Causes of Braiding

There are two primary causes of braided streams:

Steep slopes and high sediment loads in coarse textured bed and banks can cause a wide, shallow channel in which bars and islands readily form. The stream may be supplied with more sediment than it can carry (overloaded), and part of that sediment may be deposited. Thus there are multichannels resulting in braiding.

There is another explanation of braided channels based on consideration of bank erosion and sediment transport.

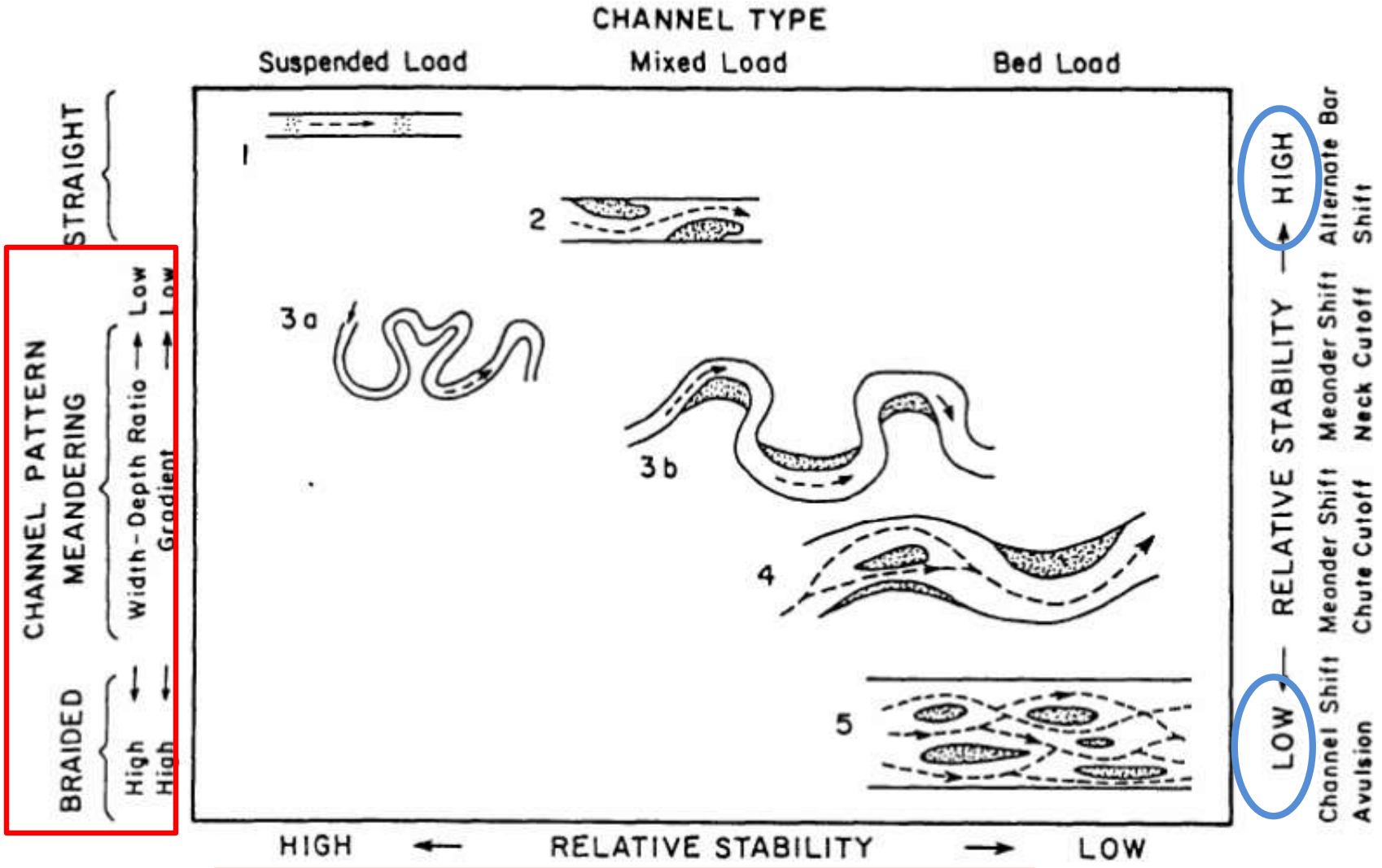
The basic principle is that in a narrow stream the entire bed can act as a unit to aggrade or degrade according to the difference between the sediment supply and the capability of the flow to transport it. However, when a stream cross section is too wide (because of excess bank erosion during high flow or weak bank resistance or both), the entire channel cross section cannot act as a single unit, and thus part of the wide channel may be covered by numerous small channels and result in a braided stream.

Channel Stability

In order to provide information on the stability of alluvial channels, classification of such channels should be based not only on channel pattern but also on the variables that affect channel morphology. Many empirical relations demonstrate that channel dimensions are attributable mostly to water discharge, whereas channel shape and pattern are also related to the type and amount of sediment load that moves through the channel.

Stream channels form a continuum, from straight to meandering to braided, that can be illustrated by the five patterns shown in Figure. These patterns illustrate the range to be expected in nature. The variables that influence pattern characteristics and the relative stability of the patterns are also indicated in Figure.
Although a pattern 1 straight channel may occur only rarely, when it is found it means that the banks are relatively stable and will erode slowly. In the case of a pattern 2 straight channel, the outer banks are relatively stable but the thalweg between them can shift.

Channel Stability



Channel patterns 3 and 4 are meandering channels in which the outer banks are not straight and parallel and may shift frequently. In this case, the shifting of the thalweg and the banks follows a more or less regular pattern. Most rivers meander, and the continuum of meandering channels by only three patterns: patterns 3a, 3b, and 4.

The braided channels are shown in 5 and here the channels can be with submerged bars and those with islands. The changes of the thalweg within the cross section of a braided channel cannot be predicted, and bank cutting is usually relatively rapid. Submergence or emergence of an island is very much a function of the frequency of flow.

Analysis of Stability

The basis of classification (stability) is the type of sediment load transported by the channel. The absolute quantity of water and sediment that moves through the channel can be less important than the type of sediment load. For example, in nature there are large and small channels of each of the types shown in Figure, and in each case the large channel forms in response to a larger water discharge but the pattern itself and the shape of the channel depend on the proportion of the total sediment load (silt, clay, sand, and gravel).

When bed-material load is small, wash load is a large part of the total load and the channel is narrow and deep (with a width-depth ratio of <10) and, depending on valley slope, the channel can be straight (pattern 1) or very sinuous (pattern 3a).

When the percentage of bed-material load is intermediate, the width-depth ratio is less and sinuosity is between about 2.0 and 1.3 (pattern 3b). This sandy channel may also be relatively straight, but the thalweg or the deepest part of the straight channel may be sinuous (pattern 2).

As the proportion of bed-material load increases, width-depth ratio increases (to > 40) and sinuosity is low. There is a tendency for multiple thalwegs to form (pattern 4). The greatest development of channels and bars occurs in the braided channel (pattern 5) when the ratio of bed-material load to total load is high.

The channel stability decreases from pattern 1 to pattern 5, patterns 4 and 5 being the least stable.

In nature, there is a continuum of patterns between patterns 3 and 4 of decreasing sinuosity, increasing gradient and width-depth ratio, and decreasing bank and channel stability.

Suspended-load channel patterns 1 and 3a are associated with small amounts of bed-material load; as a result, the banks tend to be relatively stable because of their high silt-clay content and thus the channels are not characterized by serious bank erosion or channel shift.

Channels with higher bed-material loads and banks that contain less cohesive sediment are less stable than suspended-load channels (patterns 3b and 4). Alternate bars migrate through the low-sinuosity channel (pattern 2), causing alternating reaches of stable and eroding banks.

When channels have large loads of coarse sediments, bank sediments are easily eroded, gravel bars and islands form and migrate through the channel (pattern 5).

ENVIRONMENTAL FACTOR	Meandering Channels	Braided Channels
Valley slope	Low	High
Hydrologic regime	Regular	Erratic
Sediment-transport mode	Suspended-load dominant	Bed-load dominant
Sediment supply	Low	High
Sediment load	Low	High
Stability	High	Low

Conceptually, planform stability (PS) of rivers can be of two simple force ratios (called PS ratio):

PS1 = stream eroding power / boundary material strength
PS2 = bed load supply / bed load transport capacity

PS1 reflects the capacity of a river channel to withstand the erosive force of the river it carries.
Meandering tends to be the most stable planform when PS1 is low and braiding is the most stable at high values of PS1. One of the most common causes of a high value of PS1 is a steep channel slope.

PS2 reflects the capacity of the river to transport the bedload that is delivered to it.

When PS2 is low a river is more likely to be able to transport the sediment supplied to it, a condition typical of a meandering channel.

If PS2 increases to a high value because of either bedload is increased or bedload transport capacity is decreased, sediment will be deposited to form mid-channel bars and a braided planform is established.

The divided channels are steeper due to aggradation (deposition) and together can transport a greater amount of bedload than the original single channel.

But if the divided channel still has a high PS2 ratio the river may deposit additional bars to divide the channel yet again until the reduced discharge lowers PS2 into a more stable domain and in doing so establishes a more intensely braided river planform.

In general meandering can be regarded as the default river planform that is stable in a wide range of conditions found in nature.

Braiding occurs in less usual circumstances where river erosional power is very high or channel bank strength is very low or where sediment supply relative to bedload transport capacity is unusually high.

Modes of Sediment Transport

The aggregate of sediment particles which are transported by a flow at a given time is called the sediment load, or just the load.

The load can further be subdivided in three different ways:

- on the basis of its physical nature
- Its presence or absence in the bed
- how it travels.

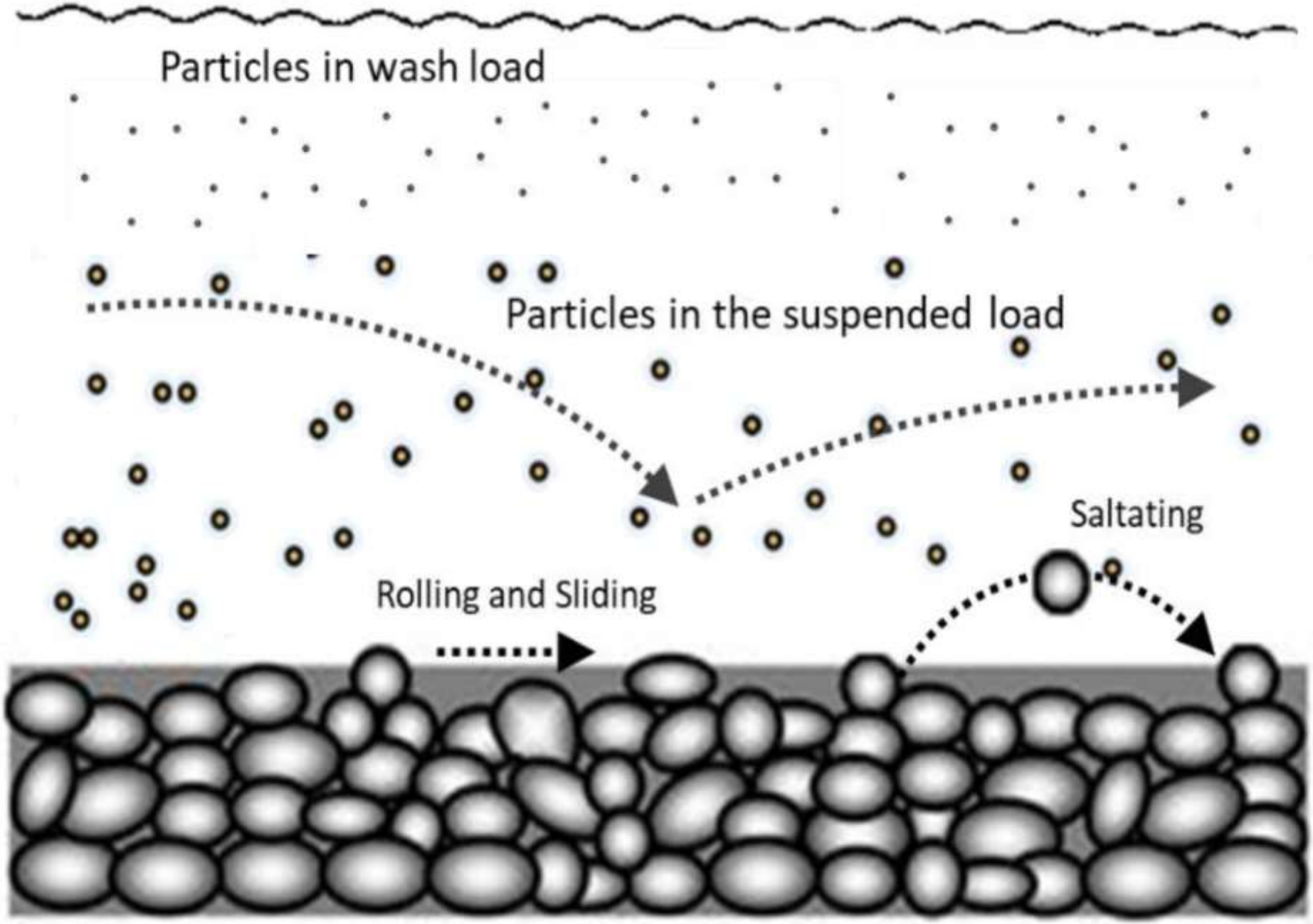
On the basis of its physical nature, the sediment load of rivers is divided into particulate load and dissolved load.

On the basis of presence or absence in the bed, the particulate load can also be divided into bed-material load and wash load.

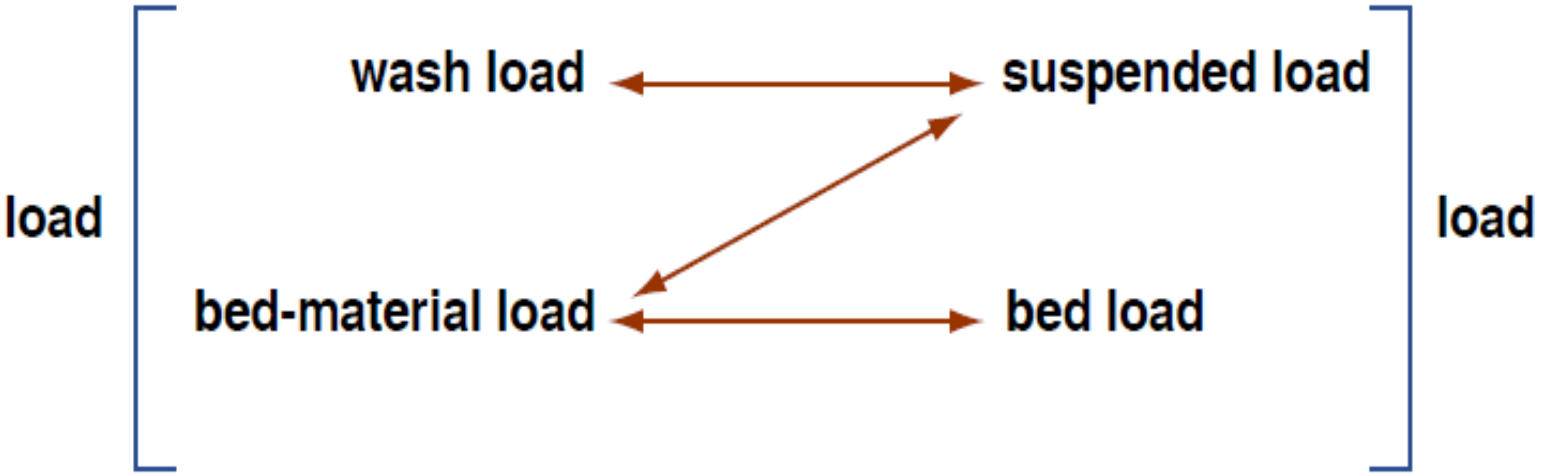
Bed-material load is that part of the load whose sizes are represented in the bed in non-negligible percentages.

Wash load, is that part of the load whose sizes are not present in the bed in appreciable percentages. Thus, the wash load, which is always the finest fraction of the load (mainly clay or finest silt size), is carried through a long segment of a river without any exchange of sediment between the bed and the flow.

Figure: Sketch of sediment transport in water.



In terms of how the load travels, it can be divided into bed load, which travels in direct contact with the bed or so close to the bed as not to be substantially affected by the fluid turbulence, and suspended load, which is maintained in temporary suspension above the bed by the action of upward-moving turbulent eddies.



Thus, *bed load is always bed-material load, and suspended load is likely to be partly bed-material load and partly wash load*, although in particular cases it could be all wash load, part wash load and part bed material load or all bed-material load.

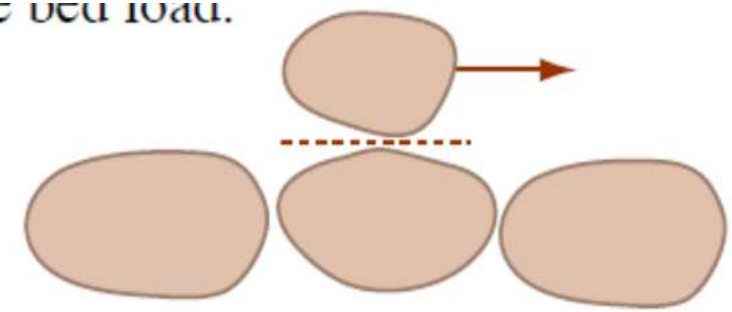
Although the distinction between bed load and suspended load is a convenient one, there's no sharp break between bed load and suspended load.

Also, a given particle can be part of the bed load at one moment and part of the suspended load at another moment, depending upon the time history of fluid forces and motions to which it is subjected. Therefore, *at any given time there's an appreciable overlap in the size distributions of the bed load and the suspended load*, although clearly the *suspended load tends always to be finer on the average than the bed load.*

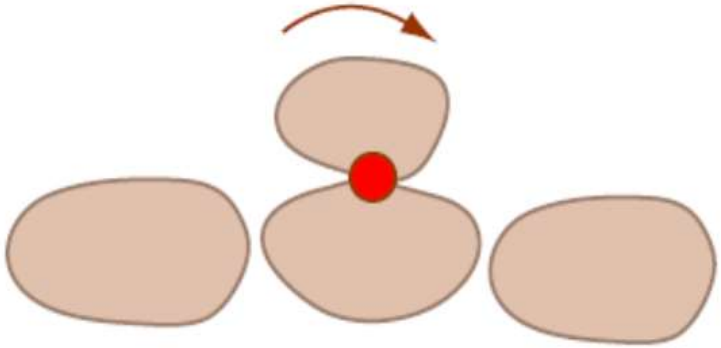
Particles moving as bed load are susceptible to being carried up into suspension when the maximum vertical turbulent velocity fluctuations are greater in magnitude than the settling velocities of the particles.

Bed-load movement can be by rolling, sliding, or hopping/saltation. While rolling or sliding, the sediments are in contact with the bed and the movement is intermittent. In saltation, the particles lose contact with the bed and bounce from one point to another

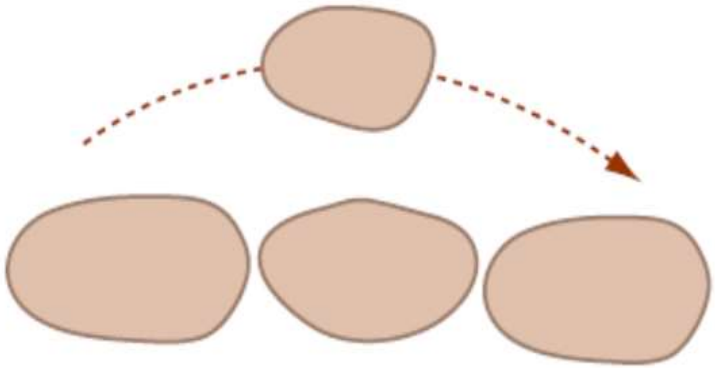
the bed load.



sliding



rolling



hopping **or saltation**

Modes of Sediment Transport

The sediment load of a river is transported in various ways although these distinctions are to some extent arbitrary and not always very practical in the sense that not all of the components can be separated in practice:

1. Dissolved load
2. Suspended load
3. Wash load
4. Bed load

Dissolved Load

Dissolved load is the material that has gone into solution and is part of the fluid moving through the channel. Since it is dissolved, it does not depend on forces in the flow to keep it in the water column.
The amount of material in solution depends on supply of a solute and the saturation point for the fluid. For example, in limestone areas, calcium carbonate may be at saturation level in river water and the dissolved load may be close to the total sediment load of the river.

Dissolved Load

- All stream water contains dissolved ions and anions

- The bulk of the dissolved content of most rivers consists of seven ionic species:
  - Bicarbonate (HCO_3^-)
  - Calcium (Ca^{++})
  - Sulfate (SO_4^{--})
  - Chloride (Cl^-)
  - Sodium (Na^+)
  - Magnesium (Mg^{++})
  - Potassium (K^+)
  - Dissolved silica as $Si(OH)_4$

Dissolved load is not important to channel processes because it is simply part of the fluid.

Suspended-sediment load

Suspended-sediment load (or suspended load) is the particulate material that moves through the channel in the water column. These materials, mainly silt and sand, are *kept in suspension by the upward flux of turbulence generated at the bed of the channel*. The upward currents must equal or exceed the particle fall-velocity for suspended-sediment load to be sustained.

Suspended-sediment concentration is conventionally measured as milligrams per liter (mg/L).

As the rate of flow in a water course increases, the depths, velocities and turbulent intensities also increase. The stage is finally reached where the fluctuating lift forces generated by the turbulence generally exceed the weight of the particles. Accordingly the particles no longer follow a well defined trajectory, instead they follow random paths within the fluid.

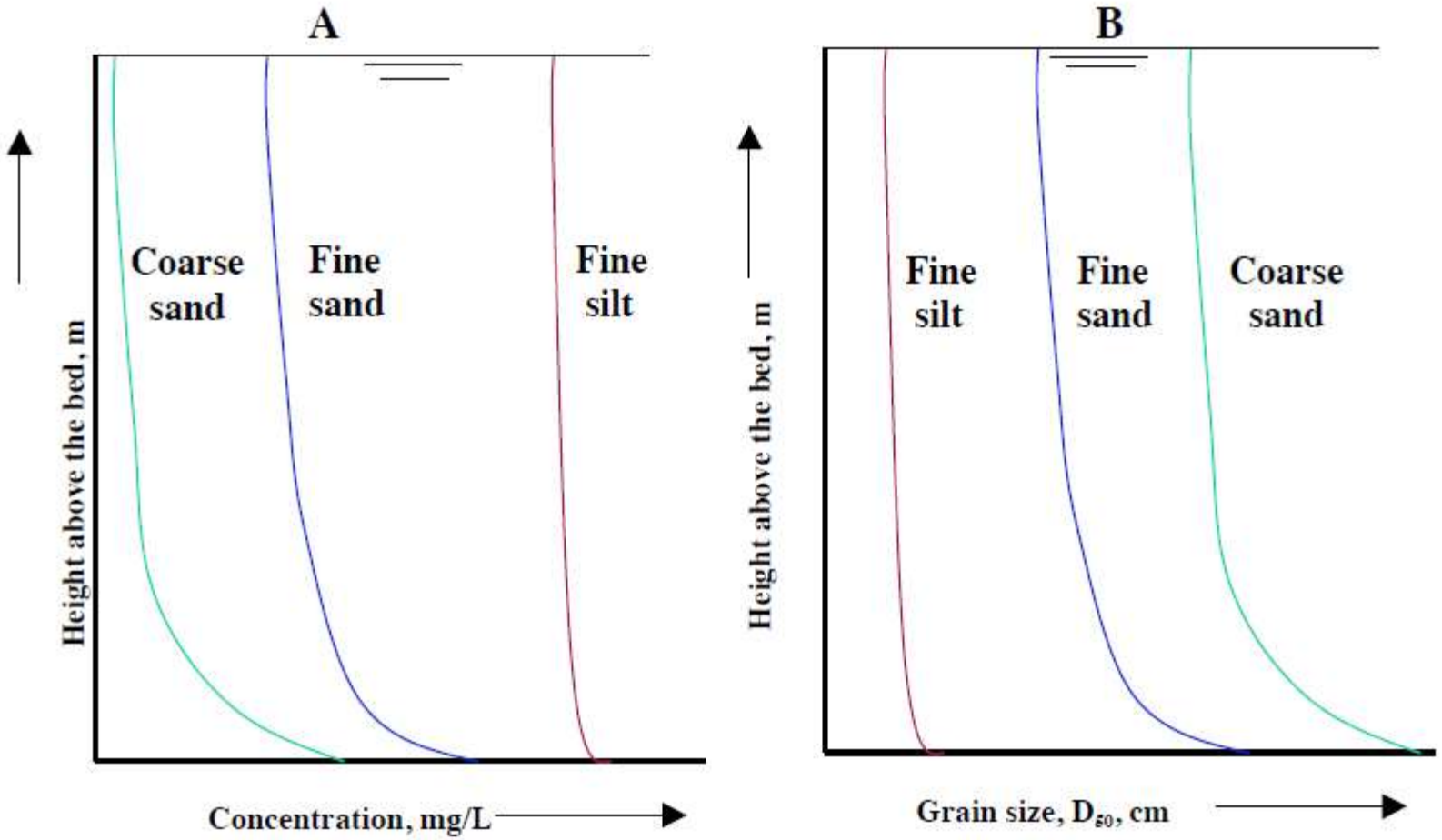
These random paths occasionally redeposit particles on the bed and hence individual particles may, at different times, constitute part of the bed load and part of the suspended bed material load. Thus the *distinction between the bed load and the suspended bed material load is difficult to make in a scientific sense*.

In reality there is a continuum of behaviour going from bed load at one extreme to suspended load at the other. The *division between bed load and suspended load depends upon both the sediment size and the flow.*

Thus a particular sediment size may behave as bed load under one flow condition and as suspended load under another flow condition.

The *size and concentration of suspended-sediment typically varies logarithmically with height above the bed (increase in depth).* That is, concentration and grain size form linear plots with the logarithm of height above the bed. Coarse sand is highly concentrated near the bed and declines with height at a faster rate than does fine sand. Fine silt is so easily suspended that it is far more uniformly distributed in a vertical section than is the coarser material.

Variation of distributions of concentrations and sizes of silt and sand



Similarly, the grain-size distribution within a sample of sand displays far more vertical variation than does the vertical distribution of grain size within the silt range. The former is too large for the flow to move much of it into the upper water column and the latter is so small and easily suspended that it is well represented at all levels thus giving rise to a more uniform grain-size profile.

Wash load

Although wash load is part of the suspended-sediment load it is useful here to make a distinction. Unlike most suspended-sediment load, wash load does not rely on the force of mechanical turbulence generated by flowing water to keep it in suspension.

The size generally it is within the range 0.06 mm to 0.10 mm (divide between cohesive and non-cohesive materials).

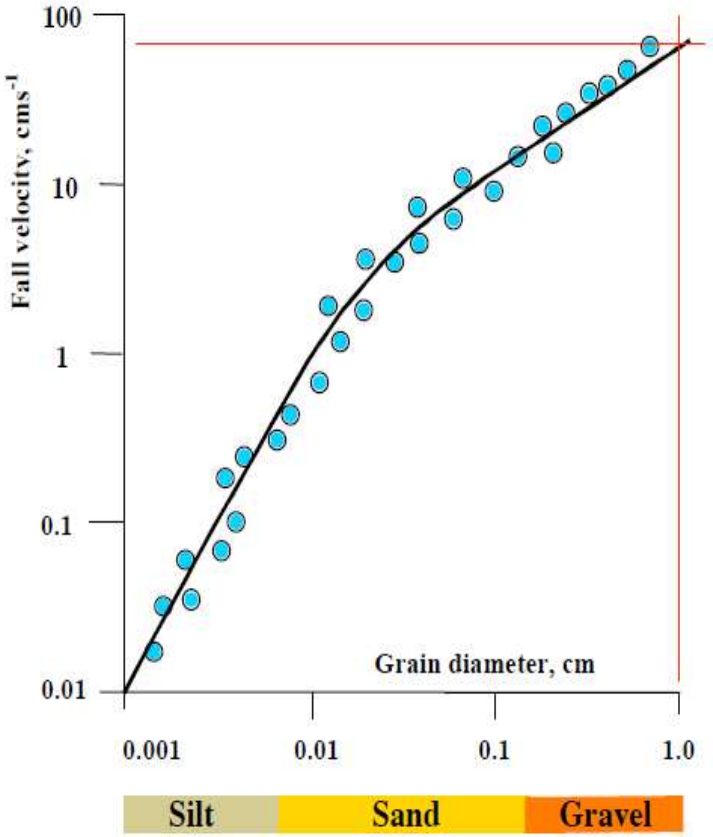
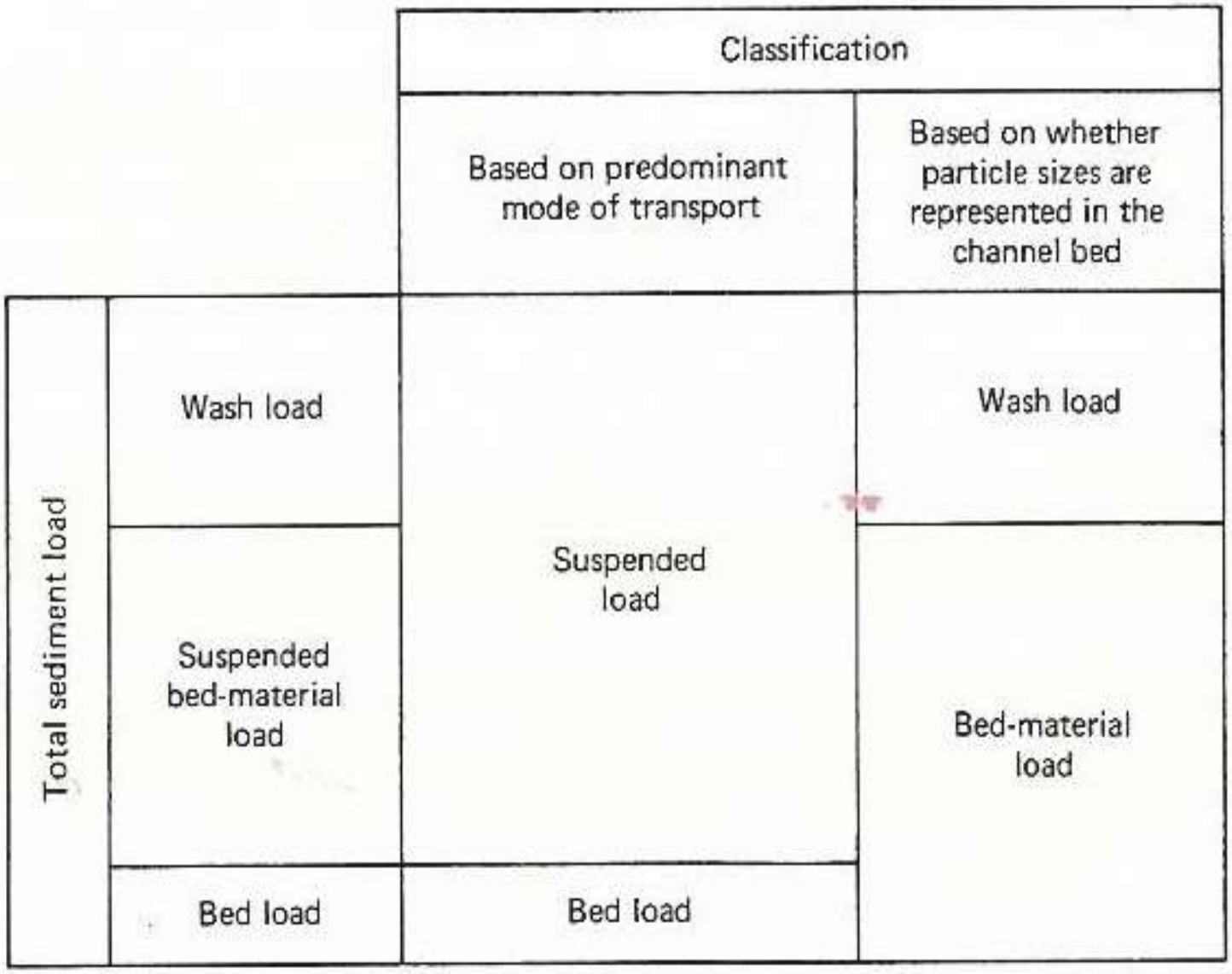


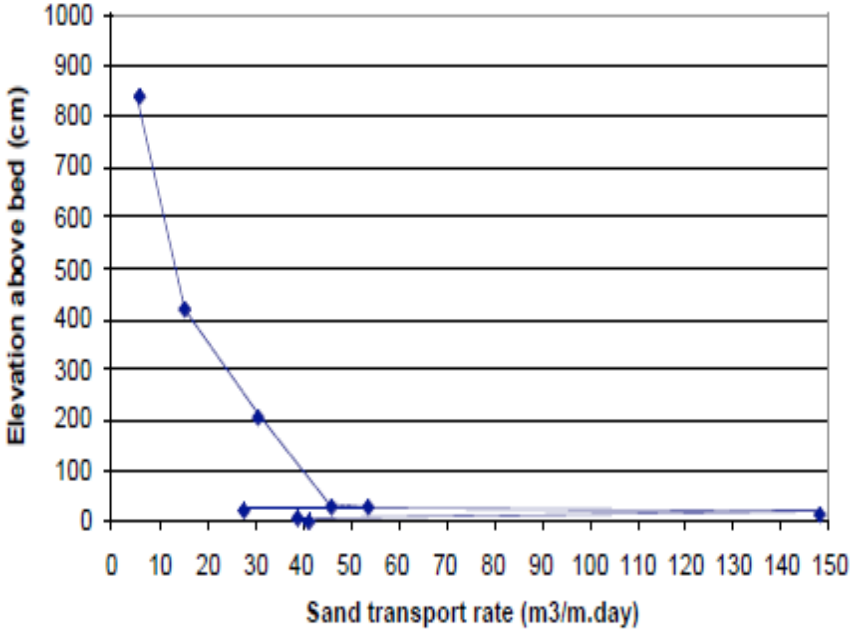
Figure 4.2: Fall velocity in relation to diameter of a spherical grain of quartz

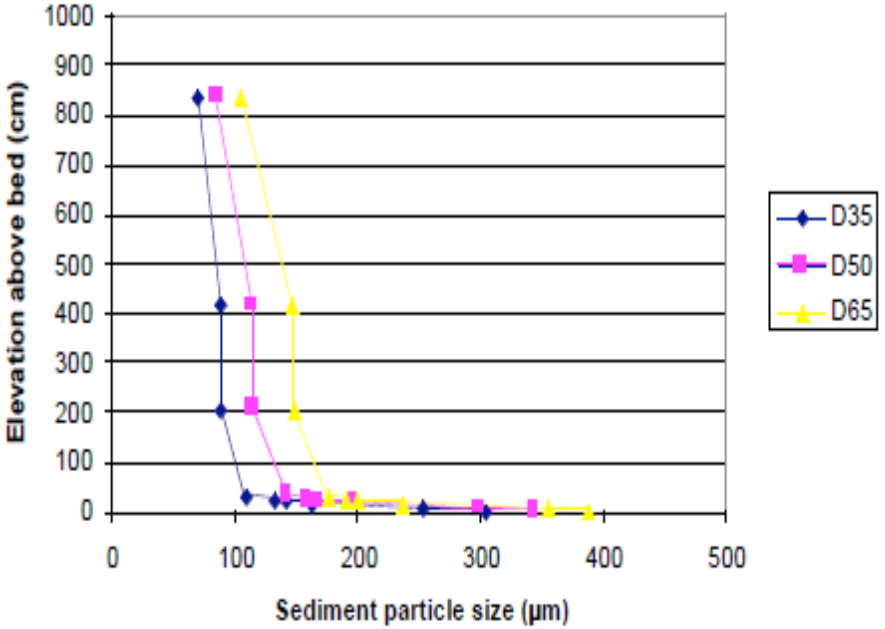
It is so fine (in the clay range) that it is kept in suspension by thermal molecular agitation (sometimes known as Brownian motion). The amount of fine material in suspension is not governed directly by the local hydraulic conditions. Because these clays are always in suspension, wash load Is that component of the particulate load that is "washed" through the river system.
Unlike coarser suspended-sediment, wash load tends to be uniformly distributed throughout the water column. That is, unlike the coarser load, it does not vary with height above the bed.

Bed Load (Traction Load)
Increases in the hydrodynamic forces over and above those necessary to create incipient motion cause movement of bed material in the direction of flow. Those particles in motion close to the bed and moves through the channel fully supported by the channel bed itself constitute the bed load. These materials, mainly sand and gravel, are kept in motion (rolling, sliding and saltation) by the shear stress acting at the boundary. *Unlike suspended load, the bed-load component is almost always capacity limited (function of hydraulics rather than supply).*

Classification of Sediment Load







Smaller sizes are more or less uniform along the depth.

Larger sizes are predominantly at the bottom.

Similar field observations in the Jamuna (Brahmapoutra) river, Bangladesh (1995)

Detailed profile close to the bed show a gradual decrease of the sediment size from the bottom upwards, despite the irregular variation in sediment transport rate (figure above)

