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Fast Flow in Unsaturated Coarse Sediments

Tetsu K. Tokunaga, Jiamin Wan, and Keith Olson
Lawrence Berkeley National Laboratory
1 Cyclotron Road, 90-1116
Berkeley, CA 94720
510-486-7176
tktokunaga@lbl.gov

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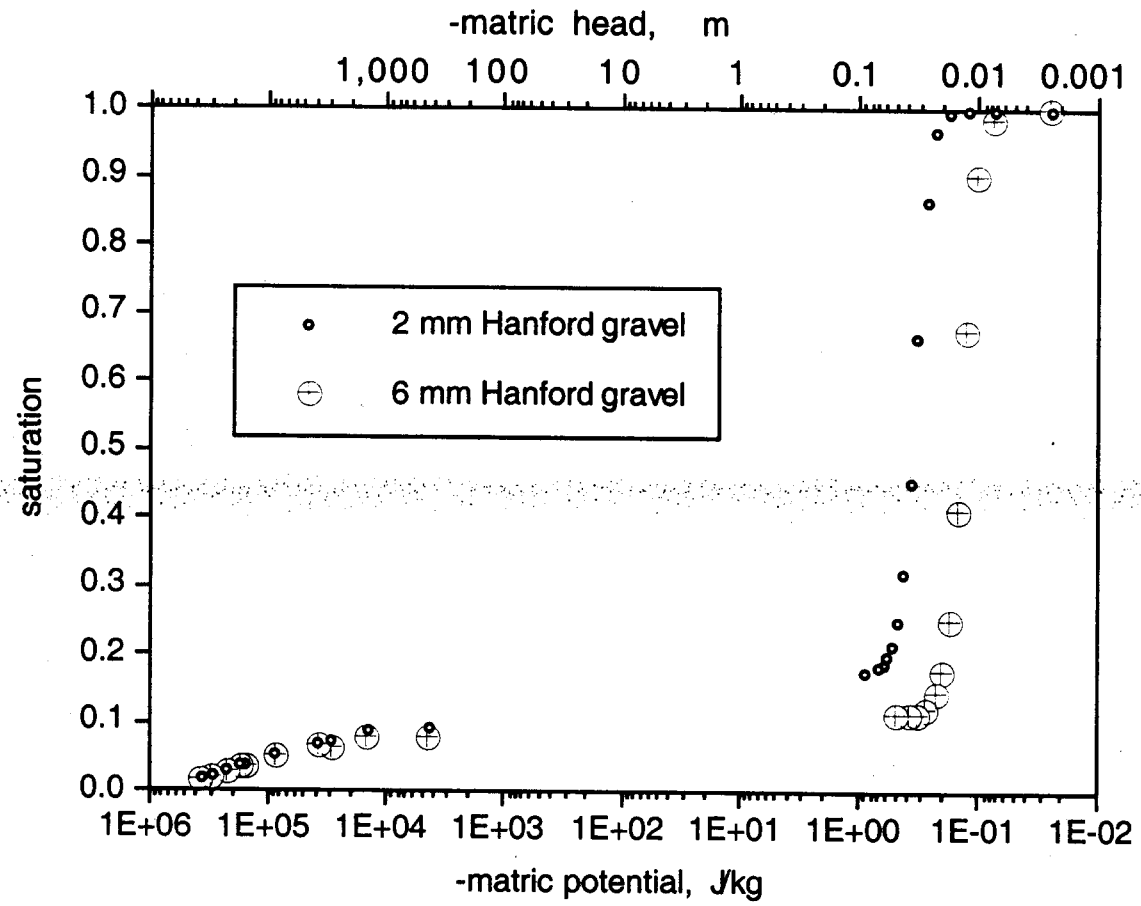
Why Study Unsaturated Hydraulic Properties of Gravels in the Near-Zero Matric Potential Region?



1. This energy region is where the most significant changes in hydraulic properties occur.

2. This is the only unsaturated region where fast flow can occur.

3. This is the region in which capillary barrier failure occurs.

4. We hypothesize that this strongly gravity-influence region will exhibit significant deviations from capillary scaling behavior.

5. We hypothesize that this energy region in gravels can exhibit turbulent, i.e. non-Darcy, unsaturated flow.

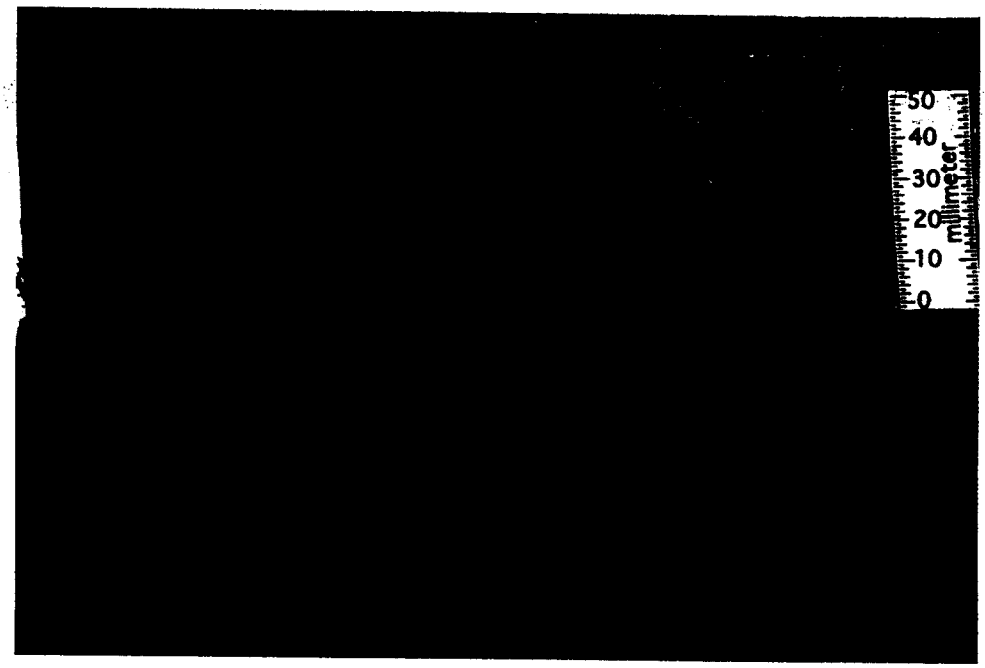
6. This energy region is largely unexplored in gravels.

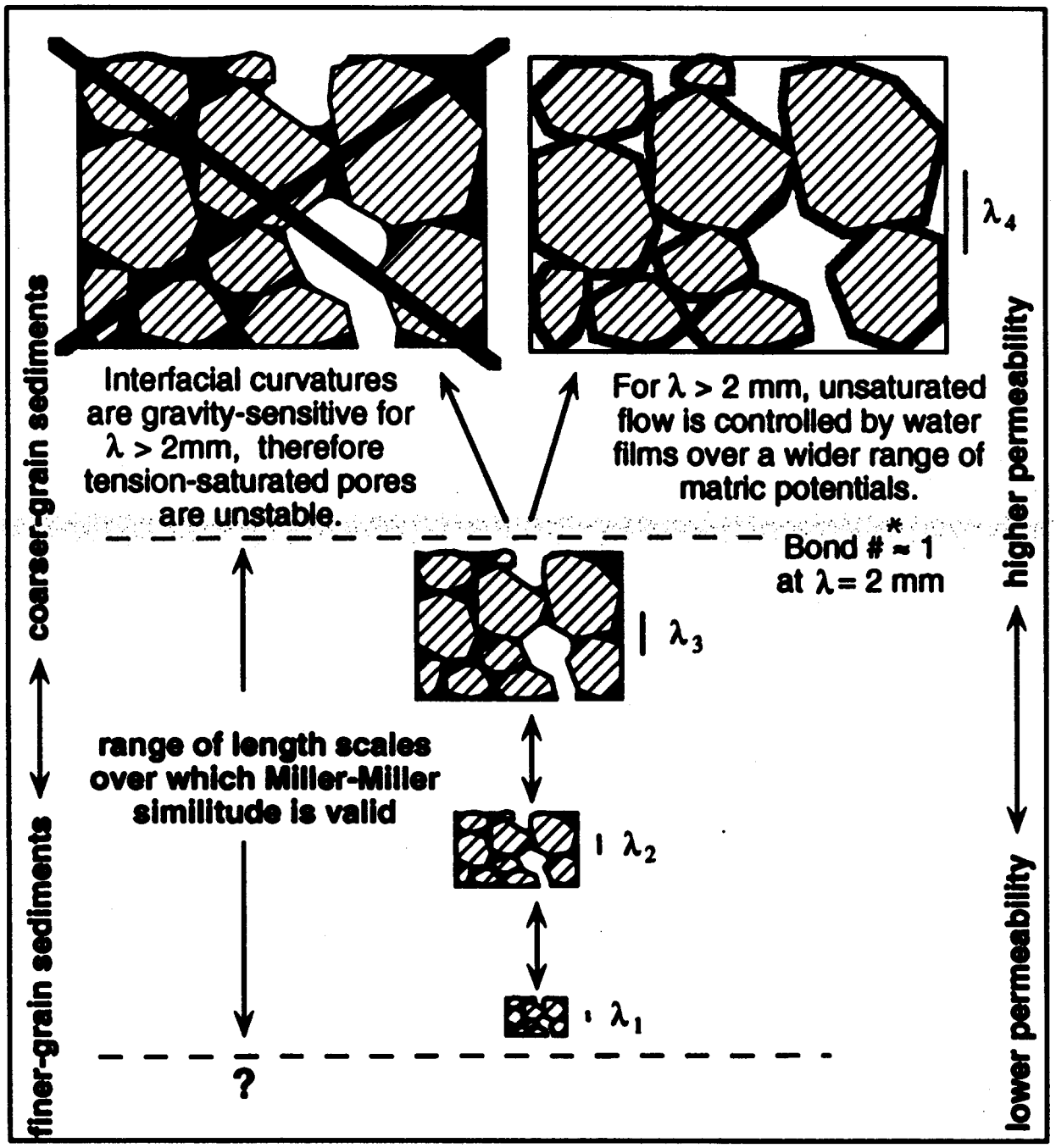
Hypotheses

Water films at near-zero matric potentials can enhance flow and transport in unsaturated coarse sediments.

Films of sufficient thickness and connectivity permit significantly faster flow than predicted by classical scaling theory.

Grain surface topography can exert strong controls on thick film connectivity.


50
40
30
20
10
0
millimeter



Capillary Scaling of Sediment Hydraulic Properties Has It Limits

$$^{*}\text{Bond \#} = \frac{\text{gravity } F}{\text{surface tension } F} = \frac{\rho g L^2}{\sigma}$$

Methods

Macroscopic measurements

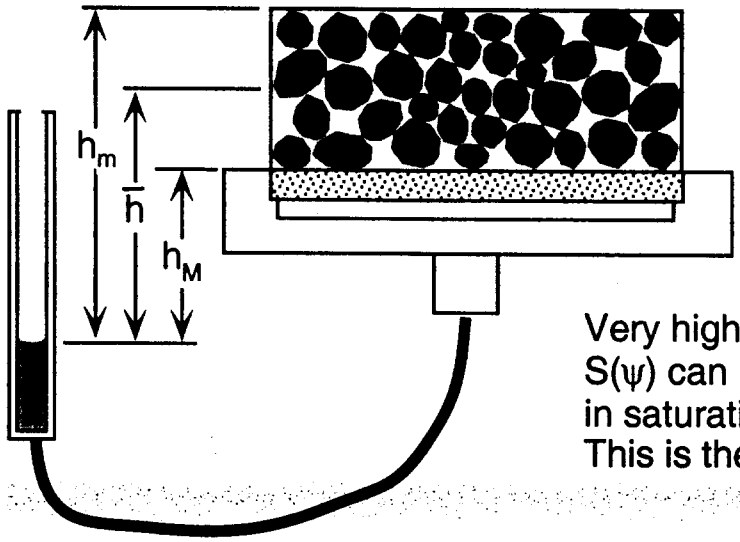
- Moisture characteristics (w. gravity correction)
- Water vapor adsorption isotherms
- Unsaturated hydraulic conductivities

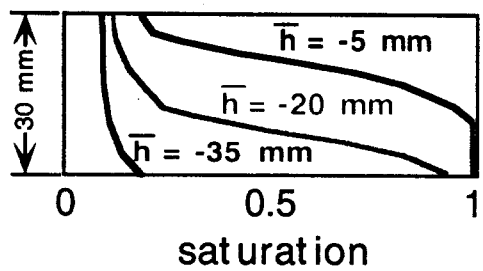
Microscopic (grain surface, film) measurements

- grain topography
- water film thicknesses
- water film transmissivities

Scaling analyses

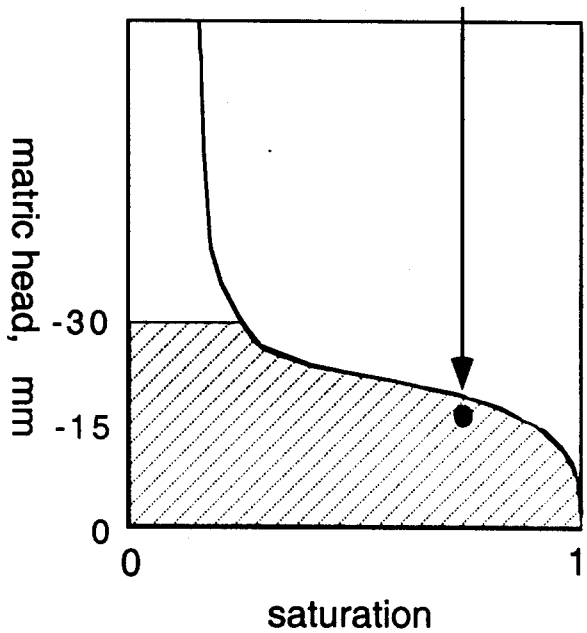
Gravity (high Bond #s) can complicate measurements and interpretations of unsaturated hydraulic properties in very coarse, granular sediments.



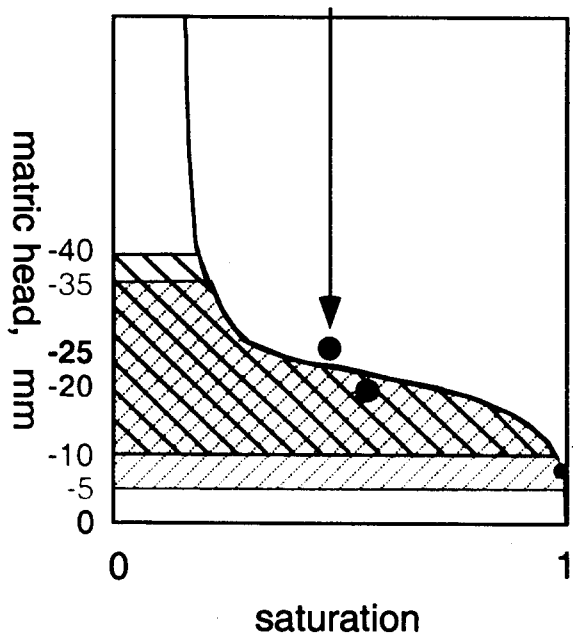


Very high moisture capacity regions of $S(\psi)$ can lead to unaccounted variability in saturation, hence wrong $S(\psi)$ and $K(\psi)$. This is the case for gravels.

The measured average saturation can be less than that associated with the average matric potential.



The measured average saturation can also be more than that associated with the average matric potential.



Measurements obtained with small increments in average matric potential change can be used collectively to improve resolution of moisture characteristics.

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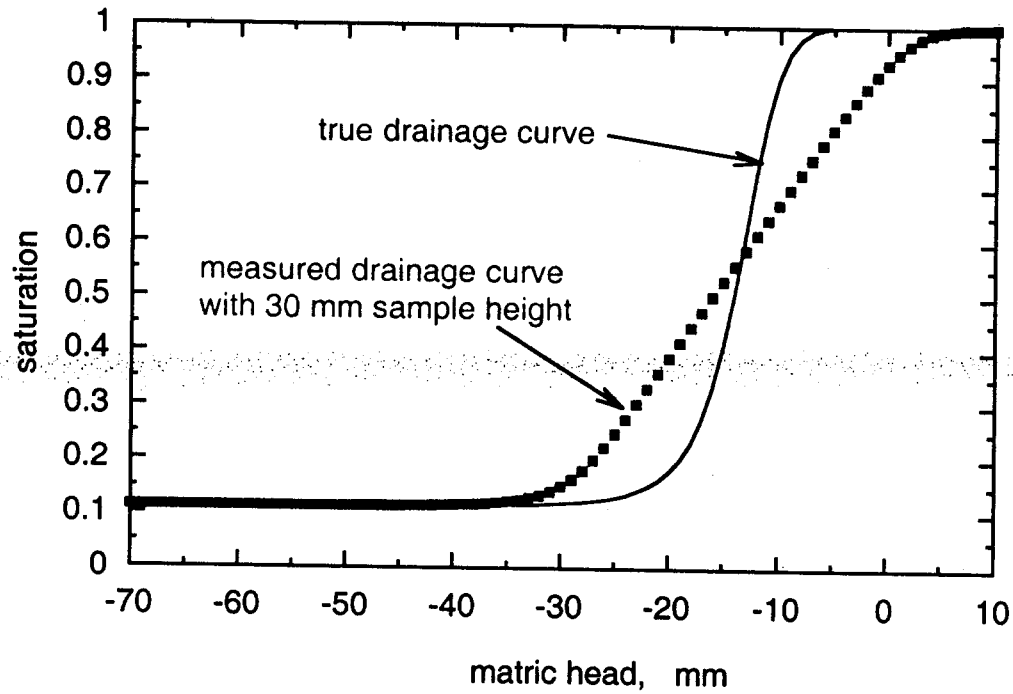
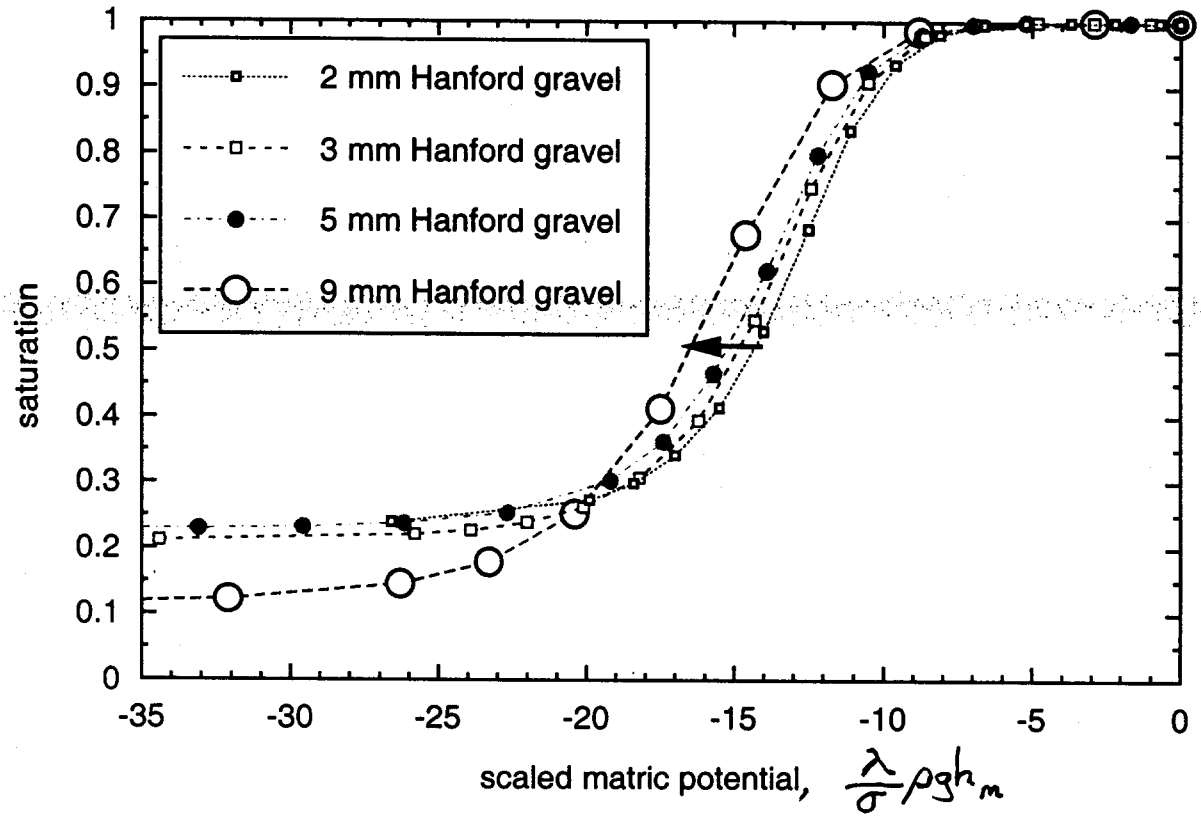

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
saturation
true drainage curve
measured drainage curve
with 30 mm sample height
-70
-60
-50
-40
-30
-20
-10
0
10
matric head, mm

Gravity-corrected Moisture Characteristics Exhibit Shifts to Higher Saturations in the Inflection Region of Scaled Drainage Curves



To what extent can this be attributed to thicker water films at near-zero matric potentials of very coarse sediments?

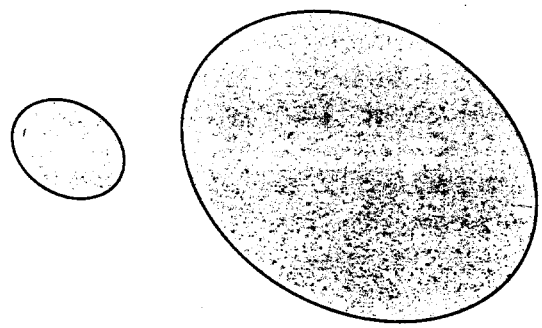
How well connected are the local topographic minima (channels) on grain surfaces?

What ranges of water film transmissivities are characteristic of the near-zero matric potential region for these gravels?

What accounts for the high "residual saturation" values of these gravels?

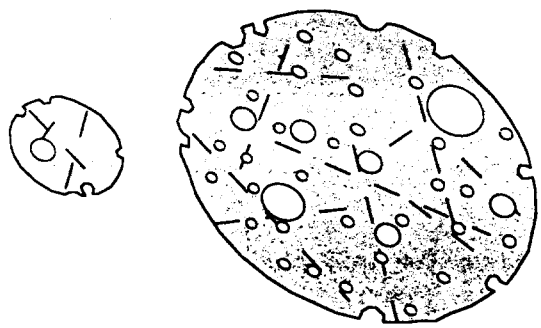
What Conceptual Model(s) Best Represent the Surface and Interior Hydraulic Structure of Gravel Particle?

(Hydraulically) smooth surface
Negligible internal porosity

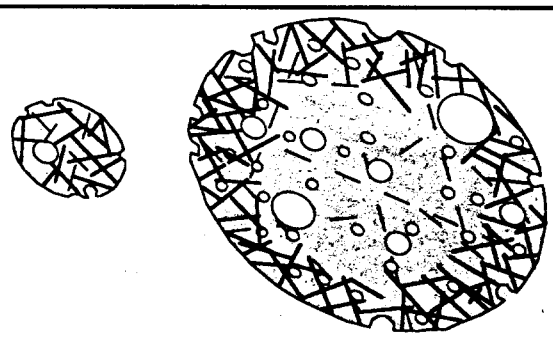


(Hydraulically) rough surface
Negligible internal porosity

(Hydraulically) rough surface
"Significant" internal porosity
(Hydraulically) insignificant
weathering porosity



(Hydraulically) rough surface
"Significant" internal porosity
(Hydraulically) significant
weathering porosity



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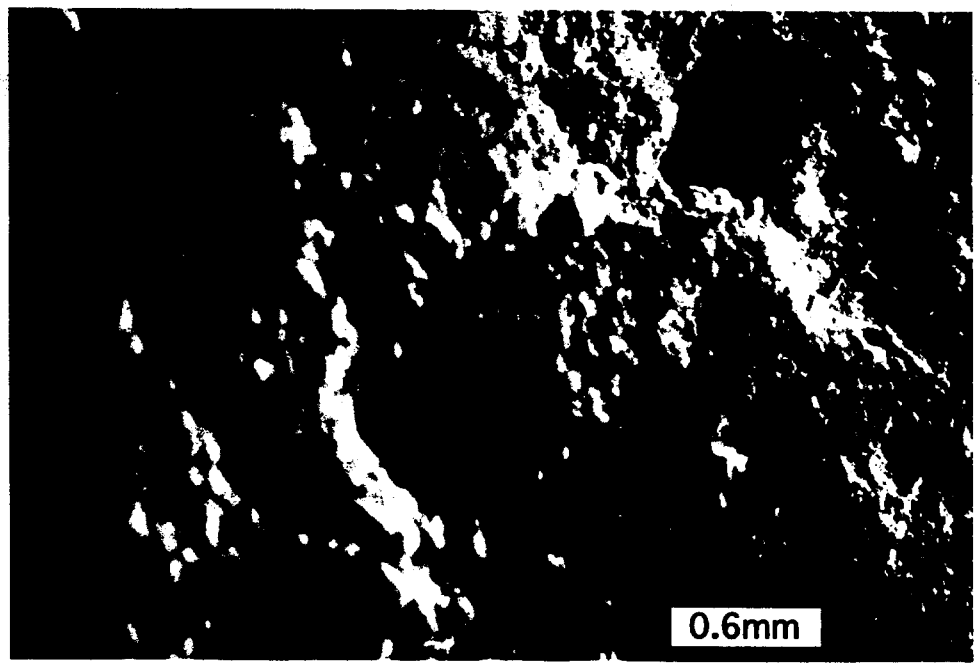
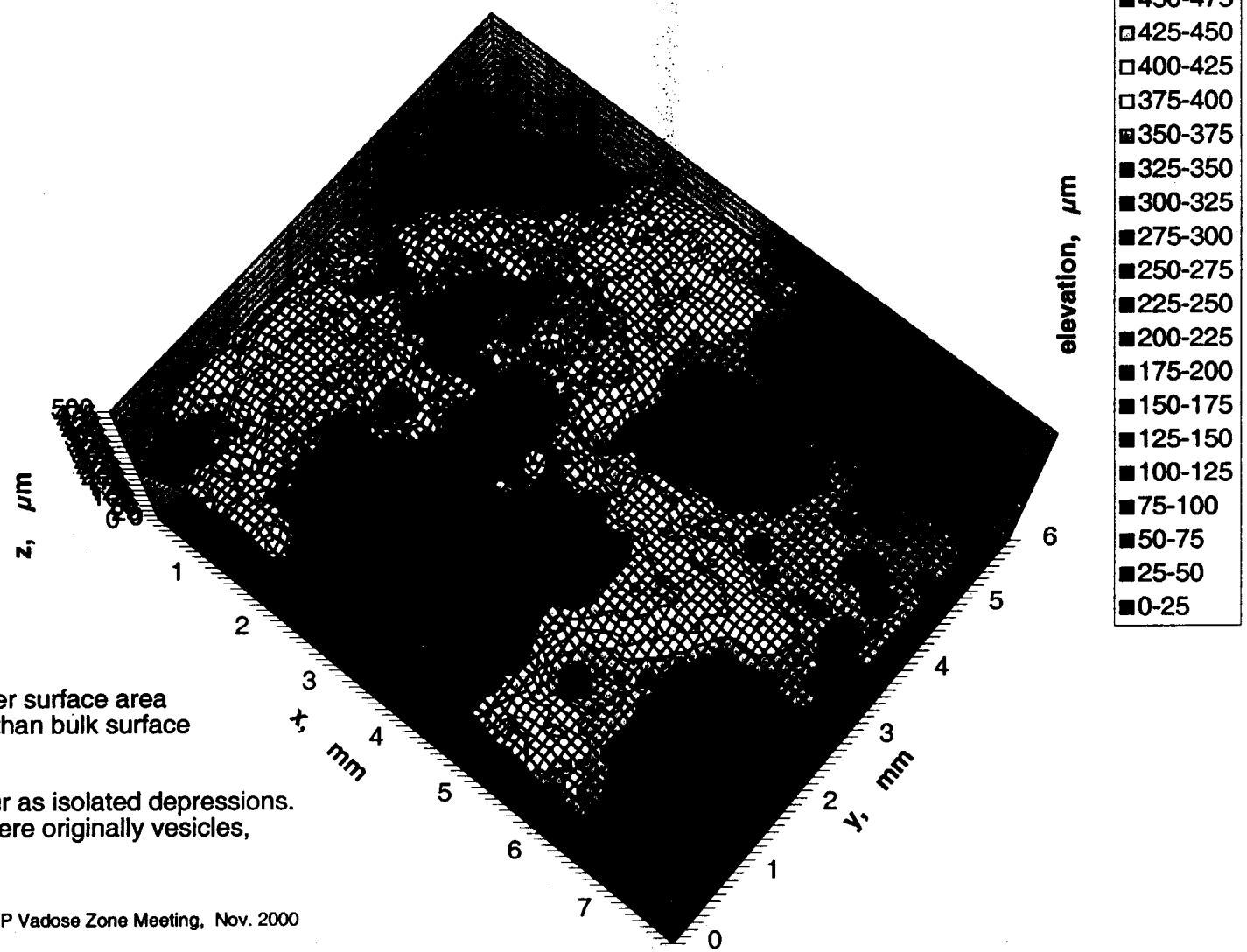

0.6mm

H3 laser scan



Micrometer-resolution, outer surface area is only about 10% greater than bulk surface area.

Major surface minima occur as isolated depressions. These local depressions were originally vesicles, exposed by weathering.

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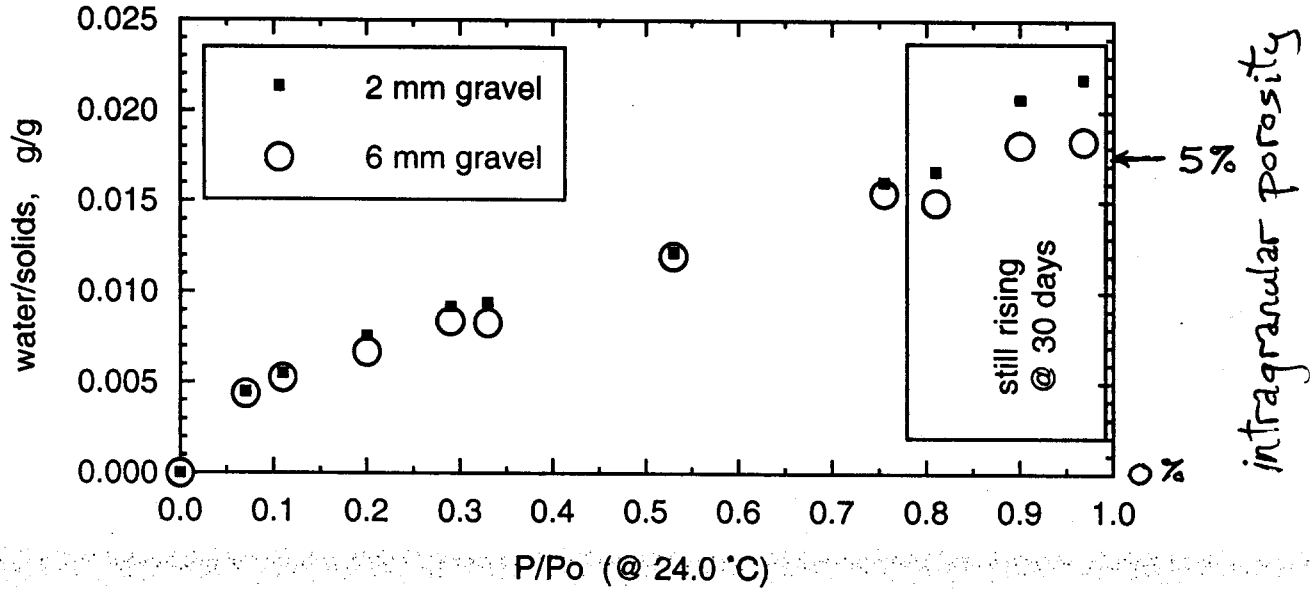
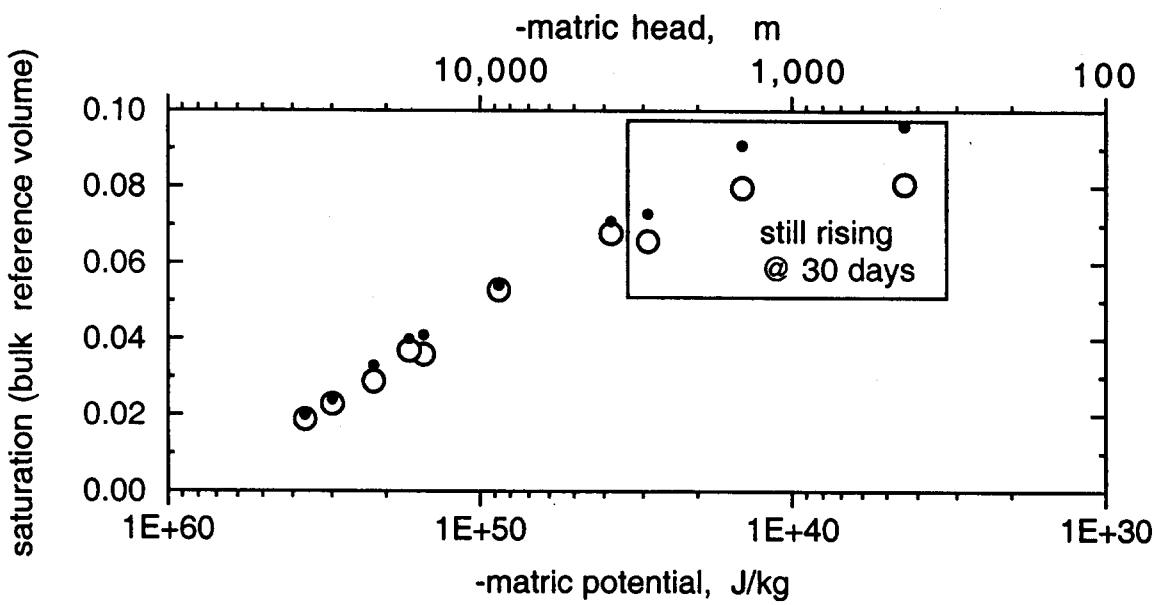
Water Vapor Adsorption Isotherms for Hanford Gravels

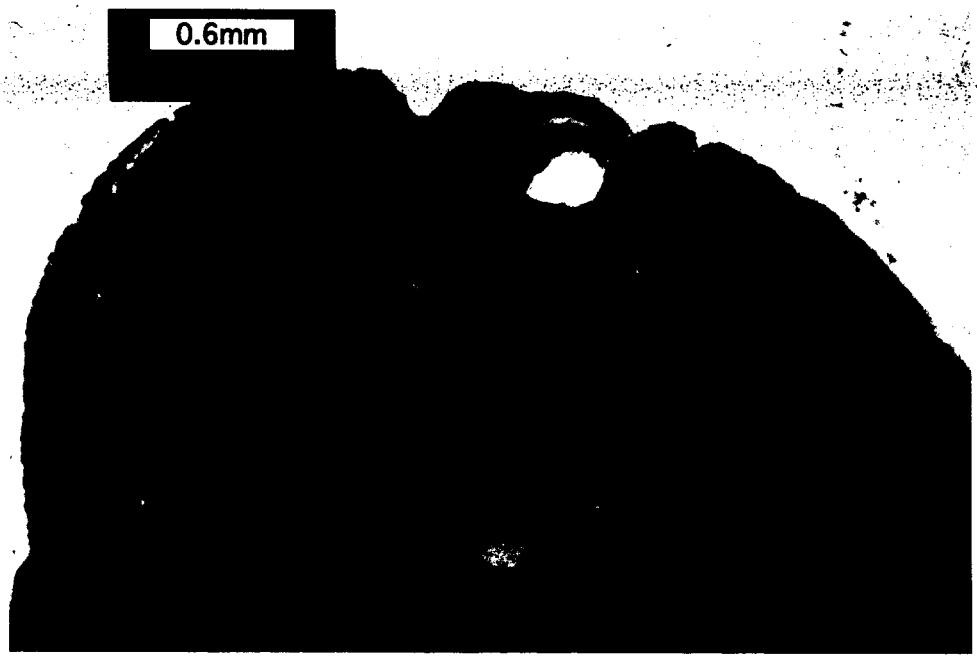


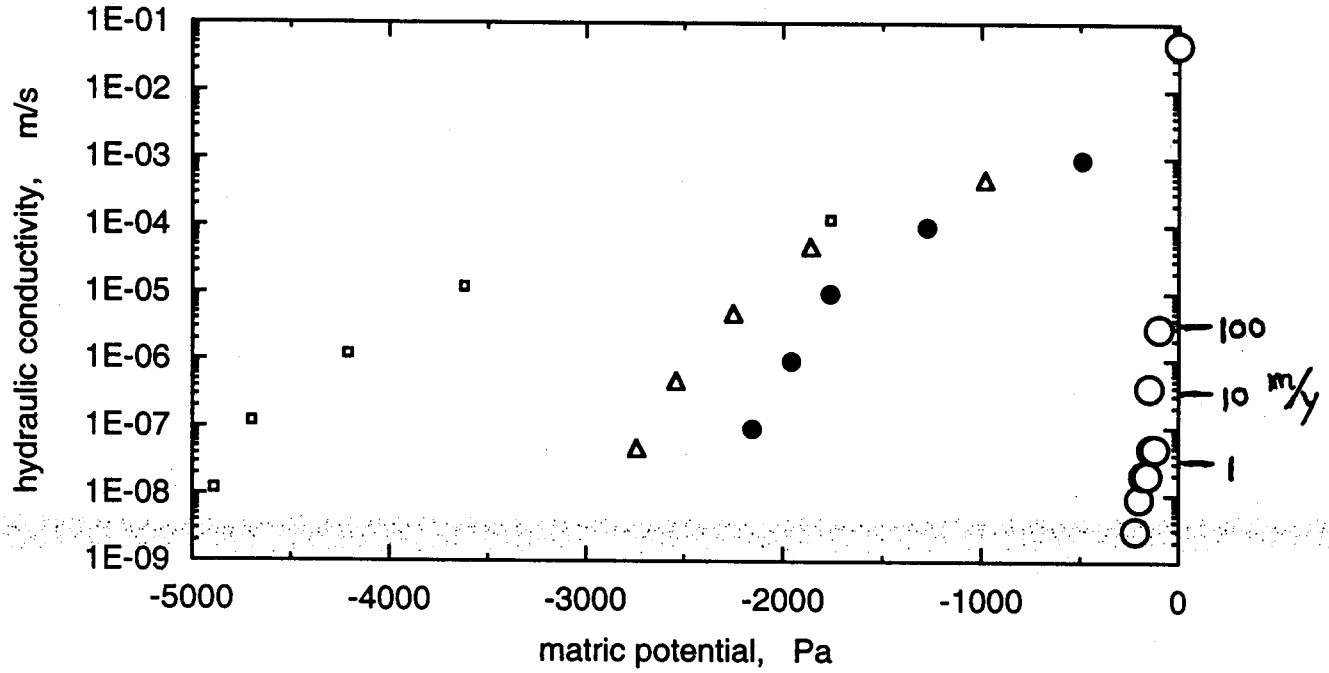


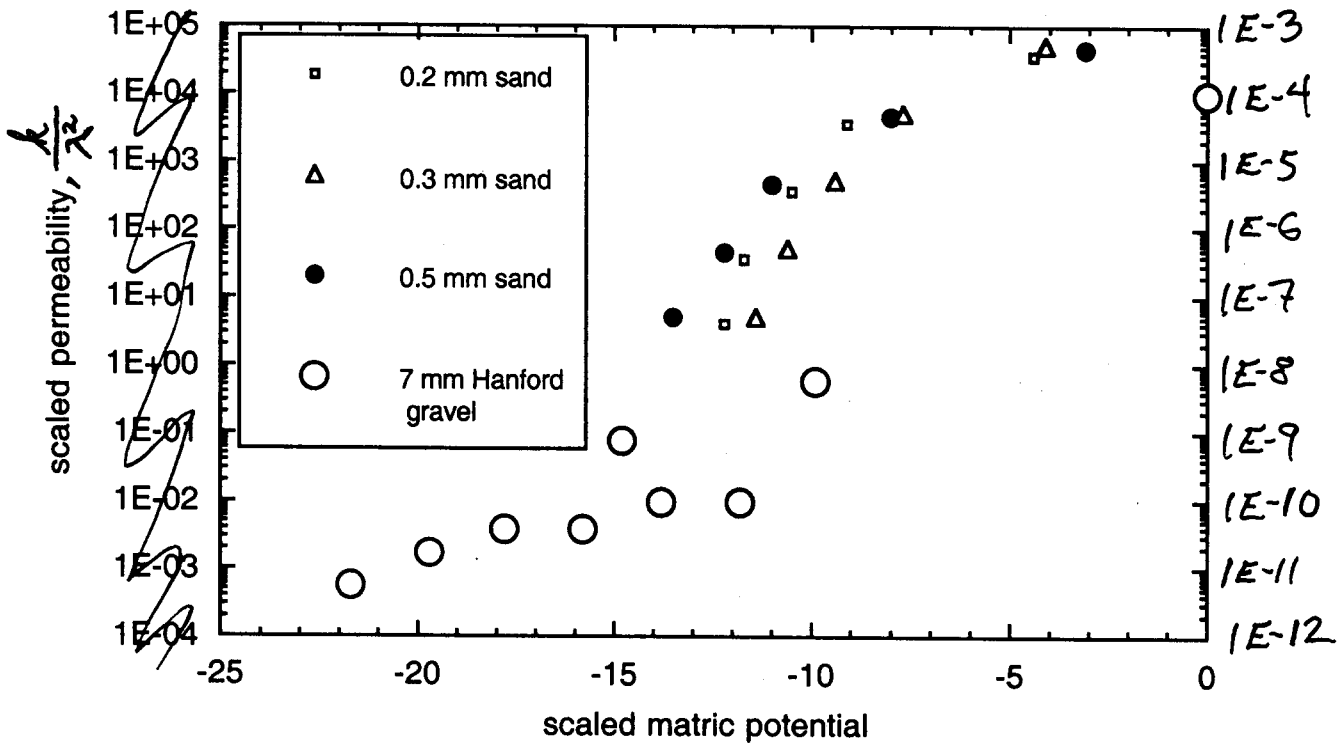
The high "residual" water content is largely adsorbed and condensed at very low (very negative) energies, hence is mostly "immobile".

Intragranular gravel porosity is a moderately large reservoir for slow, diffusion-limited solute exchange.

No measureable grain-scale-dependence to the low energy region of these adsorption isotherms. Intragranular porosity and pore structure is probably not very grain-size-dependent.


0.6mm





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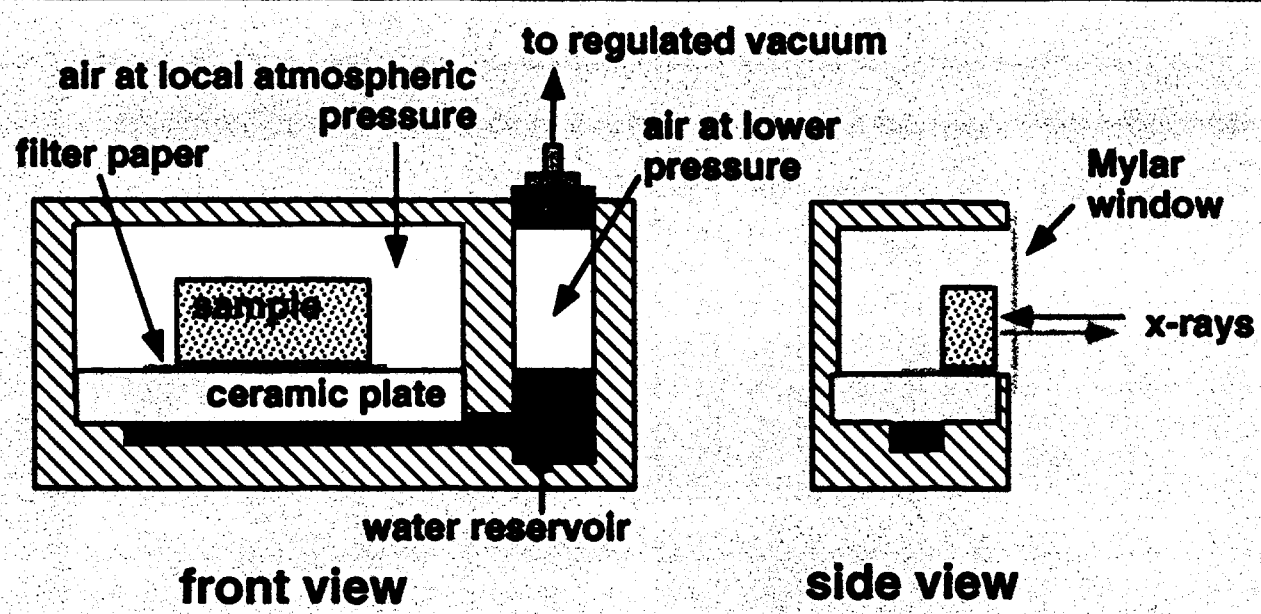
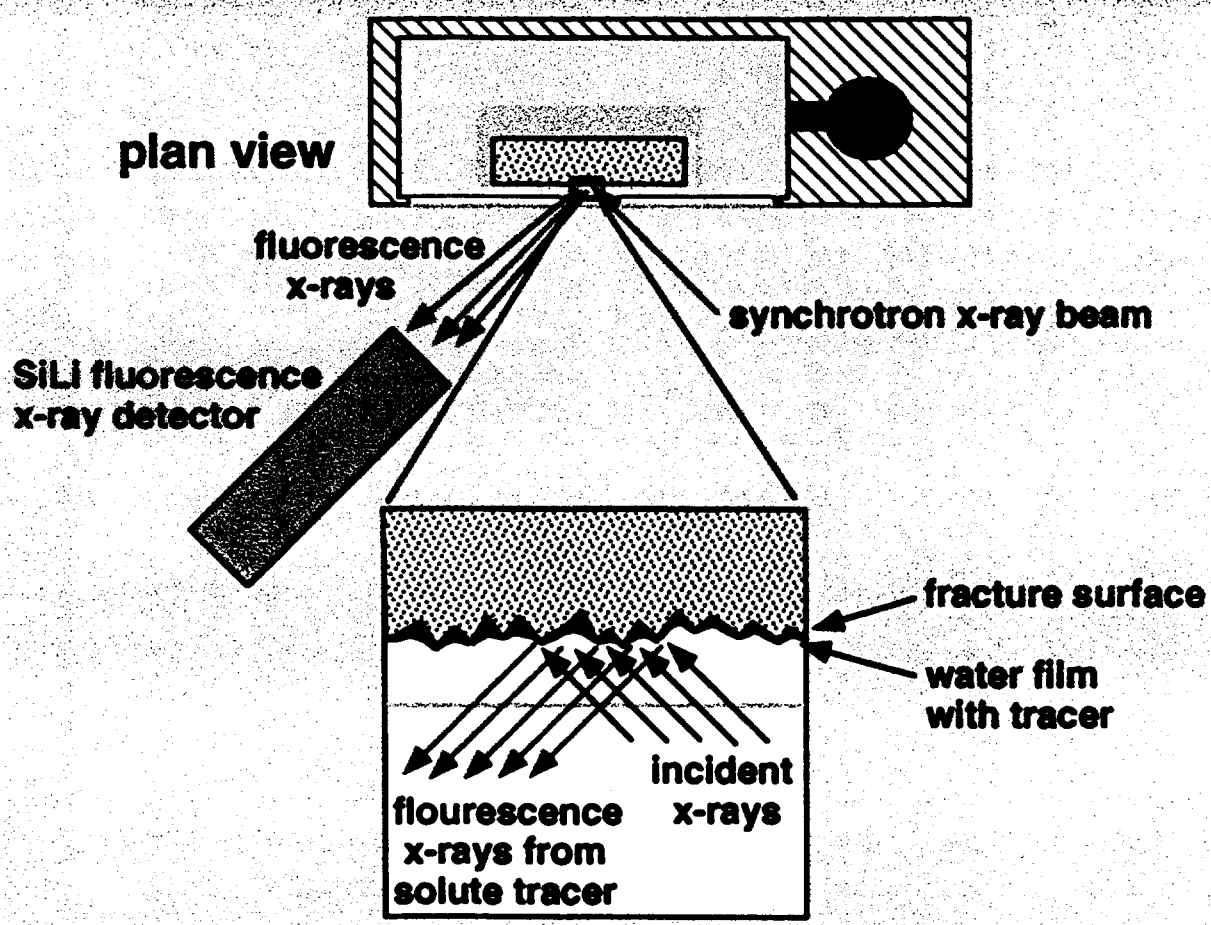
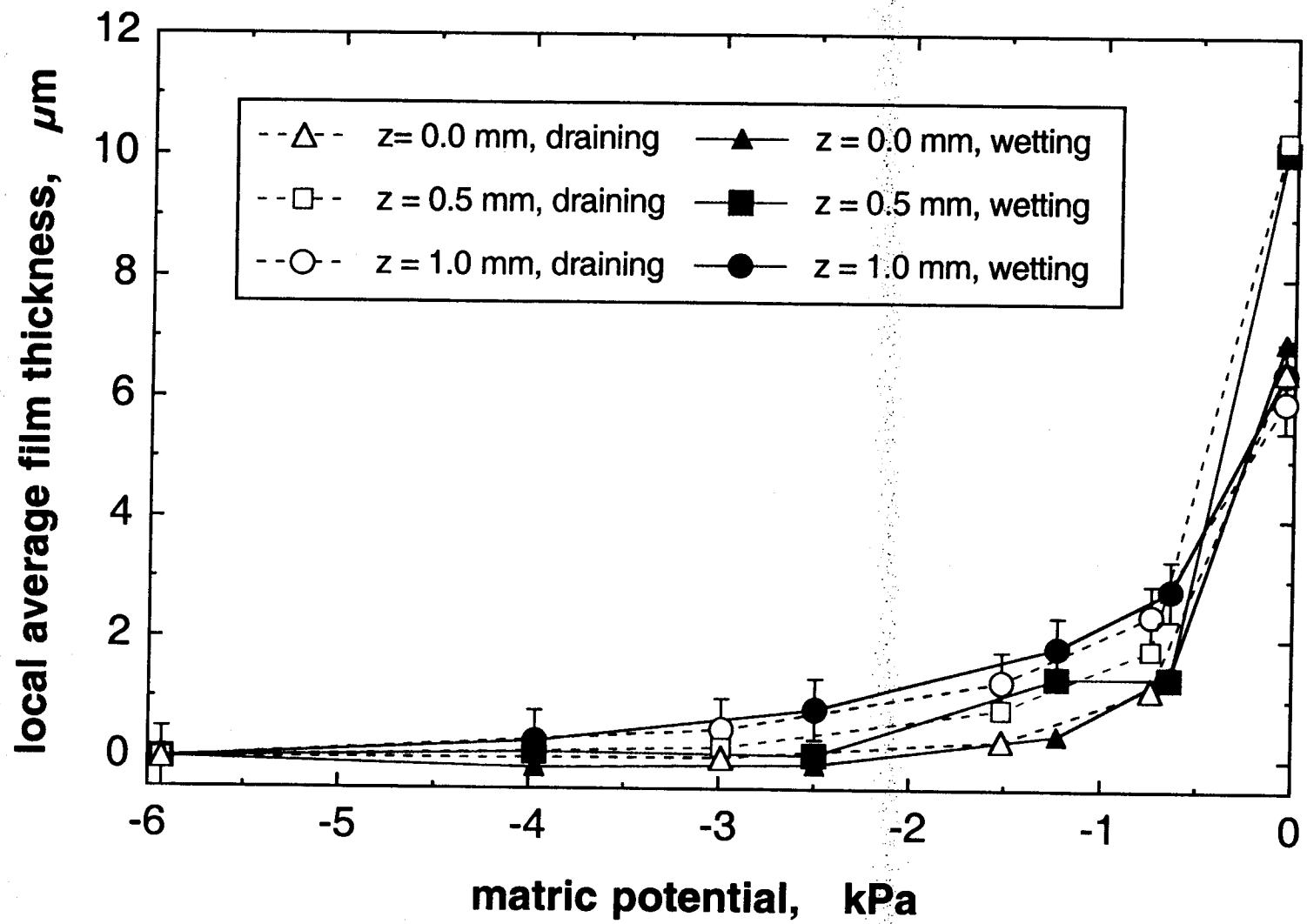




x-ray fluorescence from solute tracer is proportional to average film thickness


z= 0.0 mm, draining
z = 0.5 mm, draining
z = 1.0 mm, draining
z = 0.0 mm, wetting
z = 0.5 mm, wetting
z = 1.0 mm, wetting
local average film thickness, μm
matric potential, kPa
12
10
8
6
4
2
0
-6
-5
-4
-3
-2
-1
0

Results-Summary

Identified unsaturated flow in gravels as a frontier in vadose zone hydrology.

Developed new approaches for measuring unsaturated properties of gravels.

Identified significant intragranular porosity in Hanford basalt gravel.

Showed that grain surface topography strongly influences film flow.

Our measured $K(\Psi)$ show that fast, unsaturated flow is possible in Hanford gravels.

Acknowledgments

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Film flow concepts were originally developed through our BES Geosciences supported studies on flow in unsaturated fractures.