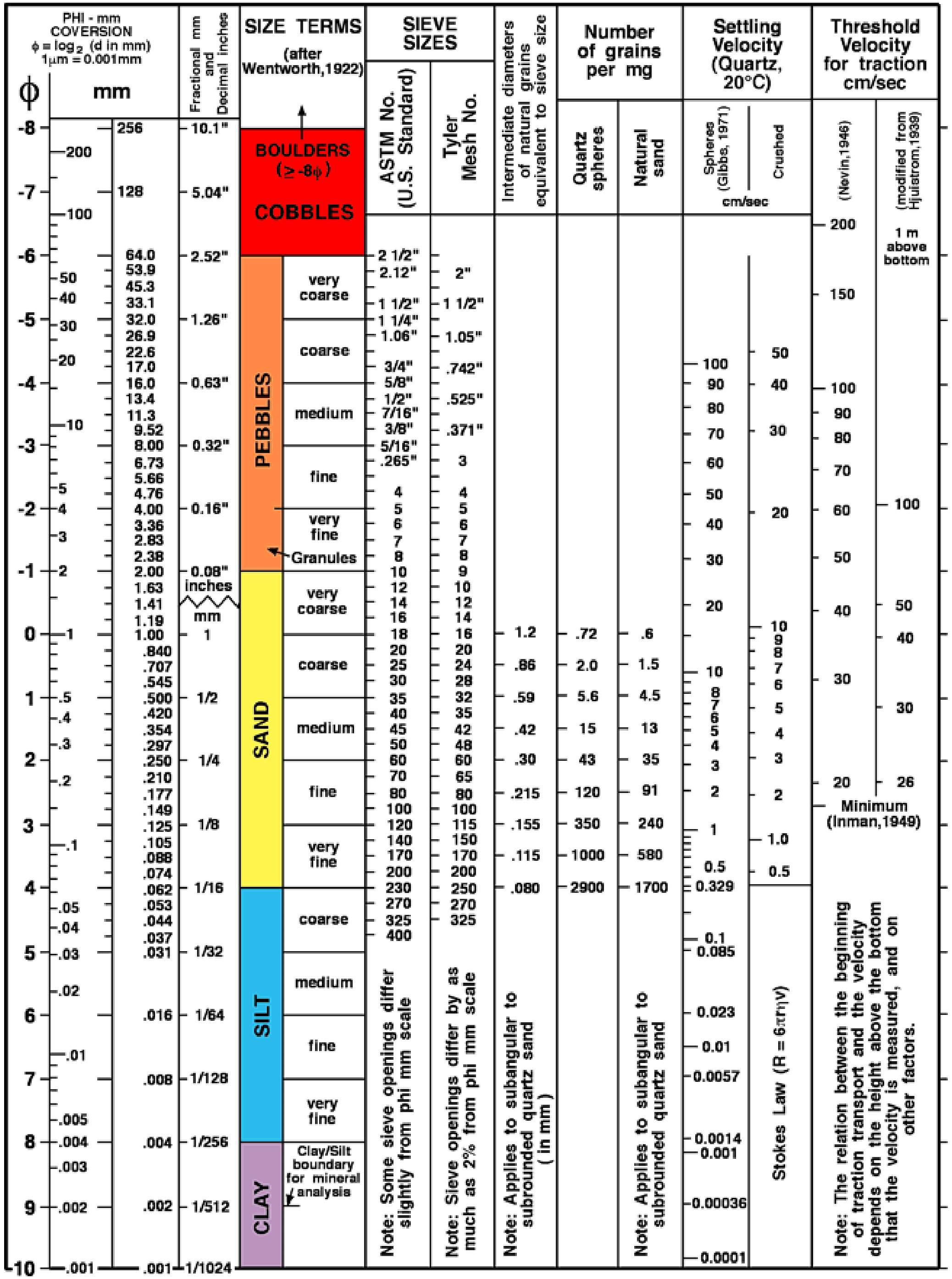
Part II: Physical Properties of Sedimentary Rocks

Chapter 3. Sedimentary Textures

Sedimentary texture (usually is of “grain-scale”) refers to the size, shape, and arrangement of the grains that make up a sedimentary rock.

3.2 **Grain size** (gravel to mud, grain-size variation (sorting))
3.3 **Particle shape** (form, roundness, surface texture)
3.4 **Grain fabric** (grain orientation, grain-to-grain relations)



3.2 Grain size

Table 3.1 The Wentworth grain-size scale for sediments, showing Wentworth size classes, equivalent phi (ϕ) units, and sieve numbers of U.S. Standard Sieves corresponding to various millimeter and ϕ sizes

	U.S. Standard sieve mesh	Millimeters		Phi (ϕ) units	Wentworth size class
GRAVEL		4096		−12	
GRAVEL		1024		−10	Boulder
GRAVEL		256	256	−8	
GRAVEL		64	64	−6	Cobble
GRAVEL		16		−4	Pebble
GRAVEL	5	4	4	−2	
GRAVEL	6	3.36		−1.75	
GRAVEL	7	2.83		−1.5	Granule
GRAVEL	8	2.38		−1.25	
GRAVEL	10	2.00	2	−1.0	
SAND	12	1.68		−0.75	
SAND	14	1.41		−0.5	Very coarse sand
SAND	16	1.19		−0.25	
SAND	18	1.00	1	0.0	
SAND	20	0.84		0.25	
SAND	25	0.71		0.5	Coarse sand
SAND	30	0.59		0.75	
SAND	35	0.50	½	1.0	
SAND	40	0.42		1.25	
SAND	45	0.35		1.5	Medium sand
SAND	50	0.30		1.75	
SAND	60	0.25	¼	2.0	
SAND	70	0.210		2.25	
SAND	80	0.177		2.5	Fine sand
SAND	100	0.149		2.75	
SAND	120	0.125	⅛	3.0	
SAND	140	0.105		3.25	
SAND	170	0.088		3.5	Very fine sand
SAND	200	0.074		3.75	
SAND	230	0.0625	1/16	4.0	
MUD – SILT	270	0.053		4.25	
MUD – SILT	325	0.044		4.5	Coarse silt
MUD – SILT		0.037		4.75	
MUD – SILT		0.031	1/32	5.0	
MUD – SILT		0.0156	1/64	6.0	Medium silt
MUD – SILT		0.0078	1/128	7.0	Fine silt
MUD – SILT		0.0039	1/256	8.0	Very fine silt
MUD – CLAY		0.0020		9.0	
MUD – CLAY		0.00098		10.0	Clay
MUD – CLAY		0.00049		11.0	
MUD – CLAY		0.00024		12.0	
MUD – CLAY		0.00012		13.0	
MUD – CLAY		0.00006		14.0	

3.2.1 Grain-size scales

1. **Geometric scales**: fixed ratio between successive elements. Udden-Wentworth scale (from < 1/256 mm to > 256 mm): each value in the scale is twice as large as the preceding value.

2. **Logarithmic phi scale**: A modification of Udden-Wentworth scale. Useful for graphical plotting and statistical calculations:

$$\phi = -\log_2 d$$

where ϕ is phi size and d is the grain diameter.

Boggs (2006), p.53

3.2.2 Measuring grain size

Table 3.2 Methods of measuring sediment grain size

Type of sample	Sample grade	Method of analysis
Unconsolidated sediment and disaggregated sedimentary rock	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Sieving, settling-tube analysis, image analysis
	Clay	Pipette analysis, sedimentation balances, photohydrometer, Sedigraph, laser-diffractometer, electro-resistance (e.g., Coulter counter)
Lithified sedimentary rock	Boulders Cobbles Pebbles	Manual measurement of individual clasts
	Granules Sand Silt	Thin-section measurement, image analysi
	Clay	Electron microscope

Boggs (2006), p.54

Settling-tube analysis (mainly for clay-sized particles)

A custom-made settling column that analyzes the grain-size composition of sediment samples by measuring the settling velocities of grains. (Coastal Geology and Process Laboratory, 中山大學海洋地質及地球化學研究所)

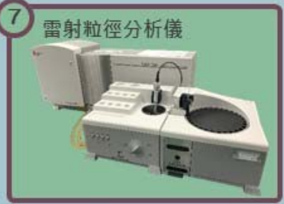
雷射粒徑分析儀

Beckman Coulter LS 13 320 Particle Size Analyzer

Particle Size Range	0.017 µm - 2000 µm
Typical Analysis Time	15 - 90 secs per sample
Illuminating Sources	Diffraction: Solid State (780 nm) PIDS: Tungsten lamp with high quality band-pass filters (450,600 and 900 nm)
Humidity	0 – 90% without condensation
Temperature	10 – 40 °C
Sample Modules	Aqueous Liquid Module (ALM) Auto Prep Station (APS)

國立中央大學地球科學系沉積實驗室

沉積物分析室(國立中央大學地球科學系)



沉積物分析室-主要儀器

① **立體顯微鏡(S8 APO/Leica)**
觀察沉積物、礦物、岩石、化石等實體樣本。

② **偏光顯微鏡(DM EP/Leica)**
將岩石或沉積物製作成厚度約30 um的薄片，在穿透光下，利用礦物的光學性質以及各類組成物的形態、構造等性質鑑定樣本特性。

③ **真密度測定儀 (PENTAPYC 5200e/Quantachrome)**
灌入氦氣並以理想氣體方程式計算出樣本的實際體積並算出密度，可避免物體的孔隙造成的誤差。

④ **元素分析儀(Vario EL cube/Elementar)**
分析樣本之碳、氮、氫、硫元素或含該元素之化合物的重量百分比。應用於樣本有機碳含量分析。樣本需求量小。

⑤ **X光螢光分析儀(S8 TIGER/Bruker)**
對樣本的所有元素及化合物組成進行定量分析，樣本需求量大，用過的樣本無法重複使用。

⑥ **X光繞射儀(D2 PHASER/Bruker)**
對樣本的晶體結構進行非破壞性定性分析，進行礦物鑑定。樣本需求量小，可重複使用。

⑦ **雷射粒徑分析儀 (LS 13 320/BECKMAN COULTER)**
利用光的散射原理，分析顆粒之粒徑大小，測量範圍17 nm到2 mm。

其他儀器

- **冷凍乾燥機(FD12-24P-D/KINGMECH)**
為避免某些樣本會因加熱而變質，將樣本冷凍而後再將水昇華以去除水分，乾燥樣本。
- **超純水製造系統(A4SL Plus,RS-75T/Purity)**
在任何化學分析的前處理時必須確保使用的水無汙染樣本疑慮，製水系統依實驗需求可提供去離子水、逆滲透水以及蒸餾水。
- **離心機(5922/KUBOTA)**
藉由高速旋轉產生高於重力數倍的離心力，以加快液體中顆粒的沉降速度，把樣品中不同沉降系數和密度質量的物質分離。
- **高溫爐(Lindberg Blue M/Thermo)**
將樣本加熱至高溫，最高溫度為攝氏1200度。
- **岩石切割機(MC-420, MC-110/MARUTO)**
切割樣本。
- **岩石磨片機(RYOBI/RS)**
磨製薄片。

國立中央大學地科院固樣製備室

五、重要貴儀：

1. 中/小型切割機：採用手動推進的方式，將岩石塊樣切割至適當大小。

圖 1、切割機

2. 金剛石線切割機： 採用自動推進的方式，提供各式材料進行精密切割，並可搭配無線顯微鏡以提高切割精密度，最薄厚度可達 0.08 mm。

圖 2、金剛石線切割機

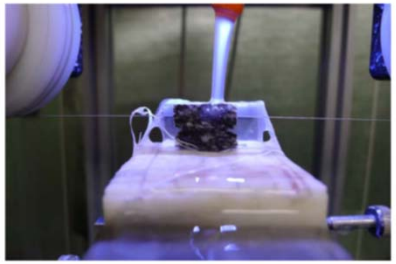


圖 3、樣品精密切割中

3. 岩芯研磨機：採用手動設定內、外徑大小，並利用砂輪精密研磨圓環試體以供各式岩石力學實驗使用。

圖 4、岩芯研磨機#

圖 5、經由岩芯研磨機可控制內外徑大小以生成圓環試體

4. 岩芯鑽取機：採用自動推進的方式，利用不同尺寸的鑽頭鑽取直徑大小各異的試體，可應用於不規則塊體。

圖 6、岩芯鑽取機#

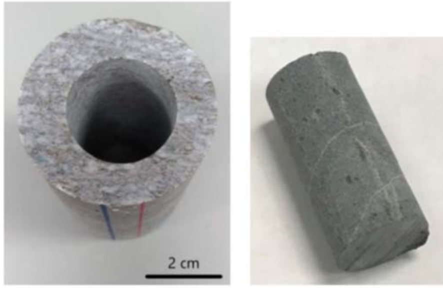


圖 7、透過岩芯鑽取機可自既有塊體中鑽取所需柱狀試體

5. 光薄片製備機：採用自動推進的方式，將固定於薄片上的塊樣精密切割至適當厚度，誤差厚度可達±5μm 內。

圖 8、光薄片製備機#

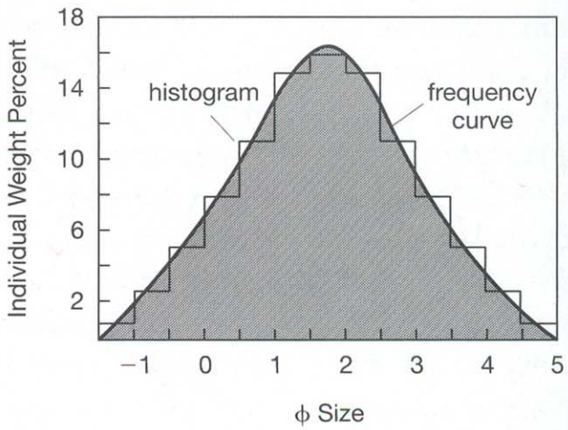
6. 冷凍乾燥機：以真空抽取的方式移除試體中的水汽，避免樣本受到高溫烘烤的影響，並可保有原本的鬆散結構。

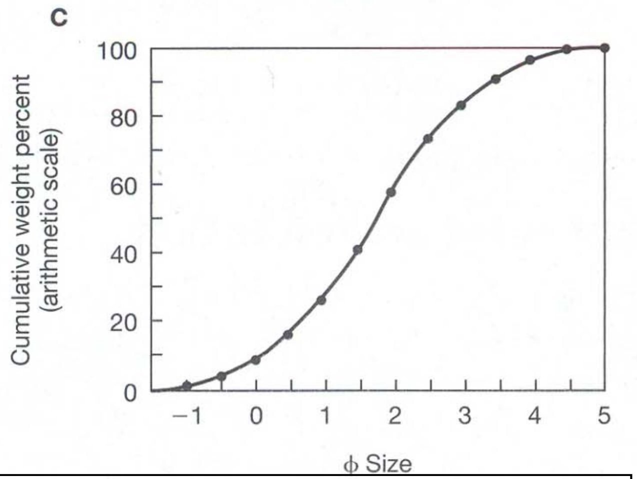
圖 9、冷凍乾燥機#

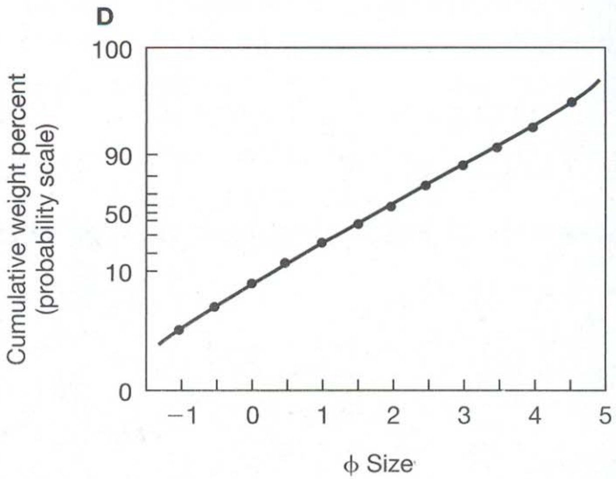
3.2.3 Graphical and mathematical treatment of grain-size data

Graphical
methods
(weight% vs. ψ)

ϕ Size	Raw weight (gm)	Individual weight percent	Cumulative weight percent
−1.0	0.43	0.5	0.5
−0.5	2.13	2.5	3.0
0.0	4.25	5.0	8.0
0.5	6.80	8.0	16.0
1.0	9.35	11.0	27.0
1.5	12.75	15.0	42.0
2.0	13.58	16.0	58.0
2.5	12.75	15.0	73.0
3.0	9.35	11.0	84.0
3.5	6.80	8.0	92.0
4.0	4.25	5.0	97.0
4.5	2.13	2.5	99.5
5.0	0.43	0.5	100.0
	85.00		







Cumulative curve (arithmetic ordinate): Typically S-shaped, the slope of the central part of this curve reflects the sorting of the sample.

Cumulative curve (log-probability ordinate): Typically straight line.

Fig. 3.1 Common visual methods of displaying grain-size data. A. Grain-size data table. B. Histogram and frequency curve plotted from data in A. C. Cumulative curve with an arithmetic ordinate scale. D. Cumulative curve with a probability ordinate scale.

Another example

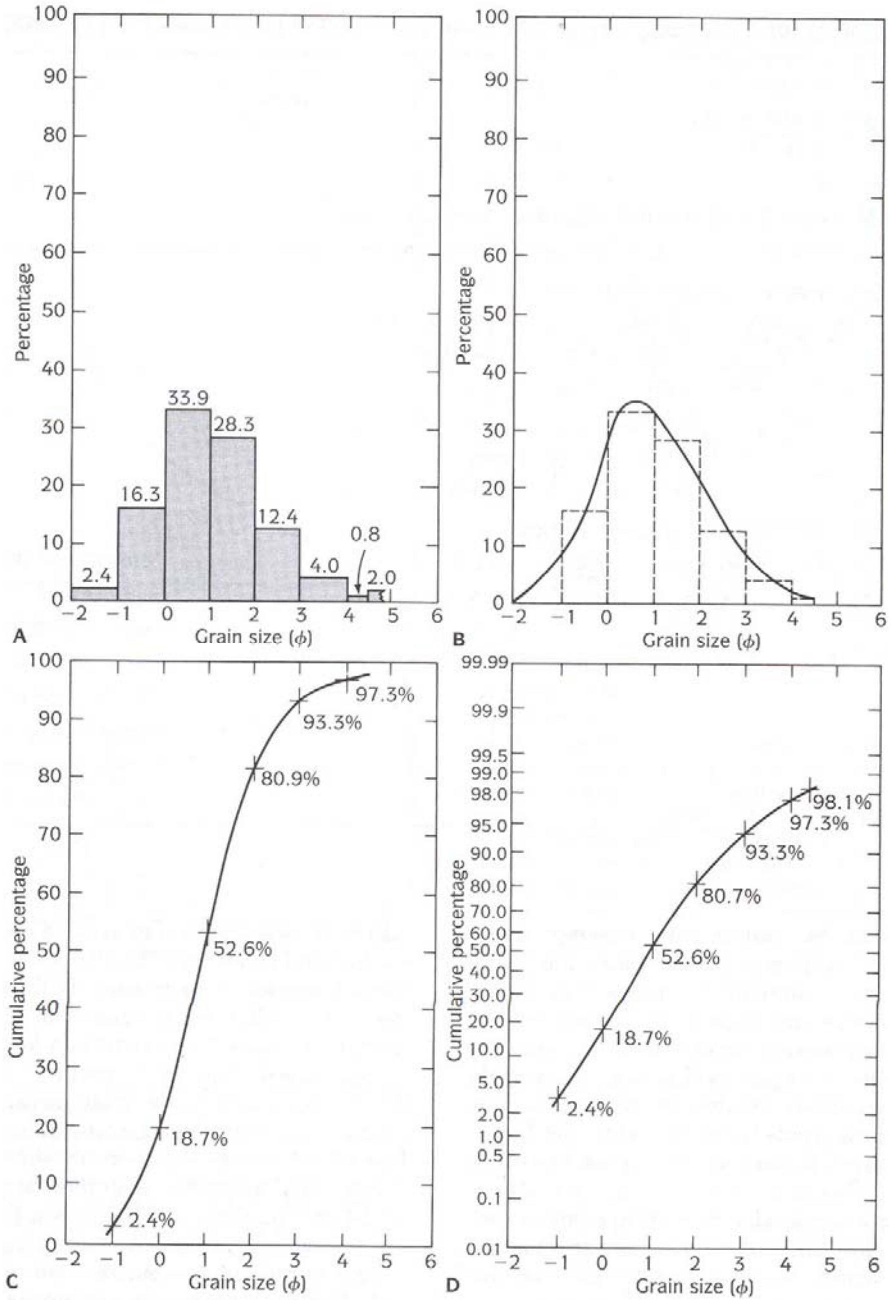


Figure 5.14

Results of a single sieve analysis displayed in various ways. (A) Histogram. (B) Noncumulative size-frequency curve. (C) Cumulative curve on normal graph paper with a standard arithmetic ordinate scale. (D) Cumulative curve on probability graph paper. The ordinate scale collapses the values in the center (the 10%–80% range) and stretches out the values on the tails (less than 10% and greater than 90%), making the curve in (C) into a straight line. On probability paper, therefore, each normal distribution plots as a straight line segment. The phi values can be read directly from these plots and plugged into the formulas shown in Table 5.3 to calculate statistics quickly and easily. (Modified from Blatt, 1992, *Sedimentary Petrology*, 2nd ed., Fig. 16-5, p. 474; by permission of W. H. Freeman, New York.)

Prothero & Schwab (1996) Sedimentary Geology, p. 87

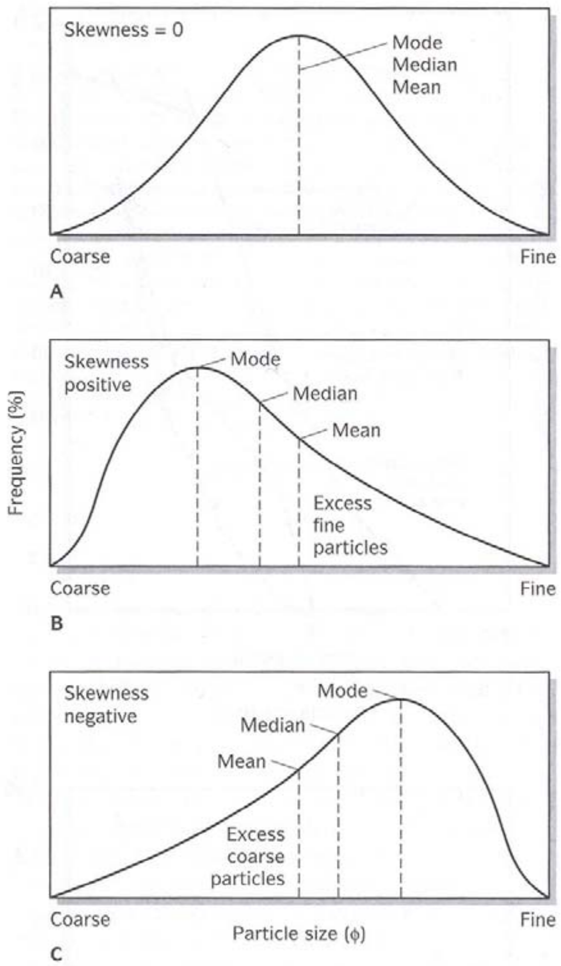


Figure 5.15

Size-frequency curves of three sediments having an identical sorting but different skewness. (A) Sediment is unskewed and shows a symmetrical distribution. Mean, mode, and median coincide. (B) Sediment is positively skewed; the coarser half of the population shows better sorting than the finer half (that is, both the median and the mode are shifted toward finer grain sizes). (C) Sediment is negatively skewed; the finer half of the population is better sorted than the coarser tail (both the median and the mean are shifted away from the mode toward the coarser grain sizes). (After Friedman and Sanders, 1978, *Principles of Sedimentology,* Fig. 3-18, p. 75; by permission of John Wiley, New York.)

Mathematical methods

- **Mode** - The most common grain size in the population (the highest point in the histogram plot or the steepest point (inflection point) on a cumulative curve).

- **Median** - The grain size for which 50% of the sample is finer. Note that these are *not* affected by the normality of the population.

- **Mean** - The average grain size in the deposit.

Graphic mean = $$\frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

For a normally (or log normally) distributed population; the mean, median, and mode are the same.

Prothero & Schwab (1996) Sedimentary Geology, p. 89

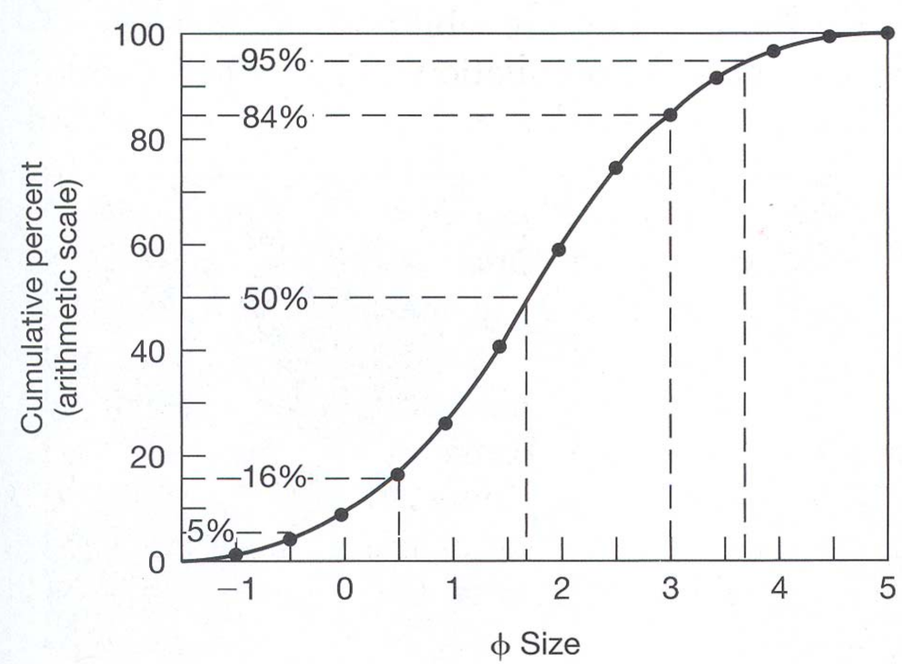


Fig. 3.2 Method for calculating percentile values from the cumulative curve.

Table. 3.1 Formulas for calculating grain-size statistical parameters by graphical methods.

Graphic mean	$M_z = \dfrac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$	(1)
Inclusive graphic standard deviation	$\sigma_i = \dfrac{\phi_{84} - \phi_{16}}{4} + \dfrac{\phi_{95} - \phi_5}{6.6}$	(2)
Inclusive graphic skewness	$SK_t = \dfrac{(\phi_{84} + \phi_{16} - 2\phi_{50})}{2(\phi_{84} - \phi_{16})} + \dfrac{(\phi_{95} + \phi_5 - 2\phi_{50})}{2(\phi_{95} - \phi_5)}$	(3)
Graphic kurtosis	$K_G = \dfrac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})}$	(4)

Source: Folk, R. L., and W. C. Ward, 1957, Brazos River bar: A study in the significance of grain-size parameters: *Jour. Sed. Petrology*, v. 27, p. 3–26.

Sorting – The range of grain sizes present and the magnitude of the spread or scatter of these sizes around the mean size. The mathematical expression of sorting is standard deviation, which is expressed in phi (ϕ).

Sorting (inclusive graphic standard deviation) =

$$\frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$$

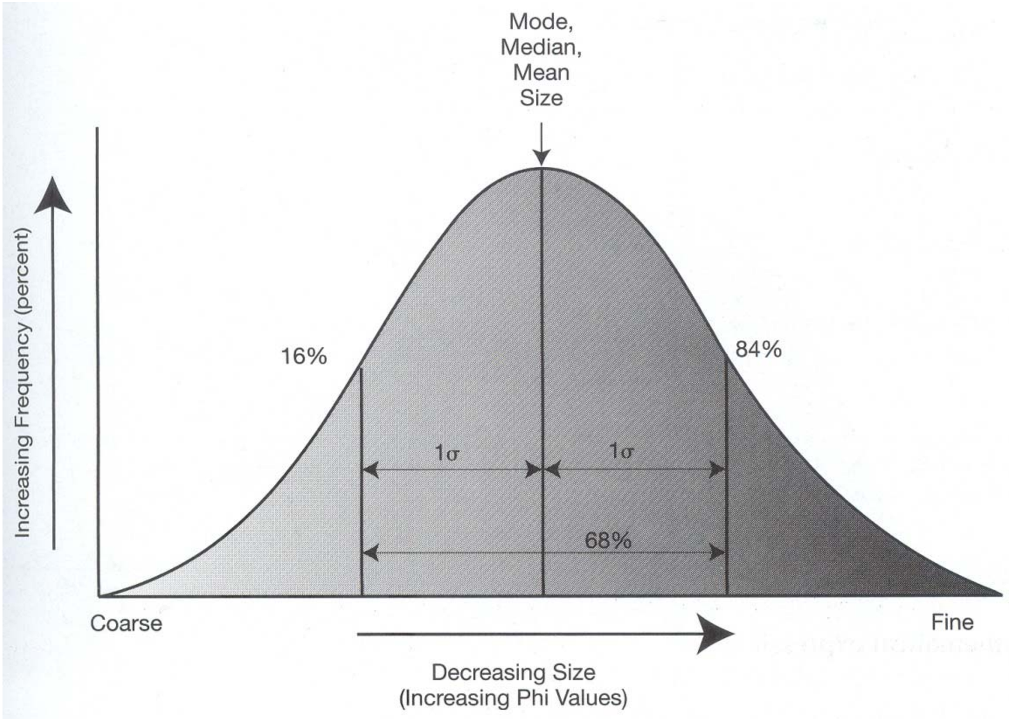


Fig. 3.4 Grain-size frequency curve for a normal distribution of phi values, showing the relationship of standard deviation to the mean, mode, and deviation (1σ) on either side of the mean size accounts for the frequency curve.

Standard Deviation (σ**)** - The measure of how large a range of variation of particle size occurs around the mean. In conventional statistics, one standard deviation encompasses the central 68% of the area under the frequency curve.

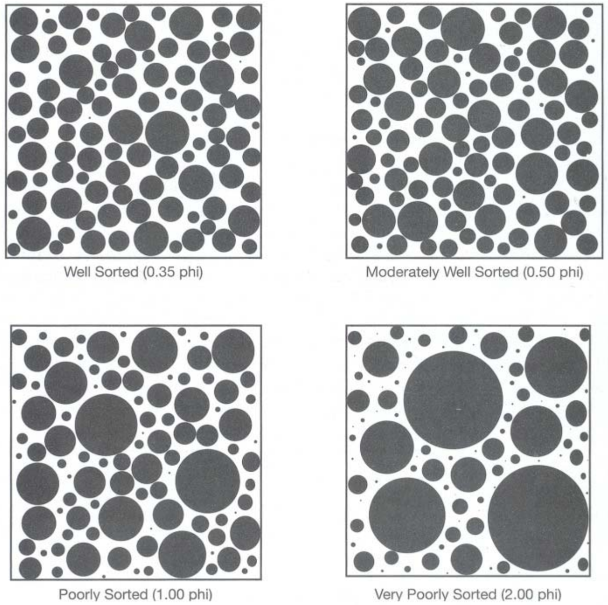


Fig. 3.3 Visual images for estimating grain-size sorting.

Standard Deviation	
<0.35ϕ	very well sorted
0.35–0.50ϕ	well sorted
0.50–0.71ϕ	moderately well sorted
0.71–1.00ϕ	moderately sorted
1.00–2.00ϕ	poorly sorted
2.00–4.00ϕ	very poorly sorted
>4.00ϕ	extremely poorly sorted

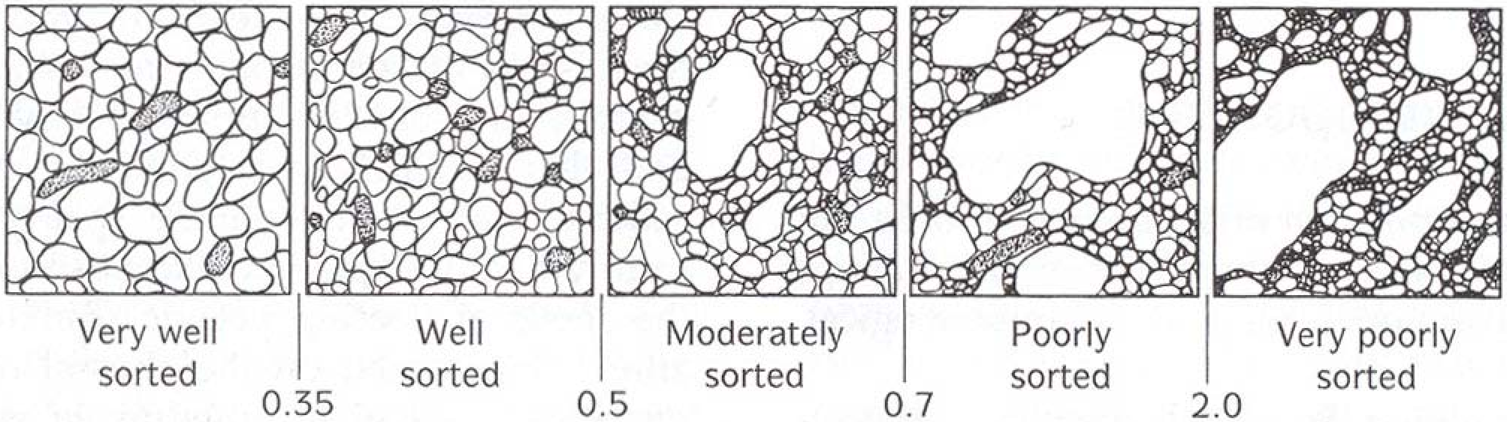


Figure 1.2

Sorting for cemented rocks

Prothero & Schwab (1996) Sedimentary Geology, p. 6

Standard images for visually estimating sorting. Numbers are sorting (standard deviation) values expressed in phi units that can be calculated using the standard formula shown in Table 5.3. (After Compton, 1962, *Manual of Field Geology*, p. 214; by permission of John Wiley, New York.)

Skewness (degree of asymmetry 歪斜度):

Skewness reflects sorting in the “tails” of a grain size population.

Skewness	
>+0.30	strongly fine skewed
+0.30 to +0.10	fine skewed
+0.10 to –0.10	near symmetrical
–0.10 to –0.30	coarse skewed
<–0.30	strongly coarse skewed

$$SK_t = \frac{(\phi_{84} + \phi_{16} - 2\phi_{50})}{2(\phi_{84} - \phi_{16})} + \frac{(\phi_{95} + \phi_5 - 2\phi_{50})}{2(\phi_{95} - \phi_5)}$$

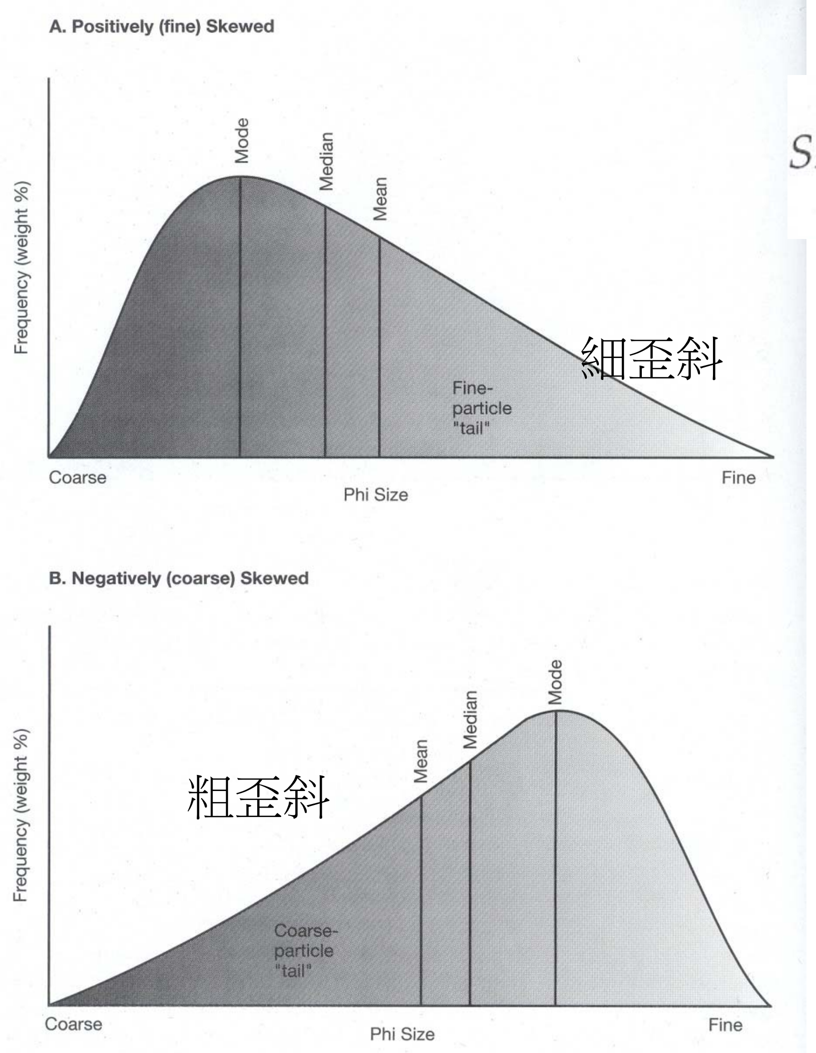


Fig. 3.5 Skewed grain-size frequency curve, illustrating the difference between positive (fine) and negative (coarse) skewness. Note the difference between these skewed, asymmetrical curves and the normal frequency curve shown in Figure 3.4.

Kurtosis (峰度)： 平峰、中峰、陡峰

The degree of peakness of a grain-size frequency curve.

$$K_G = \frac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})}$$

3.2.4 Application and importance of grain-size data

1. To interpret coastal stratigraphy and sea-level fluctuations.
2. To trace glacial sediment transport and the cycling of glacial sediments from land to sea.
3. By marine geochemists to understand the fluxes, cycles, budgets, sources, and sinks of chemical elements in nature.
4. To understand the mass physical (geotechnical) properties of seafloor sediment, i.e., the degree to which these sediments are likely to undergo slumping, sliding, or other deformation.
5. To interpret the depositional environments of ancient sedimentary rocks.

The relationship between grain-size characteristics and depositional environments has **NOT** been firmly established.

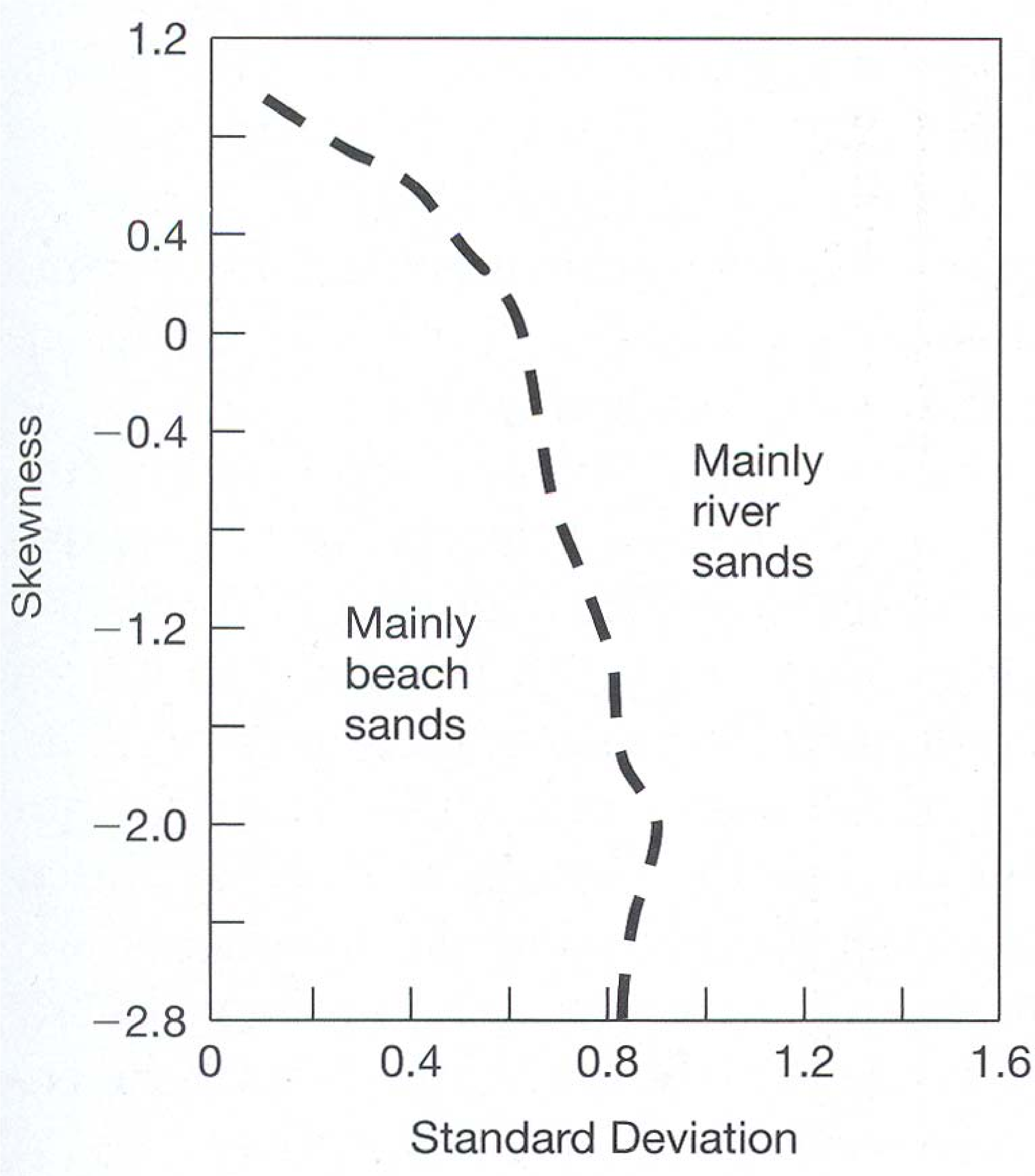
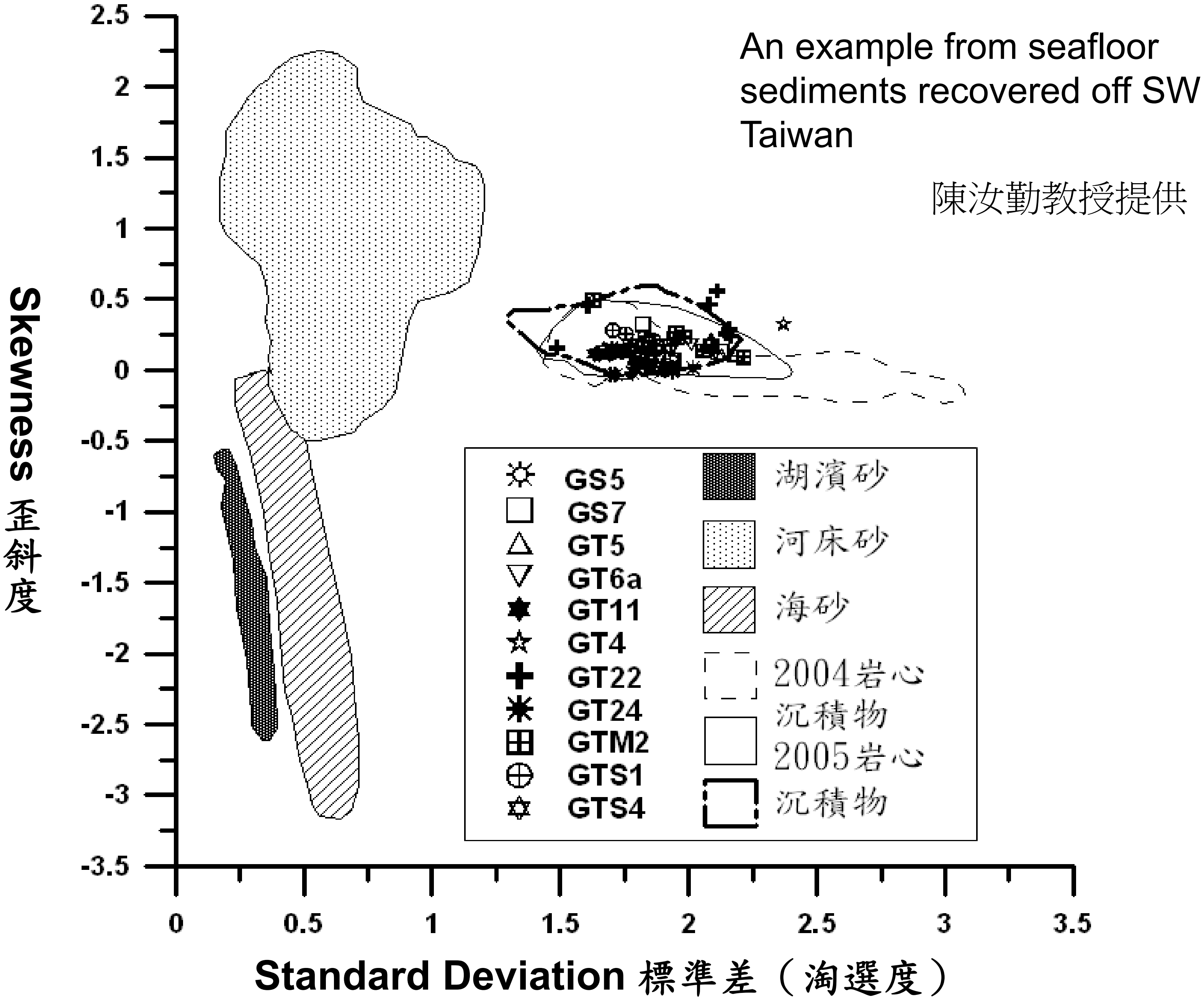


Fig. 3.6 Grain-size bivariate plot of moment skewness vs. moment standard deviations showing the fields in which most beach and river sands plot.



岩心沈積物標準差對歪斜度作圖，湖濱砂、河床砂與海砂分布範圍依據Friedman（1961）

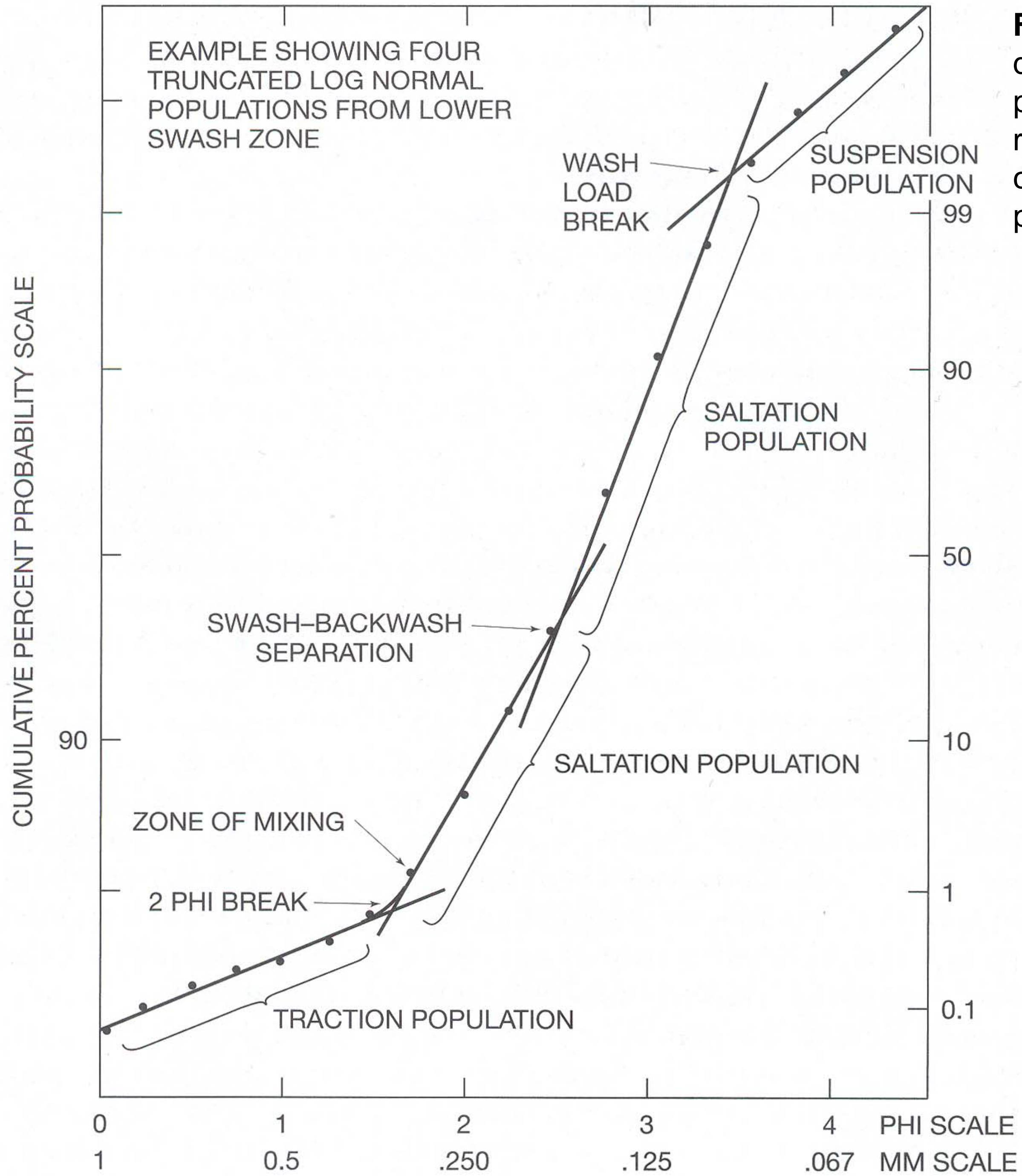


Fig. 3.7 Relation of sediment transport dynamics to populations and truncation points in a grain-size distribution as revealed by plotting grain-size data as a cumulative curve on log probability paper.

3.3 Particle shape

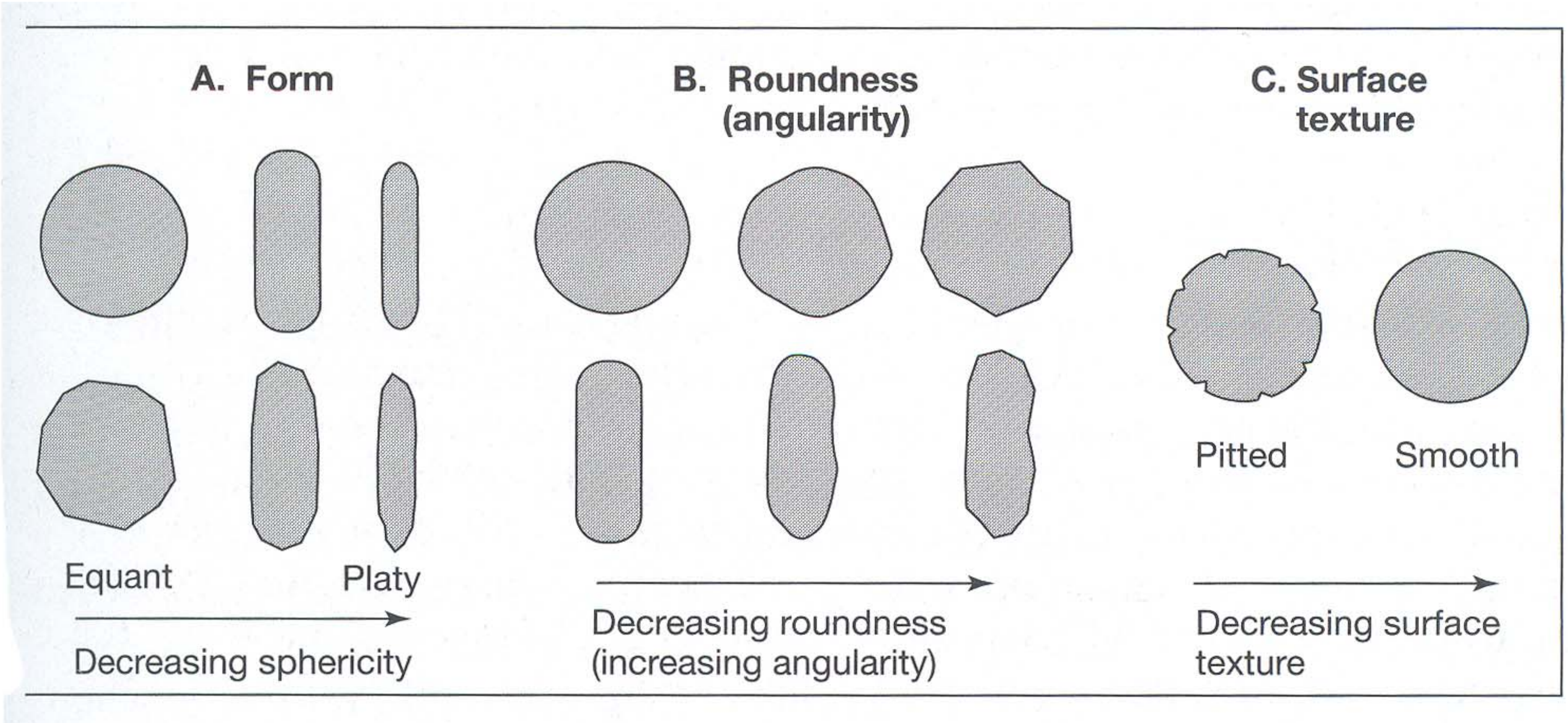


Fig. 3.8 Schematic representation of the principal aspects of particle shape: form, roundness, and surface texture. Note that sphericity and roundness are independent properties. For example, a highly spherical (equant) particle can be either well rounded or poorly rounded, and a well-rounded particle can have either high or low sphericity.

3.3.1 Particle form (sphericity)

Grain shape: The four classes of grain shape (mainly for gravel) based on the ratios of the long (*DL*) intermediate (*DI*) and short (*DS*) diameters.
Oblate (扁長形), bladed (扁平形)；equant (球形)；prolate (棍棒形)

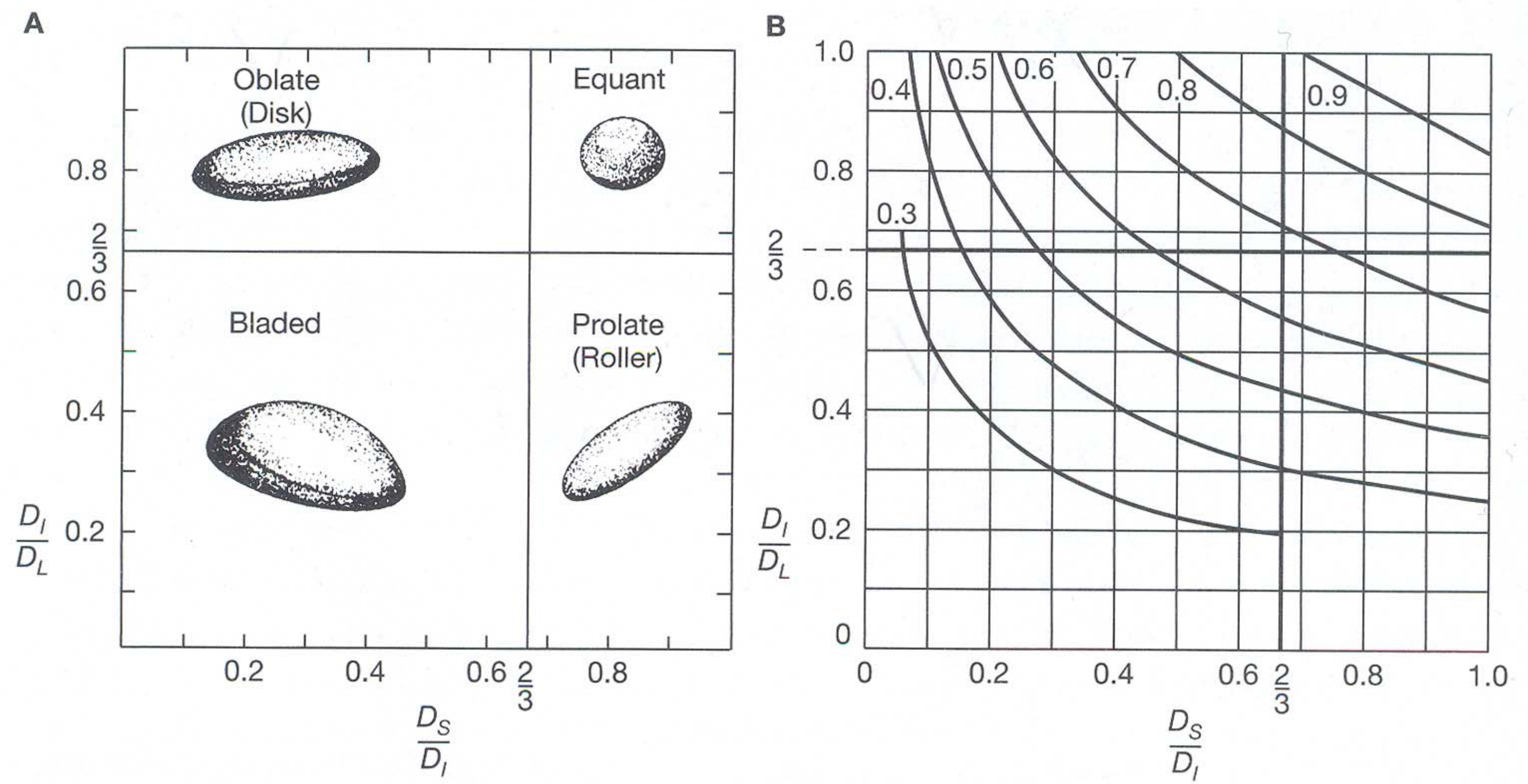
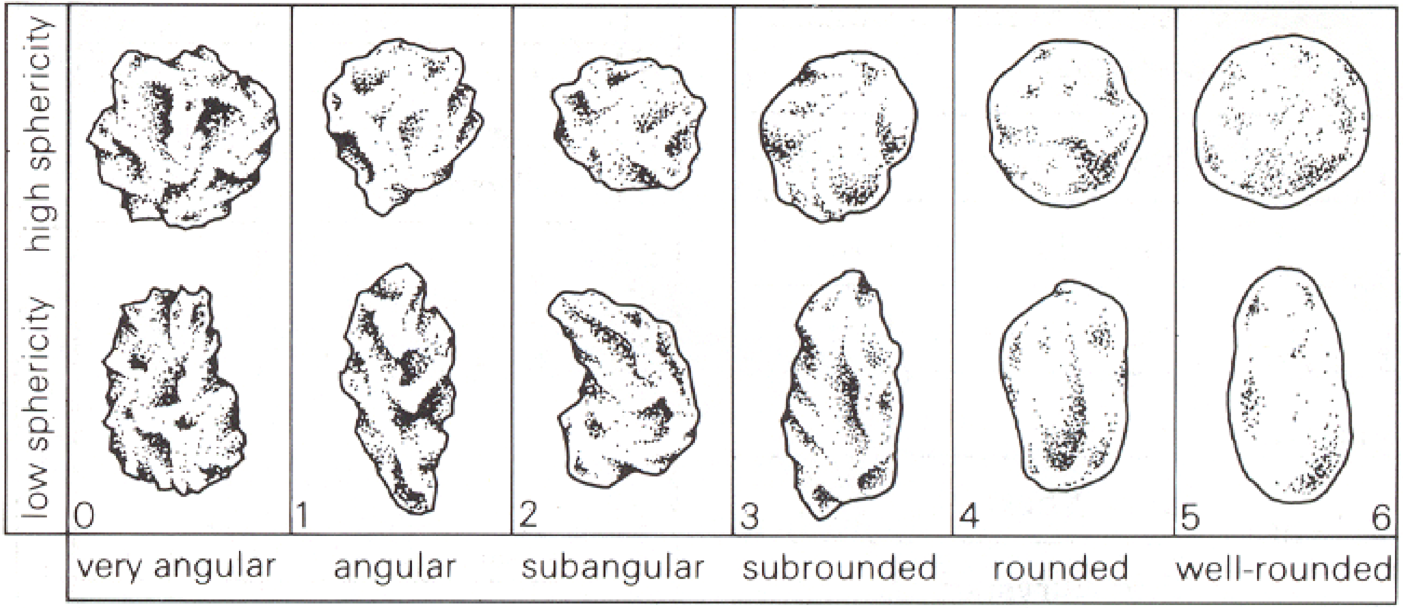


Fig. 3.9 A. Classification of shapes of pebbles after Zingg (1935). B. Relationship between mathematical sphericity and Zingg shape fields. The curves represent lines of equal sphericity.

3.3.2 Particle roundness



Tucker (2003) Sedimentary Rocks in the Field, p.72.

Fig. 4.5 Categories of roundness for sediment grains. For each category a grain of low and high sphericity is shown.

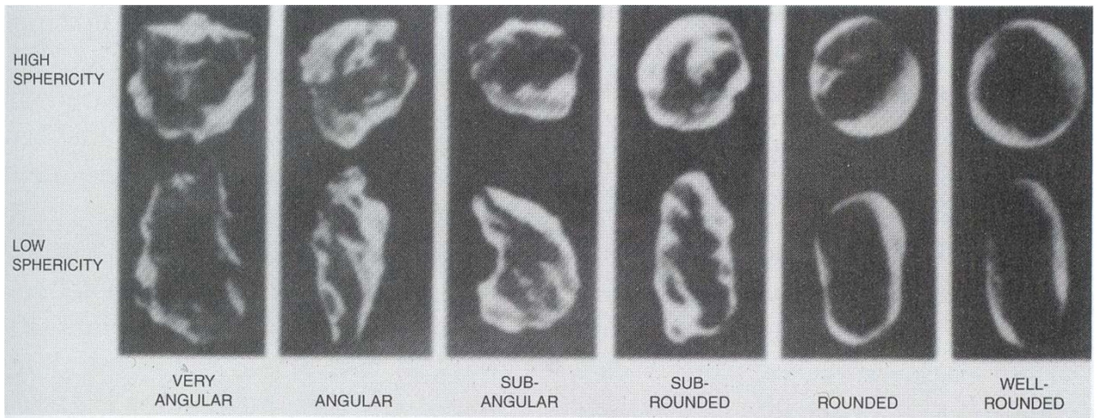
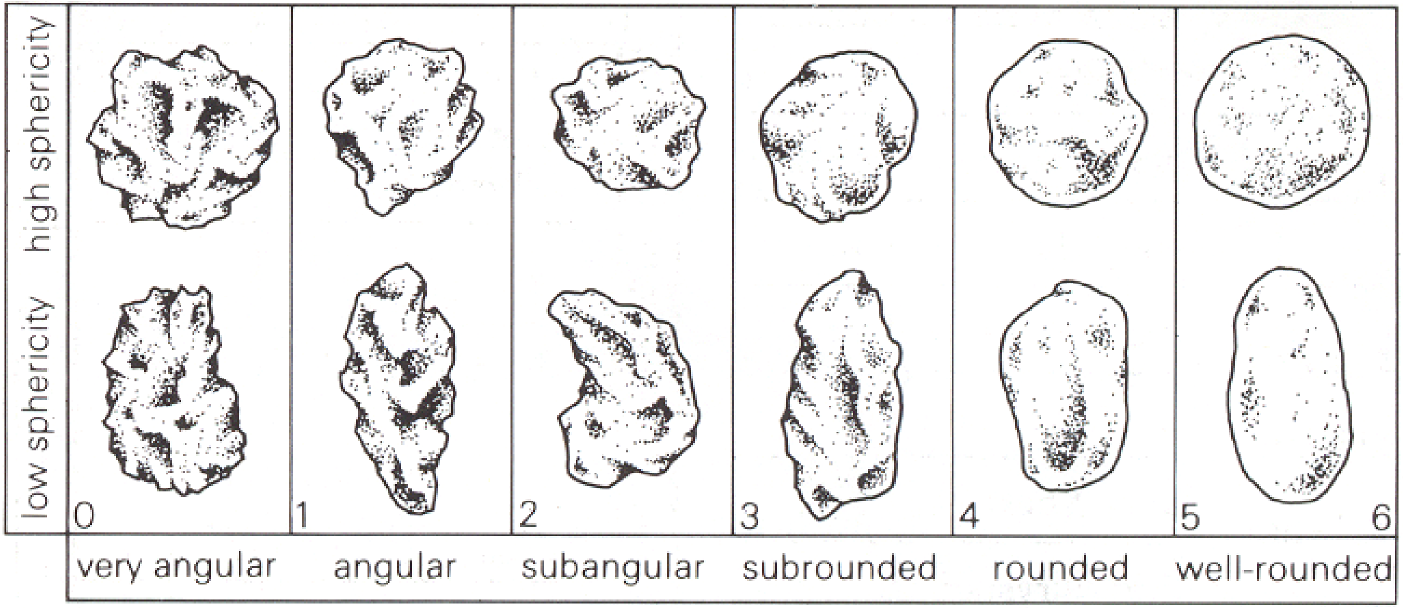


Fig. 3.10 Powers' grain images for estimating roundness of sedimentary particles.

3.3.2 Particle roundness



Tucker (2003) Sedimentary Rocks in the Field, p.72.

Fig. 4.5 Categories of roundness for sediment grains. For each category a grain of low and high sphericity is shown.

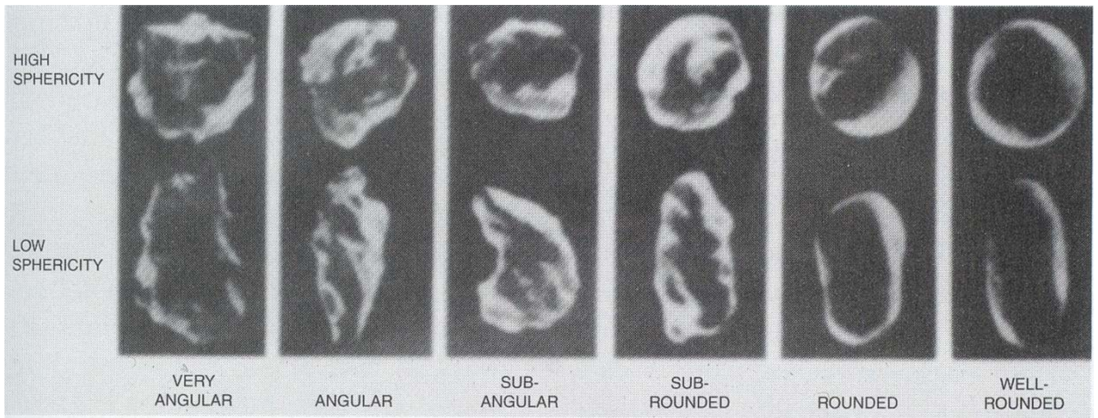


Fig. 3.10 Powers' grain images for estimating roundness of sedimentary particles.

3.3.5 Surface texture

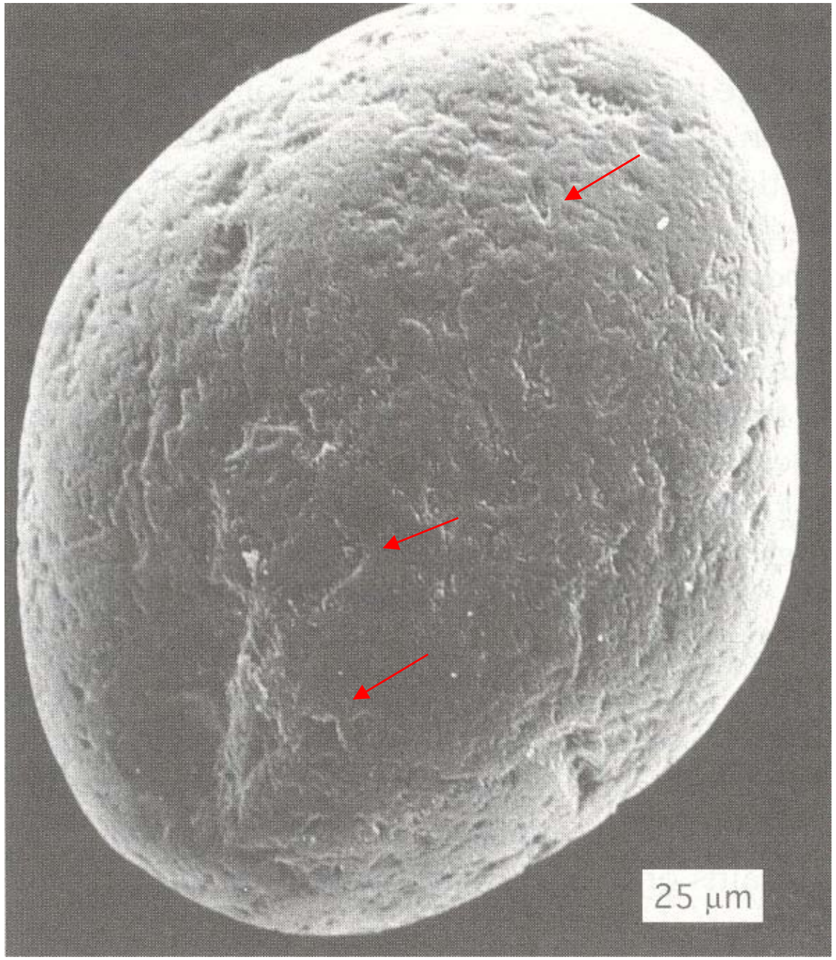


Fig. 3.11 Electron micrograph of a quartz grain from unconsolidated Plio-Pleistocene sand, Louisiana salt dome edge, southern Louisiana, showing details of the surface texture. The grain has been well rounded by wind transport and contains tiny “upturned plates” (pointed by arrows) characteristic of dune sands.

3.4 Fabric

3.4.1 Grain orientation

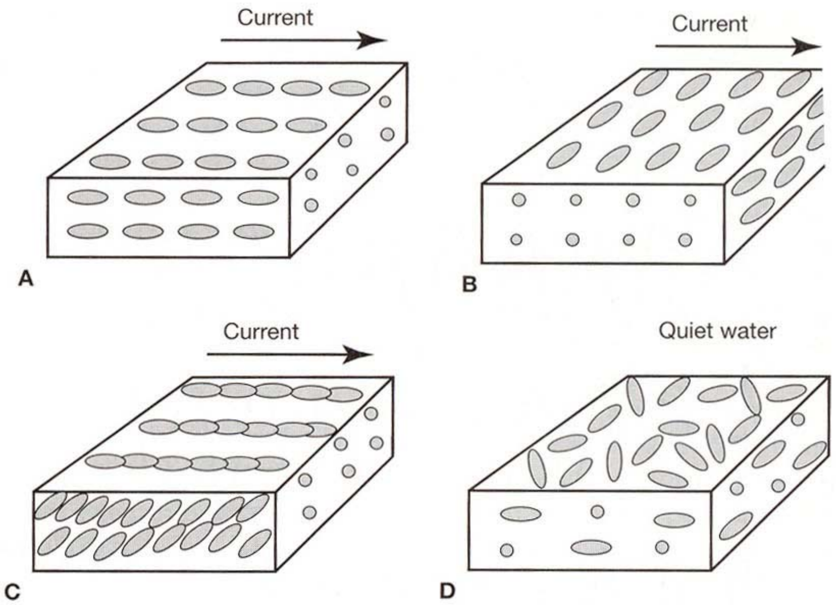


Fig. 3.12 Schematic illustration of the orientation of elongated particles in relation to flow. A. Particles oriented parallel to current flow. B. Particles oriented perpendicular to current flow. C. Imbricated particles. D. Randomly oriented particles, characteristic of deposition in quiet water.

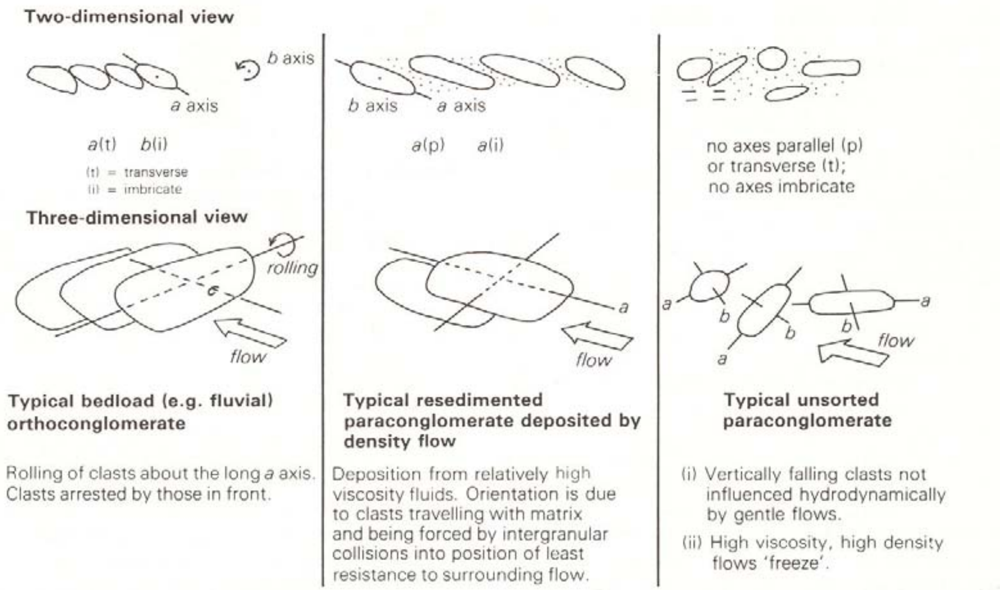


Figure 7.7 The nature and processes of origin of imbricated disc- and blade-like clasts.

Collinson & Thompson (1989), p. 119

Imbricated gravels in the Ta Cha River after flood (2004/7/2)

Fig. 3.13 Well-developed imbrication of river cobbles, Kiso River, Japan. Imbrication was produced by river currents flowing from left to right (arrow). Note hammer for scale.

3.4.2 Grain packing, grain-to-grain relations, and porosity

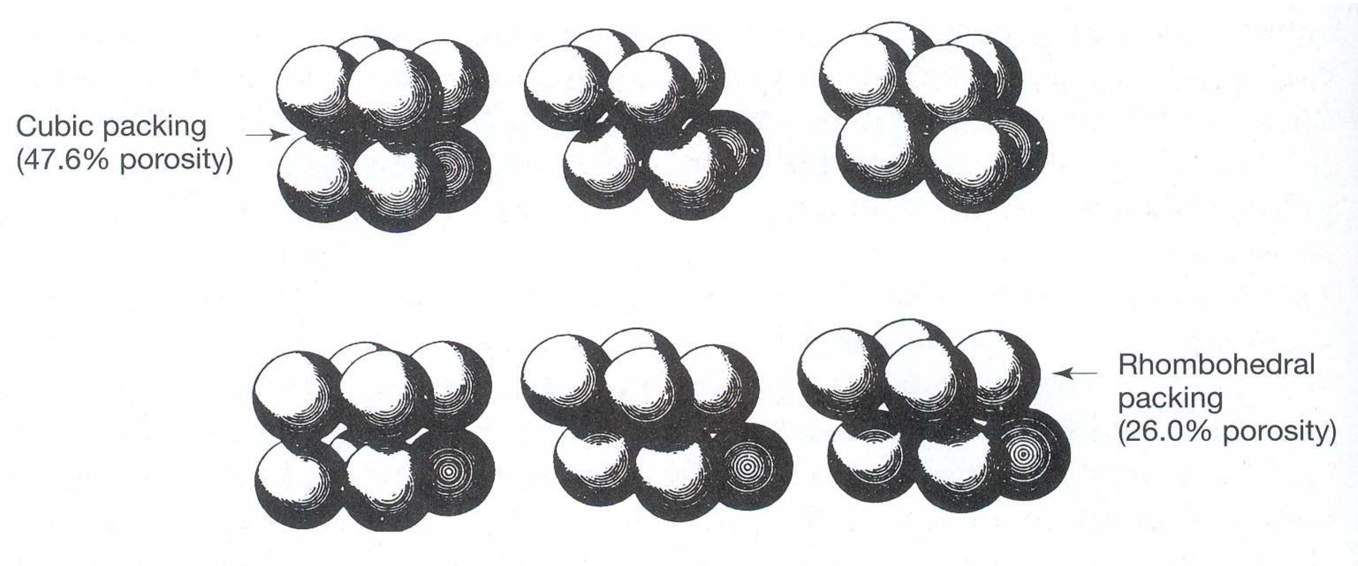


Fig. 3.14 Progressive decrease in porosity of spheres owing to increasingly tight packing.

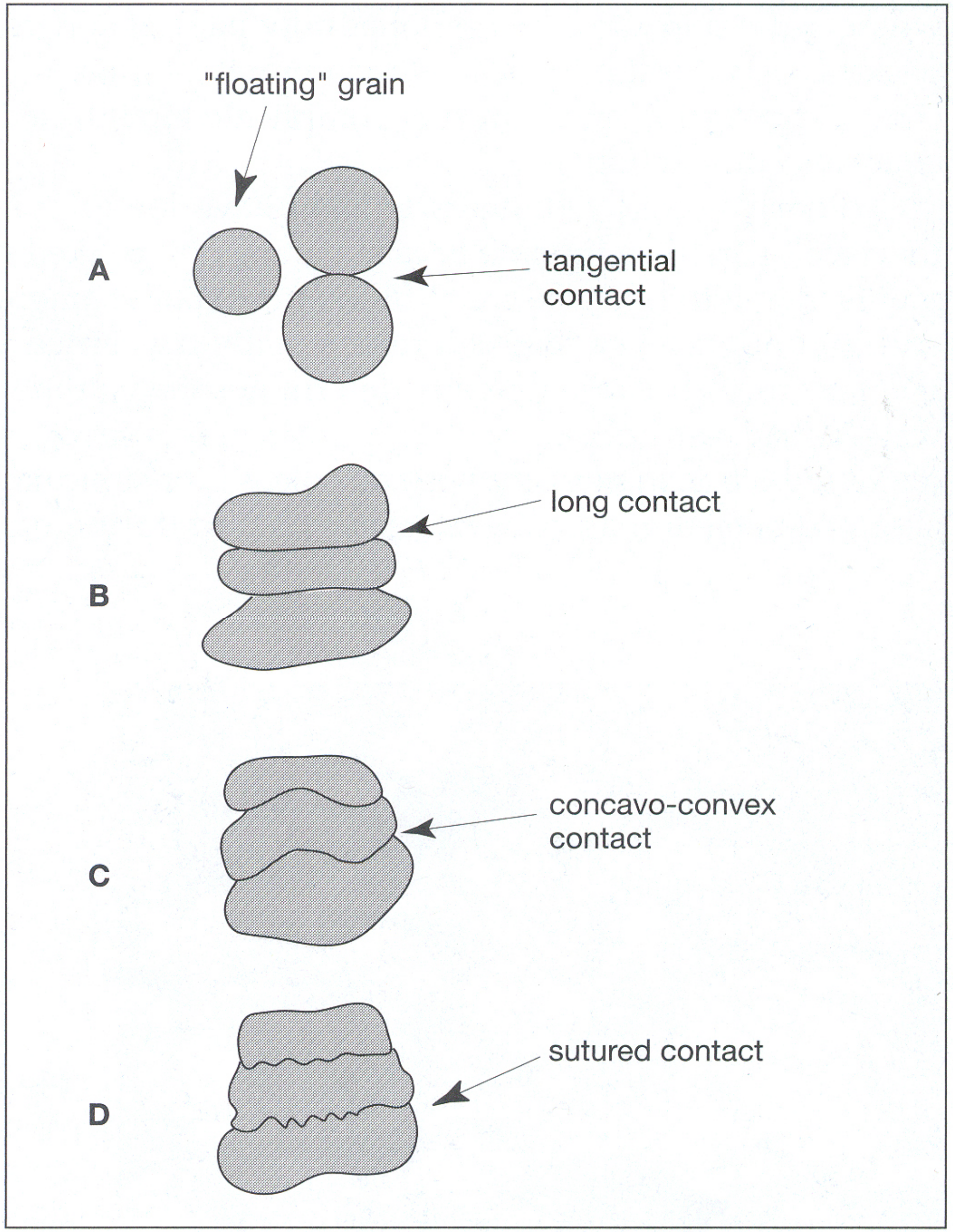


Fig. 3.15 Diagrammatic illustration of principal kinds of grain contacts. A. Tangential. B. Long. C. Concavo-convex. D. Sutured.

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