

# HWRS 561b: Physical Hydrogeology II

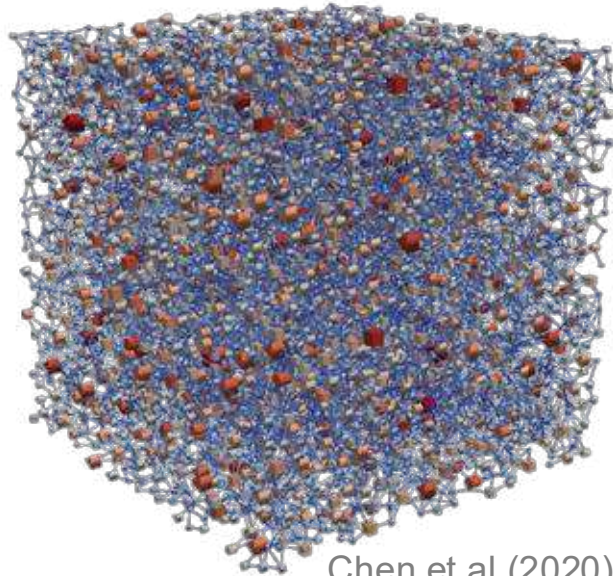
## Porous medium models and macroscopic description (Part 1)

### Agenda:

1. Advanced porous medium models
2. Macroscopic description

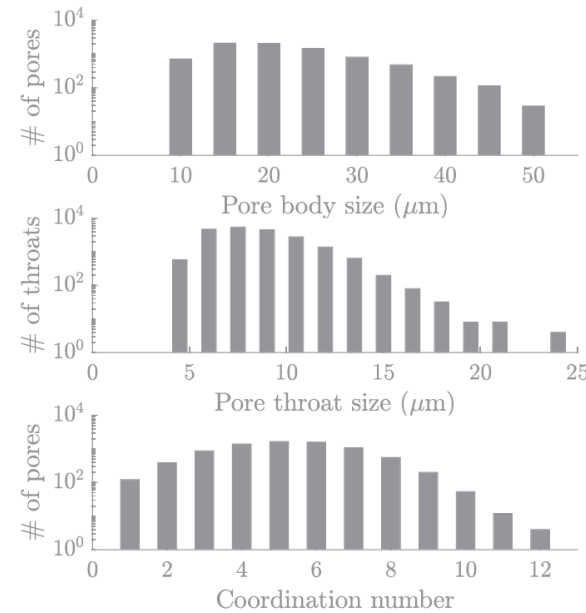
# Advanced Porous Medium Models

## *Pore network model*



Chen et al (2020) WRR

A network of interconnected tubes (pore bodies and pore throats)



Statistical input

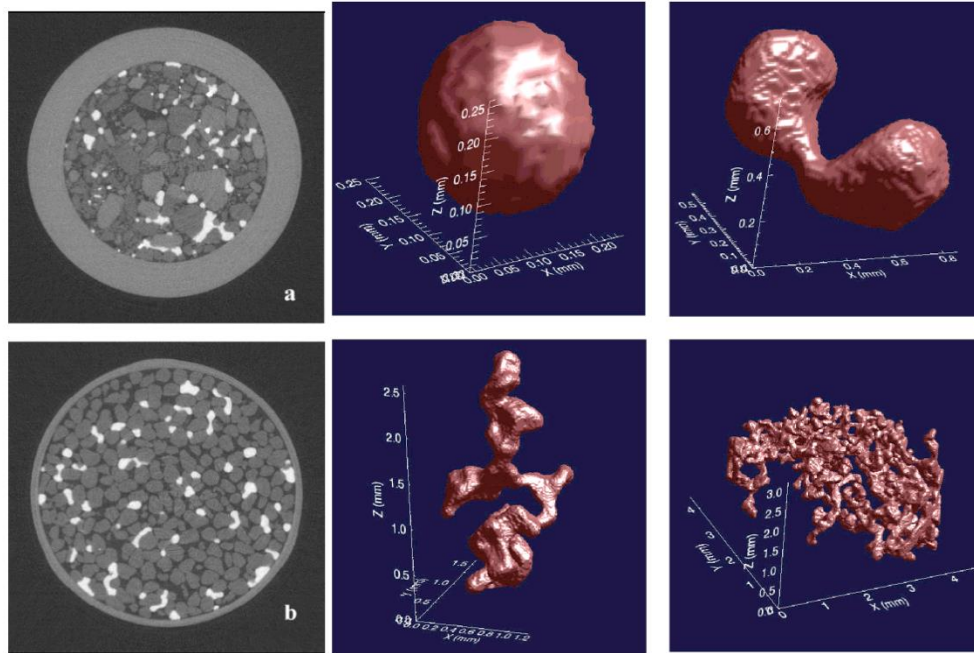
- The physical laws and governing equations (w/ some assumptions) can be solved analytically within each pore and between pores.
- Employing mass conservation in each pore leads to the governing equation for the entire network.

# Advanced Porous Medium Models

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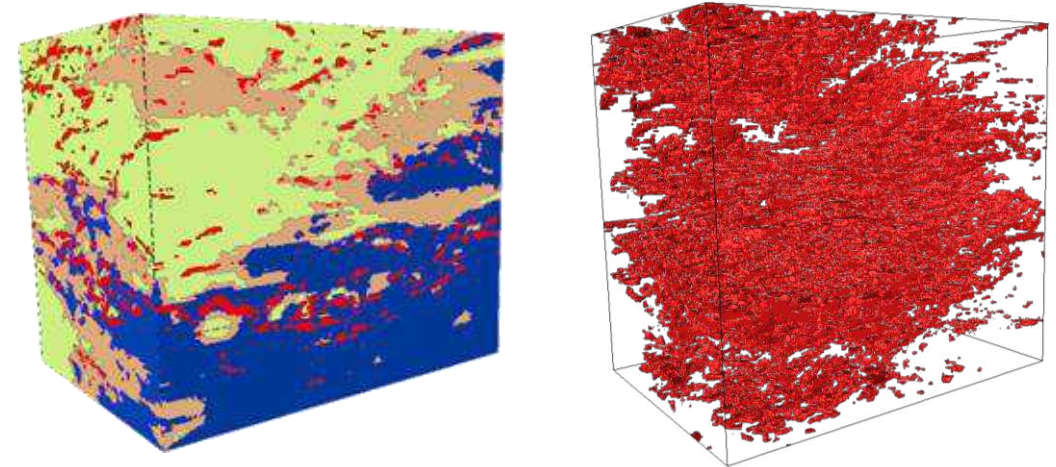
## *Direct imaging of soil and rock pore structures and fluid distributions*

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



Schnaar and Brusseau (2005) ES&T

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



- Resolved pores
- Nanoporous organic matter
- Granular minerals
- Nanoporous clay

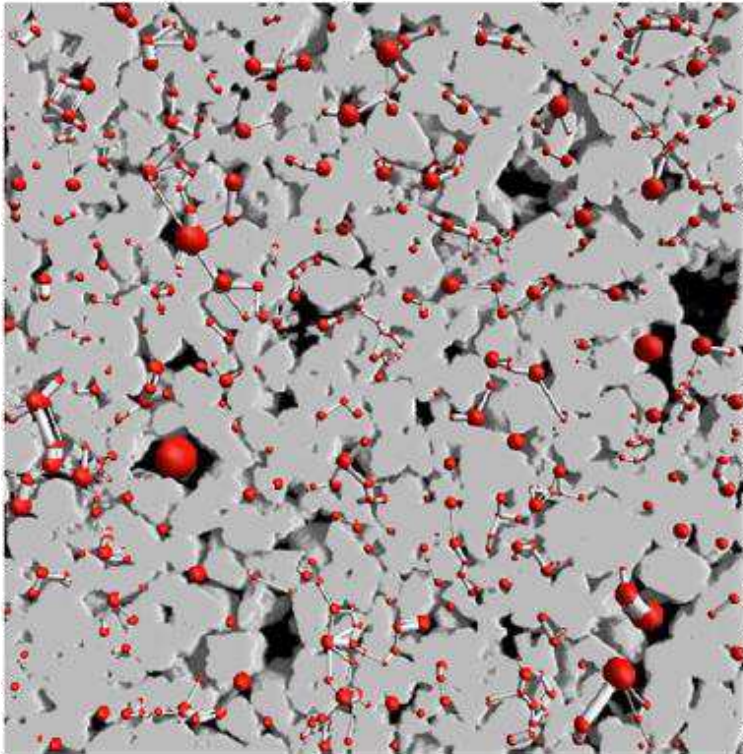
Size: 7.22  $\mu\text{m}$  x 5.11  $\mu\text{m}$  x 6.82  $\mu\text{m}$   
Voxel: 10 nm x 10 nm x 20 nm

Guo et al. (2018) AWR



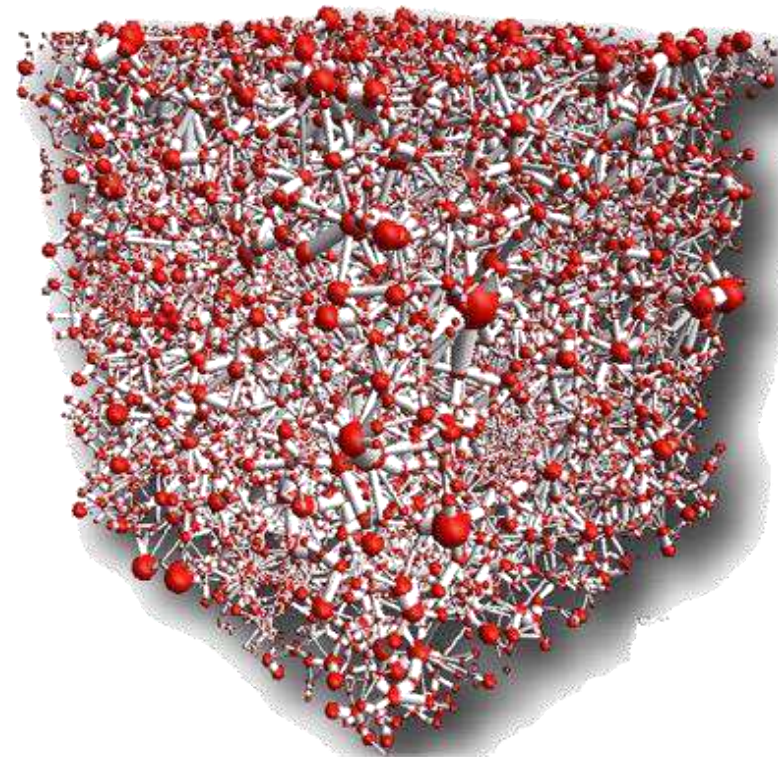
# Advanced Porous Medium Models

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



Bultreys et al (2016) AWR

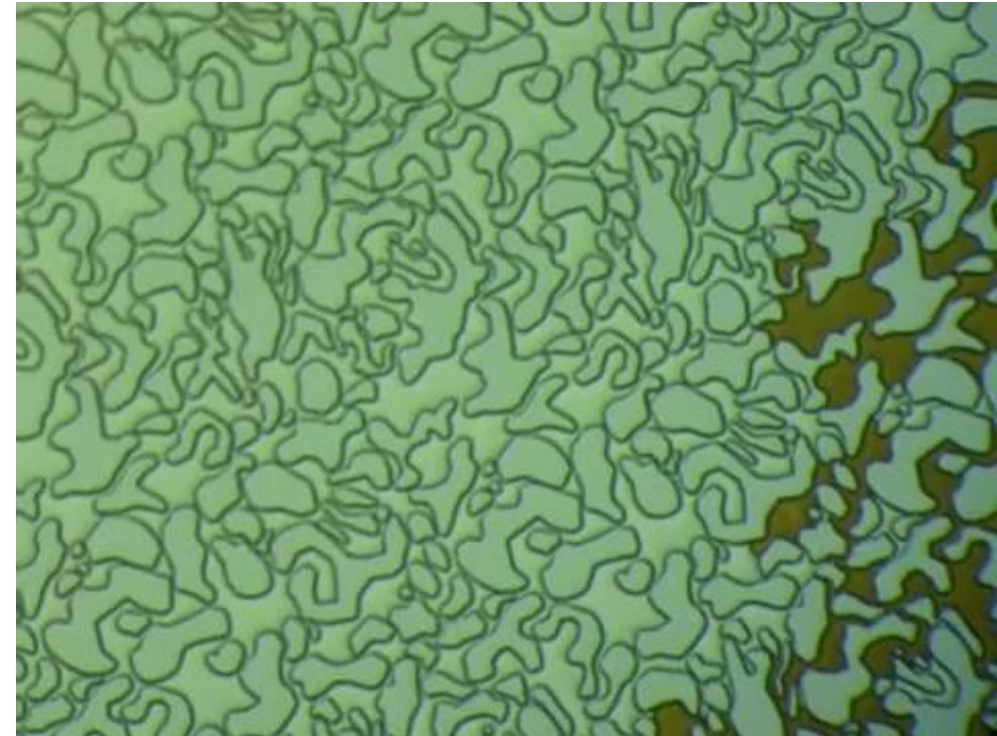
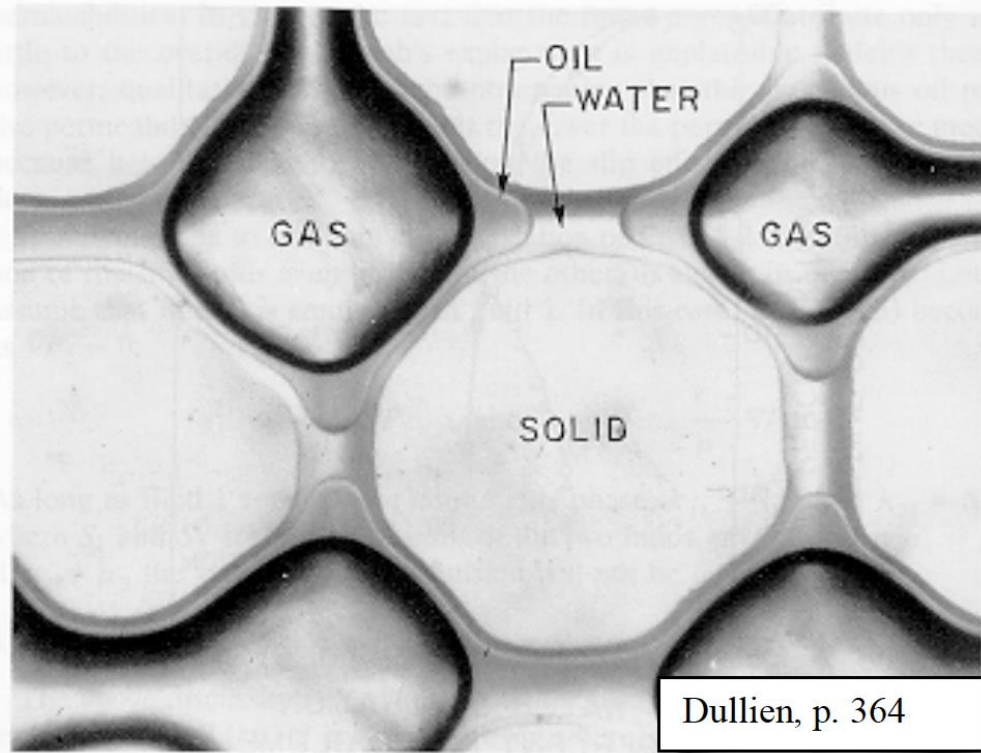
Network extraction



# Advanced Porous Medium Models

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



Kovscek, Stanford University

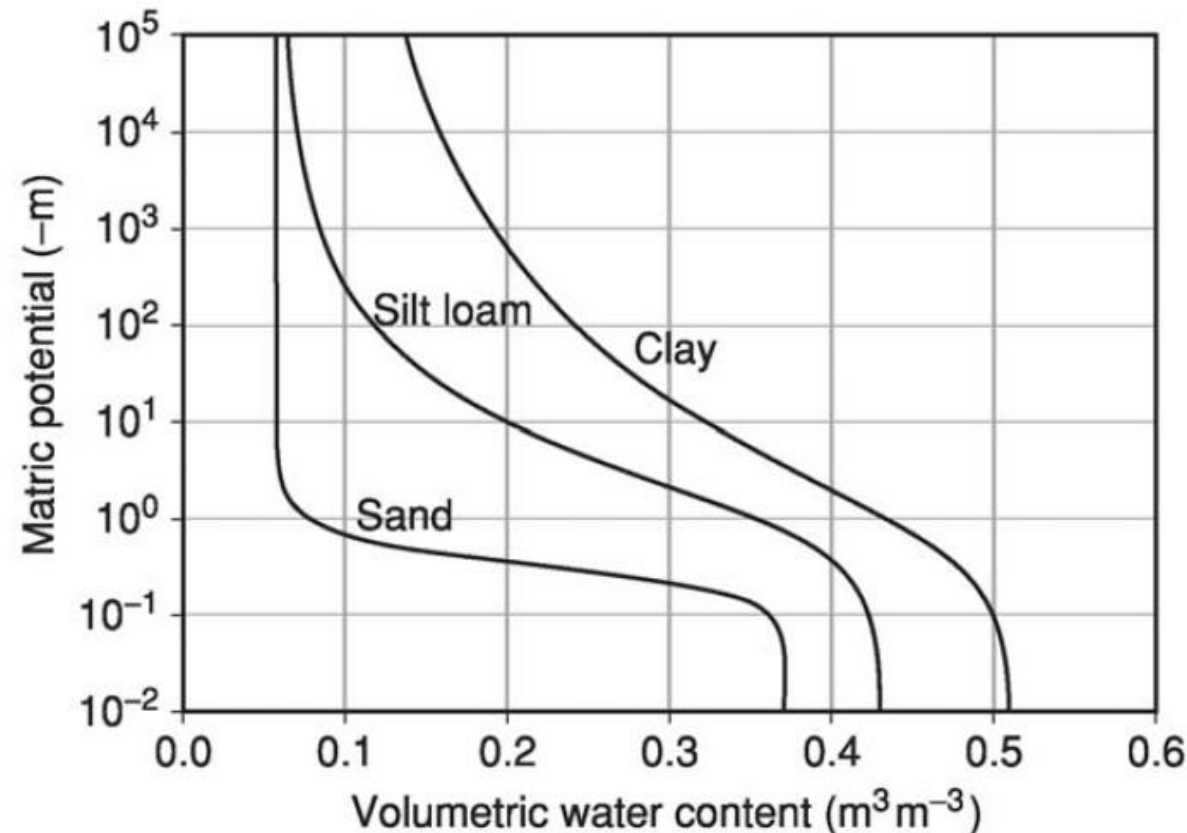


# Macroscopic Description of Soil Characteristics

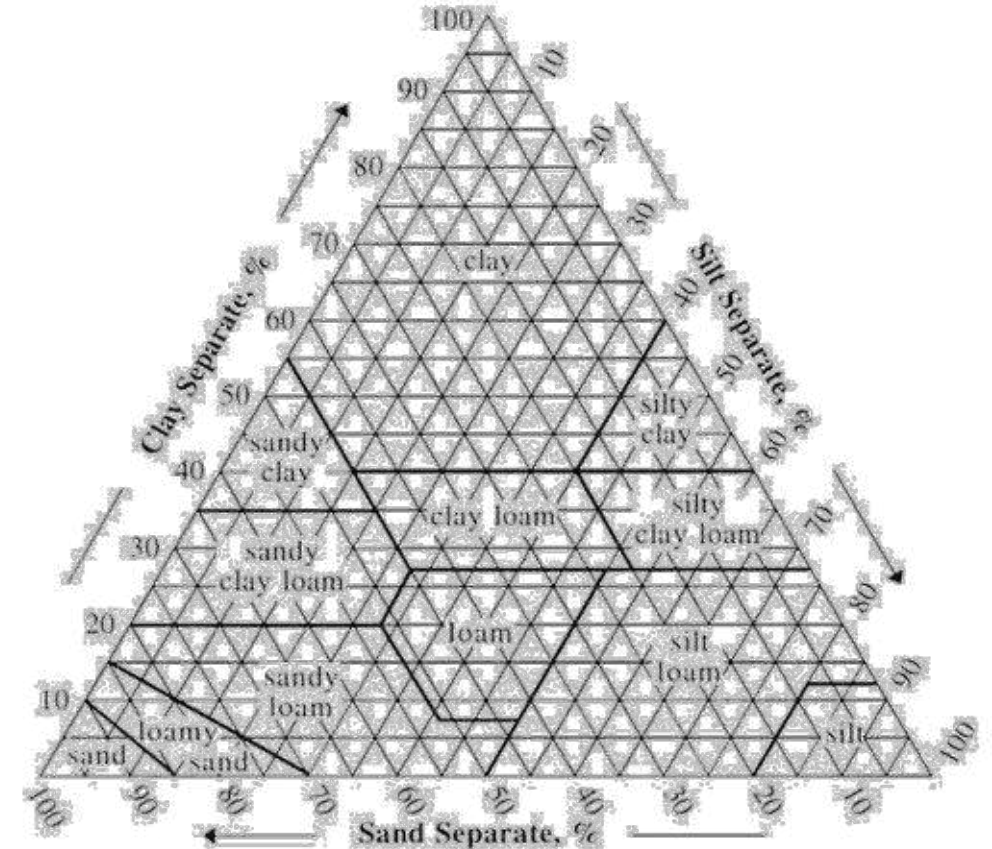
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**How do we describe the water retention capacity of soils?**

=> Soil-water characteristic curves



Tuller & Or (2004)



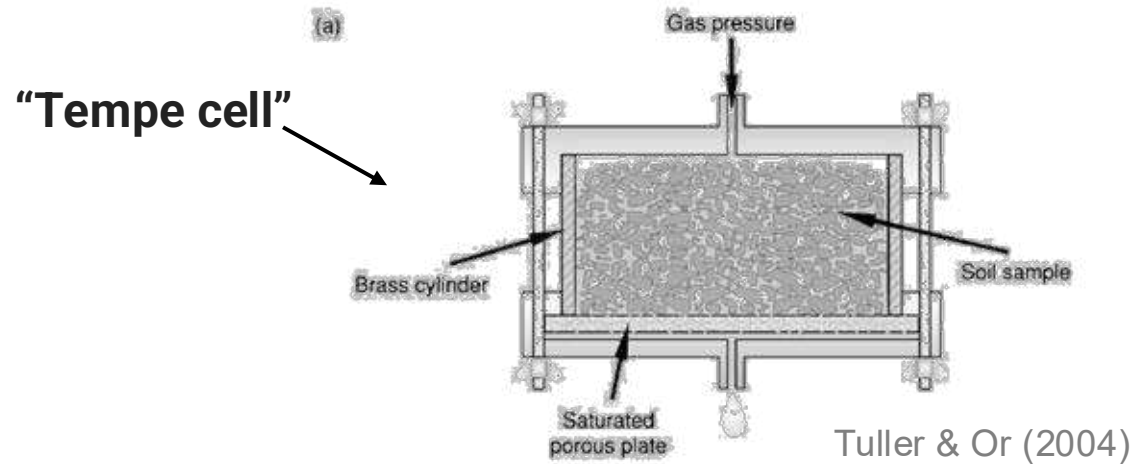
[https://en.wikipedia.org/wiki/Soil\\_texture](https://en.wikipedia.org/wiki/Soil_texture)

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

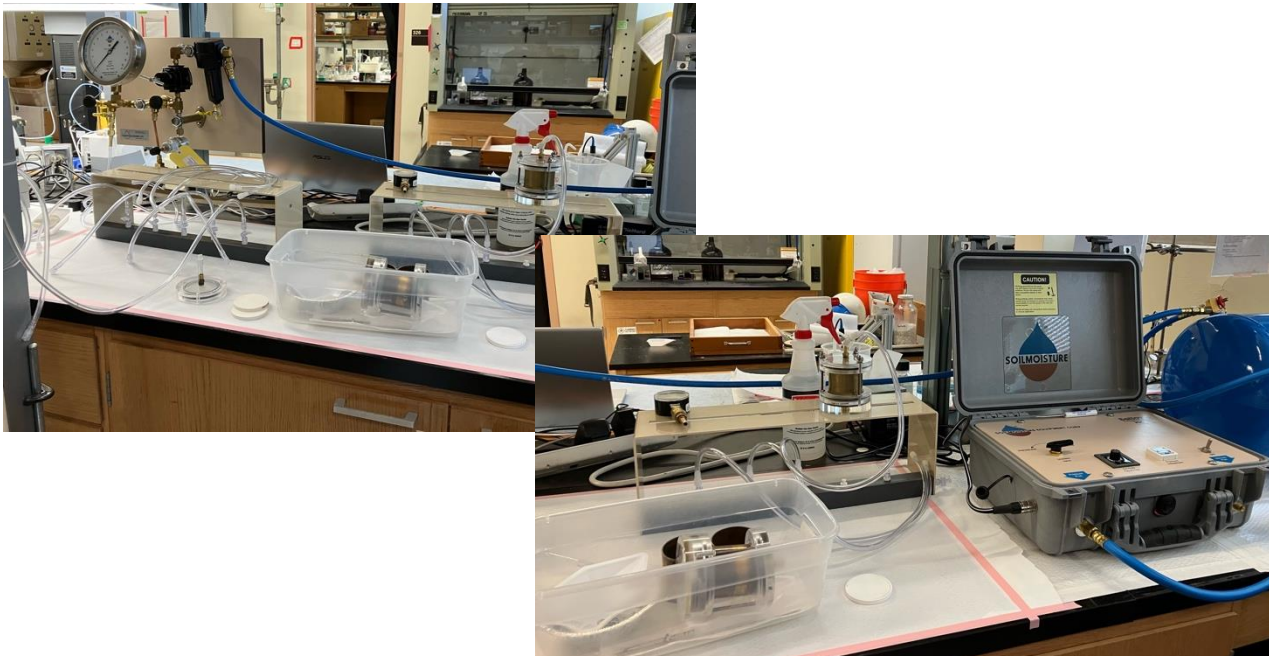
# Macroscopic Description of Soil Characteristics

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## How to measure soil-water characteristics?



A variety of methods may be used to obtain requisite  $\theta$  and  $\psi_m$  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  $\theta$  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



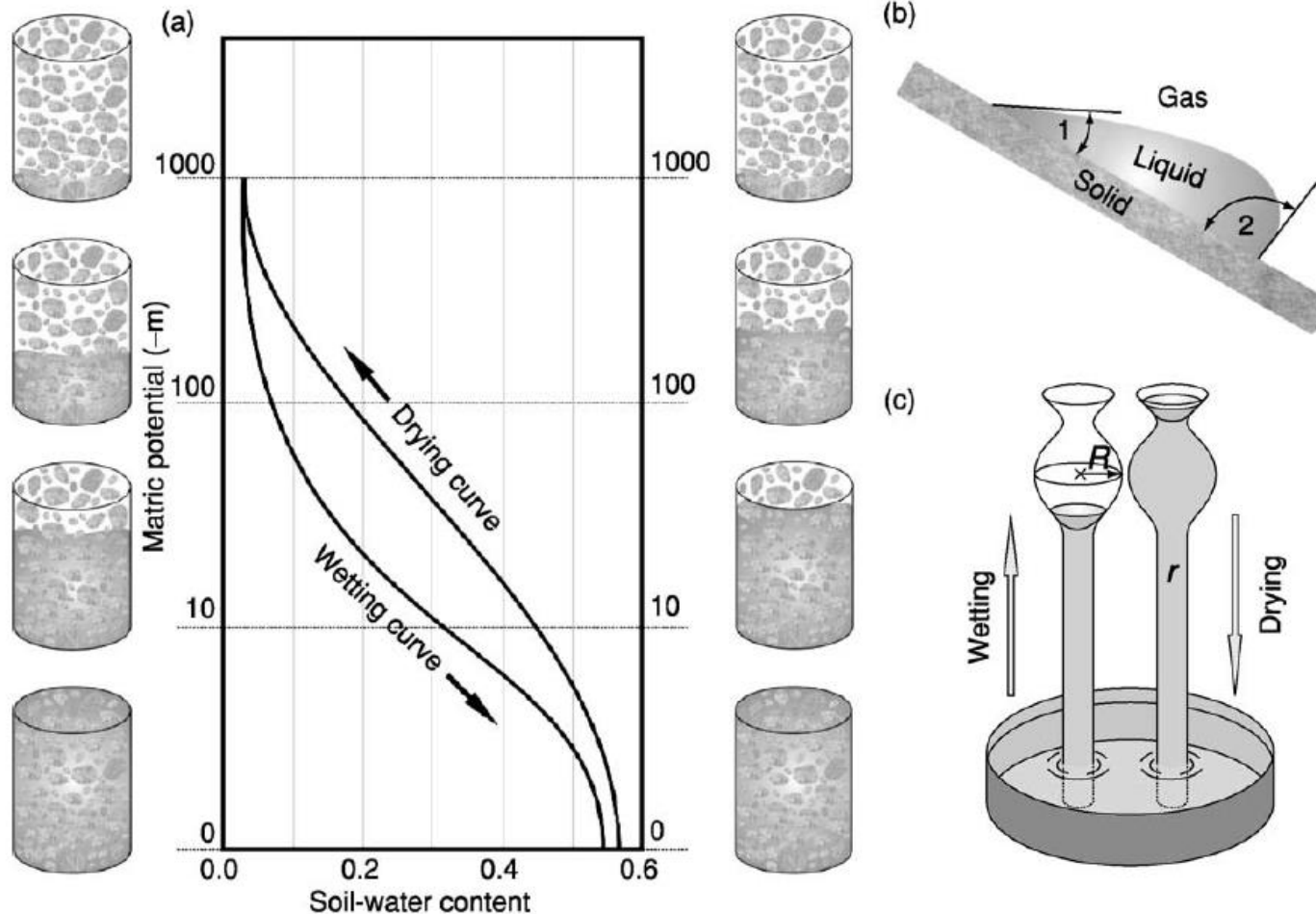
Field soil sampling at Davis Monthan Air Force Base (August, 2022)



# Macroscopic Description of Soil Characteristics

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## *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.



# Mathematical Description of Soil Characteristics

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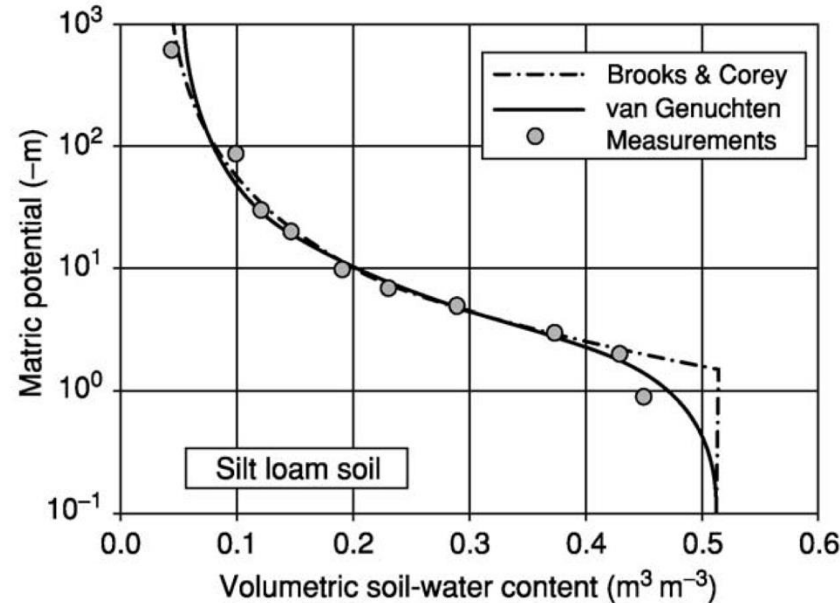
## Brooks-Corey (1964)

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

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

$p_d$  is entry pressure

$\lambda$  is a parameter related to pore size distribution



**Table 1** Typical van Genuchten model parameters ( $\alpha$ ,  $n$ ) including residual ( $\theta_r$ ) and saturated ( $\theta_s$ ) water contents compiled from the UNSODA database

Textural class	N	$\theta_r$ (cm³ cm⁻³)	$\theta_s$ (cm³ cm⁻³)	$\alpha$ (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	37	0.086	0.40	0.033	1.49
loam					
Clay loam	23	0.129	0.47	0.030	1.37
Silty clay	20	0.098	0.55	0.027	1.41
loam					
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)

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

$\alpha$  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