Thaw Mechanism of Unsaturated Frozen Soil during Water Infiltration through a Macropore

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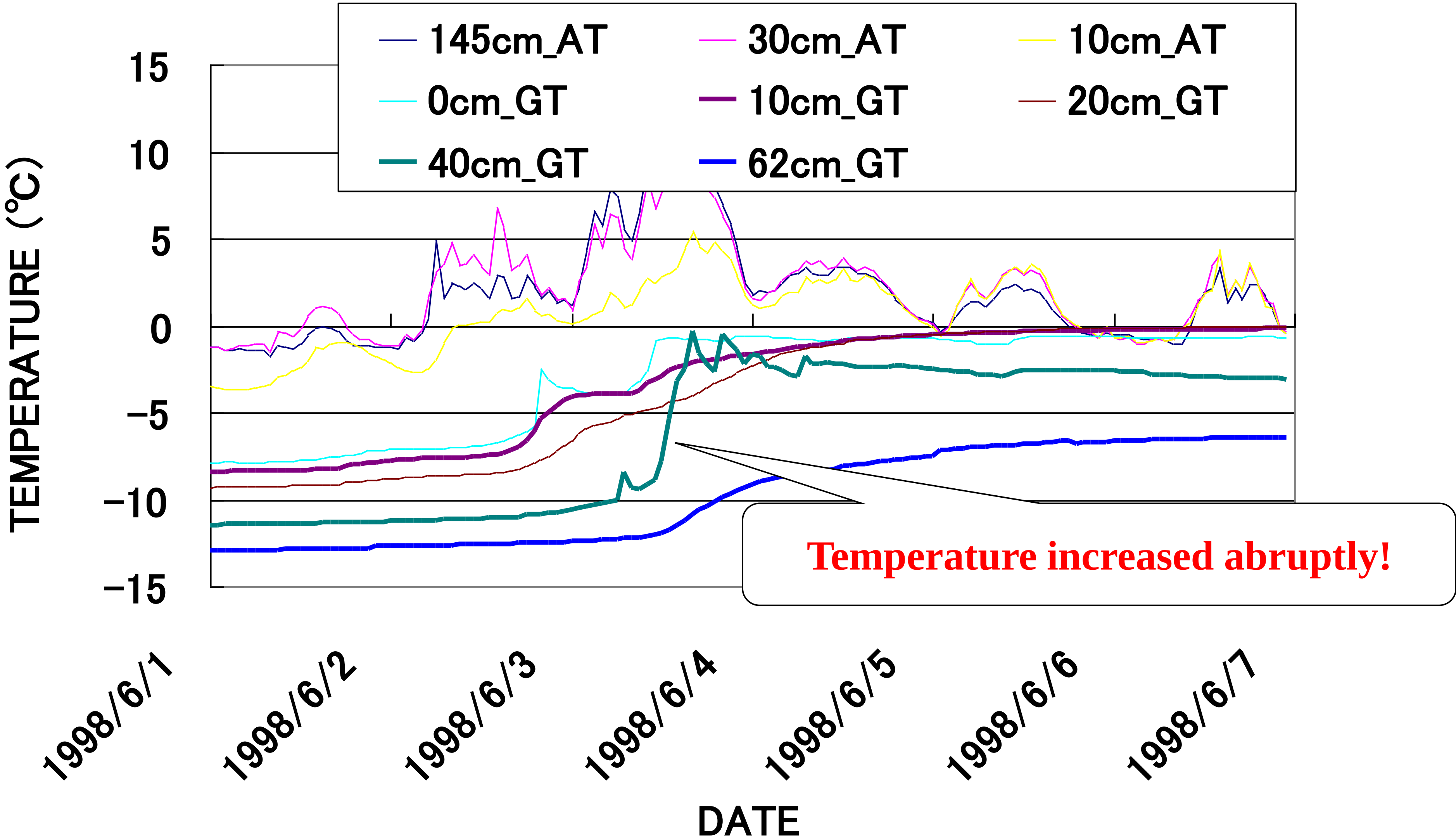
Tundra basin near Tiksi, Russia, surveyed in August, 1998

ABSTRACT

- Freezing-thawing cycle of soil influences the hydrological processes in the permafrost region. If snowmelt water infiltrates into unsaturated frozen soil, the water will carry heat into the frozen soil and accelerate thawing of the soil. To investigate the effect of infiltration on thawing of the frozen soil, we measured infiltration rate in columns with different water content. As a result, we found that infiltration stopped above a certain water content. In addition, we measured one-dimensional temperature profiles in dry sand during infiltration. The temperature of frozen sand jumped to 0°C at the depth where infiltration front reached. Moreover, we observed two-dimensional temperature distribution during infiltration around an artificial macropore in frozen dry sand by using thermography. The temperature distribution revealed the mechanism that bypass flow through the macropore accelerated thawing of the frozen soil.

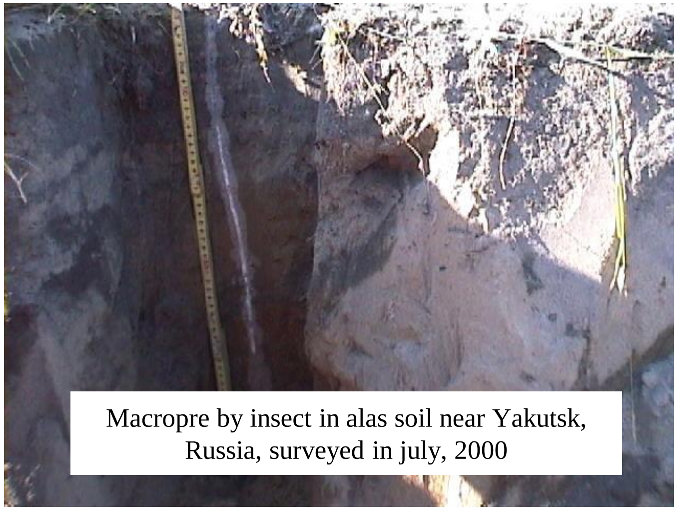


- **Fig.1 Air (A) and ground (G) temperatures during 1998 snowmelt season in tundra near Tiksi, Siberia. The temperature at 40 cm depth increased abruptly in a few hours.**

BACKGROUND

- Permafrost
  - Influences water and energy cycle in cold regions
  - Good sensor of global warming
- Thawing mechanism of frozen soil
  - Abrupt increase in ground temperature during snowmelt season
  - Infiltration effect into unsaturated frozen soil
- Contribution of macropore
  - Root, crack, insect, etc

Macropre by root in alas soil near Yakutsk, Russia, surveyed in july, 2000



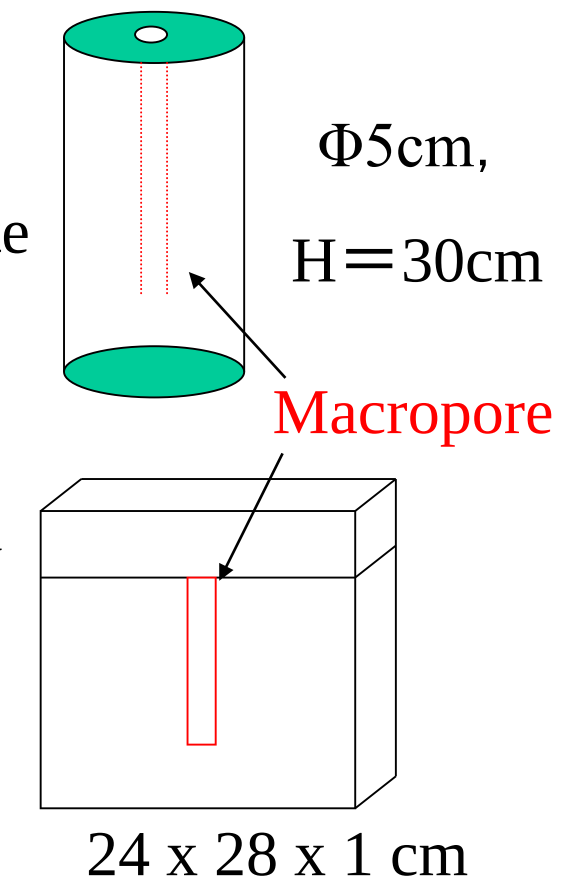
Macropre by insect in alas soil near Yakutsk, Russia, surveyed in july, 2000

OBJECTIVE

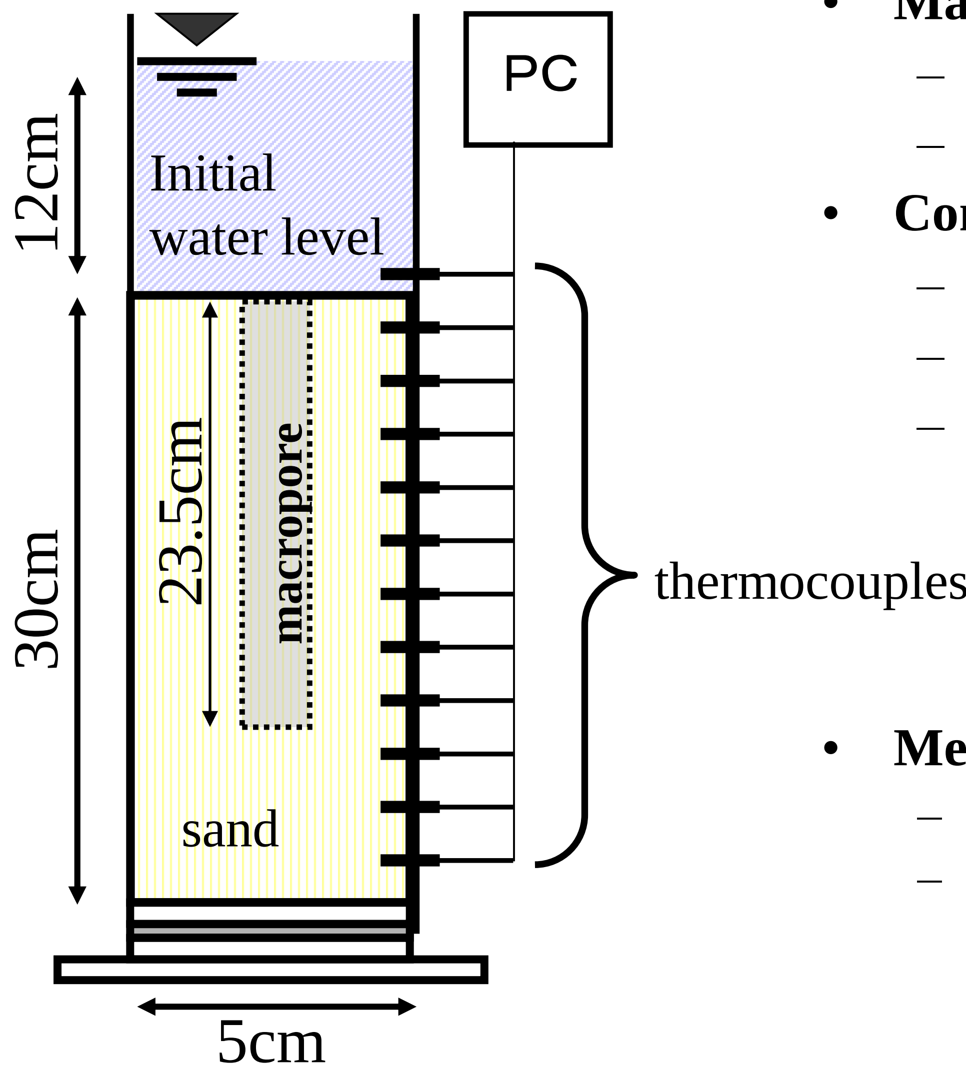
- To evaluate the contribution of infiltration through a macropore to thawing of the unsaturated frozen soil
  - Infiltration rate as a function of initial water content in unsaturated frozen sand
  - One-dimensional temperature profiles with a macropore in a frozen dry sand
  - Two-dimensional temperature distribution around a macropore

EXPERIMENTS

- ***Infiltration rate measurement without macropore***
  - Effect of initial water content
- ***One-dimensional test with a macropore***
  - Change in soil temperature and infiltration rate during infiltration
- ***Two-dimensional test with a mocropore***
  - Soil temperatures visually with thermography during infiltration

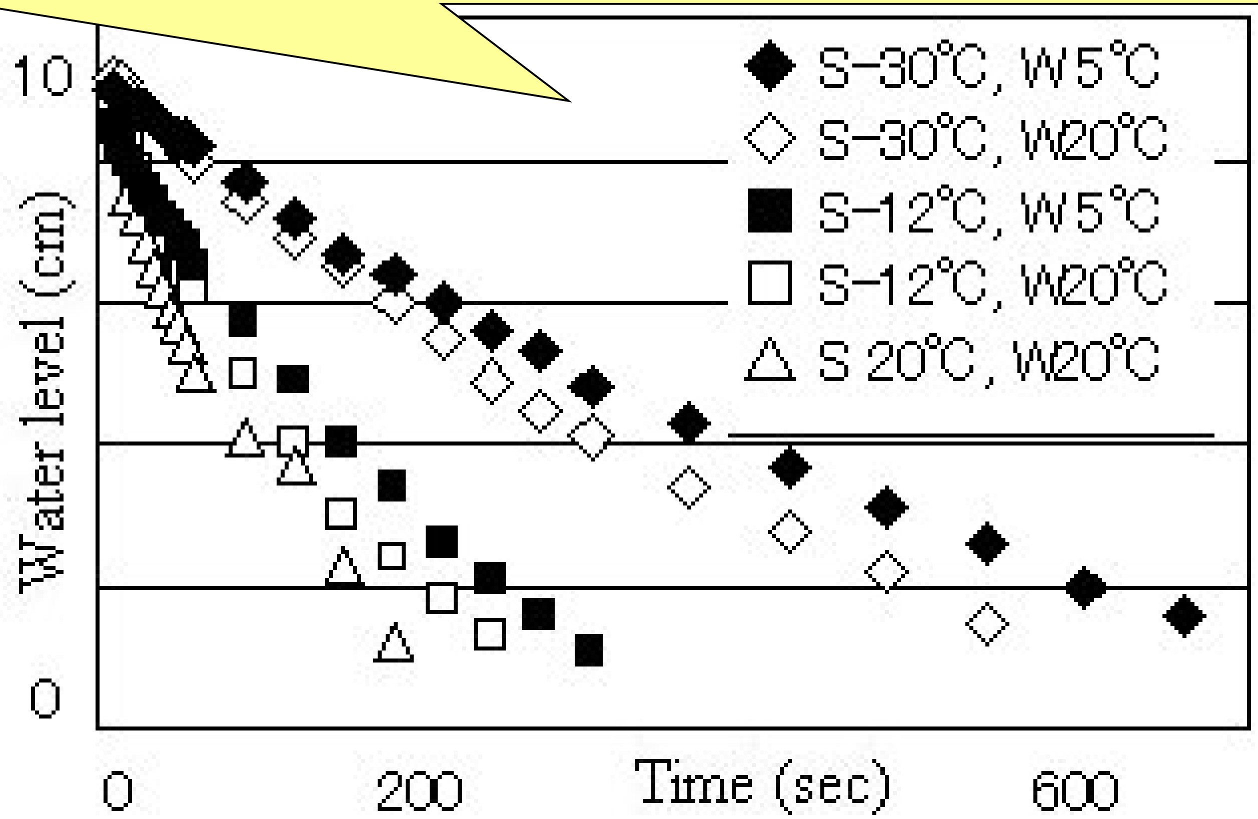


One-dimensional test



- **Materials**
  - Toyoura sand (air-dried,w=1.1%)
  - Bulk density, 1.5g/cm^3
- **Conditions**
  - Initial soil temperature, -15℃
  - Initial water temperature, 15℃/5℃
  - macropore
    - **Glass tube-1（φ2.8mm×23.5cm）**
    - **Glass tube-2（φ 5.2mm ×23.5cm）**
    - **Cotton (1cmx1cm×23.5cm）**
    - **none**
- **Measured**
  - **Change in water level vs. time**
  - **Soil temperatures at 1 cm each**

The higher the sand and the water temperatures, the faster the water level decreased. Some of the water will infiltrates into pores which are partly clogged by ice formed at the infiltration front

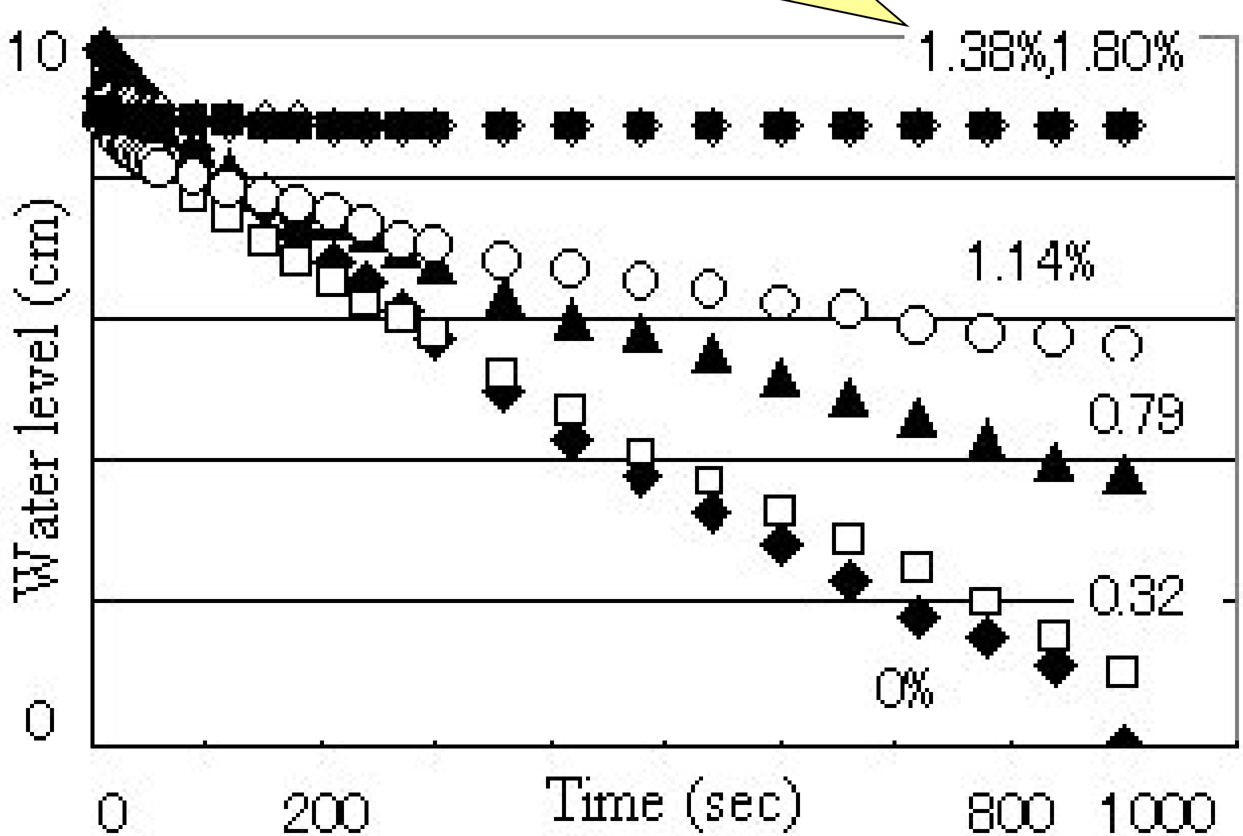


- **Fig. 3 Changes in water level as a function of time during infiltration into dry sand columns.**

S: initial temperature of sand

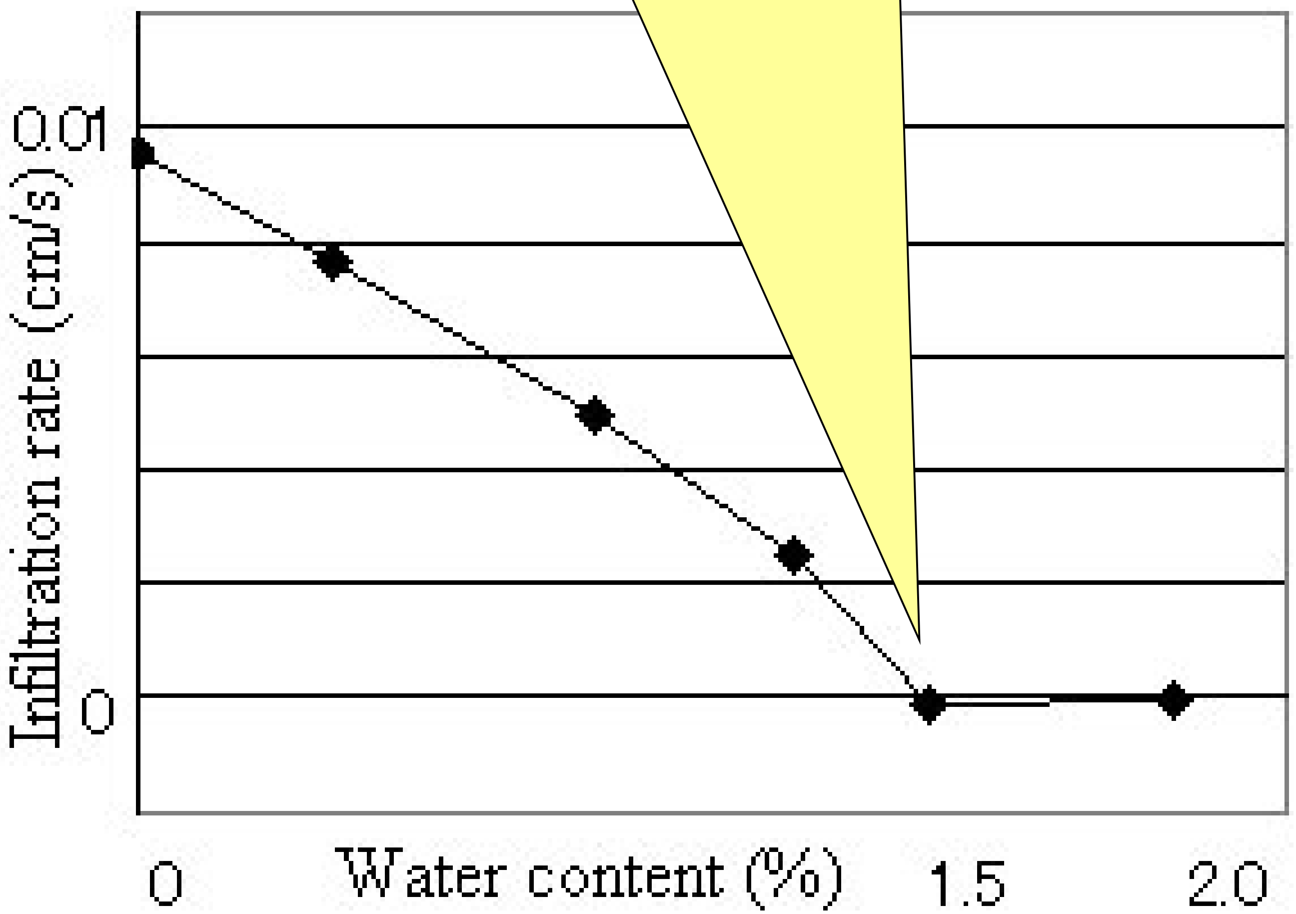
W: initial temperature of infiltrated water

The higher the initial water content, the slower the water level decreased.



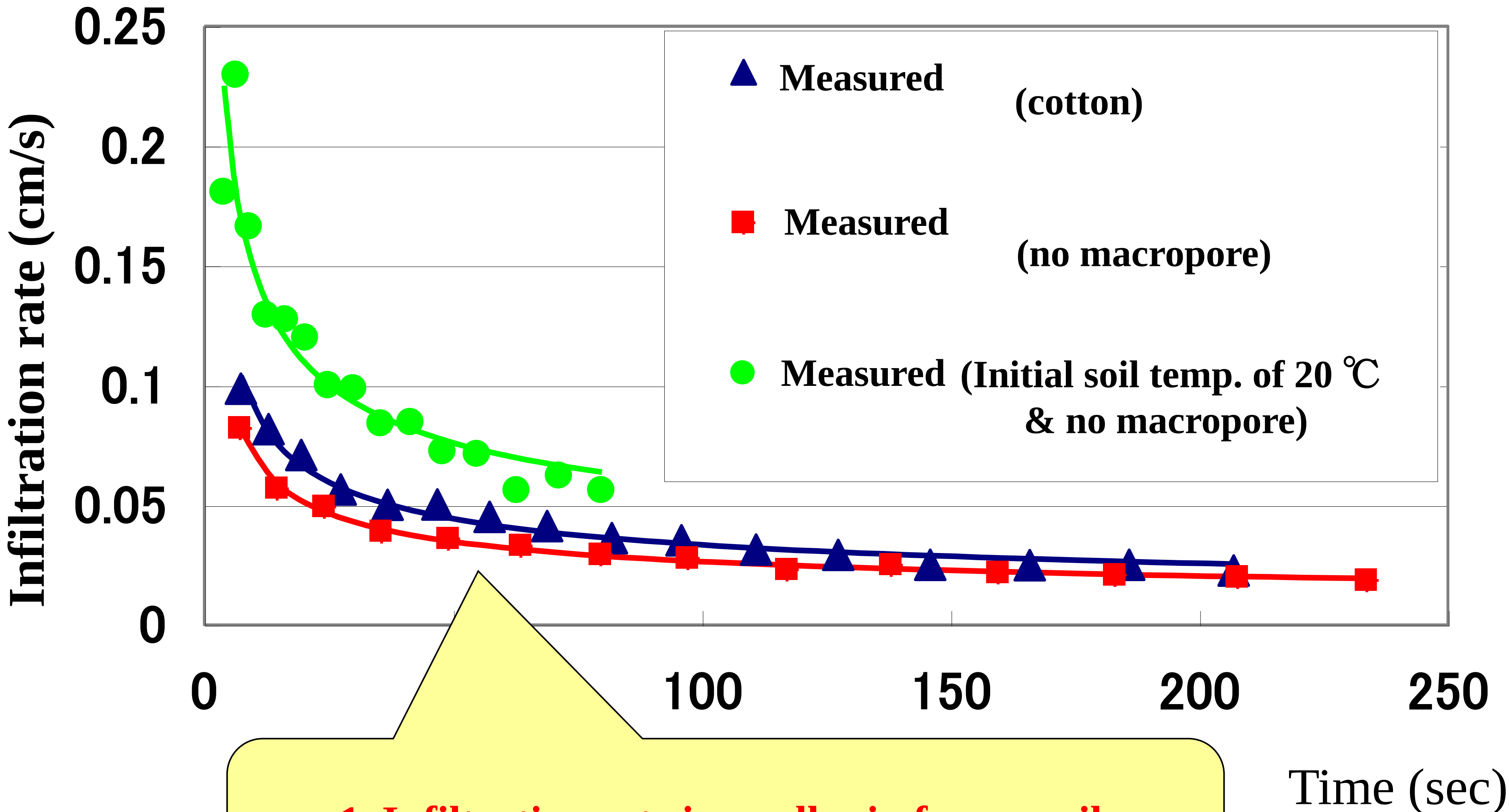
- **Fig. 4 Changes in water level as a function of time during infiltration of 5 ºC water into -30ºC sand columns with different initial water content.**

Infiltration stops perfectly above a certain water content, 1.38 %.



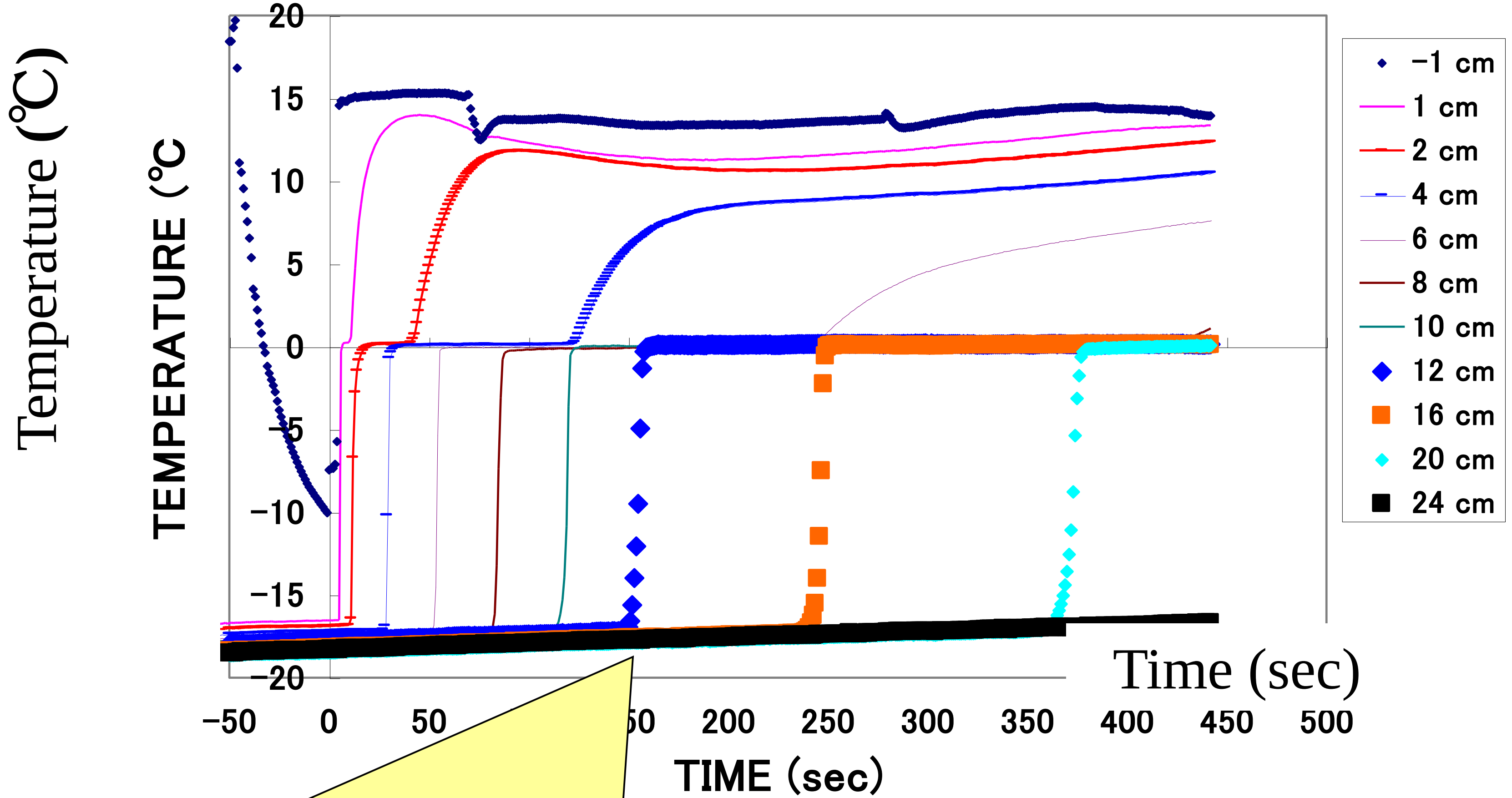
- **Fig. 5 Infiltration rate as a function of water content during infiltration of 5 ºC water into -30 ºC sand column.**

Fig. 6 Infiltration rate as a function of time during infiltration of 15ºC water into -15 ºC sand columns with/without macropore.



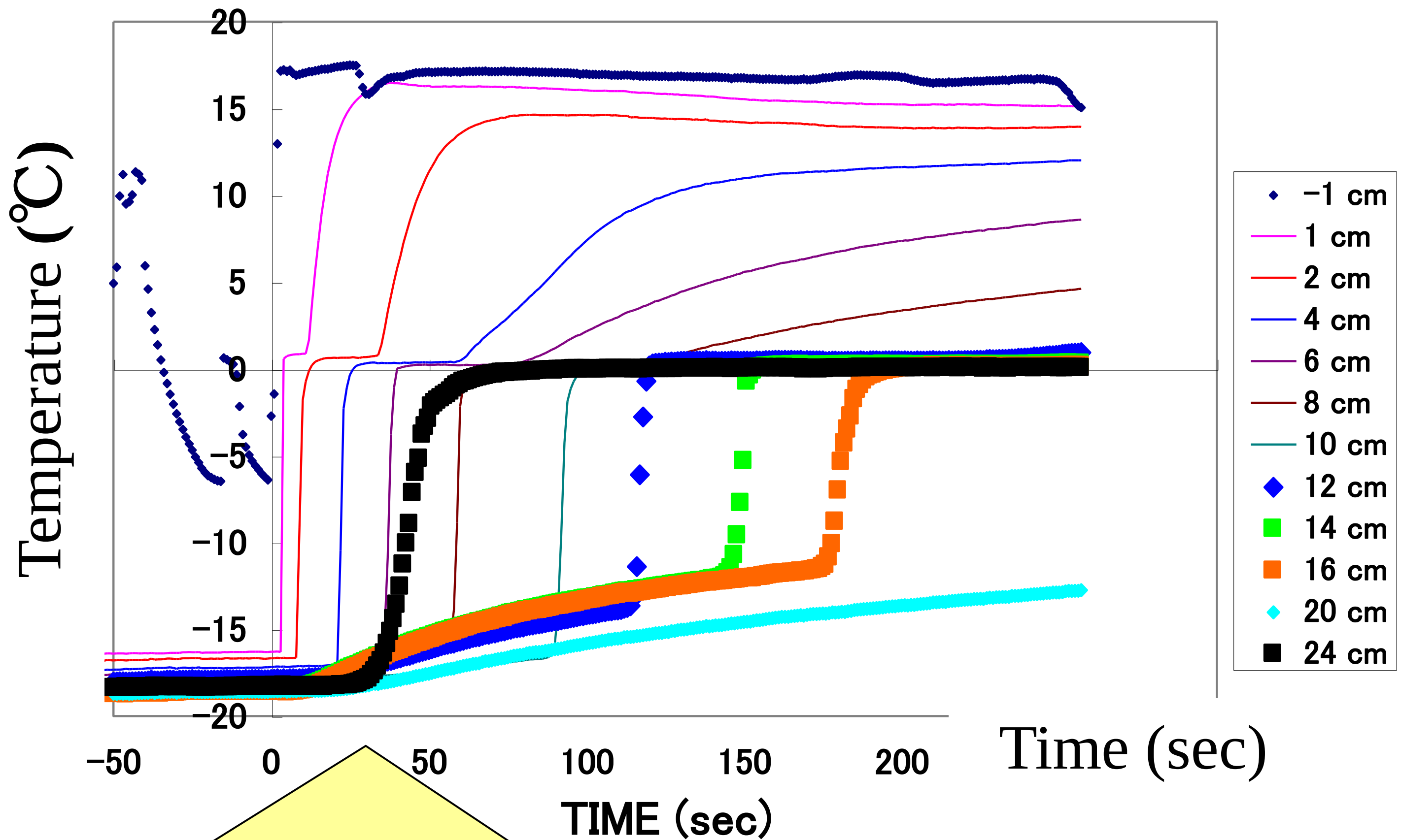
1. Infiltration rate is smaller in frozen soil
2. Macropore accelerates infiltration

Fig. 7 Temperatures at each depth as a function of time during infiltration of 15°C water into -15°C dry sand column without macropore.



Temperature increases abruptly to 0 ℃ when infiltration front reaches and keeps 0 ℃ for a while, then increases slowly.

Fig. 8 Temperatures at each depth as a function of time during infiltration of 15°C water into -15°C dry sand column with a φ5.2mm × 23.5 cm glass tube.



Temperature at 24 cm increases faster than at 10-20 cm, and temperatures at 14 cm and 16cm increase slowly before abruptly increase.

Fig. 9 Temperature profiles at 300 sec during infiltration of 15ºC water into -15 ºC sand columns with/without macropore.

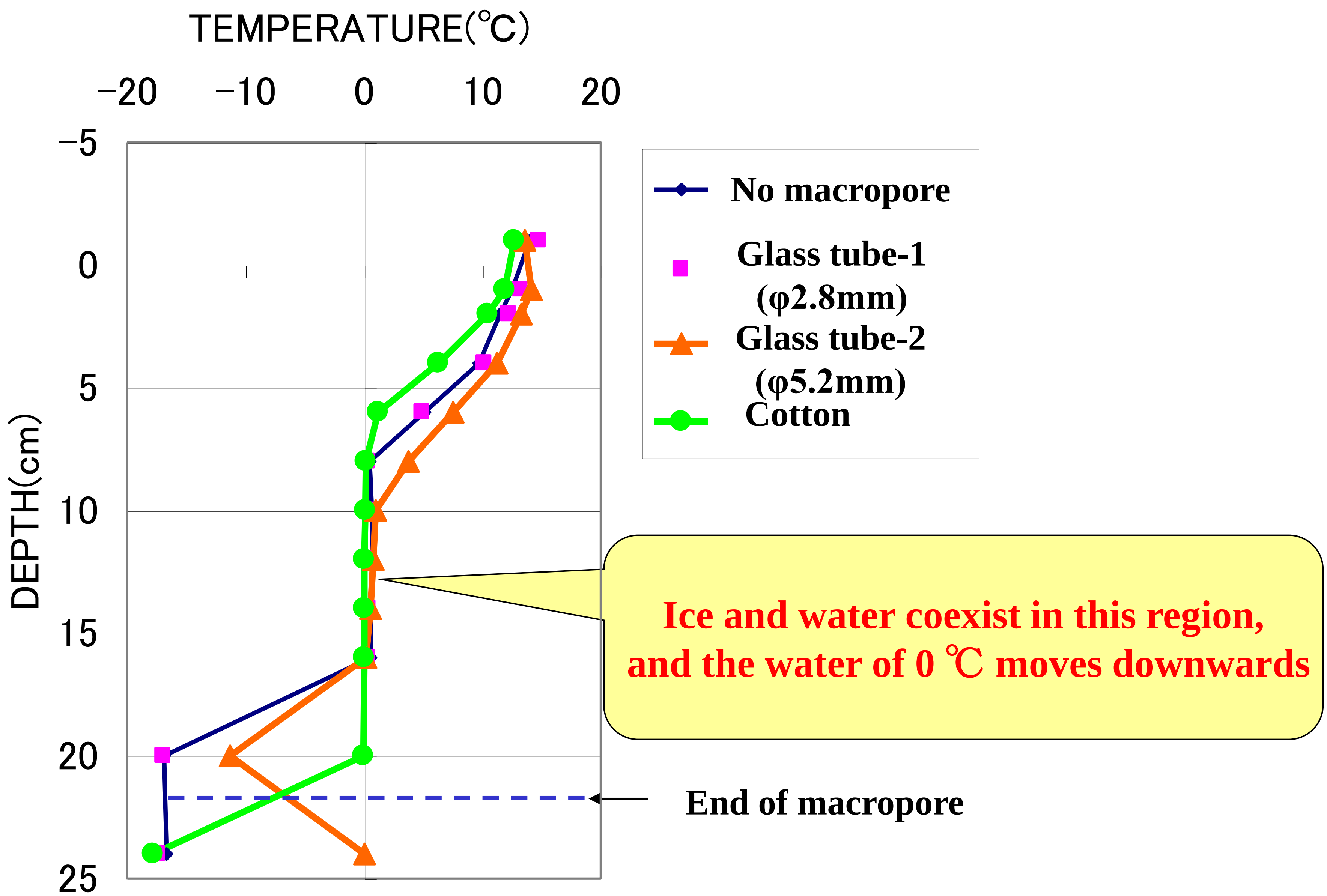
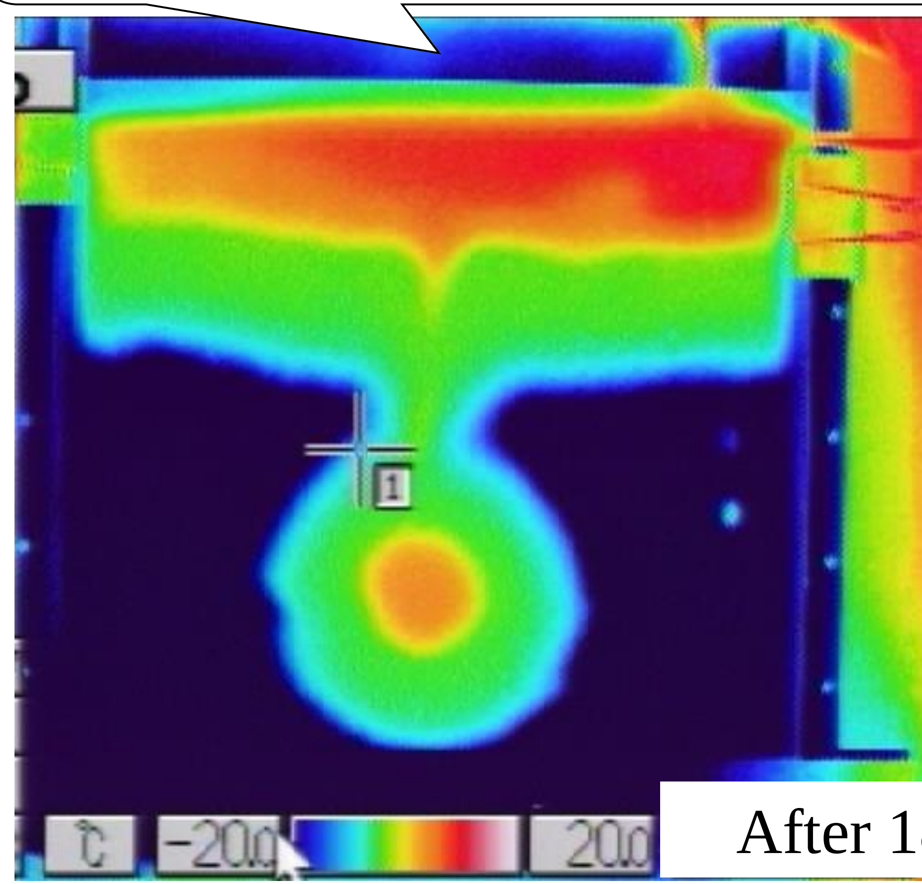
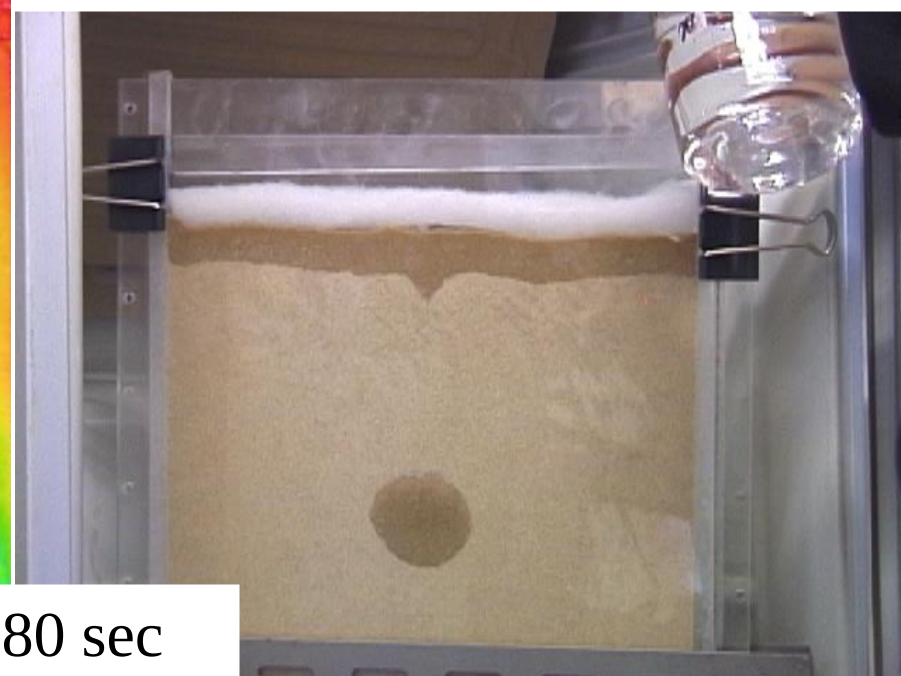


Fig. 10 Thermal images by thermography during infiltration of 18 °C water into -20°C dry sand; (a) the 5.2 mm-glass tube macorore at 180 sec

- **Materials**
  - Toyoura sand (air-dried,w=1.1%)
  - Bulk density, 1.5g/cm³
- **Conditions**
  - Initial soil temperature, -20℃
  - Initial water temperature, 18℃

1. Infiltration from the end of glass tube
2. Thermal conduction from the side of glass tube

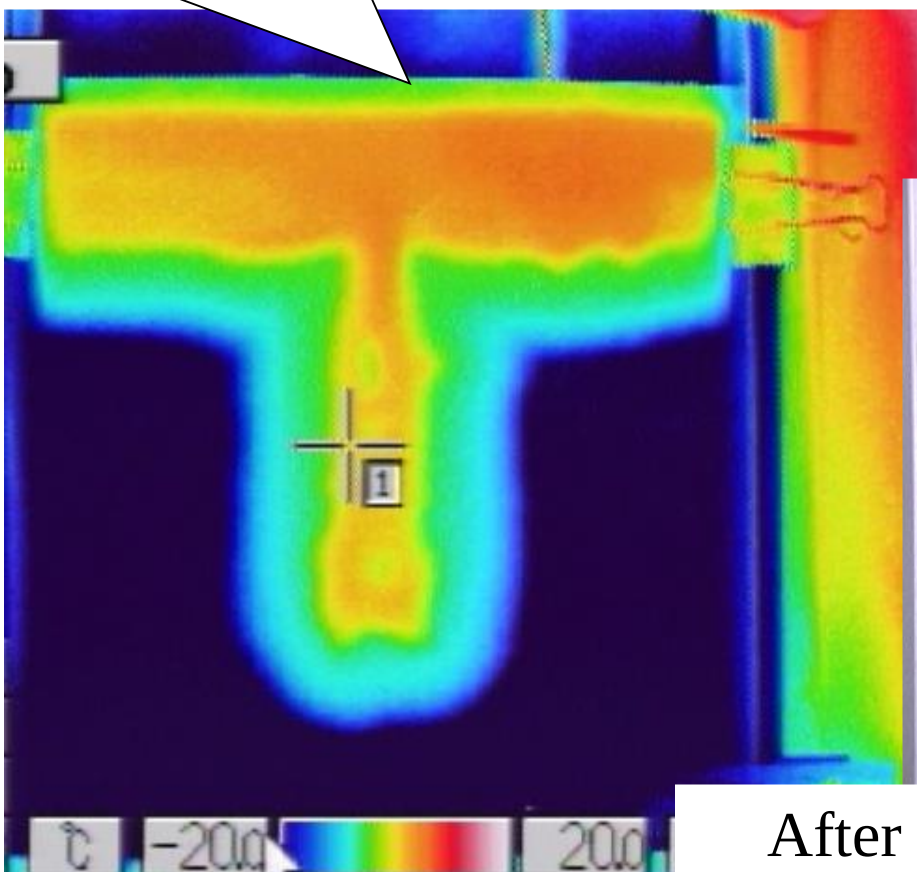




After 180 sec

Fig. 10 Thermal images by thermography during infiltration of 18 °C water into -20°C dry sand; (b) the cotton macropre at 70 sec.

Infiltration from the side of cotton



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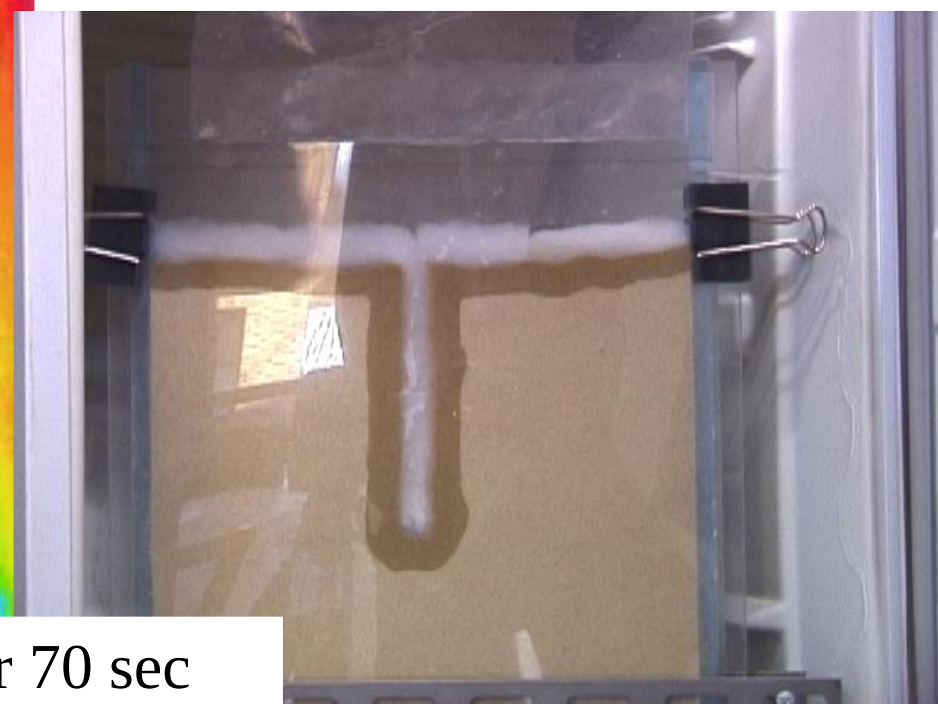

After 70 sec

CONCLUSIONS

- Infiltration into frozen soil stopped above a certain water content
- Temperature jumped to 0^{o}C at the depth where infiltration front reached
- Bypass flow through a macropore accelerates thawing of the frozen soil
- Infiltration through macropres has a great influence on abrupt increase in ground temperature during snowmelt season and spatial distribution of thaw depth in tundra and alas.

Acknowledgement

- This study was conducted within the framework of GAME project. The GAME-Siberia field observations in Tisksi (1997, 1998) and Yakutsk (2000) gave us an excellent motivation for the laboratory study. We would like to acknowledge the members of GAME project.

References

- Kane, D. L., 1980: Snowmelt infiltration into seasonally frozen soils, Cold Re. Sci. Technol., 3, 153-161
- Kane, D. L., and J. Stein, 1983: Water movement into seasonally frozen soils, Water Resour. Res. 19, 1547-1557
- Stadler, D., M. Stahli, P. Abey, and H. Fluhler, 2000: Dye tracing and image analysis for quantifying water infiltration into frozen soils, Soil Sci. Sco. Am. J., 64, 505-516
- Mizoguchi, M., N. Kondo, H. Tanaka, H. Kiyosawa, H. Yabuki, Y. Ishii, T. Ohata, 2001: Soil Physical Properties of Active Layer in Alas, Eastern Siberia, Proceedings of the 5th international GAME conference
- Mizoguchi, M., N. Kondo, 2000: Thermographical observation of infiltration into unsaturated frozen soil containing a macropore, Annual meeting abstracts of Nougyou Dobokugakkai, 684-685 (in Japanese)