Lecture Two: Porosity

2.1. Definition

The porosity of a rock is a measure of the storage capacity (pore volume) that is capable of holding fluids. Quantitatively, the porosity is the ratio of the pore volume to the total volume (bulk volume). This important rock property is determined mathematically by the following generalized

$$Porosity\ (\emptyset) = \frac{Pore\ volume}{Bulk\ volume} \qquad \text{.......(2-1)}$$

$$Pore\ volume = Bulk\ volume \times \emptyset$$

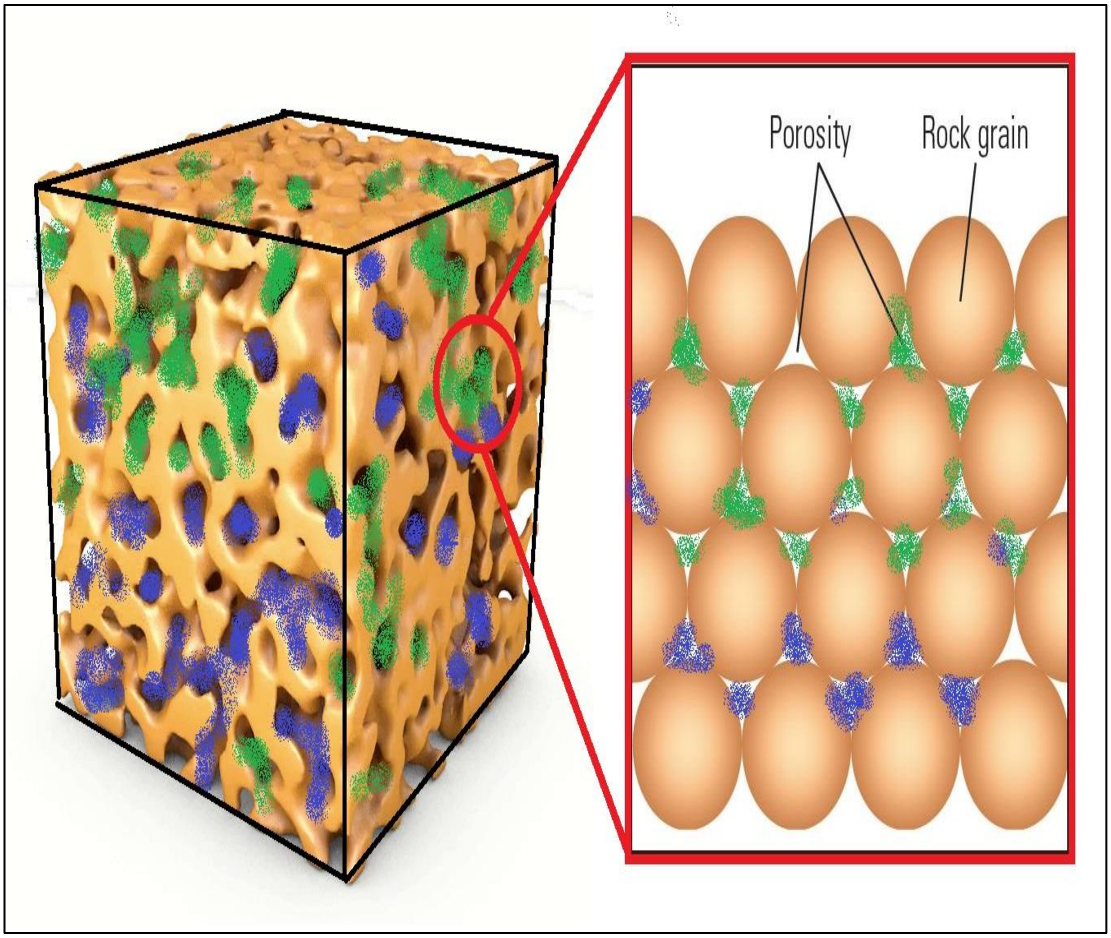


Fig 2-1 reservoir porosity

2.2. Porosity classification

1-Geological Classification

- **Primary Porosity:** refers to the void spaces remaining after sedimentation of the granules in the matrix and hence is a matrix porosity.

Processes after sedimentation (cementation, re-crystallization, weathering, fracturing etc.) can modify substantially the proportion and distribution of pore space. In reservoir engineering, only the interconnected or effective porosity is of interest since this is the only capacity which can make a contribution to flow. Pore spaces initially present but subsequently sealed off by cementation or recrystallization effects are of no interest.

- **Secondary Porosity** is the contribution from pits, bugs, fractures and other discontinuities in the bulk volume of the matrix. The contribution of secondary porosity to the overall bulk porosity is generally small yet it can lead to dramatic increase in the ease with which hydrocarbons flow through the rock.

2-Engineering classification

As the sediments were deposited and the rocks were being formed during past geological times, some void spaces that developed became isolated from the other void spaces by excessive cementation. Thus, many of the void spaces are interconnected while some of the pore spaces are completely isolated. This leads to two distinct types of porosity, namely:

- **Absolute porosity**
  The absolute porosity is defined as the ratio of the total pore space in the rock to that of the bulk volume. A rock may have considerable absolute porosity and yet have no conductivity to fluid for lack of pore

interconnection. The absolute porosity is generally expressed mathematically by the following relationships:

$$\emptyset_a = \frac{Total\ Pore\ volume}{Bulk\ volume} \qquad \text{.......(2-2)}$$

$$Or:\ \emptyset_a = \frac{Bulk\ volume - Grain\ volume}{Bulk\ volume} \qquad \text{.......(2-3)}$$

where $\emptyset_a$= absolute porosity.

- **Effective porosity**

  The effective porosity is the percentage of *interconnected* pore space with respect to the bulk volume

$$\emptyset_e = \frac{interconnected\ pore\ space}{Bulk\ volume} \qquad \text{.......(2-4)}$$

where $\emptyset_e$= effective porosity.

The effective porosity is the value that is used in all reservoir engineering calculations because it represents the interconnected pore space that contains the recoverable hydrocarbon fluids.

3- Average porosity

The reservoir rock may generally show large variations in porosity vertically but does not show very great variations in porosity parallel to the bedding planes. In this case, the arithmetic average porosity or the thickness-weighted average porosity is used to describe the average reservoir porosity. A change in sedimentation or depositional conditions, however, can cause the porosity in one portion of the reservoir to be greatly different from that in another area. In such cases, the areal weighted average or the volume-weighted average porosity is used to characterize the average rock porosity. These averaging techniques are expressed mathematically in the following forms:

- Arithmetic average $\emptyset = \sum \emptyset_i / n$ …….(2-5)
- Thickness-weighted average $\emptyset = \sum \emptyset_i \, h_i / \sum h_i$ …….(2-6)
- Areal-weighted average $\emptyset = \sum \emptyset_i \, A_i / \sum A_i$ …….(2-7)
- Volumetric-weighted average $\emptyset = \sum \emptyset_i \, A_i \, h_i / \sum A_i \, h_i$ …….(2-8)

where n = total number of core samples

h_i = thickness of core sample i or reservoir area i

$\emptyset_i$ = porosity of core sample i or reservoir area i

A_i = reservoir area i

Example1:

Calculate the arithmetic average and thickness-weighted average from the following measurements:

Sample	Thickness, ft	Porosity, %
1	1.0	10
2	1.5	12
3	1.0	11
4	2.0	13
5	2.1	14
6	1.1	10

Solution

- Arithmetic average

$$\phi = \frac{10 + 12 + 11 + 13 + 14 + 10}{6} = 11.67\%$$

- Thickness-weighted average

$$\phi = \frac{(1)\,(10) + (1.5)\,(12) + (1)\,(11) + (2)\,(13) + (2.1)\,(14) + (1.1)\,(10)}{1 + 1.5 + 1 + 2 + 2.1 + 1.1}$$

$$= 12.11\%$$

2.3. Factors affecting porosity

The factors that affected the value of the porosity are:

1. Particle shape
2. Packing arrangement
3. Particle size distribution
4. Compaction
5. Cementation
6. Vugs and fractures

1- Particle shape

The porosity of the formation increases as the particles that forming it are closer to sphere shape and less angled.

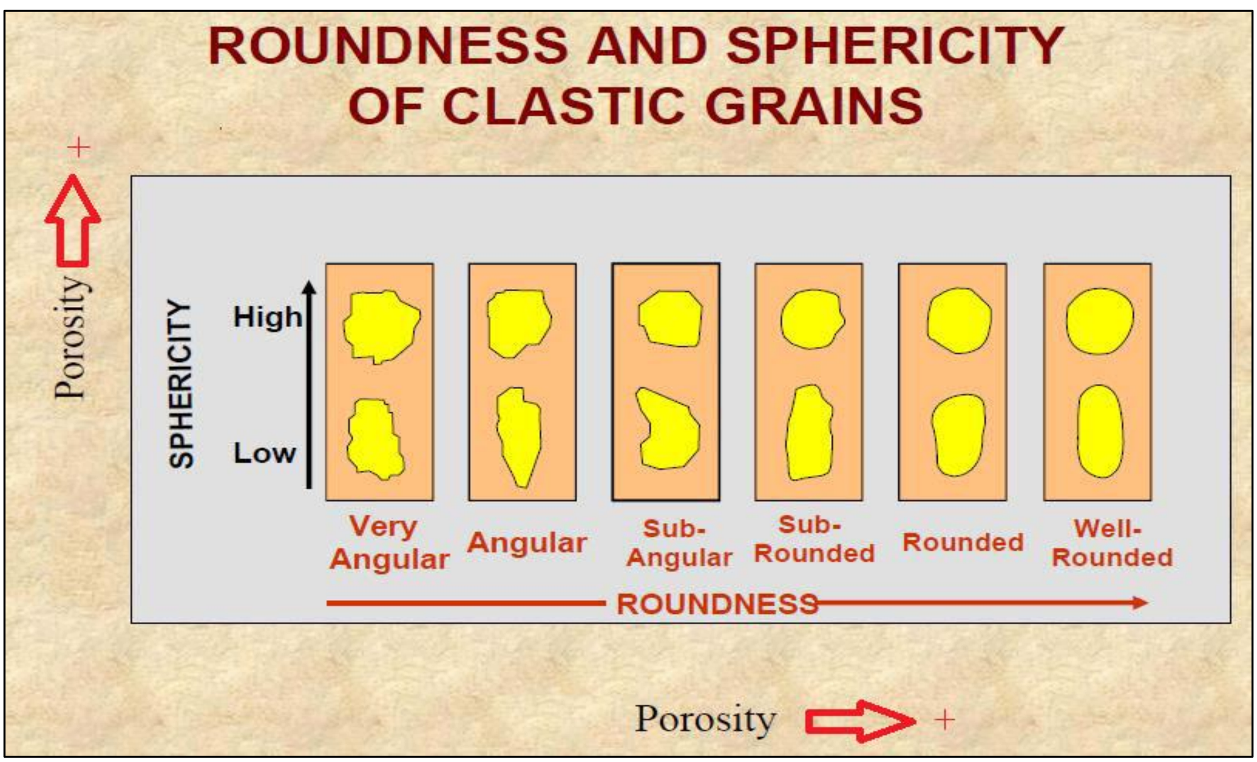


Fig 2-2 the effect of partials shape on formation porosity

2- Packing arrangement

Figure 2-3 shows schematic diagram of packing arrangements for spheres. Porosity values are calculated for cubic (47.6%), orthorhombic (39.5%), rhombohedral (26%), and tetragonal (30.2%) packing.

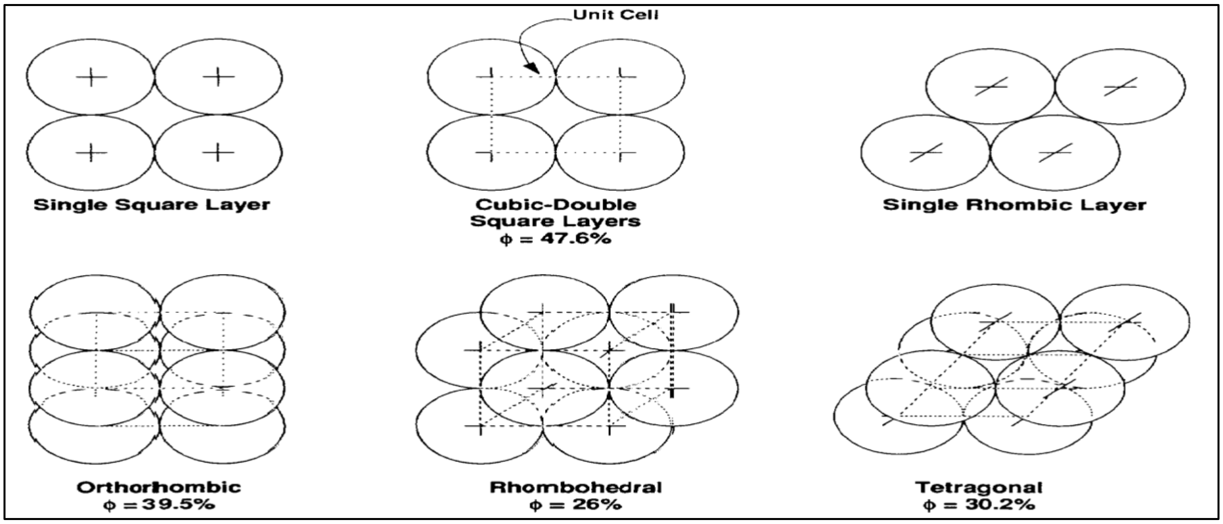


Fig 2-3 the effect of packing arrangement on porosity

3- Particle size distribution

Porosity decreases as the range of particle size increases

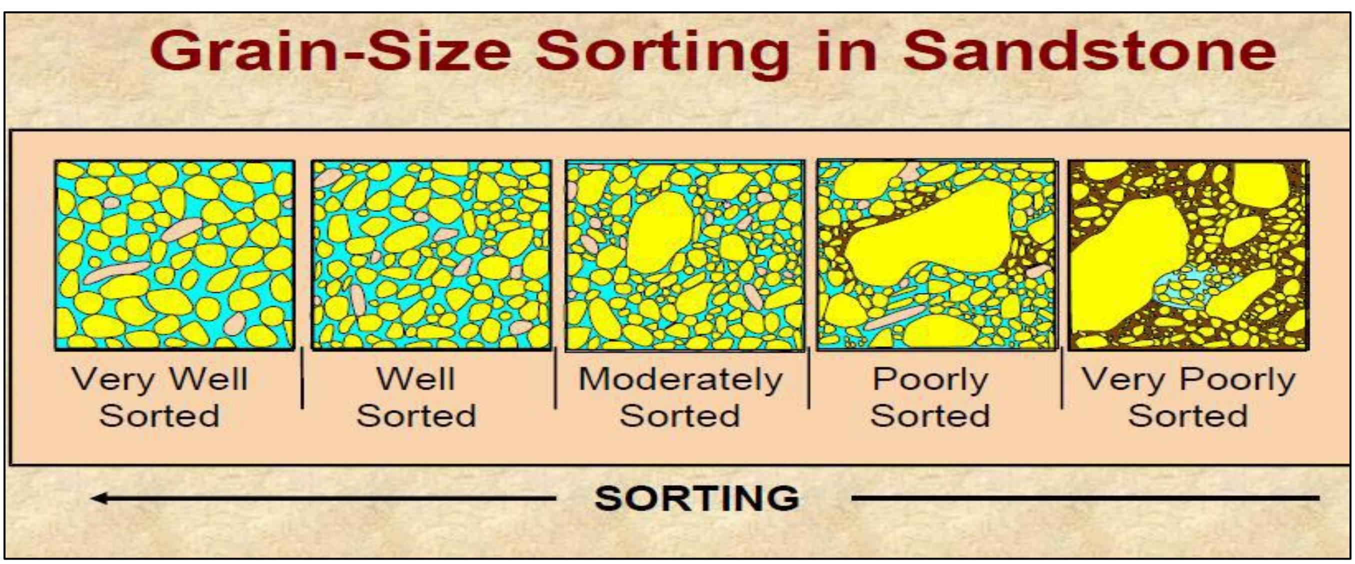


Fig 2-4 the effect of partials size on formation porosity

4- Compaction

Porosity decreases as the compaction increases.

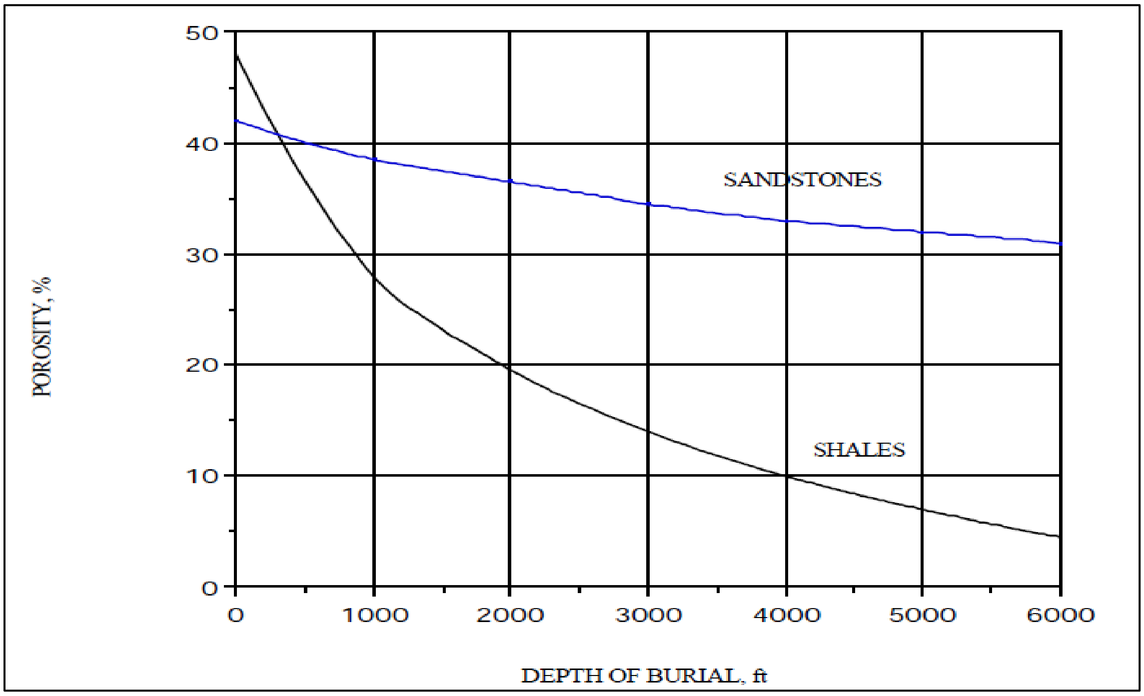


Fig 2-5 the effect of compaction on formation porosity

5- Interstitial and Cementing Material

1. Porosity decreases as the amount of interstitial material increases
2. Porosity decreases as the amount of cementing material increases
3. Clean sand - little interstitial material

   Shaly sand - has more interstitial material

6- Vugs and Fractures

1. Contribute substantially to the volume of pore spaces
2. Highly variable in size and distribution
3. There could be two or more systems of pore openings - extremely complex

Example2: Calculate maximum porosity value obtained from a cubic packing of uniform spheres.

Solution:

Maximum porosity value obtained from a cubic packing of uniform spheres:

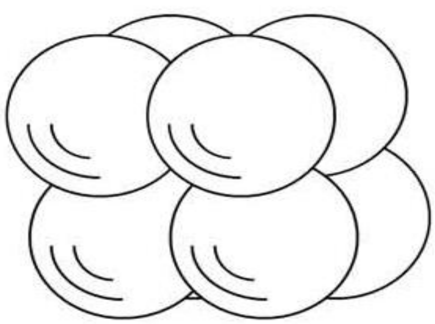
r = sand grain radius

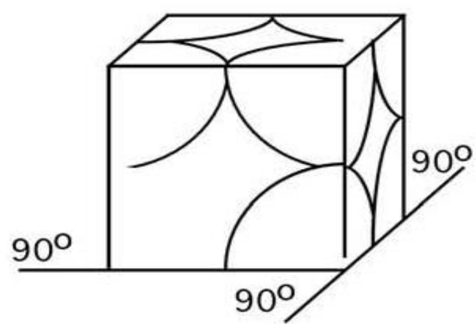
$V_b = (2r)^3 = 8r^3$

$V_m = 8(1/8 \text{ sphere}) = 1 \text{ sphere} = (4/3)\pi r^3$

$$\phi = \frac{V_b - V_m}{V_b} = \frac{8r^3 - (4/3)\pi\, r^3}{8r^3}$$

$\phi = 1 - \pi/6 = 0.476$ <u>max. value</u>





$\phi = 0.476$