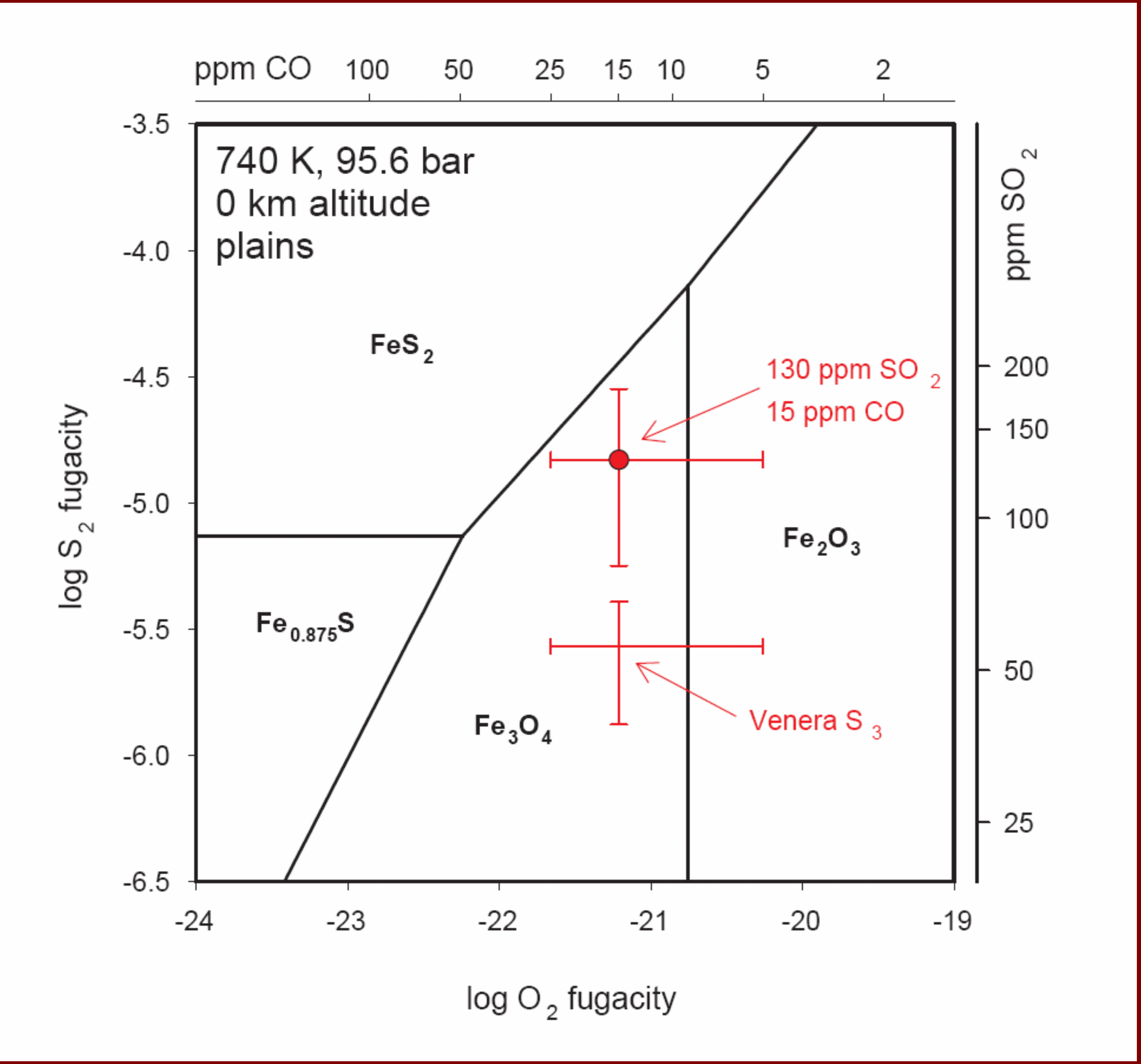
Reactions with S gases: Sulfur Cycle

- iron in silicates is susceptible to oxidation and/or sulfurization
  - which phases are stable? what is surface redox?



after Fegley et al (1995)

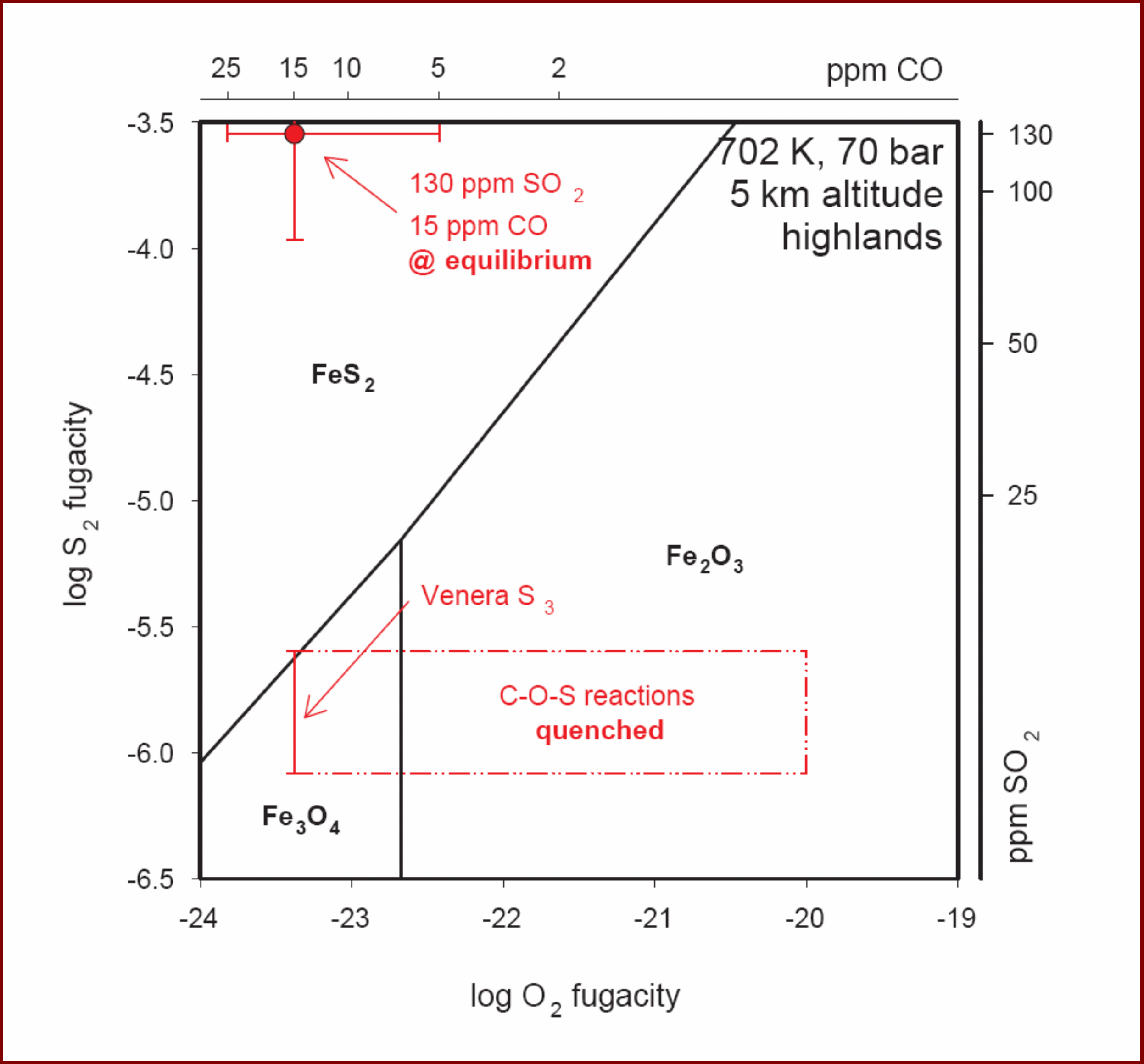
Surface Redox Conditions: 0 km altitude



- oxygen fugacity calculated using CO = 15 ± 10 ppm
- sulfur fugacity calculated using SO_2 = 130 ± 50 ppm
  S_3 = 0.02-0.08 ppb
- evidence for MH from Venera color imagery

modified after Fegley (1997), Figure 2a

Surface Redox Conditions: 5 km altitude



- assumptions diverge!
- equilibrium among C-O-S gases is unlikely
- redox conditions from lower altitudes prevail if mixing rate > rate of chemistry

modified after Fegley (1997), Figure 2b

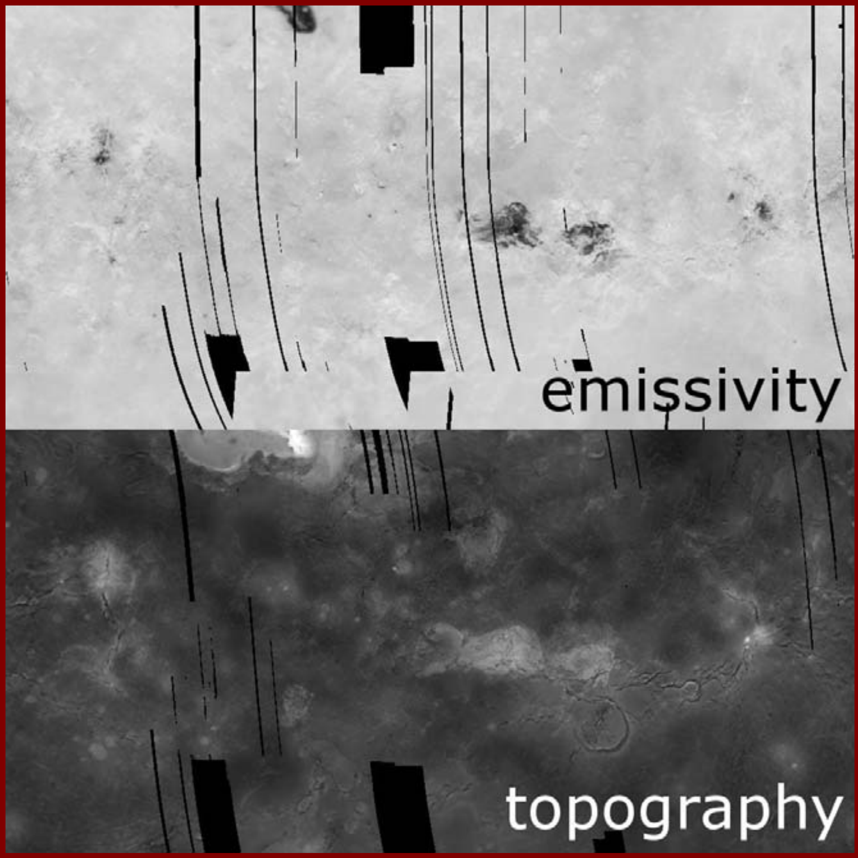
While we're up here at 5 km…

- what is responsible for low-radar emissivity?
  - altitude correlation suggests *T*-dependent chemical process

- dielectric loading in surface rock (e.g. Fe_3O_4, FeS_2, etc; *Klose et al 1992*)

- ferroelectric minerals (e.g. perovskites; *Shepard 1994*)

- metallic compound vapor deposition (e.g. Te, PbS; *Bracket et al. 1995, Schaefer & Fegley 2004*)



Magellan emissivity and topography

Summary

- carbonates are scarce if present, are not buffering CO_2
  - potentially more abundant beneath the surface

- sulfurization is the dominant weathering process
  - formation of anhydrite from calcium silicates, carbonates

- magnetite-hematite likely coexist at surface
  - plausibly regulating surface redox conditions (*Zolotov 2007*)
  - system is probably too oxidizing/sulfur-poor for pyrite (*Fegley 1997*)

- HCl (0.5 ppm), HF (5 ppb) <u>do</u> appear to be buffered by surface minerals

Measurement Requirements

- surface materials: **mineralogy**
  - carbonates and sulfates
  - Fe-bearing phase(s)
  - low radar emissivity substance

- **near-surface** (<12 km) atmosphere: **redox conditions**
  - CO, SO_2, H_2O,
  - OCS, H_2S

- **reaction kinetics**