2019.10.22
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Let's learn "thermodynamics of frozen soil"

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Background

- Frost heaving
  - Ground surface is often lifted during soil freezes
  - Soil water moves from unfrozen region to the freezing front that ice is growing in soil
  - even on the condition that the ground surface is fixed mechanically
- Why does soil water move to the freezing front against the pressure on the freezing front?

Background (cont.)

- Although many researchers have tried to explain the movement of water during frost heaving, a clear answer has not been given from the viewpoint of soil physics
- In order to understand the phenomenon, I believe thermodynamics of unfrozen soil water is important

Background (cont.2)

- However, young generation are not interested in this classic thermodynamic theory of soil water.
- Therefore, I try to recall thermodynamics of frozen soil and chemical potential of unfrozen water based on the paper that I wrote in 1993.

Content

1. Phase diagram of water
2. Chemical potential
3. Water potential of soil
4. Thermodynamics of soil water
5. Matric potential in frozen soil

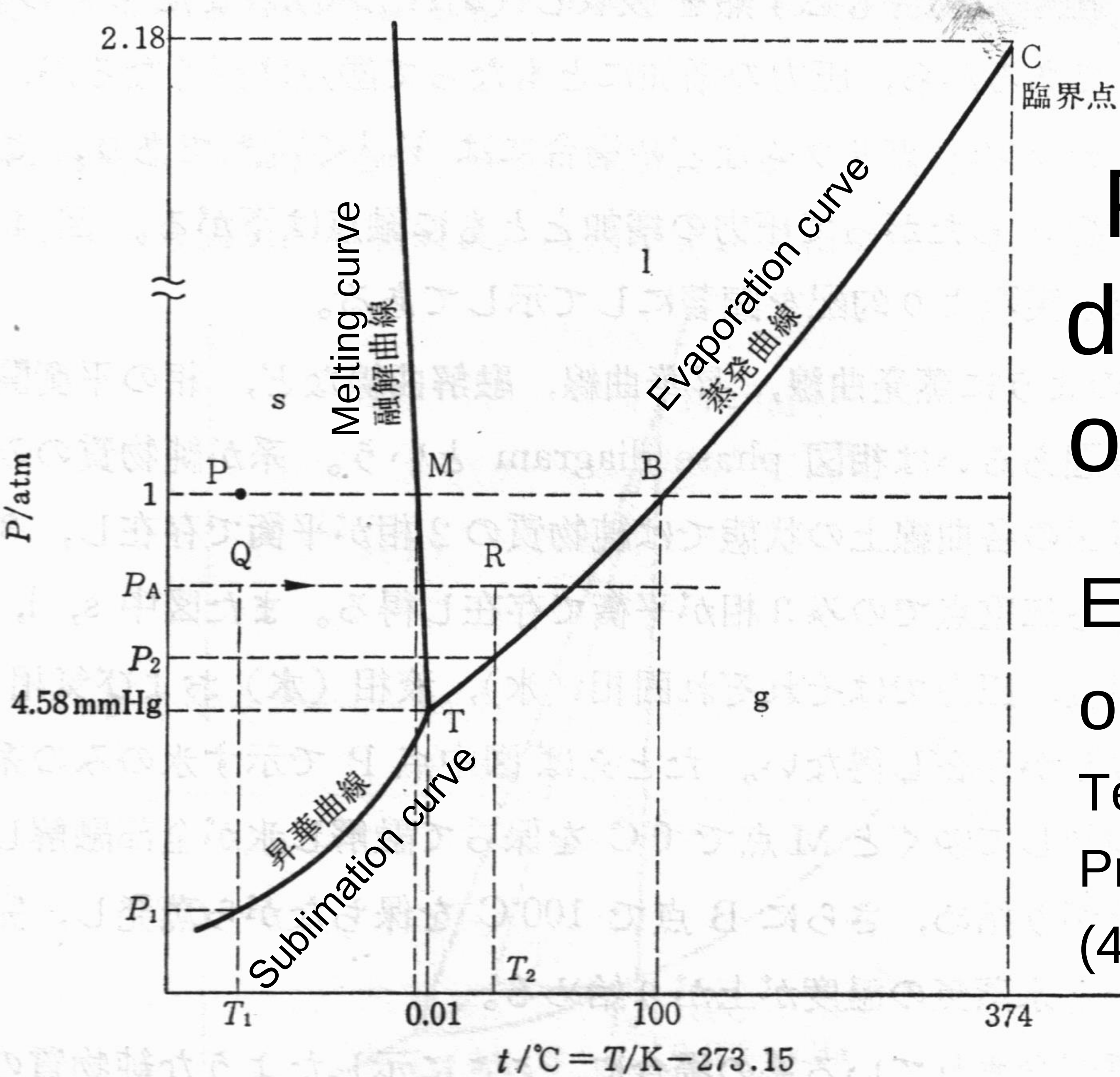


図 4.4 水の状態図の略図

Phase diagram of water

Environment on Mars

Temp = -63℃

Press =6 hPa

(4.5mmHg)

Chemical potential

The first law of TD

$$dU = dQ + dW \quad \cdots ①$$

Only volumetric work

$$dW = -PdV \quad \cdots ②$$

The second law

$$dQ = TdS \quad \cdots ③$$

From ①②③

$$dU = TdS - PdV \quad \cdots ④$$

Gibbs free energy (GFE)

$$G = U + PV - TS \quad \cdots ⑤$$

$$dG = VdP - SdT \quad \cdots ⑥$$

Chemical potential

＝GFE per unit mol.

$$G / n \equiv \mu \quad \cdots ⑦$$

$$d\mu = vdP - sdT \quad \cdots ⑧$$

Equilibrium of adsorbed water and vapor
at constant temp

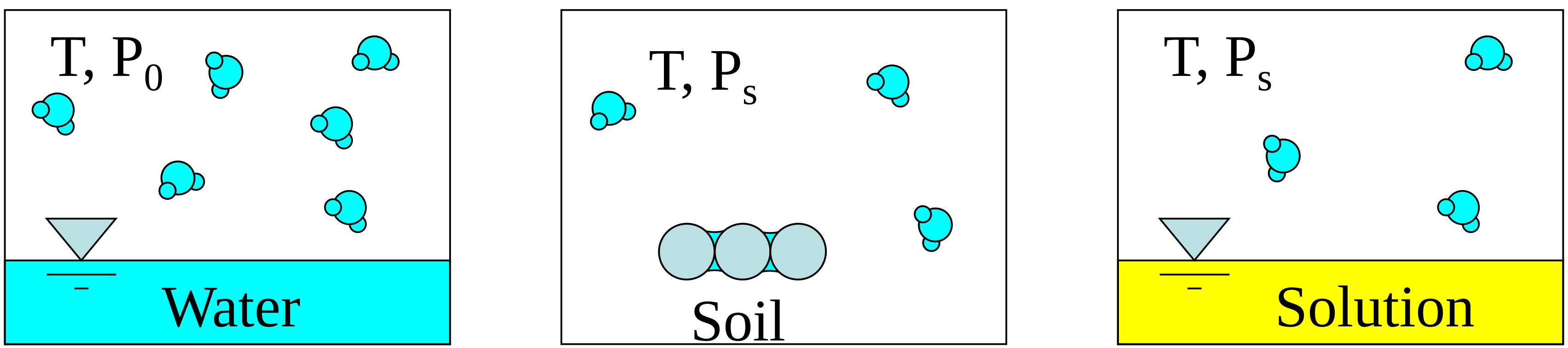
The difference between Vapor-A and Vapor-B（C) ＝Work required $P_s \rightarrow P_0$

$$\mu_0 - \mu_s = \int_{P_s}^{P_0} v dP = \int_{P_s}^{P_0} \frac{RT}{P} dP = -RT \ln\left(\frac{P_s}{P_0}\right) > 0$$

$$PV = nRT$$

$$v = \frac{V}{n} = \frac{RT}{P}$$

P:Vapor press.　v：specific volume
R：Gas constant　T：Abs. Temp
P_s/P_0：Relative Humidity



(A) vapor-pure water　(B) vapor-soil water　(C) vapor-solution

Chemical potential of absorbed water

$$\mu_s(T) = \mu_0(T) + RT\ln(\frac{P_s}{P_0})$$

Unit of enegy

- Per Mol. J/mol
- <u>Per Mass J/kg</u>
- Per Volume J/m^3 =Pa
- Per weight J/gw =m

$$\Delta\mu_s(T) = \frac{RT}{M}\ln(\frac{P_s}{P_0})$$

Using below:

R=8.314 (J/mol/K)

T=293.15 K(20°C)

M=18x10^{-3} (kg/mol)

$$\Delta\mu_s(T) = 3.12\times10^5\log(\frac{P_s}{P_0})$$

Relative humidity and Potential of absorbed water

$$\Delta\mu_s(T) = 3.12\times10^5 \log(\frac{P_s}{P_0})$$

RH Potential of absorbed water 20 ℃

Ps/P0	J/kg	Pa	cmH2O	pF
1	0	0	0	∞
0.99999	−1	1000	10.2	1
0.99993	−10	10000	102	2
0.99926	−100	100000	1020	3
0.99264	−1000	1000000	10200	4
0.92877	−10000	10000000	102000	5
0.8	−30214	30214000	308185	5.5

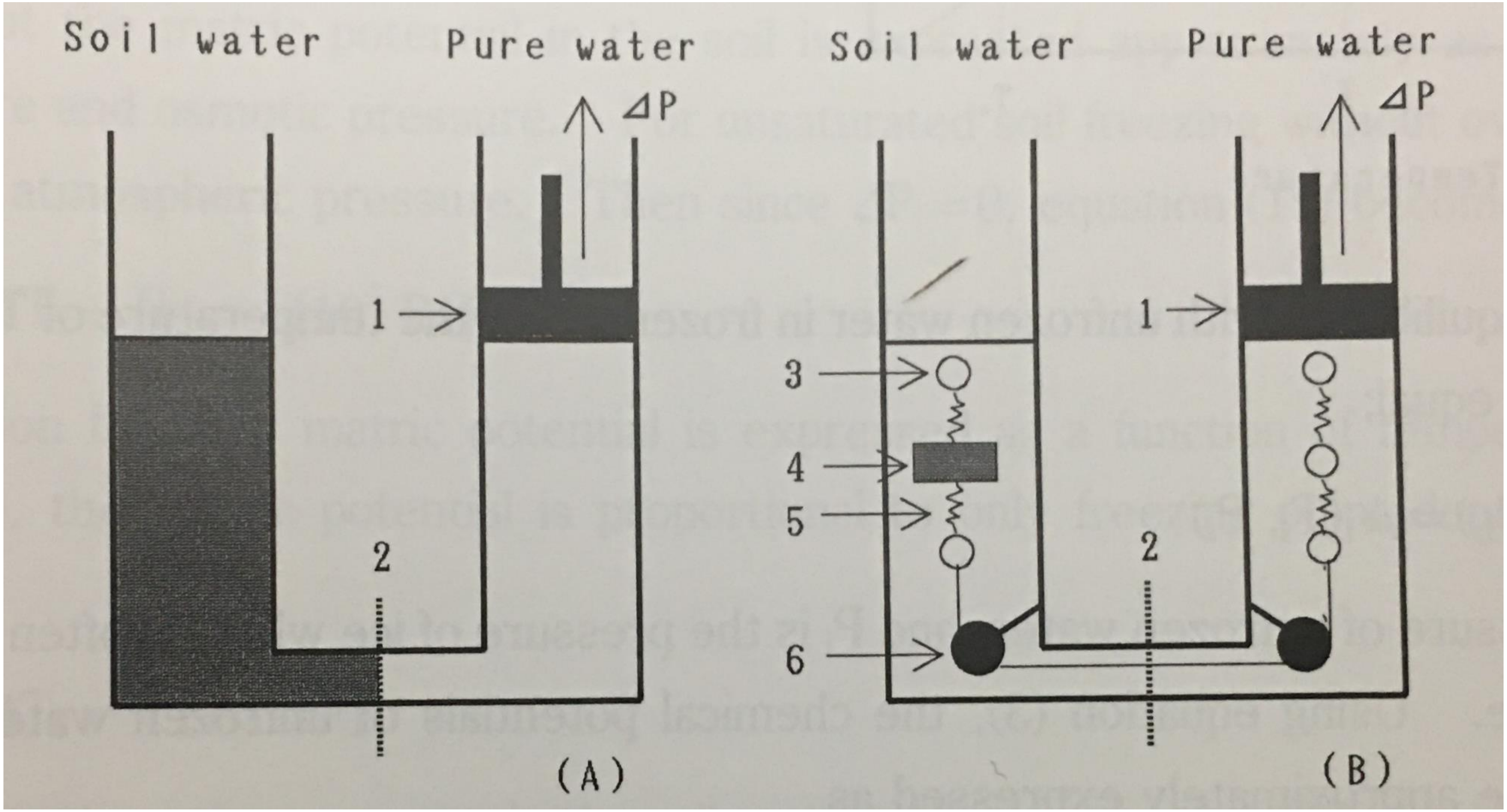
- pF is used conventionally

$$pF = \log\left|cmH_2O\right|$$

Thermodynamics of soil water

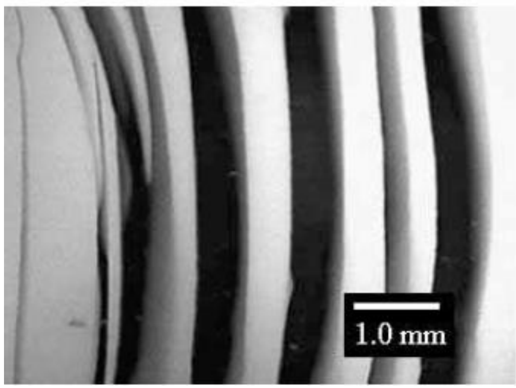
$$d\mu = v\,dP - s\,dT$$

Mechanical model of Equilibrium between soil water and pure water



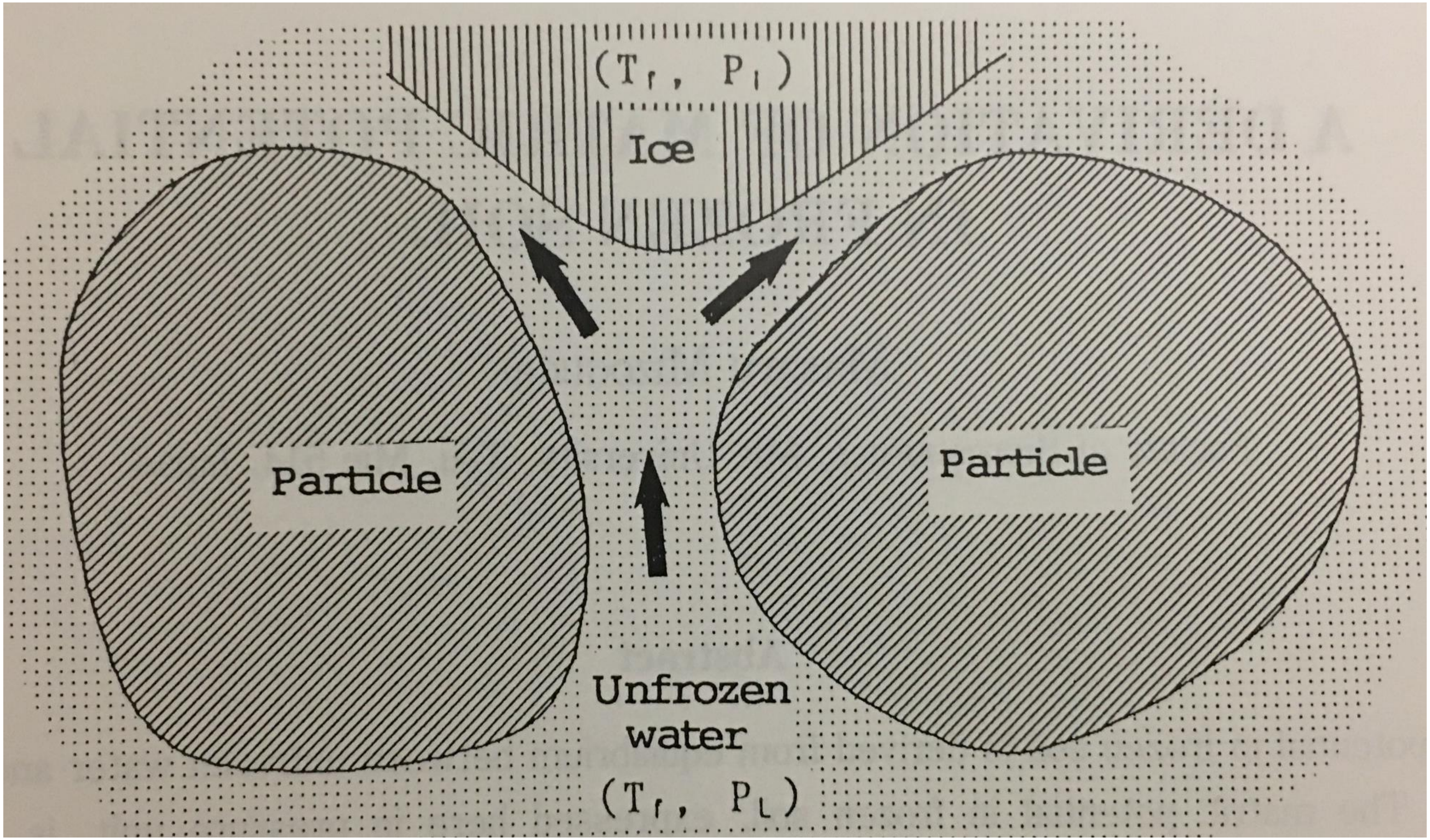
Frozen soil

Ice needle(by Watanabe)

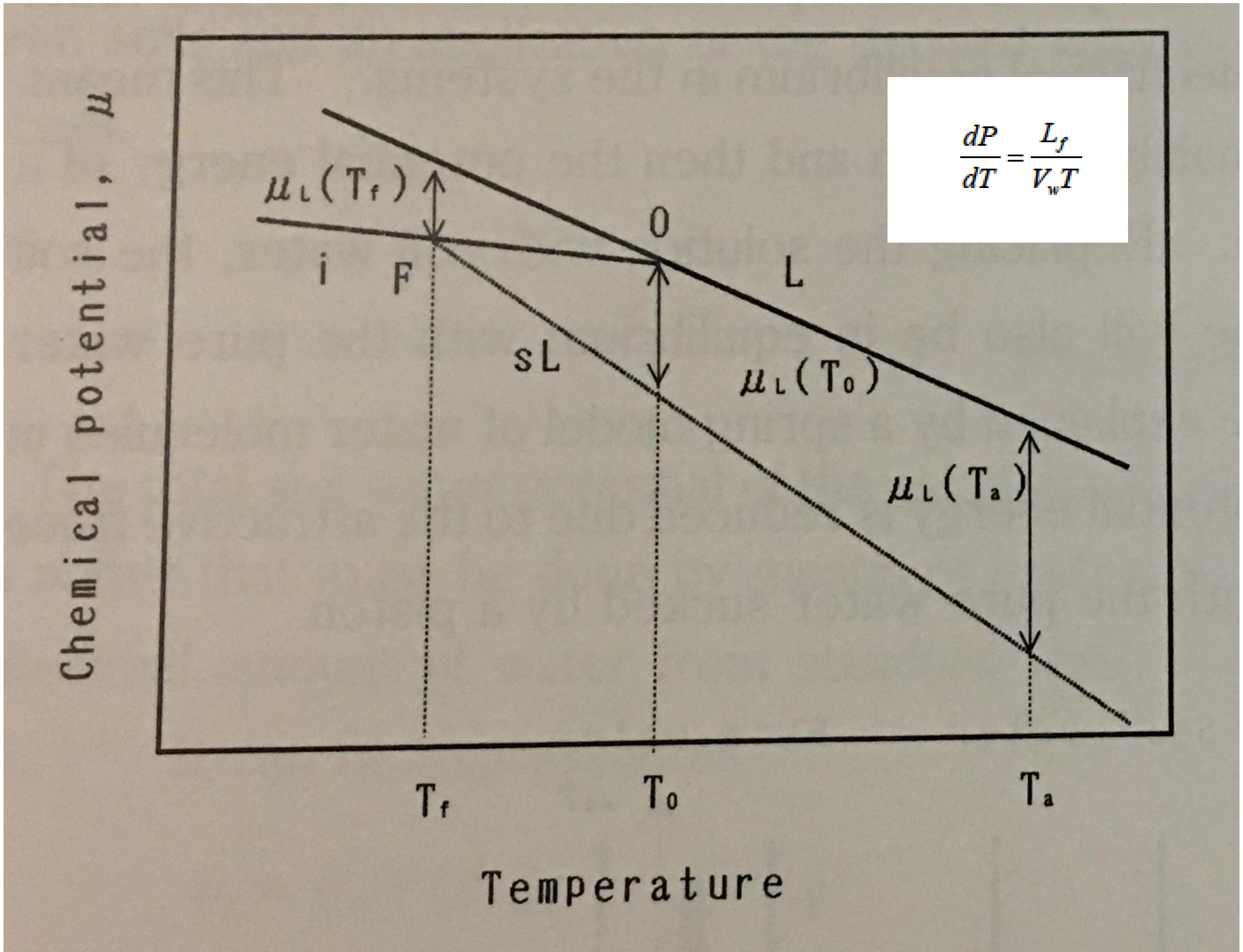


Ice lens in glass beads (by Muto)

Equilibrium between ice and unfrozen water in frozen soil



Chemical potentials of pure and ice



$$\frac{dP}{dT} = \frac{L_f}{V_w T}$$

Challenge

- Let’s try to understand “thermodynamics of frozen soil” reading a paper of chemical potential of unfrozen water based on the paper that I wrote in 1993

Conclusion

- In order to understand frozen soil, thermodynamics of unfrozen soil water is important.
- Let's learn "thermodynamics“ again !