Ice sintering timescales at the surface of Europa and implications for surface properties

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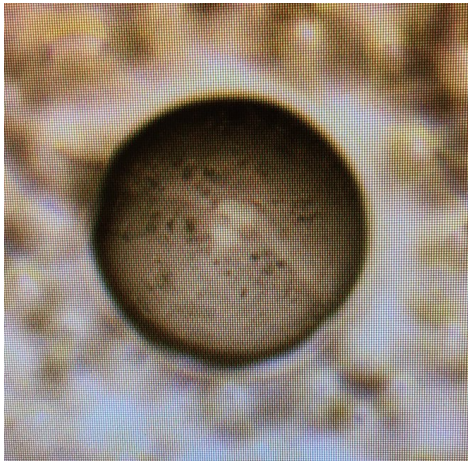
What is ice sintering?

Ice sintering is a form of frost metamorphism whereby contacting grains diffuse together over time.



→ microstructural evolution of snow

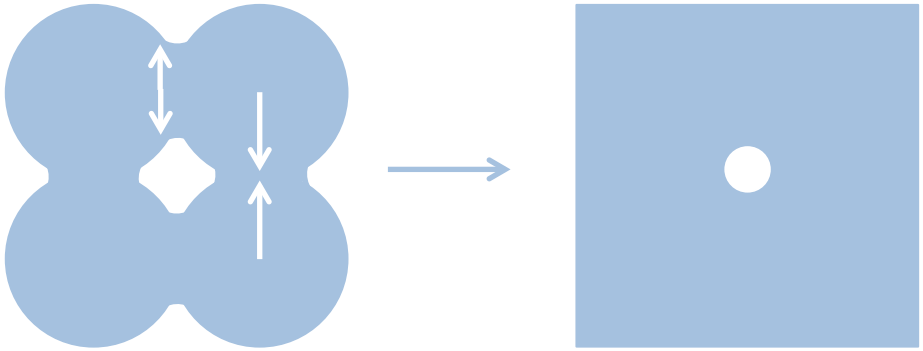
- porosity
- thermal conductivity
- strength
- frictional properties

How does this affect interpretation of remote sensing data?
How does this affect spacecraft or sample system design?
How does sintering interact with other surface processes?

(This process happens in different regimes, focus here is on pressure-less sintering.)

Sintering Model

Ice sintering is a form of frost metamorphism whereby contacting grains diffuse together over time.



STAGE 1: Neck growth and densification occur. Grains are distinguishable.

STAGE 2: Isolated, spherical pores disappear during final densification.
→*This part of the model does not behave well for ice.*

Sintering Model

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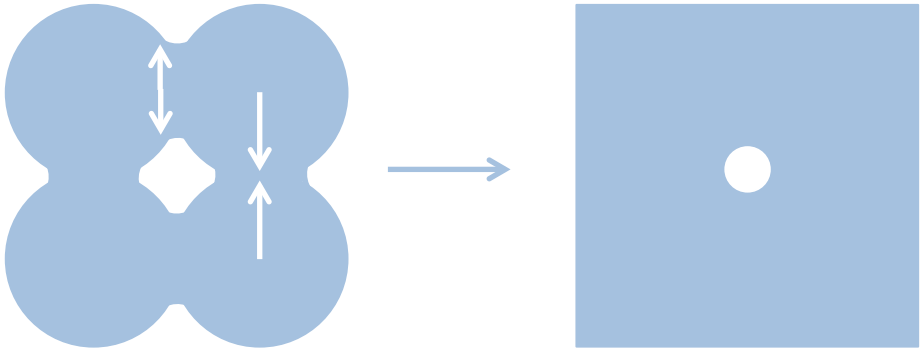
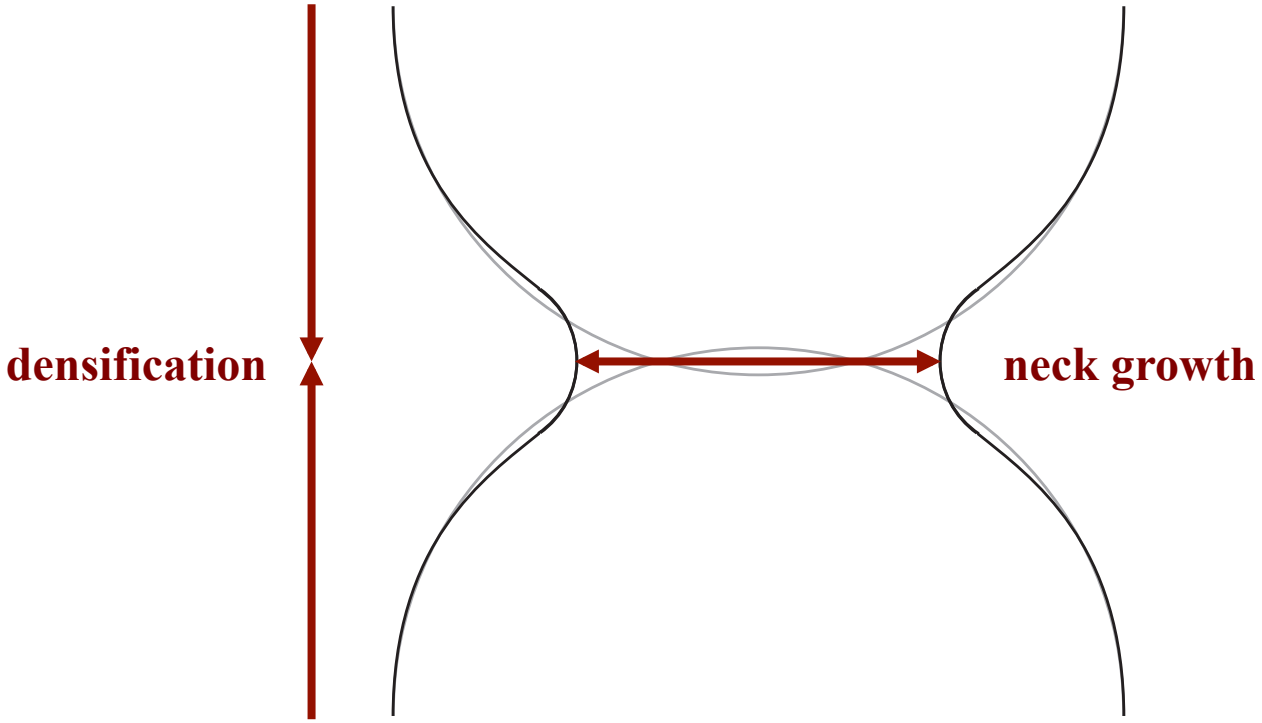


STAGE 1: Neck growth and densification occur. Grains are distinguishable.

Most of the modification occurs in Stage 1. Ends when the neck is ~60% of grain diameter, pores begin to close off and are approaching sort of spherical.

Sintering Model

Modification is driven by six surface, volume, and grain-boundary diffusion mechanisms that contribute to neck (contact) growth and densification (decrease in interparticle distance).



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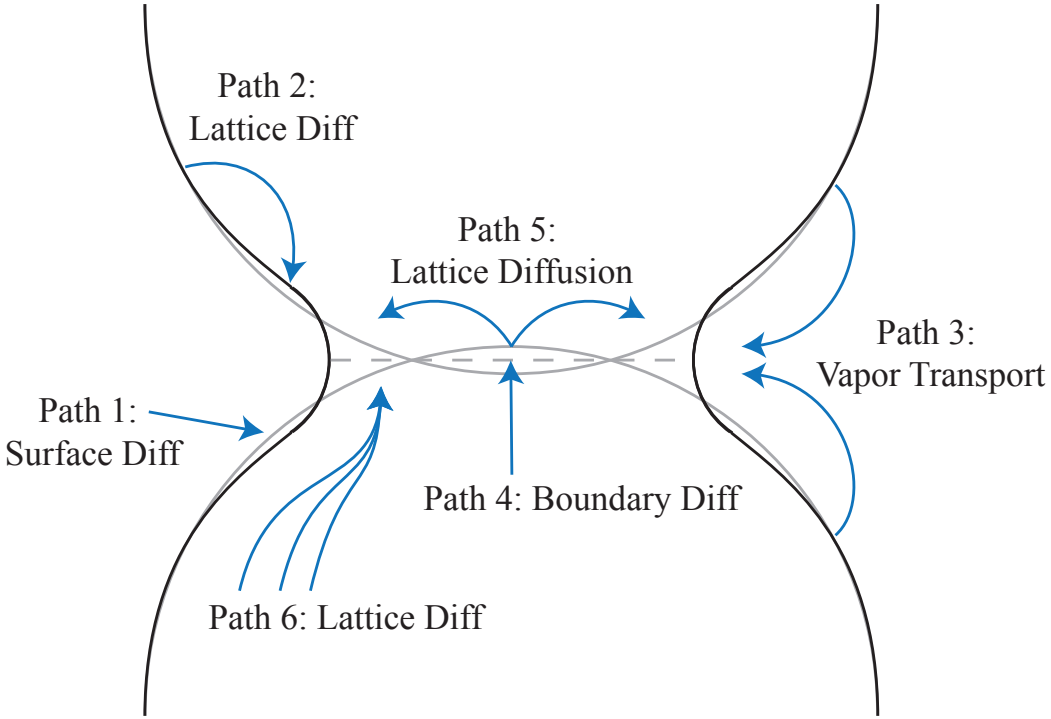


Because I know you're going to ask…

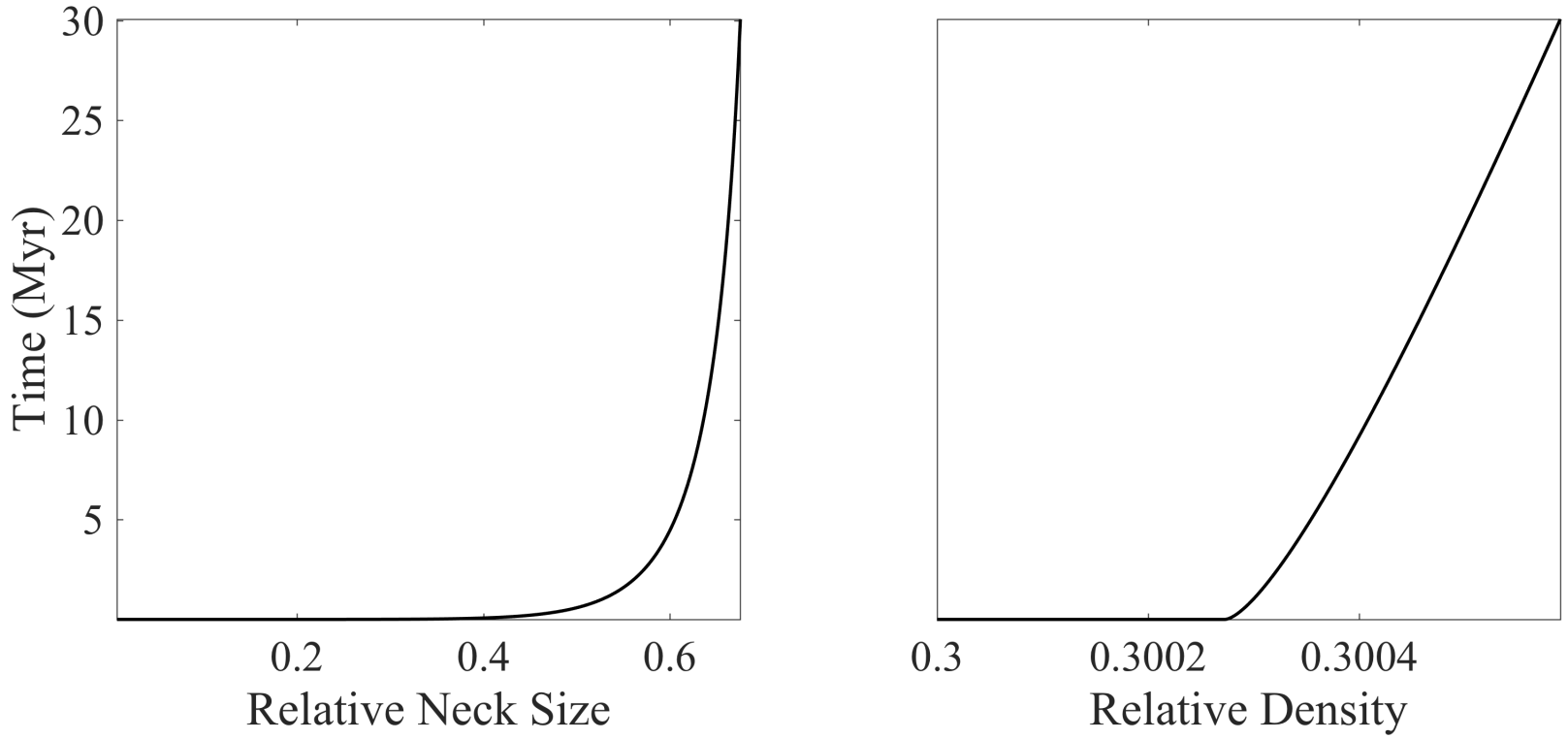
There are several factors not yet included in the model:

- Salts
- Radiation
- Crystallization of amorphous ice
- Diurnal/Seasonal thermal cycles
- Overburden pressure
- Interaction with other surface processes

These results are likely upper limits on timescales, as most of the above will enhance sintering rates. The first step is to robustly validate the model experimentally (working on this now) before adding more complications.

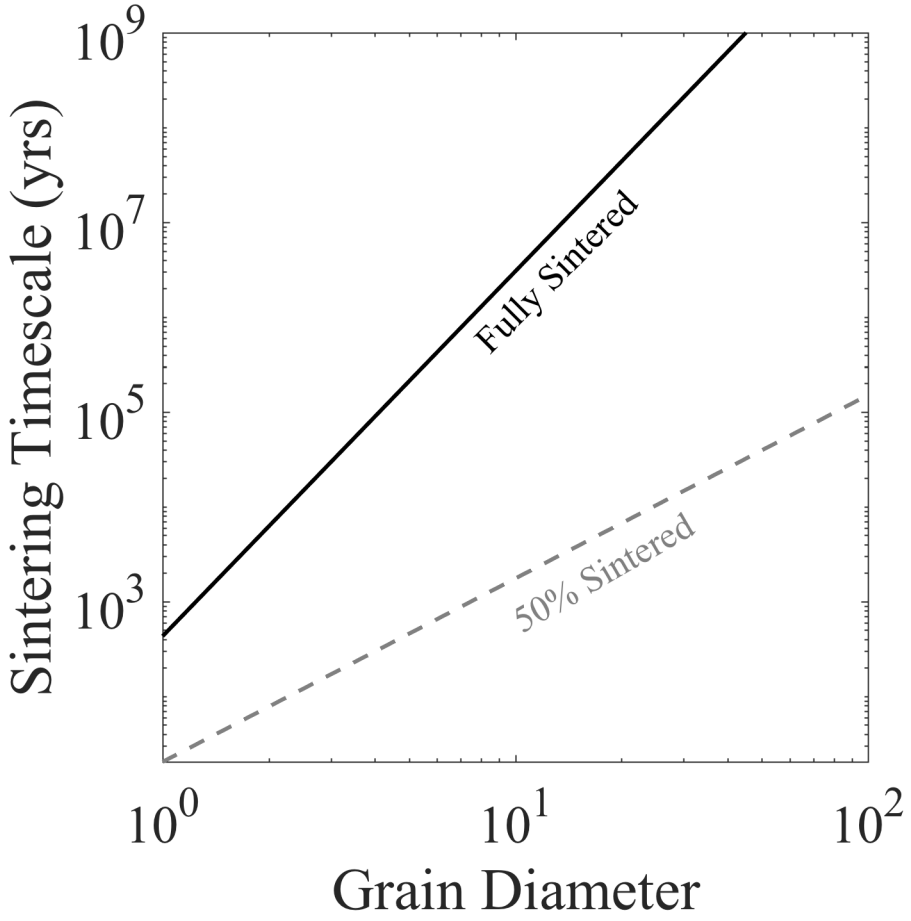
Sintering on Europa

For 30 μm grains at 130 K with the density of fresh snow:



Significant neck growth occurs over Europa's surface age, but no substantial densification, suggesting that **Europa's surface regolith may form a porous crust.** This crust is fairly strong, with a crushing strength on the order of 100s of kPa.

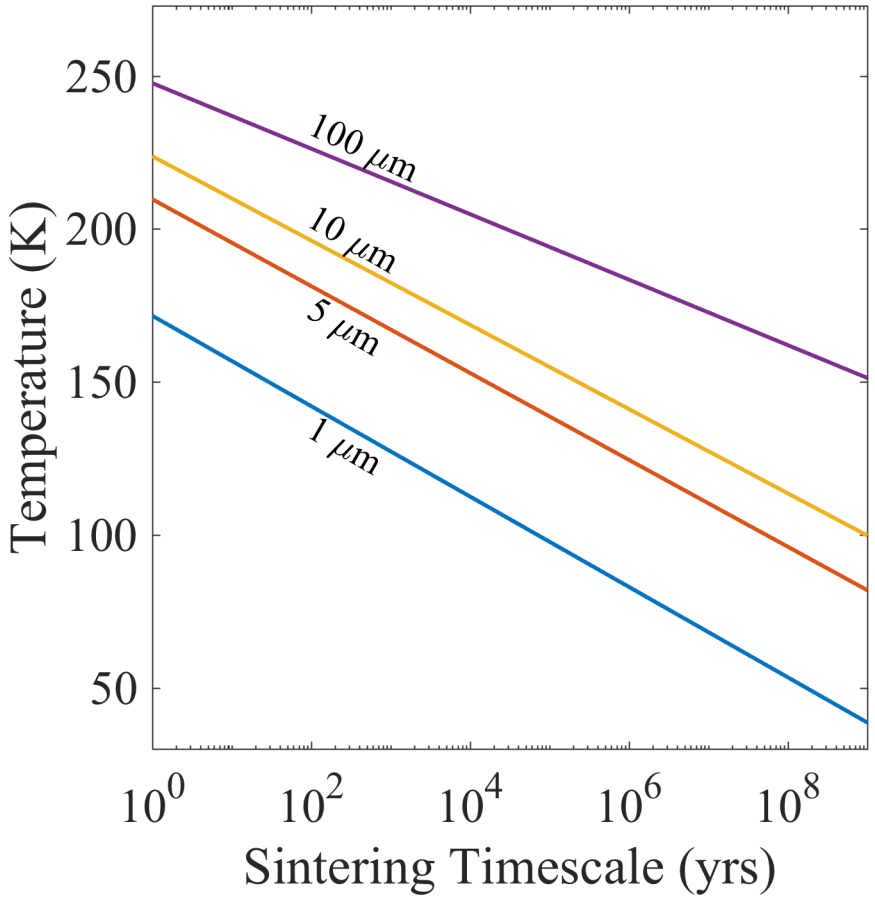
Sintering on Europa



Sintering timescales are extremely sensitive to grain size. Large grains will only be partially sintered over Europa's surface age.

30 μm – 10^8 / 10^4 years (full / 50%)

Sintering on Ocean Worlds



Conclusions:

Sintering timescales increase exponentially with grain size and temperature.

"Snow" on icy satellites does sinter, but does not become more dense.

To discuss this week–

- How will this process effect a drilling system?
- What do we need to know? (e.g., surface strength, porosity, thermal conductivity)
- Am I missing other factors that are important in this context? I can address any sintering questions/challenges over time if we identify what they are.