Briefing Document: Analysis of Sediment Properties and Their Significance in Transport Dynamics

Executive Summary

Sediment properties—primarily grain size, density, sorting, and porosity—are foundational inputs to sediment transport models. These characteristics directly control:

- Settling velocity
- Threshold of motion
- Partitioning between bedload and suspended load

A central theme is the **statistical characterization of grain size distribution**. Because natural sediments commonly follow a log-normal distribution, analysis is best conducted using the logarithmic **phi (φ) scale**, which simplifies statistical treatment.

Key descriptive parameters include:

- Median diameter d_{50}
- Geometric mean diameter d_g
- Sorting parameter σ_g

For non-log-normal distributions, calculations are performed in phi-space and then transformed back to millimeter-space.

Density—particularly the submerged relative density R—is essential in calculating the Shields parameter and settling velocity, demonstrating the interconnectedness of sediment properties in predicting transport behavior.

1. Foundational Role of Sediment Properties

Sediment properties are not merely descriptive—they directly govern transport dynamics.

Reliable modeling requires accurate characterization of:

- Grain size
- Density contrast
- Sorting
- Porosity

Key Controlled Processes

Settling Velocity

Determined by particle size, shape, and density.

Threshold of Motion

Controlled by grain size and submerged weight.

Bedload vs. Suspended Load

Strongly influenced by grain size and settling velocity.

These properties underpin:

- Shields parameter
- Transport rate formulas
- Dimensionless mobility parameters

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2. Core Physical Properties of Sediments

2.1 Composition

Natural sediments consist of mineral particles and organic matter.

Common Mineral Constituents

- Quartz
- Feldspar
- Limestone
- Basalt
- Mica
- Heavy minerals (e.g., magnetite, ilmenite)

In most fluvial and coastal sands, **quartz and feldspar dominate** due to weathering resistance.

Mineralogy influences:

- Density
- Durability
- Transport behavior

2.2 Density

Density controls submerged weight and mobility.

Definitions

- Sediment density: ρ_s
- Fluid density: ρ

Relative density:

$$s = \frac{\rho_s}{\rho}$$

Submerged relative density:

$$R = s - 1 = \frac{\rho_s - \rho}{\rho}$$

Rappears directly in:

- Settling velocity formulas
- Shields parameter

Typical Relative Density Values

Material	Relative Density (s)
Quartz sand	~2.65
Limestone	2.6–2.8
Basalt	2.7–2.9
Magnetite	3.2–3.5

2.3 Porosity

Porosity describes void fraction:

$$n = \frac{V_{void}}{V_{total}}$$

Typical Ranges

Material Type	Porosity
Uniform sands	0.30–0.50
Poorly sorted mixtures	< 0.30
Fresh clay	> 0.8

Clay deposits consolidate over time, reducing porosity.

Porosity influences:

- Bulk density
- Permeability
- Bed stability

2.4 Particle Shape

Natural grains are rarely spherical.

Shape factor:

$$\Psi = \frac{c}{(ab)^{1/2}}$$

where a, b, c are principal axes.

In practice, shape effects are often absorbed into empirical transport coefficients.

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3. Grain Size Analysis and Distribution

Grain size is the most influential sediment property.

3.1 Grain Size Definitions

Characteristic diameter:

$$d$$

Common percentiles:

- d_{16}
- d_{50} (median)
- d_{84}

Diameter concepts:

- Sieve diameter
- Equivalent sediment diameter

Sediment Size Classes

Material	Diameter (mm)	Behavioral Note
Clay	< 0.002	Cohesive
Silt	0.002–0.063	Transitional
Sand	0.063–2	Non-cohesive
Gravel	2–60	Non-cohesive
Cobbles	60–200	—
Boulders	> 200	—

3.2 The Phi (φ) Scale

Defined as:

$$\phi = -\log_2(d)$$

Inverse:

$$d = 2^{-\phi}$$

Advantages:

- Converts log-normal distribution in mm-space
- Produces approximately normal distribution in phi-space
- Enables standard statistical analysis

3.3 Grain Size Representation

Size-Frequency Distribution

- Histogram of grain size classes
- Often approximated by log-normal distribution

Cumulative Grain Size Curve

- S-shaped curve
- Used to extract d_{16}, d_{50}, d_{84}

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4. Statistical Characterization of Grain Size

4.1 Log-Normal Distribution Parameters

For log-normal distributions:

Geometric Mean Diameter

$$d_g = \sqrt{d_{16} \cdot d_{84}}$$

Sorting (Geometric Standard Deviation)

$$\sigma_g = \sqrt{\frac{d_{84}}{d_{16}}}$$

Sorting Interpretation

σ_g	**Interpretation**
= 1	Uniform
< 1.3	Well sorted
> 1.6	Poorly sorted

4.2 Advanced Method for Non-Log-Normal Distributions

When distribution deviates from log-normal:

Step 1: Work in Phi-Space

Compute:

$$\bar{\phi} = \sum(\phi_i^* p_i)$$
$$\sigma_\phi^2 = \sum((\phi_i^* - \bar{\phi})^2 p_i)$$

where:

- ϕ_i^*= class midpoint
- p_i= class fraction

Step 2: Back-Transform

$$d_g = 2^{-\bar{\phi}}$$
$$\sigma_g = 2^{\sigma_\phi}$$

These parameters are then used in transport formulas.

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5. Synthesis and Application

Sediment properties are foundational inputs controlling transport systems.

Reliable modeling requires:

- Accurate grain size statistics
- Proper density characterization
- Porosity assessment

The phi-scale transformation is essential for handling log-normal distributions.

Consistent notation ensures compatibility across:

- Shields parameter formulations
- Transport rate equations
- Morphodynamic models