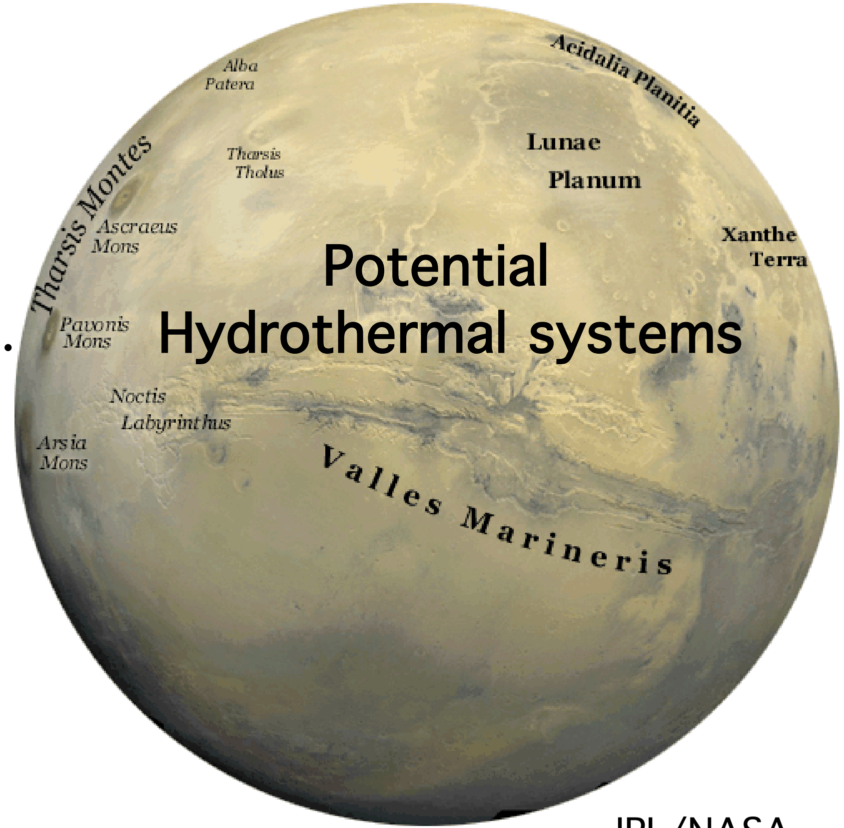
Yoshiko Ogawa

Research interests:

- Water-related features on other planets.
- Physical process of their formation.
- Their (sub)surface environment.

Methods:

- Numerical simulation. Data analysis.



JPL/NASA

I would appreciate it if you could speak slowly when you could give me some comments or questions.

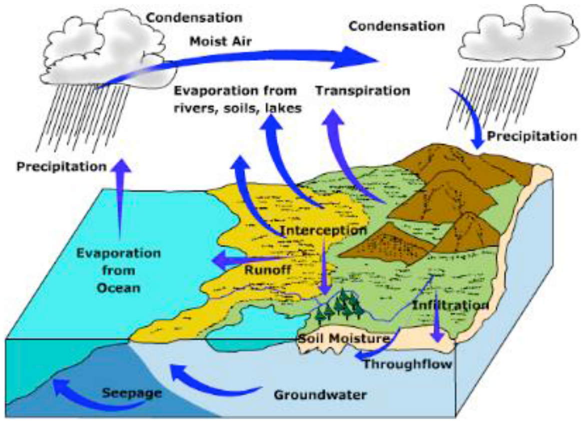
An Approach to Hydrology on Mars.

Interaction of magma and ground ice/water

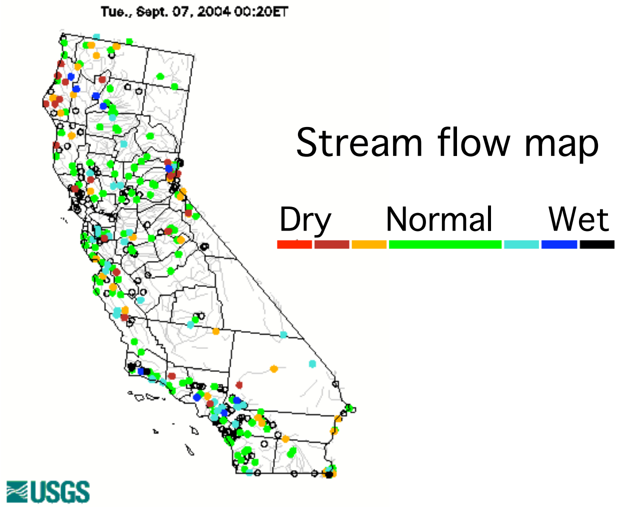
Generation / migration of liquid water on Mars,
associated with formation of flow features.

1. Water environment on Mars
2. Problems about water flows on Mars
3. Our model and scenario of forming chaos with outflow channel
4. Magma-hydrothermal systems on Mars
5. Observation

Hydrology on the Earth - Studies about current water with various kinds of observational data.

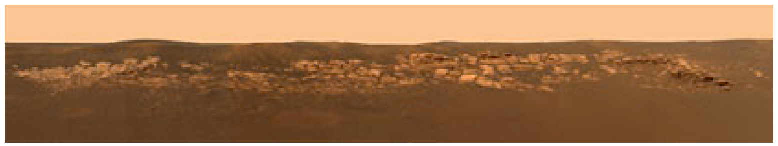


From Redrawb after Gabler et al., 1999



Hydrology on Mars? - Studies about water in the past and present with limited data in quantity and quality.

 # No liquid water exists now on the surface.



MER, Panorama NASA/JPL

Water Environment on Mars (in the past and present): Observational facts and their interpretation

cf.) Polar caps, Vapor

- 1. Erosion and deposition (landform) <Image data>
  → Abundant water near the surface in the past
  (Through its history. Latest:Gully<several Myr)
  Ex.) flow ('fluvial') features --direct&clear evidence
- 2. Water(H) content in soil <GRS obs./Neutron detection>
  → Current water under the ground
- 3. Salt[*1] deposition <In-situ compositional analysis>
  → Standing water at their formation times
- 4. Particular Minerals[*2] on the surface < IR spectroscopic obs.>
  → Hydrothermal environment at their formation times

[*1] sulfate etc. [*2] gray hematite, magnetite

Water is not stable now.

⬍

Past Water indicated by observations

abundant, on/near the surface

What kind of condition existed at that time ?

☝ *One of the most enigmatic puzzles on Mars*
A big theme of martian hydrology

How were the fluvial features formed?

■ Information from Image data

Flow Features on Mars: 3 types

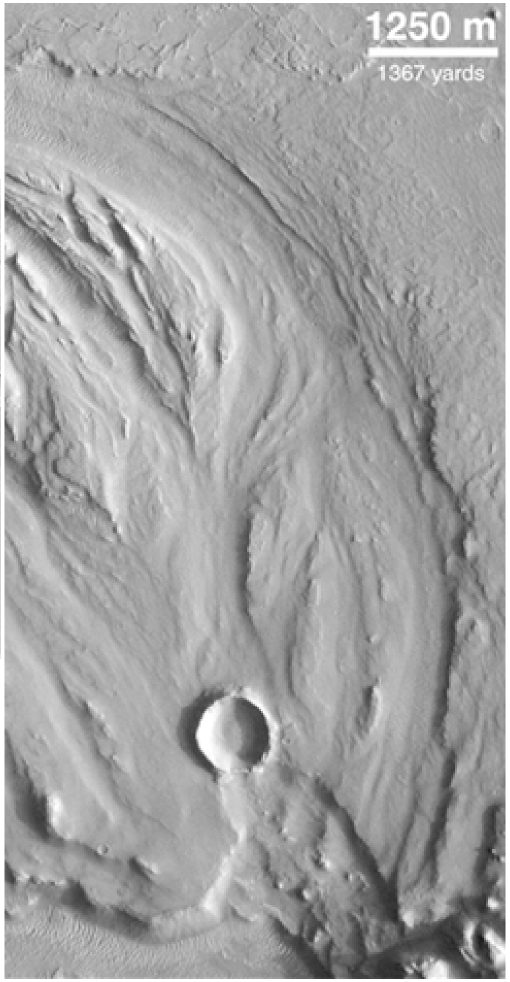
outflow channel > **valley network** >> **gully**

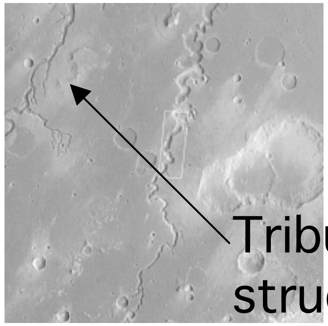
outflow channel: L~$10^{2\text{-}3}$km, W~$10^{1\text{-}2}$km, D~$10^{1\text{-}3}$m

valley network: L~$10^{0\text{-}3}$km, W~$10^{0\text{-}1}$km, D~10^{2}m

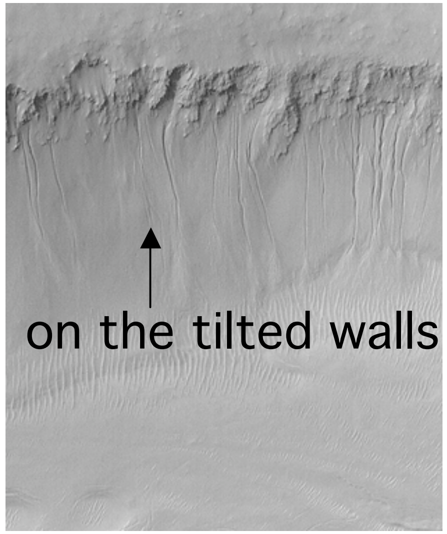
gully: L~$10^{2\text{-}3}$m, W~$10^{1\text{-}2}$m, D~$10^{0\text{-}1}$m

Stream-lined hills

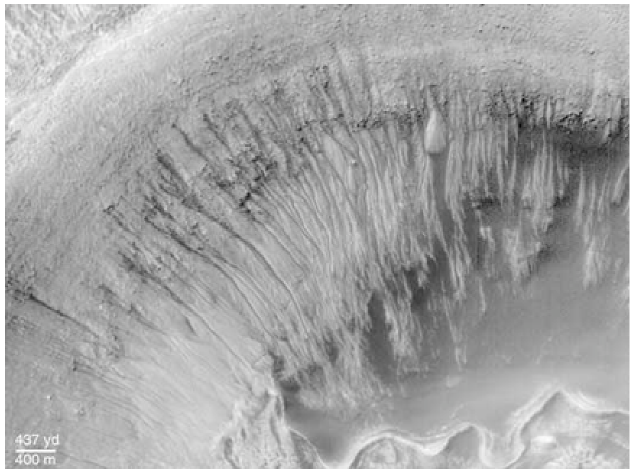




Tributary structure



on the tilted walls



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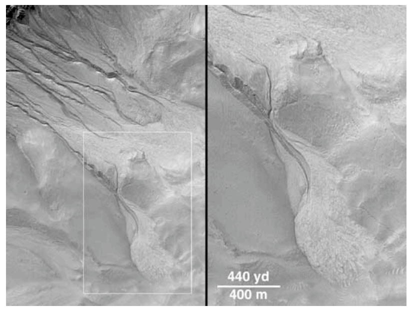
What is known about their formation?

Information ● Flow characteristics from Morphological analysis
flow rate (flux), total volume, duration, drainage density
● Age from crater chronology
● Spatial distribution:

How did water flow?

Consensus: Erosion system
○ Outflow channel - surface flow of water
○ Valley network - groundwater flow (?)
○ Gully (-*controversial**)



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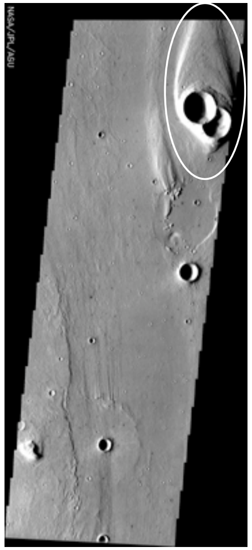
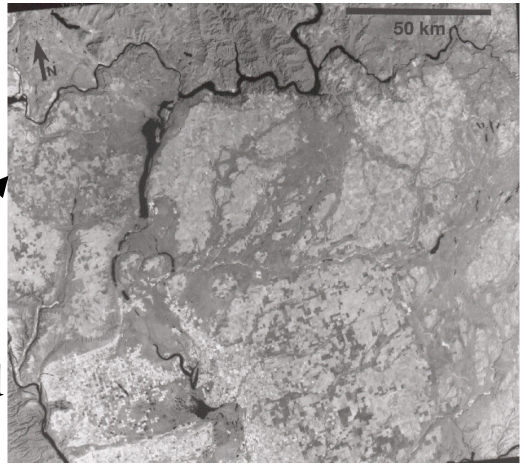
* Malin and Edgett, 2000; Hartmann et al., 2003; Costard et al., 2002; Musselwhite et al., 2001; Treiman, 2003 etc.

Outflow channels: ⇨ Huge flood event
- Groundwater discharge
- Catastrophic: Flux~$10^{7\text{-}9}$ m^3/s
- Massive water: V_{total}~$10^{3\text{-}5}$ km^3
- Short lived: ~wks-months?





East area of the Washington St. Channeled Scabland (Flux~10^7 m^3/s)

Ares Vallis (20°N, 32°W)

NASA/JPL

Problem: The origin of huge amount of water. Where did water come?

⇨ **Melting process of the Permafrost layer induced by magmatic intrusion**

Structure of headwater regions of OC ➡⇨ Chaos

Our target:igneous melting of permafrost layer

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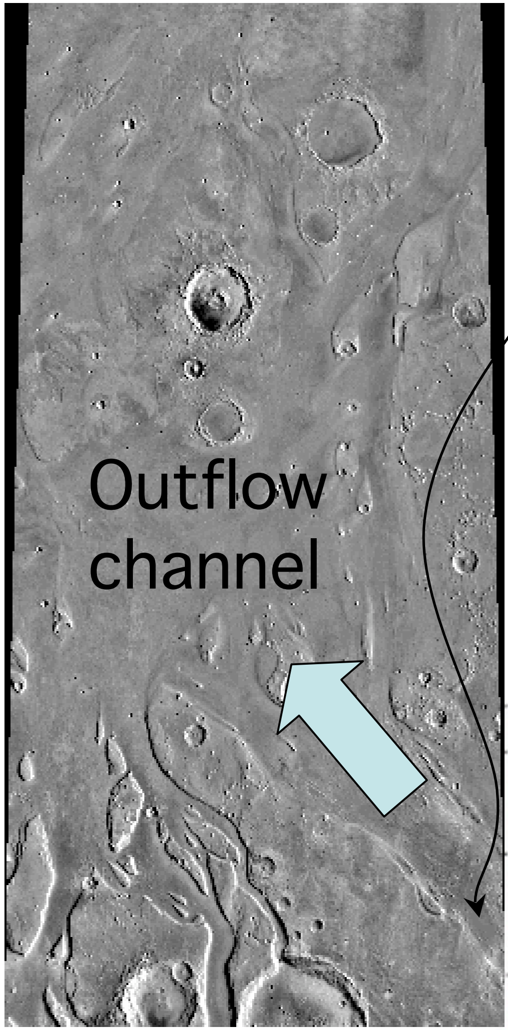
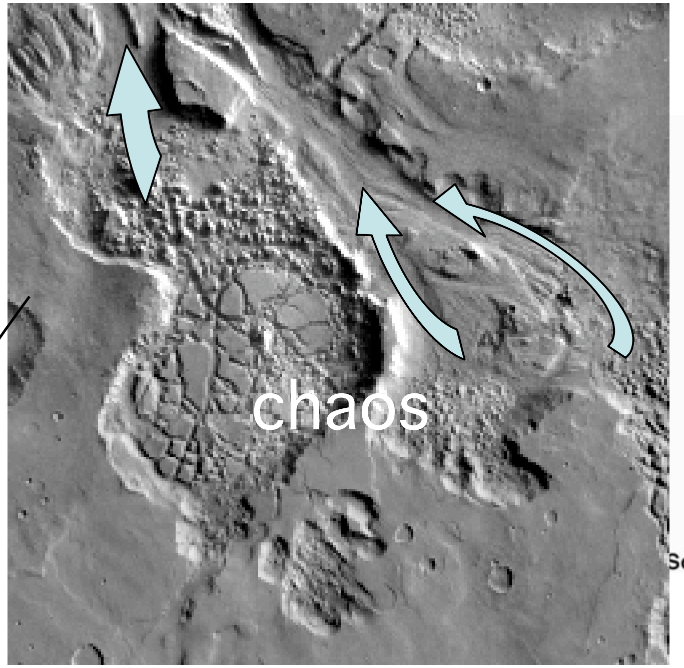
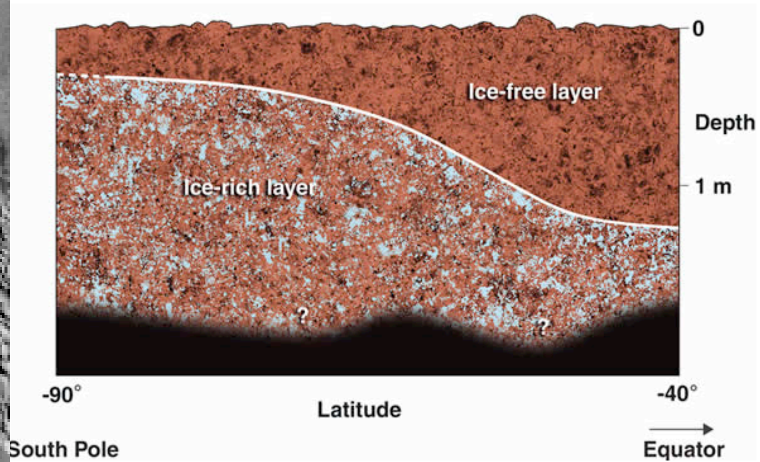


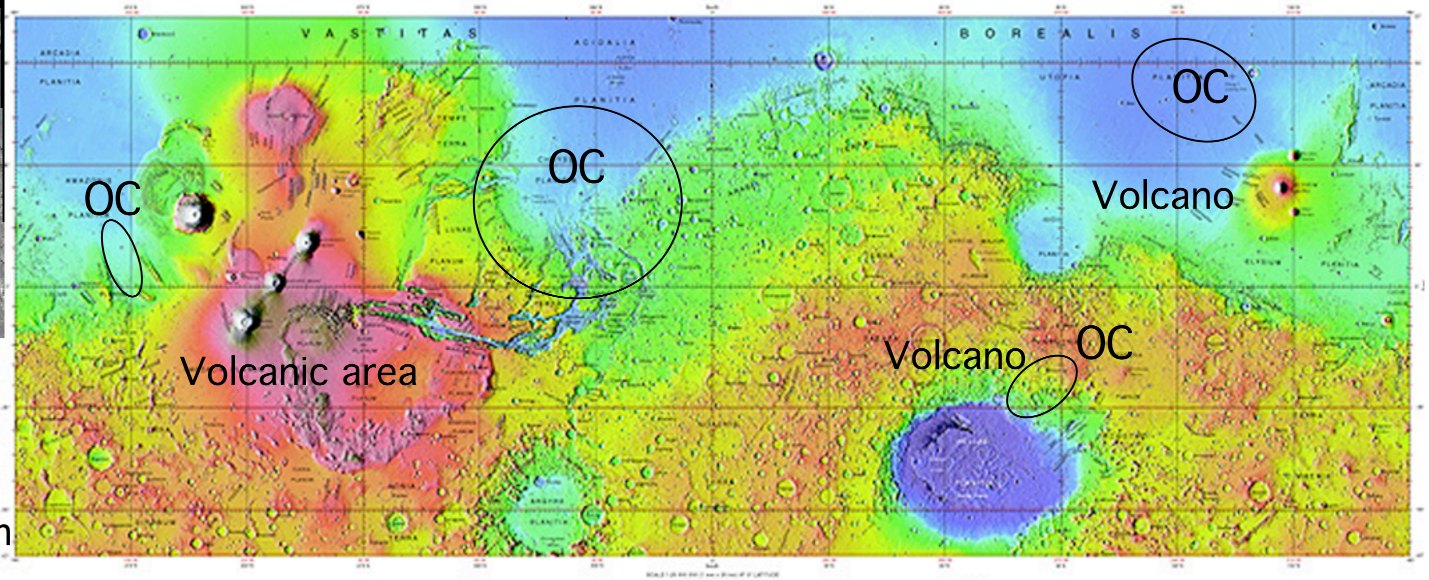


Age: Hesperian

Subsurface structure



Distribution of OC



NASA MGS/MOLA team

Numerical simulation of igneous melting of the permafrost layer on Mars

The point:

Thermal convection in the melted zone

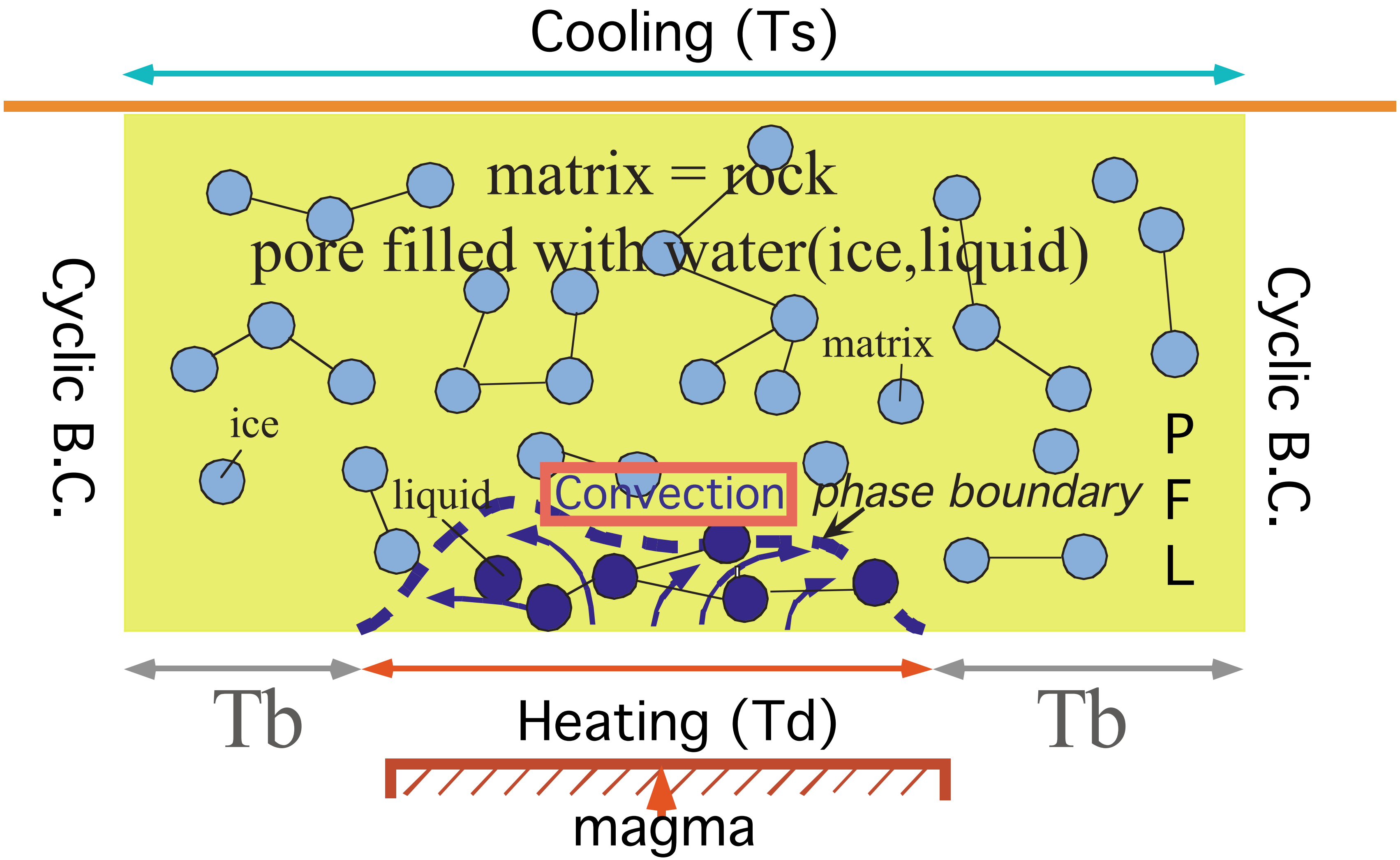
Changes the system of heat transfer
---> controlling the shape of the melted zone,
timescale of melting, Water supply system

⇓ important effects/implication

Formation of surface features

Modeling of the Permafrost layer ⇒ porous media

Phase-change with convection within the porous media



Governing eq.(dimensionless)

Momentum e.q.

$$\nabla P = -\kappa \cdot \mathbf{U} + Ra \cdot \theta\, \mathbf{e}_\eta$$

Energy e.q.

$$\Omega \cdot \partial \theta / \partial \tau + \mathbf{U} \cdot \nabla \theta = \nabla \cdot (\Lambda \nabla \theta)$$

$$\underline{- 1 / Ste \cdot \partial \delta / \partial \tau}$$

Evaluation of Phase Change
(Enthalpy Method)

P : Pressure, $\mathbf{U}$: Velocity, θ :Temperature

τ : Time, $\mathbf{e}_\eta$: Vertical Unit Vector

$\delta = \varepsilon\gamma$: liquid fraction

γ : liquid fraction in fluid

g: gravity [m/s^2]

K: permeability [m^2]

α: thermal diffusivity [m^2/s]

k: thermal conductivity [W/(m K)]

β: coefficient of thermal expansion ratio [1/K]

$T_H - T_C$: characteristic temperature difference [K]

c: specific heat [J/(kg K)]

Δh: latent heat of fusion [J/kg]

ν: kinematic viscosity [m^2/s]

ε: porosity

$$k_{eff} = f\,(k_m, k_f)$$

$$k_{eff} + \varepsilon\,((k_m - k_f) / kf^{1/3})k_{eff}^{1/3} - k_m = 0$$

$$k_f = \gamma k_l + (1-\gamma)k_s$$

Subscript note---l: liquid, s: solid, f: fluid=l+s, m:porous matrix=soil (rock)

$$\overline{\rho c} = \varepsilon\rho_f(\gamma c_l + (1-\gamma)c_s)) + (1-\varepsilon)\rho_m c_m$$

$$K(\delta) = d_m{}^2\delta^3 / 175(1-\delta)^2$$

Dimensionless Parameters

$Ra = g\beta_l(T_H - T_C)KH/\alpha_l\nu_l$: Rayleigh num.

$Ste = c_l(T_H - T_C)/\Delta h$: Stefan num.

$\kappa = K\varepsilon/K(\delta)$: permeability ratio

$\Omega = (\rho\overline{c})/(\rho_l c_l)$: thermal capacitance ratio

$\Lambda = K_{eff}/K_l$: thermal conductivity ratio

Ra & Ste

in relation to probable Martian conditions

< Intrusive magma >

T :$>3\times10^{2}$-1×10^{3}[K]
Size: (H $\times$1/2-2)

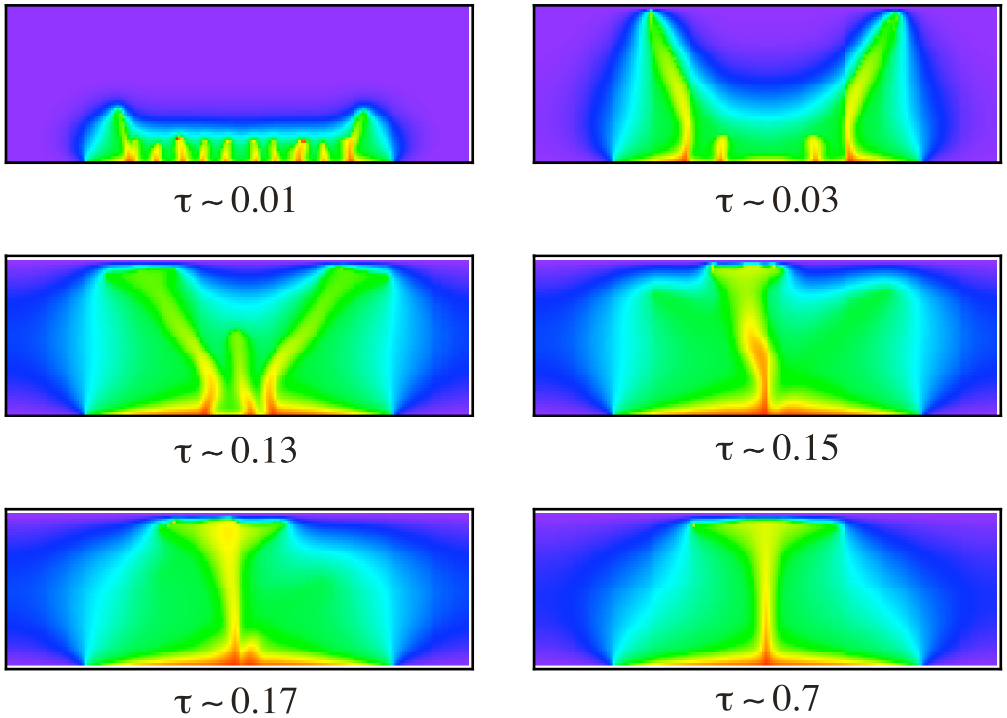
< Permafrost layer >

Thickness(H): $\sim10^{2\text{-}4}$ [m]
Surface T: $\sim$200[K]
Permeability: $10^{-14\,\text{-}\,-11}$[m^2]

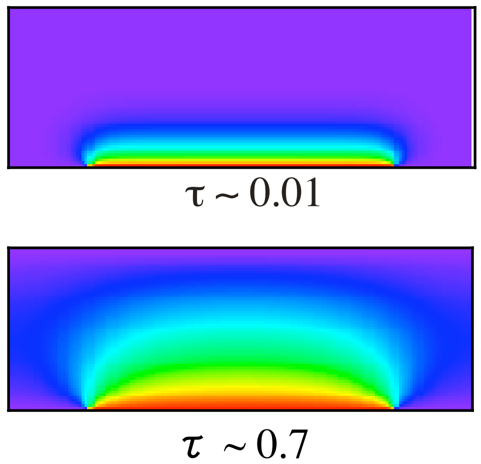
Ra : $>10^{2}$- $10^{3\text{-}4}$
Ste : $\sim10^{0}$

Development of T field (melted zone) with time

Ra=700 (ε=0.2, W=2H, Ste=1.87)



Conduction



[Ogawa et al., 2003]

A plume with a vertical column

Focusing occurred in a earlier stage

Progress of T field (melted zone) & Comparison between each of the cases

(ε=0.2, W=2H, Ste=1.87)

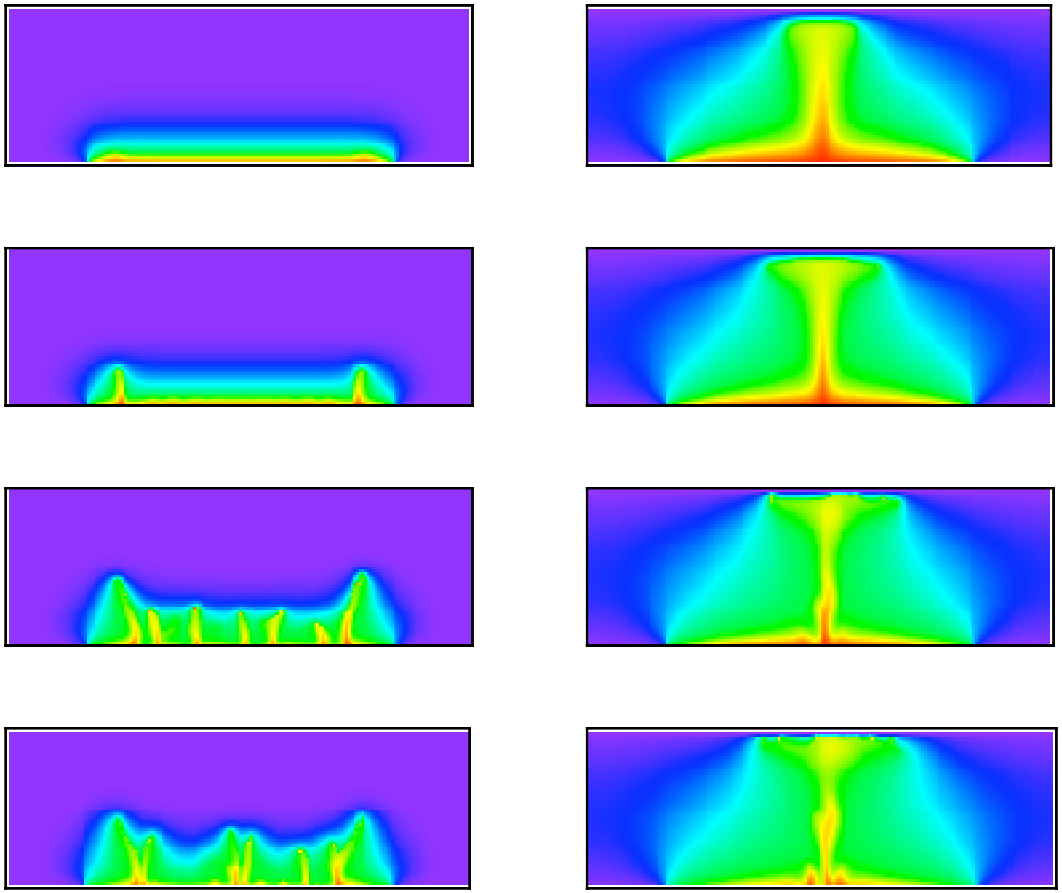
τ ~ 0.01 → τ ~ 0.7 (~equilibrium)

Ra = 150

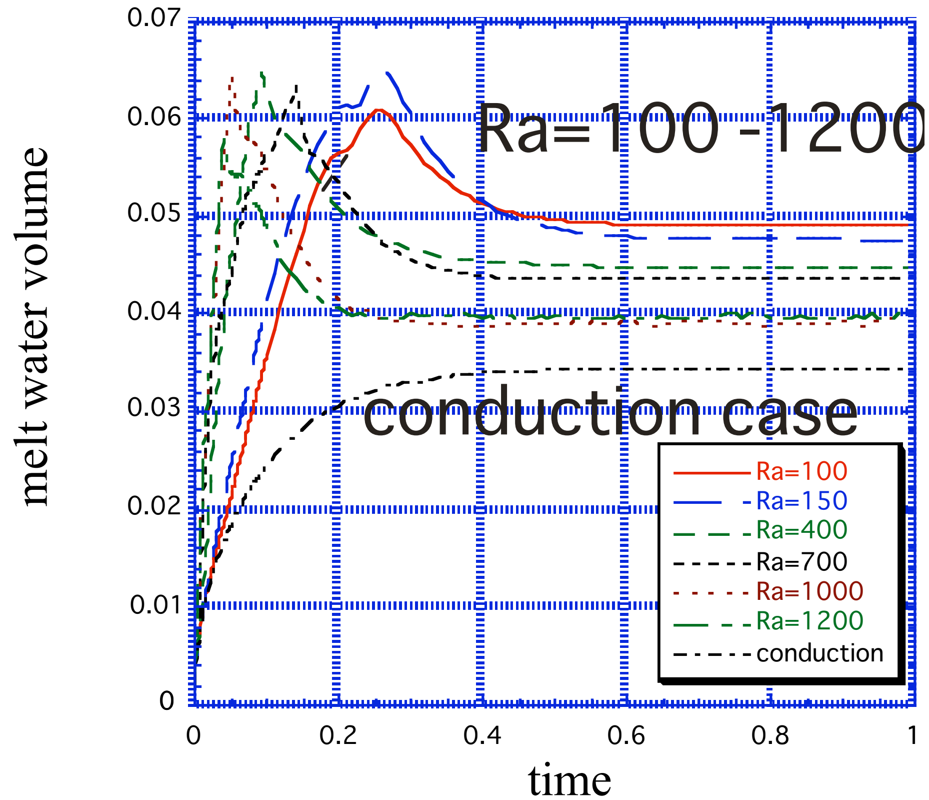
Ra = 400

Ra = 1000

Ra = 1200



Volume of meltwater



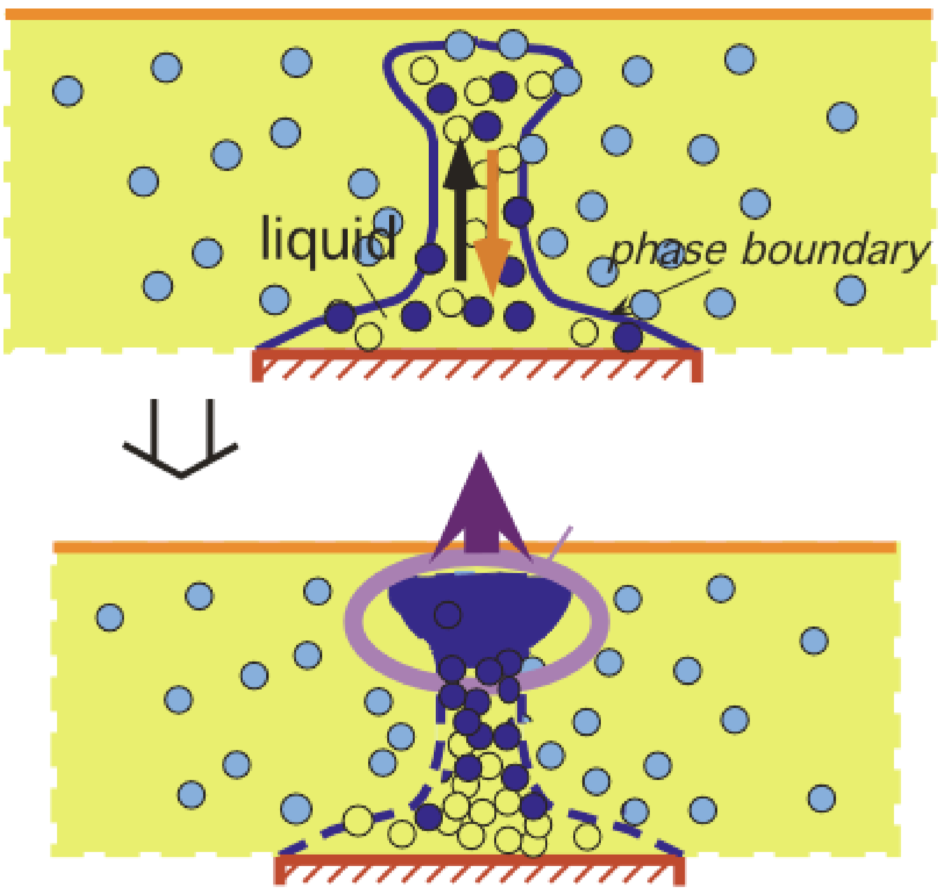
Total mass
>10 $^{9\text{-}10}$ m^3
For H～2km
(↑potential discharge)

Sufficient to match the inferred flux of OC as 10 $^{6,7\text{-}9}$m^3/s from morphology

More active convection
---> enhance heat transfer toward the stable state
in a shorter time.

Implication for observed surface features

Compaction & segregation within the melted zone



compaction time: T_C

$$T_C = \frac{L_C}{V_D}$$

the effective bulk viscosity of the matrix (solid)

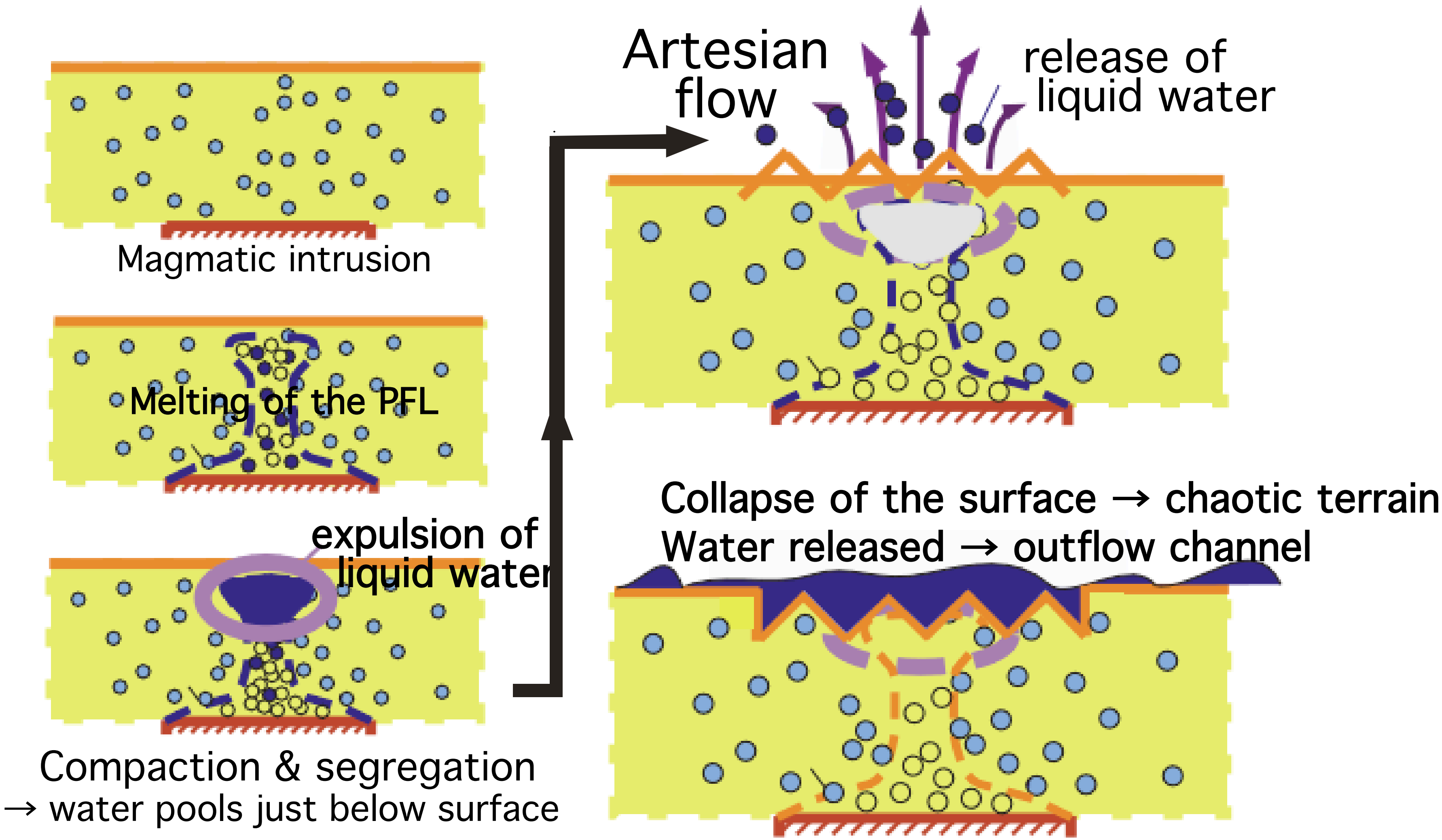
$$= \frac{1}{\Delta\rho g}\left(\eta_{\phi 0}\eta_f / K_{\phi 0}\psi_0\right)^{1/2}$$

$$\sim 10^{11} - 10^{13}\ [s]$$

$$\sim t_{melting} \sim 10^{12\text{-}13} [s] \sim 1\,[Myr]$$

$$<< t_{cooling}$$

A scenario of forming chaos with release of water

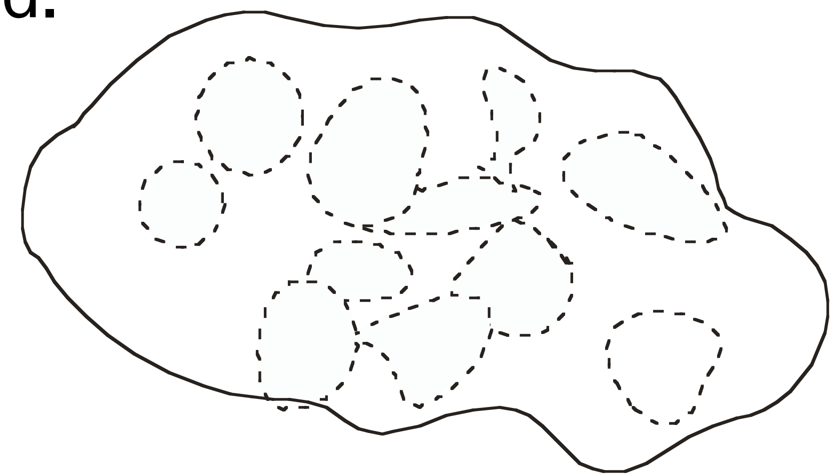


Outflow channels ⇨ Huge flood event

Our numerical results and scenario shows:

- Catastrophic water discharge, forming chaos.
- Available water amounts to $\sim 10^{9\text{-}10} m^3$ or more.
  (assuming $H \sim 2km$ permafrost layer)

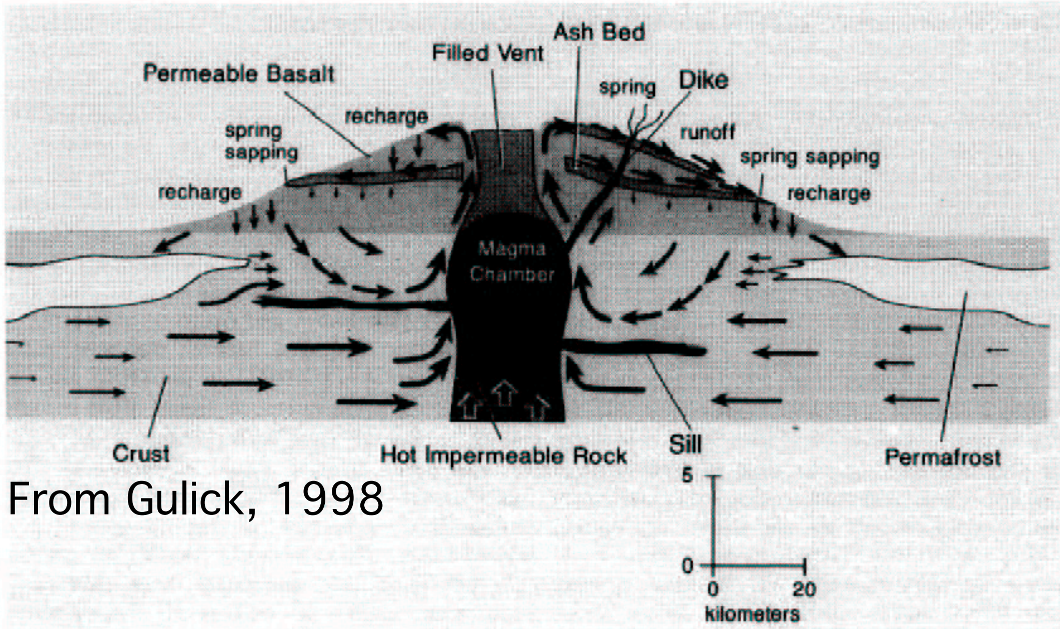
⇨● Flux $\sim 10^{7\text{-}9} m^3/s$ is affordable.
⇨● $V_{total} \sim 10^{3\text{-}5} km^3$ seems a trouble,
but nesting of chaos suggests several such events.
⇨● Duration is not restricted.



Magma-hydrothermal systems on Mars

Precipitation is less important on Mars.

Interaction between magma and aquifer (host rock)
⇨ Formation of Valley networks, Water circulation



From Gulick, 1998

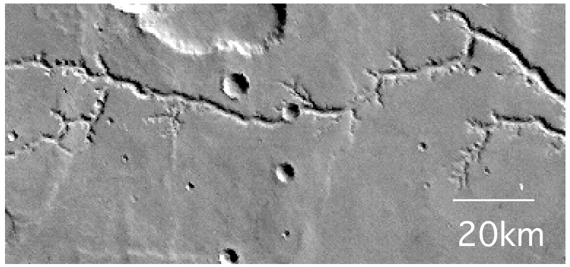
Estimate of water discharge from aquifer

Gulick, 1998

Harrison and Grimm, 2002

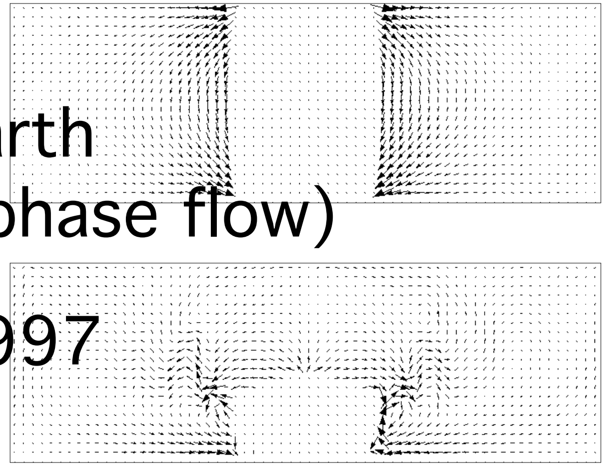
Formation of Valley networks --- Mainly ground water sapping

- Tributary structure
- Low drainage: 10^{-2}km/km^{2} (density)
- Long lived: >10^{5}yr?Gradual erosion



Application of Earth hydrothermal system to Mars

Use established codes,
originally developed for the Earth
hydrothermal systems (3D, 2phase flow)



Ex.) Hyba and Ingebristen, 1997

Some difference between Mars and the Earth:

- Gravity
- Scale of magmatic intrusion
- State of aquifer (permeability distribution, thermal condition)
- Existence of permafrost layer

Not well incorporated

Observation

Trace of subsurface water-rock interaction

Detection and their mapping
of ore deposits (hydrothermal, epithermal)
Expected location
-At head regions of flow features:
chaos, chasma
Morphology of chaos

⬆

Mid-IR spectroscopic observation
High resolution image

Enthalpy method

[Voller et al., 1990 etc.]

～conventional treatment of phase-change～

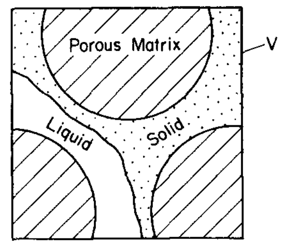
Latent heat
→ incorporated into the enthalpy
(in the phase changing area)

called ‘pseudo enthalpy’

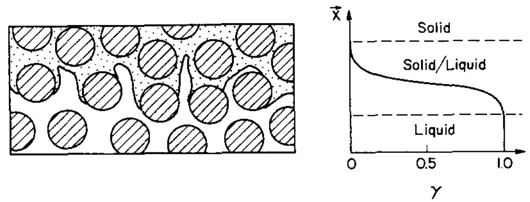
$$\rho c^{*} = \rho c + \varepsilon \rho_l \Delta h / 2\Delta\theta$$

$$\delta = \begin{cases} \varepsilon & : \theta \geq \theta m + \Delta\theta \\ \varepsilon(\theta - \theta m + \Delta\theta)/2\Delta\theta & : \theta m - \Delta\theta \leq \theta \leq \theta m + \Delta\theta \\ 0 & : \theta \leq \theta m - \Delta\theta \end{cases}$$

δ: liquid fraction, ε: porosity, θm: melting temperature,
Δh: latent heat of fusion



(a)



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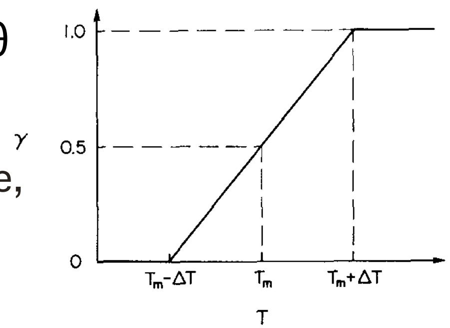

(c)

from Beckermann&Viskanta, 1988