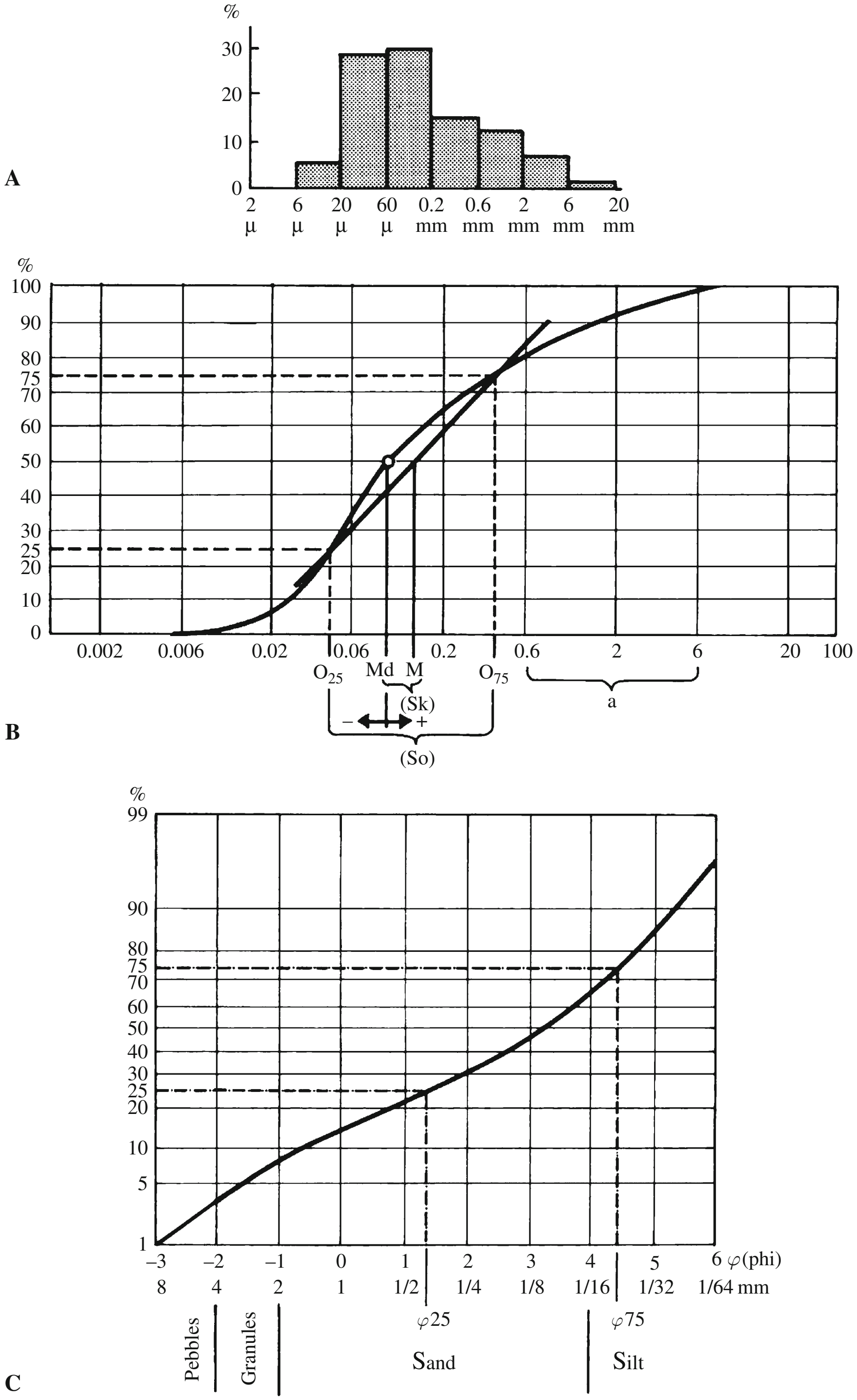


Fig. 2.3 Presentation of the same grain-size distribution data as (**a**) histogram, (**b**) cumulative curve, and (**c**) cumulative curve on probability paper. When plotted on probability paper, a logarithmic normal distribution, like a Gaussian curve, will plot as a *straight line*

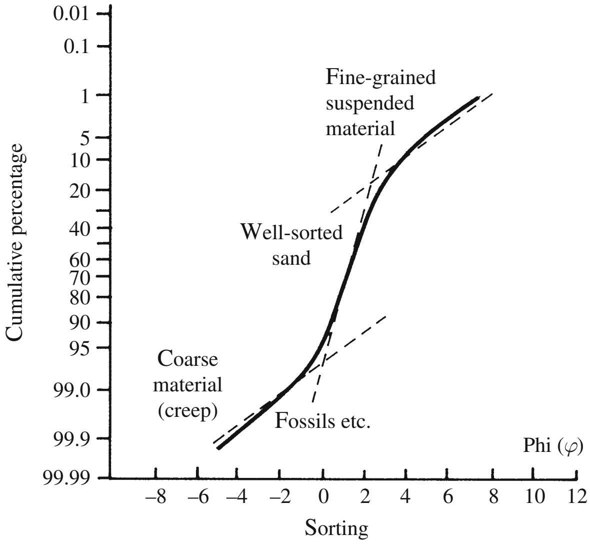


Fig. 2.4 Grain-size distribution curve presented as a function of grain size in φ values against a logarithmic cumulative percentage

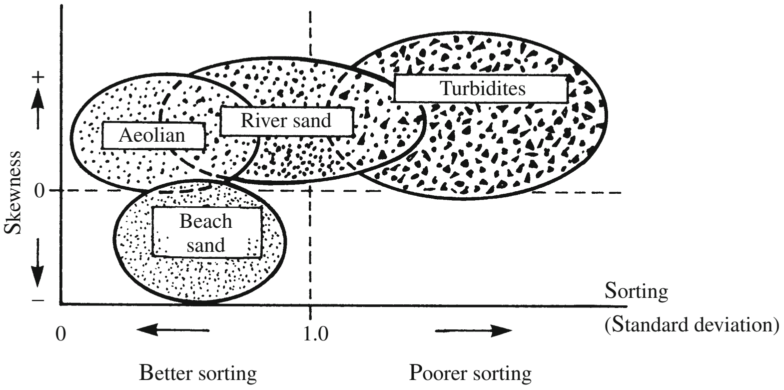
material. The fine material in dunes may also be protected by a cover of larger particles *(lag)* against further erosion and transport. Beach sand deposits, on the other hand, are clearly negatively skewed, i.e. the distribution curve shows a definite lower limit, while there is often a "tail" of larger particles, i.e. granules and pebbles. The hydrodynamic conditions on a beach are such that each wave brings some sediment in suspension. Whereas sand grains, particularly medium to coarse sand, will rapidly settle from suspension and be deposited on the beach again, fine sand, silt and clay will remain in suspension longer. This finer material will be transported further out and at a depth of some metres (1–50 m), depending on how strong the waves are (and consequently the depth of the wave base), we will have poorer sorted deposits because the fine fractions will be deposited and mixed with coarser-grained sediments which are carried out during storms.

Sediments deposited from suspension have poor sorting and positive skewness. This is very typical of turbidites. Clay suspensions which are deposited on land as high-density suspensions (mud flows), have negative skewness because they often contain large clasts.

Kurtosis is an expression for the spread of the extreme ends of a grain-size distribution curve in relation to the central part. This distribution parameter is used somewhat less than the others, but relatively small amounts of silt and clay can have a significant effect on the properties of coarse-grained sand. Pebbles and stones in otherwise fine-grained sediment may also be important.

One of the most important points to bear in mind when interpreting grain-size distributions is the availability of grain sizes supplied to the area where the process is taking place. Strong currents or wave energy will only be able to deposit coarse-grained sediments if there is coarse-grained sediment present in the area. A source area where sediments are generated by erosion and weathering will often supply specific grain sizes. Chemical weathering of acid rocks (granites), for example, will lead to the formation of sediments consisting of quartz grains corresponding in size to the quartz crystals in the granite, and clay (kaolinite, smectite, illite) formed through weathering of the feldspars. Weathering of basic rocks (basalts and gabbros) will produce almost exclusively clay minerals, and practically no sand grains.

Fig. 2.5 Sorting and skewness are grain-size distribution parameters which are suitable for distinguishing between sediments deposited through various processes and in different environments of deposition. Turbidites and fluvial sediments have a tail of small sediment particles while beach sand may have coarser grains such as pebbles



The grain-size distribution in a depositional area also depends on the transport mechanisms carrying sediment to the area. The grain-size distribution we observe in a sediment therefore reflects both the hydrodynamic conditions and the grain-size population of sediments available from the source area. Furthermore, although a particular grain-size distribution may be characteristic for a type of deposit, it does not point unambiguously to a particular environment of deposition because similar hydrodynamic conditions can exist in different environments. Statistical comparison of high resolution (minimum ½ Phi sampling interval) grain-size distributions, applying pairs of Folk and Ward or Krumbein parameters, can provide some diagnostic criteria for hydrodynamic interpretations.

Sediments may change their grain-size distribution by diagenetic processes at quite shallow burial as well as at greater depth. The formation of the clay minerals kaolinite and smectite from feldspar and rock fragments (volcanics) in a sediment certainly results in very different grain-size distributions from those at the time of deposition.

2.6 Grain Shape

We distinguish between three parameters:

1. *Roundness* is a property of surface shape – whether it is smooth or angular. A visual scale is most commonly used.
2. *Sphericity* is an expression for how much a particle deviates from a spherical form, and is defined as the ratio between the diameter of a circumscribed circle round the grain and the diameter of a sphere of the same volume (the *nominal diameter).*
3. We also use various expressions for grain shape such as (a) *discoid* or *bladed* for grains which are flat, (b) *Prolate* or *roller* for grains with one dimension considerably greater than the two others, (c) *equant* for grains with three relatively equal dimensions and (d) *oblate* for grains with one large, one medium and one small dimension.
4. *Surface textures* are concerned with the nature of the surface itself, whether it is rough, smooth, pitted, scratched etc. Some textures are diagnostic of specific modes of transport, and superimposed texture features may reveal the transport history of a grain. The surface texture of grains can best be studied under the scanning electron microscope. Aeolian sand grains may develop fine pitting on their surfaces due to the collisions of grains during transport, clearly visible under a binocular microscope.

Large grains become rounded far more rapidly than smaller ones because the impact energy released in collisions with other grains declines in proportion to the cube root of the radius. Blocks may be rounded after only a few hundred metres or several kilometres of transport. Grains less than 0.1 mm in diameter undergo little rounding even when carried very long distances in water, for example by tidal currents.

2.7 Sediment Transport

Sedimentary grains can be transported by water or by air. In order to understand the transportation processes we must know a little about the hydrodynamic (or aerodynamic) principles involved. When a liquid or gas flows in a channel or pipe it exerts a force (shear stress) against the walls or bottom. This force is counteracted by friction from the walls.

Pure water without suspended sediment is a Newtonian fluid which obeys Newton's law:

$$\tau = \mu \, dv/dh$$

A Newtonian fluid has no shear strength, so it will be deformed even by an infinitely small shear stress (dv/dh).

$\tau =$ *shear stress*, which is an expression of force per unit area (N/m^2). μ is the dynamic viscosity expressed in poise (g/cm/s or 0.1 N s/m^2), dv/dh is the change in velocity (dv) or velocity gradient (deformation velocity) as a function of distance from the boundary (dh). The viscosity of pure water decreases with increasing temperature. Suspended material may also affect viscosity, but the concentration of suspended material must be quite high (15–25%) before the viscosity increases significantly. If the water contains a large percentage of swelling clay minerals (smectite), however, the viscosity will increase at lower concentrations. The kinematic viscosity v is the dynamic viscosity (μ) divided by density ρ, i.e. $v = \mu/\rho$ and units are cm^2/s.

We distinguish between laminar flow, where each point in the liquid moves along a straight line parallel to the bed, and turbulent flow, where each point follows an irregular path so that eddies form (Fig. 2.6) Reynold's number (Re) is a dimensionless number which describes flow in channels and pipes. It is defined as:

$$\mathrm{Re} = vh\rho/\mu$$

Here v is the mean velocity, h is the depth of a channel or the diameter of a pipe in which fluid is flowing, ρ is the fluid density and μ its viscosity. If Reynold's number exceeds a certain value, about 2,000, the flow changes from laminar to turbulent. The density of water is 1 g/cm^3 and the viscosity is one centipoise (0.01 Ps = 0.01 g/cm/s). We see that the boundary between laminar and turbulent flow corresponds to 20 cm/s.

This means that for the flow of water to be laminar the product of velocity (cm/s) and depth (cm) must not exceed 20. If the velocity is 1 cm/s, there will be turbulence if the depth (h) is greater than 20 cm. In practice, then, flow in rivers and channels is always turbulent. For turbulent flow the expression for shear stresses which applies to laminar flow, is no longer adequate. The shear stress in turbulent flow will then increase as a function of velocity because of the eddies which produce an *eddy viscosity* (η) (Fig. 2.6). The total shear stresses will then be: $\tau = (\eta + \mu)/dv/dh$

2.8 Flow in Rivers and Channels

For all types of water flow the forces acting on the water must be in equilibrium. In most cases it is the force of gravity which balances bed frictional forces. In order to understand geological processes in connection with the erosion, transport and deposition of sediments, it is important for us to be aware of the relationships which govern the flow of water in channels.

If the channel has a cross-section A and we look at a stretch L of the channel, the force of gravity will be:

$$F_1 = \rho \cdot g \cdot L \cdot A \cdot \sin\alpha,$$

where ρ is the density of water, g is the force of gravity (constant) and α is the angle of slope of the channel. The resistance to flow consists of frictional forces against the bed and against the air. If we disregard friction against the air, the frictional forces are:

$$F_2 = \tau \cdot L \cdot P$$

where τ = shear stress (force per unit area) and $L \cdot P$ is the area of the bed on which the forces are acting. P is

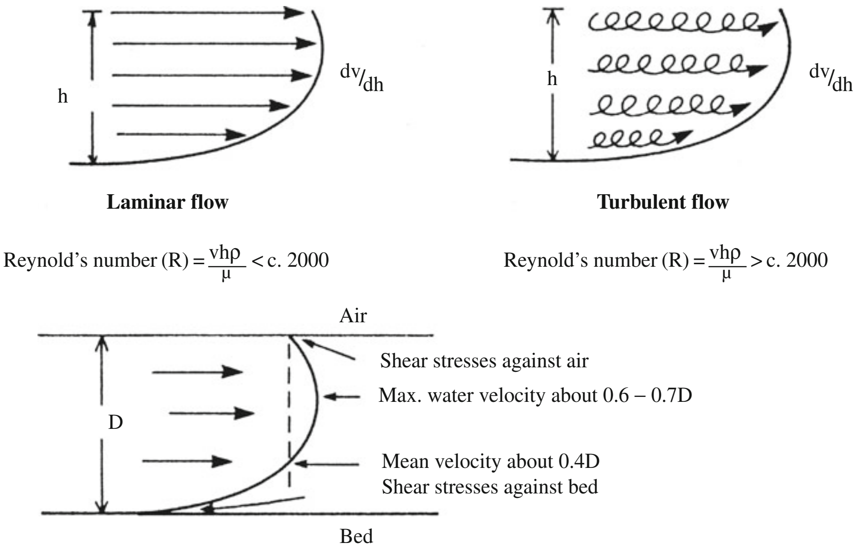


Fig. 2.6 Diagram showing principles of turbulent and laminar flow and the shear stress against the underlying bed