भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES) DHANBAD

GPC510 - Well logging

Semester - Winter 2025; Lecture - 6

Partha Pratim Mandal
Assistant Professor
Department of Applied Geophysics
E: partham@iitism.ac.in

TEACHING OUTLINE

Week 3

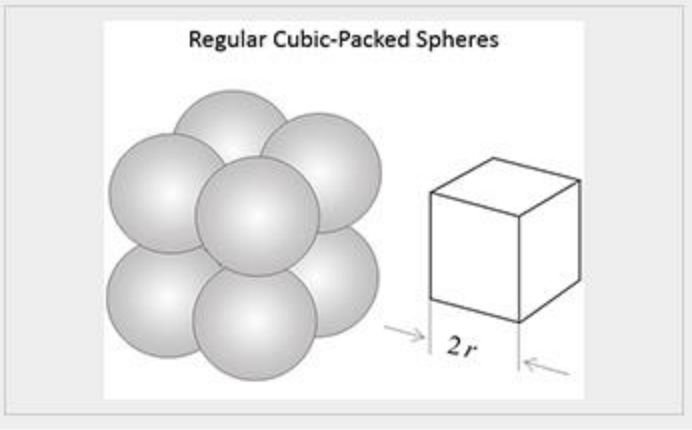
Tutorial 8 – Core porosity, porosity variation with depth, permeability

AGENDA

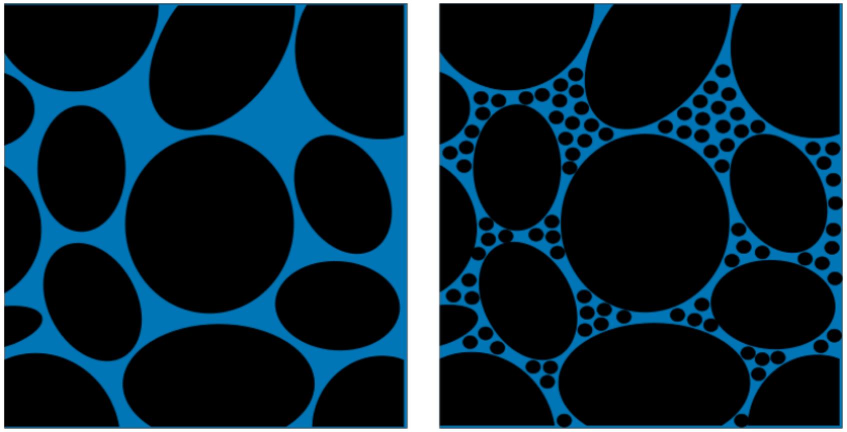
- Porosity measurement techniques (lab scale)
- Darcy’s law of fluid flow
- Permeability (k) definition and permeability ranges of different rock
- Effective and relative permeability

POROSITY OF IDEALIZED GRAINS

- Calculate porosity of regular cubic-packed sphere?



- Which section has larger porosity?



Serra, 1985; Wikipedia, 2021

POROSITY FROM CORE SAMPLE

- Measurement of porosity in the laboratory is part of Routine Core Analysis (RCA). Several methods exist for intergranular porosity measurement
- **Bulk volume** (V_b) – physical measurement (dimensions of a cylindrical shape) and displacement method for irregular shape sample
- The fluid volume that the sample displaces can be determined volumetrically or gravimetrically in three different ways:

- Coating the sample with paraffin
- Saturating the rock with same fluid into which it is to be immersed
- By using mercury, generally not enter the pore space

Regular geometry

Irregular geometry

POROSITY FROM CORE SAMPLE

- Gravimetric determination of bulk volume either by loss of weight when immersed in fluid or change in weight of pycnometer filled with mercury
- **<u>Grain volume</u>** (V_g) – require dry weight of sample and grain density. Crushed powder sample is required to determine grain volume by displacement method

Gas Pycnometer

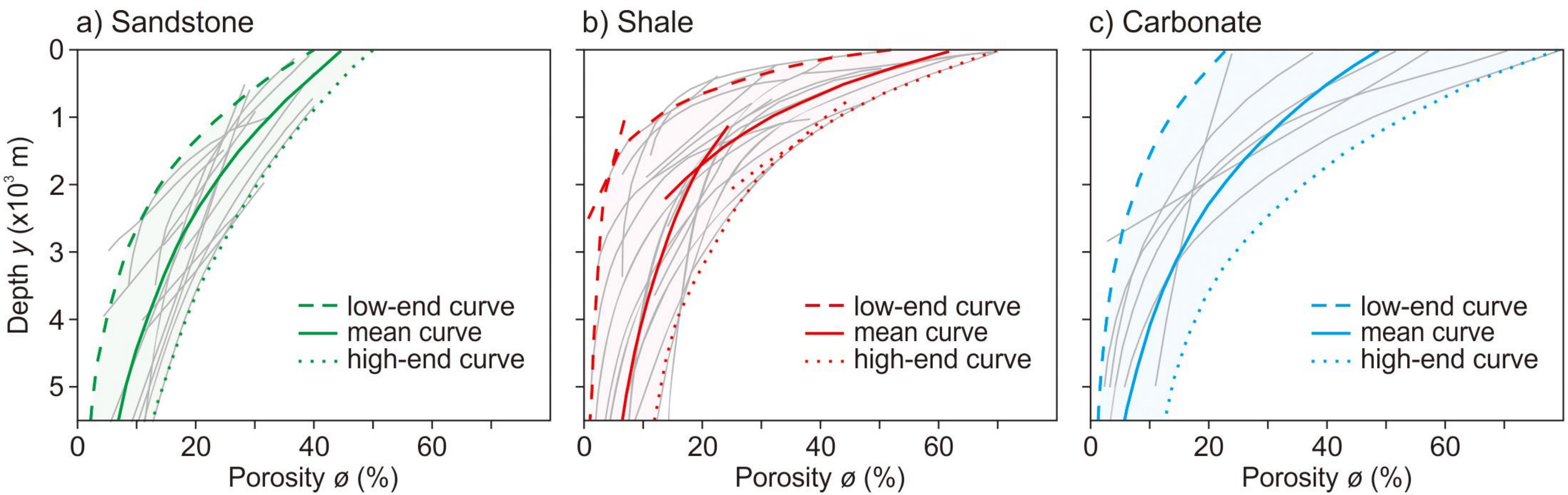
CSIRO; PERM TIPM Lab, 2021

POROSITY VARIATION WITH DEPTH

- Beside the mechanism of grain packing, the degree of compaction with the depth of burial is an important factor
- Porosity decreases with increasing depth in a predictable manner for a normal pressurized subsurface reservoir such as

$\varphi = \varphi_0 e^{-z\alpha}$ in which φ_0 is the porosity at surface and α is the compact constant (1/m or 1/ft) for a particular geological area

POROSITY VARIATION WITH DEPTH

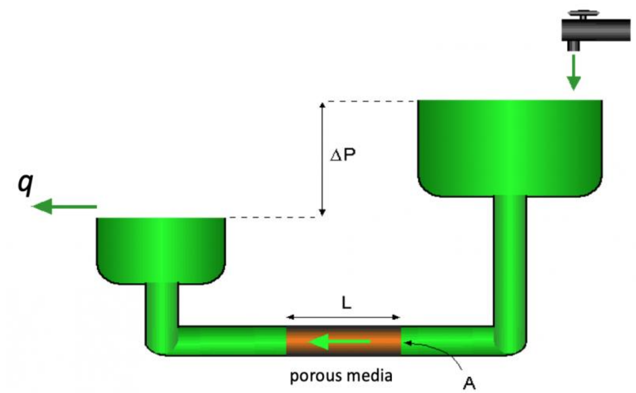


Compilation plots of published compaction trends (gray lines) of a) sandstone, b) shale, c) carbonate (Giles, 1997). The compaction trend range of each lithology is defined by three sets of exponential curves; low-end curve (dashed line), mean curve (solid line) and high-end curve (dotted line).

DARCY'S LAW OF FLUID FLOW

- Darcy's law is the fundamental law of fluid motion in porous media of single fluid under steady state flow with constant fluid compressibility and temperature

- Darcy's law is $q = \frac{k}{\mu}\frac{A}{L}(P_1 - P_2)$ which is similar to Fourier's law of heat conduction/ Ohm's law of electricity

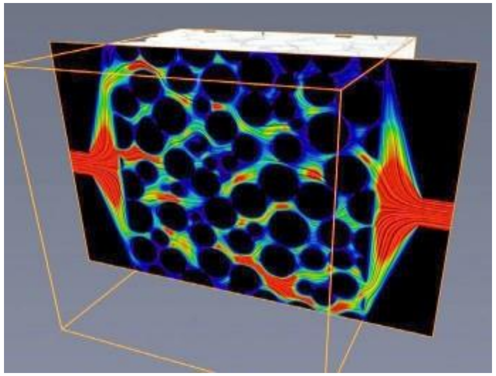


in which k = absolute permeability (Darcy); A= cross-sectional area (cm^2); L = length (cm); P_1, P_2 – pressure in atm at up and downflow faces; μ = fluid viscosity (centipoise)

- If the flow is changed from linear to radial, the above equation will change accordingly

PERMEABILITY

- A measure of ability of the rocks to transmit fluids
- Permeability (petroleum industry) is expressed in millidarcy (1 Darcy = 1000 mD)
- Model based approach can be used to derive continuous permeability profile from well logs
- Similar to porosity, permeability is part of RCA
- Permeability is a directional dependent property (anisotropic in nature)



Ref: Geomore.com

PERMEABILITY CHART OF ROCKS

Permeability	Pervious				Semi-Pervious				Impervious				
Unconsolidated Sand & Gravel	Well Sorted Gravel		Well Sorted Sand or Sand & Gravel			Very Fine Sand, Silt, Loess, Loam							
Unconsolidated Clay & Organic					Peat		Layered Clay			Unweathered Clay			
Consolidated Rocks	Highly Fractured Rocks				Oil Reservoir Rocks			Fresh Sandstone		Fresh Limestone, Dolomite		Fresh Granite	
κ (cm^2)	0.001	0.0001	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}	10^{-11}	10^{-12}	10^{-13}	10^{-14}	10^{-15}
κ (millidarcy)	10^{+8}	10^{+7}	10^{+6}	10^{+5}	10,000	1,000	100	10	1	0.1	0.01	0.001	0.0001

Source: modified from Bear, 1972

EFFECTIVE AND RELATIVE PERMEABILITY

- Effective permeability refers to flow of fluid through a rock in presence multiple pore fluids. It depends not only rock but also to the percentage of fluids presents in the pores [i.e., saturation]
- Multiphase fluid flow is described by relative permeability (k_{rw}, k_{ro}, k_{rg}). It is expressed as ratio of effective permeability ((k_w, k_o, k_g) to their absolute permeability k as below

$k_{ro} = \frac{k_o}{k}$ for oil

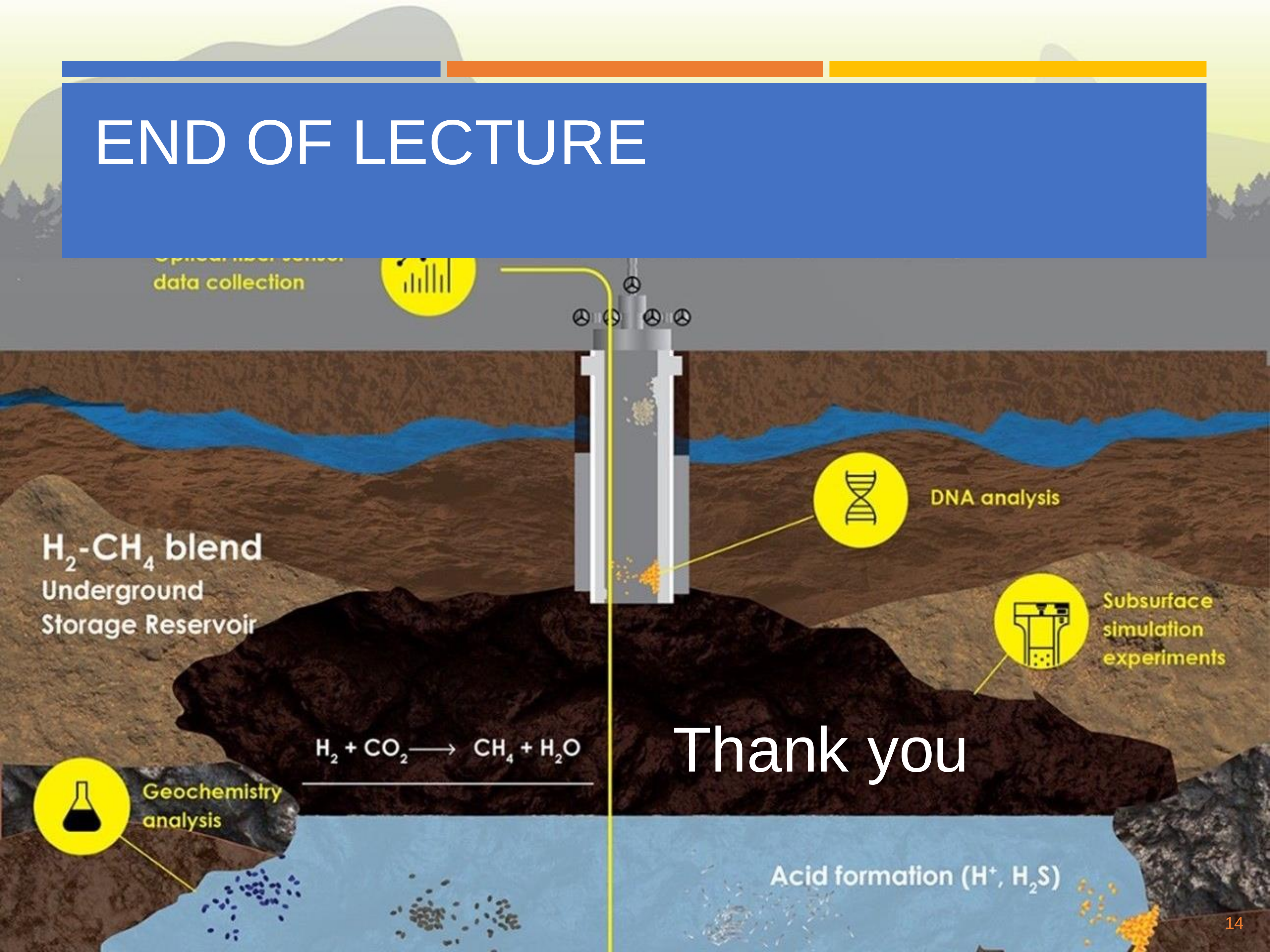
$k_{rg} = \frac{k_g}{k}$ for gas

$k_{rw} = \frac{k_w}{k}$ for water

EFFECTIVE AND RELATIVE PERMEABILITY

- **Effective permeability** is the ability to preferentially flow or transmit a particular fluid through a rock when other immiscible fluids are present in the reservoir (for example, effective permeability of gas in a gas-water reservoir).
- The **relative saturations** of the fluids as well as the nature of the reservoir affect the effective permeability.
- Relative permeability is the ratio of **effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation.**
- Basically, absolutely permeability for a particular rock-fluid pair will be specific. That's why there are **different absolute permeabilities for gas and brine.**
- Generally, we choose **brine-rock pairs** for measuring absolute permeability and then take that as a reference for calculating relative permeabilities for other phases.

END OF LECTURE



Thank you