Water Transport and the Evolution of CM Parent Bodies

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Introduction

- Meteorites have amino acids and hydrated minerals which constrain the peak temperature ranges they have experienced
  - CMs in particular have a narrow range (273-325K)
  - Bulk fluid motion during hydration constrained to small scales (<mm)
- Some asteroids are known to have hydrated minerals on their surfaces
- It is presumed these two facts may be related

- Problem:
  - hydration only occurs (significantly) with liquid water
  - melting water only occurs early on in nebula (1-10 Myrs ANC)
  - in nebula asteroid surface temperature very cold (~150K)

- Can indigenous alteration produce CMs and/or surface hydration?
  - Issue of timescales: $t_{diffuse} < t_{heat} < t_{conduct} < t_{vap}$

  (last condition not true, so surface hydration probably not)

Fundamentally a 1D radial thermal diffusivity problem with heat source Q due to decays and reactions and a heat capacity modified to include latent heat of H_2O:

$$\frac{\partial T}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \kappa \frac{\partial T}{\partial r}\right) - \left(\frac{(\rho c_p)_l}{(\rho c_p)_{ave}} v_l + \frac{(\rho c_p)_g}{(\rho c_p)_{ave}} v_g\right)\frac{\partial T}{\partial x} + \frac{Q}{c_p}$$

where the liquid and gas velocity are found via two-phase Darcy flow:

$$v = \frac{-ks}{\mu}\left(\frac{\partial P}{\partial r} - \rho g\right)$$

Here k is the permeability (modified by a appropriate relative permeability), P is the relevant pressure, mu is the viscosity, s is the volume fraction of liquid or gas in the voids (porosity, ε) given by f_{gas}/ε or f_{liq}/ε, rho is the gas or liquid density and g is the local acceleration due to gravity.

Flow is mostly driven by capillary pressure gradients:

$$P_{liq} = P_{gas} - P_{cap} = \frac{R_g T M_{gas,j} f_{gas}}{dV_j} - \sigma(T) J(s) \sqrt{\varepsilon / k}$$

where σ is liquid water surface tension, J is an empirical surface tension correction function, $M_{gas,j}$ is the mass of water vapor and dV_j is the total volume of the jth cell

Permeability is given by:

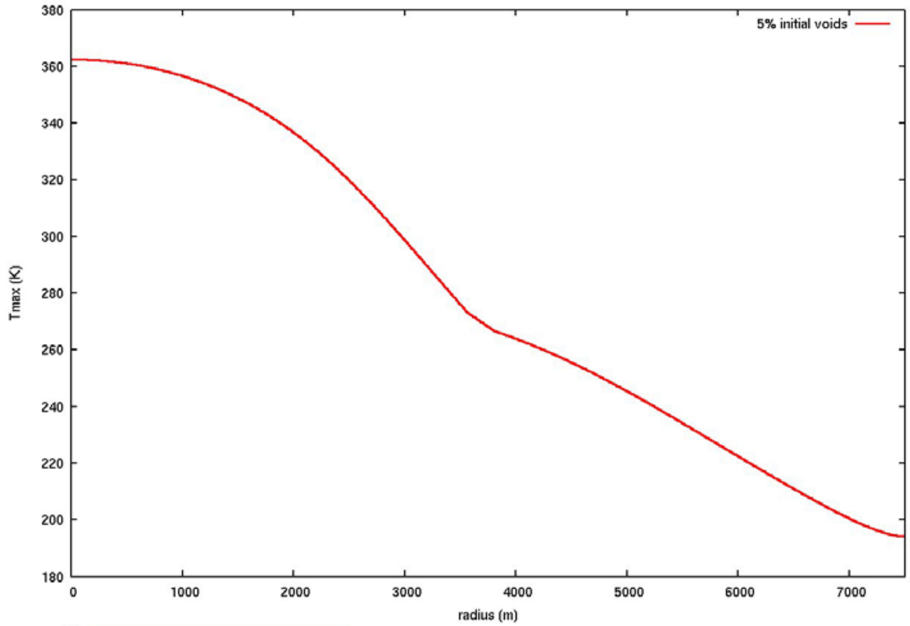
$$k = \frac{\varepsilon {r_H}^2}{h_{ck}} = \frac{\varepsilon^3 d^2}{36 h_{ck} (1-\varepsilon)^2}$$

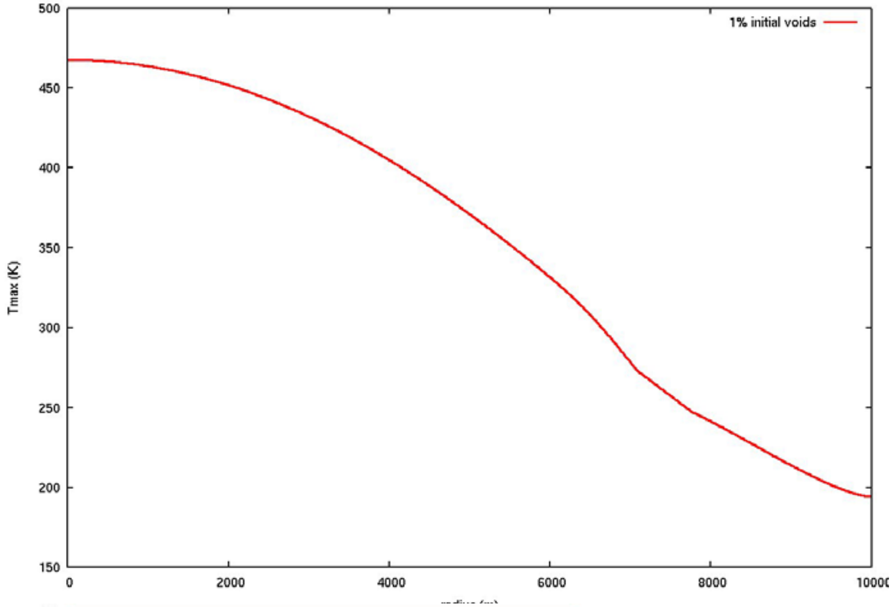
Where h_{ck} is a geometry factor, r_h is the mean particle hydraulic radius, and d is a mean pore diameter

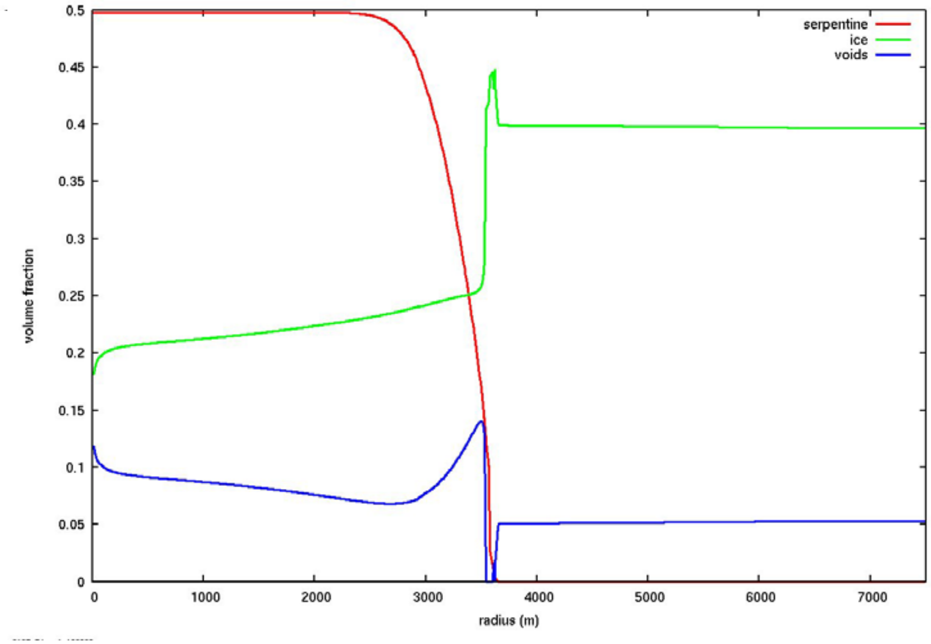
Constraints: r_h~0.002-0.02 μm and d~20-200 nm and h_{ck}~5,

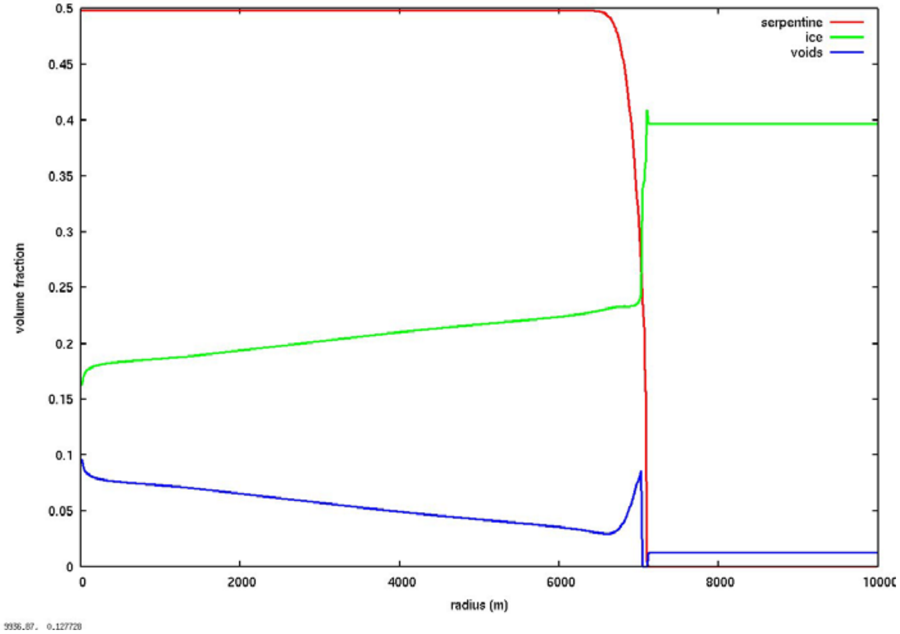
→ k ~10^{-19} to 10^{-17} m^2 (relative permeability reduces this)

Sample of Results









Takeaways

- Given nebula boundary condition and no pre-accretion hydration the PB:
  1) Cannot form less than 0.9 Myr ANC (or no hydration)
  2) Cannot be less than 3km in diameter (or no hydration)
  3) If forms at 10 Myr ANC, needs to be > ~180 km in diameter
  4) Thus, minimum diameter is roughly 20t-13 km (t in Myrs ANC)
  5) Weak dependence on composition
  6) Initial Al (or e.g. Fe) just shifts timescales slightly
  7) Weak dependence on permeability
  8) Warmer nebula (~200K) moves rind out and makes thicker

- Given peak temp seen by CMs is < 50°C and CMs are ~50% serpentine:
  1) Thin (few kms max) slice of larger (>~12 km diam) PB produces CMs
  2) Central <1/6 volume of smaller (<~12 km diam) PBs produces CMs
  3) Pre-accretion hydration just makes '12 km' threshold slightly bigger
  4) fills voids above reaction zone with ice (no venting or fracturing)
  5) No CMs near surface of PB

Takeaways (cont.)

- Liquid water
  1) Persists for ~1Myr (20 km diam)
  2) Capillary flow (using canonical k, rH, pores) peaks at ~few m/Myr
  3) Transport scale of ~m, 1000x too large (not all during reactions)
  4) Volume ratio transported ~1 (~0.1 for small k, rH) during reactions
  5) More movement results in thicker CM ‘rind’ if not limiting reagent
  6) Sloshing occurs after reactions
  7) Low permeability leads to no convection
  8) 2nd reaction wave ~always fills voids above reaction zone with ice
  9) Reduction in reaction rate 10x reduces peak T but moves rind inward

No combination gets:

- A CM zone within ~20% of the surface by radius
  - Larger PBs closer to the surface
- A CM zone more than ~25% thick by radius
  - Only small PBs get even this much and only in the center

IMPACTS…..