TOPIC 02: FOUNDATIONAL INPUTS

Sediment Properties & Grain Size Statistics

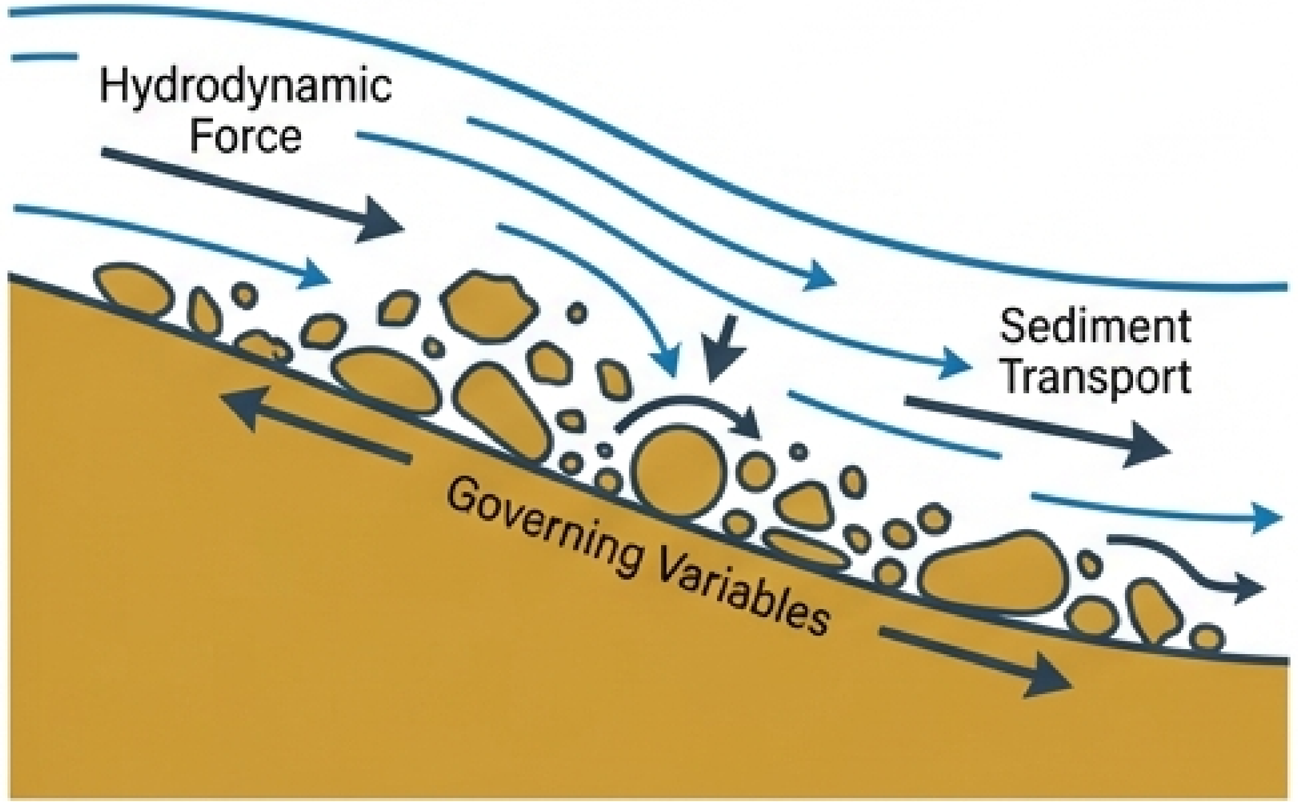
Fundamental definitions and statistical inputs for sediment transport mechanics.

1 mm

Why Precise Definitions Matter

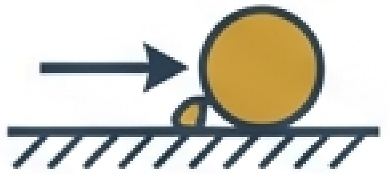
The Concept

Sediment properties are not merely physical descriptors; they are the governing variables for hydrodynamic behavior. Every transport rate formula relies on these inputs.

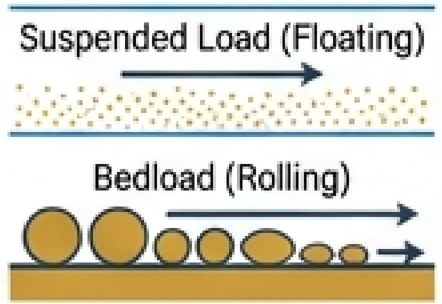


The Application

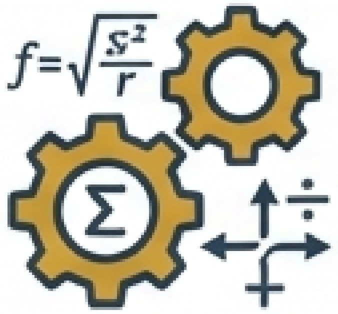
Settling Velocity: Controls how fast particles fall through the water column.



Threshold of Motion: Determines the exact shear stress required to initiate movement.



Transport Mode: Dictates the partition between bedload (rolling) and suspended load (floating).



Mathematical Relevance: These variables form the foundation for the Shields parameter and sediment continuity equations.

Sediment Composition and Mineralogy

Natural sediments consist of a mixture of mineral and organic particles. The composition determines the density and durability of the grain.

Dominant Constituents

Quartz and Feldspar dominate most fluvial and coastal sands due to their high resistance to chemical and mechanical weathering.

Other Constituents

- Limestone, Basalt, Mica
- Heavy minerals (e.g., Ilmenite, Magnetite)
- Organic matter

Microscopic view illustrating mineralogical diversity

Density: The Driver of Transport

The Variables

- Sediment density: ρ_s
- Water density: ρ

Submerged Relative Density (R)

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

This variable is the primary buoyancy input for Shields parameter calculations.

Standard Values

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

Porosity and Particle Shape

Porosity (n)

Ratio of void volume to total volume ($n = V_{void}/V_{total}$).

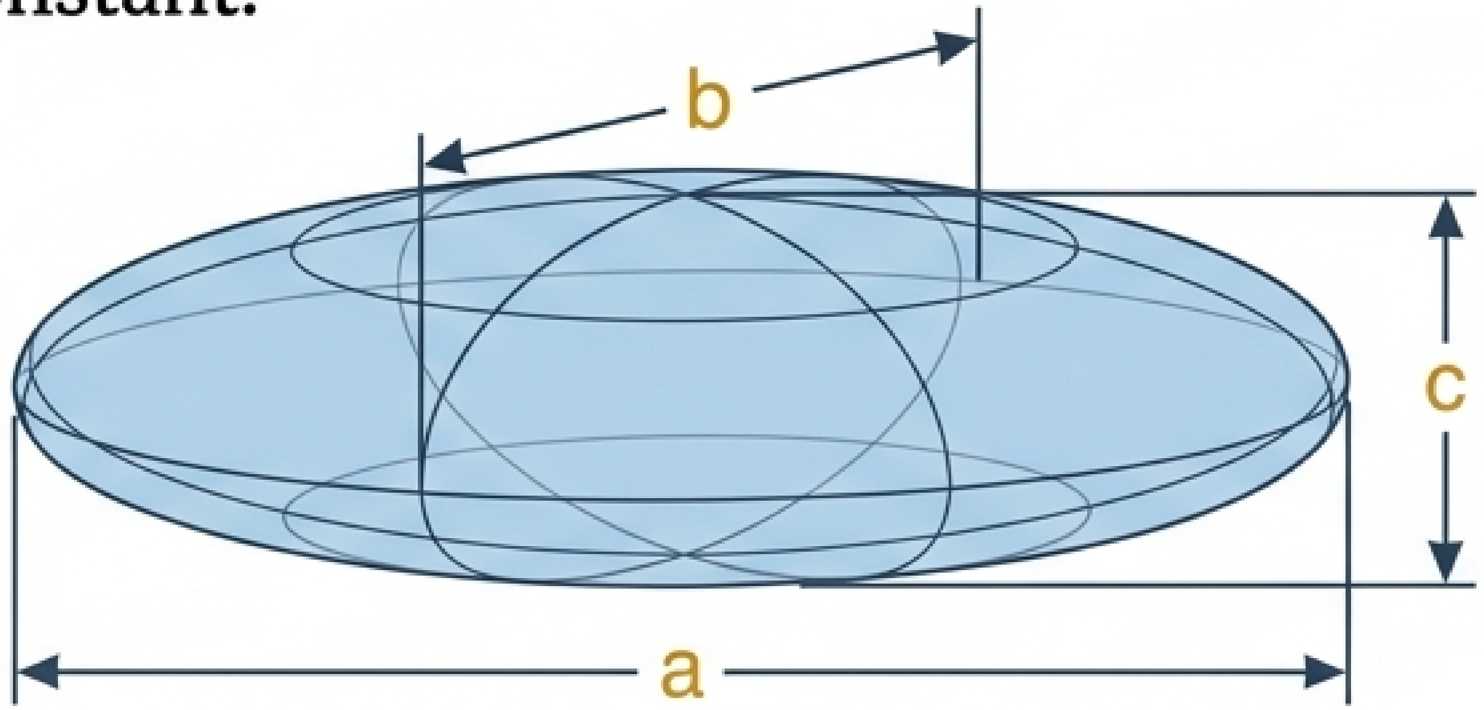
- Uniform Sands: 0.30 – 0.50
- Poorly Sorted Mixtures: < 0.30 (small grains fill voids)
- Fresh Clay: > 0.8 (decreases with consolidation)

Particle Shape & Shape Factor (Ψ)

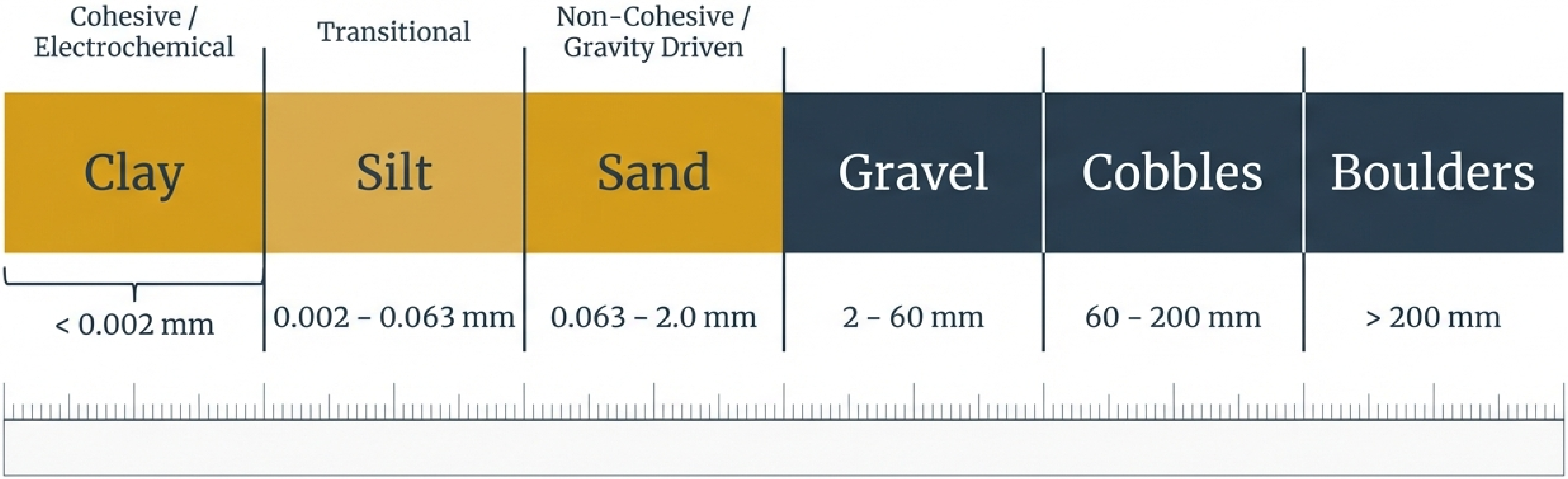
Natural grains are non-spherical. We define shape using principal axes.

$$\Psi = \frac{c}{\sqrt{ab}}$$

For natural sands, Ψ is often treated as constant.



Standardizing Grain Size Classes



The Phi (ϕ) Scale Transformation

Nature sorts sediment logarithmically. To simplify statistical analysis and normalize distributions, engineers convert linear millimeters into the logarithmic **Phi** scale.

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

(where d is diameter in mm)

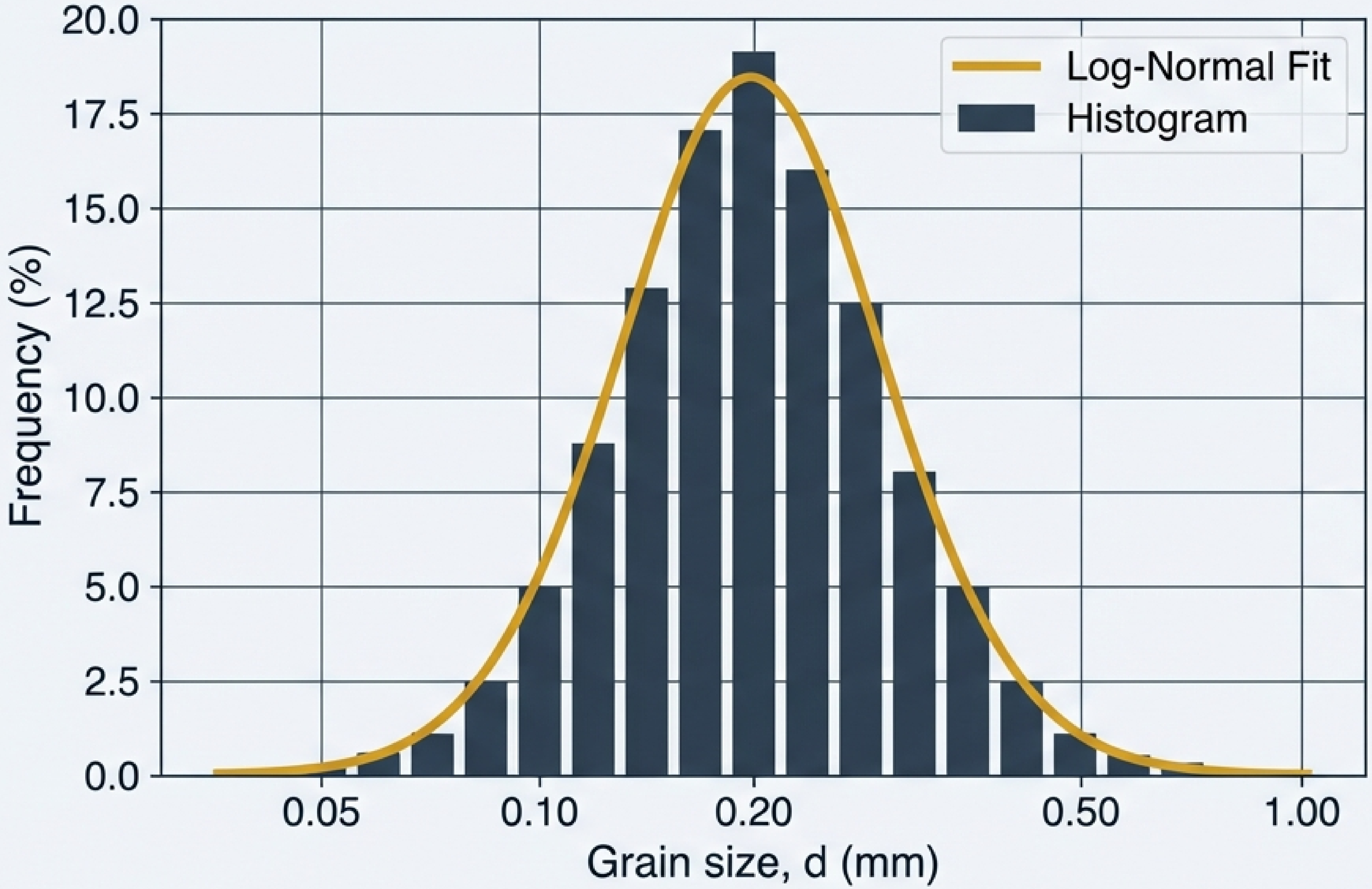
$$d = 2^{-\phi}$$

(Inverse transformation)

Benefits of the Phi Scale:

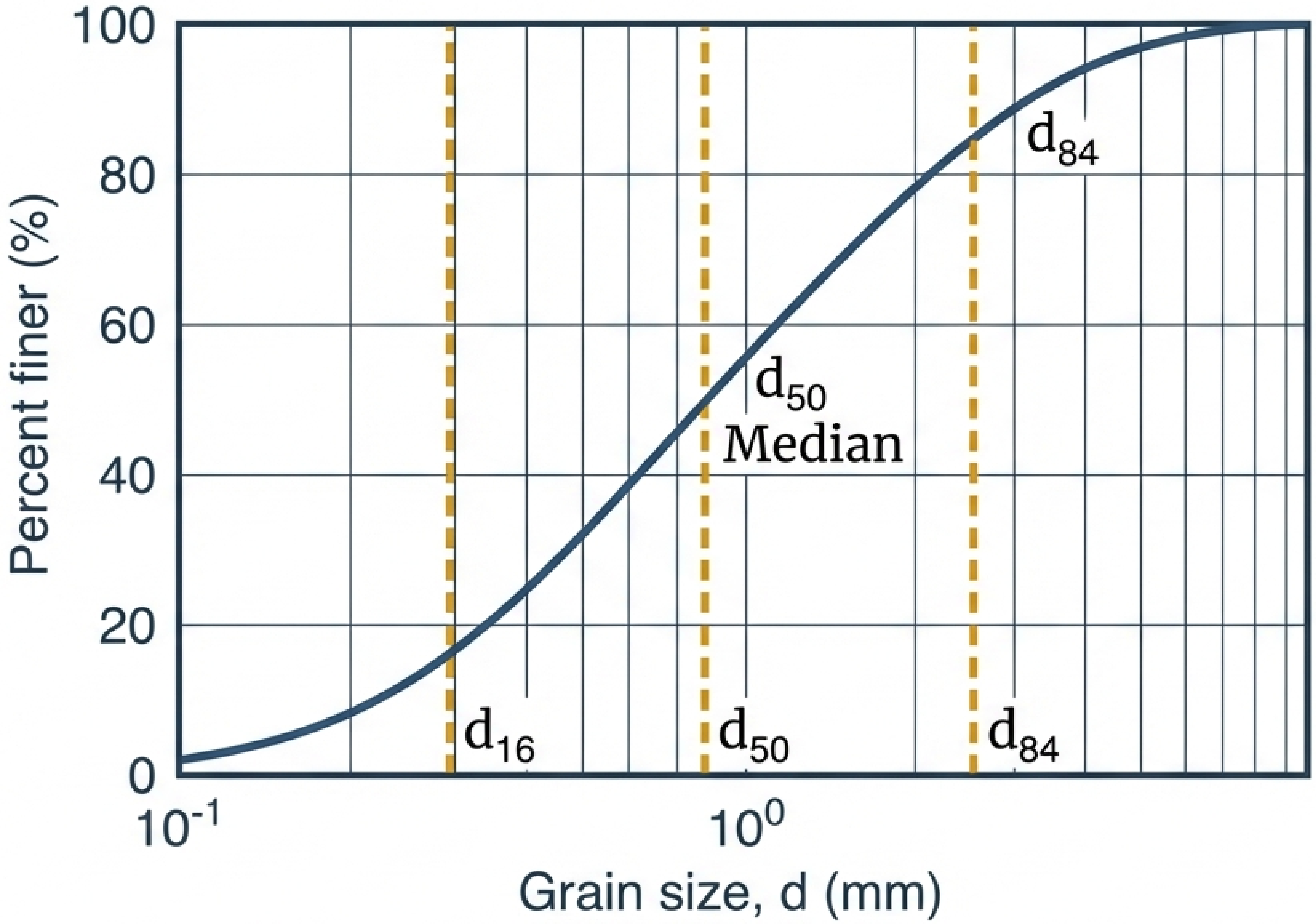
- creates equal spacing for statistical classes
- simplifies analysis of size-frequency distributions
- allows log-normal behavior to appear as a Normal Bell Curve

The Size-Frequency Distribution



The Histogram displays the sediment fraction vs. grain size. Natural sediments often approximate a Log-Normal distribution, revealing the dominant grain sizes in a sample.

The Cumulative Grain-Size Curve



The Cumulative Curve is the standard tool for parameter extraction. It plots “Percent “Percent Finer” against grain size, allowing engineers to isolate specific percentiles (d_x) for use in transport formulas.

Geometric Statistics for Log-Normal Sediments

Simplified parameter estimation for ideal distributions

Geometric Mean Diameter (d_g)	Geometric Standard Deviation (σ_g)
$d_g = \sqrt{d_{16} * d_{84}}$ Represents the "effective" grain size for transport calculations.	$\sigma_g = \sqrt{d_{84}/d_{16}}$

Sorting Classification based on σ_g:

$\sigma_g = 1.0$: Perfectly Uniform

$\sigma_g < 1.3$: Well Sorted

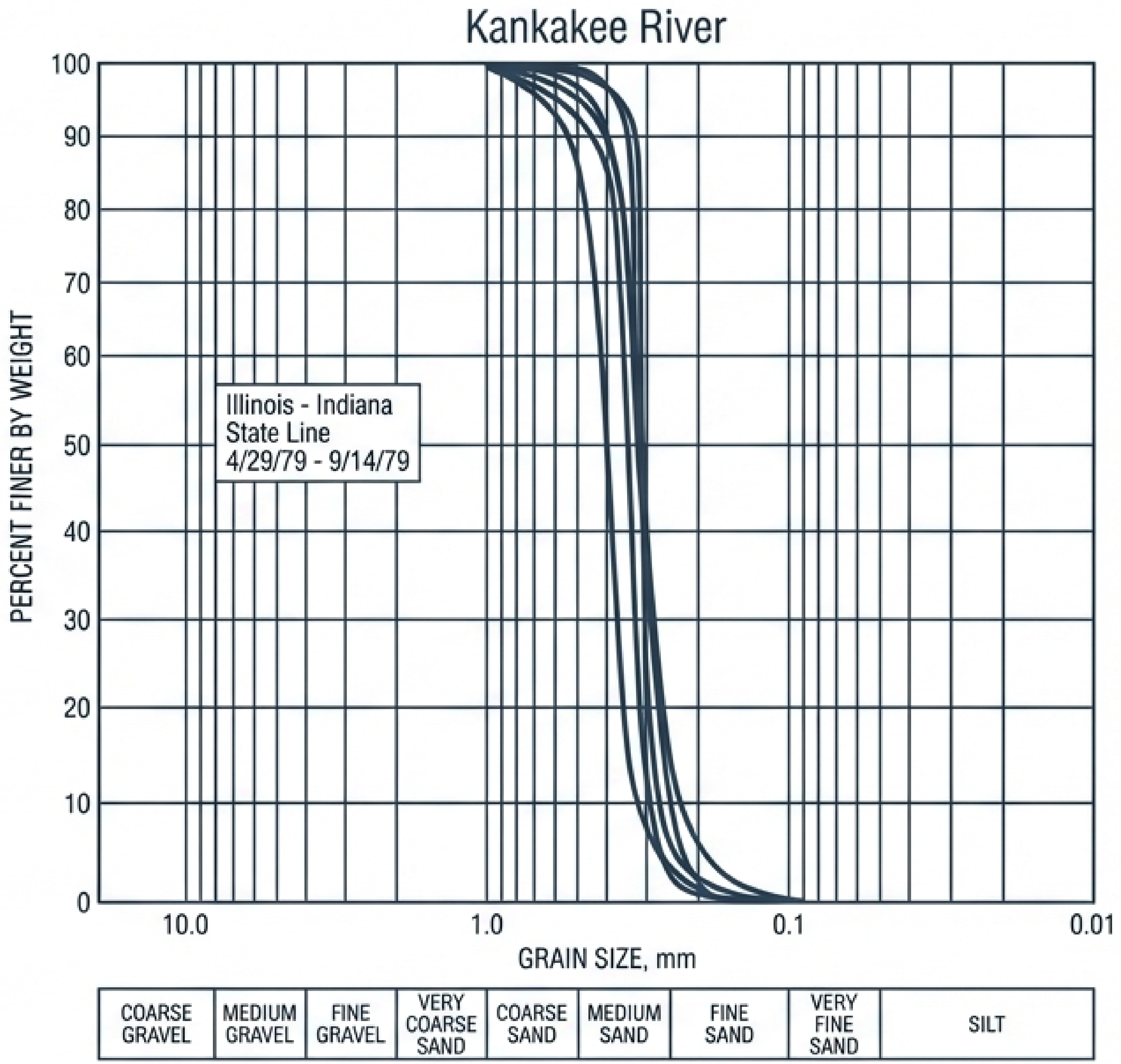
$\sigma_g > 1.6$: Poorly Sorted

When Nature Deviates from Normal

Real-world data often breaks the rules. Natural river sediments, like these samples from the Kankakee River, frequently deviate from the idealized log-normal shape.

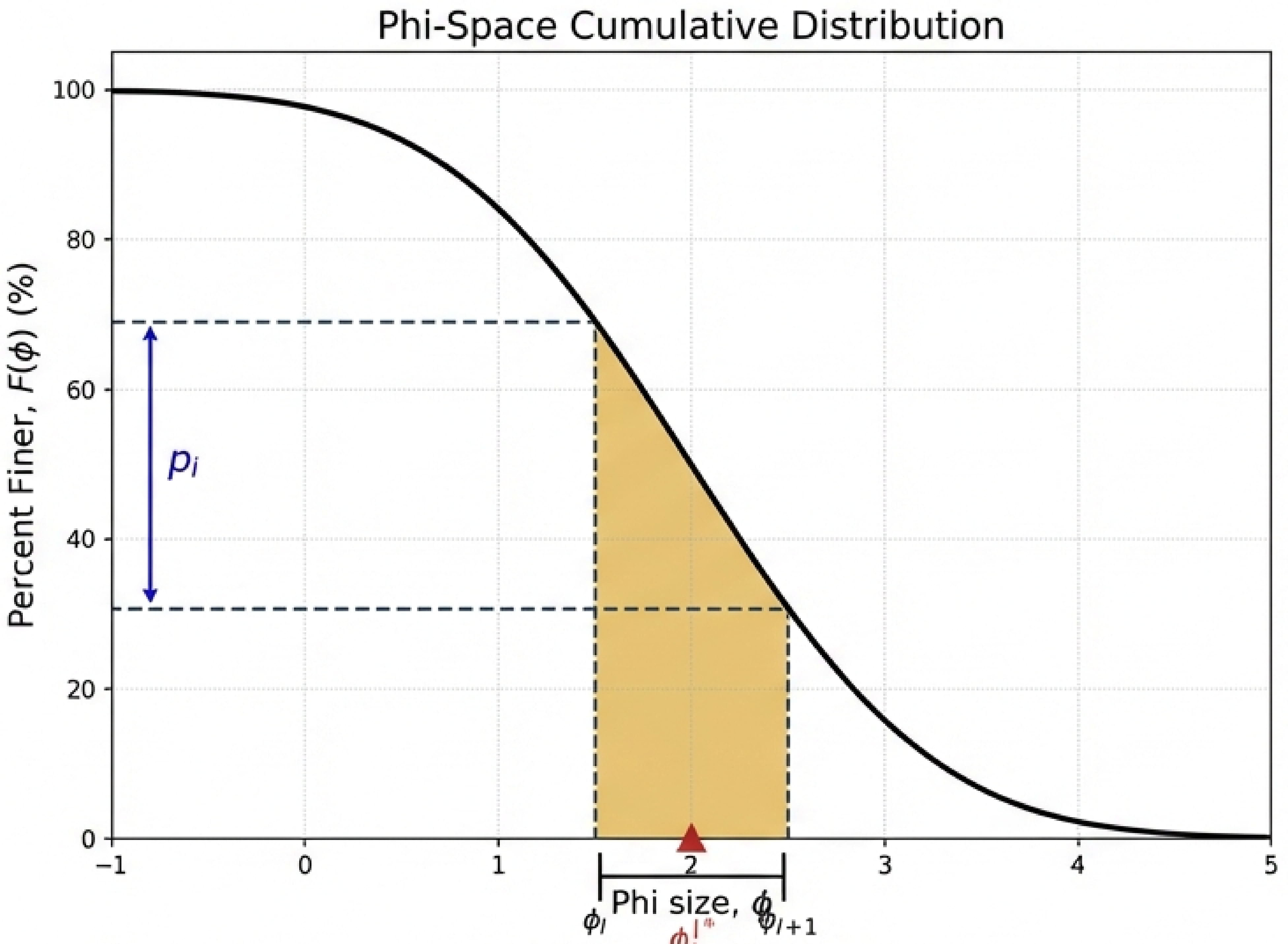
The Problem: Using simple 2-point formulas (d16, d84) on these complex curves leads to calculation errors.

The Solution: We must calculate statistics using the complete cumulative distribution in Phi Space.



Phi-Space Statistical Methodology

Discretizing the curve for robust calculation.



Step 1: Determine Class Midpoint

$$\phi_i^* = \frac{\phi_i + \phi_{i+1}}{2}$$

Step 2: Determine Class Fraction

$$p_i = F(\phi_i) - F(\phi_{i+1})$$

Calculating Moments: Mean and Variance

Once the distribution is discretized, we compute the moments of the distribution:

The First Moment (Mean)

$$\bar{\varphi} = \sum (\varphi_i^* \; p_i)$$

(Description: The center of gravity of the distribution in Phi space.)

The Second Moment (Variance)

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

(Description: The spread or width of the distribution.)

Back-Transformation to Physical Parameters

Transport formulas (like Soulsby's) operate in physical dimensions, not Phi space. We must convert the robust statistical moments back into millimeters.

Phi Statistics
$(\overline{\varphi}, \sigma_\phi)$

→

Physical Inputs
(d_g, σ_g)

Geometric Mean Diameter:

$$d_g = 2^{-\overline{\phi}}$$

Geometric Standard Deviation:

$$\sigma_g = 2^{\sigma\phi}$$

These derived values are the most accurate inputs for modeling initiation of motion and transport rates in non-uniform sediments.

Summary: From Particles to Parameters

1. **Foundational Inputs**: Sediment properties (Density, Porosity, Size) are the control variables for all hydrodynamic behavior.
2. **Logarithmic Nature**: Grain size statistics require logarithmic treatment (Phi scale) to effectively handle the vast range of natural sizes.
3. **Robust Integration**: While ideal sediments allow for simple geometric formulas, natural sediments often require full integration in Phi space.
4. **Standardization**: The Soulsby-style notation and parameters derived here (d_g, σ_g, R) ensure consistency across modern transport models.