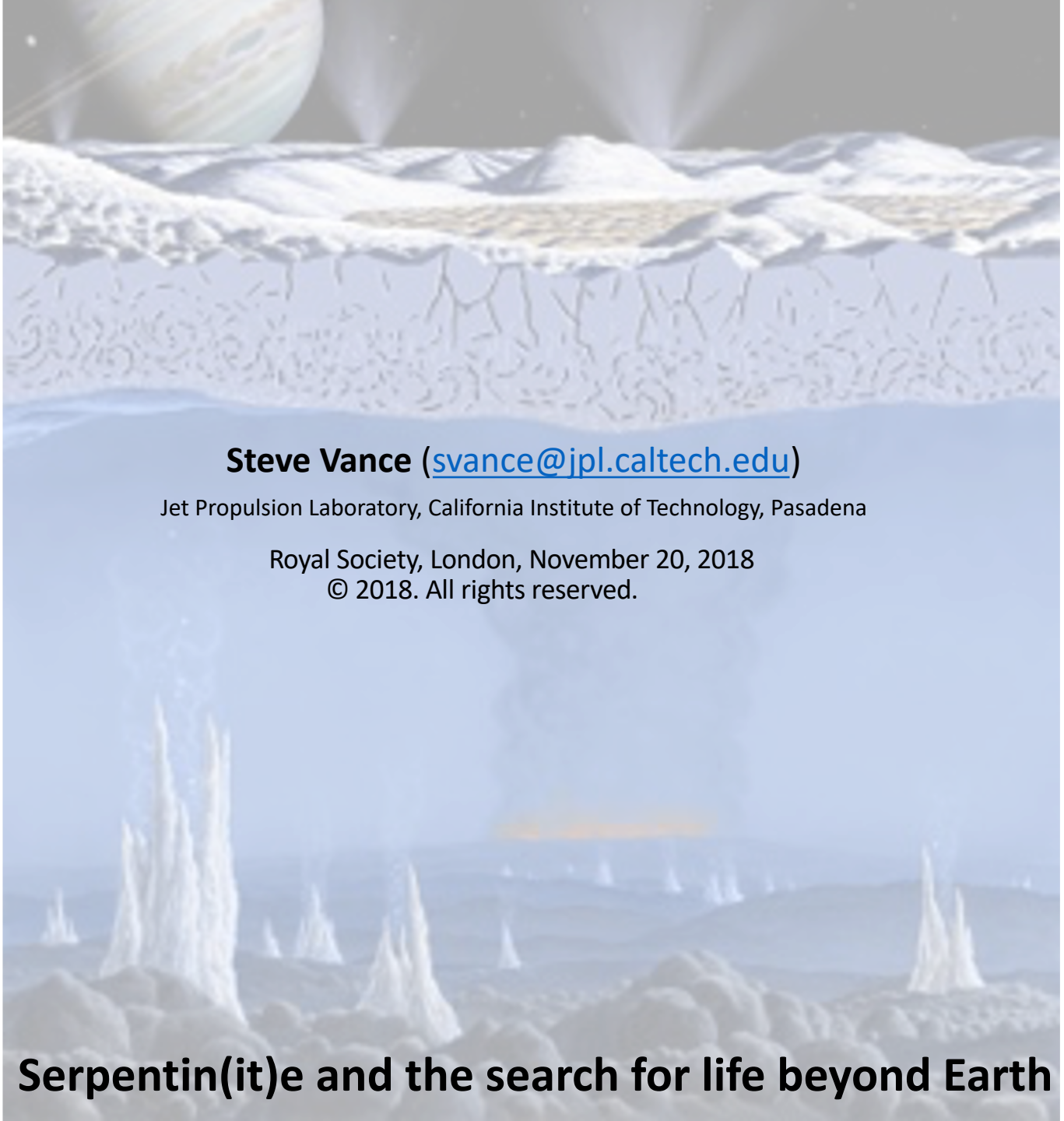
PLEASE
HANDLE WITH CARE
FRAGILE
THANK YOU



Steve Vance (svance@jpl.caltech.edu)

Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Royal Society, London, November 20, 2018

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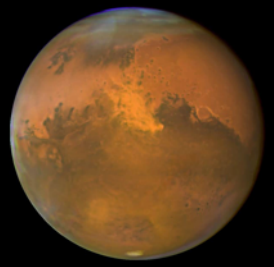
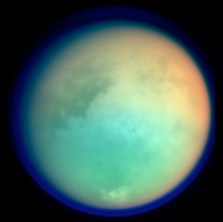
Serpentin(it)e and the search for life beyond Earth

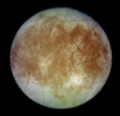
Earth



Mars

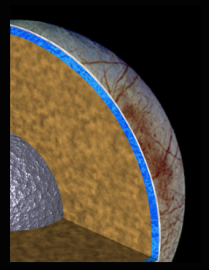


Titan

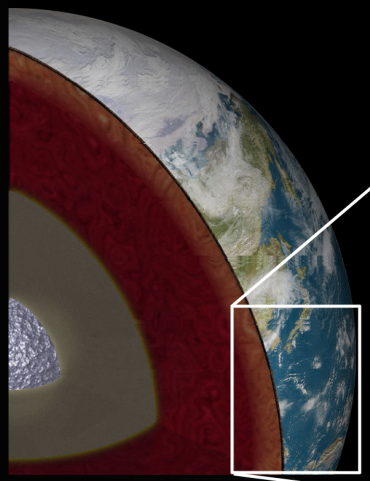


Europa

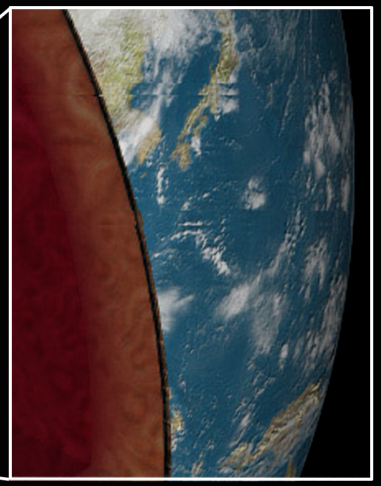
Enceladus



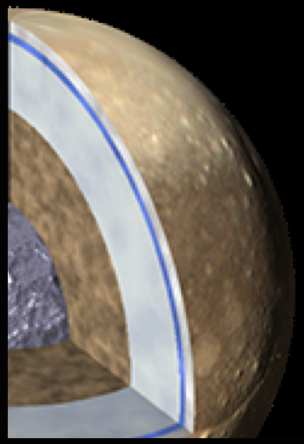
Europa



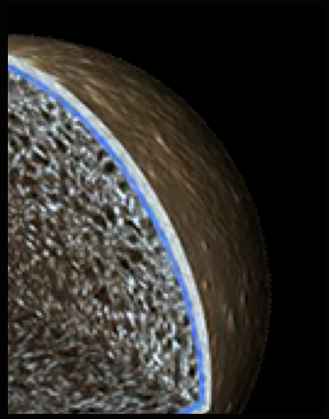
Earth



Earth to Scale



Ganymede

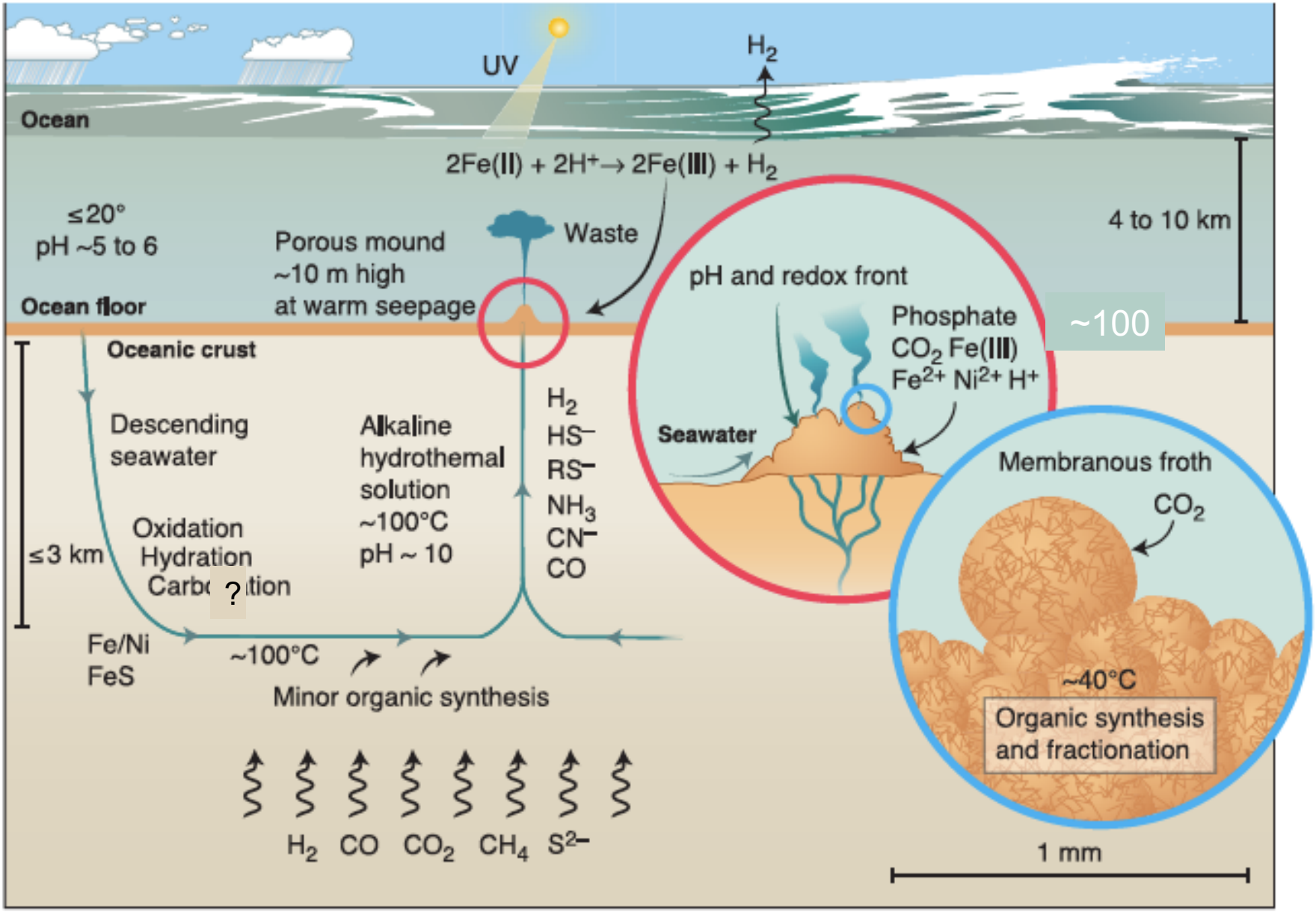


Callisto

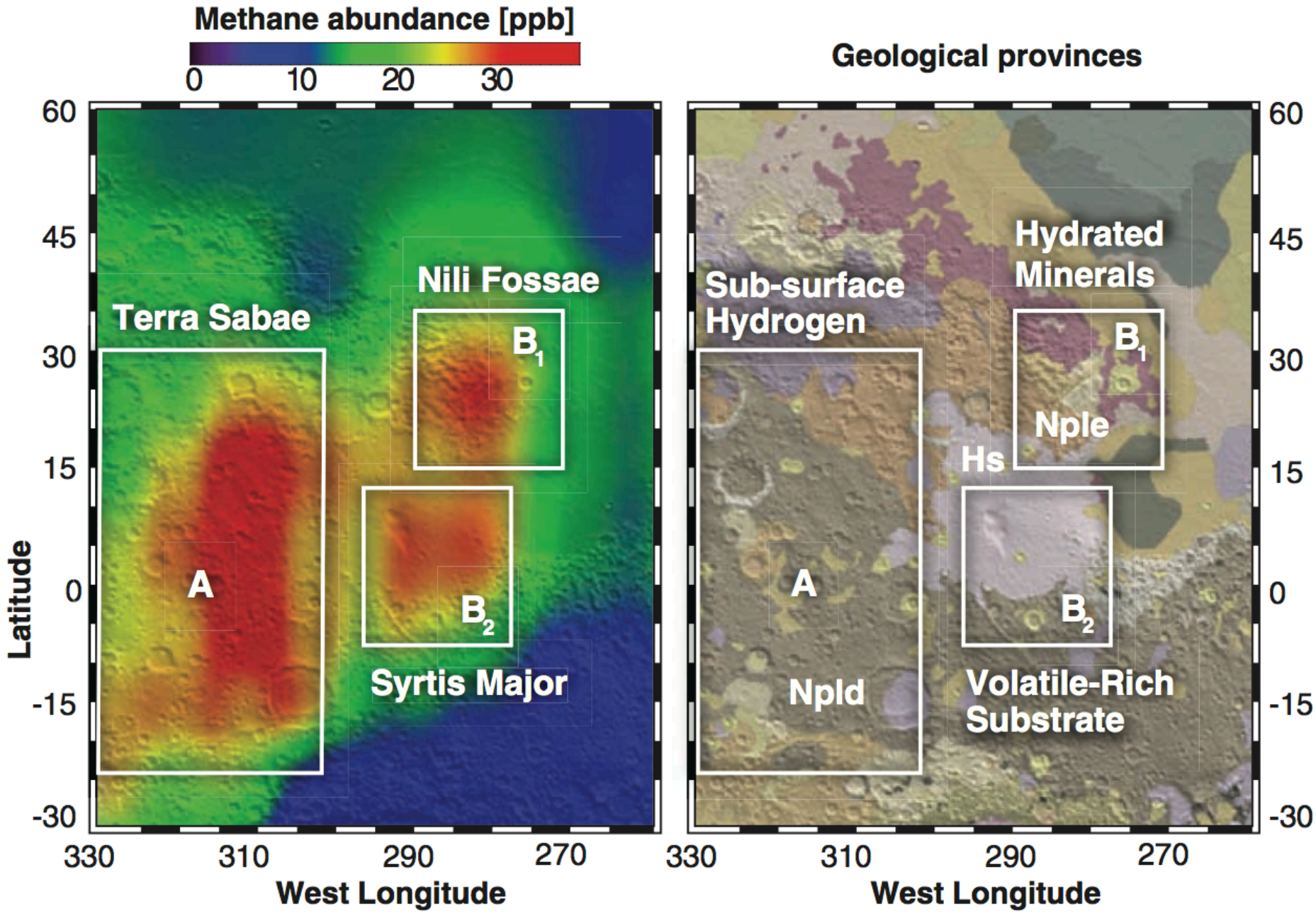
Titan

ice
water
rock
metal

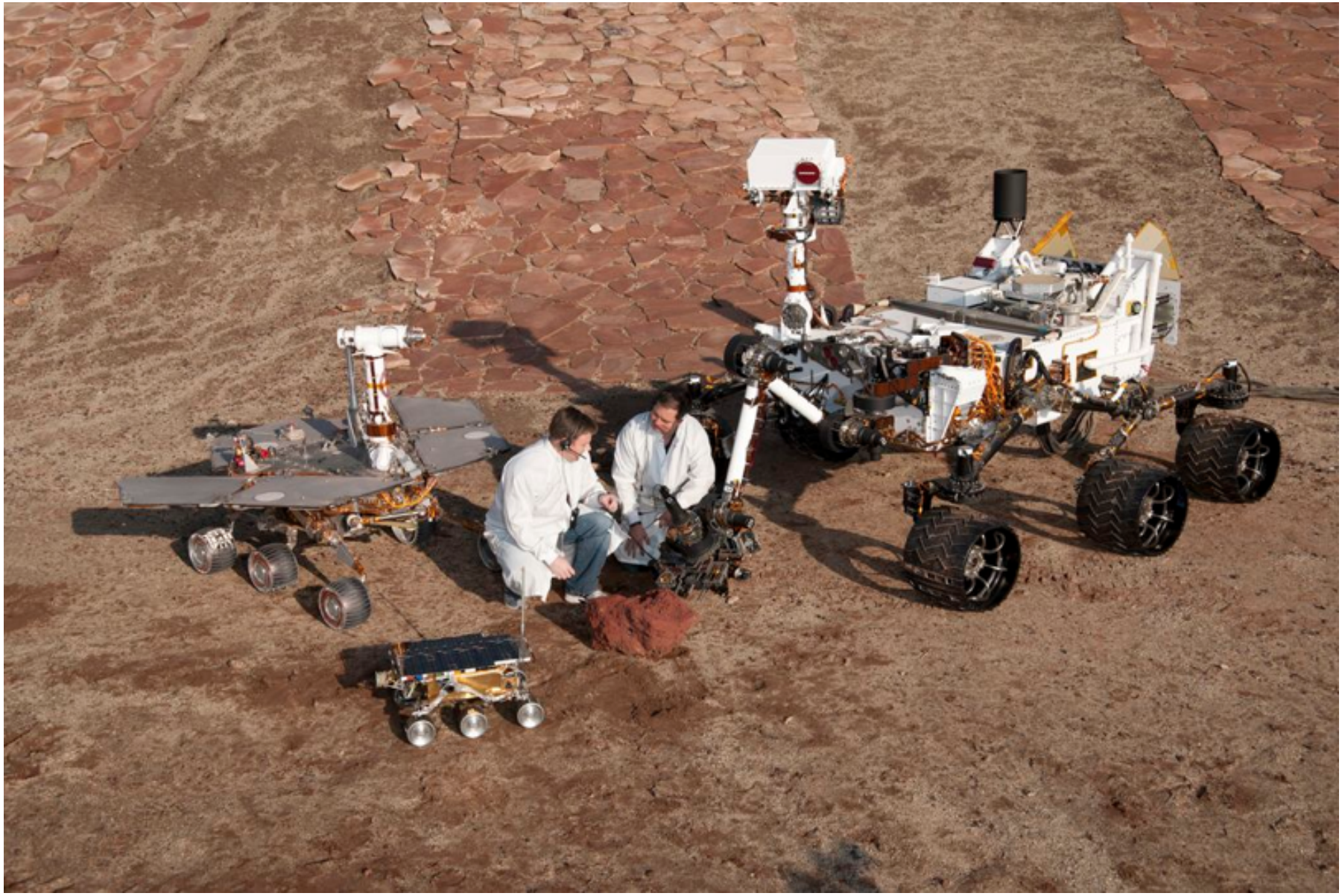
Enceladus



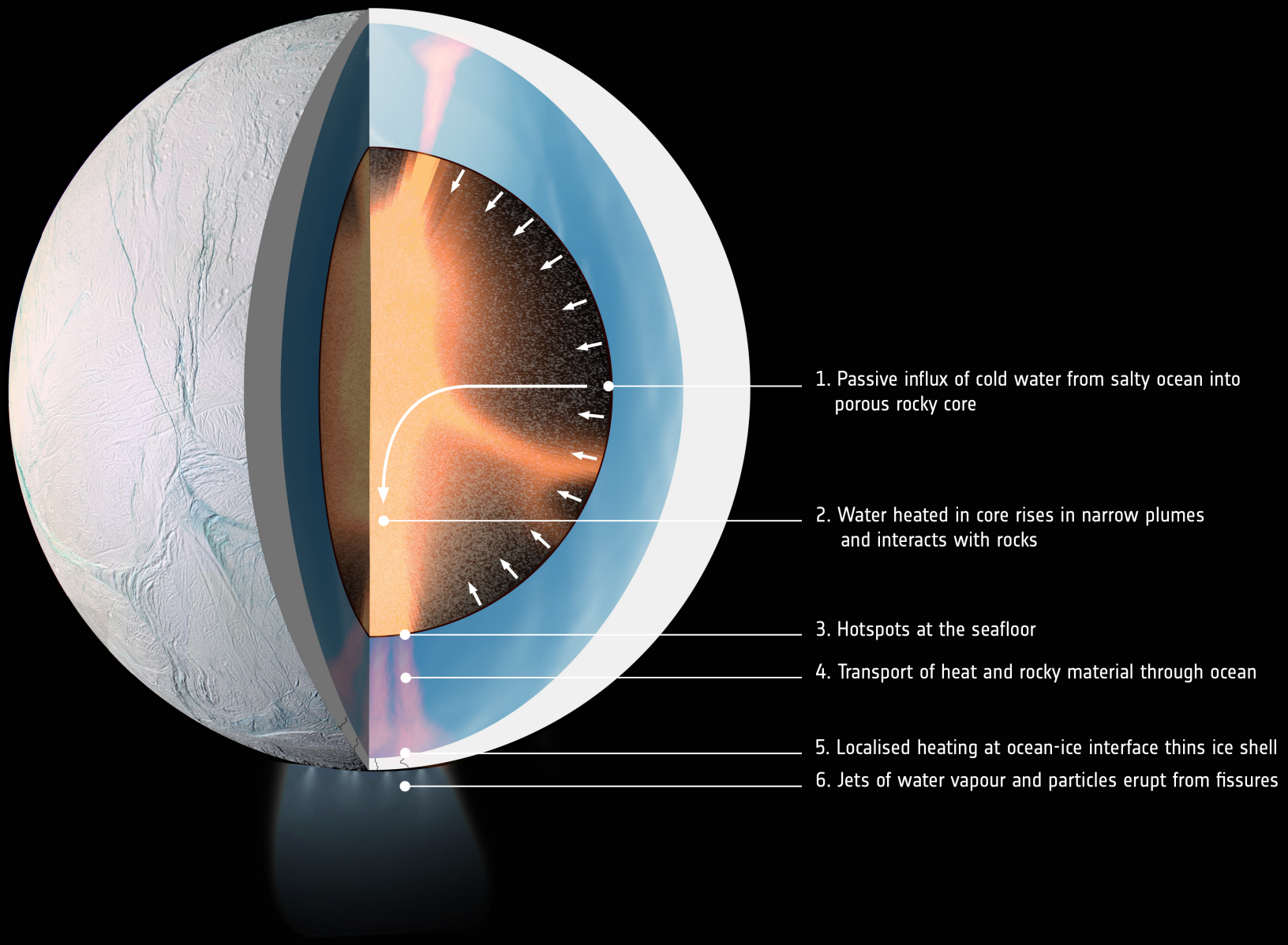
(Martin and Russell, 2007)



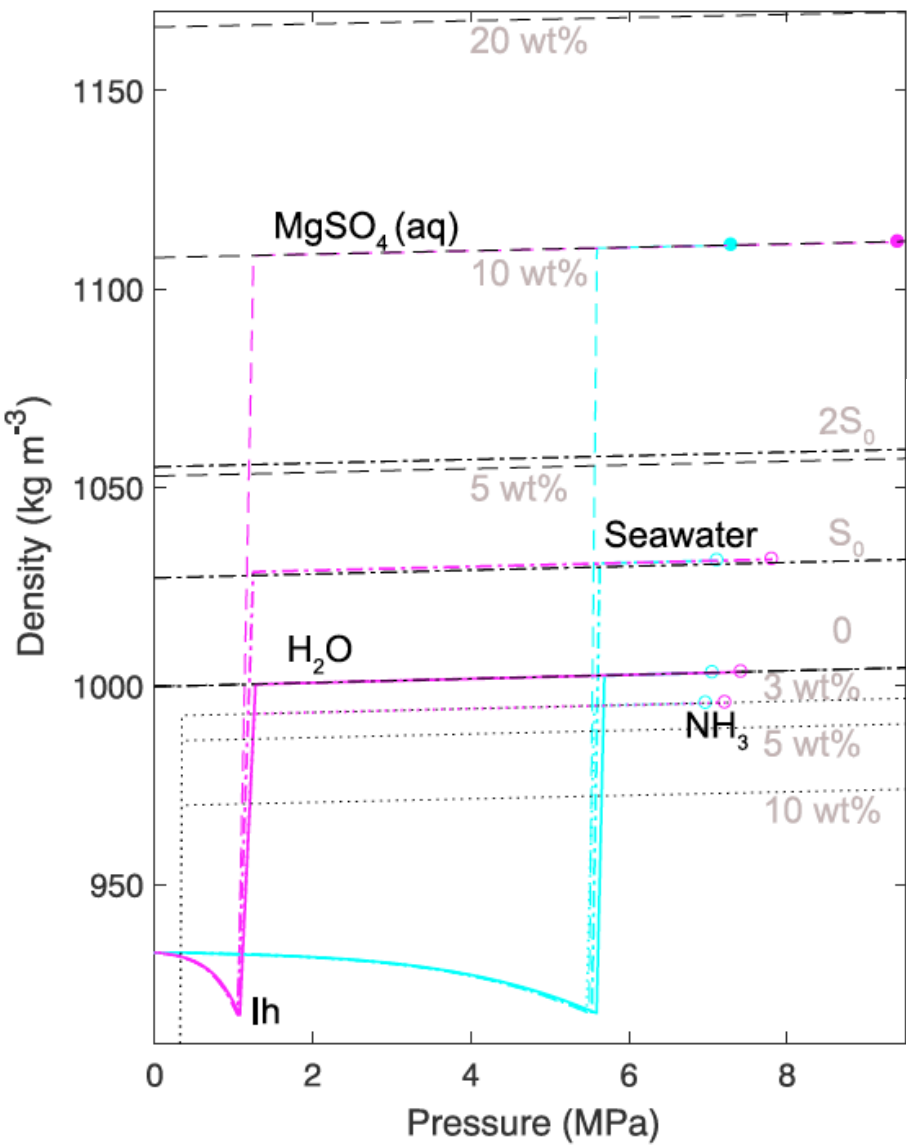
Mumma et al. 2009

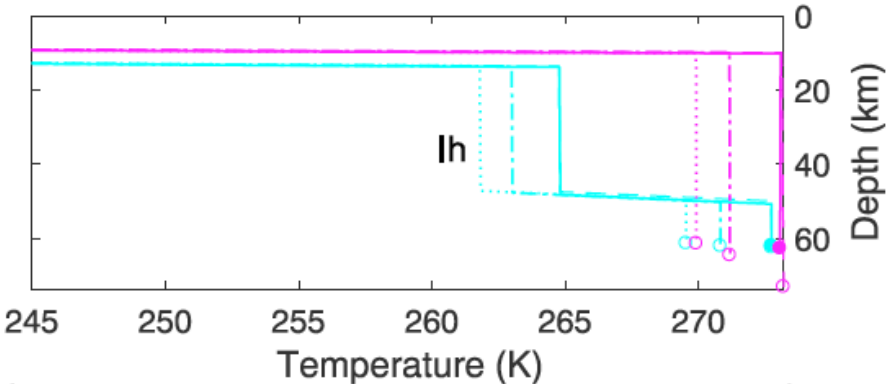


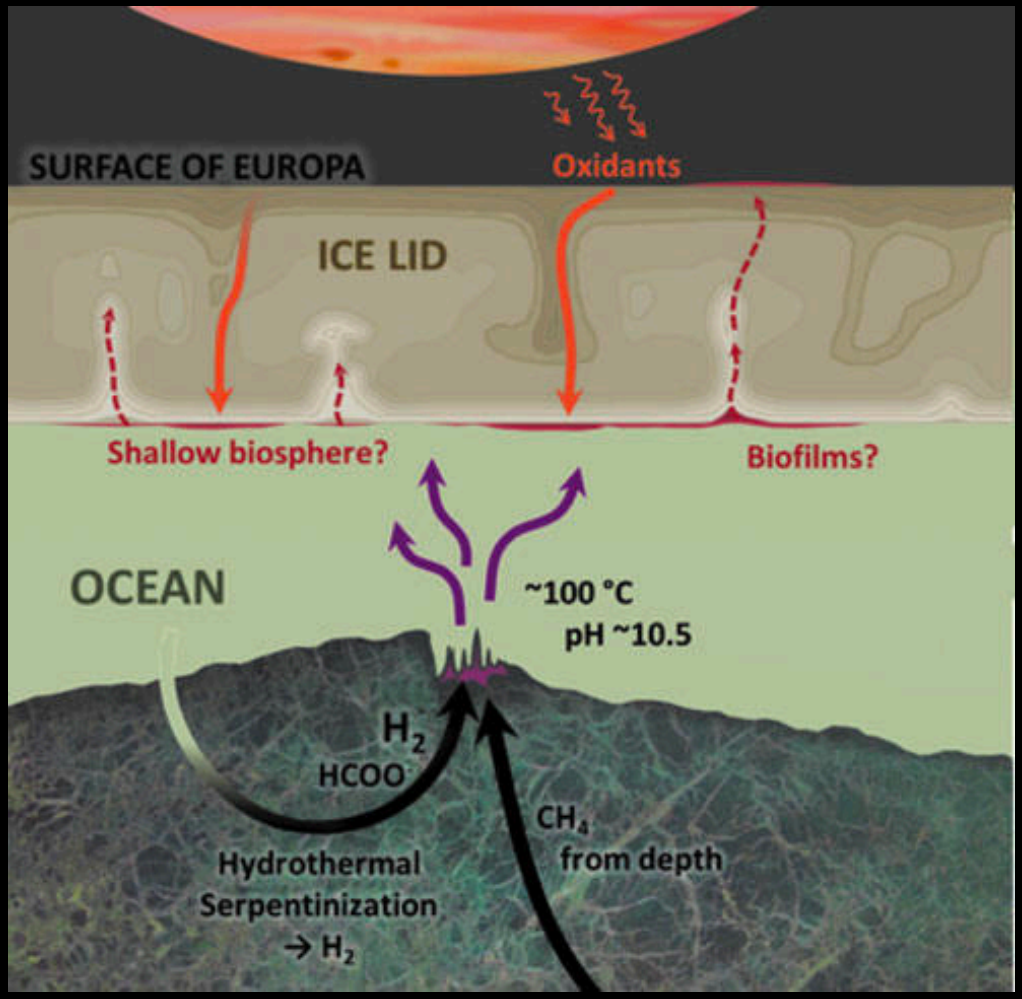
Choblet et al. 2018



NASA/JPL/ LPG-CNRS/U. Nantes/U. Angers/ ESA

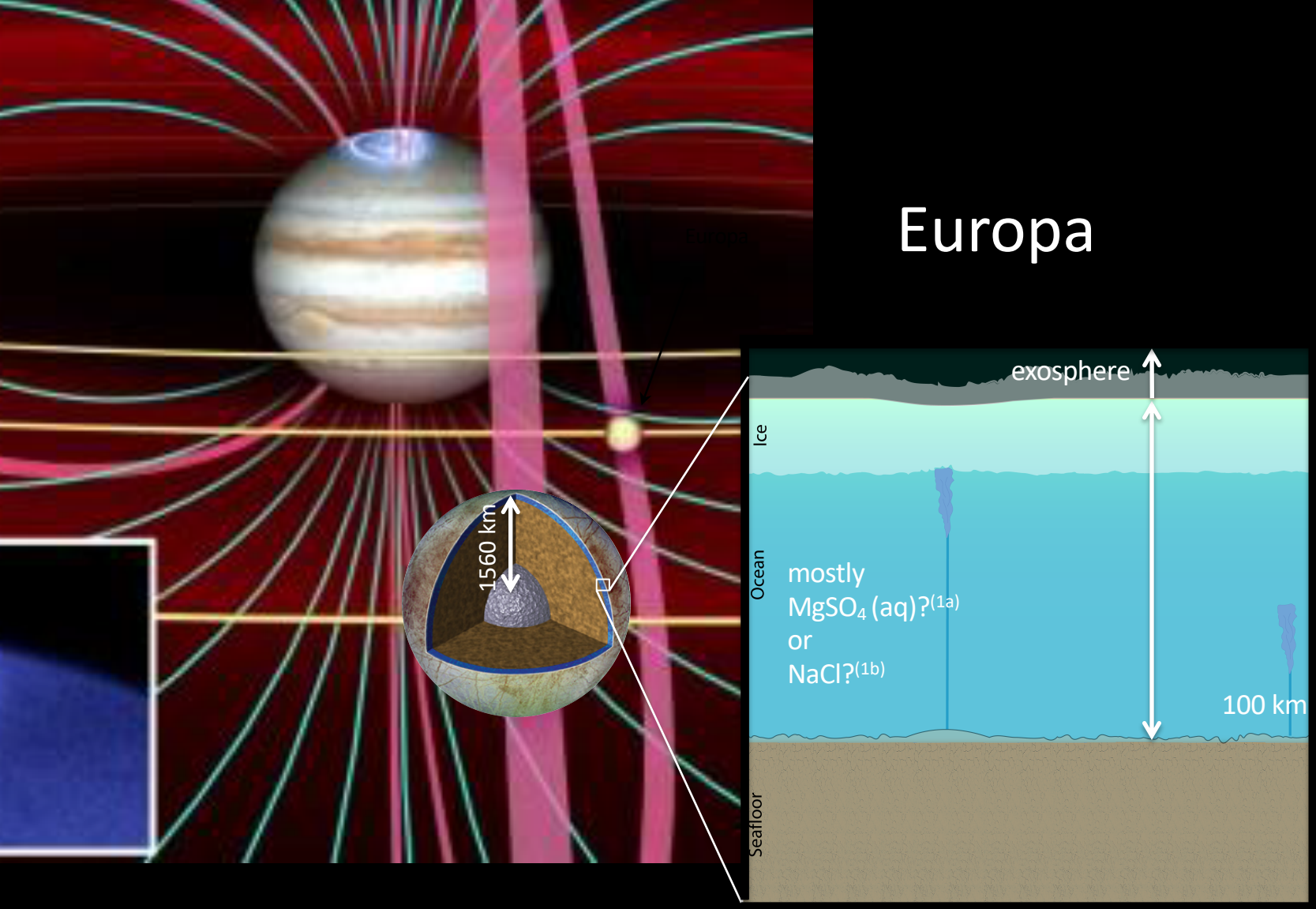

20 wt%
MgSO4(aq)
10 wt%
2S0
5 wt%
Seawater
S0
0
H2O
3 wt%
NH3
5 wt%
10 wt%
Ih
1150
1100
1050
1000
950
0
2
4
6
8
Density (kg m-3)
Pressure (MPa)


Ih
245
250
255
260
265
270
Temperature (K)
0
20
40
60
Depth (km)



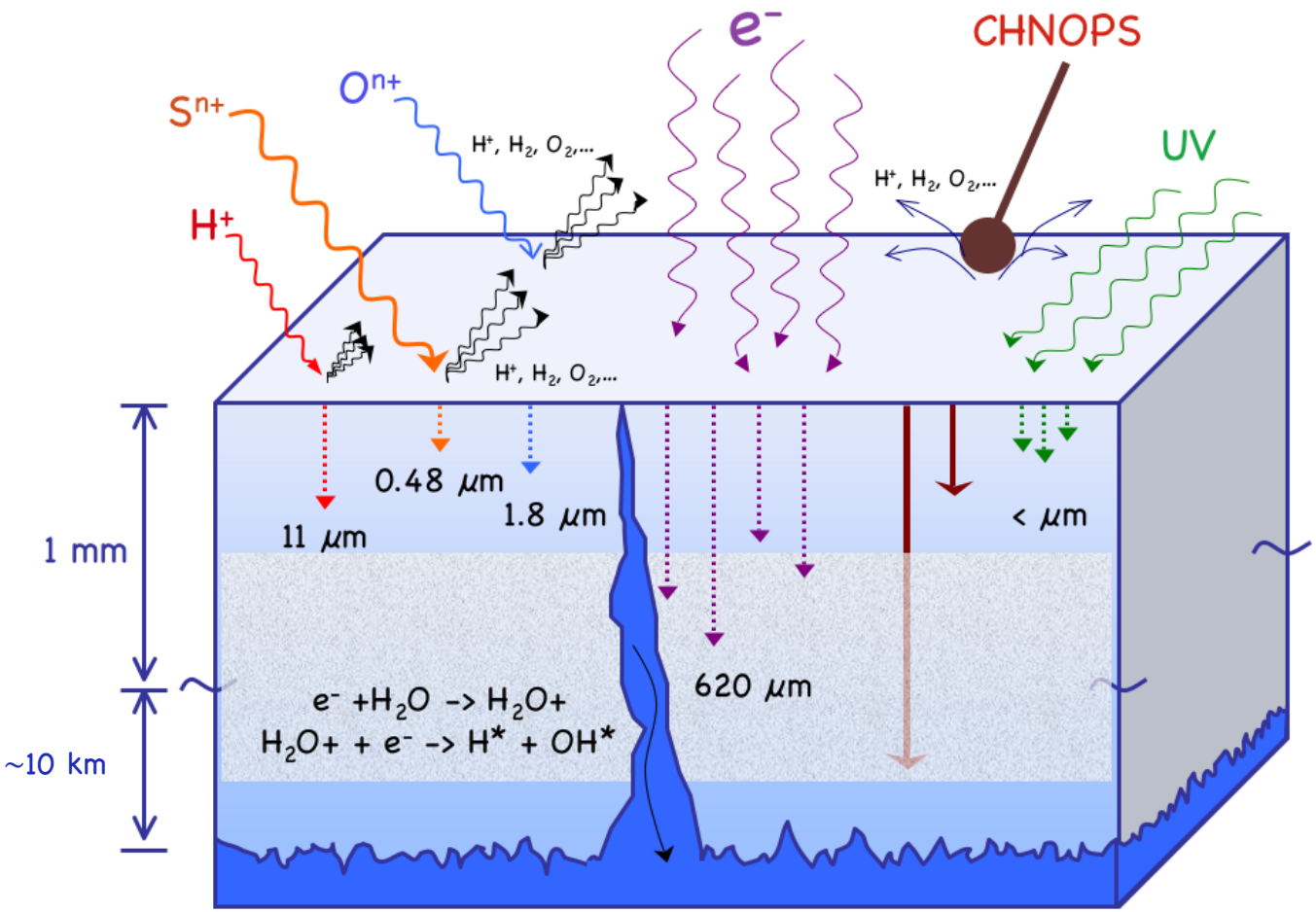
Russell et al. 2017

Europa



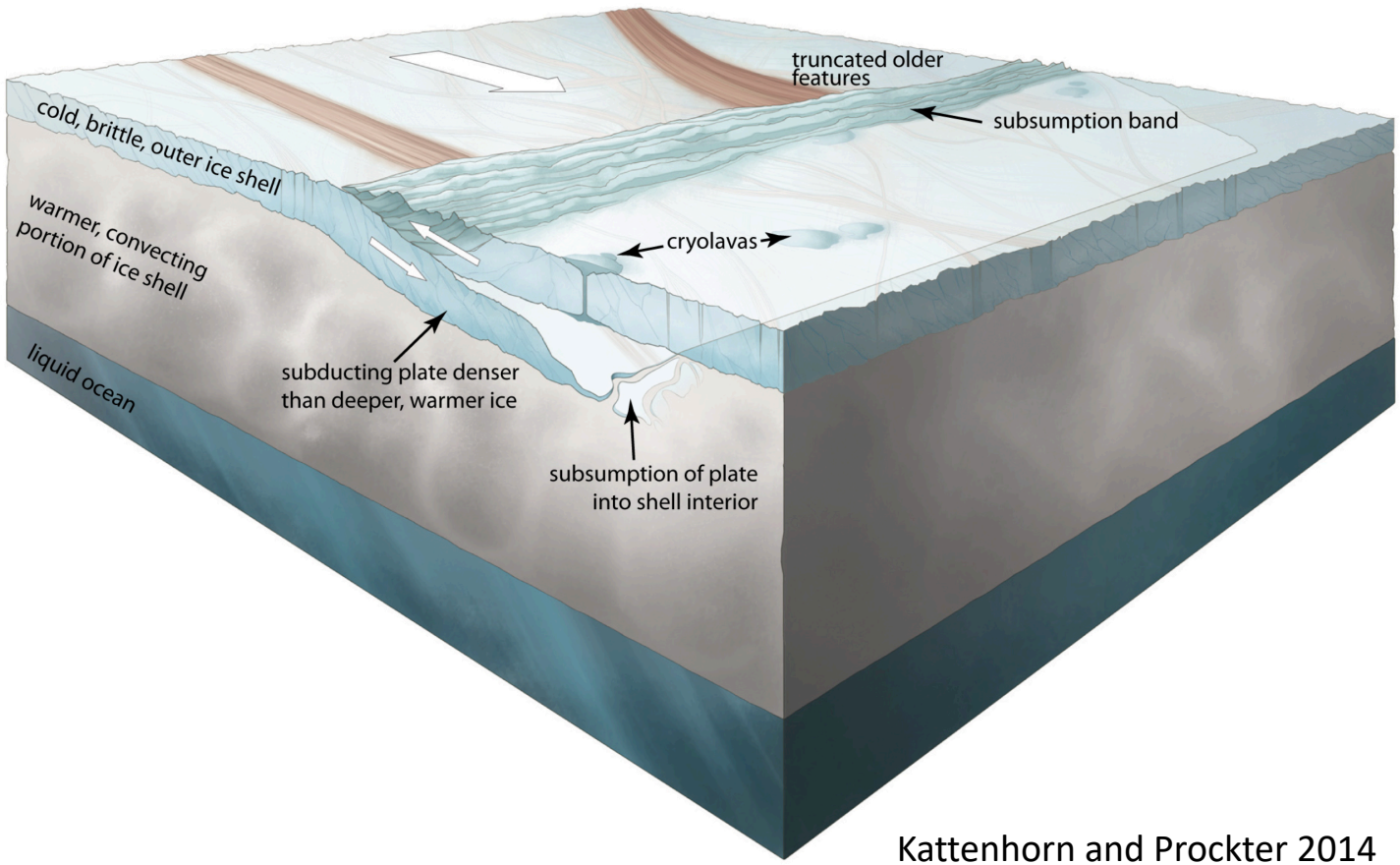
[1a]e.g., Zolotov and Kargel 2009
[1b] Brown and Hand 2013

The Surface Radiation Environment of Europa



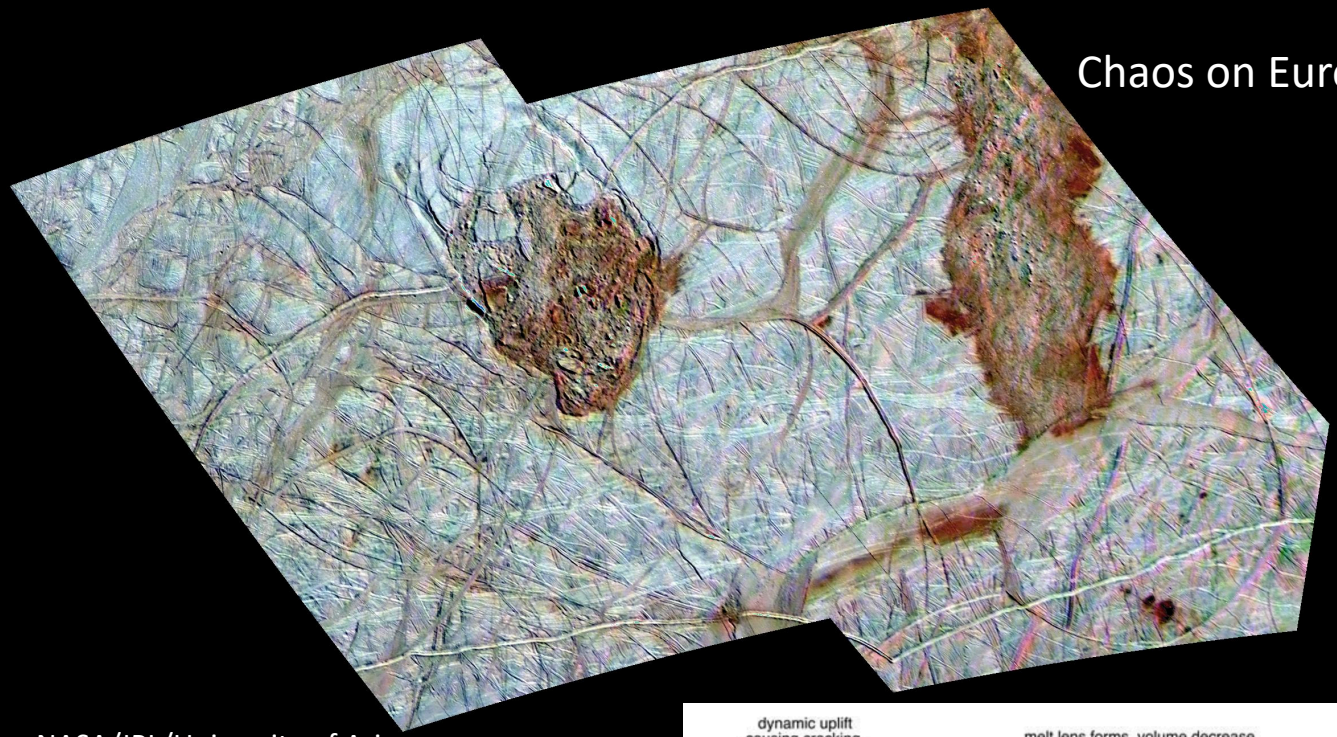
Graphic: Kevin Hand

“Plate Tectonics” on Europa

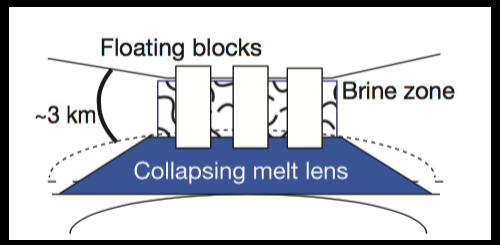


Kattenhorn and Prockter 2014

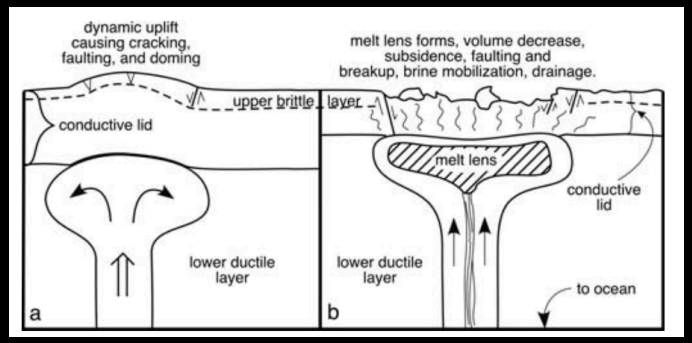
Chaos on Europa



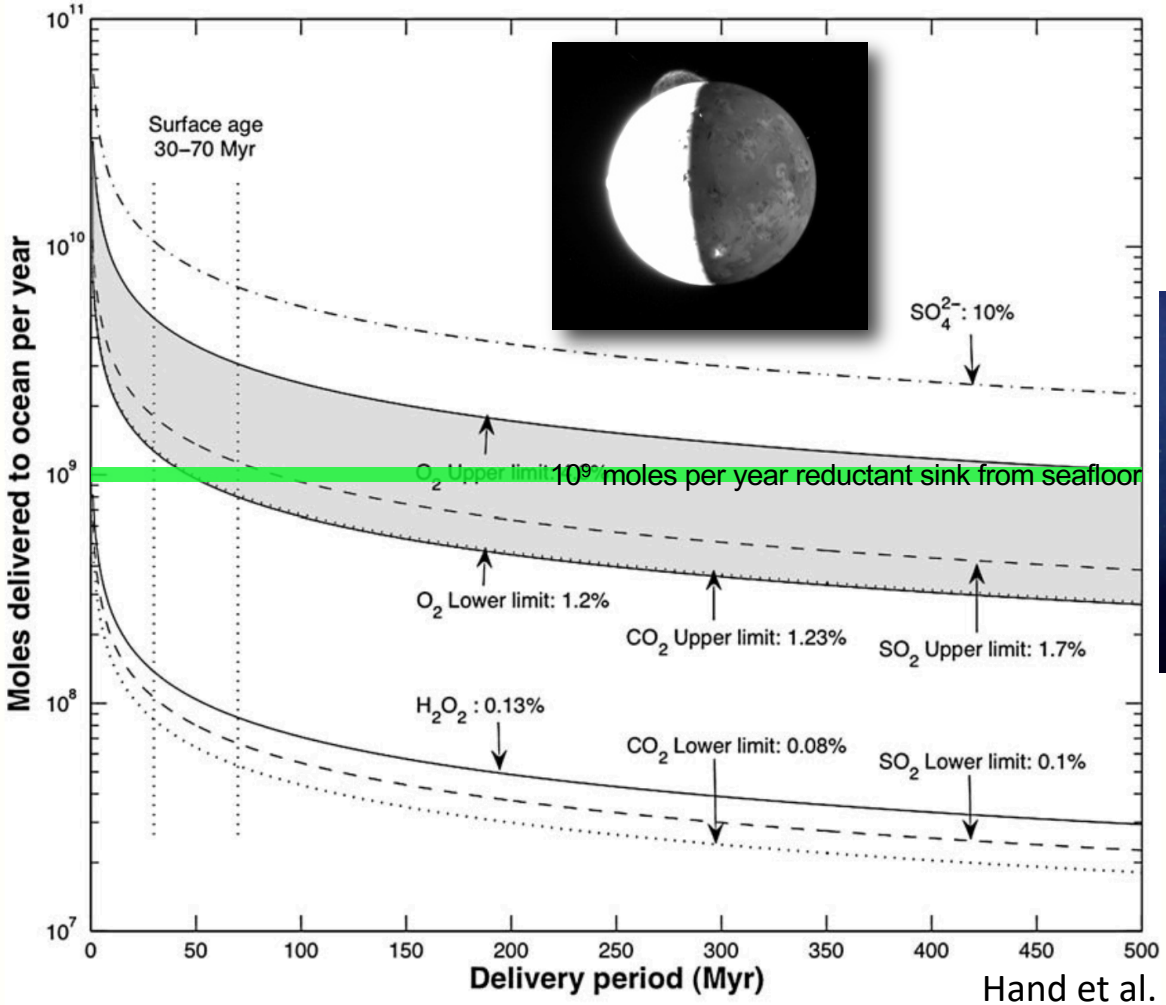
NASA/JPL/University of Arizona



Schmidt et al. 2011



Sotin et al. 2002



Hand et al. 2007, 2009

High-T Hydrothermal Reductants

	(m*m*)	($x10^9$ moles yr^{-1})
CH_4	4.9	0.15
H_2	12.0	3.6
H_2S	33.0	1.0
Fe^{2+*}	0.30	0.09

1) McCollom 1999
2) McCollom (1999), scaled from Earth's $3x10^{13}$ kg yr^{-1} (Elderfield and Schultz 1996)

*flux Fe^{2+} could be higher if Europa has less iron in its core.

Hand et al. 2007, 2009

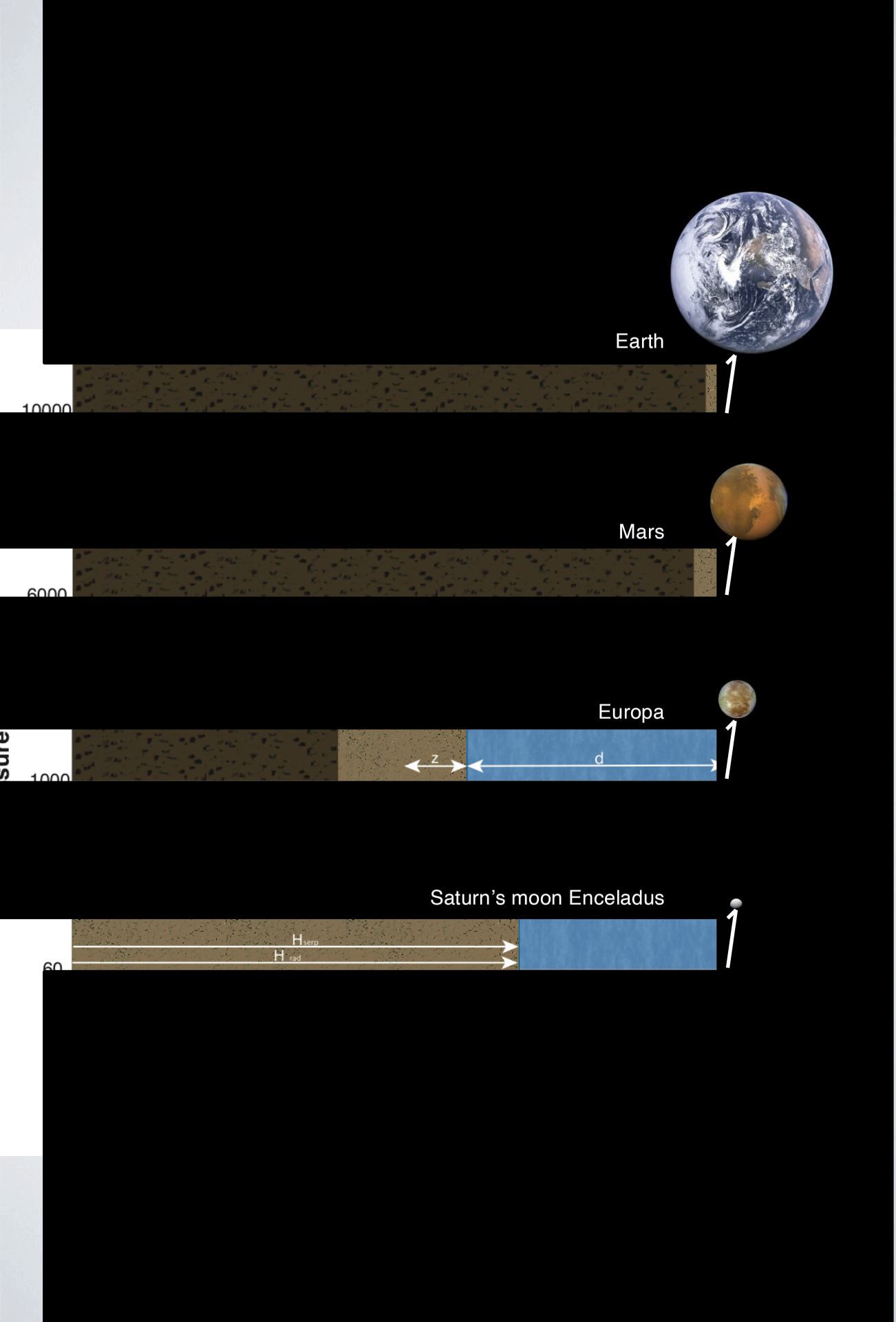
Volcanic hydrothermal flux should scale with Europa's heat:

$$Q = H/c_w \Delta T$$ (Lowell and Dubose 2004)

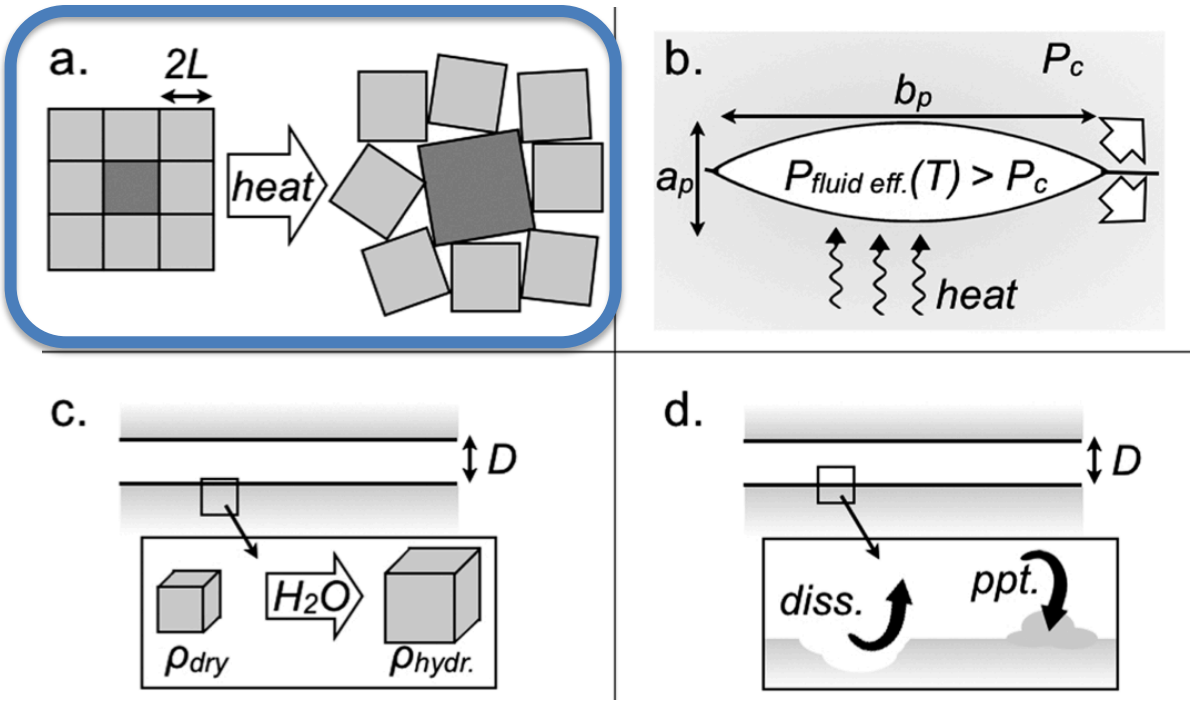
assume ΔT=350°C and 2-6 m*m* H_2 (Holland 2002)

Low-T Hydrothermal Reductants

A reducing mantle interface without tides heating the rock

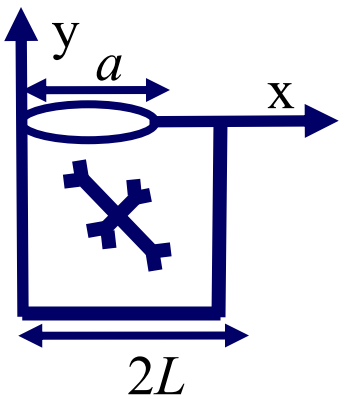

Earth
10000
Mars
6000
Europa
1000
z
d
Saturn's moon Enceladus
60
H serp
H rad

Vance et al. 2007, Vance and Goodman 2009



Neveu et al. 2014

A cracking model is applied to a cooling mantle



$$K_I = \sqrt{\frac{2}{\pi a}} \int_0^a \frac{\sigma_{yy}(x)\sqrt{x}}{\sqrt{a-x}} dx - P_c\sqrt{\pi a}$$

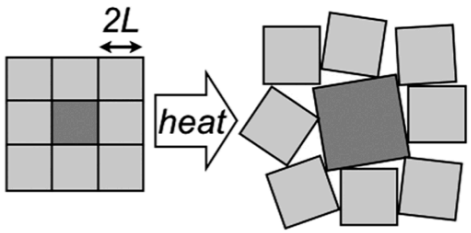
$$\sigma_{yy}(x) = \frac{E\Delta\alpha(T'-T)}{2\pi(1-\nu^2)} \left(\frac{4L^2}{4L^2+(2L-x)^2} - \frac{4L^2}{4L^2+x^2} + \ln\left[\frac{2L-x}{x}\right] - \frac{1}{2}\ln\left[\frac{4L^2+(2L-x)^2}{4L^2+x^2}\right] \right)$$

<u>olivine</u>

Grain size = 2*L*

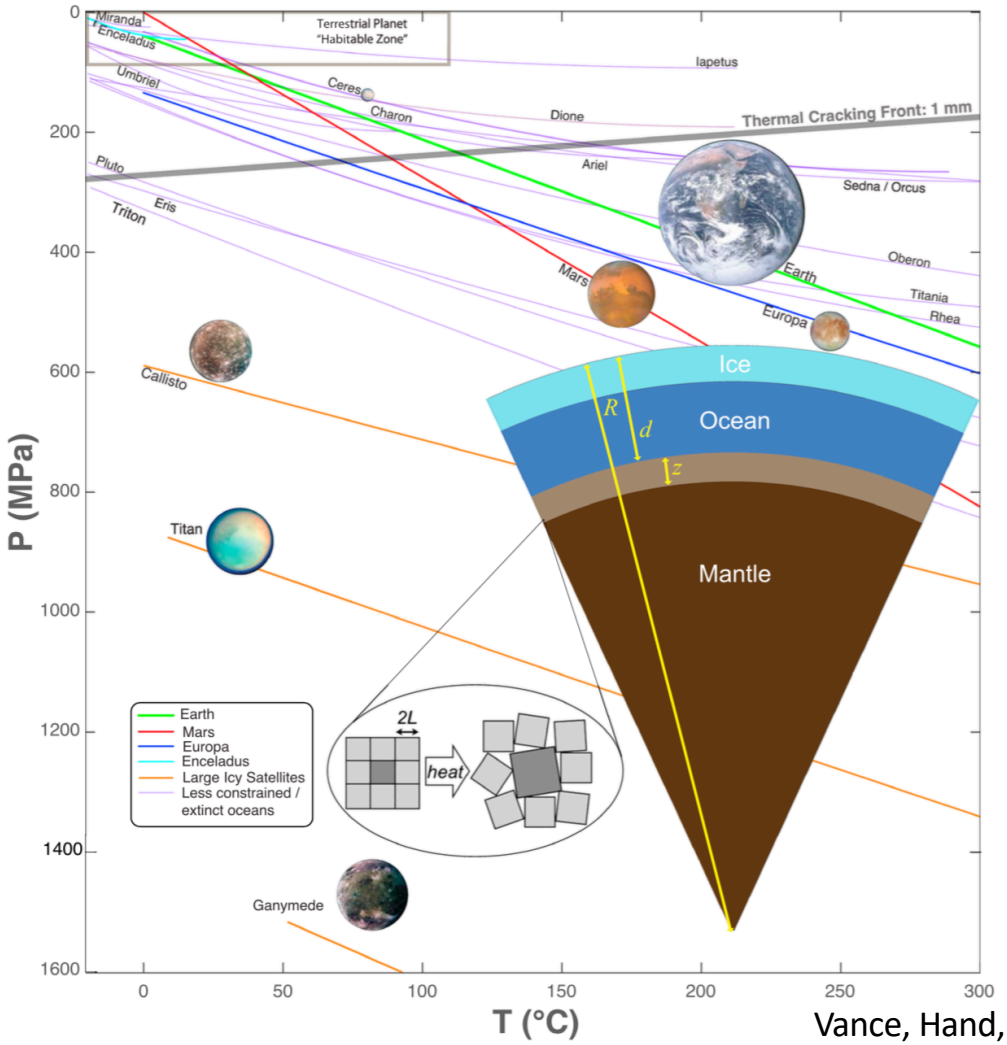
Max flaw size = *a*

$$\frac{d\langle\sigma\rangle}{dT} = \frac{12\Omega\dot{\delta}_b D_o E}{\sqrt{3}k_b L^3 \dot{T}} \frac{e^{-Q/RT}}{T}\langle\sigma\rangle - \frac{\beta E\Delta\alpha}{(1+\nu)} \Rightarrow T' \approx \frac{Q/R}{\ln\left[\frac{\sqrt{3}nk_b L^3\dot{T}}{12\Omega\delta_b D_o E}\right]}$$



Neveu et al. 2014

Vance et al. 2007, Vance and Goodman 2009



Vance, Hand, and Pappalardo, 2016

$$3Fe_2SiO_4 + 2H_2O = 2Fe_3O_4 + 3SiO_2(aq) + 2H_2(aq)$$

fayalite + water = magnetite + silica + hydrogen

$$3FeSiO_3 + H_2O = Fe_3O_4 + 3SiO_2(aq) + H_2(aq)$$

ferrosilite + water = magnetite + silica + hydrogen.

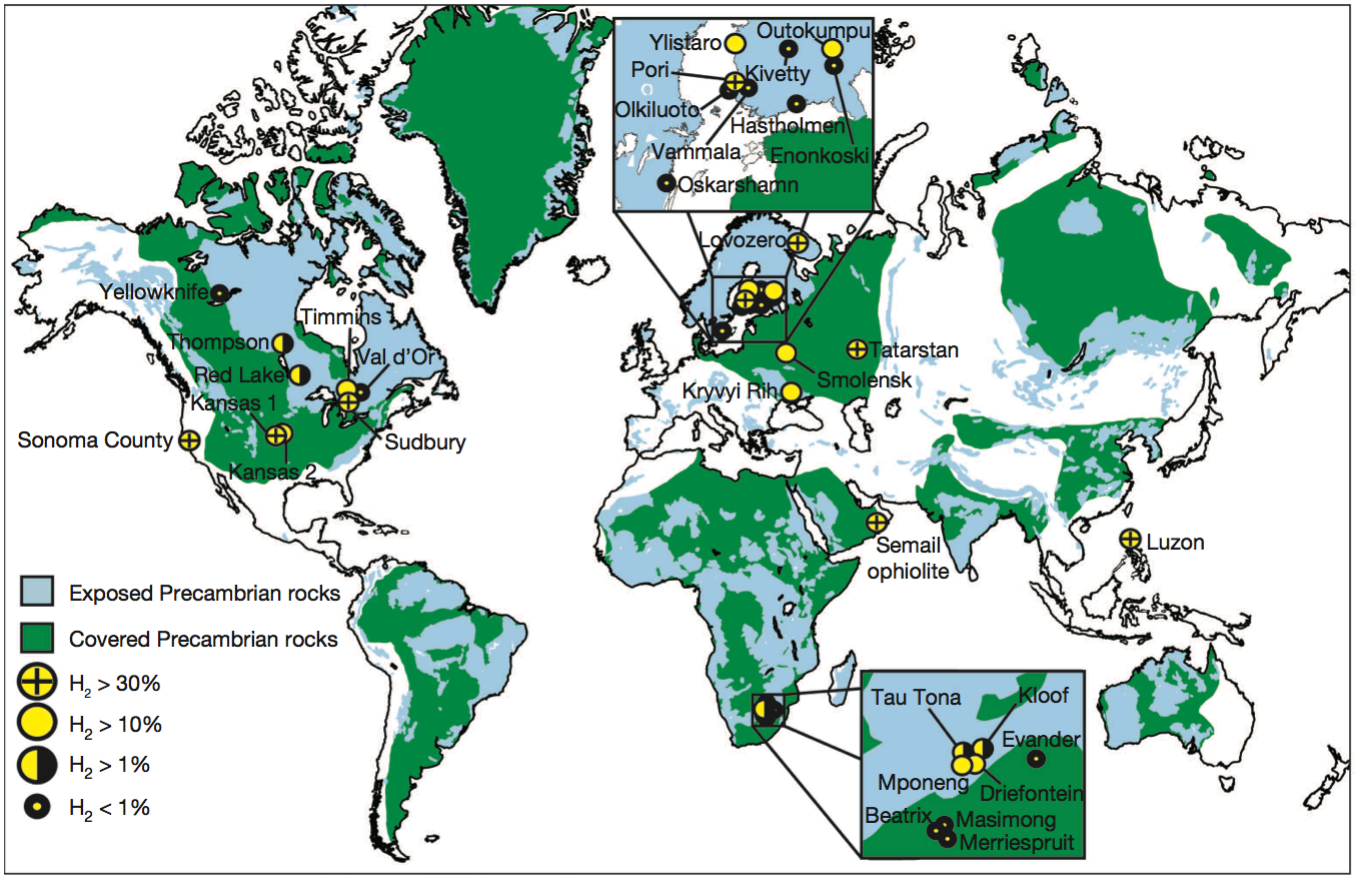
H_2

$$2Mg_2SiO_4 + 3H_2O = Mg(OH)_2 + Mg_3Si_2O_5(OH)_4$$

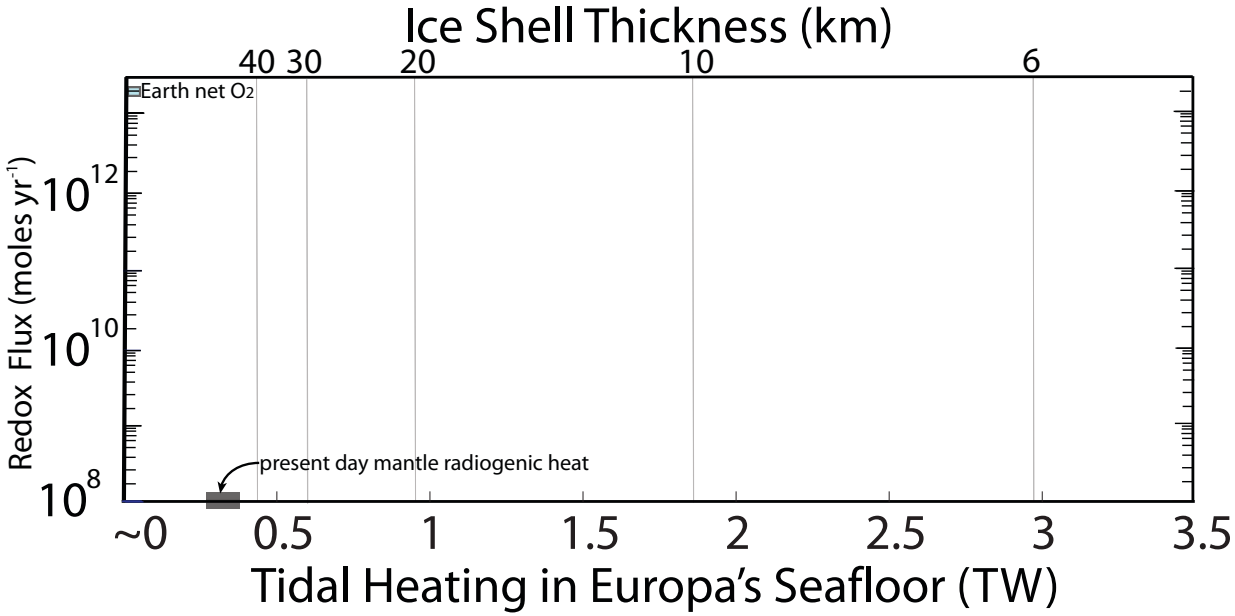
forsterite + water = brucite + serpentine.

Heat
41 kJ/mol olivine

Now accounting for estimates of H_2 and O_2 from the Earth System

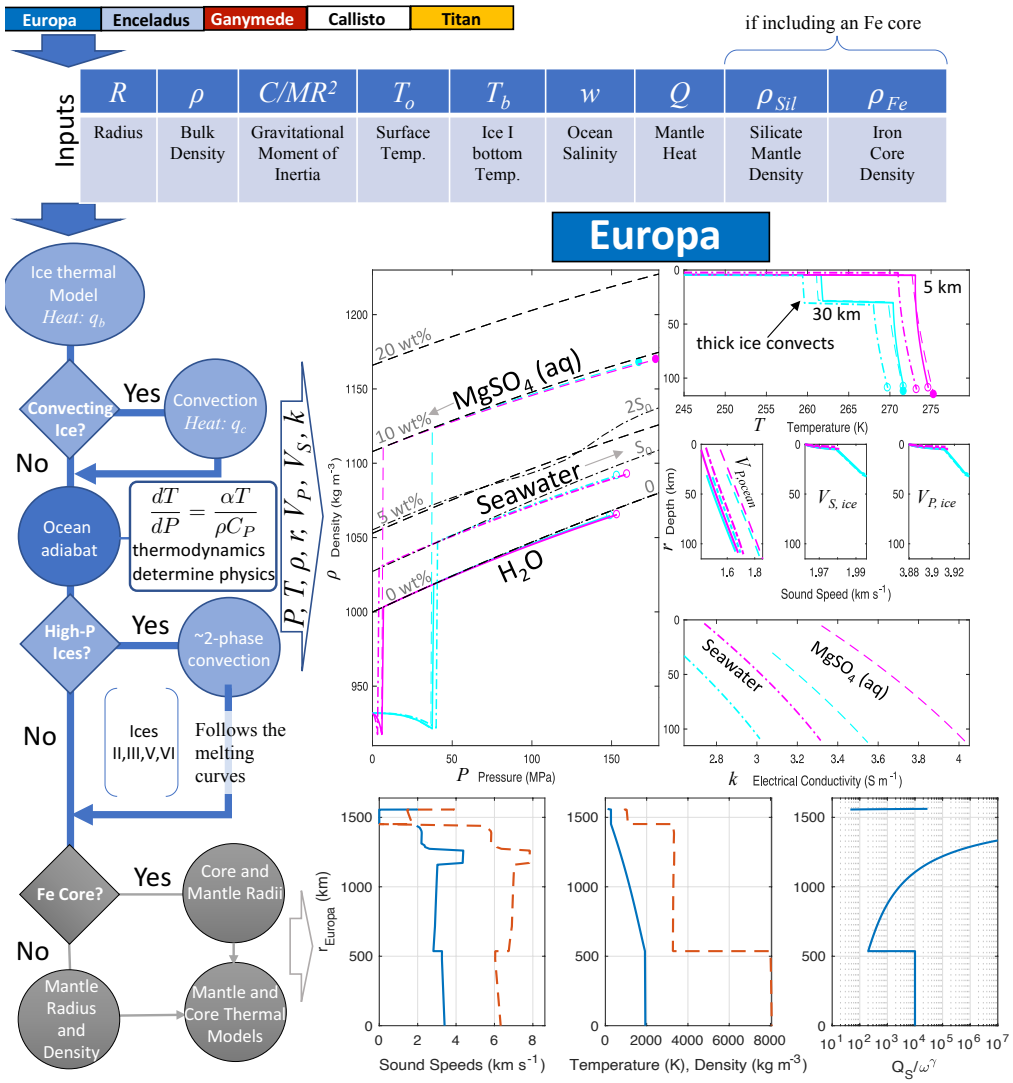


Sherwood-Lollar et al. 2014



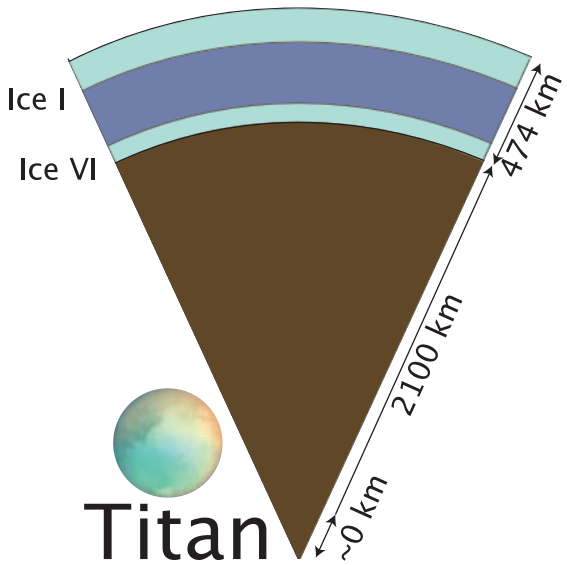
Vance, Hand, and Pappalardo, 2016

PlanetProfile

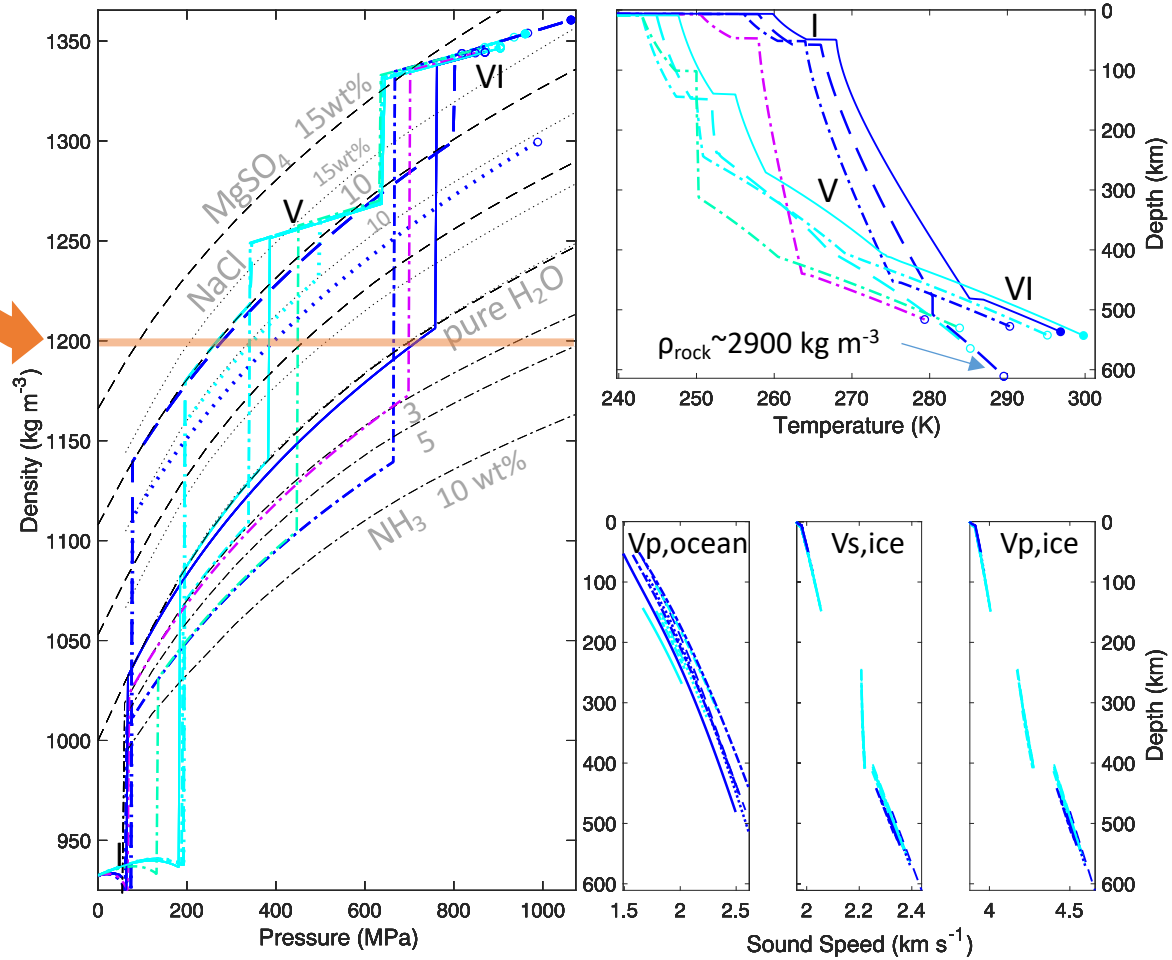


github.com/vancesteven/PlanetProfile

Vance et al. 2018 *JGR: Planets*



Mitri et al. 2014

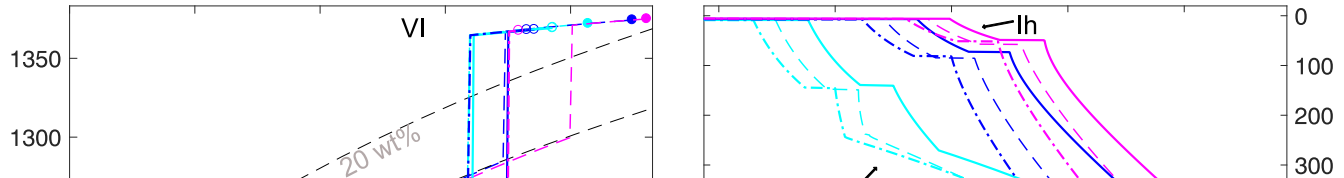


MoI = 0.3318

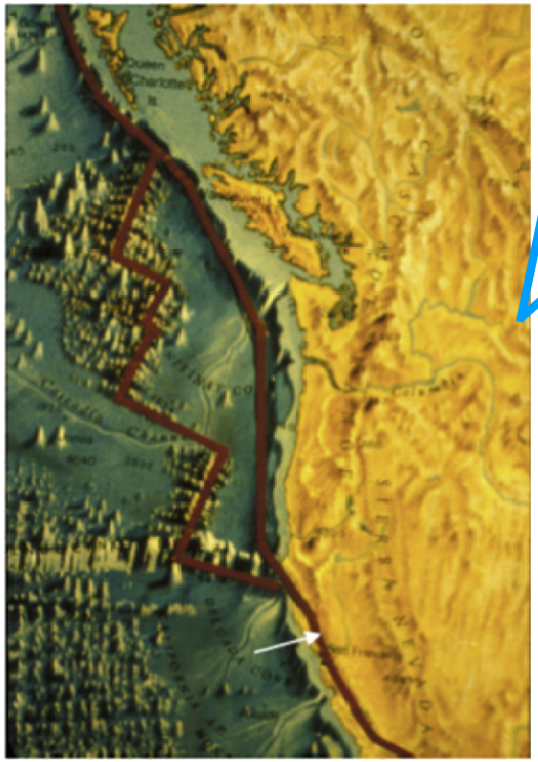
ρ_{rock}~2900 kg m^{-3}

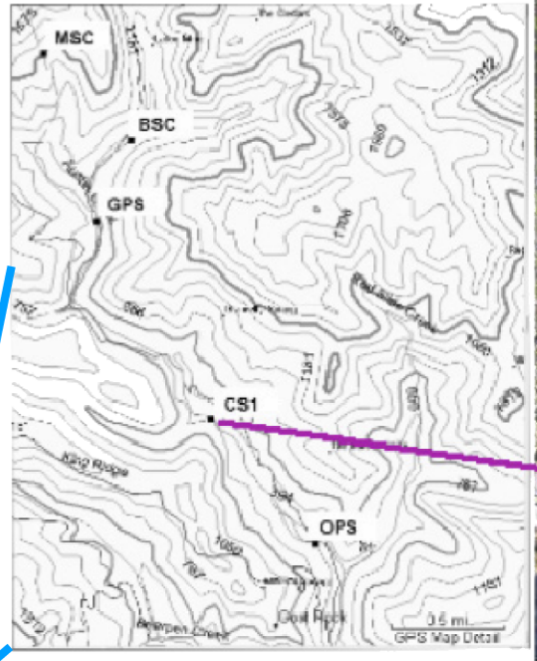
Vance et al. 2018 JGR: Planets

*moment of inertia

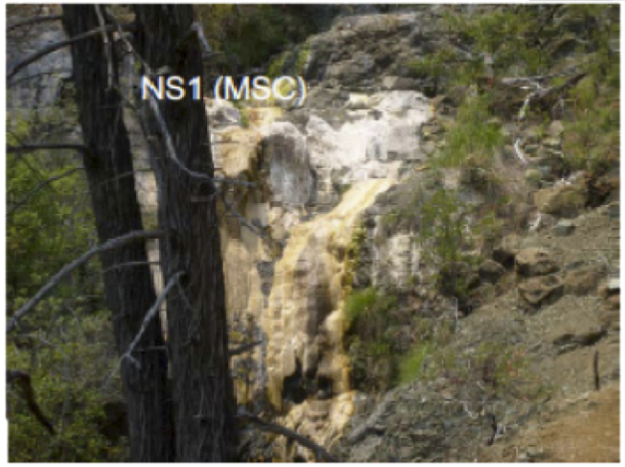


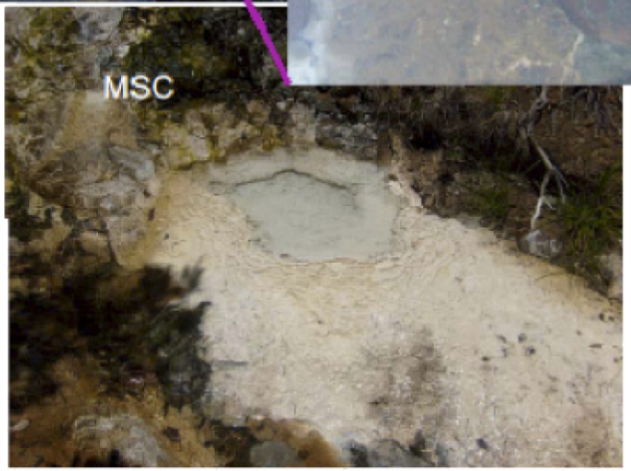
The Cedars, CA





(Morrill et al. GCA, in revision)





Nipple Spring