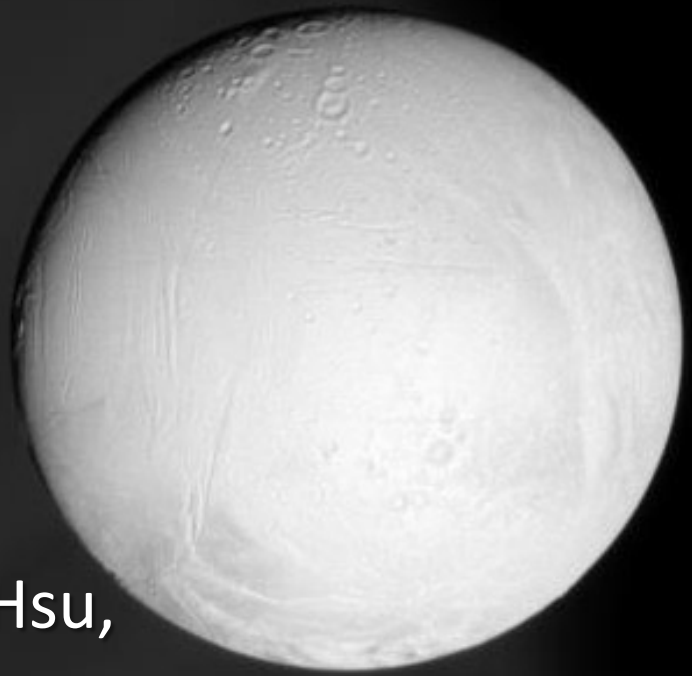
Enceladus' hydrothermal activity: Another habitable world?



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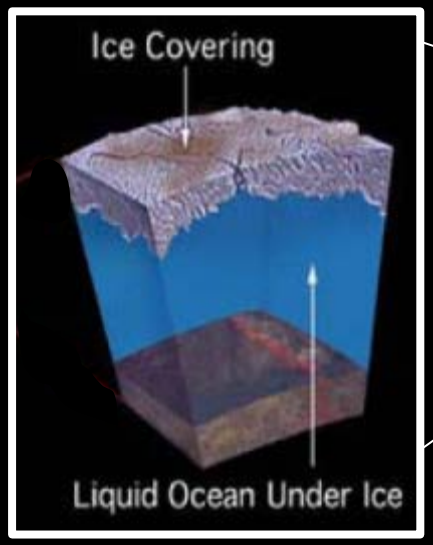
What are icy satellites?

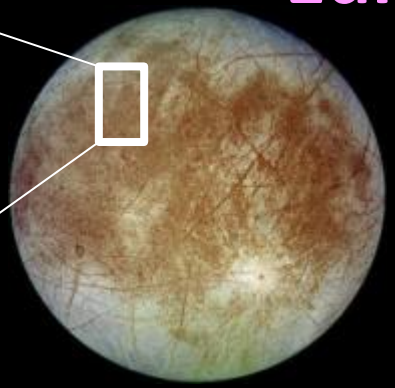
- **Ice-covered moons** around giant planets
- **Wide variety** in activity, surfaces, & interiors

Callisto

Low geological activity

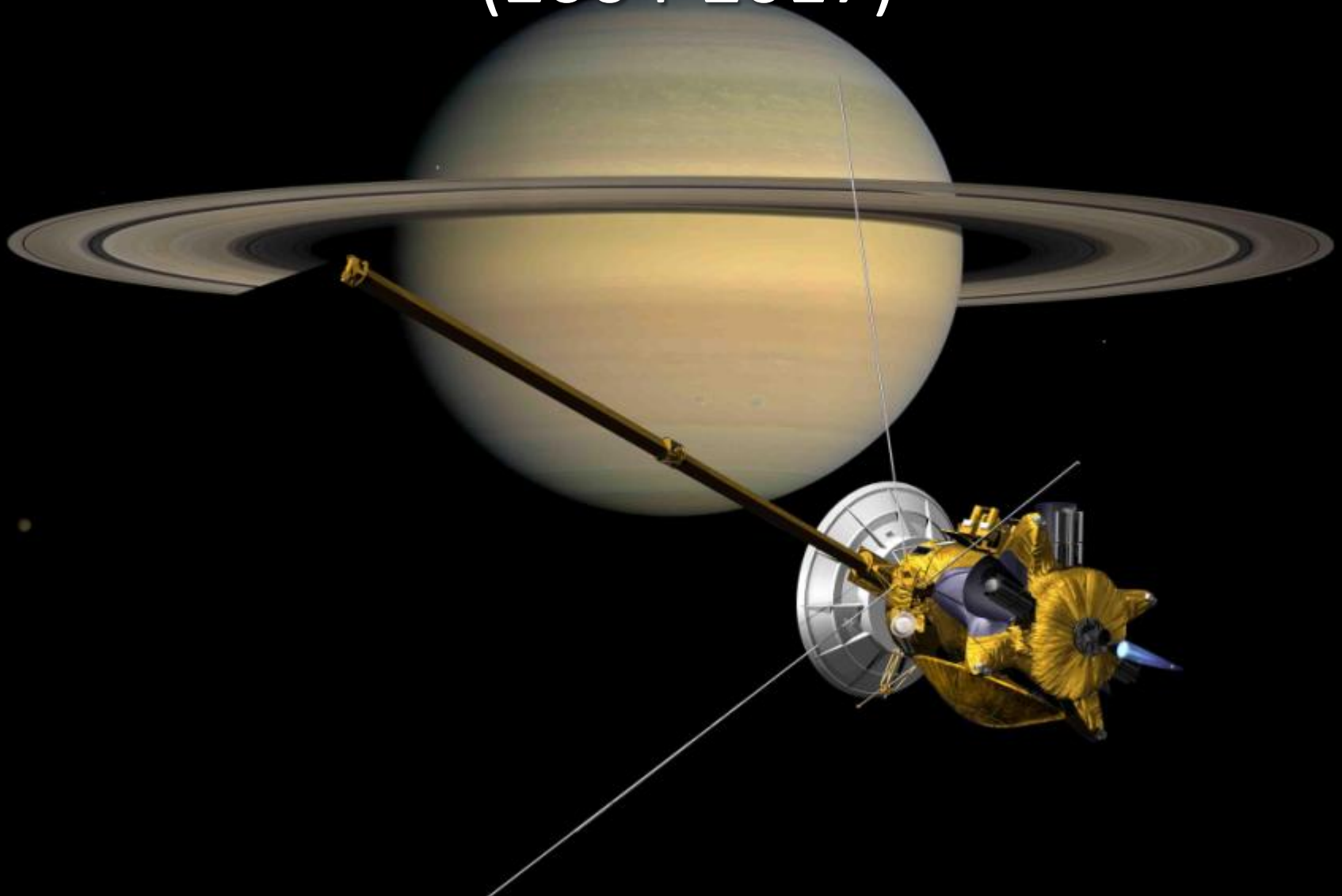


Europa



Extensive & prolonged activity, interior ocean

Cassini mission to the Saturnian system (2004-2017)



Mass spectra of Enceladus' plume

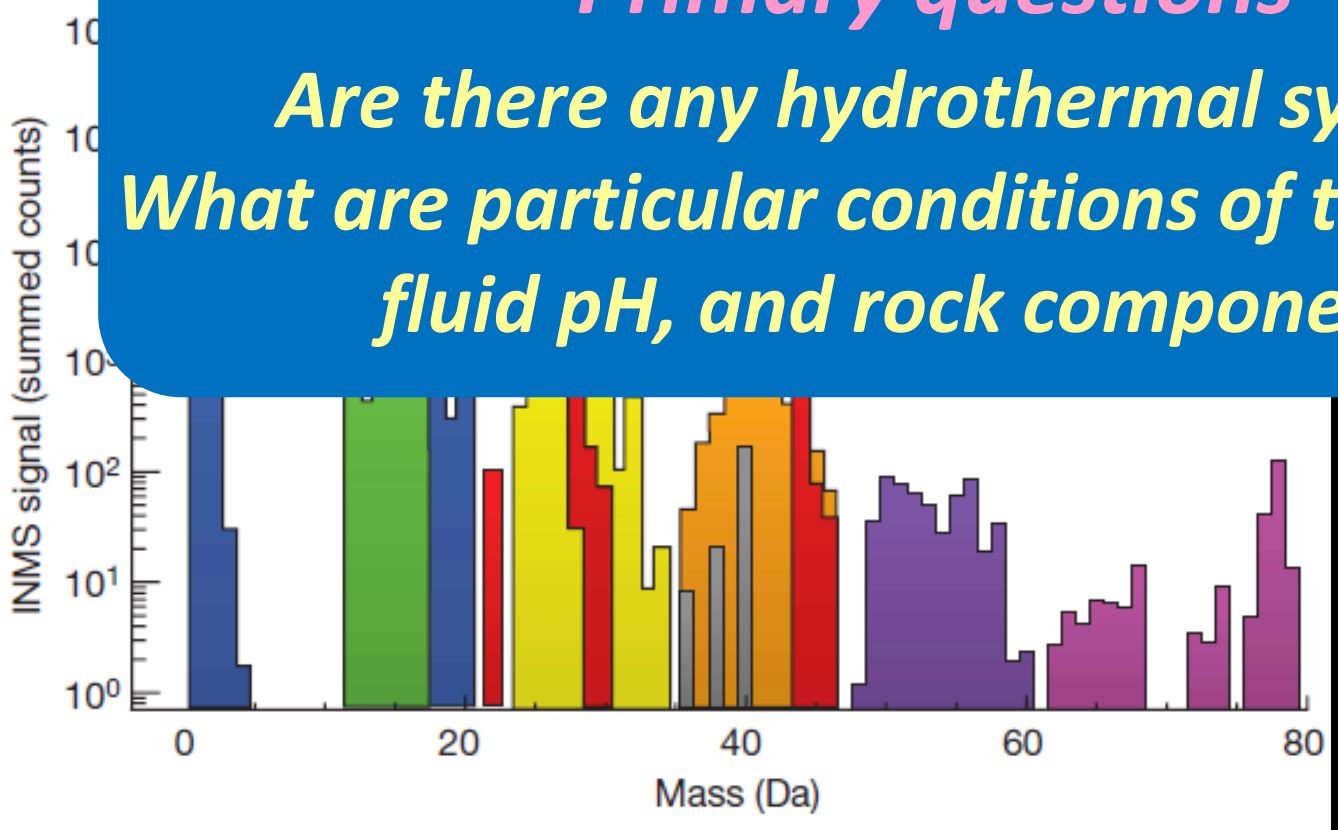
Gas: H_2O + C-species (CO_2 (1-5%), CH_4 (1%), alcohols, aldehydes)
+N-species (NH_3 (1%), HCN) (Waite et al. 2009)

Solids: H_2O ice with Na-salts, carbonates (Postberg, 2009; 2011)

Primary questions

Are there any hydrothermal systems?

What are particular conditions of temperature fluid pH, and rock components?



Cold or hot in Enceladus?

- If hot, N_2 should be observed in the plumes formed by thermal dissociation of NH_3: **$2NH_3 \Rightarrow N_2 + 3H_2$** (Matson et al. 2007).

Cold interior
(< ~0℃)

The lack of N_2

Low temp. << 150℃

Warm interior

The presence of N_2
(～1% relative to H_2O)

High temperature

Cassini's observations: lack of N_2 & abundance of NH_3 in plume could support a cold Enceladus? **(Hansen et al., 2011)**

Nano-silica in E-ring: active geochemistry?

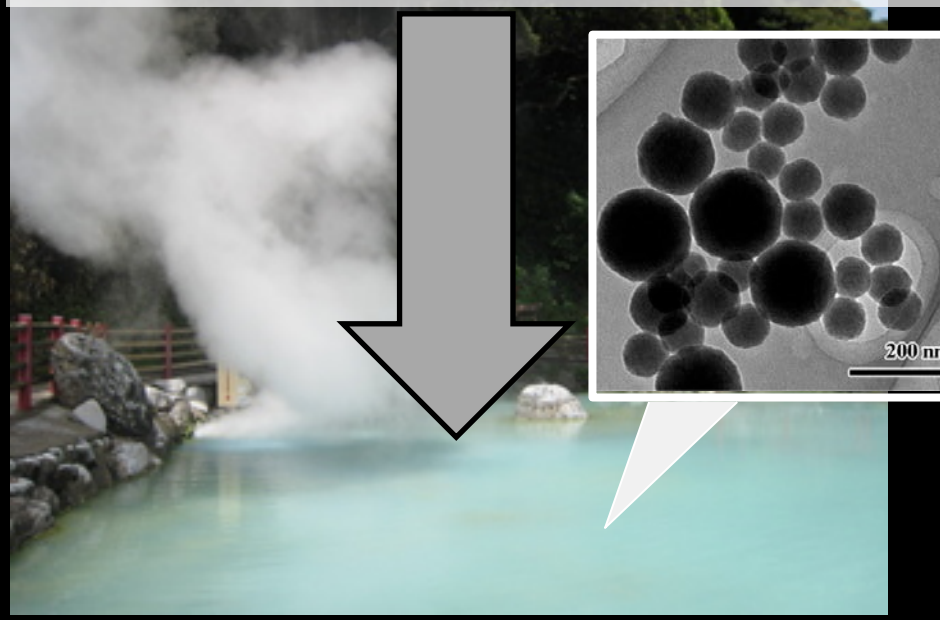
ToF-MS spectra of nano-silica (Hsu et al. in prep.)

O

Si

Nano-silica
Pure Si & O

Nano-silica colloids in geothermal fields, e.g., hot spring



Hot fluids with high silica concentration are cooled

The nature of water-rock interactions are poorly understood

Objectives

Hydrothermal experiments & equilibrium calculations simulating Enceladus' interior

Interactions of cometary composition water with primitive minerals

- To investigate the fate & roles of primordial volatiles in Enceladus' ocean
- To discuss the factors, which determine silica concentrations in hydrothermal fluids in Enceladus
- To constrain temperature & rock compositions that can sustain nano-silica formation

Experimental setup

- Steel-alloy autoclave (P = 400 bar: T = 120-400°C)
- Flexible gold tube reaction cell (inert to high-Temp water)

Aqueous solution: NH_3 (2%) & $NaHCO_3$ (350 mM)

1. Olivine (100%)

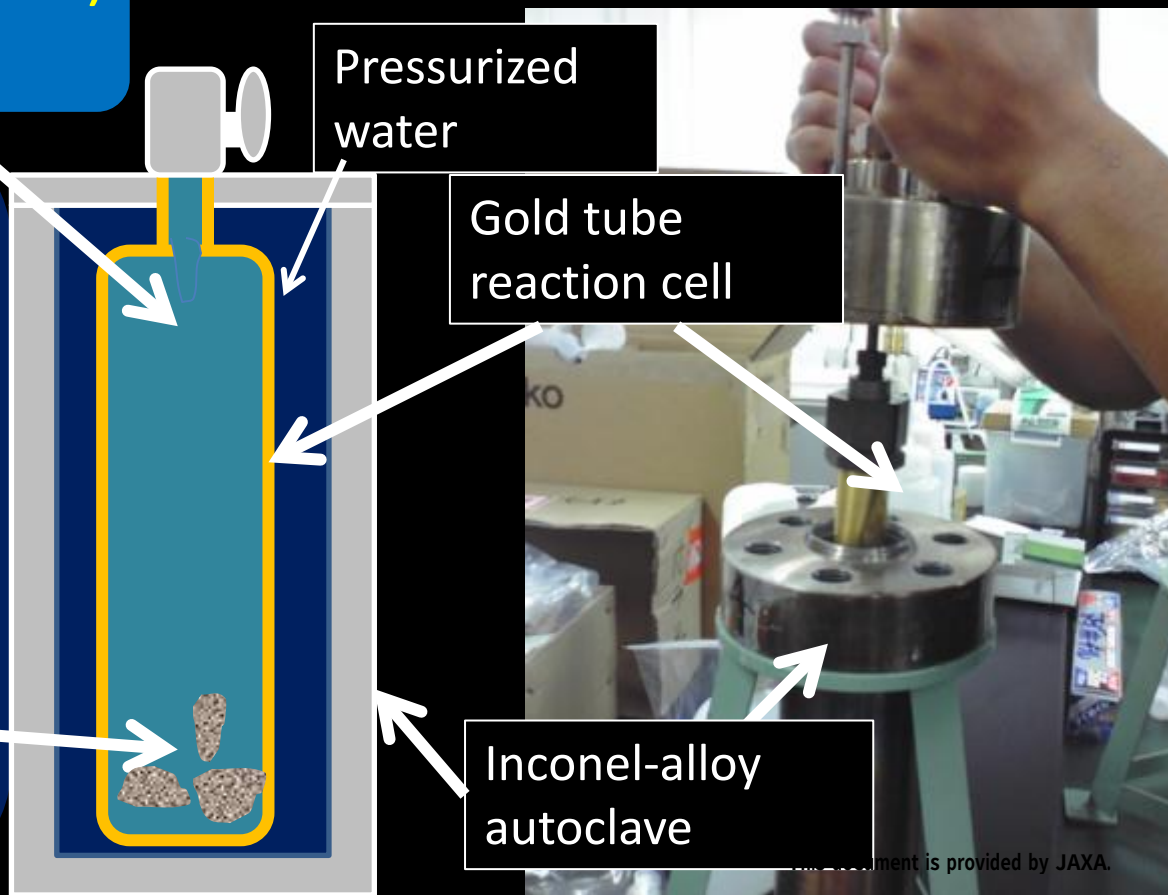
($Mg_{1.8}Fe_{0.2}SiO_4$) : Mg/Si ~1.8

highly differentiated Earth's mantle-like core

2. Pyrx (70%) + oli (30%)

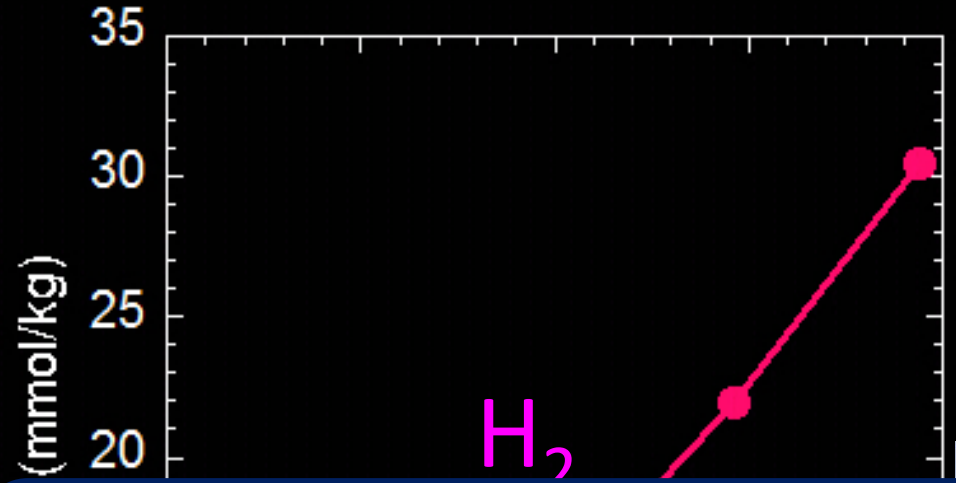
$MgSiO_3$: Mg/Si~1.2

Undifferentiated chondrite-like core



Results: Gas products at 300℃

- Dissolved gas species



- Mineralogical analyses for the rock material

65% of olivine was converted to serpentine & magnetite

NH_3 dissociation is kinetically inhibited due to high activation energy and high concentrations of H_2

pH

Earth: secondary mineral (e.g., brucite ⇔ $Mg^{2+} + 2OH^-$)

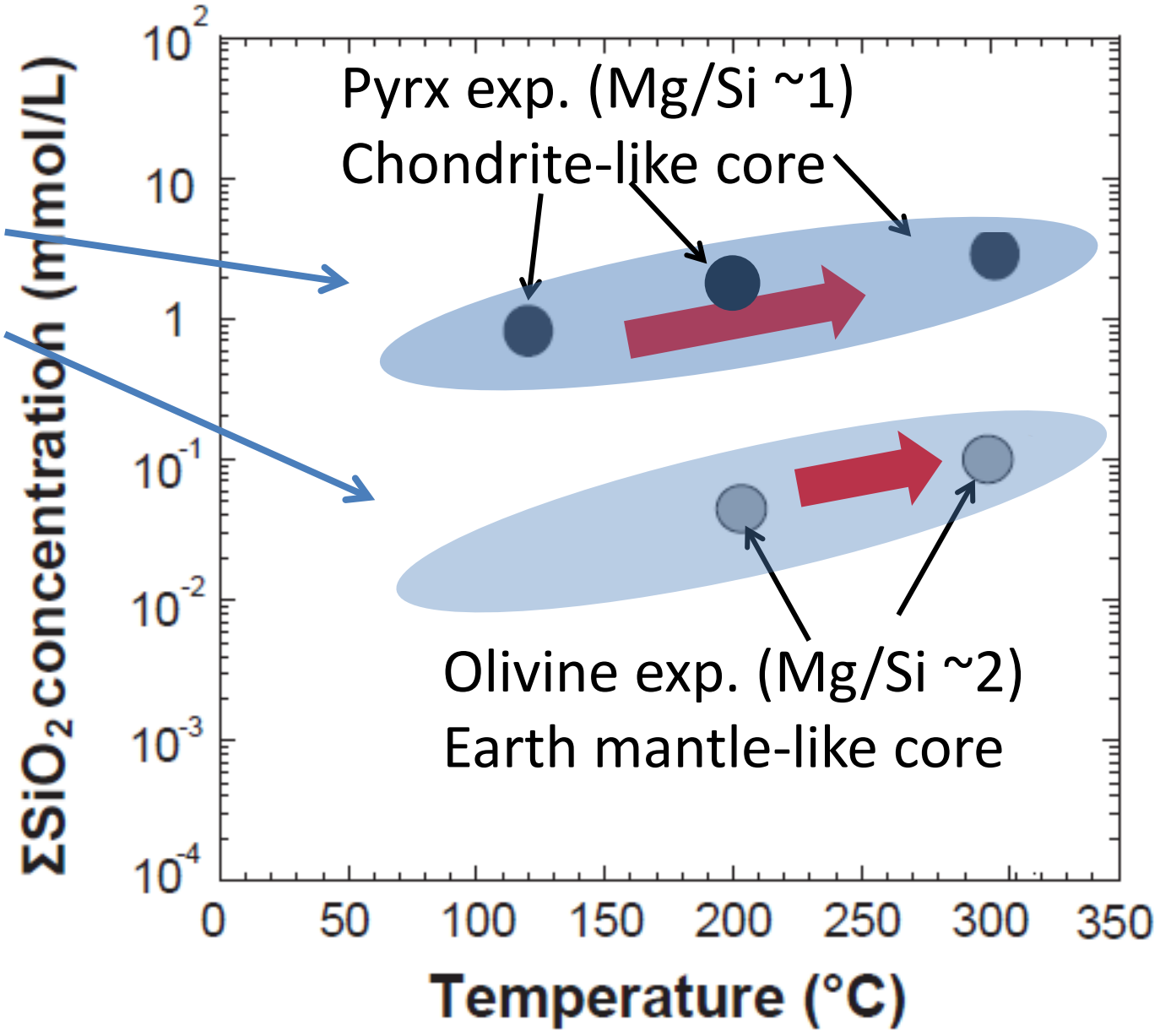
Enceladus: volatiles & salts (e.g., NH_3 ⇔ $NH_4^+ + OH^-$)

→ **pH ~8-10**

Results: silica concentration

1. Strong dependence on starting minerals

2. Some temperature dependence



What controls silica concentrations in fluids?

Secondary minerals

Olivine experiments
Earth's mantle-like core

$Mg_3Si_2O_5(OH)_4$ (serpentine)

$Mg(OH)_2$ (brucite)

$MgCO_3$ (carbonate)

Fe_3O_4 (magnetite)

Mg/Si~1.5

Pyroxene experiments
Chondrite-like core

$Mg_3Si_2O_5(OH)_4$ (serpentine)

$Mg_3Si_4O_{10}(OH)_2$ (saponite/talc)

$MgCO_3$ (carbonate)

Fe_3O_4 (magnetite)

serpentine-brucite buffer

serpentine + H_2O
⇔ 3brucite + + $2SiO_{2,aq}$

serpentine-talc/saponite buffer

serpentine + $2SiO_{2,aq}$
⇔ saponite(talc) + $2H_2O$

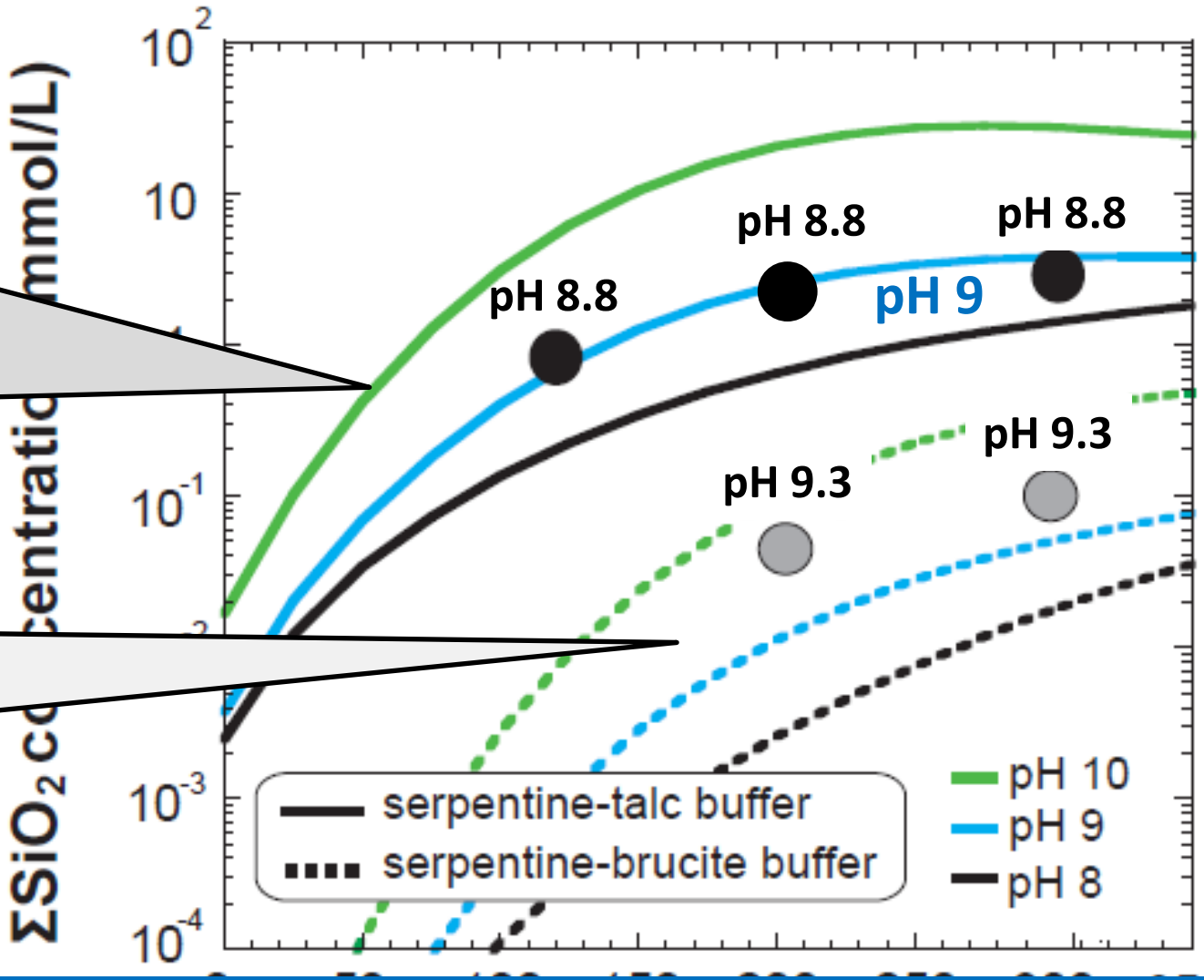
Results: Silica concentration vs calculation

serpentine-saponite-talc buffer

serpentine + $2SiO_{2,aq}$ ⇔ saponite + $2H_2O$

serpentine-brucite buffer

serpentine + H_2O ⇔ brucite + $2SiO_{2,aq}$



Silica concentration in hydrothermal fluids of Enceladus is controlled by the reactions of the secondary minerals

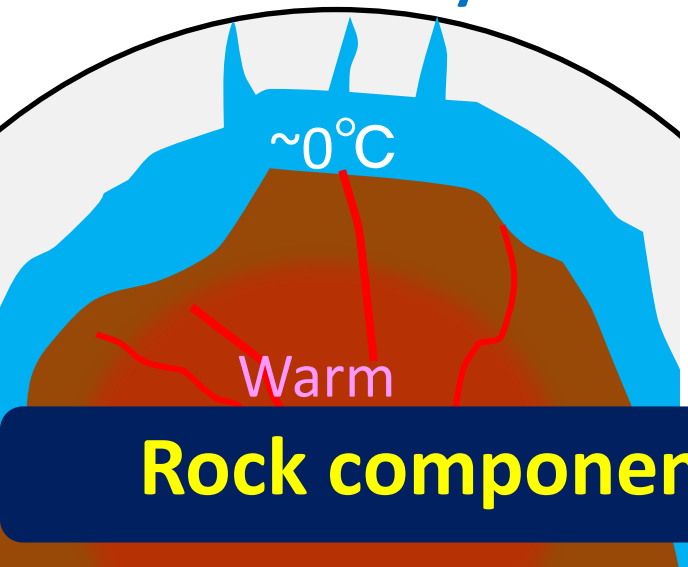
Discussion: rock composition

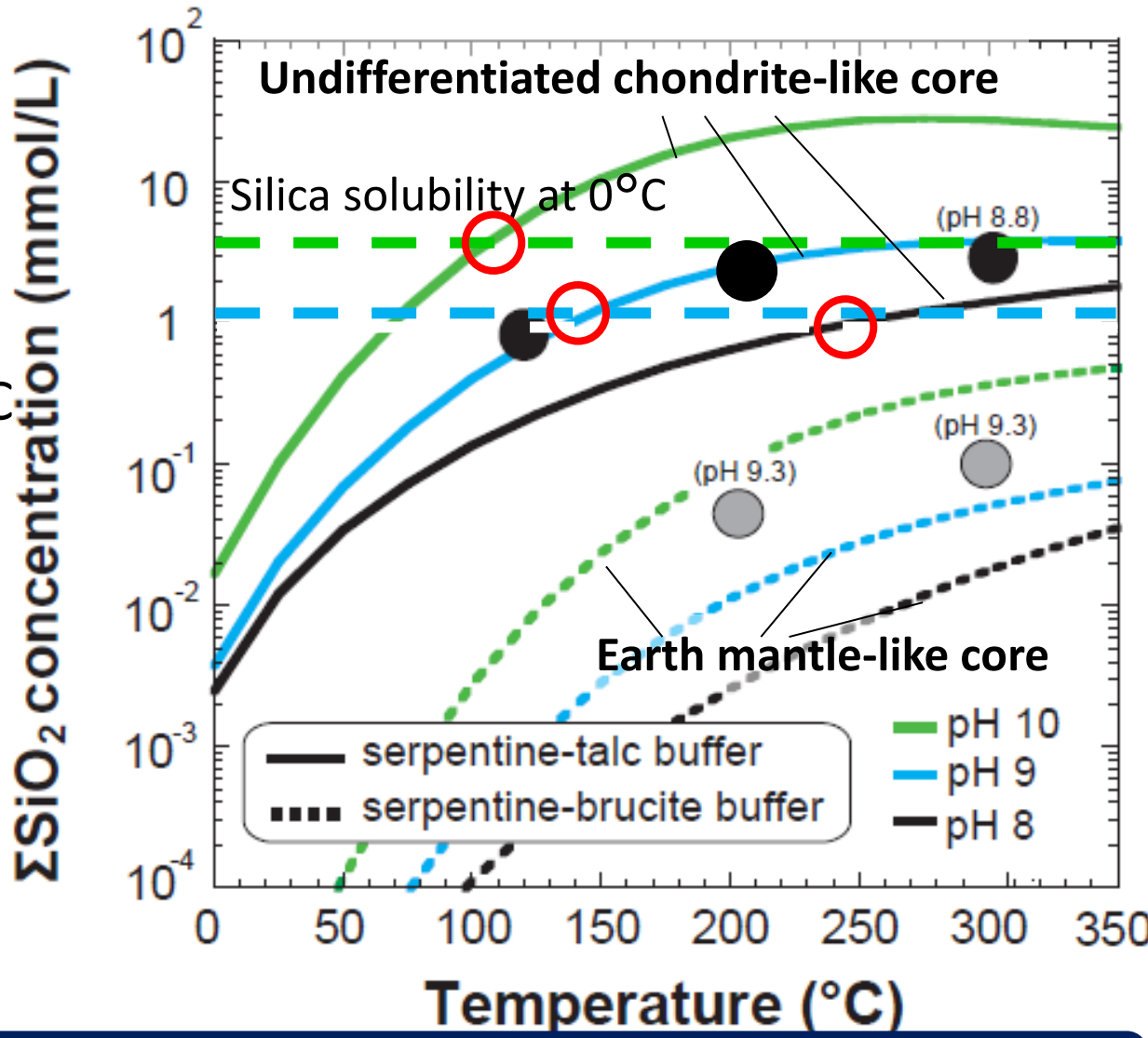
Deep water circulation model (Vance et al., 2007)

1. High-*T* fluids in chemical equilibrium with the rock core
2. enter in ocean at 0°C

Nano-silica formation →

Silica in high-*T* fluids > silica solubility at 0°C

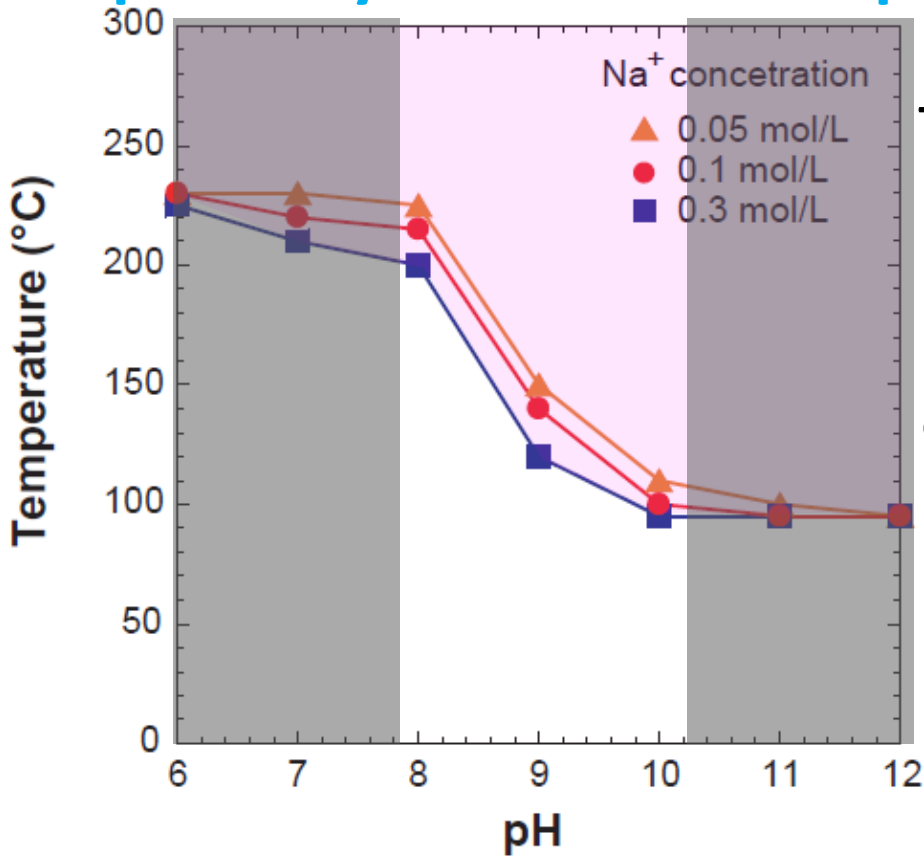




Rock components should be chondrite-like one

Discussion: temperature & formation age

Required hydrothermal temperature for chondrite-like core



Temperature needs to reach at least **≥ 100°C**

Aggregation of nano-particles occurs in geologically short time in ocean (Hsu et al., in prep) → **Recent or current hydrothermal activity**

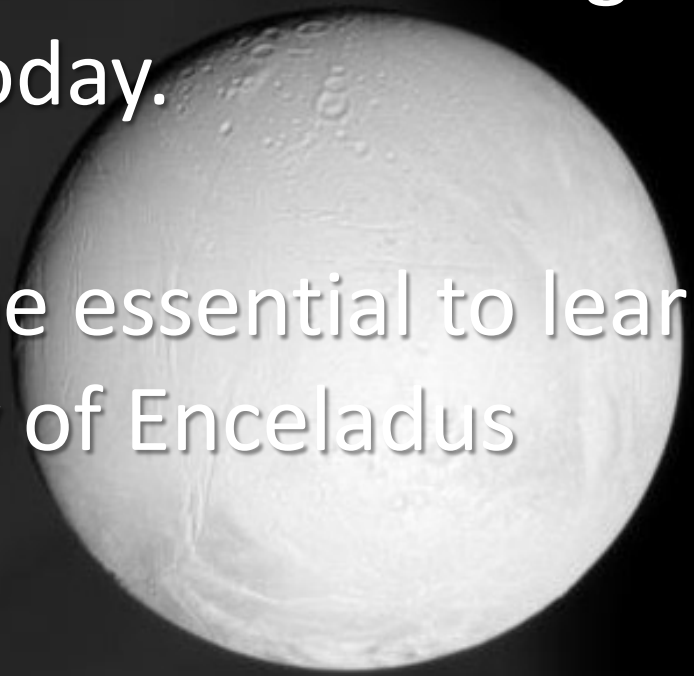
Enceladus' interior has been warm (Castillo-Rogez et al., 2007), if the **Saturnian system formed within 4 Myrs**

Ongoing exothermic **serpentinization triggered by recent, incidental heating**, such as crust overturn/orbital evolution (O'Neill & Nimmo, 2010)

Conclusions

Enceladus would be another habitable world, where liquid water, organic molecules, and energy (heat & rock) are available in geologically recent past or even today.

Future missions will be essential to learn more about the habitability of Enceladus



Results: pH, silica, & temperature

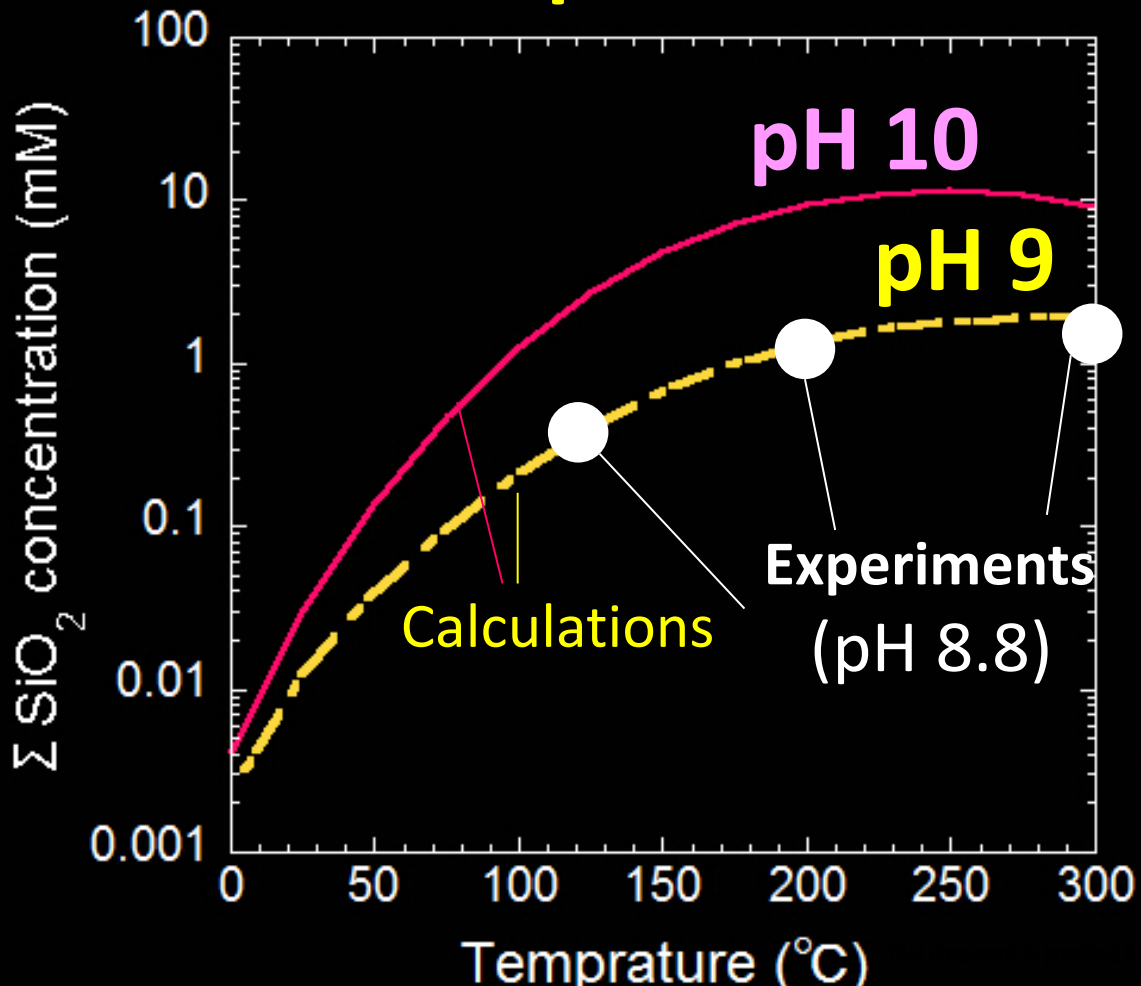
Fluid pH

- Earth: mineral (e.g., brucite ⇔ $Mg^{2+} + 2OH^-$)
- Enceladus: volatiles (e.g., NH_3 ⇔ $NH_4^+ + OH^-$)

→ **pH ~9**

serpentine-saponite buffer

serpentine + $2SiO_{2,aq}$ ⇔ saponite + $2H_2O$



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