Dynamics of Planetary Bodies:

From Solar System Formation to Internal Evolution and Magnetic Fields

Supervised by Dr. Wladimir Neumann | TU Berlin, Geodesy and Geoinformation Science

Delaram Darivasi, Maria Paula Bustos Moreno, Hari Bharath Chitta, Taruna Parihar, Yertay Yeskaliyev, Khizar Rustam, Jiaying Gong |
StuROP^x of BUA | X-Student Research Group “The Physics of Water-Rich Asteroids” SS2023

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Topics

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2. **The Size-Frequency Distribution of Asteroids** - Jiaying Gong
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4. **Thermal Pressurization of Pore Water** - Yertay Yeskaliyev

Part II - Saturn's Icy Moon Enceladus

5. **Moment of Inertia (MOI)** - Delaram Darivasi
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Part I - Origins and Evolution of Planets and Asteroids

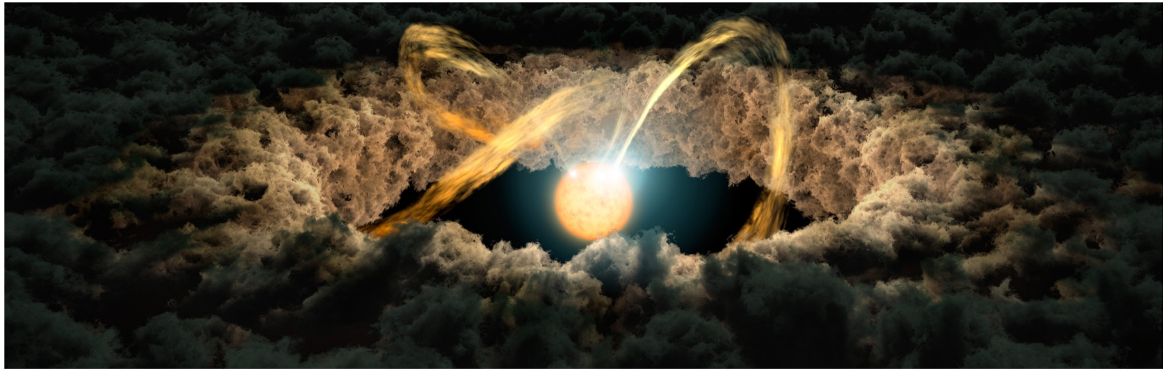


Illustration: Protoplanetary Disc cr. NASA/JPL-Caltech

Protoplanetary Disc (cooling, condensing)

Planets and asteroids formation
(accretion process)

asteroid belt

near-Earth asteroids e.g., Ryugu

evolution similar to the planets e.g., Vesta

1. Modeling Protoplanetary Disc Evolution

- **Objective:** To understand the evolution of massive protoplanetary discs and their role in planetary formation.
- **Method:** Utilizing Smoothed Particle Hydrodynamics (SPH) simulations with an approximate radiative cooling prescription.
- **Simulation Details**
  - **SPH Code:** Gadget-3 (an updated version of the code by Springel, 2005).
  - Particle Representation:
    - Gas and dust components
    - Adaptive SPH smoothing lengths
    - Two-fluid approach for dust

1. Modeling Protoplanetary Disc Evolution

Analysis and Visualization

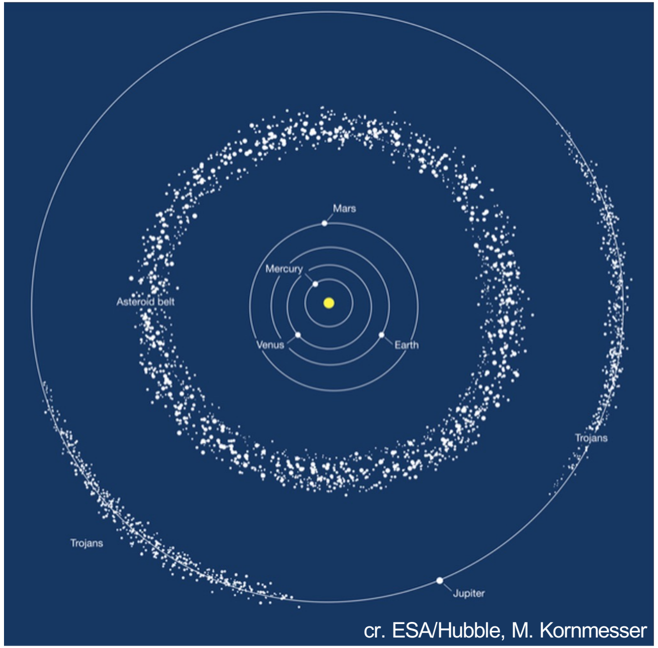
- **Simulated Evolution**
  - Monitoring temperature, density, and mass distribution
  - Assessing radiative cooling effects
- **Output Visualization:** Plots and animations to illustrate disc evolution and potential planet formation regions

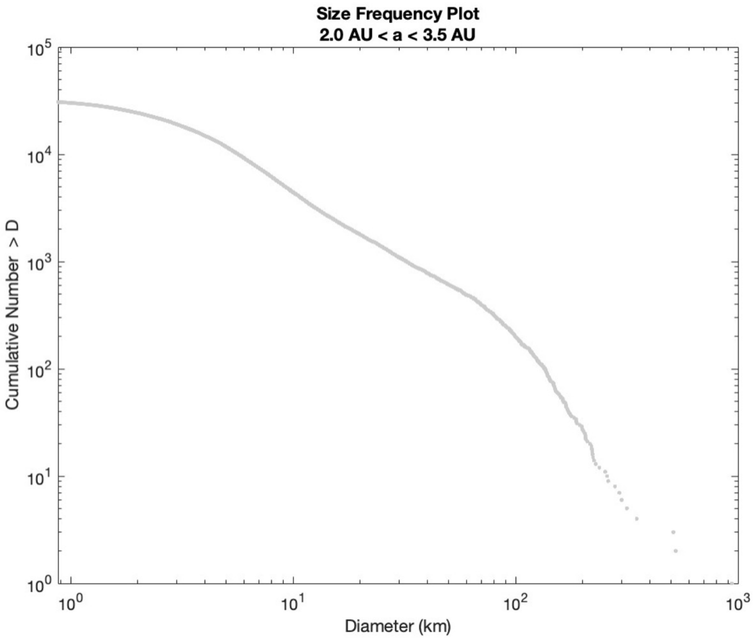
Conclusion

- **Significance:** Understanding protoplanetary disc evolution aids in comprehending planet formation.
- **Future Work:** Further refinements and exploration of complex processes.

2. The Size-Frequency Distribution of Asteroids

- **Asteroids Belt**

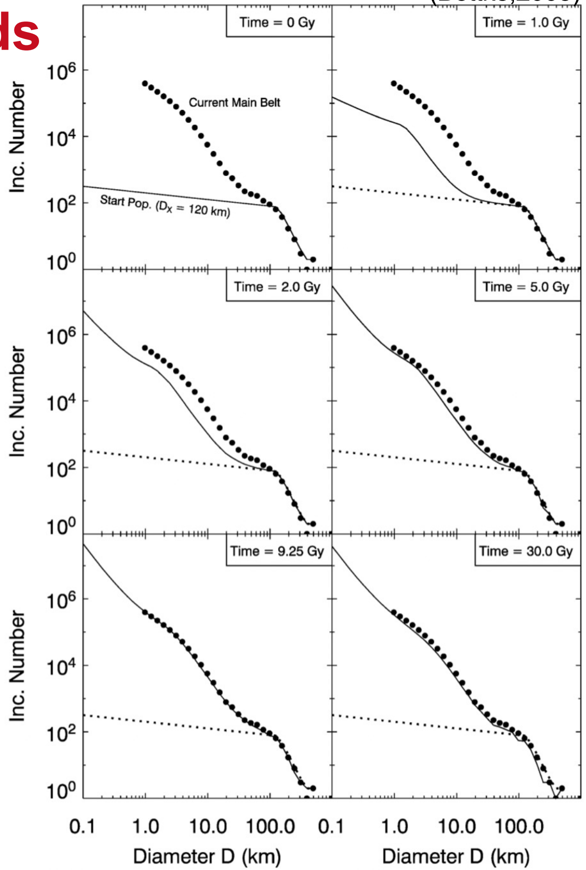




2. The Size-Frequency Distribution of Asteroids

- **Methods**
  - CoEM - Collisional Evolution Model
- **Results**
  - the initial main belt size distribution after accretion
  - the asteroid disruption scaling law
- **Outlooks**
  - compare calculated values with observations
  - apply up-to-date data to repeat the model

(Bottke,2005)

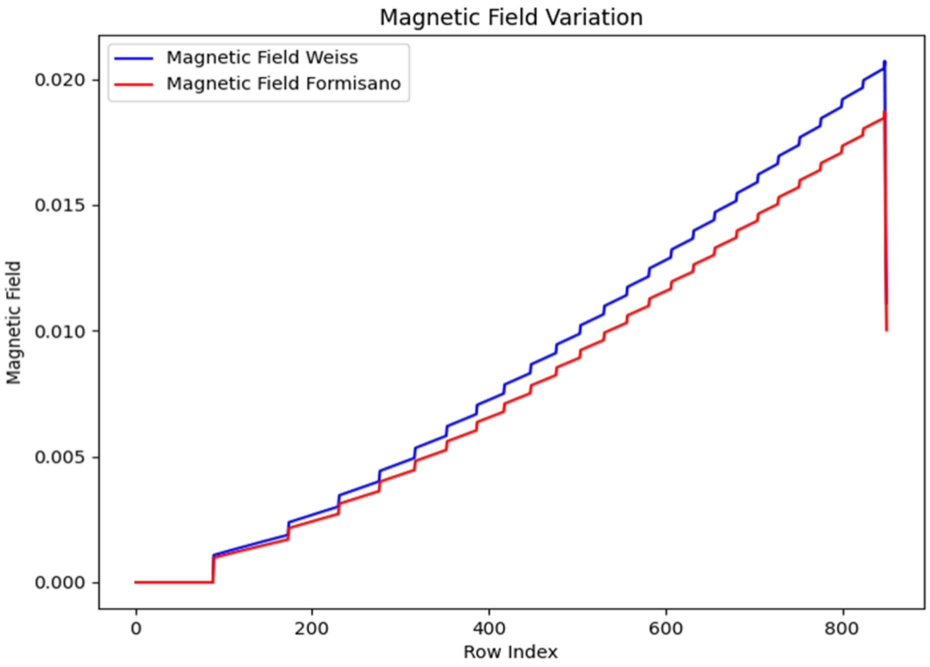


3. The Magnetic Field of Asteroid Vesta

- **Methods**
  - Magnetic Field calculation by Formisano incorporating thermal convection, without any approximations.
  - Magnetic Field calculation by Weiss, using Archimedean and Coriolis forces with approximations.
- **Results**
  - Both methods were tested on the Vesta’s time evolution file.
  - Even with the set of approximations, the presence of early stage dynamo presence was validated.

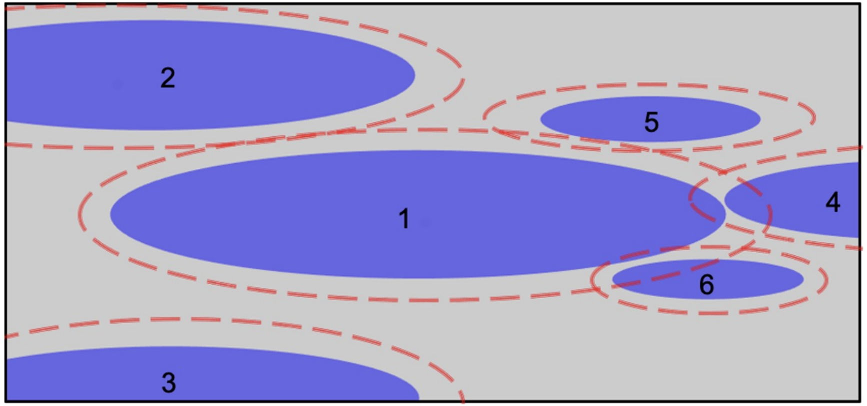
3. The Magnetic Field of Asteroid Vesta

- **Outlooks**
  - The validation could be done in depth considering the real core radius from the metal fraction in the core.



4. Thermal Pressurization of Pore Water

- **Ryugu's parent body**
  - cracks in Ryugu samples (by JAXA mission Hayabusa)
- **Methods**
  - Numerical modelling using Finite differences



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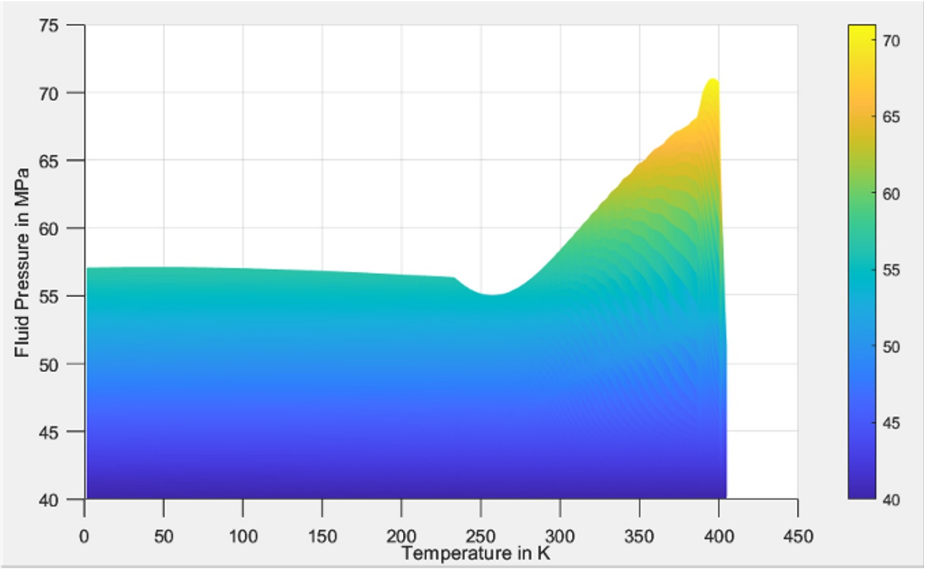
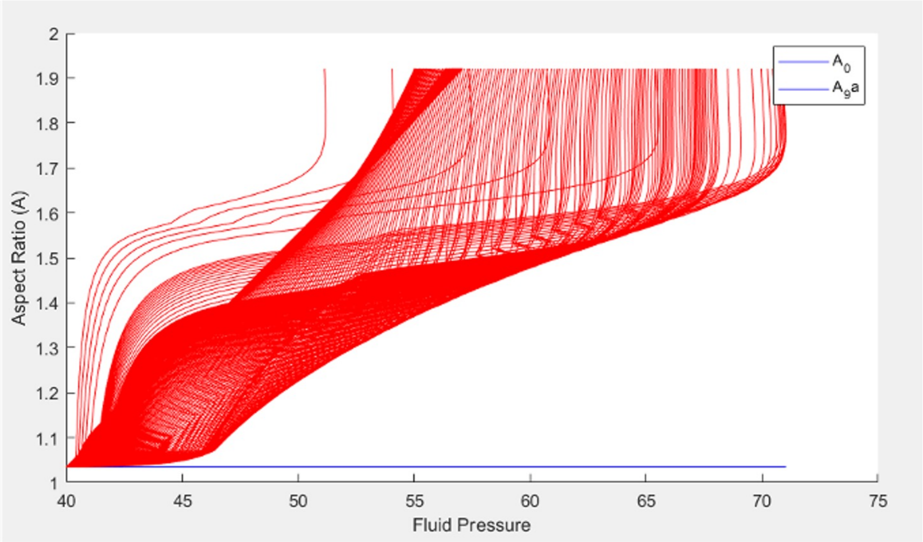
4. Thermal Pressurization of Pore Water

- **Results**





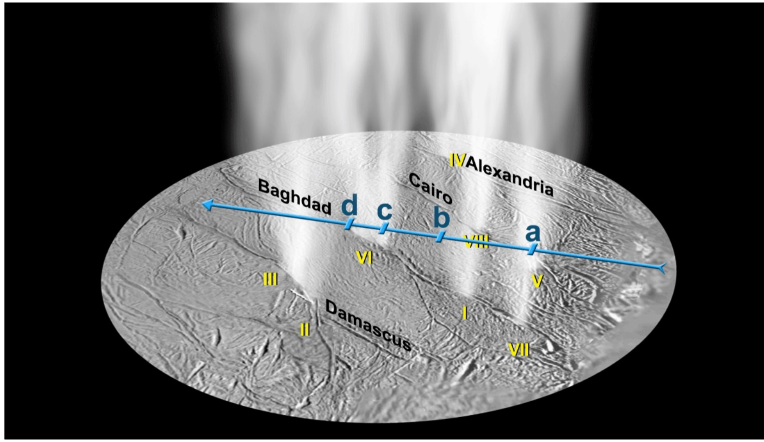
4. Thermal Pressurization of Pore Water

- **Results**
  - The pore expansion is mostly contributed by aspect ratio of the pores
  - Expansion of pores start by big aspect ratio pores, due to higher sensitivity to pressure variations

- **Outlooks**
  - Behavior of pores are unstable in high fluid pressure, the reasoning is yet unknown and must be further investigated
  - As pore size drastically affects the thermal pressurization, aspect ratio of pores needs to be grouped or discretized for more accurate modelling of pore expansion

Part II - A Journey to Enceladus

- An Icy satellite of Saturn
- Was studied by Cassini in 2005
- A dense cloud of water vapor and ice grains was ejecting from a region in the South pole called “Tiger-stripes” region
- It shows that Enceladus is active
- Tidal forces from Saturn and neighboring moons
- Highly probable to have a subsurface ocean



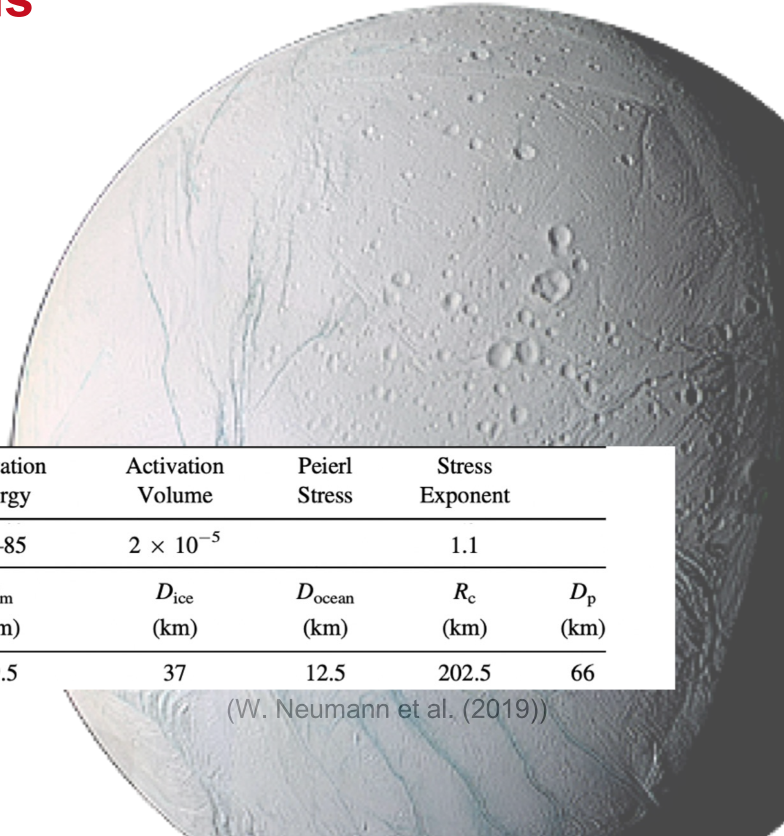
Colorado university

5. Moment Of Inertia (MOI) of Enceladus

- MOI : shows the mass distribution inside a body
- MOI Coefficient = [0.33, 0.34] (Iess et al. (2014)))

$$\Theta = \rho \int_0^R dr \int_0^\pi d\vartheta \int_0^{2\pi} d\varphi \; r^4 \sin^3\vartheta$$

J. Oberst (2022)

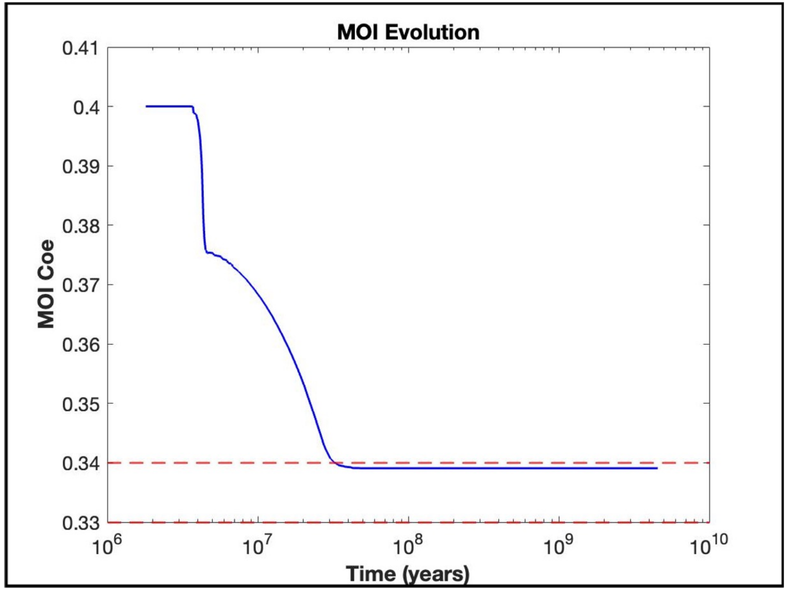


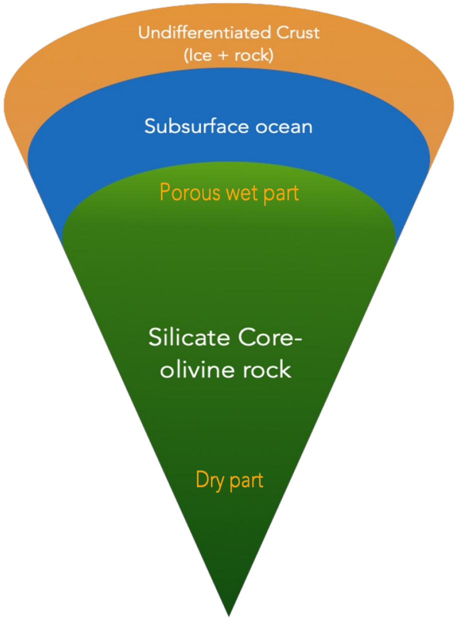
Parameter		Pre-factor	Water Fugacity	Grain Size	Grain Size Exponent	Activation Energy	Activation Volume	Peierl Stress	Stress Exponent	
Rheology	Olivine (wet)	$10^{4.7}$	$50–10^3$	0.1–50	3	56–85	2×10^{-5}		1.1	
Model	t_0 (Ma)	ϕ_0	$\mathcal{E}$ (kcal mol^{-1})	d (μm)	f_{H_2O} (MPa)	D_m (km)	D_{ice} (km)	D_{ocean} (km)	R_c (km)	D_p (km)
B3	1.8	0.6	60	0.1	60	49.5	37	12.5	202.5	66

(W. Neumann et al. (2019))

5. MOI of Enceladus

Red dash-line : MOI Coefficient that less proposed

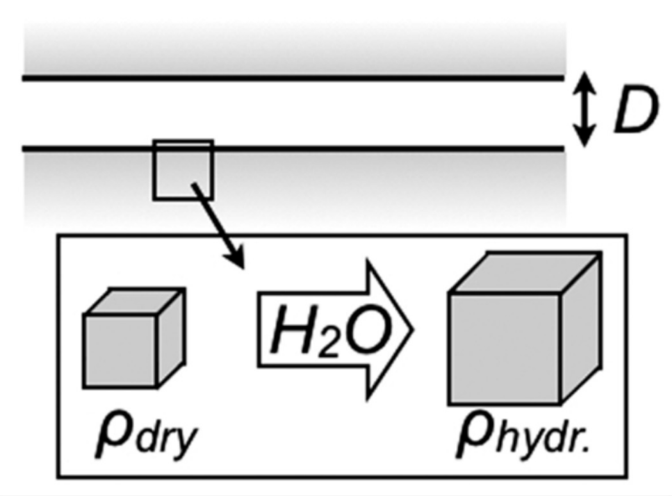




(W. Neumann et al. (2019))

6. Hydration Swelling & Dehydration Shrinking of rock Minerals

- Hydration occurs in the cracked areas to a degree that depends on temperature
- Hydration or dehydration leads to changes in the volume of the rock
- This change in volume relates to the crack width variations
- Cracks may open or close due to hydration swelling or dehydration shrinking



Neveu et al 2015

$$\Delta D = -2\left[\left(\frac{\rho_{hyd}}{\rho_{dry}}\right)^{-1/3} - 1\right] * \bar{x}$$

7. Mineral Dissolution and Precipitation in the Ocean layer of Enceladus

- Open cracks provide circulation of chemical fluids
- Dissolution erodes conduit walls - widens cracks
- Precipitation narrows or clogs cracks

- Chemical found - CO_2, NaCl, $NaHCO_3$
- Definition of the chemical reaction and equilibrium constant
- Calculate Precipitation and Dissolution rates
- Calculate the change in the crack width

(Perera. (2021))

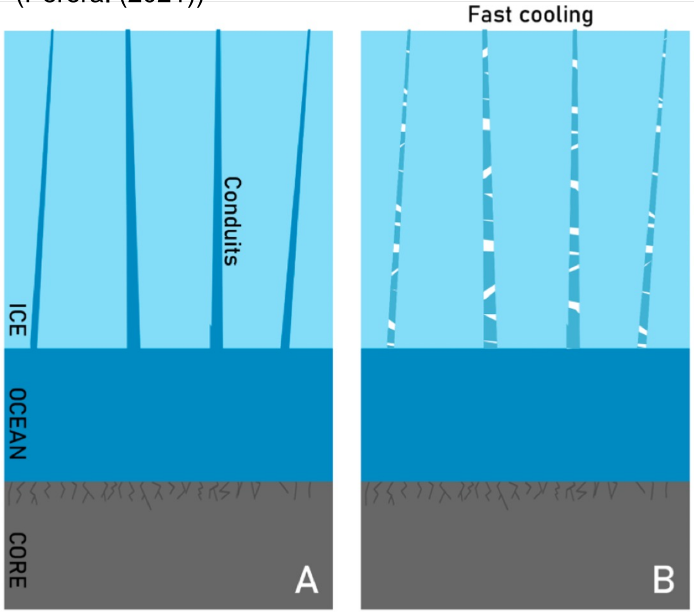


Figure 4.24: **Schematic of potential fast freezing systems on Enceladus** A. Initial formation of plume and non-plume water filled conduits. B. Freezing of these conduits with salt rich ice. (Not to scale)

Summary & Conclusion

- **Existing models applied for different objects**
  - Models for Ceres work for Ryugu, Enceladus
- **Model improvement**
  - Update with new data
  - Simplified models can be more complex
  - Comparison with other models / methods
- **Outlooks - research is ongoing**

Thank you for your attention!

Questions?

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