Movement of Oil and Petroleum Products in Permafrost Impacted Soils

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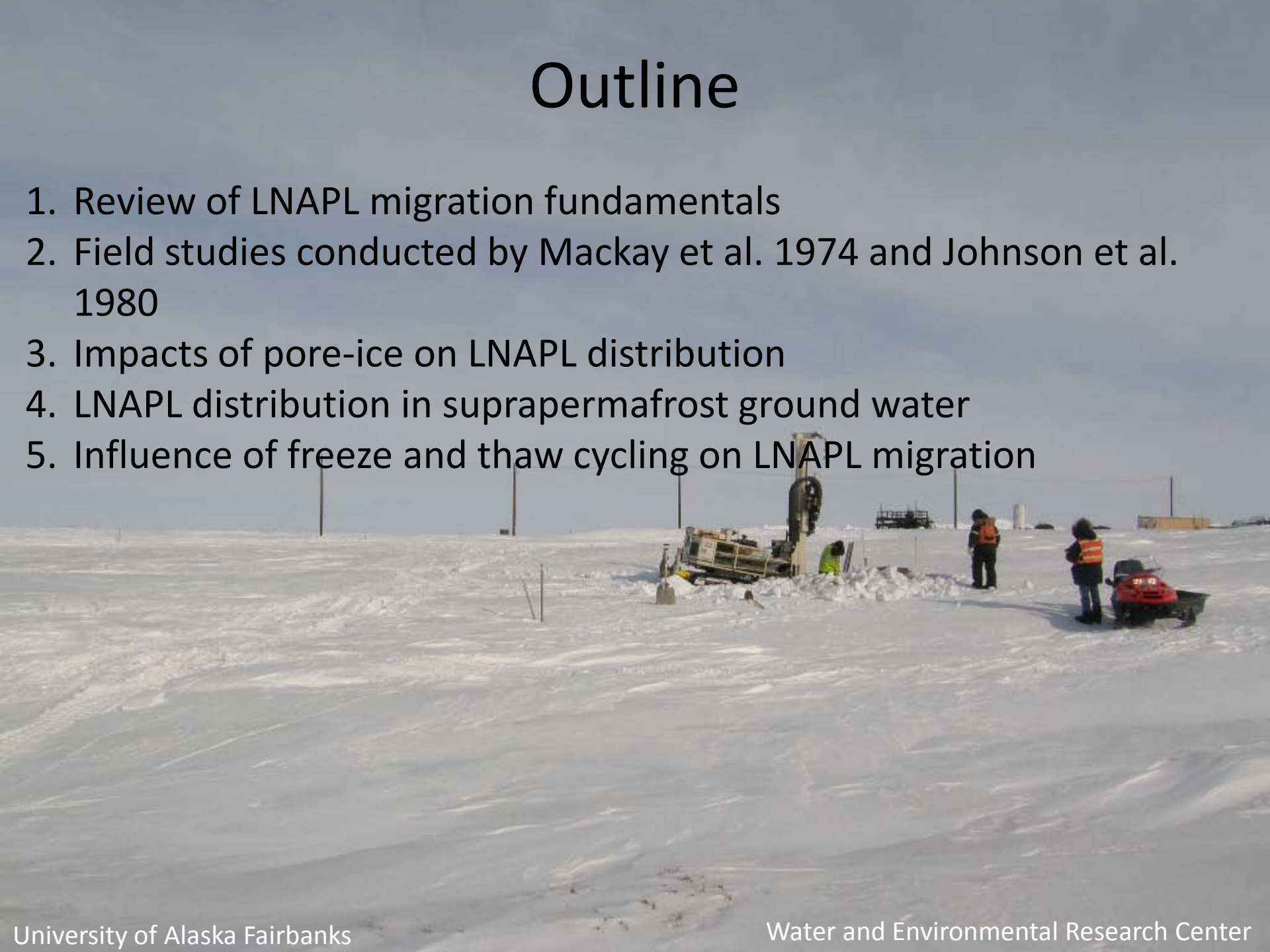
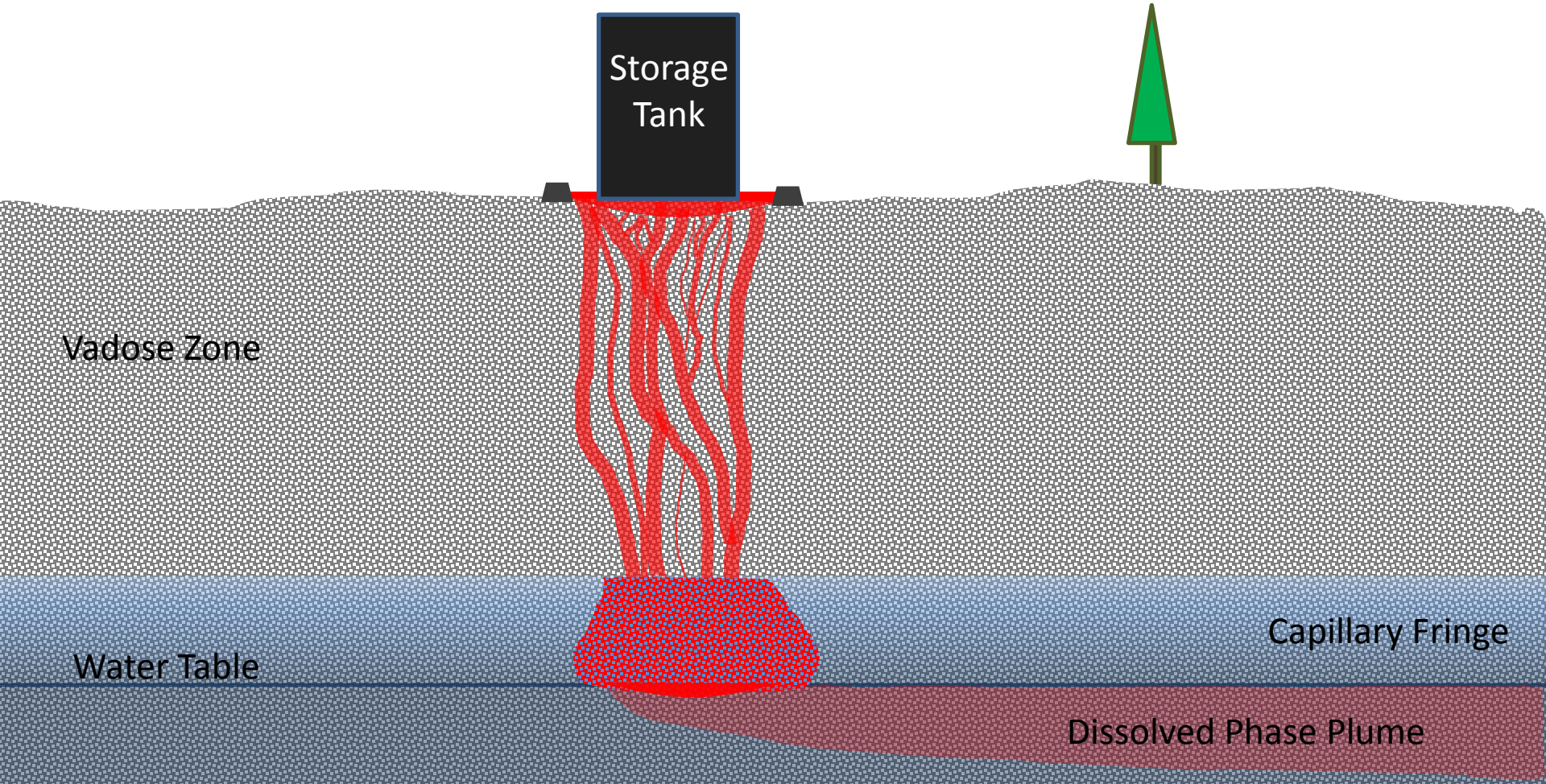
Outline

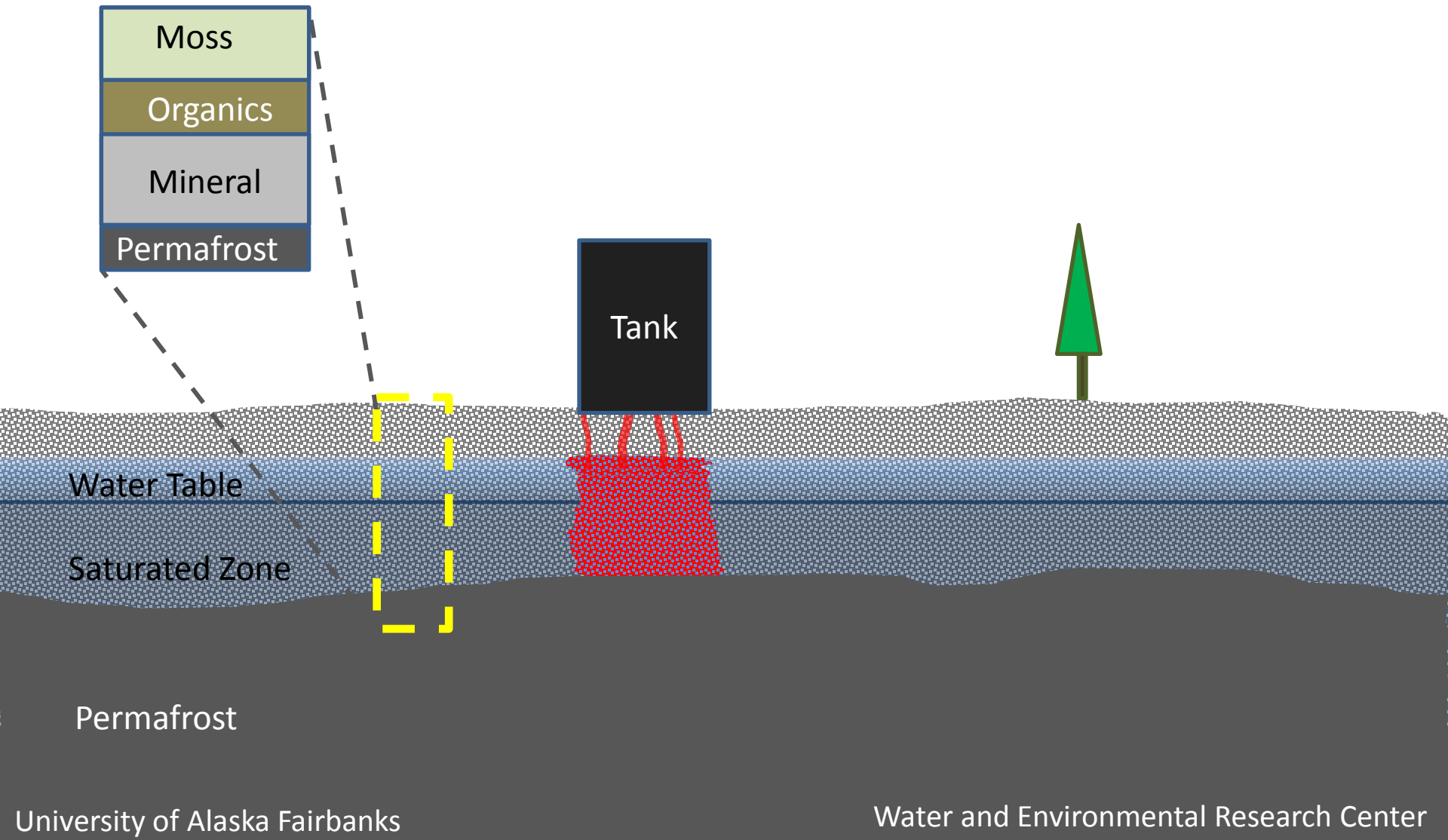
1. Review of LNAPL migration fundamentals
2. Field studies conducted by Mackay et al. 1974 and Johnson et al. 1980
3. Impacts of pore-ice on LNAPL distribution
4. LNAPL distribution in suprapermafrost ground water
5. Influence of freeze and thaw cycling on LNAPL migration



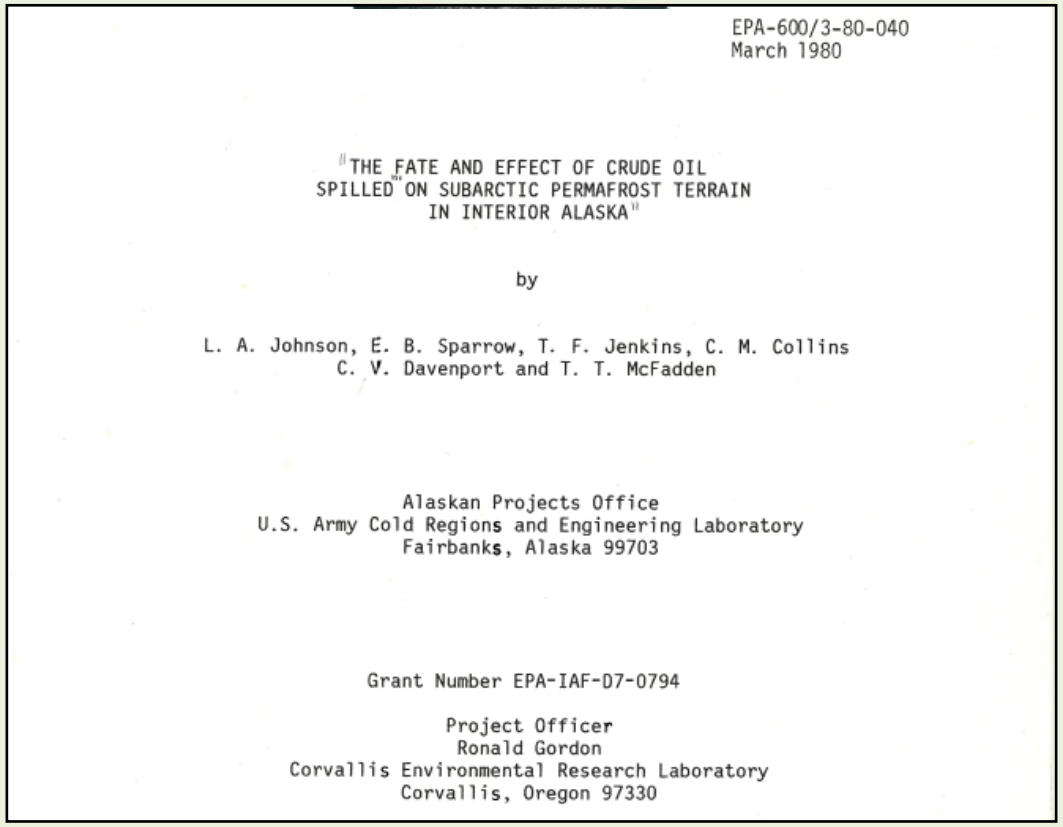
Fundamental Principles of LNAPL Migration



Infiltration of LNAPL into the Subsurface in Continuous Permafrost Regions



Past Field Studies



EPA-600/3-80-040
March 1980

"THE FATE AND EFFECT OF CRUDE OIL
SPILLED ON SUBARCTIC PERMAFROST TERRAIN
IN INTERIOR ALASKA"

by

L. A. Johnson, E. B. Sparrow, T. F. Jenkins, C. M. Collins
C. V. Davenport and T. T. McFadden

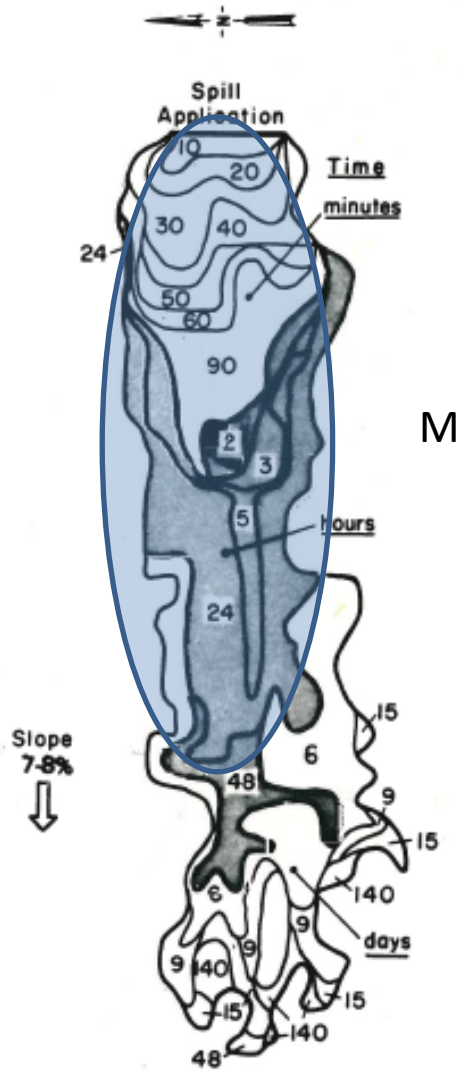
Alaskan Projects Office
U.S. Army Cold Regions and Engineering Laboratory
Fairbanks, Alaska 99703

Grant Number EPA-IAF-D7-0794

Project Officer
Ronald Gordon
Corvallis Environmental Research Laboratory
Corvallis, Oregon 97330

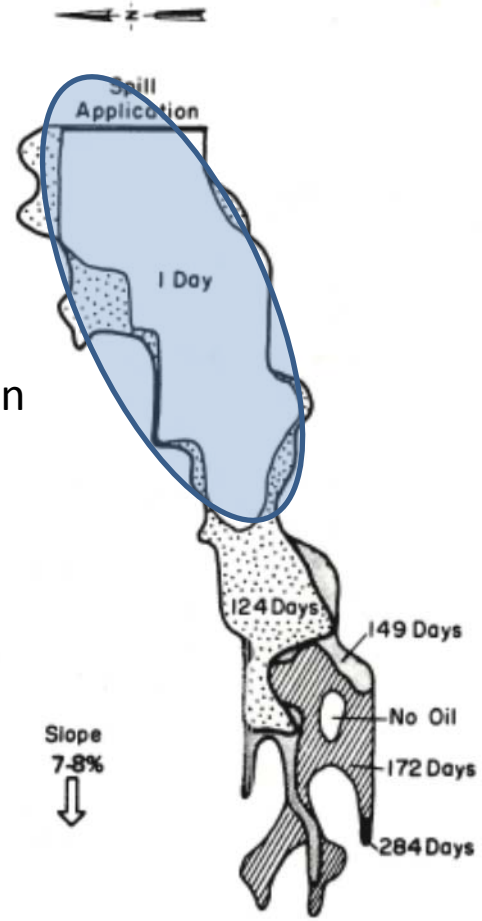
Mackay, D., Charles, M.E., and Phillips, C.R. 1974 and 1975. *The Physical Aspects of Crude Oil Spills In Northern Terrain.* 1st, 2nd and final reports. Task Force on Northern Oil Development, Environmental – Social Committee.

Extent of Oil Migration with Time
Results from Johnson et al., 1980



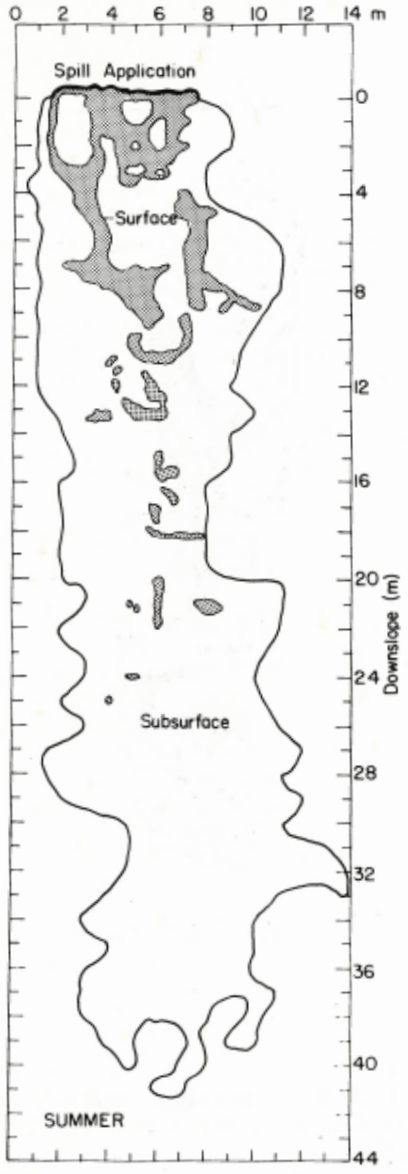
Summer

Migration extent in one day

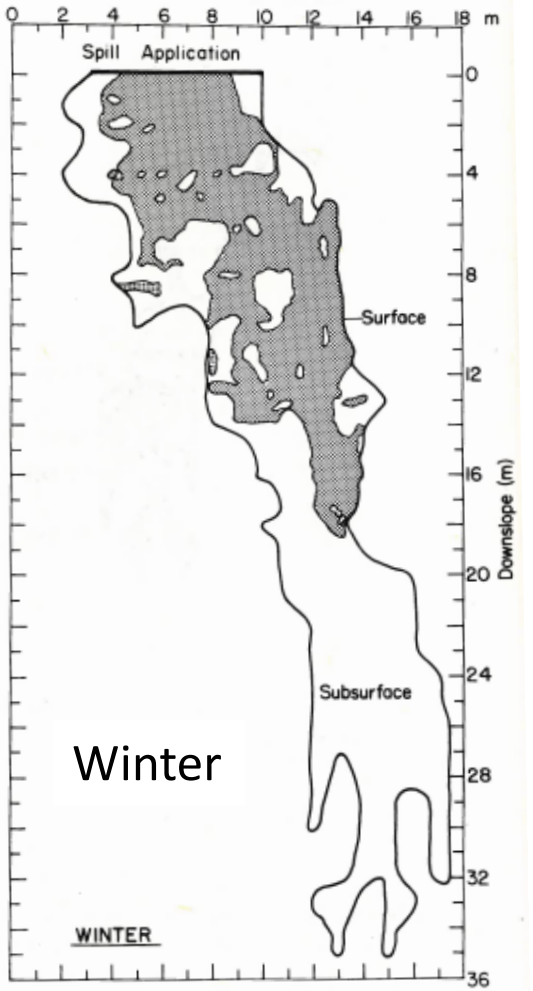


Winter

Oil on Surface versus Subsurface. Results from Johnson et al., 1980



Summer



Winter

Oiled Areas

Surface ■

Subsurface □

Major Finding from Summer Release Field Studies

- Both Mackay et al. and Johnson et al. showed oil released in the summer primarly flowed through an organic layer that overlaid water saturated mineral soils.
- Mackay et al. noted that in tests on summer releases in tundra soils, oil penetrated through the organic layer and flowed down gradient through very permeable soils directly above the frost line.
- The release by Johnson et al. still showed downslope migration 15 years after the release (Collins et al, 1994).
- Infiltration of oil into the mineral soil layer was observed by Johnson et al. in areas of relatively large oil volume accumulation.

Major Finding from Winter Release Field Studies

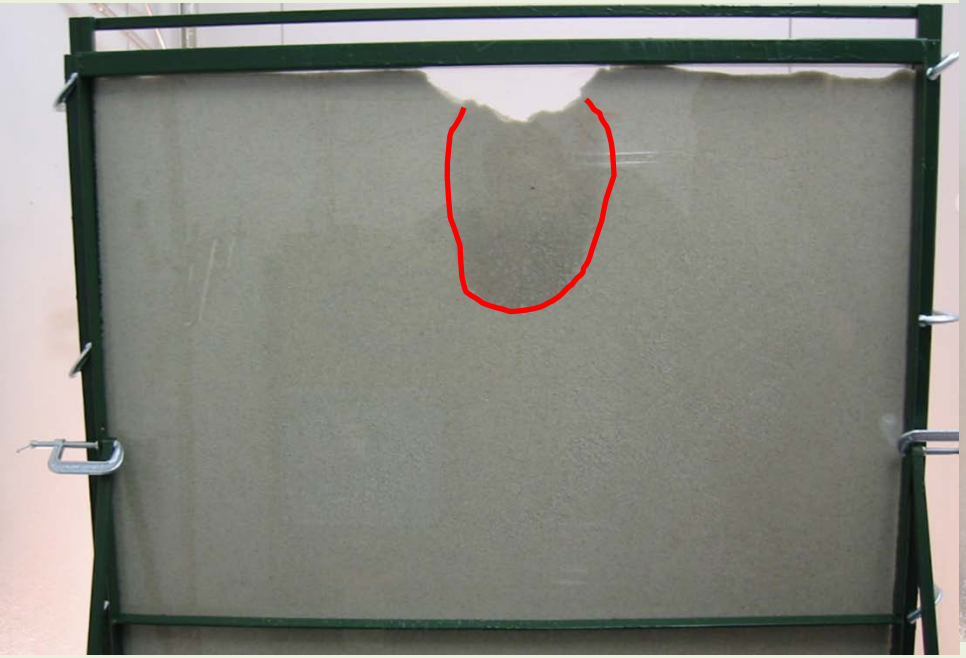
- Minimal penetration of oil below the top moss layer.
- Increased viscosity of oil limited downslope migration.
- Migration recommenced in summer.

Infiltration in Coarse Grain Soils
2-D Lab Studies

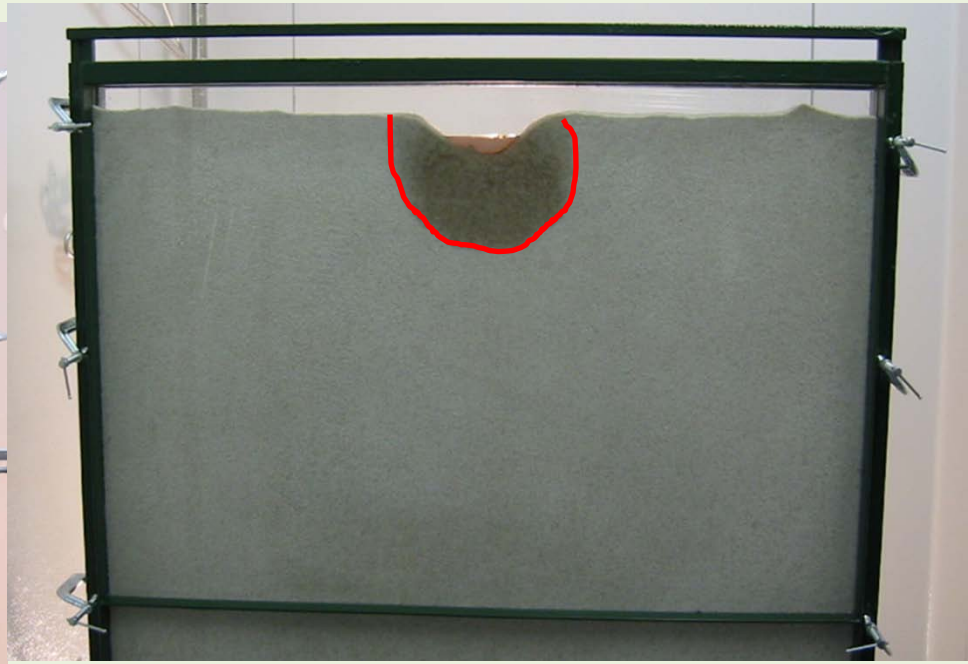
Purpose

Determine qualitatively the influence of pore ice on the movement of petroleum hydrocarbons through soil.

Infiltration of JP 2 into Homogenous Medium Grain Sand
One Minute After Introduction into Flume

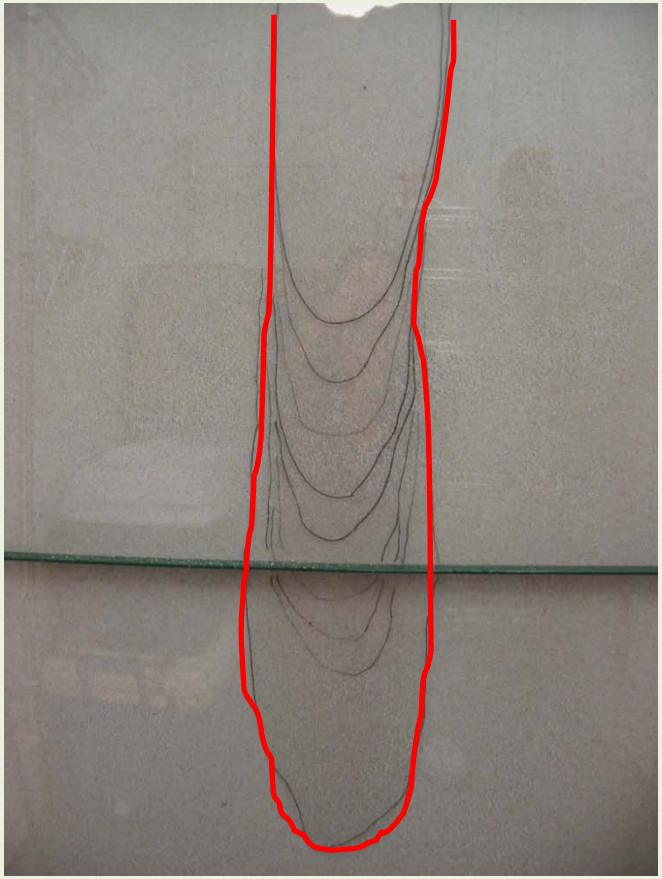


26% Ice Saturation

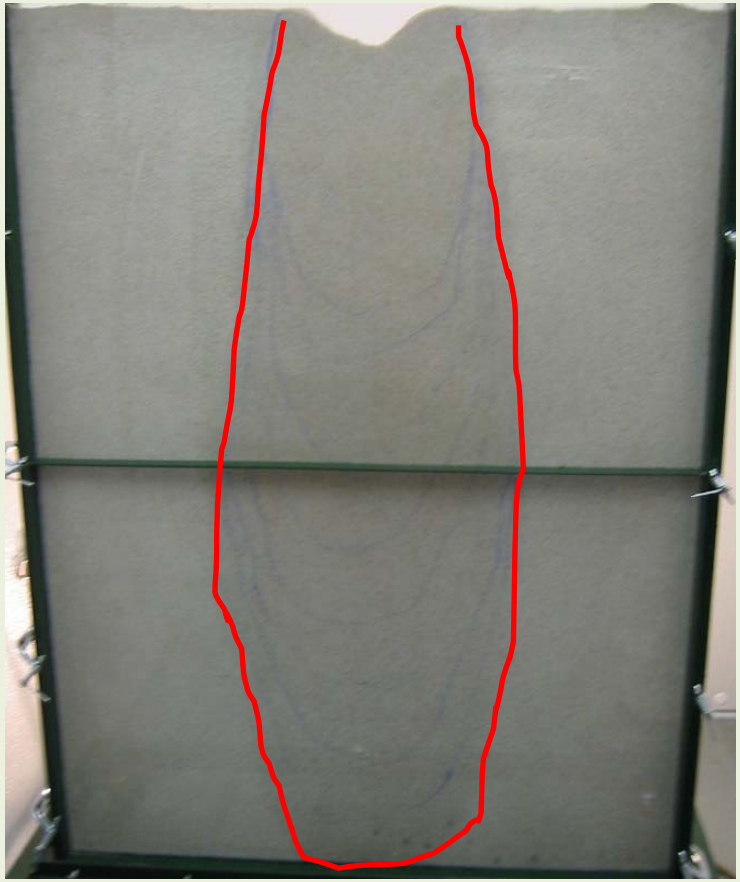


54% Ice Saturation

Infiltration of JP 2 into Homogenous Medium Grain Sand
24 Hours After Introduction into Flume

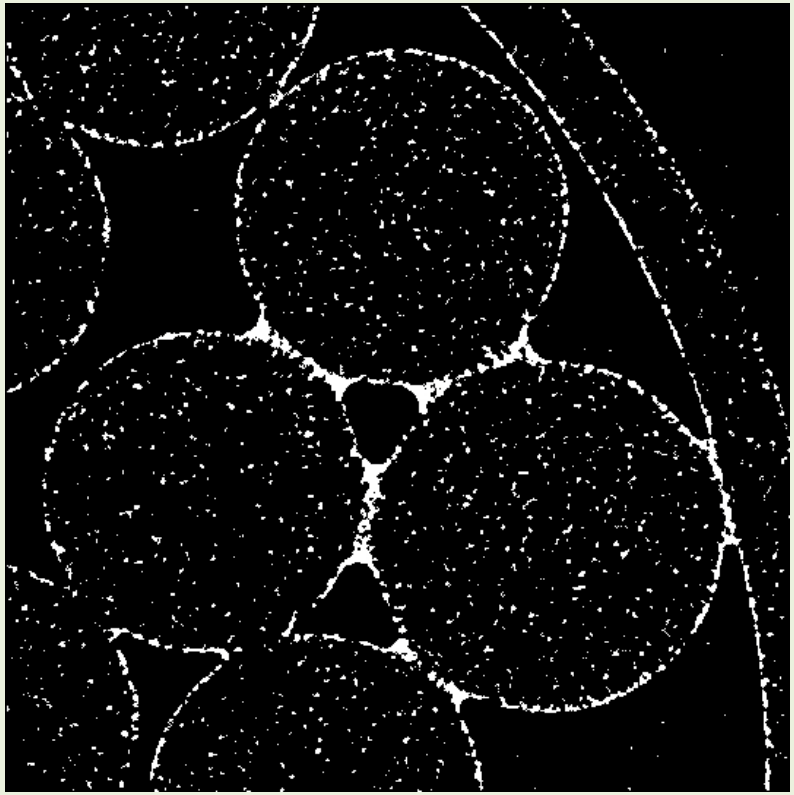


26% Ice Saturation

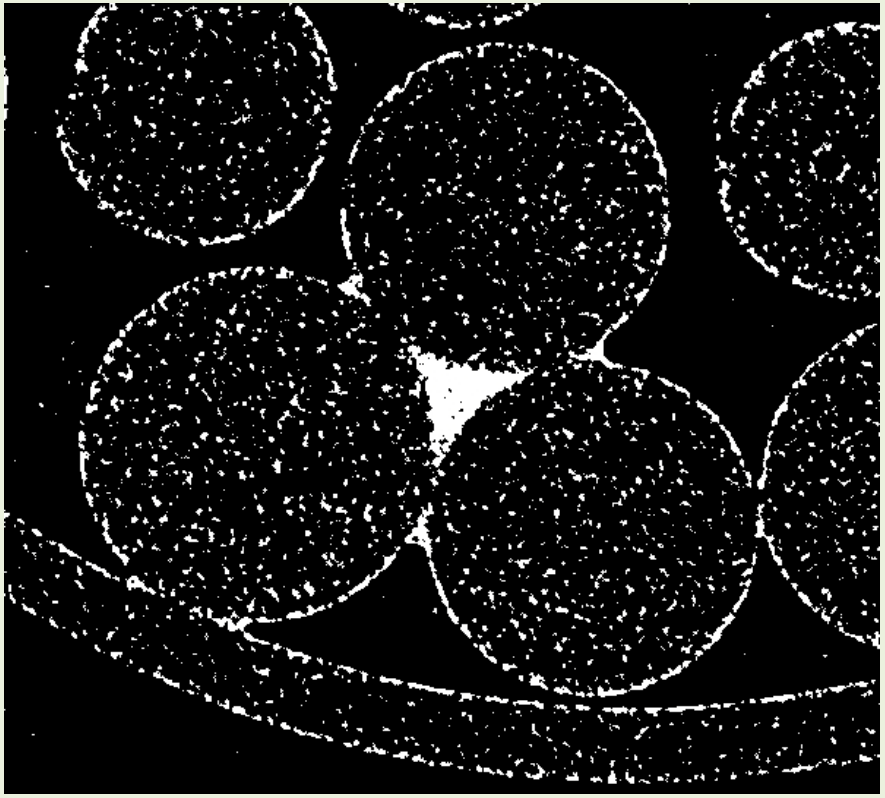


54% Ice Saturation

Preferential Flow Paths – Pore Scale

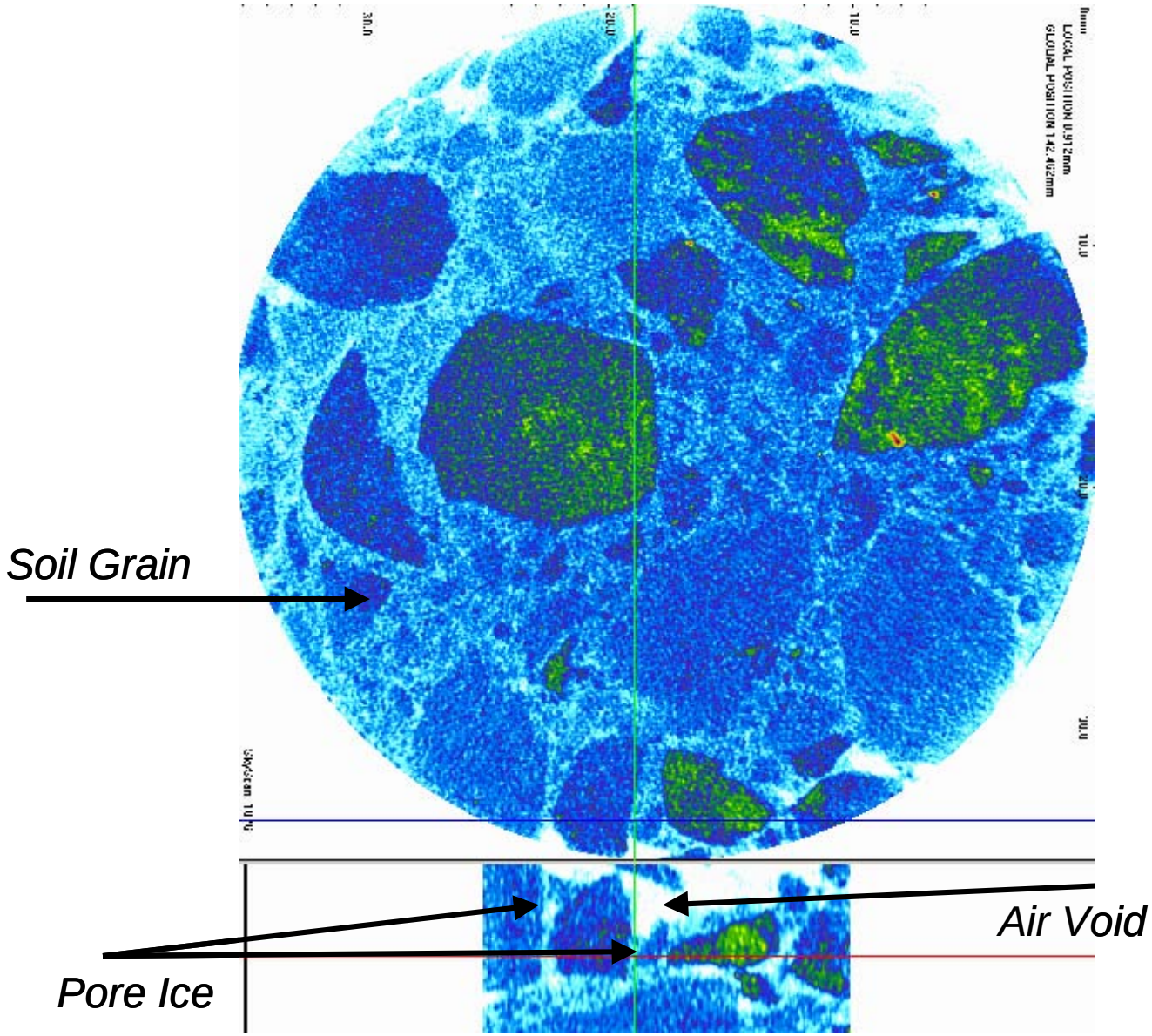


(a)

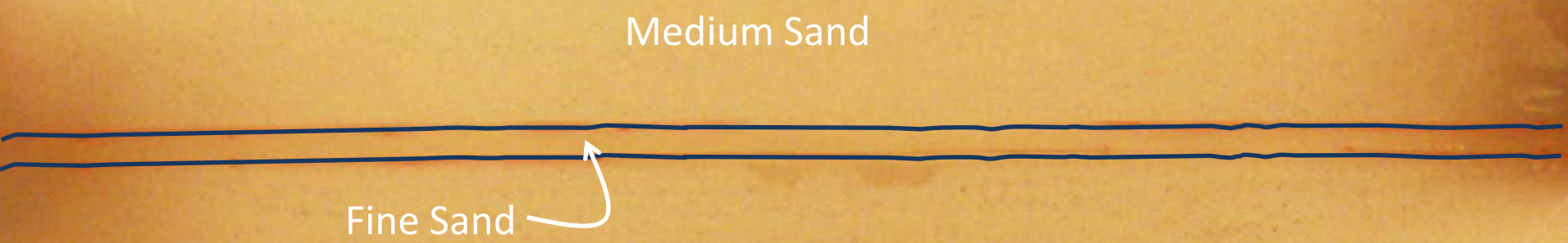


(b)

X-Ray CT Evidence of Blocked Pore Space Formation



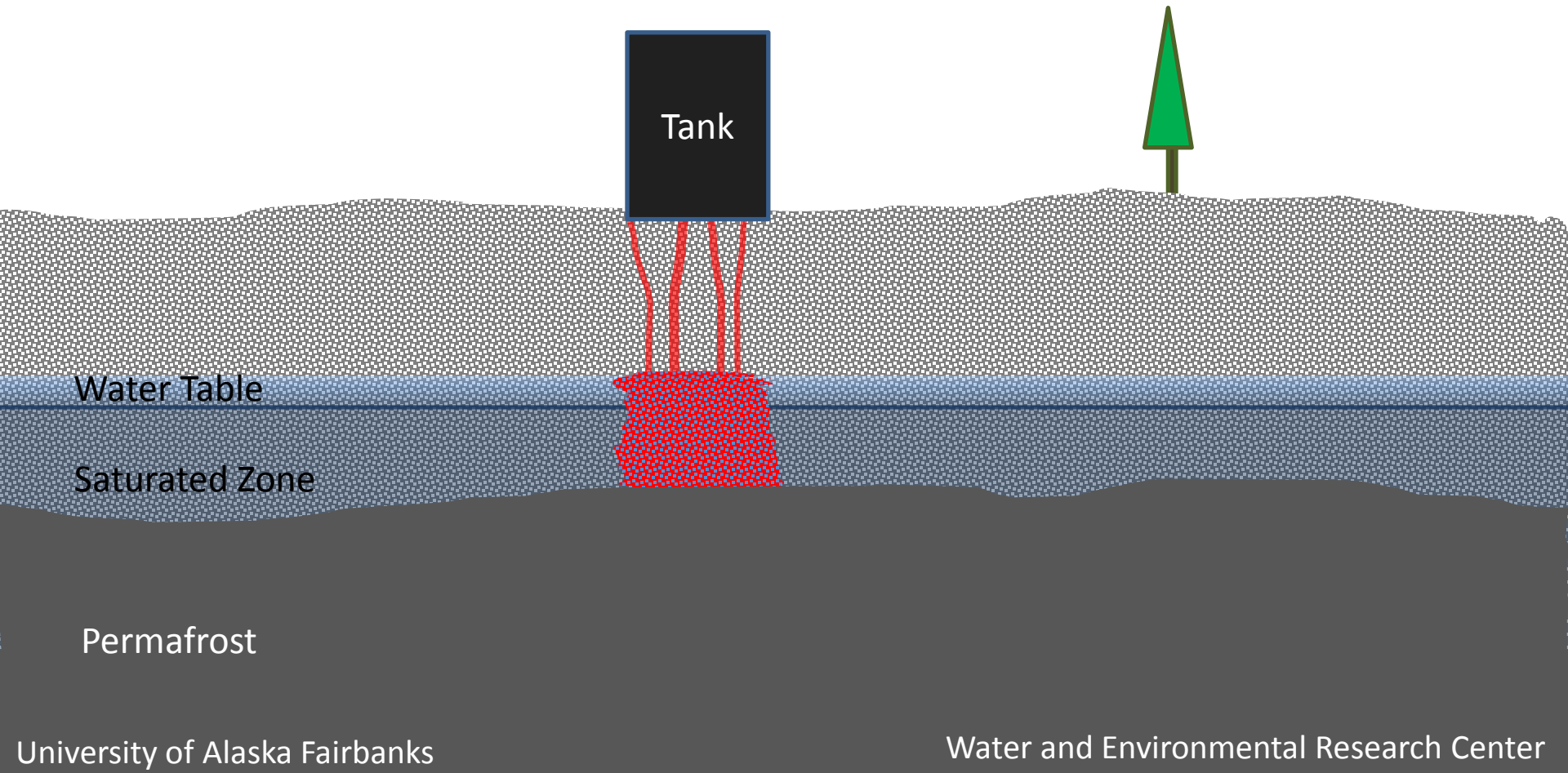
Petroleum Migration Through Layered Soils



frozen 5.wmv

unfrozen 2.wmv

Infiltration into Suprapermafrost Ground Water Characterized by Small Saturated Depths



Petroleum Saturation in Shallow Aquifers

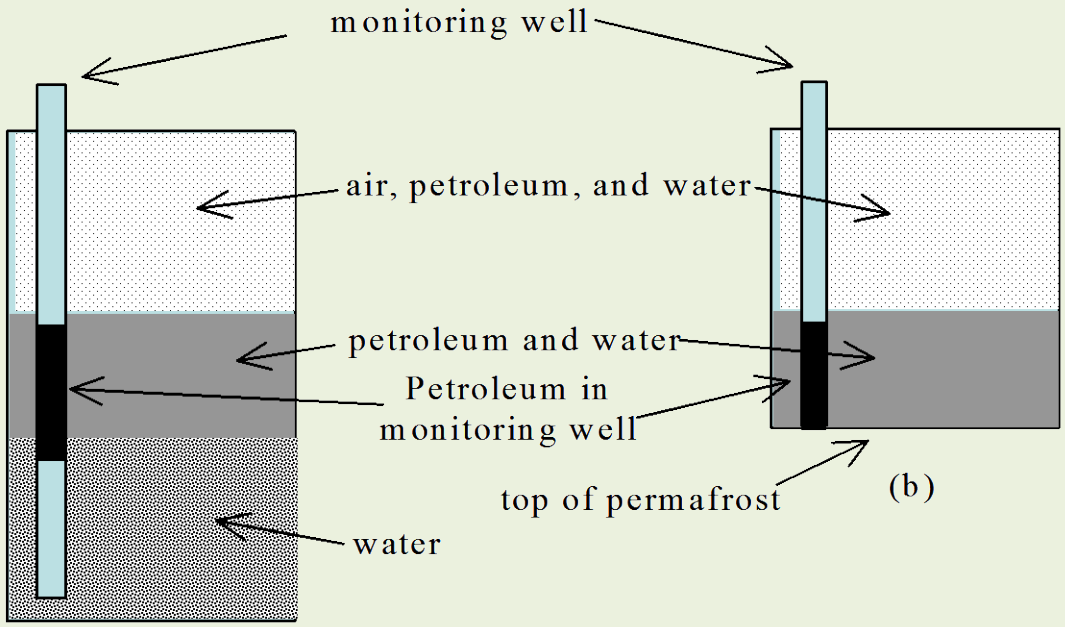
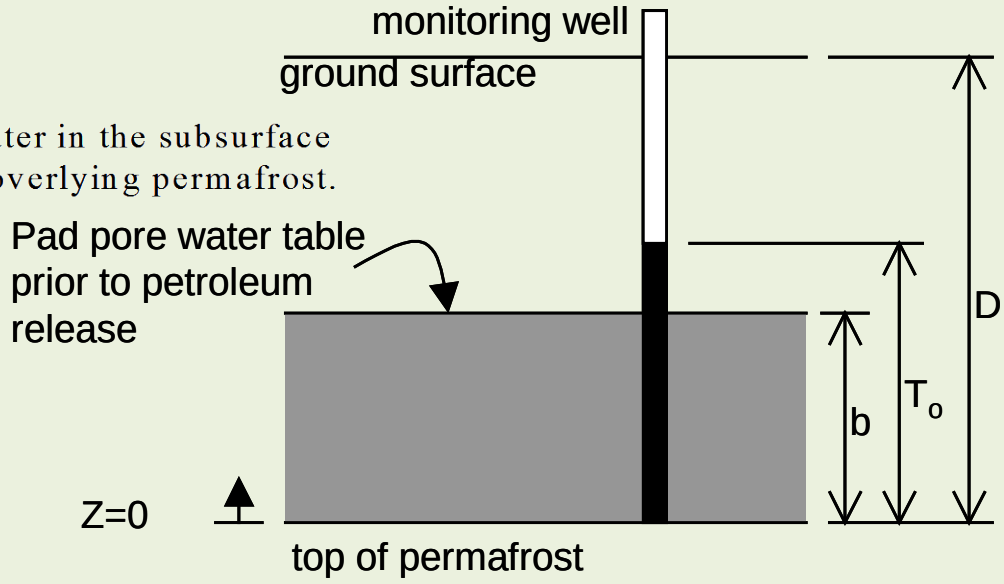
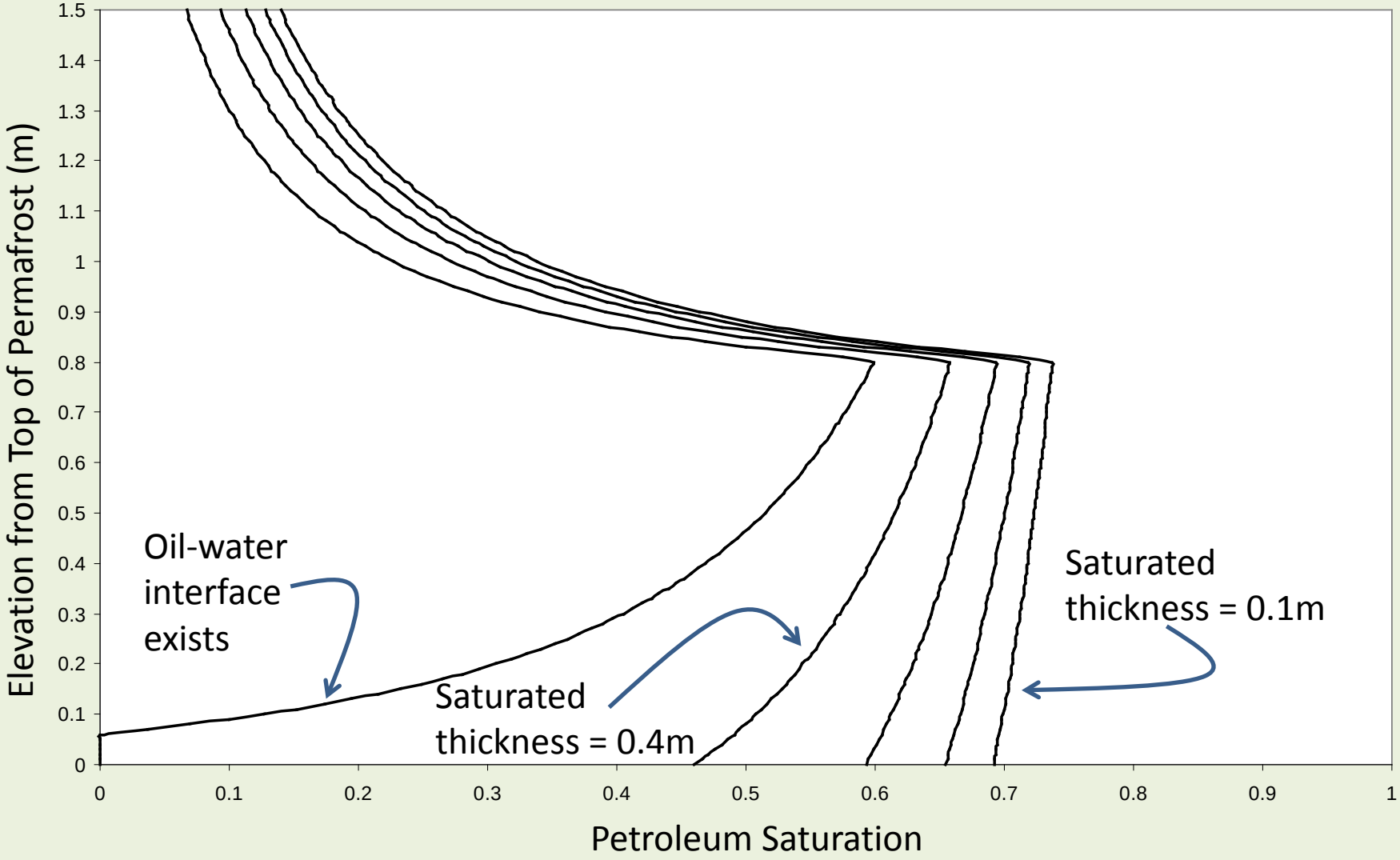


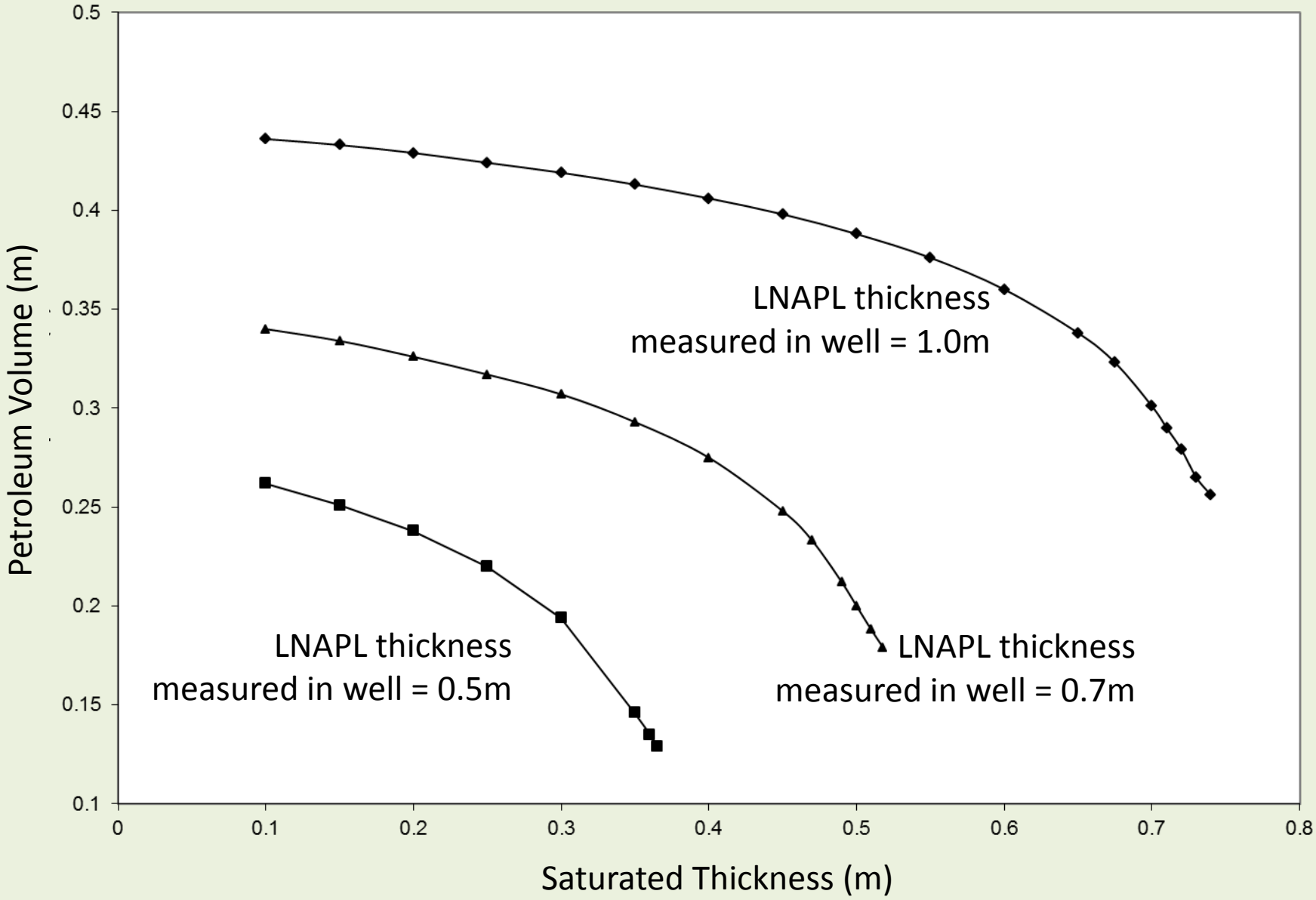
Figure 4. Distribution of air, peteroleum, and water in the subsurface for (a) a deep aquifer, and (b) a shallow aquifer overlying permafrost.



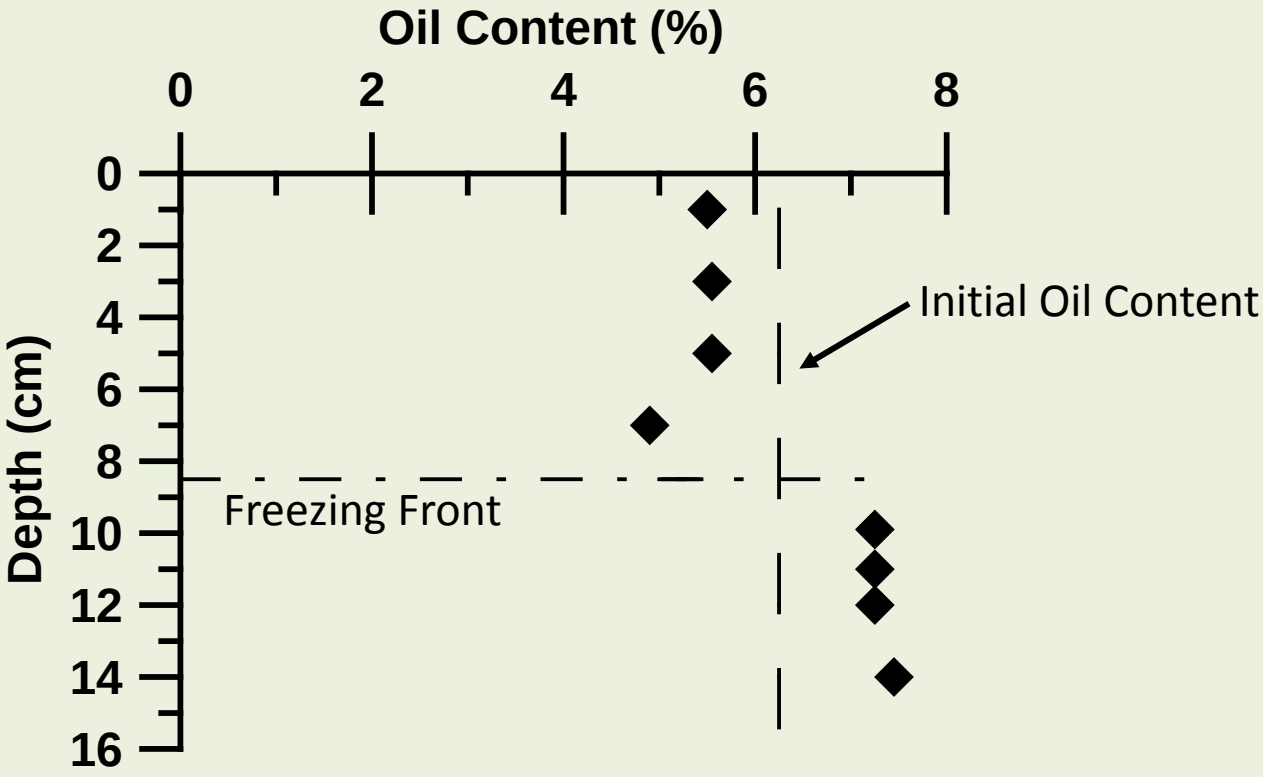
Petroleum Saturation as a Function of Saturated Zone Thickness



Petroleum Volume as a Function of Saturated Thickness



Displacement of Petroleum

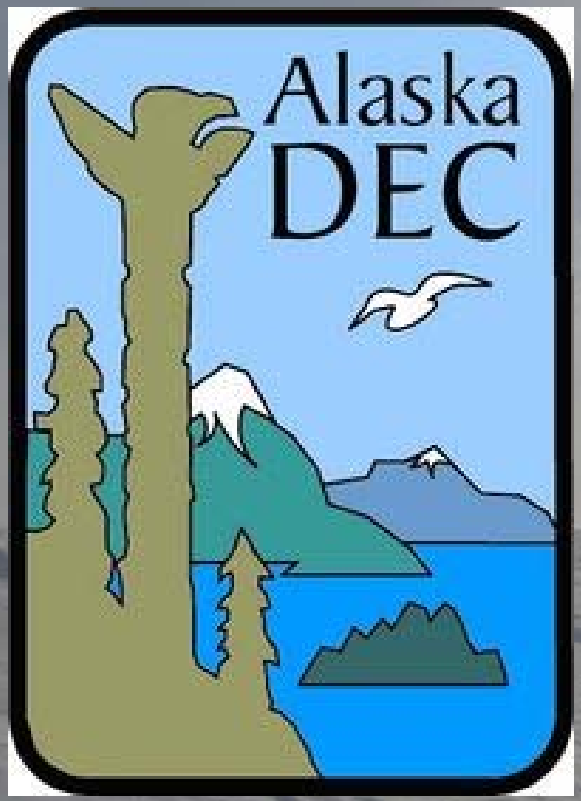


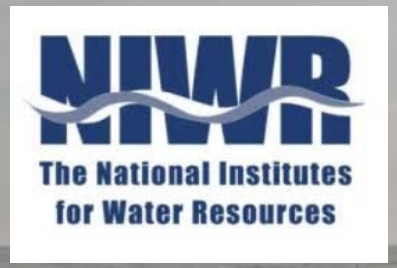
Reproduced from Chuvilin et al., 2001

Conclusions

1. Fine grain soils and high water saturations control migration during thawed months.
2. Presence of pore-ice can result in the creation of preferential flow paths resulting in wider lateral petroleum distributions than may be expected.
3. Preferential flow paths in frozen soil may result in LNAPL migrating into permafrost.
4. Freeze and thaw cycling can remobilize petroleum.
5. Shallow nature of the active layer and thin saturated zone impacts vertical distribution of petroleum and subsequent dissolved phase plume

Funding Sources





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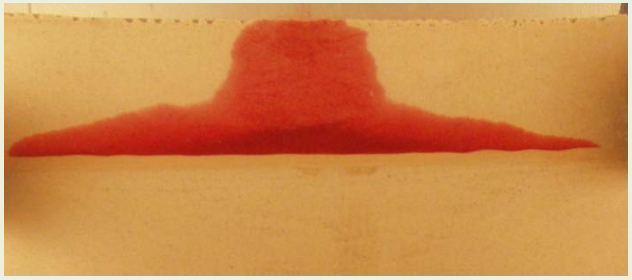
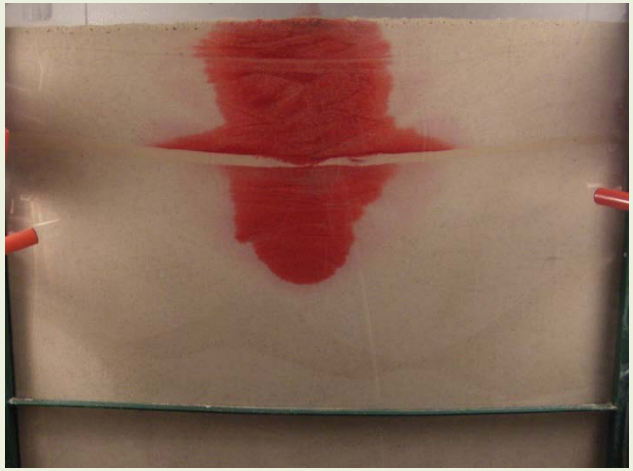
Questions?

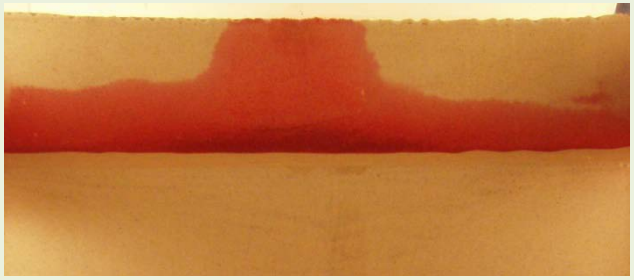
Petroleum Migration Through Frozen and Unfrozen Layered Soils

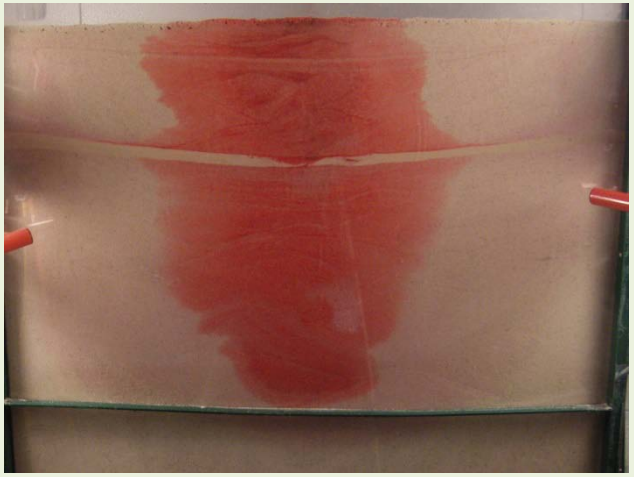
1 hour





1 day





After Frozen Soil Thawed