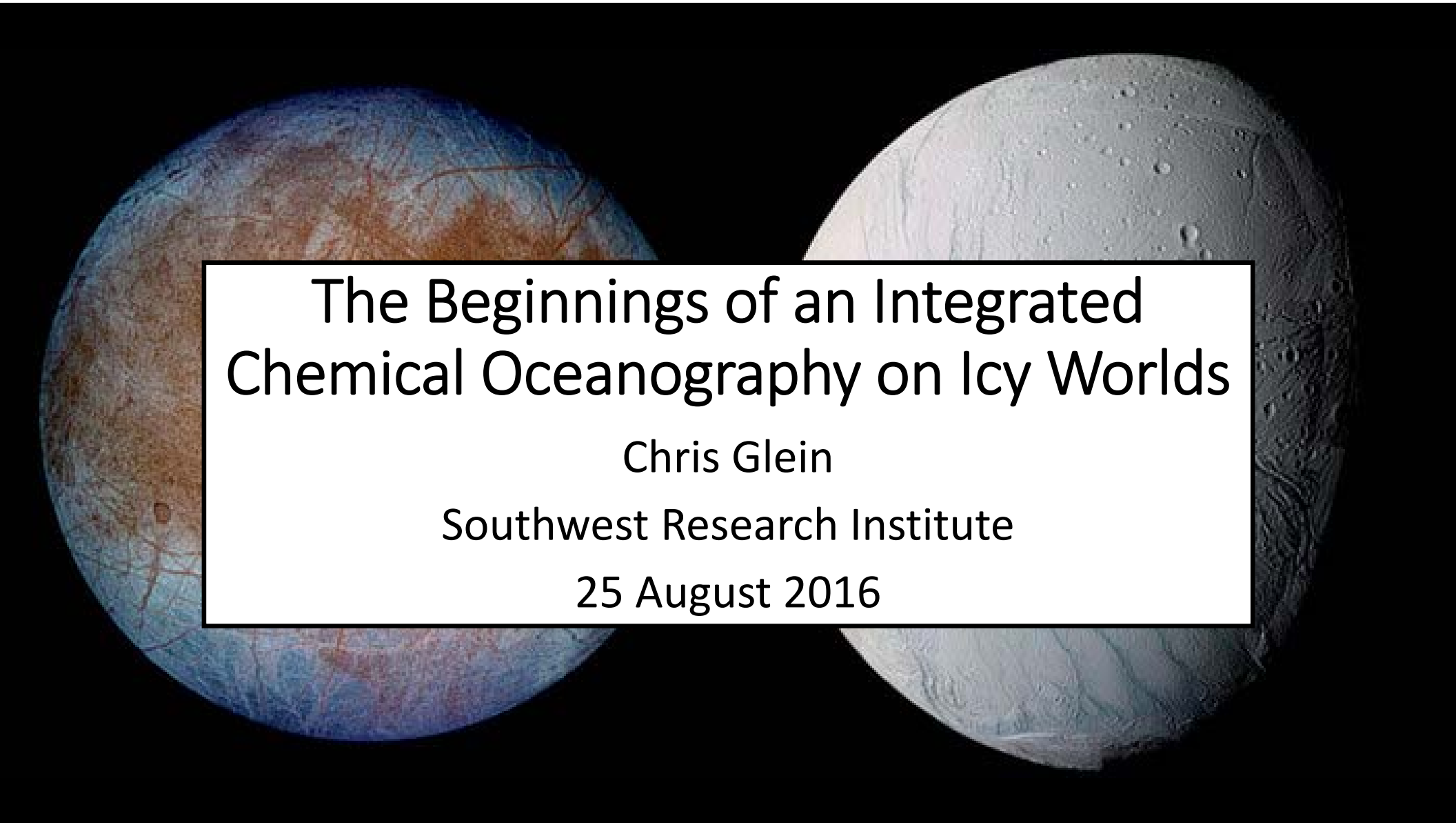


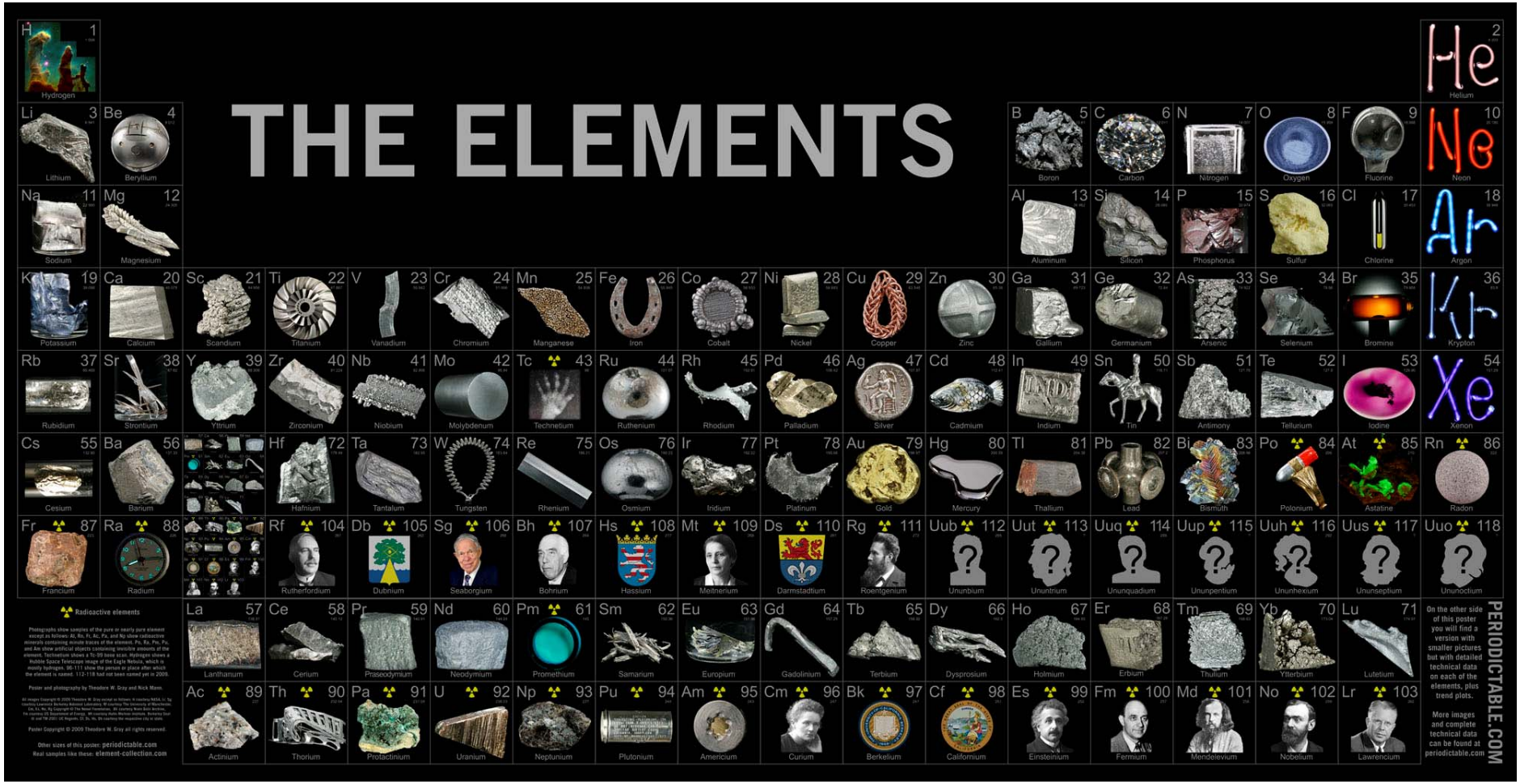
The Beginnings of an Integrated Chemical Oceanography on Icy Worlds

Chris Glein

Southwest Research Institute

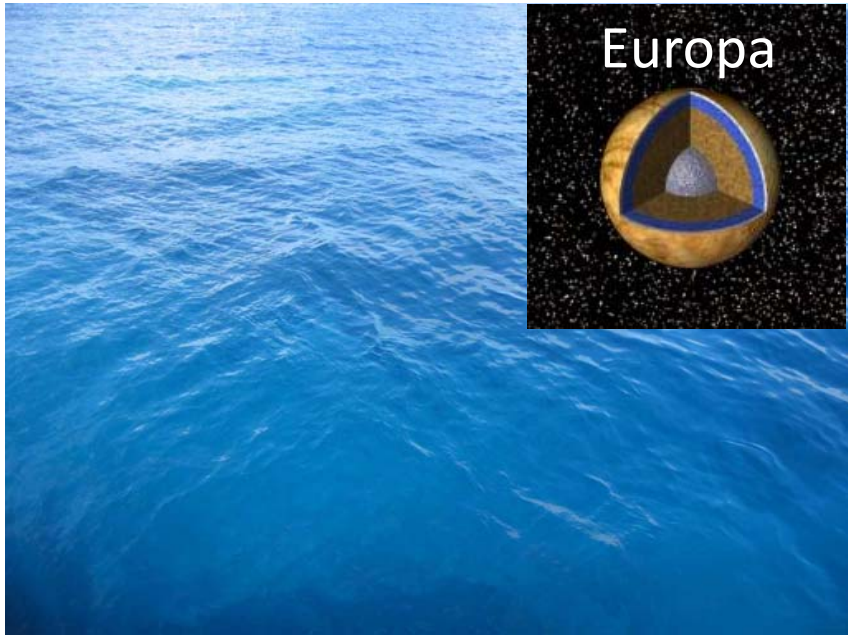
25 August 2016

Goal: Understand the chemical composition of oceans and the processes that control them



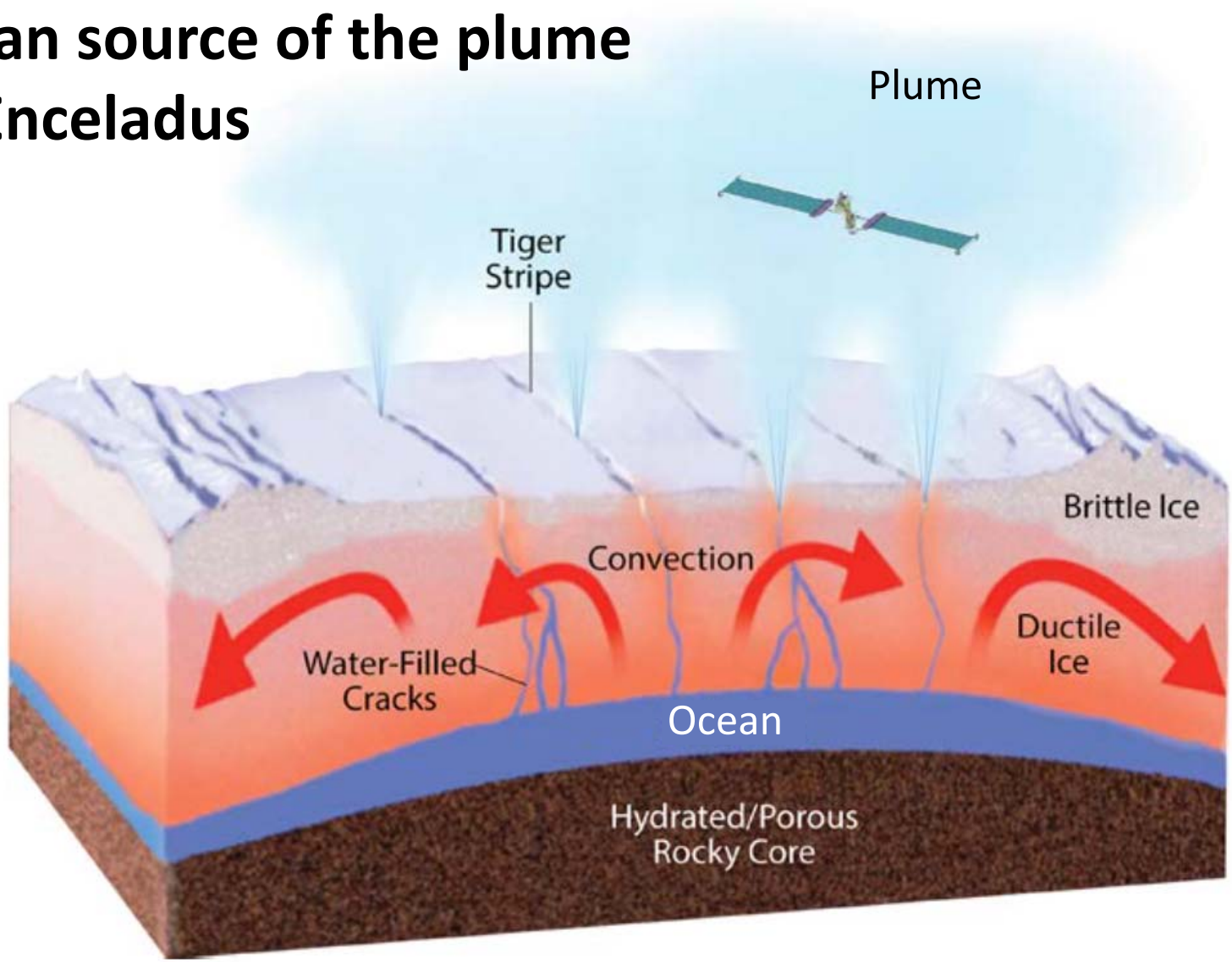
Parameters to understand the geochemistry of liquid water oceans and their habitability

- Temperature
- Pressure
- Composition
- Major cations, anions, neutrals
- pH (measure of acidity/basicity)
- Eh (measure of oxidation state)
- Nutrient species
- Organic compounds
- Chemical disequilibria (energy)



Let’s visit Enceladus

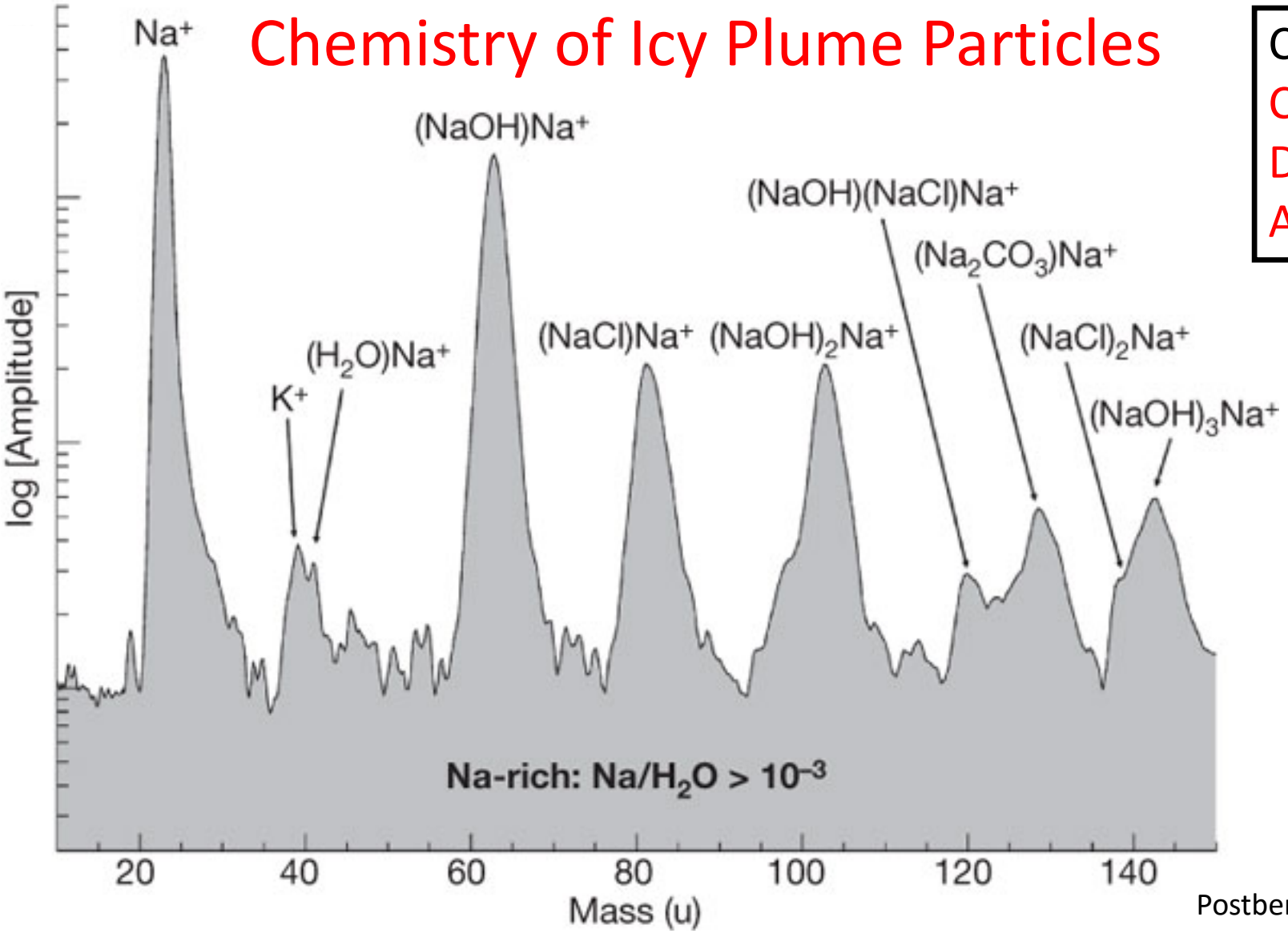
Ocean source of the plume on Enceladus



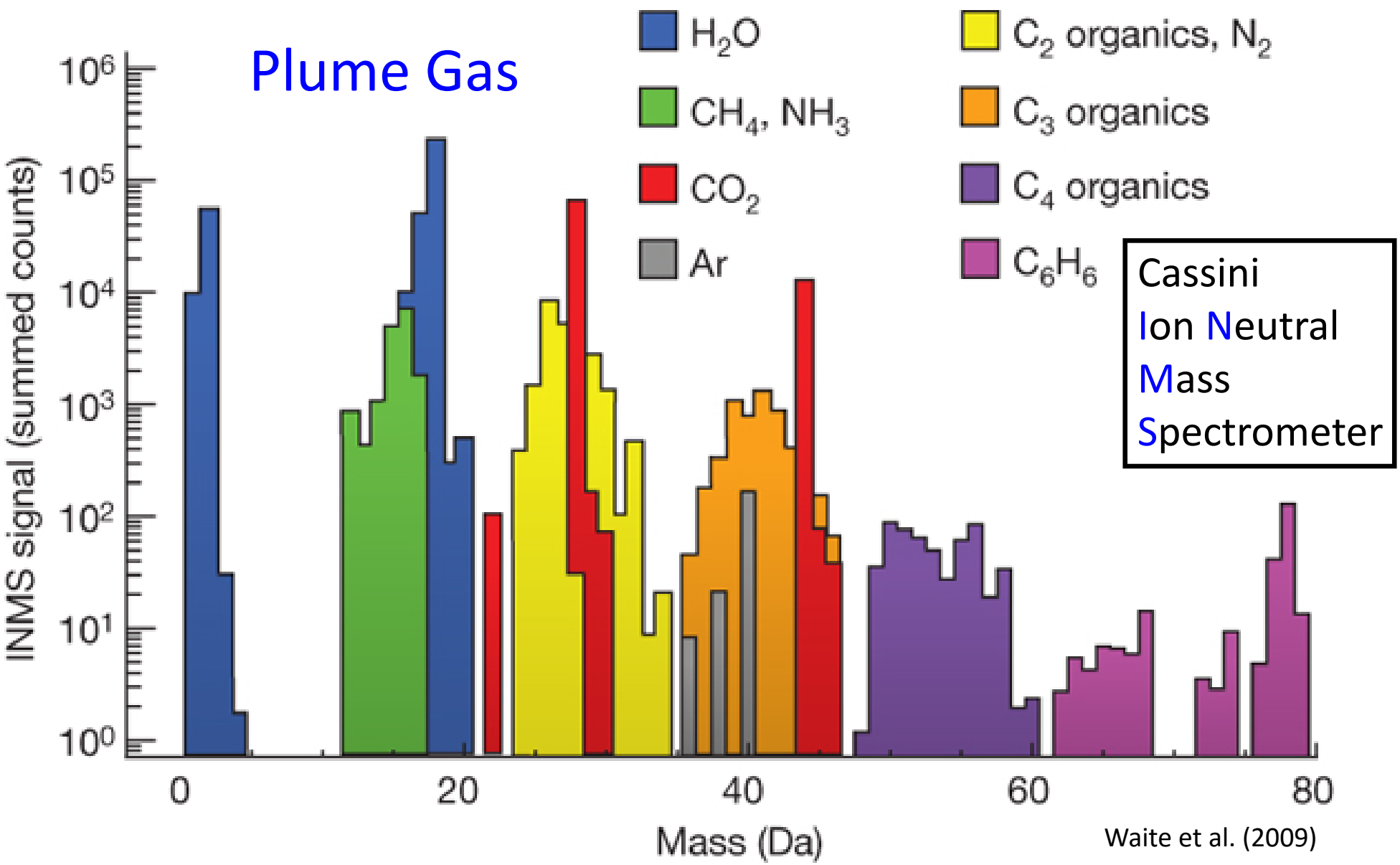
Porco et al. (2014)

Chemistry of Icy Plume Particles

Cassini
Cosmic
Dust
Analyzer



Postberg et al. (2009)



Waite et al. (2009)

Plume Composition

-Major identified constituents-

Ice Grains (CDA)

Component	Concentration (mol/kg H_2O)
NaCl	0.05-0.2
$NaHCO_3 + Na_2CO_3$	0.01-0.1
KCl	~0.001

Postberg et al. (2009, 2011)

<u>Terrestrial seawater</u>

0.5 *m* NaCl
0.01 *m* KCl
0.03 *m* SO_4^{-2}
0.002 *m* HCO_3^-

Gas Phase (INMS)

Species	Molar Percentage
H_2O	~98
CO_2	0.3-0.8
CH_4	0.1-0.3
NH_3	0.4-1.3

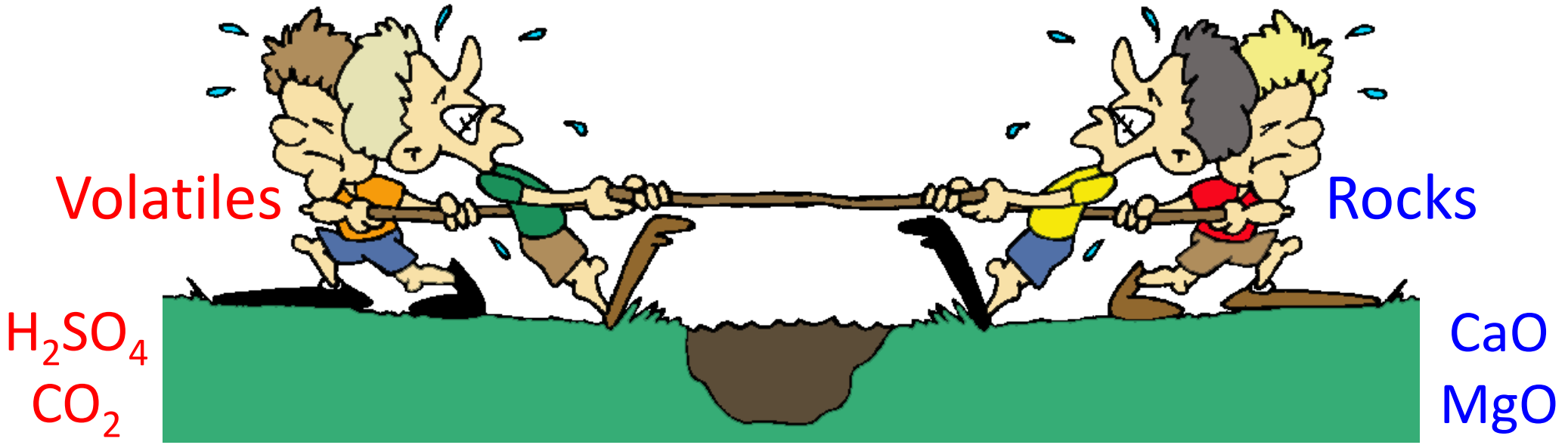
Waite et al. (submitted)

Minor organic compounds

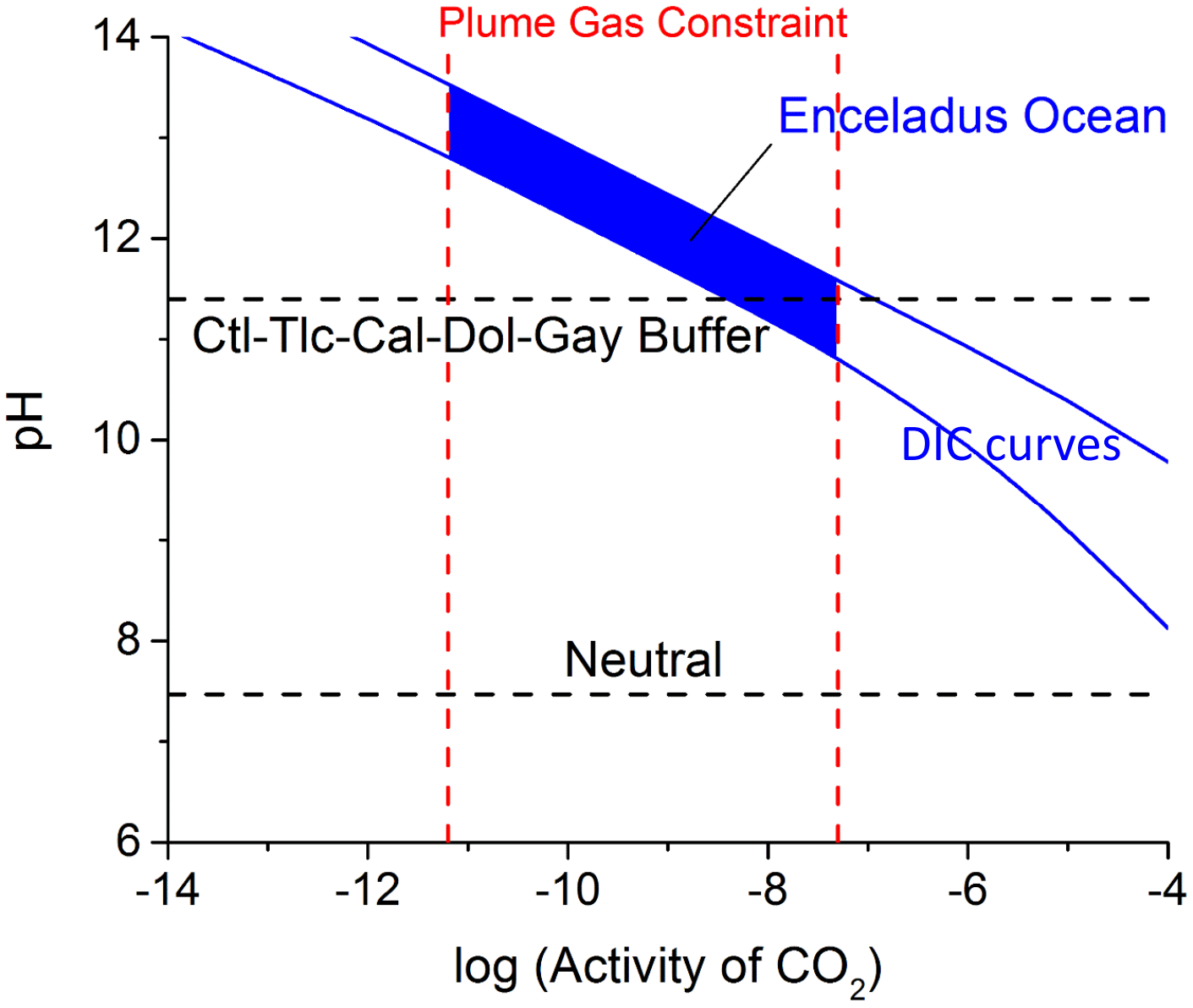
H_2 (more later in this talk)

Acidic Ocean pH from acid-base war Basic

0 7 14



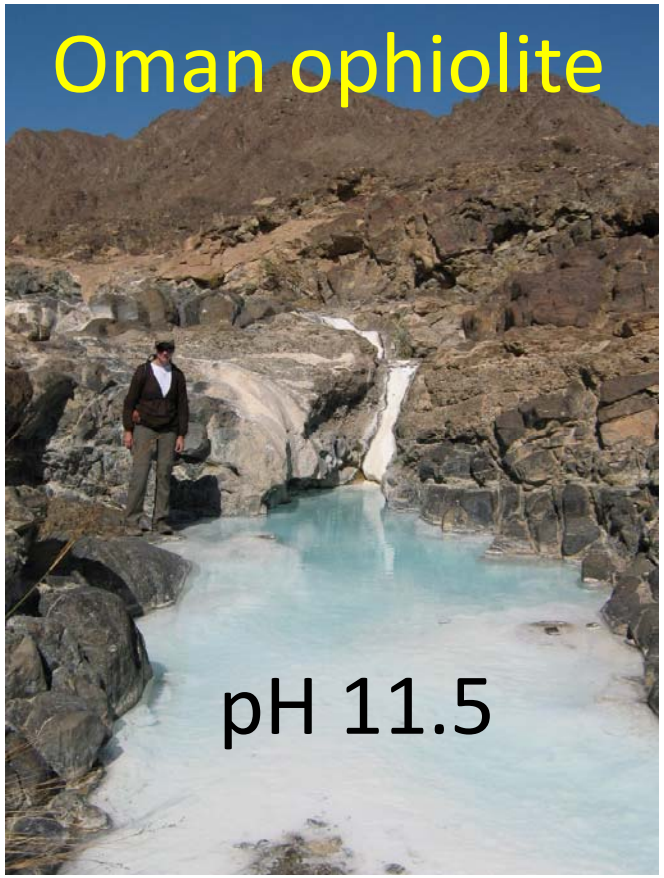
Key to understanding the processes that generate acids/bases and promote their interaction

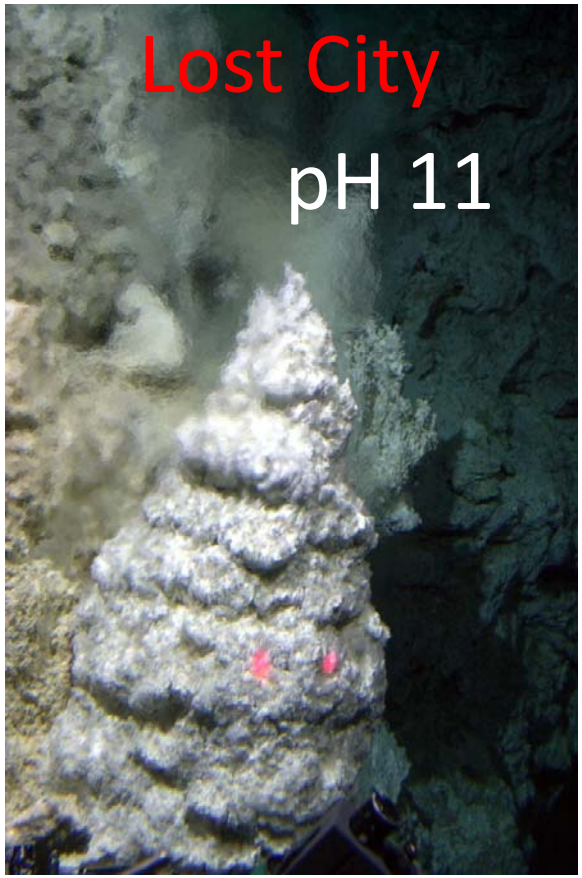


Equilibrium speciation indicates a **high pH** would be consistent with the observations, perhaps buffered by minerals on the ocean floor

Glein et al. (2015)

On Earth, pH 9-12.5 from serpentinization

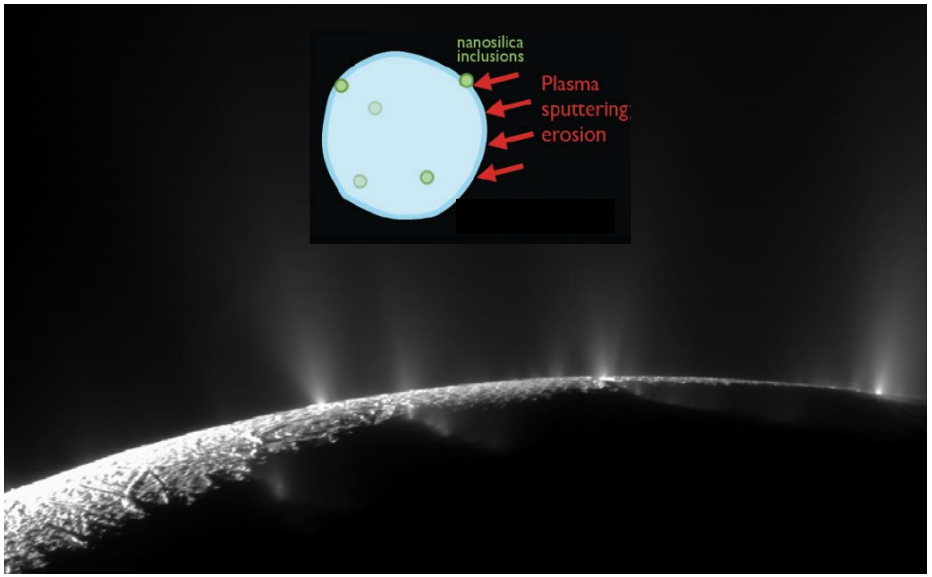




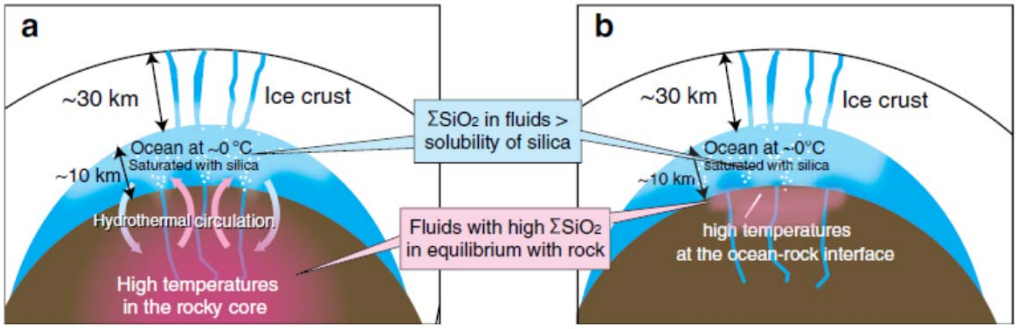
Also Malamud & Prialnik (2013)

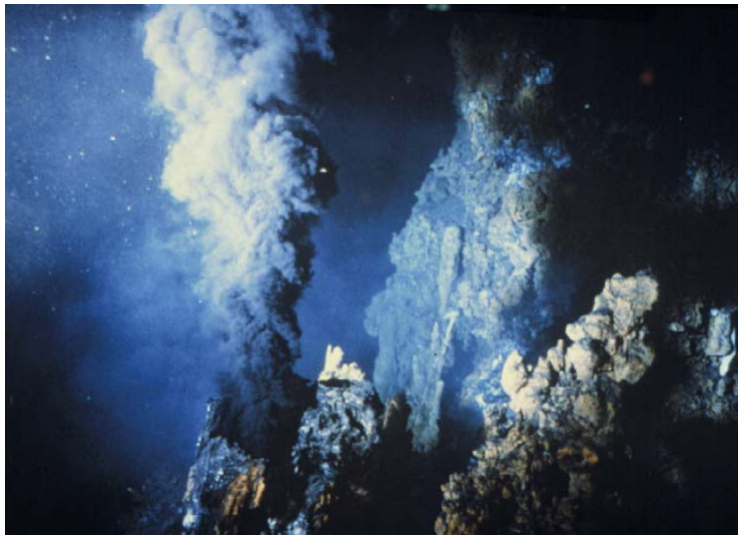
Hydrothermal systems in Enceladus

Earlier ideas: Matson et al. (2007), Glein et al. (2008)

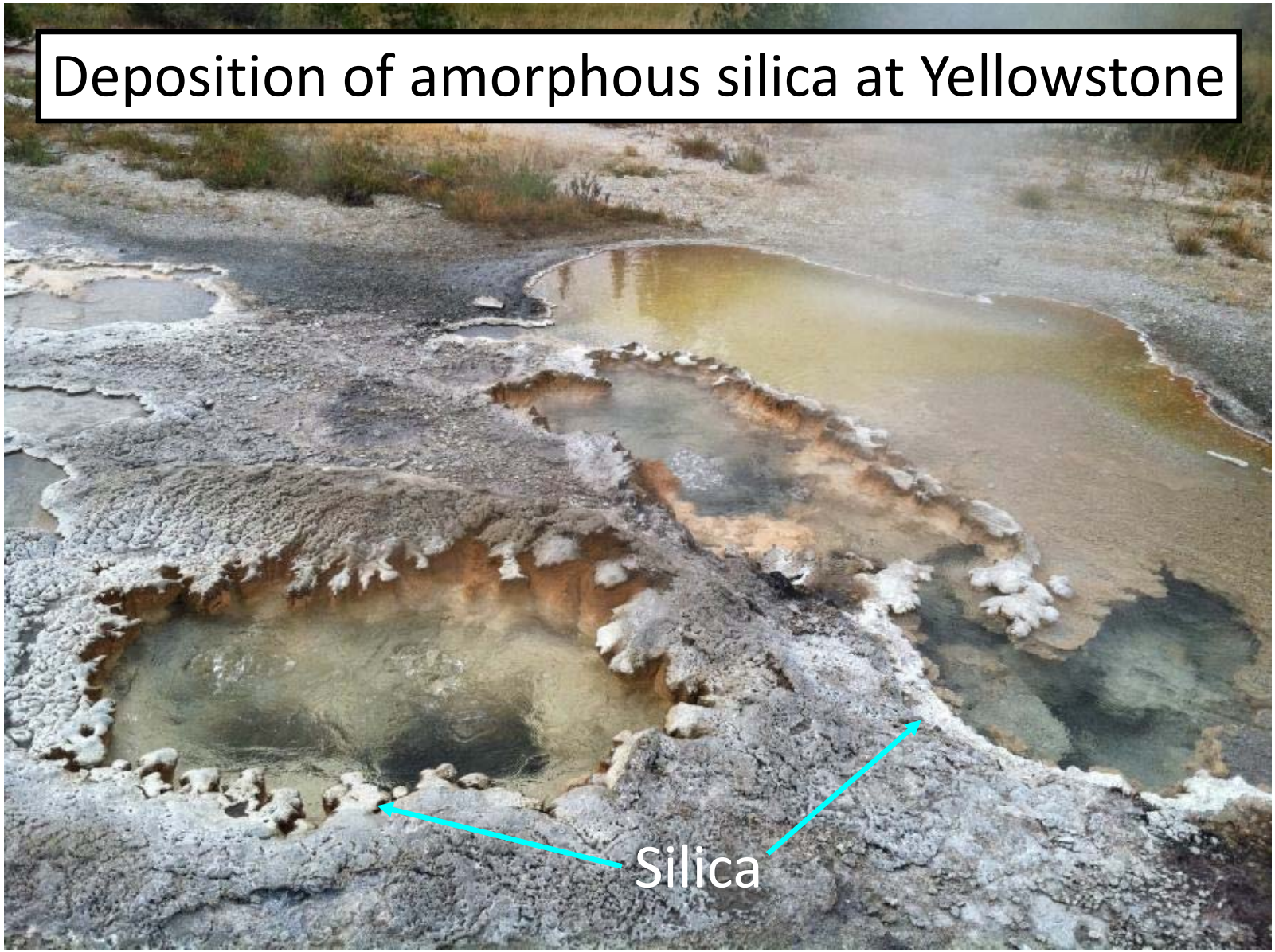


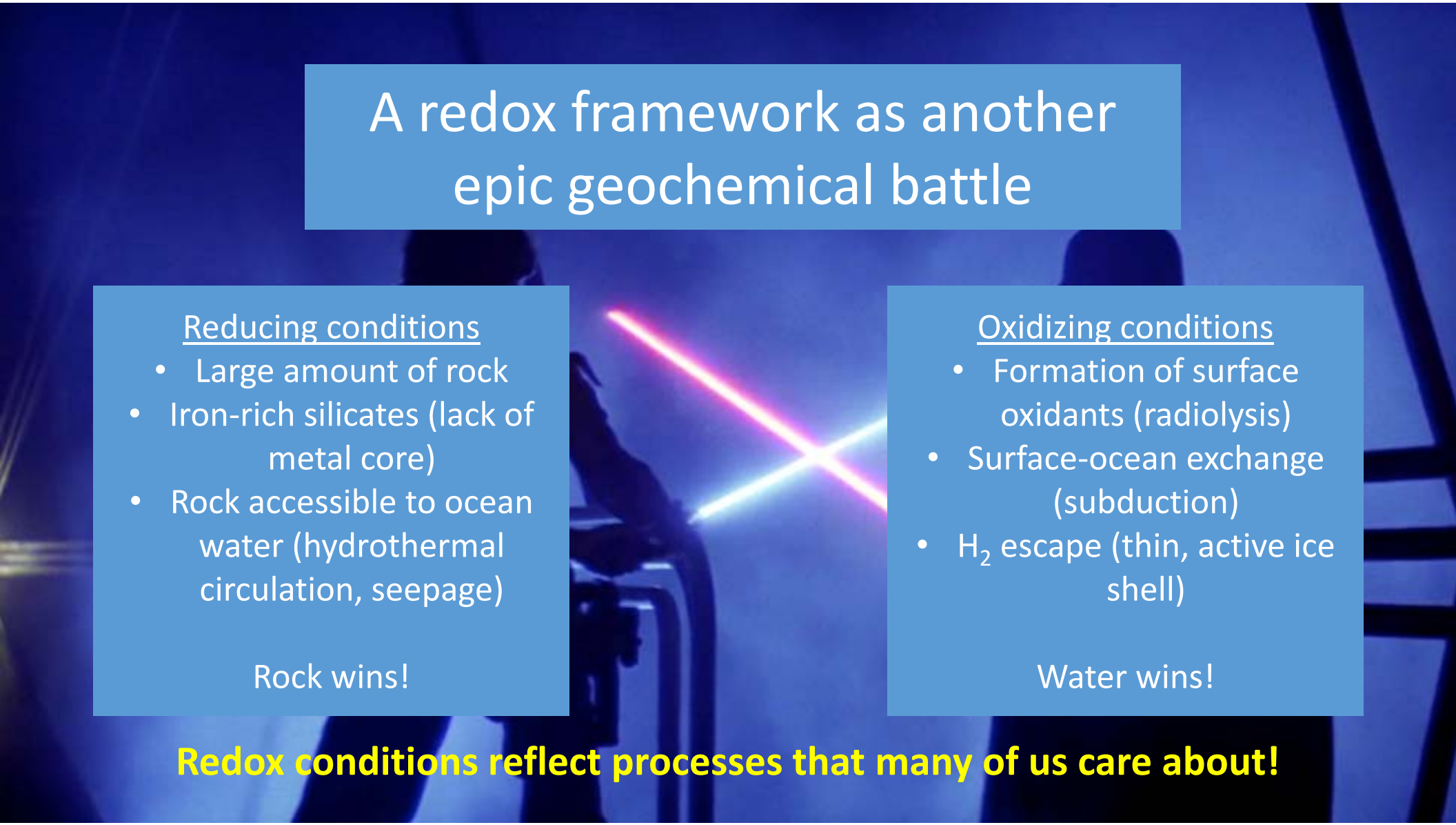
Hsu et al. (2015); Sekine et al. (2015)





Silica particles form when hot vent fluids mix with cold ocean water at the ocean floor


Deposition of amorphous silica at Yellowstone
Silica



A redox framework as another epic geochemical battle

Reducing conditions

- Large amount of rock
- Iron-rich silicates (lack of metal core)
- Rock accessible to ocean water (hydrothermal circulation, seepage)

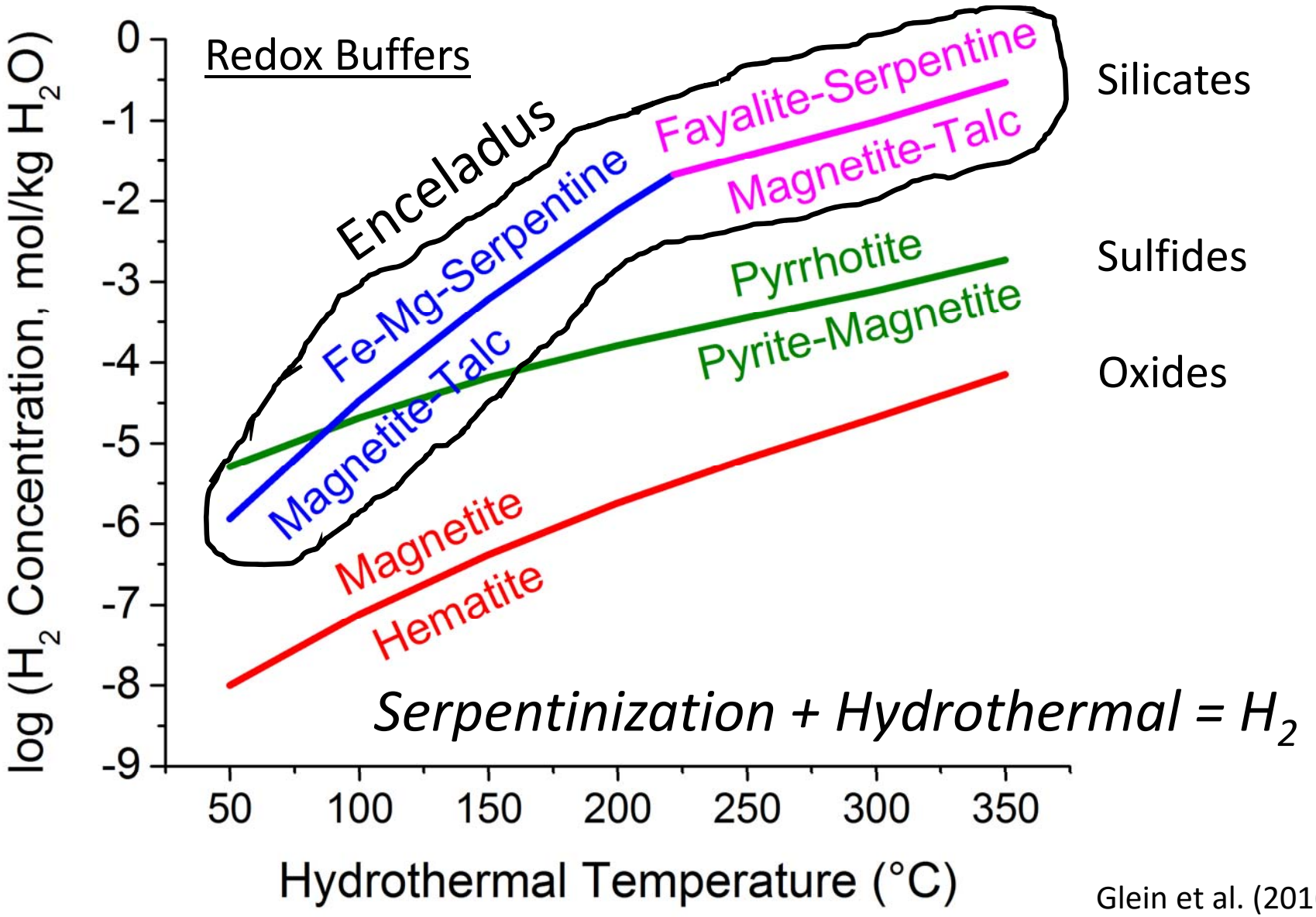
Rock wins!

Oxidizing conditions

- Formation of surface oxidants (radiolysis)
- Surface-ocean exchange (subduction)
- H_2 escape (thin, active ice shell)

Water wins!

Redox conditions reflect processes that many of us care about!



Glein et al. (2016)

October 2015 E21 Flyby – The Hunt for H_2

Jet Propulsion Laboratory
California Institute of Technology

Education | Intern Learn Teach News Events

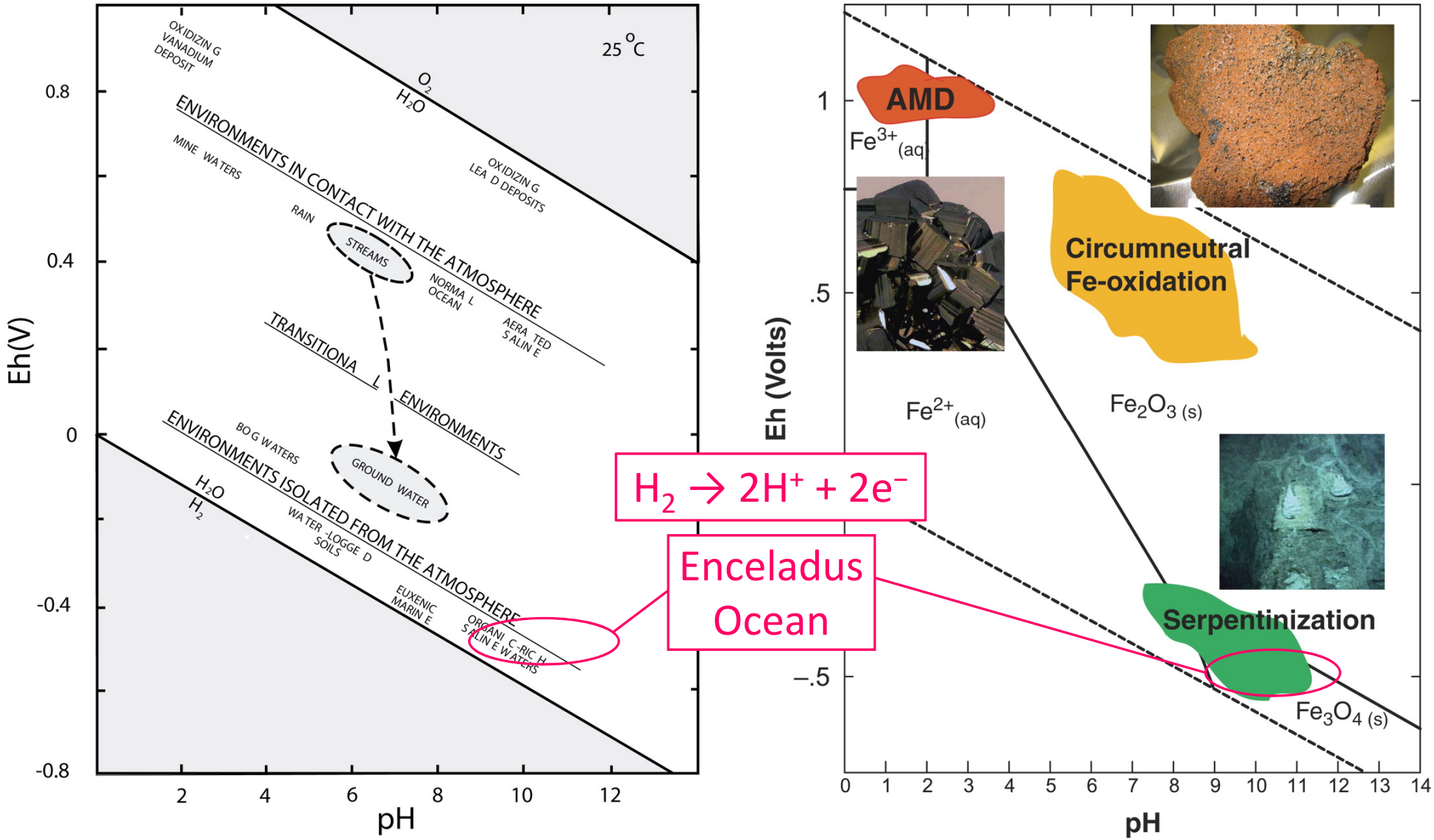
Why It's Important

Cassini will use its Cosmic Dust Analyzer to study the solid plume particles and an instrument called the Ion and Neutral Mass Spectrometer to "sniff" the gas vapor in order to determine the composition of the jets. Specifically, the latter instrument is looking for H_2, or molecular hydrogen. Finding H_2 in the plume will strengthen the evidence that hydrothermal activity is occurring on Enceladus' ocean floor. And the amount of H_2 in the plume, will tell scientists just how much activity is happening.

In addition to indicating that hydrothermal activity is taking place, figuring out the amount of hydrothermal activity will give scientists a good indication of how much internal energy there is deep inside Enceladus.

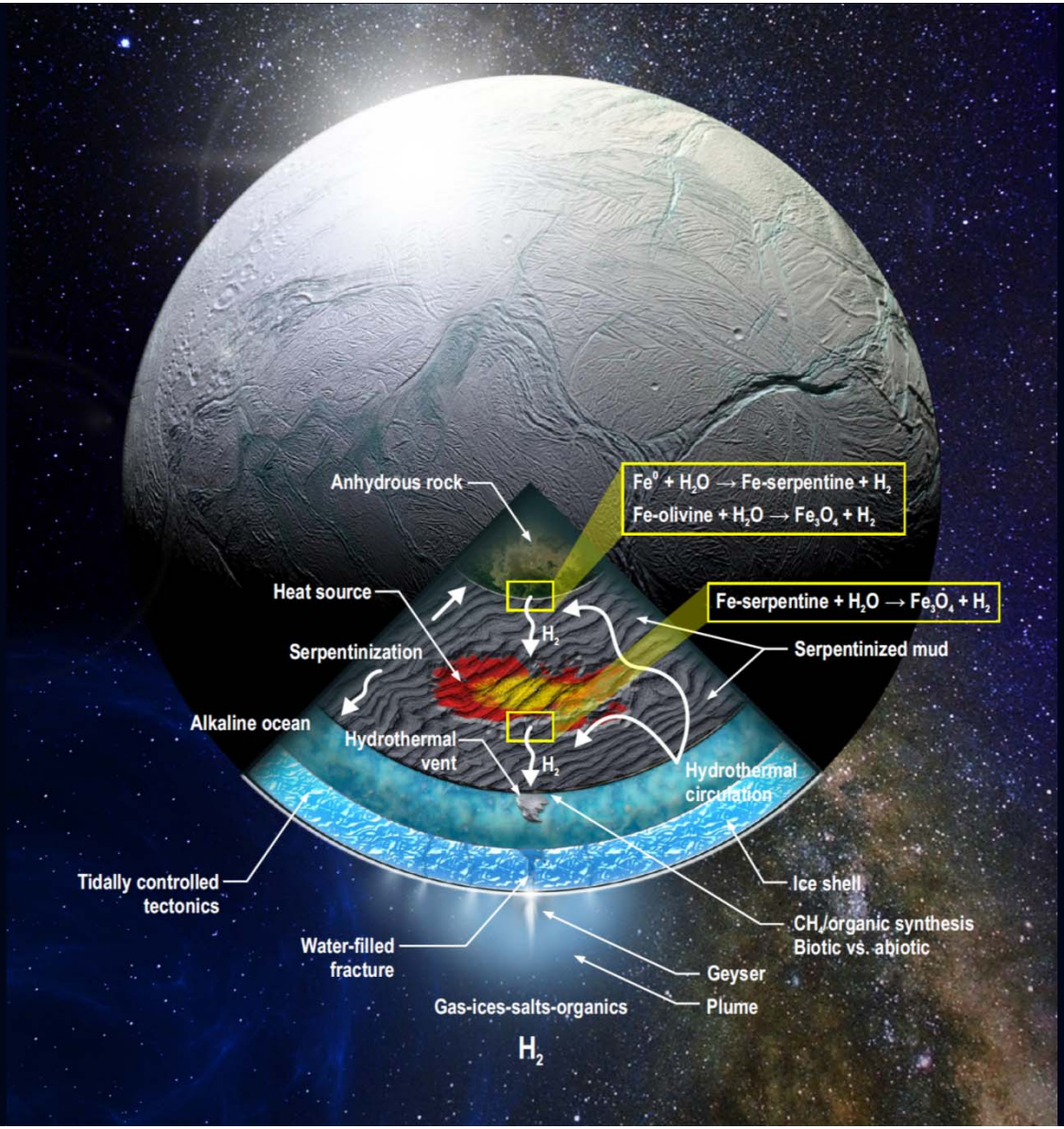
That Cassini is making a pass through the plume at such a low, 49-kilometer-high altitude is also important. Organic compounds -- substances formed when carbon bonds with hydrogen, nitrogen, oxygen, phosphorus or sulfur -- tend to be heavy and would fall out of the plume before reaching the heights of Cassini's previous, higher altitude flybys and be undetected. Organic compounds are the building blocks of life on

Coming soon!
Waite et al.
(submitted)



$H_2 \rightarrow 2H^+ + 2e^-$

Enceladus Ocean


Anhydrous rock
$Fe^0 + H_2O \rightarrow$ Fe-serpentine + H_2
Fe-olivine + $H_2O \rightarrow Fe_3O_4 + H_2$
Heat source
Fe-serpentine + $H_2O \rightarrow Fe_3O_4 + H_2$
H_2
Serpentinization
Serpentinized mud
Alkaline ocean
Hydrothermal vent
H_2
Hydrothermal circulation
Tidally controlled tectonics
Ice shell
CH_4/organic synthesis
Biotic vs. abiotic
Water-filled fracture
Geyser
Plume
Gas-ices-salts-organics
H_2

The message is in the molecules…Let’s go find them!