Chapter two (physical properties of sedimentary rocks)

Sedimentary texture:

Sedimentary texture refers to the shape, size and arrangement (orientation) of the particles that make up a sedimentary rock. Sedimentary texture encompasses three fundamental properties of sedimentary rocks: **grain shape**, **grain size** and **fabric.** The interrelationships of these primary textural properties control other, derived, textural properties such as **bulk density**, **porosity**, and **permeability.**

The textures of siliciclastic sedimentary rocks (conglomerates, sandstones, siltstones and claystones.) are produced primarily by *physical processes* of sedimentation, whereas the textures of nonsiliciclastic sedimentary rocks (such as rock salt, reef, and limestones) are caused principally by *chemical* or *biological* sedimentation processes.

The characterization of textures can aid in interpreting depositional environments and transport conditions.

Particle Shape

Sedimentary particles (minerals and clasts) display a wide range of shapes, depending on a variety of factors: (1) the original shapes in the source rocks, (2) the orientation and spacing of fractures in bedrock, (3) the nature and intensity of sediment transport, and (4) sediment burial processes such as compaction**. Particle shape** defined by three related attributes. These are **form**, **roundness** and **surface textures**.

• **Form (spherecity);** refers to the degree to which a particle approaches a sphere, which expressed by the relative lengths of the 3 major axes; long (L), intermediate (I), and short (S).

Sneed and Folk (1958) suggest maximum projection sphericity which is better expresses the behavior of particles in fluid by the relationship

$$\psi p = \sqrt[3]{\frac{\mathbf{DS^2}}{\mathbf{DLDI}}}$$

The mathematical value of sphericity is 1 for a perfect sphere, less spherical particles have lower fractional value (<1).

• **Roundness;** refers to the degree of sharpness of the corners and edges of grain. If the corners and edges are quite smooth, the grain is well rounded. If the corners and edges are sharp and angular, the grain is poorly rounded.

The roundness value of 1 for perfectly rounded particles and small fractional value for less well rounded particles. Because of the laborious process to measure and express roundness mathematically, most workers use **Powers chart** to estimate the roundness (Fig. 2.1).

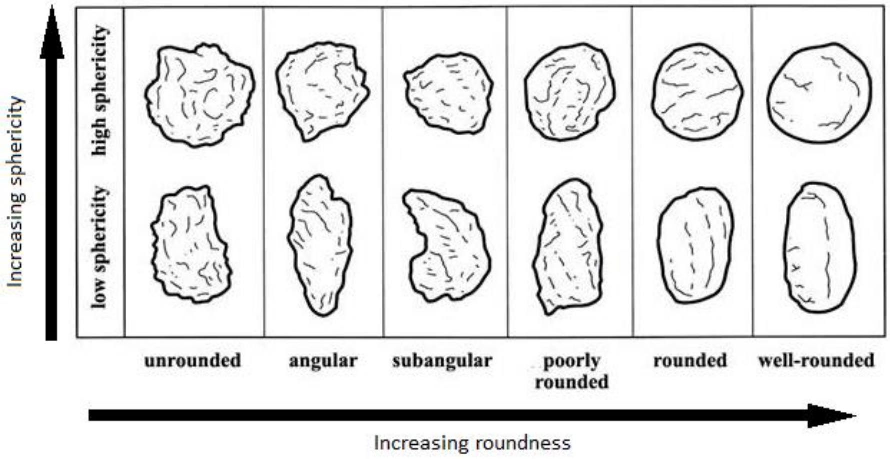

Fig. 2.1 Visual grain roundness scale (After powers, 1953)

Factors affecting roundness:

(1) Grain composition (Hardness "mineral type"); Hard resistant grains such as quartz and zircon are rounded less readily during transport than are weakly durable grains such as feldspar and pyroxene.

(2) Grain size; Pebble- to cobble size grains commonly are more easily rounded by abrasion during transport than are sand-size grains.

(3) Type of transport process; Transport by wind (desert) is more effective in rounding grains than transport by water (river or littoral).

(4) Distance of transport; Soft pebbles such as shale and limestone become rounded much more readily than quartzite or chert pebbles.

(5) Large pebbles and cobbles are commonly better rounded than smaller pebbles (short transport distance).

Classification of pebble shapes:

There are many classification schemes to describe the shape of the particles. These are as follows:

1. Classification of Zingg (1935):

Plotting on a bivariate diagram the ratio of the intermediate to long particle axis versus the ratio of the short to intermediate particle axis (Fig 2.2A). Four classes of grain shape (mainly for gravel) are recognized: **roller**, **bladed**, **oblate**, and **equant**.

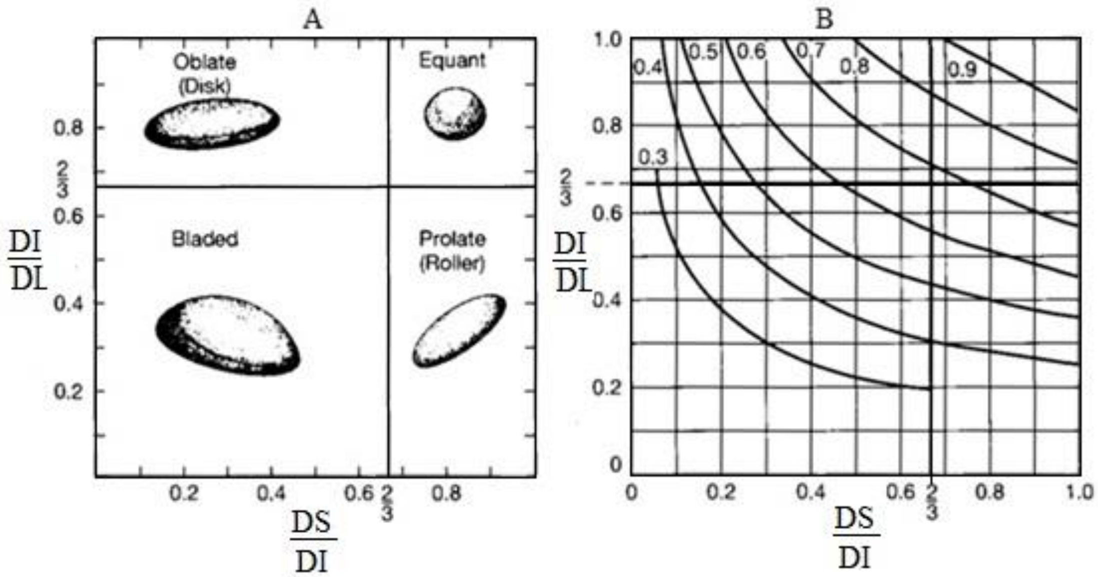

Figure 2.2 A. Classification of shapes of pebbles after Zingg (1935). B. Relationship between mathematical sphericity and Zingg shape fields. The curves represent lines of equal sphericity.

2. Classification of Sneed and Folk (1958):

Plotting DS/DL against DL-DI/ DL- DS to create ten form fields (Fig. 2.3). End member particle shapes are **compact**, **platy**, **bladed** and **elongated**.

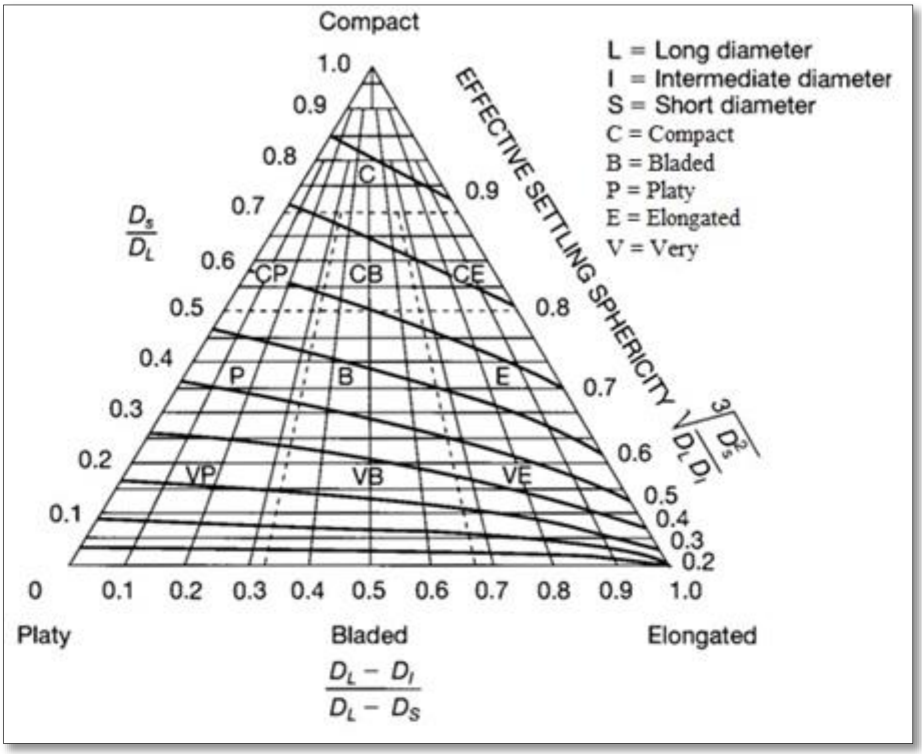

Fig. 2.3 Classification of pebble shapes (After Sneed and Folk, 1958)

Surface texture

Surface texture; refers to microrelief features, such as scratches, ridges, fractures and pits, that appear on the surfaces of clastic particles (pebbles and mineral grains), particularly particles that have undergone transport.

• The surface of particles may be polished, frosted (dull, matte) or marked by a variety of surface markings.

• Surface textural features can be observed with naked eye, binocular or petrographic microscope; however, detailed study of surface textures requires high magnification (SEM).

• Most investigators carry out their study on quartz grains because of the *physical hardness* and *chemical stability* of quartz grains allow these particles to retain surface marking for geologically long periods of time.

The surface textures originate in diverse ways including:

1) Mechanical abrasion during sediment transport.
2) Tectonic polishing during deformation.
3) Chemical corrosion, etching, and precipitation of authigenic growths on grain surfaces during diagenesis and weathering.

Geologists considered surface textural features as possible indicators of ancient transport conditions and depositional environment. **However, the usefulness of surface texture in environmental analysis is limited because:**

(1) Several markings can be produced in the same environment.
(2) The markings produced on grains in one environment may be remained on grains that are transported into another environment.
(3) Surface markings can be changed during diagenesis by addition of cementing overgrowths or chemical etching and solution.

Some markings tend to be relatively more abundant in some environments than in others. (1) Mechanical V-shaped pits are particularly common on quartz grains from high-energy subaqueous environments on **beaches** and in **rivers** (Fig. 2.5). (2) Parallel grooves (striations) and step features are common on grains from **glacial environments**. (3) Grains with low relief and abundant abrasion features (rubbed or worn grain surfaces), surface smoothness and rounding are characteristic of **wind-blown transport** (Fig. 2.4).

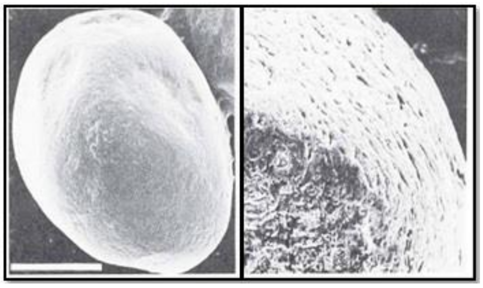

Fig. 2.4 SEM image of well-rounded sand grain showing extreme “frosting” indicating wind transport.

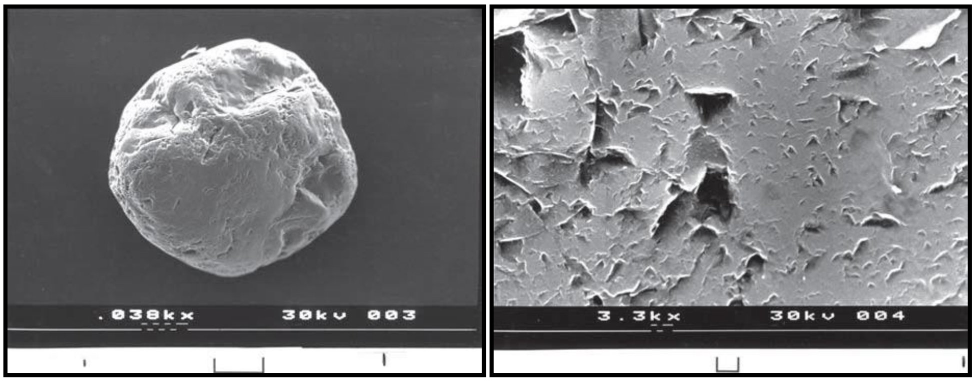

Fig. 2.5 A. Electron micrograph of surface markings on a quartz grain from a late Pleistocene high-energy **beach deposit** near Norwich, Norfolk, England. B. Enlarged portion of the extreme right edge of the grain in A. Note **abundant V-shaped markings**, which are characteristics of quartz grains from high-energy beaches. [Photograph courtesy of David Krinsley.

Grain size:

Grain-size scales:

1. Geometric scales:

The grade scale most widely used by sedimentologists is the **Udden–Wentworth scale** (Wentworth, 1922). Each value in this scale is two times larger than the preceding value. The Udden–Wentworth scale extends from < 1/256 mm (0.0039 mm) to > 256mm and is divided into four major size categories (clay, silt, sand, and gravel) , as shown in Table 2.1.

2. Logarithmic phi scale:

A modification of the Udden–Wentworth scale is the logarithmic **phi (ϕ) scale** proposed by Krumbein (1934). This scale, is based on the following relation:

Phi (ϕ) = $-\log_2 d$ Where ***d*** is the diameter (mm).

The relationship between the Wentworth and phi grade scales:

The increasing absolute value of negative phi numbers indicates increasing millimeter size, whereas increasing positive phi numbers indicate decreasing millimeter size, is shown in Table 2.1

Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class		Rock type
	4096		-12.0	Boulder	Gravel	Conglomerate/ breccia
	256		-8.0	Cobble		
	64		-6.0	Pebble		
	4		-2.0	Granule		
	2.00		-1.0	Very coarse sand	Sand	Sandstone
	1.00		0.0	Coarse sand		
1/2	0.50	500	1.0	Medium sand		
1/4	0.25	250	2.0	Fine sand		
1/8	0.125	125	3.0	Very fine sand		
1/16	0.0625	63	4.0	Coarse silt	Silt	Siltstone
1/32	0.031	31	5.0	Medium silt		
1/64	0.0156	15.6	6.0	Fine silt		
1/128	0.0078	7.8	7.0	Very fine silt		
1/256	0.0039	3.9	8.0	Clay	Mud	Claystone
	0.00006	0.06	14.0			

Table 2.1 Udden–Wentworth grain-size scale for sediments and the equivalent phi (ϕ) scale.

<u>The principle advantage of the (ϕ) scale are</u>:

1. The phi (ϕ) scale allows grain-size classes to be expressed in integers (size class become whole numbers instead of fractions).
2. The phi (ϕ) scale simplifies statistical calculations and graphic plotting of grain size data.
3. This scale is consistent with common practice of plotting coarse sizes to the left and fine sizes to the right in the graphs.

Measuring grain size:

There are many methods for measuring the grain size of siliciclastic particles. The choice of method depends largely on the *sizes* of the particles and their *state of consolidation* (Table 2.2).

<table>
<tr><th>Type of sample</th><th>Sample grade</th><th>Method of analysis</th></tr>
<tr><td rowspan="3">Unconsolidated sediment and disaggregated sedimentary rock</td><td>Boulders
Cobbles
Pebbles</td><td><u>Manual measurement of individual clasts</u></td></tr>
<tr><td rowspan="2">Granules
Sand
Silt

Clay</td><td><u>Sieving,</u> settling-tube analysis, image analysis</td></tr>
<tr><td>Pipette analysis, sedimentation balances, Sedigraph, laser diffractometry, electro-resistance size analysis (e.g. Coulter Counter)</td></tr>
<tr><td rowspan="3">Lithified sedimentary rock</td><td>Boulders
Cobbles
Pebbles</td><td><u>Manual measurement of individual clasts</u></td></tr>
<tr><td rowspan="2">Granules
Sand
Silt

Clay</td><td><u>Thin-section measurement</u>, image analysis</td></tr>
<tr><td><u>Electron microscopy</u></td></tr>
</table>

Table 2.2 Methods of measuring sediment grain size.

<u>Graphical and mathematical treatment of grain-size data</u>:

The techniques for reducing and presenting grain-size data include both graphical and statistical (mathematical measures) methods.

<u>Graphical methods:</u>

Graphical presentation of grain-size data commonly involves plotting the data on bi variate diagrams in which either individual weight percent of each grain-size class or cumulative weight percent is plotted against phi size (Fig. 2.6). <u>There are three common graphical methods for presenting grain-size data:</u>

(1) The **Histograms** (Fig. 2.6A) are plotting individual weight percent (frequency) versus the phi size of each size class. Such diagrams provide an easily visualized pictorial representation of the grain-size distribution, <u>but their shape is affected by the phi-size (sieve) interval. Also, they cannot be used to obtain mathematical values for statistical calculations</u>.

(2) The **Frequency curve** is similar to a histogram except that the bars diagram is replaced by a smooth curve (Fig. 2.6B).

(3) The **Cumulative curve** by plotting cumulative weight percent frequency against phi size. Cumulative curves can be constructed that use either an arithmetic scale (Fig. 2.6C) or a log-probability scale (Fig. 2.6D) for the ordinate.

Cumulative curve is the most useful of the grain-size plots because its shape is independent of the sieve intervals and the data can be derived from cumulative curve (phi values) allow important grain-size statistical parameters (median, mean, sorting….etc.).

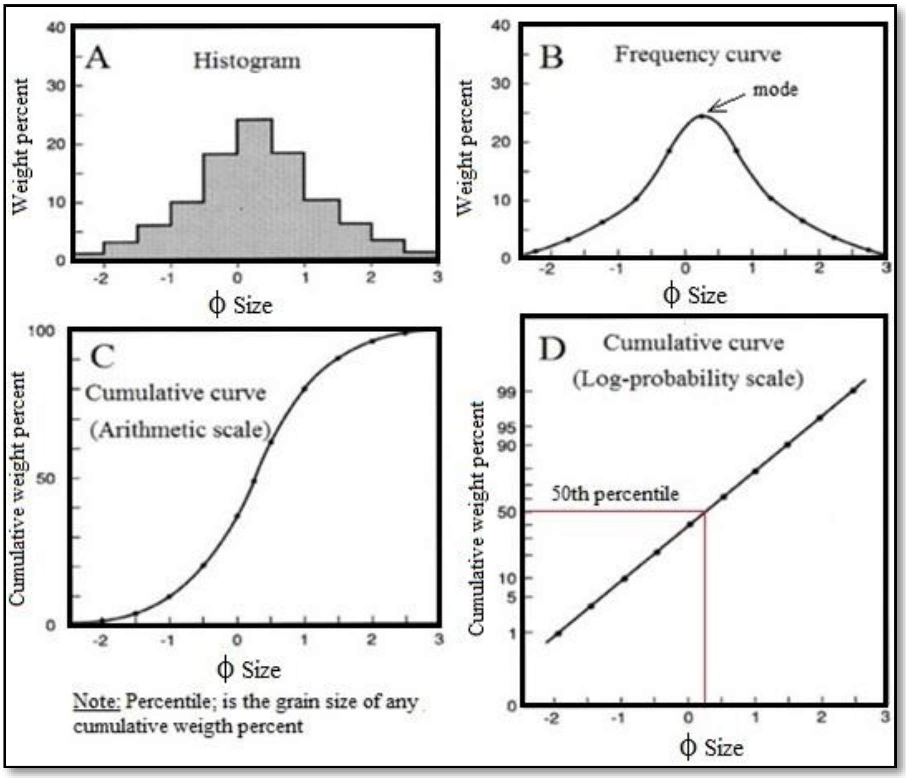

Figure 2.6 Hypothetical, nearly log-normal grain-size distribution plotted as a histogram (A), a frequency curve (B), a cumulative curve with an arithmetic ordinate (C), and a cumulative curve with a log-probability ordinate (D).

Mathematical methods:

To avoid difficulties (large of plots), mathematical methods that permit statistical treatment of grain-size data can be used to derive parameters that describe grain-size distributions mathematically.

1. Average grain sizes:

Mode; the most common grain size in the population (Fig. 2.6B). Sliciclastic sediments and sedimentary rocks commonly have a single modal size distribution, but some of them are unimodal or polymodal.

Median; represents the midpoint of the grain-size distribution or midpoint of the data. Half of the grains by weight in the sample are larger than the median and half are smaller (50th percentile diameter on the cumulative curve Fig. 2.6D).

Mean; is the average grain size in the deposit. Or it is the arithmetic average of all the particle sizes in a sample. The obtained data describe the grain-size of the sand; whether the sand is fine or coarse according to the class- size intervals of the Udden–Wentworth scale (see Table 1.1). Mean, Median and Mode are only equal in a normal distribution (Fig. 2.7A).

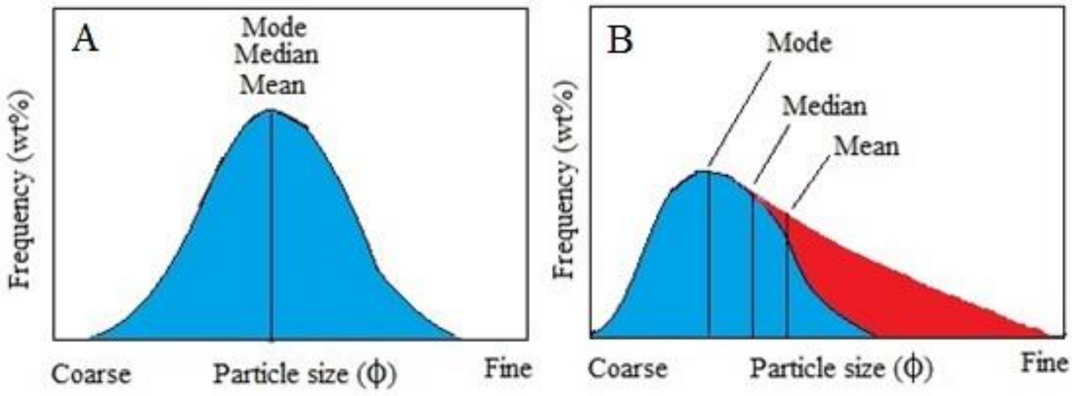

Fig. 2.7 Grain-size frequency curve, showing the relation of the mode, median and mean size for **normal** distribution (A), and **abnormal** distribution (B).

2. Grain-size sorting: the tendency for all the grains to be of one class of grain size (Range of grain sizes in a population). Sorting can be estimated chart such as that shown in Fig. 2.8. The mathematical expression of sorting is **standard deviation** ($\sigma 1$)**.**

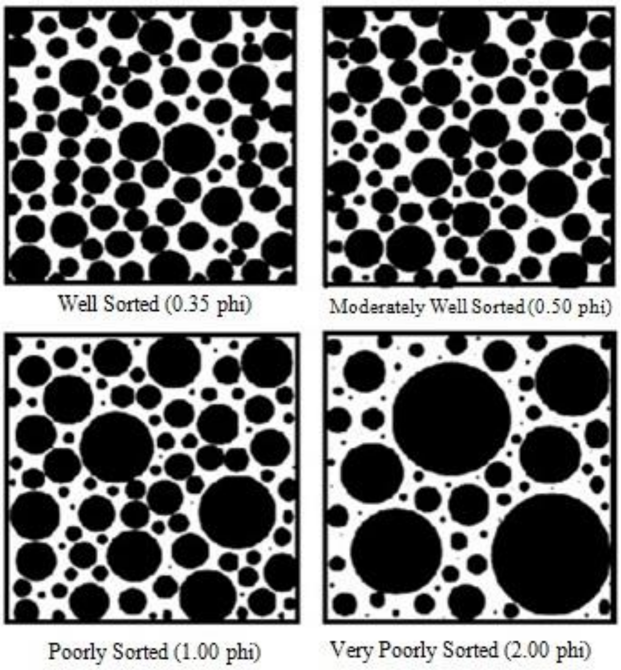

Fig. 2.8 Visual images for estimating grain-size sorting (After Harrell, 1984).

The degree of sorting can de estimated from the frequency curve and the cumulative curve. If the **frequency curve** is *narrow* and *sharp*, the base of curve occupies small range of grain sizes (well-sorted).Where the curve is *low* and *wide*, the base of curve occupies wide range of grain sizes (poorly sorted) (Fig. 2.9). On the **cumulative curve**, the slope of the central part of this curve reflects the sorting of the sample. Avery steep slope indicates good sorting, and a very gentle slope poor sorting (Fig. 2.10).

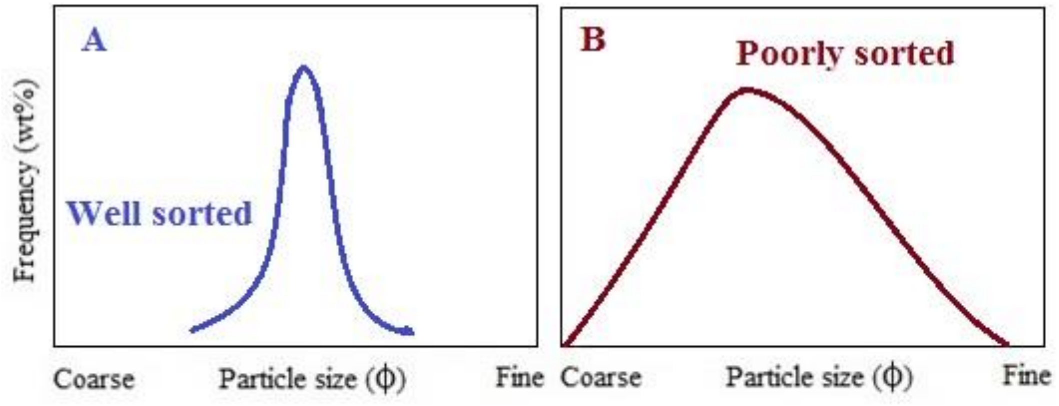

Fig. 2.9 Degree of sorting on the frequency curves. (A) Well-sorted sample and poorly sorted sample (B).

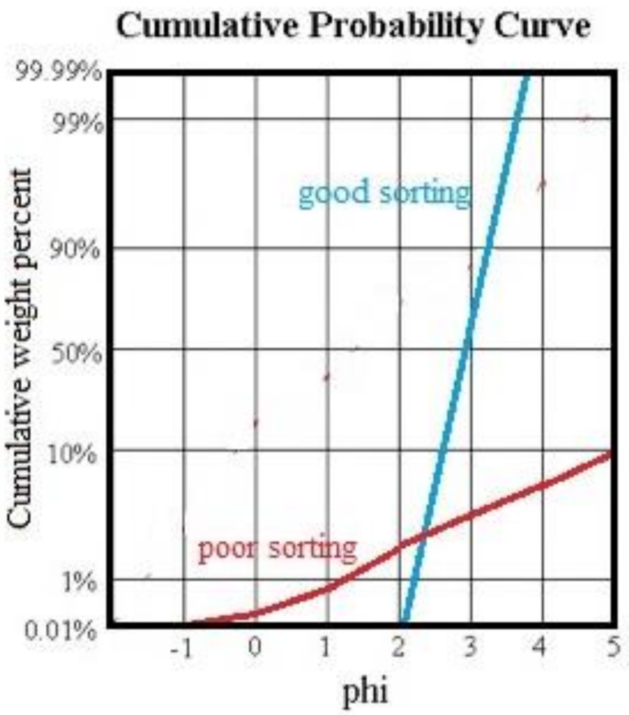

Fig. 2.10 Estimation of the degree of sorting on the cumulative curve.

3. Skewness; represents asymmetry in grain-size distribution. The mode, median and mean in a skewed population of grains are all different (Fig. 2.7B).

There are two types of skewness (Fig.2.11):-

. 1 Positive (fine) skewness: -refers to the population of grains that have a tail of excess fine particles toward larger, or positive phi values.

. 2 Negative (coarse) skewness: -refers to the population of grains that have a tail of excess coarse particles toward smaller, or negative phi values.

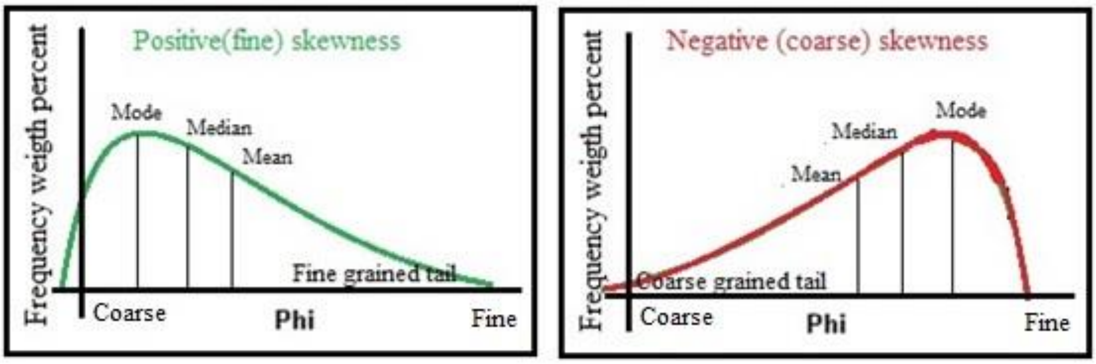

Fig. 2.11 Positive (fine) and negative (coarse) skewness in asymmetrical grain-size distribution.

4. Kurtosis; refers to the sharpness or peakedness of a grain-size frequency curve. Grain-size frequency curves can show various degree of sharpness or peakedness. Sharp-peaked curves are said to be leptokurtic; flat-peaked curves are platykurtic. Sharp peaked curves indicate better sorting in the central portion of the grain-size distribution than in the tails, and flat-peaked curves indicate the opposite (Fig. 2.12).

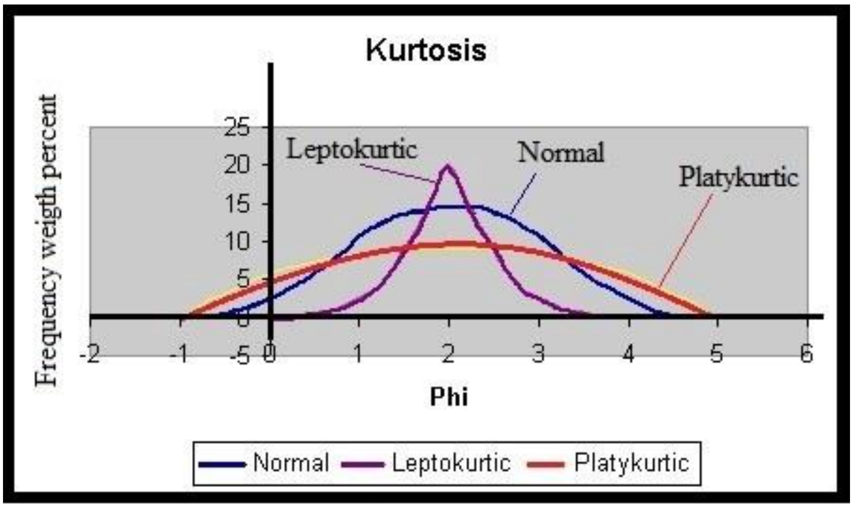

Fig. 2.12 The parameter of kurtosis in grain-size distributions.

Applications and significance of grain-size data:

1) Grain-size is useful in describing silisiclastic sediments and sedimentary rocks into gravels, sands, and muds
2) Grain-size data provide important information that is useful in evaluating the economic significance of sedimentary rocks (petroleum and groundwater) or in interpreting some aspect of Earth history.
3) Grain-size characteristics with combination of sedimentary structures ***may*** reflect depositional conditions and processes and interpreting ancient depositional environments.
4) Grain size and sorting of the sediment ***may*** be indicative of the sedimentation mechanism and depositional conditions.

The grain-size data have long been used to interpret **the depositional processes** and **sedimentary environments** of ancient sedimentary rocks. The sedimentation mechanism **(transport modes; traction, saltation and suspension)** and depositional conditions (differences in curve shapes and the locations of truncation points of the curve segments allow discrimination of sediments from different environments) (e.g. Fig. 2.13).

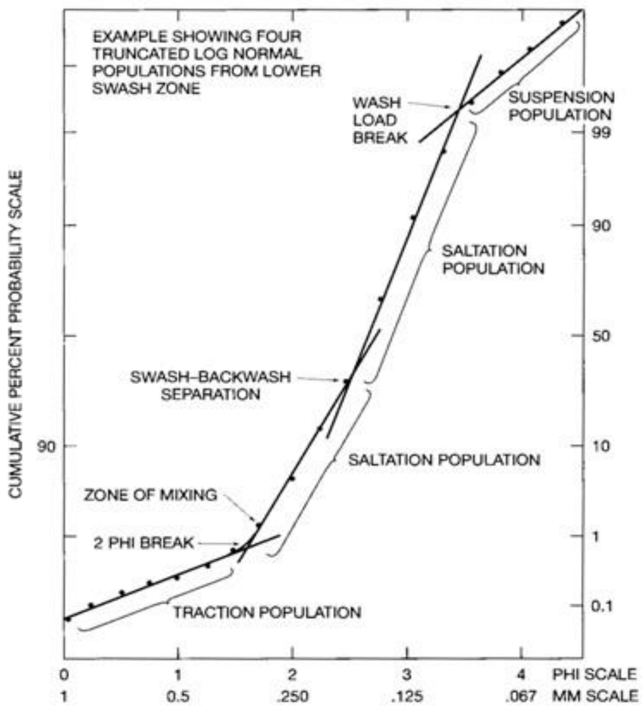

Figure 2.13 Relation of sediment transport dynamics to populations and truncation points in a grain-size distribution (After Visher, 1969).

Two principal types of graphical plots have been used extensively in environmental analysis: two-component variation diagrams and log-probability plots. For example, skewness versus standard deviation. These methods allow separation of the plots into major environmental fields, such as beach environments and river environments (e.g. Fig. 2.14).

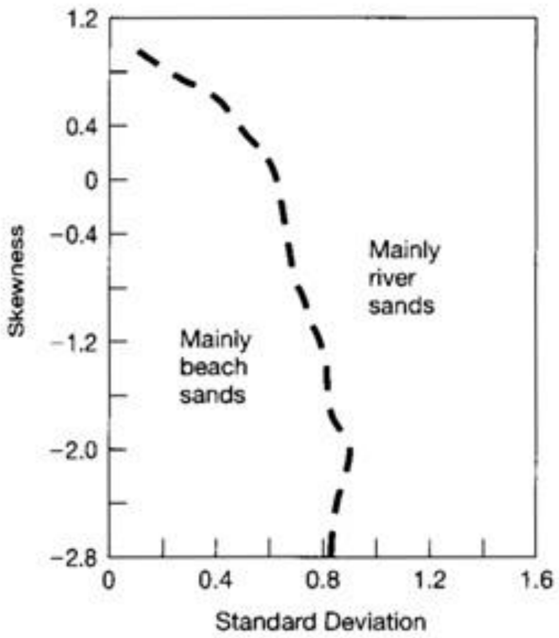

Figure 2.14 Grain-size bivariate plot of moment skewness vs. moment standard deviation, showing the fields in which most beach and river sands plot. (After Friedman, 1967)

Fabric:

Fabric; refers to grain (in sedimentary rock) orientation and packing and to the nature of contacts between them. A *fabric element* of sedimentary rocks may be a single crystal, a pebble or sand grain, a shell, or any other component.

Genetically there are two kinds of fabric:

. **Primary (apposition) fabric** is formed at the time of deposition and common in sedimentary rocks.

. **Secondary (deformation) fabric** reflects the imprint of post-depositional processes such as compaction by overlying sediments.

Significance of fabric:

. Determining the depositional processes and the transport.

. Reconstructing of the current direction at the time of deposition.

. Have an important role on the physical properties of rocks such as thermal, electrical, fluid, and sonic conductivity.

Fabric elements; are grain orientation, grain packing and grain contacts:

A. Grain orientation; the way in which particles show any preferred orientation.

Grain orientation is mainly a function of the depositional processes operating at the time of deposition and the shape of the particles. However, original grain orientation can be modified after deposition by bioturbation and compaction.

Particles in sedimentary rocks commonly display some degree of orientation that reflects the nature of the depositional process (Fig. 2.15).

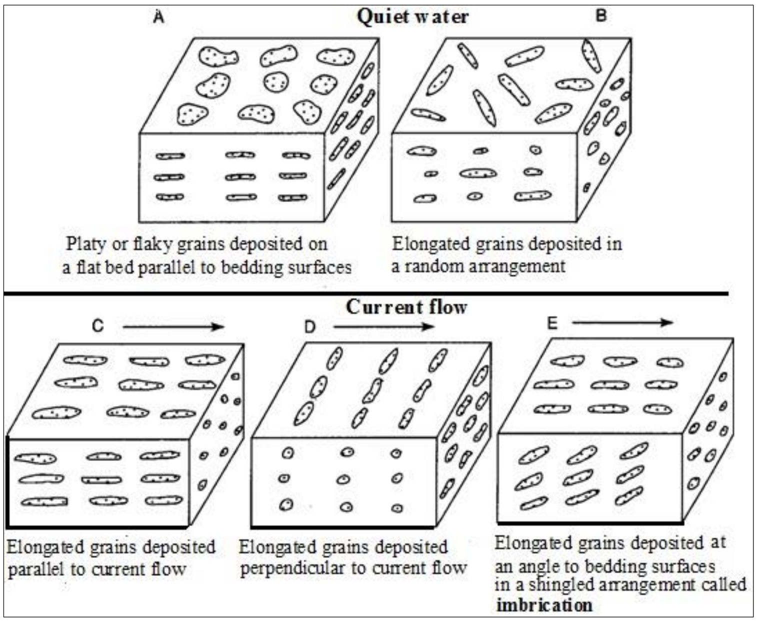

Fig. 2.15 Hypothetical, schematic arrangement of grains in sediments.

Imbrication; is the most common features of gravel fabrics in which the pebbles lie with their long axis parallel to the flow direction and dipping gently up current. This can be used to determine current flow directions in ancient rocks (Fig. 2.16).

Fig. 2.16 Well-imbricated, grain-supported stream flow gravels in terrace deposits of the Umpqua River, southwest Oregon. The **arrow** shows **direction of stream flow**.

B. Grain packing; is the spacing or density patterns of grains in sedimentary rocks. It is a function of the **grain size**, **shape** and the **compaction** of sediment.

• It strongly affect the bulk density of the rocks as well as porosity and permeability.

• Theoretically there are six possible packing geometries for spheres of uniform size. These range from the loosest "**cubic**" style, with a theoretical porosity of 48%, to the closest **rhombohedral** packing with a theoretical porosity of 26 % (Fig. 2.17). These ideal situations never occur in nature.

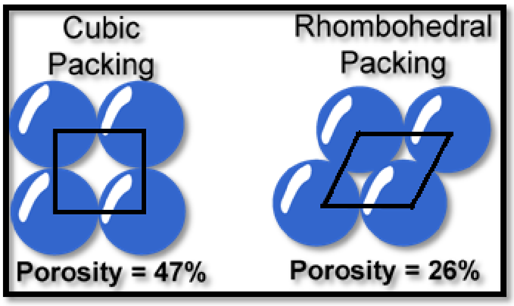

Fig. 2.17 Diagram illustrating the arrangement of (left) the loosest (cubic) packing style, with a porosity of 47 %, and (right) the tightest (rhombohedral) style, with a porosity of 26 %.

Grian packing related to porosities and permeabilities:

Poorly sorted sediments tend to have low porosities and permeabilities because grains are packed more tightly in these sediments owing to finer sediments filling pore spaces among larger grains (look at Fig 2.23).

Grian packing related to Compaction:

Compaction causes major reduction in porosity. The compaction resulting from the weight of the overlying sediment forces grains into closer contact.

C. Grain contacts: Taylor (1954) identified four types of grain contact between grains that can be observed in thin section: **Point (tangential), long, concavo–convex,** and **sutured**. (Fig. 2.18).

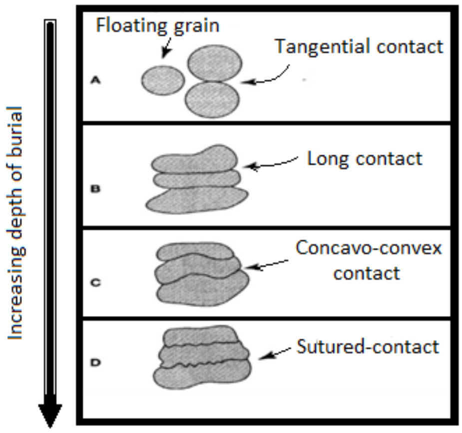

Figure 2.18 Diagrammatic illustration of principal kinds of grain contacts (Taylor, 1954)

Grian packing related to rock textures

The sand size grains in **sandstones** are commonly in continuous contact, thus they formed a **grain-supported fabric**.

In **conglomerates**, two different types of fabric are common (Fig. 2.19):-

1) **Grain supported-fabric**, clasts are in contact with each other. They are typically waterlain (e.g., stream bed or beach) and commonly show some internal structures and imbrications.

2) **Matrix support-fabric**, the matrix (finer material between the gravel clasts, such as sand, silt and mud) fills the spaces between the clasts. The rock may appear disorganized without any clear internal structure (e.g., alluvial fan deposits).

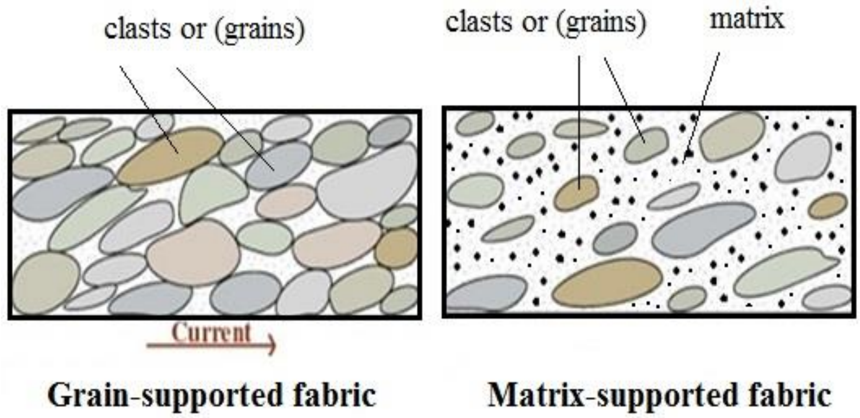

Fig. 2.19. Common fabric in conglomerates

Porosity and permeability:

Pores are the hollow spaces not occupied by grains, matrix, or cement (Fig. 2.20). Pores may contain gases (N and CO_2, or hydrocarbons such as methane) or may be filled by liquids ranging from potable water to brine and oil. Under suitable conditions of temperature and pressure, pores may be filled by combinations of liquid and gas.

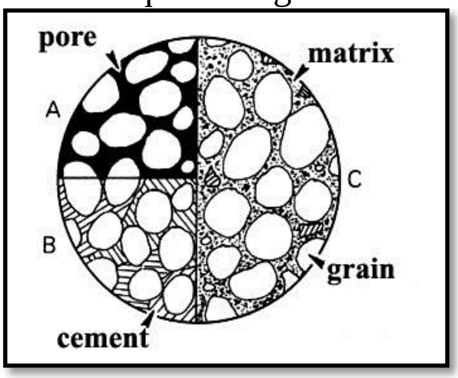

Fig. 2.20 Thin section showing that a sedimentary rock is composed of framework grains and matrix, cement and **pores** sometimes.

Porosity: is the ratio of pore space in a sediment or sedimentary rock to the total volume of the rock. It is expressed as

$$\text{Porosity (\%)} = \frac{volume\ of\ total\ pore\ space}{volume\ of\ rock\ sample\ \text{(bulk volume)}} \times 100$$

The effective porosity is the ratio of the interconnected pore space to the bulk volume of a rock.

$$\text{Effective porosity (\%)} = \frac{volume\ of\ interconnected\ pore\ space}{volume\ of\ rock\ sample\ \text{(bulk volume)}} \times 100$$

Permeability is the ability of a fluid to flow through a porous solid. Or the property of a rock that permits the passage of a fluid through the interconnected pores of the rock.

Permeability is controlled by the *effective porosity* of the rock, the geometry of the pores, including their tortuosity, and the size of the throats between pores, the capillary force between the rock and the invading fluid, its viscosity, and pressure gradient. Permeability is conventionally determined from Darcy's law.

Classification of porosity:

Descriptive and genetic classification (Choquette and Pray, 1970).

A) Primary or Depositional Porosity:

It is formed at the time of deposition (when a sediment is first laid down). Two main types of primary porosity are **intergranular** (or interparticle) and **intragranular** (or intraparticle).

1. Intergranular or interparticle porosity: occurs in the spaces ***between*** the detrital grains that form the framework of a sediment (Fig. 2.21A). This is a very important porosity type. It is present initially in almost all sediments, but is the dominant porosity type found in **sandstones**.

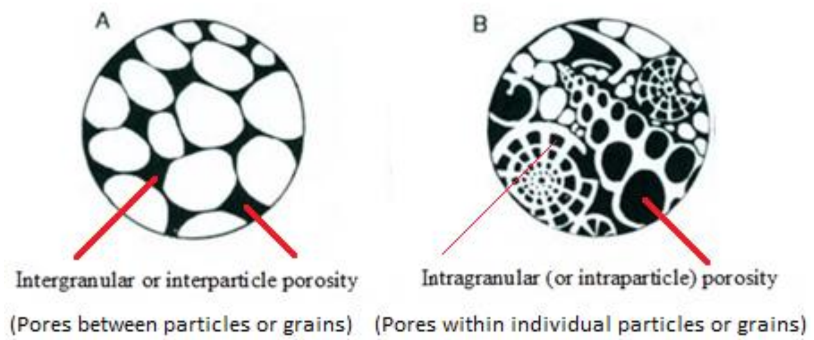

Fig. 1.21 (A) Intergranular (or interparticle) porosity, commonly found in **sandstones**. (B) Intragranular (or intraparticle) porosity, typical of skeletal sands in **carbonate rocks**.

2. Intragranular or intraparticle porosity: This type may be present ***within*** the detrital grains, particularly in skeletal carbonate. For example, the cavities of mollusks, ammonites, corals, bryozoa, and microfossils (Fig. 2.21B).

B) Secondary or Postdepositional Porosity:

It is formed after a sediment was deposited. It is more diverse in morphology and more complex in genesis than primary porosity. It is more commonly found in carbonate rocks than in siliciclastic sands.

The main types are:

1. Intercrystalline porosity occurs between the individual crystals of a crystalline rock (Fig. 2.22A). It is typical porosity type of the igneous, high-grade metamorphic rocks, and carbonates (dolomites). The latter are sometimes very important oil reservoirs because the pores are essentially planar cavities which intersect obliquely with one another with no constrictions of the boundaries or throats between adjacent pores.

2. Fenestral porosity is a primary pores in rock framework, larger than grain-supported interstices (framework grains). It is typical of carbonates, especially in pelleted muds and algal laminations (Fig. 2.22B).

3. Moldic porosity is generated by selective dissolution of an **individual** particles. It is fabric selective in which solution is confined to individual particles and does not cross-cut the primary depositional fabric of the rock. (Fig. 2.22C).

4. Vuggy porosity is formed by dissolution and, like moldic porosity; it is typically found in carbonates. **Vuggy porosity differ from moldic porosity** because the former cross-cut the primary depositional fabric of the rock (Fig. 2.22D). Vugs thus tend to be larger than molds.

5. Fracture porosity is generated by planar break (tectonic forces, desiccation, compaction…etc.) in strongly lithified rocks and is, therefore, generally formed later than the other varieties of porosity. It is common in **well cemented sandstones** and **carbonates**.

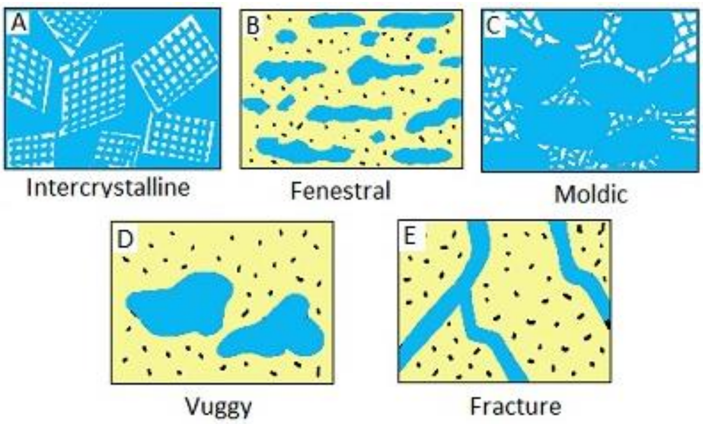

Fig. 2.22 the main kinds of secondary porosity. (After, Choqutte & Pray, 1970)

Factors affecting porosity:

(1) Physical characteristics, such as **grain size**, **sorting**, packing and grain arrangement (**fabric**) that are the result of depositional processes.
(2) Postdepositional processes such as **compaction** (which can rearrange packing), solution, and cementation.
These factors are summarized as follows:

. Effect of grain size

The porosity generally increases with decreasing grain size for unconsolidated sands (recent sediments) of uniform grain size. This relationship is not always true for ***lithified sandstones***, whose porosity often ***increases with grain size***. This may be because the finer sands have suffered more from compaction and cementation. **Permeability**, by contrast, increases with increasing grain size. This is because in finer sediments the throat passages between pores are smaller and the higher capillary attraction of the walls inhibits fluid flow. This relationship is found in ***both*** unconsolidated and lithified sand.

. Effect of sorting

The porosity increases with increased sorting. A well-sorted sand has a high proportion of detrital grains to matrix. Poorly sorted sand, on the other hand, has a low proportion of detrital grains to matrix. The finer grains of the matrix block both the pores and throat passages within the framework, thus inhibiting porosity and permeability, respectively (Fig. 2.23).

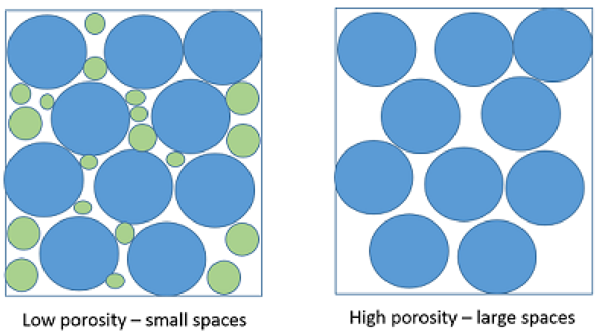

Fig. 2.23 A well-sorted sediment (right) will have better porosity and permeability than a poorly sorted one (left). In the latter the space between the framework grains is infilled, thus diminishing porosity. The heterogeneous fabric diminishes permeability by increasing the tortuosity of the pore system.

. Effect of fabric

The porosity of sediment varies according to the way in which grains are packed. Loosely packed sediments tend to have high porosities and permeabilities, and the reverse case is true (Fig. 2.24).

. Effect of compaction

Compaction causes major reduction in porosity. The load of sediments increases the tightness of grain packing with concomitant loss of porosity. For example, sandstones having an original porosity of about 40% may have been reduced to less than 10% during burial.

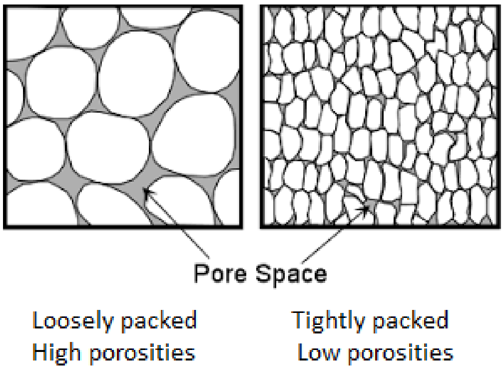

Fig. 2.24 loosely packed sediments (left) will have higher porosity and permeability than tightly packed one (right).