Water in Subsurface Environment

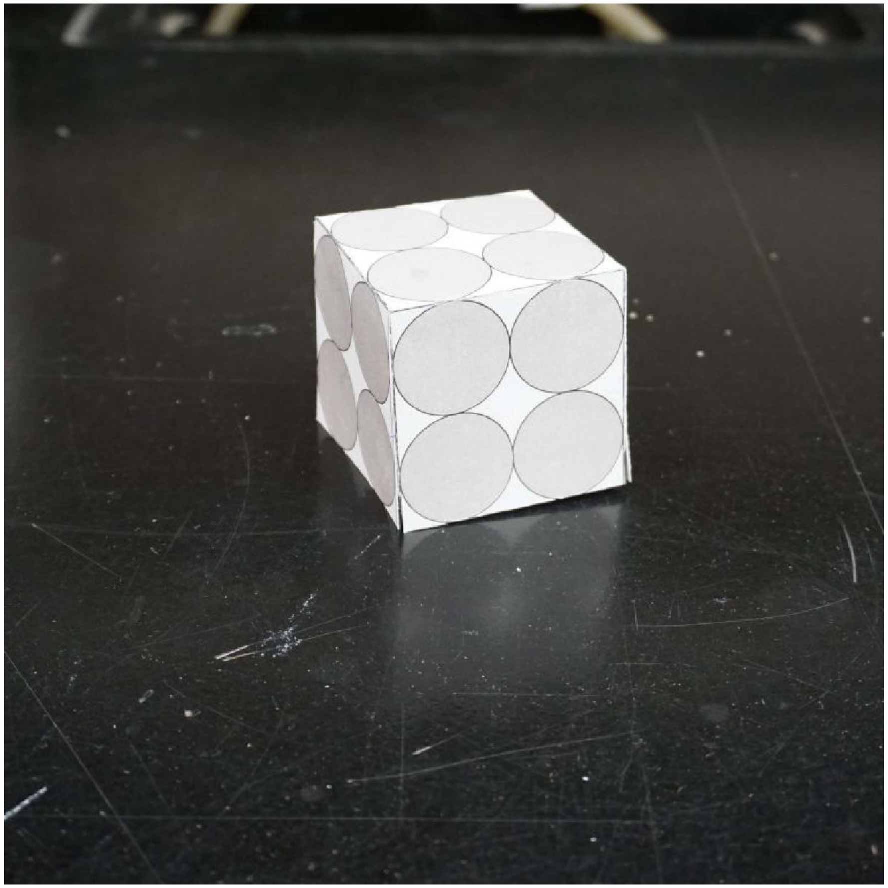
Groundwater Engineering| CE60205 Lecture:03

Learning Objective(s)

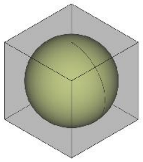
To estimate the physical properties of water, air, and porous media

Properties of Porous Media (Contd.)

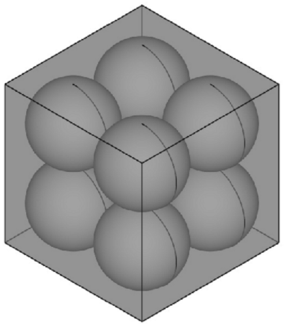
- Home Lab
- Foldable Aquifer Project -http://aquifer.geology.buffalo.edu/
- Paper aquifer model
  - Porosity and Grain Packing



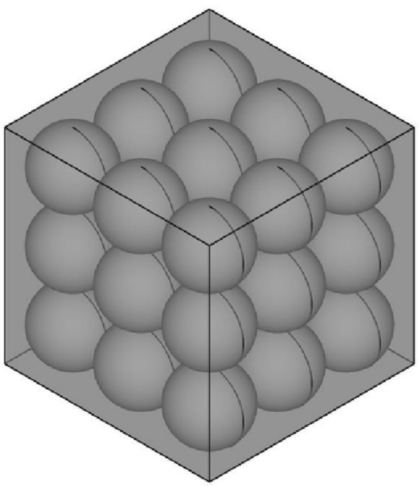
Properties of Porous Media (Contd.)



- $V_s = 1 \times \frac{\pi}{6} d^3, V = d^3, V_v = V - V_s, \eta = \frac{V_v}{V} = 1 - \frac{\pi}{6} = 0.4764$



- $V_s = 2^3 \times \frac{\pi}{6} d^3, V = (2d)^3, V_v = V - V_s, \eta = \frac{V_v}{V} = 1 - \frac{\pi}{6}$



- $V_s = 3^3 \times \frac{\pi}{6} d^3, V = (3d)^3, V_v = V - V_s, \eta = \frac{V_v}{V} = 1 - \frac{\pi}{6}$

Properties of Porous Media (Contd.)

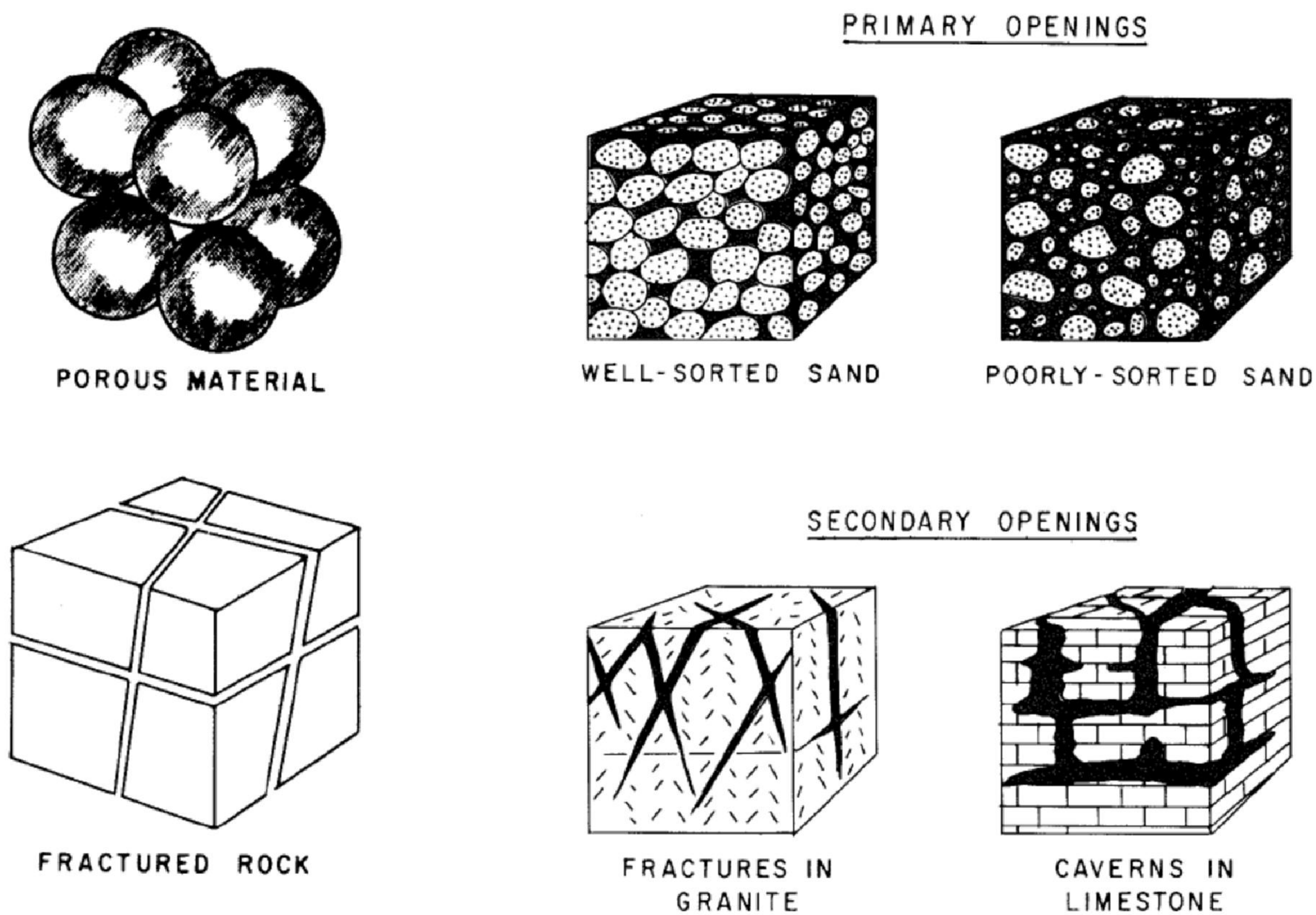
- Porosity

Table 2.2 Typical Values of Porosity

Material	n (%)
Narrowly graded silt, sand, gravel	30–50
Widely graded silt, sand, gravel	20–35
Clay, clay–silt	35–60
Sandstone	5–30
Limestone, dolomite	0–40
Shale	0–10
Crystalline rock	0–10
Massive granite	0–0.5

Properties of Porous Media (Contd.)

- Porosity



Properties of Porous Media (Contd.)

[Values in percent by volume]

Material	Primary openings	Secondary openings
Equal-size spheres (marbles):		
Loosest packing	48	--
Tightest packing	26	--
Soil	55	--
Clay	50	--
Sand	25	--
Gravel	20	--
Limestone	10	10
Sandstone (semiconsolidated)	10	1
Granite	--	.1
Basalt (young)	10	1

Properties of Porous Media (Contd.)

- Grain Size

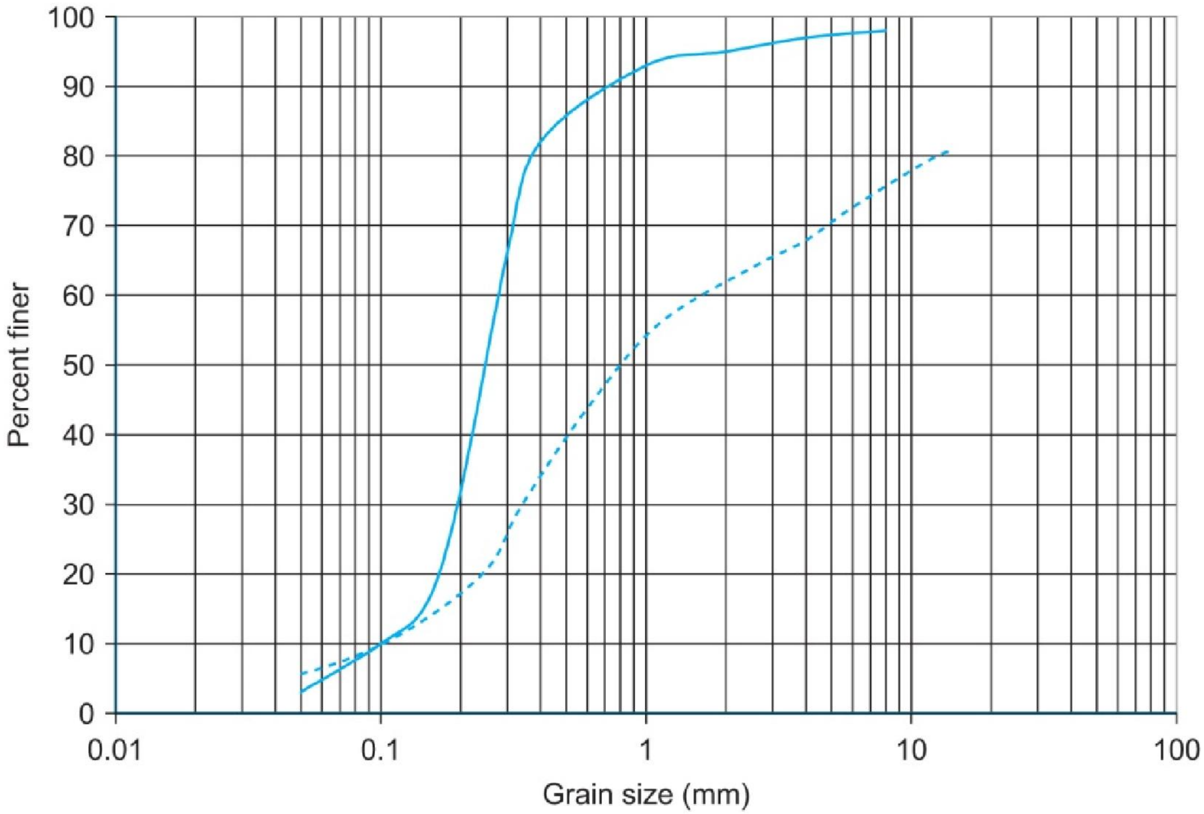
Table 2.3 U.S. Department of Agriculture Grain Size Definitions

Material	Grain Size Range (mm)
Clay	<0.002
Silt	0.002–0.05
Sand	0.05–2.0
Gravel	>2.0

Properties of Porous Media (Contd.)

- Grain Size

- Solid curve is a narrowly graded (well sorted) fine sand



The porosity of the fine sand is n = 0.38 and the porosity of the gravelly sand is n = 0.29.

- Dashed curve is a widely Graded (poorly sorted) gravelly sand

Properties of Porous Media (Contd.)

- Volumetric water content θ_v

$$\theta_v = \frac{V_w}{V}$$

- Porosity η

$$\eta = \frac{V_v}{V}$$

- Under saturated condition $\theta_v = \eta$
- Under partially saturated condition $\theta_v < \eta$
- Degree of saturation of water S_w

$$S_w = \frac{V_w}{V_v} = \frac{\theta_v}{\eta}$$

$$0 \leq S_w \leq 1$$

- Degree of saturation of air S_a

$$S_a = \frac{V_a}{V_v}$$

$$S_w + S_a = 1$$

Properties of Porous Media (Contd.)

- Volumetric water content θ_v can be expressed as

$$\theta_v = \frac{V_w}{V} = \frac{V_w}{V_v} \times \frac{V_v}{V} = S_w \times \eta$$

- Gravimetric water content θ_w

$$\theta_w = \frac{W_w}{W_s} = \frac{W_{Wet\ Soil}}{W_{Dry\ Soil}} - 1$$

- Volumetric water content and gravimetric water content

$$\theta_v = \theta_w \frac{\rho_b}{\rho_w}$$

Properties of Porous Media (Contd.)

- Bulk Density

$$\rho_b = \frac{m_s}{V_t}$$

where m_s is the mass of solids in sample volume V

- Wet or total bulk density

$$\rho_t = \frac{m_s + m_w}{V_t}$$

where m_w is the mass of water in the sample

- ρ_b is smaller than the density of the solids alone ρ_s

$$\rho_s = \frac{m_s}{V_s}$$

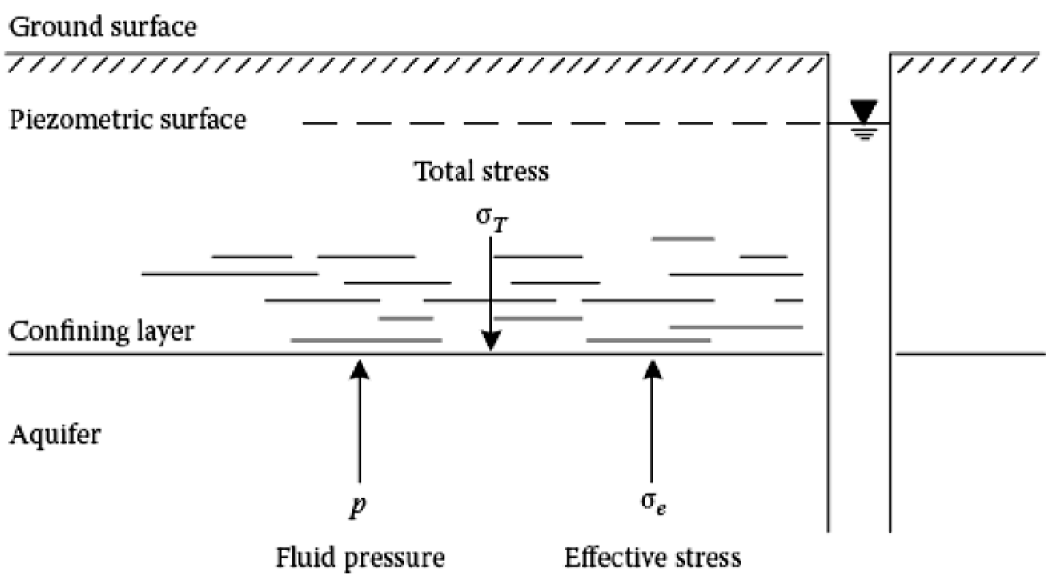
Table 2.4 Common Mineral Densities

Mineral	ρ_s (g/cm^3)
Quartz	2.65
Feldspars	2.54–2.76
Clay minerals	2.6–2.8
Micas	2.7–3.2
Pyroxene	3.2–3.6
Amphibole	2.8–3.6
Olivine	3.3–4.4
Calcite	2.71
Dolomite	2.85

Source: Klein and Hurlbut (1993).

Effective Stress

- Mechanisms
  - Compression of the water in the pores
  - Compression of the sand grains
  - Rearrangement of the sand grains and formation of a more closely packed configuration



$$\sigma_T = \sigma_e + p$$

$$d\sigma_T = d\sigma_e + dp$$

$$d\sigma_e = -dp \quad \text{as} \quad d\sigma_T = 0$$

Compressibility of a Porous Medium

$$\alpha = \frac{-dV_T / V_T}{d\sigma_e}$$

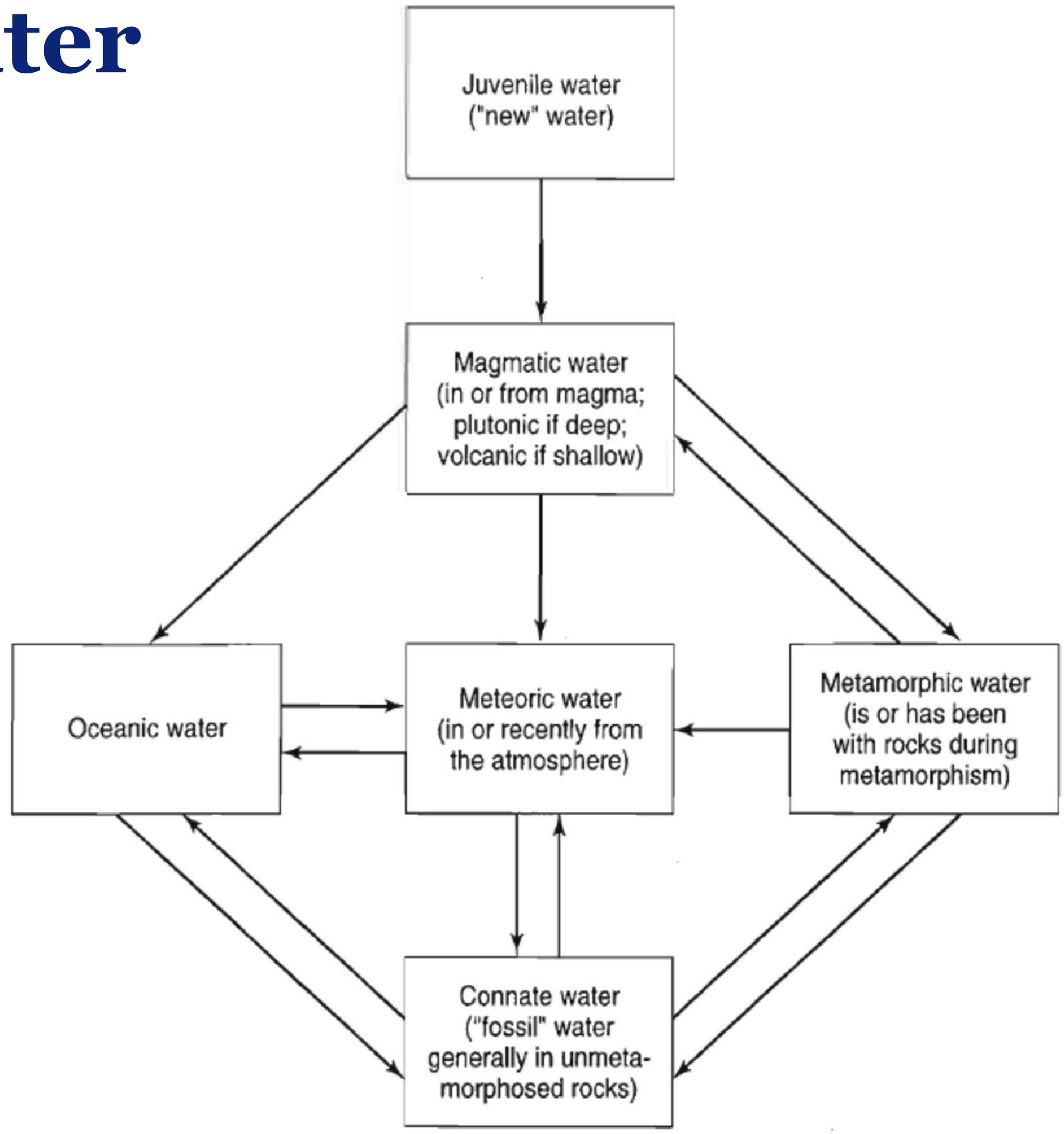
where:

V_T is the total volume of a soil mass ($V_T = V_S + V_v$)
V_S is the volume of the solids
V_v is the volume of voids.

$$dV_T = dV_S + dV_v \longrightarrow dV_S = 0 \longrightarrow dV_T = dV_v$$

$$d\sigma_e = -dp \qquad \alpha = \frac{1}{V_T}\frac{dV_T}{dp}$$

Types of Water



Types of Soil Water

- Mobile water:
  - Moves freely due to hydrodynamic forces
- Adsorbed water:
  - Governed largely by forces of attraction associated with the structure of the water molecules and the solid mineral surface.
- Capillary water:
  - water is under negative pressure, or suction
- Pendular water:
  - Residual immobile water around grain-to-grain contact points
  - Disconnected in the hydrodynamic sense

Learning Strategy

Chapter 2: Physical Properties

Section 2.1, 2.2, 2.3, 2.4

Thank you