HWRS 505: Vadose Zone Hydrology

Lecture 6

9/7/2023

Today:

1. Air-water system in capillary tubes
2. Advanced porous medium models
3. Soil water characteristics

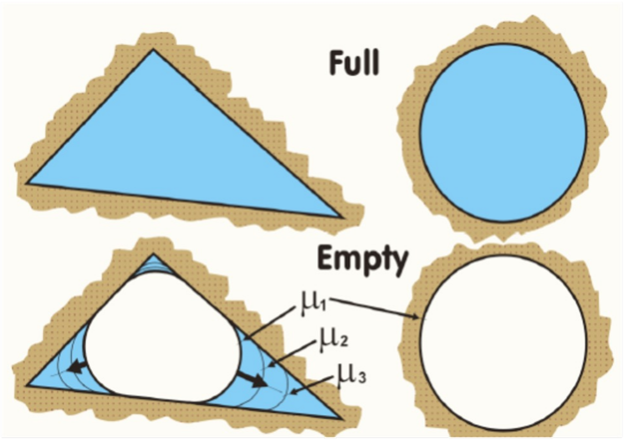
Air-water system in capillary tubes

Review of Lecture 5

- ❖ Capillary rise in a capillary tube
- ❖ Capillary rise in the presence of NAPL
- ❖ Bundle of capillary tubes as a model for a porous medium

Air-water system in capillary tubes

Bundle of triangular capillary tubes vs. bundle of cylindrical capillary tubes



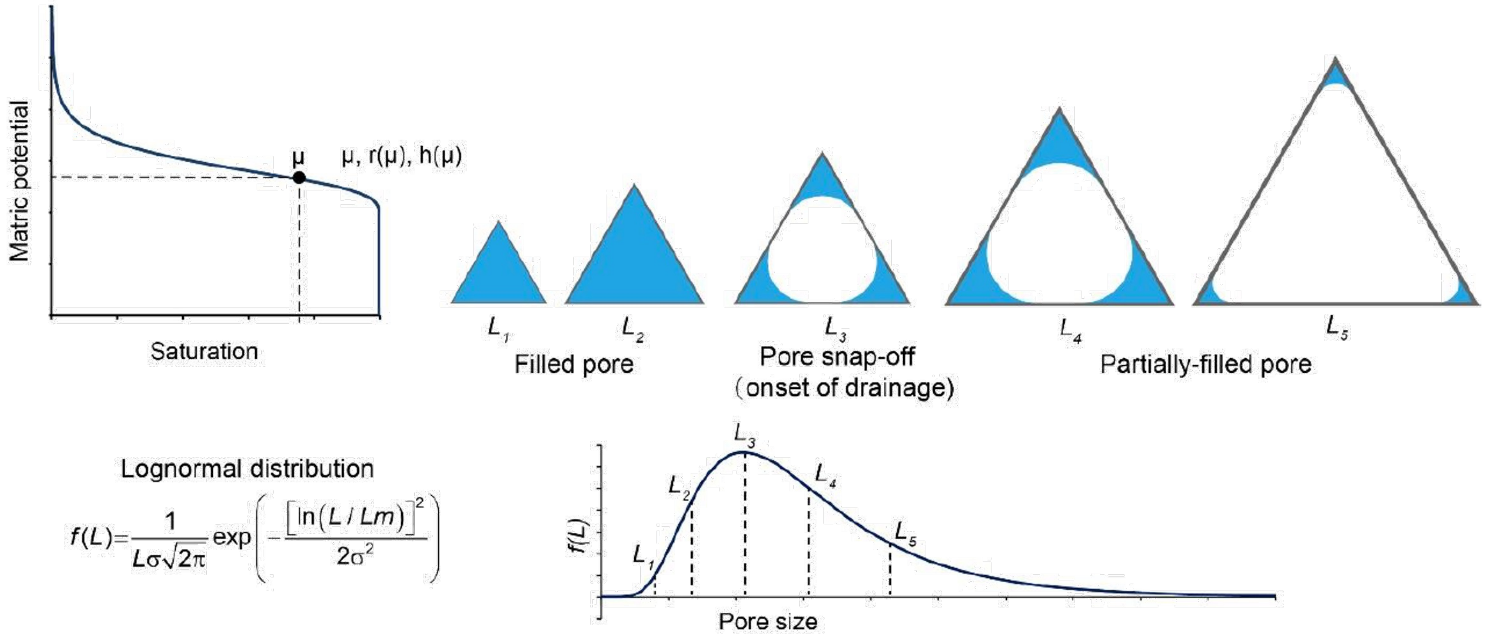
Tuller, Or, Dudley (1999)

Bundle of triangular capillary tubes model have several advantages:

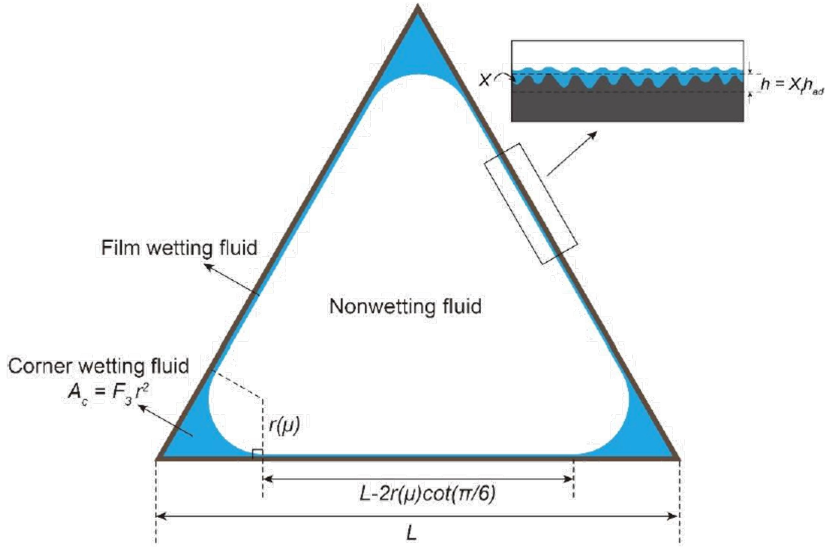
1. Can represent thin films and corner fluid
2. Saturation-dependent capillary pressure within a single-pore
3. More realistic representation of pore geometry
4. …

Air-water system in capillary tubes

An example study using the bundle of triangular capillary tubes model to examine the impact of surface roughness on fluid-fluid interfacial areas $A_{aw} = A_{aw}(S_w)$



Simulating the soil-water characteristics

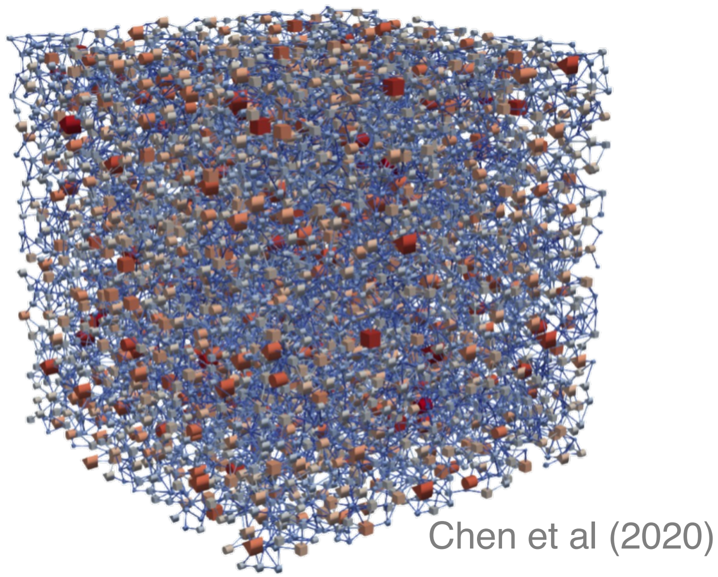


Representing the surface roughness and films

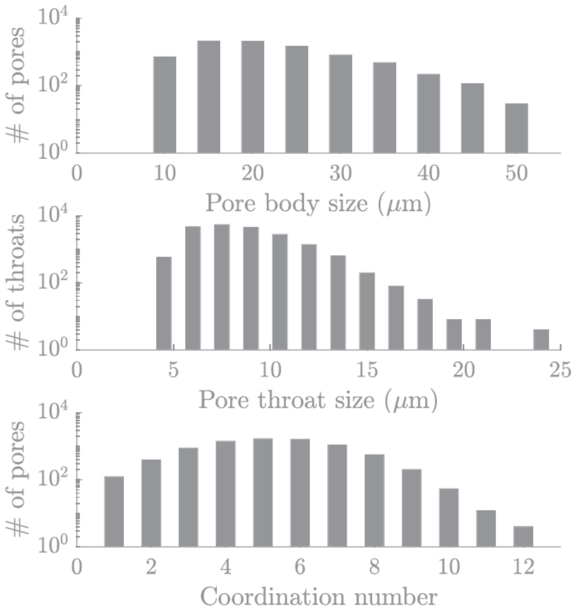
Jiang, Guo, Brusseau (2020)

Advanced Porous Medium Models

Pore network model



A network of interconnected pore bodies and pore throats



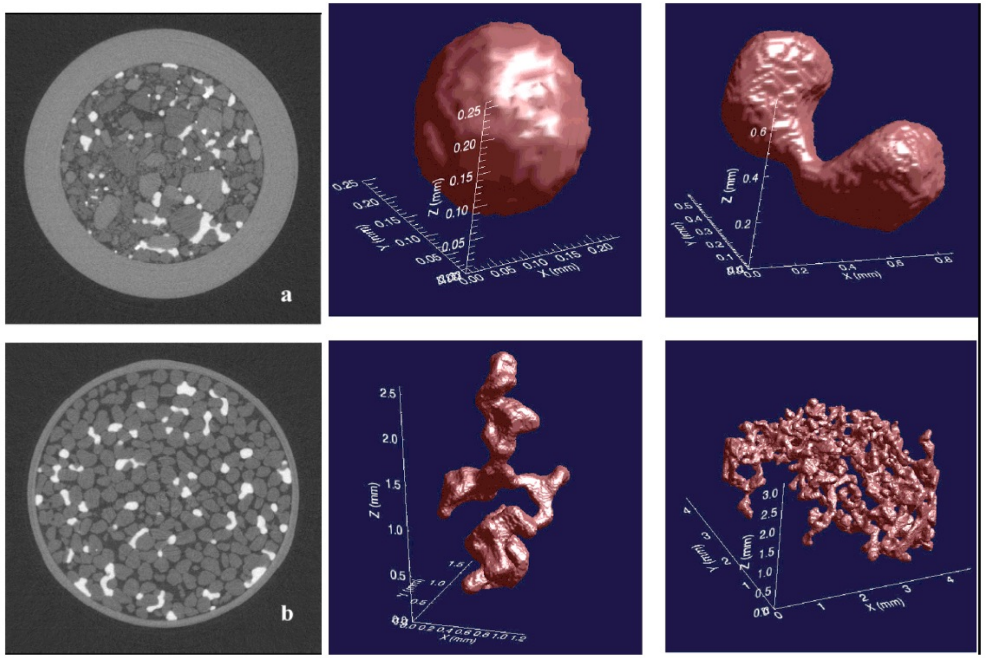
Statistical input

- The physical laws and governing equations (w/ some assumptions) can be solved <u>analytically</u> within each pore and between pores.
- Employing mass conservation in each pore leads to the governing equation for the entire network.

Advanced Porous Medium Models

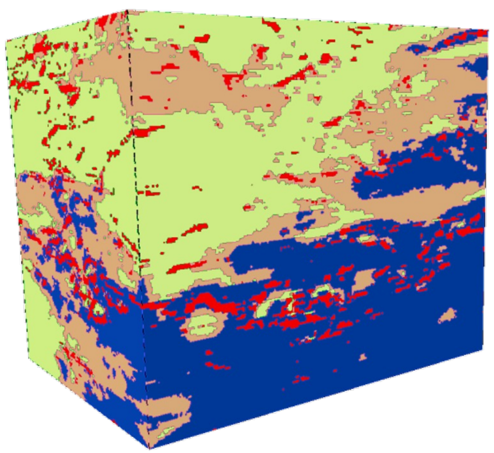
Direct imaging of soil and rock pore structures and fluid distributions

Imaging of fluid distribution in soils (X-ray micro-CT)

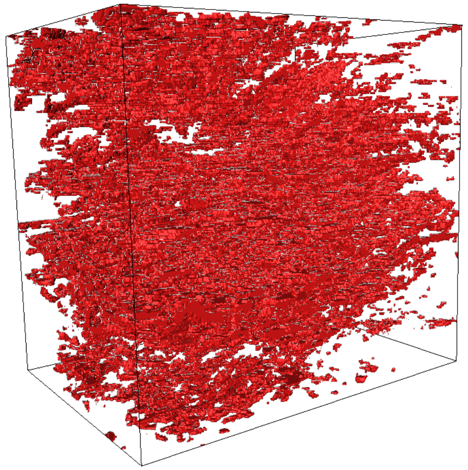


Schnaar and Brusseau (2005)

Imaging of pore-structures of shale rock (Scanning Electron Microscopy)



Resolved pores
Nanoporous organic matter
Granular minerals
Nanoporous clay

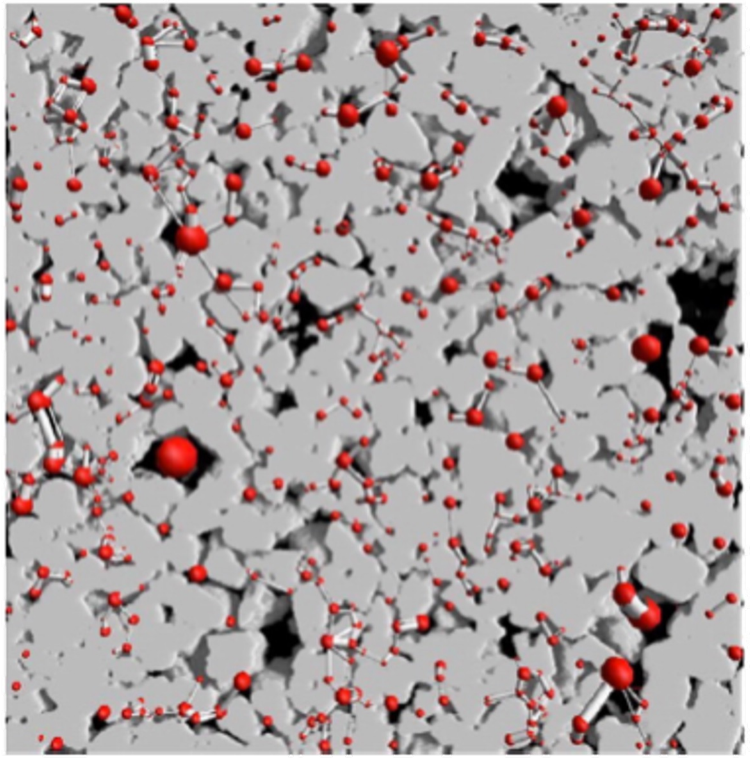


Size: 7.22 μm x 5.11 μm x 6.82 μm
Voxel: 10 nm x 10 nm x 20 nm

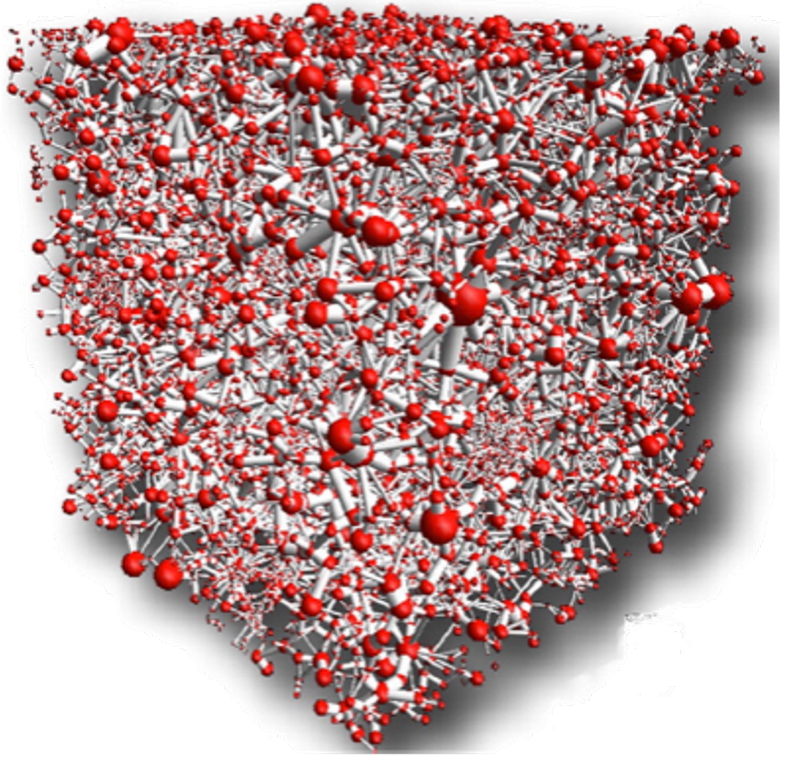
Guo et al. (2018)

Advanced Porous Medium Models

Extracting pore-networks directly from digital images of soils and rocks



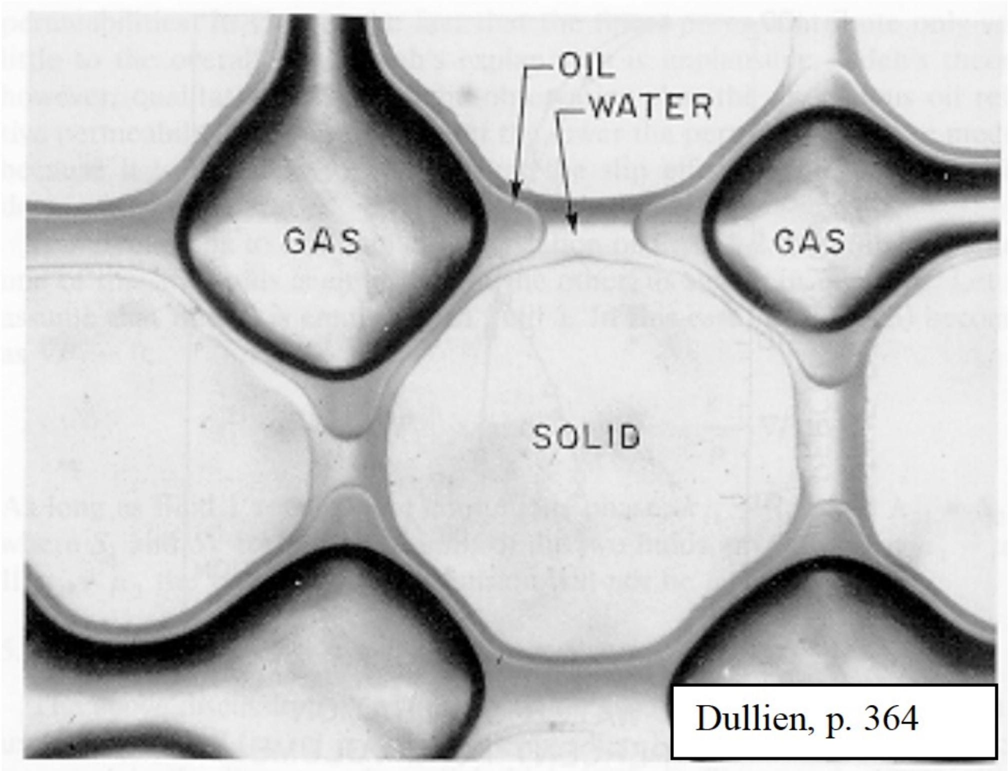
Network extraction



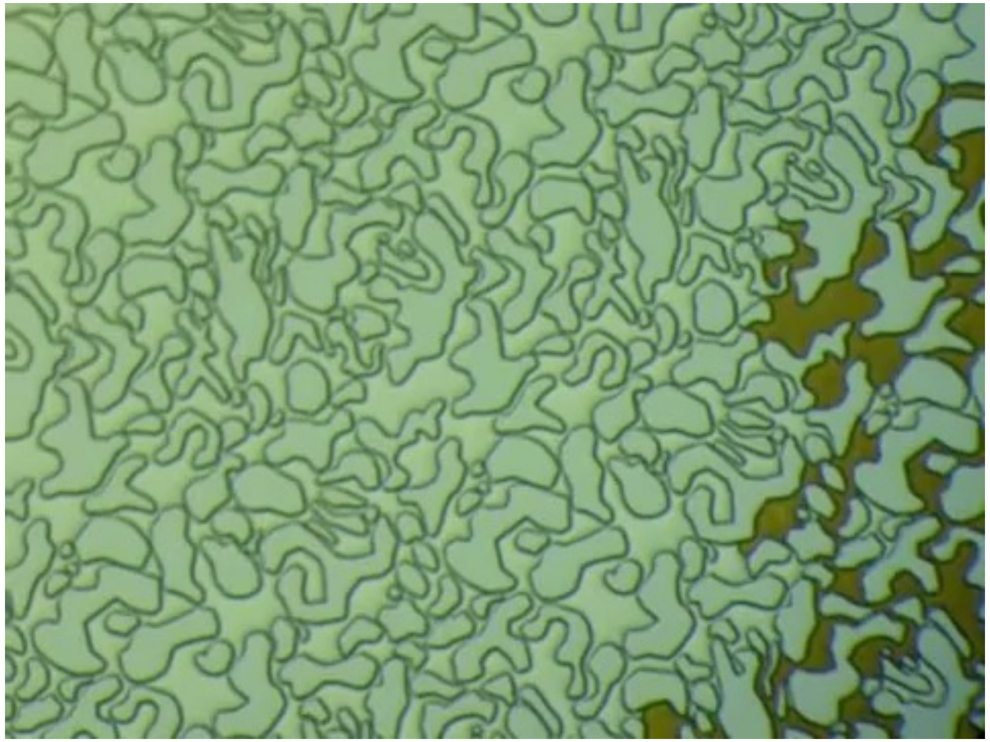
Bultreys et al (2016)

Advanced Porous Medium Models

Visualization of fluid displacement in micro-channels: using micromodels to represent porous media



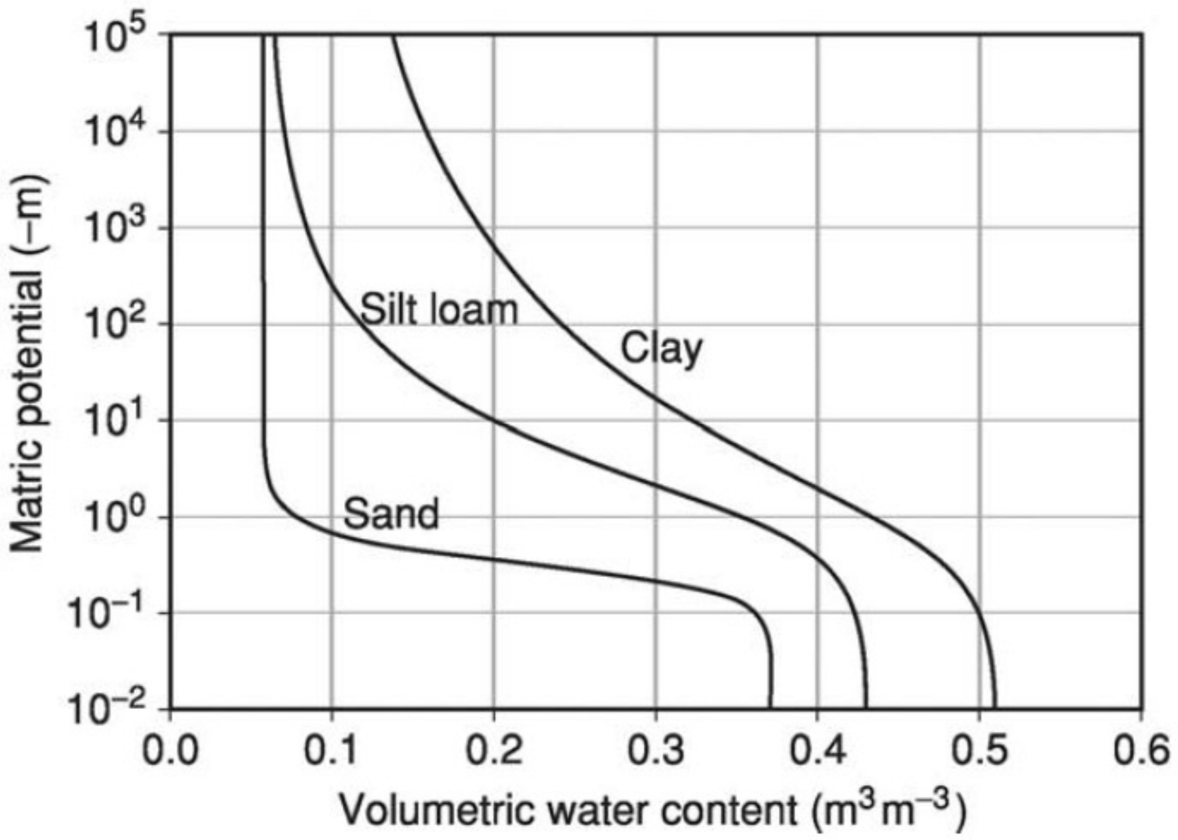
Dullien, p. 364



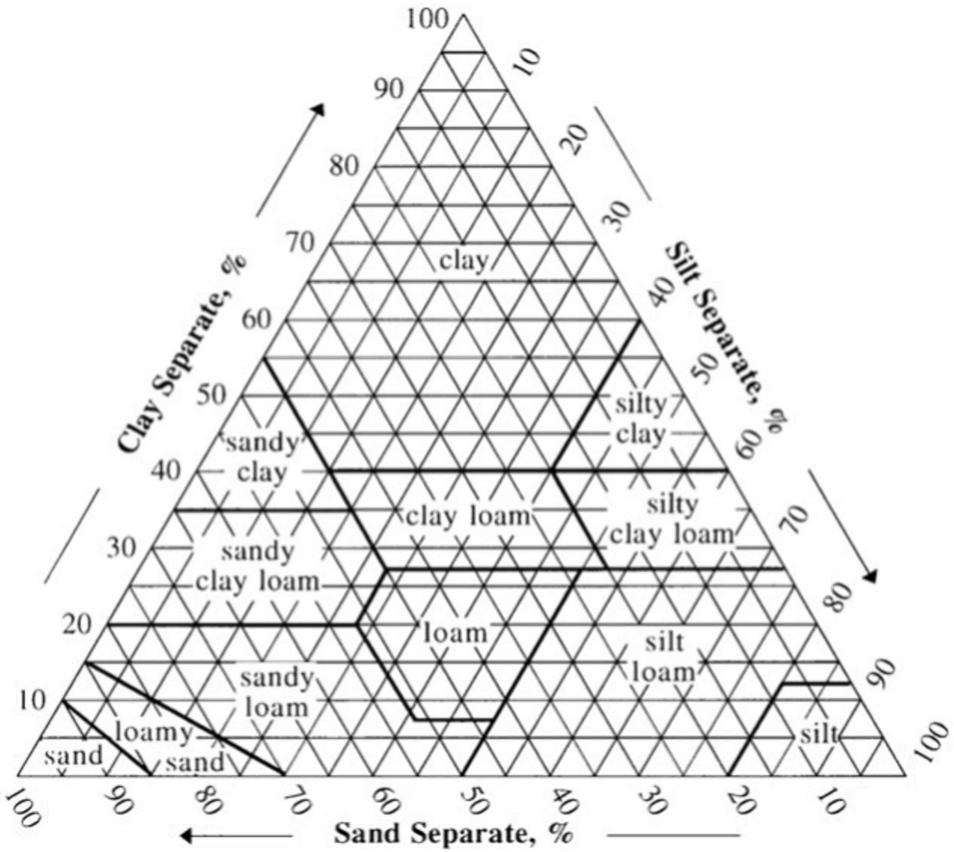
Kovscek, Stanford University

Macroscopic Description of Soil Characteristics

How do we describe the water retention capacity of soils?
=> Soil-water characteristic curves



Tuller & Or (2004)



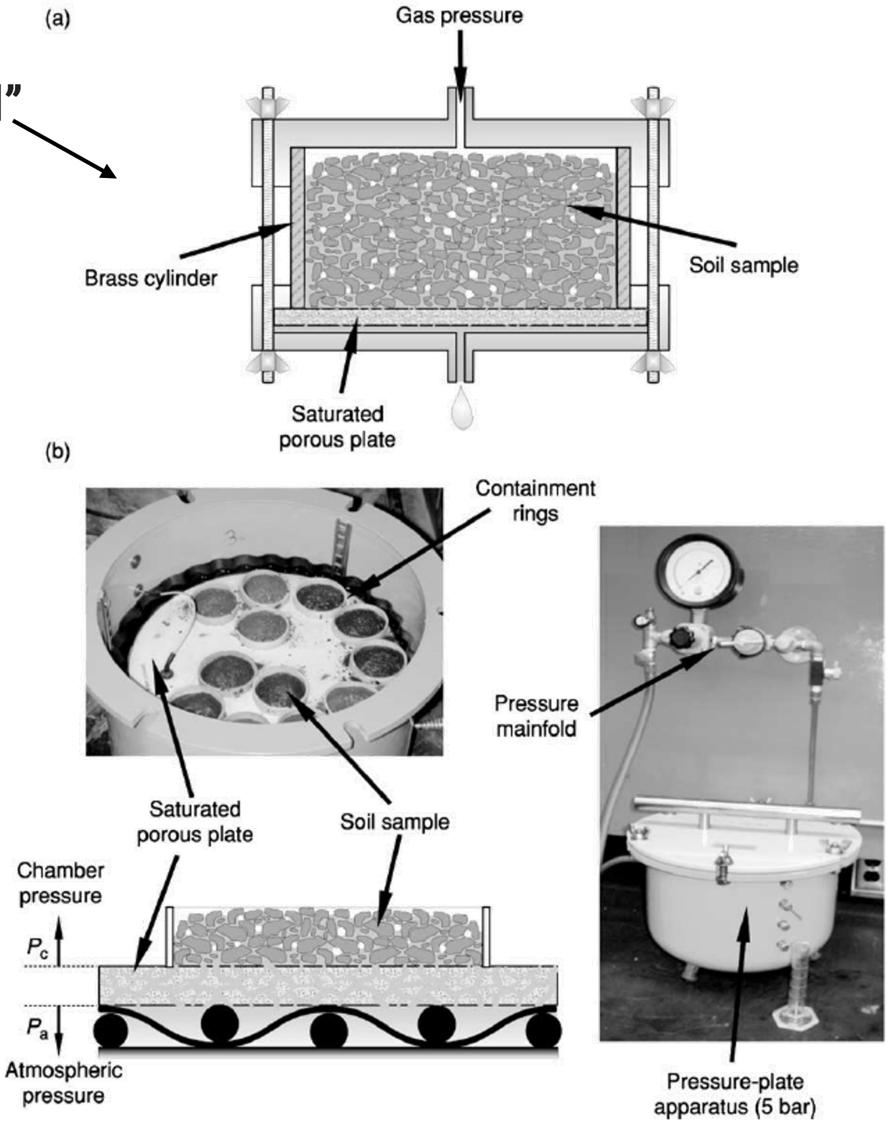
https://en.wikipedia.org/wiki/Soil_texture

Soil texture triangle, showing the 12 major textural classes, as defined by the USDA

Macroscopic Description of Soil Characteristics

How to measure soil-water characteristics?

"Tempe cell"



Tuller & Or (2004)

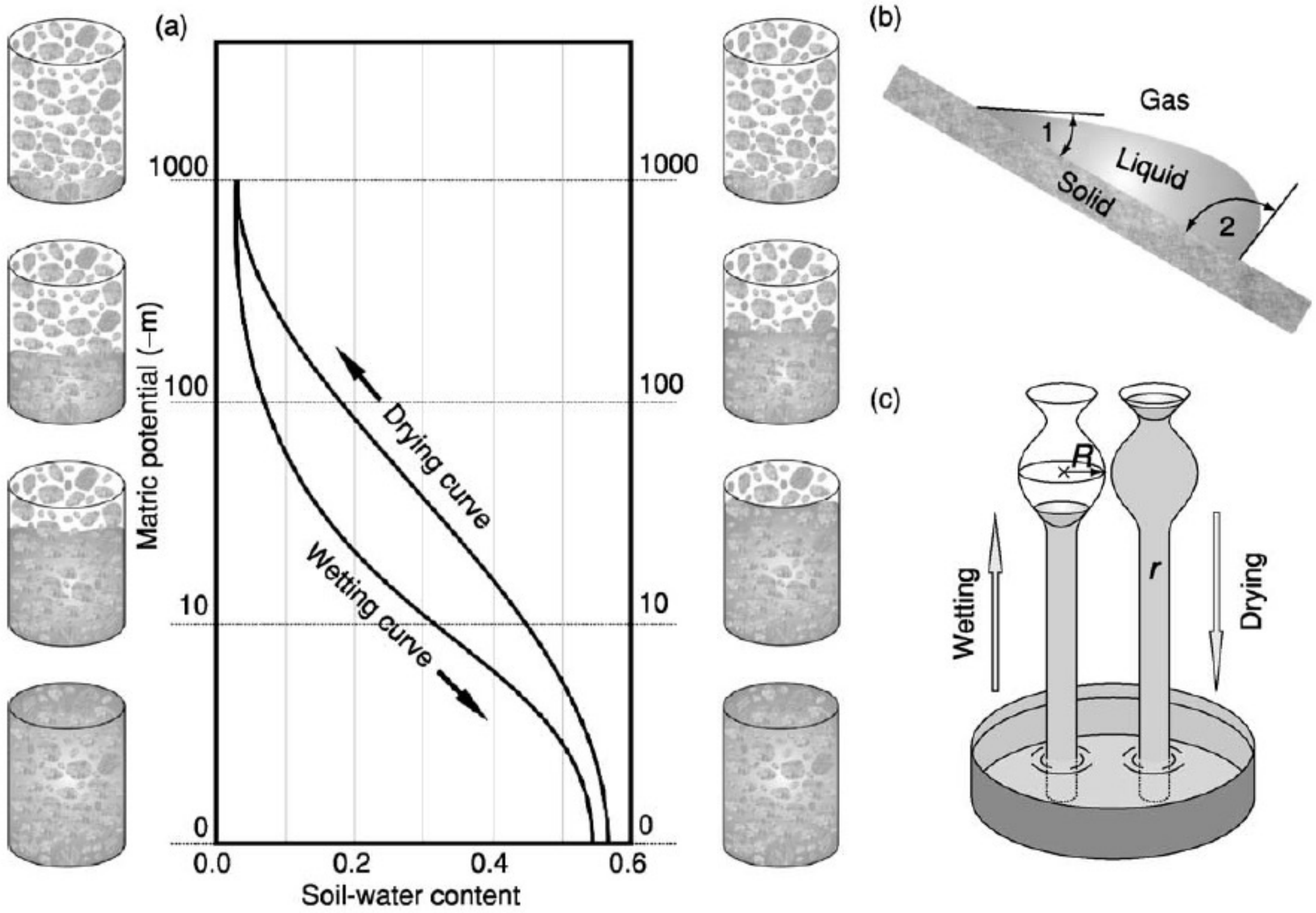
A variety of methods may be used to obtain requisite θ and ψ_m values to estimate the SWC. Potential experimental problems include: the limited functional range of the tensiometer, which is often used for *in situ* measurements; inaccurate θ measurements in some cases; the difficulty in obtaining undisturbed samples for laboratory determinations; and a slow rate of equilibrium under low matric potential (i.e., dry soils).

Collecting **undisturbed** soil samples using a stainless steel sampling ring

Field soil sampling at Davis Monthan Air Force Base (August, 2022)

Macroscopic Description of Soil Characteristics

Complication of the soil-water characteristics: hysteretic behaviors



Hysteresis in SWC can be related to several phenomena:

1. The “ink bottle” effect.
2. Different liquid-solid contact angles for advancing and receding water menisci.
3. Entrapped air in a newly wetted soil.
4. Swelling and shrinking of the soil under wetting and drying.

Tuller & Or (2004)

Mathematical Description of Soil Characteristics

Brooks-Corey (1964)

$$p_c = p_d s_e^{-1/\lambda}$$

$$s_e = (s_w - s_{w,r})/(1 - s_{w,r})$$

effective water saturation

p_d is entry pressure

λ is a parameter related to pore size distribution

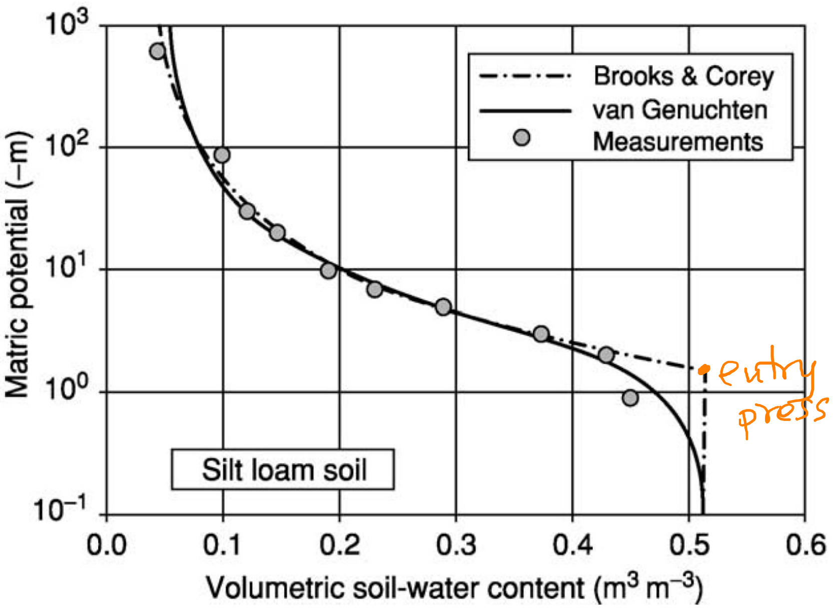


Table 1 Typical van Genuchten model parameters (α, *n*) including residual (θ_r) and saturated (θ_s) water contents compiled from the UNSODA database

Textural class	*N*	θ_r *(cm³ cm⁻³)*	θ_s *(cm³ cm⁻³)*	α *(cm⁻¹)*	n
Sand	126	0.058	0.37	0.035	3.19
Loamy sand	51	0.074	0.39	0.035	2.39
Sandy loam	78	0.067	0.37	0.021	1.61
Loam	61	0.083	0.46	0.025	1.31
Silt	3	0.123	0.48	0.006	1.53
Silt loam	101	0.061	0.43	0.012	1.39
Sandy clay loam	37	0.086	0.40	0.033	1.49
Clay loam	23	0.129	0.47	0.030	1.37
Silty clay loam	20	0.098	0.55	0.027	1.41
Silty clay	12	0.163	0.47	0.023	1.39
Clay	25	0.102	0.51	0.021	1.20

N, the number of soils or samples of a given textural class from which the mean values are compiled.

Reproduced from Leij FJ, Alves WJ, van Genuchten MT, and Williams JR (1996) *The UNSODA Unsaturated Hydraulic Database*. EPA/600/ R-96/095. Cincinnati, OH: US Environmental Protection Agency.

Tuller & Or (2004)

Mualem (1976) and Van Genuchten (1980)

$$p_c = \frac{1}{\alpha}\left(s_e^{-1/m} - 1\right)^{1/n}$$

α is a parameter related to the inverse of entry pressure

n is a parameter related to pore size distribution

$m = 1 - 1/n$ based on the Mualem assumption