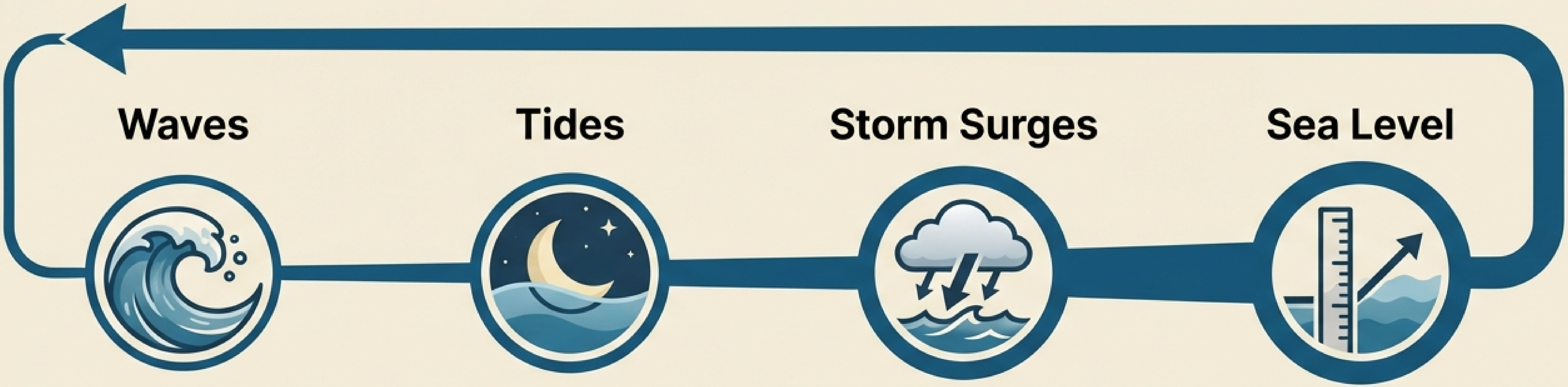
The Restless Edge: Dynamics of Coastal Processes

From Hydrodynamic Forces to Morphological Evolution

Coastal processes determine how coasts erode, accrete, and evolve. This presentation explores the physical mechanisms shaping the nearshore environment, framing the coast as a system constantly seeking equilibrium between destructive forces and resistant materials.

The Hierarchy of Hydrodynamic Forces



Waves

Seconds to Days

Primary Driver.
Wind-generated.
Key transformations:
Refraction, Shoaling,
Breaking.

Tides

Hours

Gravitational
background rhythm.
Semidiurnal, diurnal,
mixed cycles.

Storm Surges

Days

Extreme events.
Driven by wind stress
+ pressure drops.

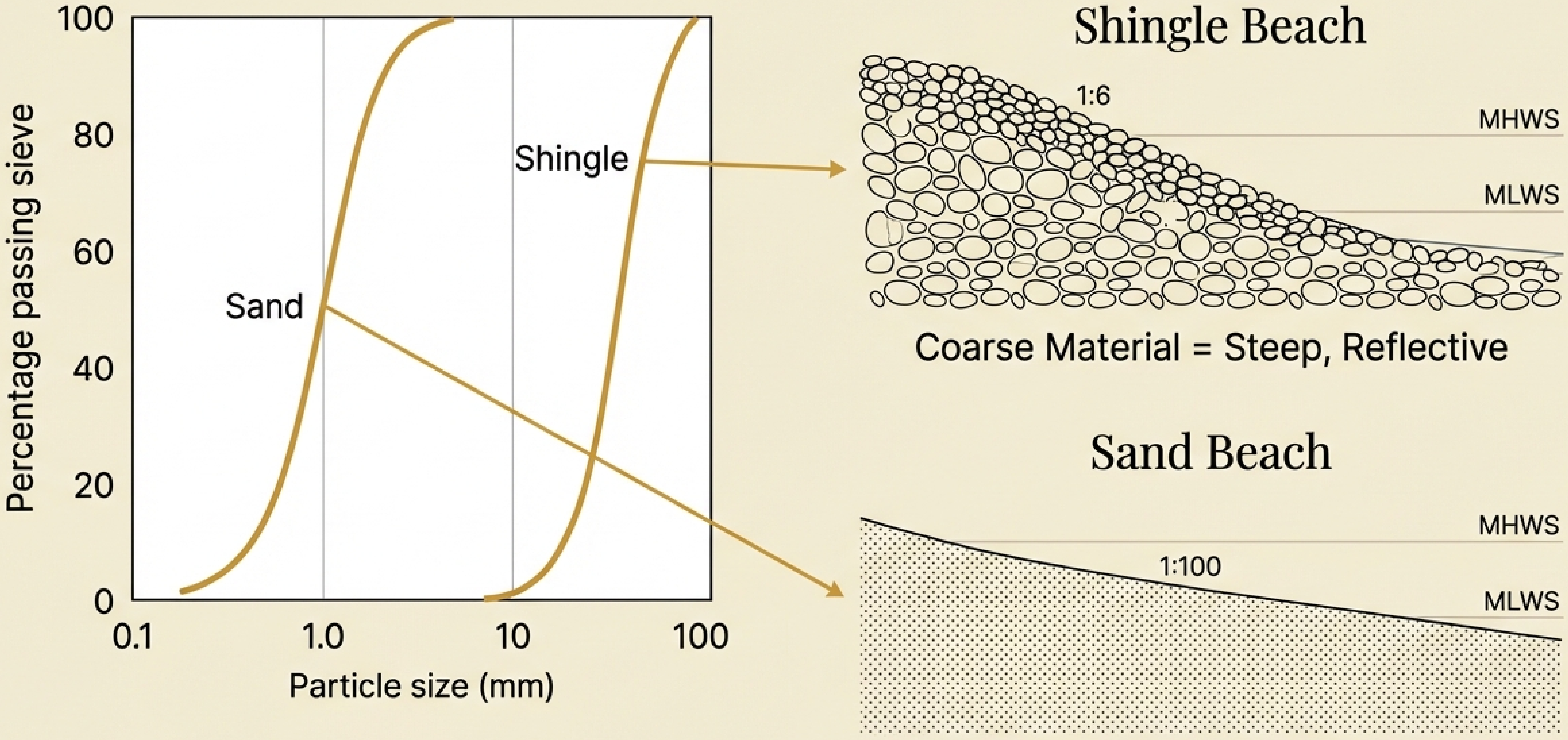
Sea Level

Centuries

Long-term trend.
Affects retreat and
inundation.

> **Key Takeaway:** While energy input varies across timescales, waves act as the primary daily engine of sediment transport.

Material Properties Dictate Coastal Form

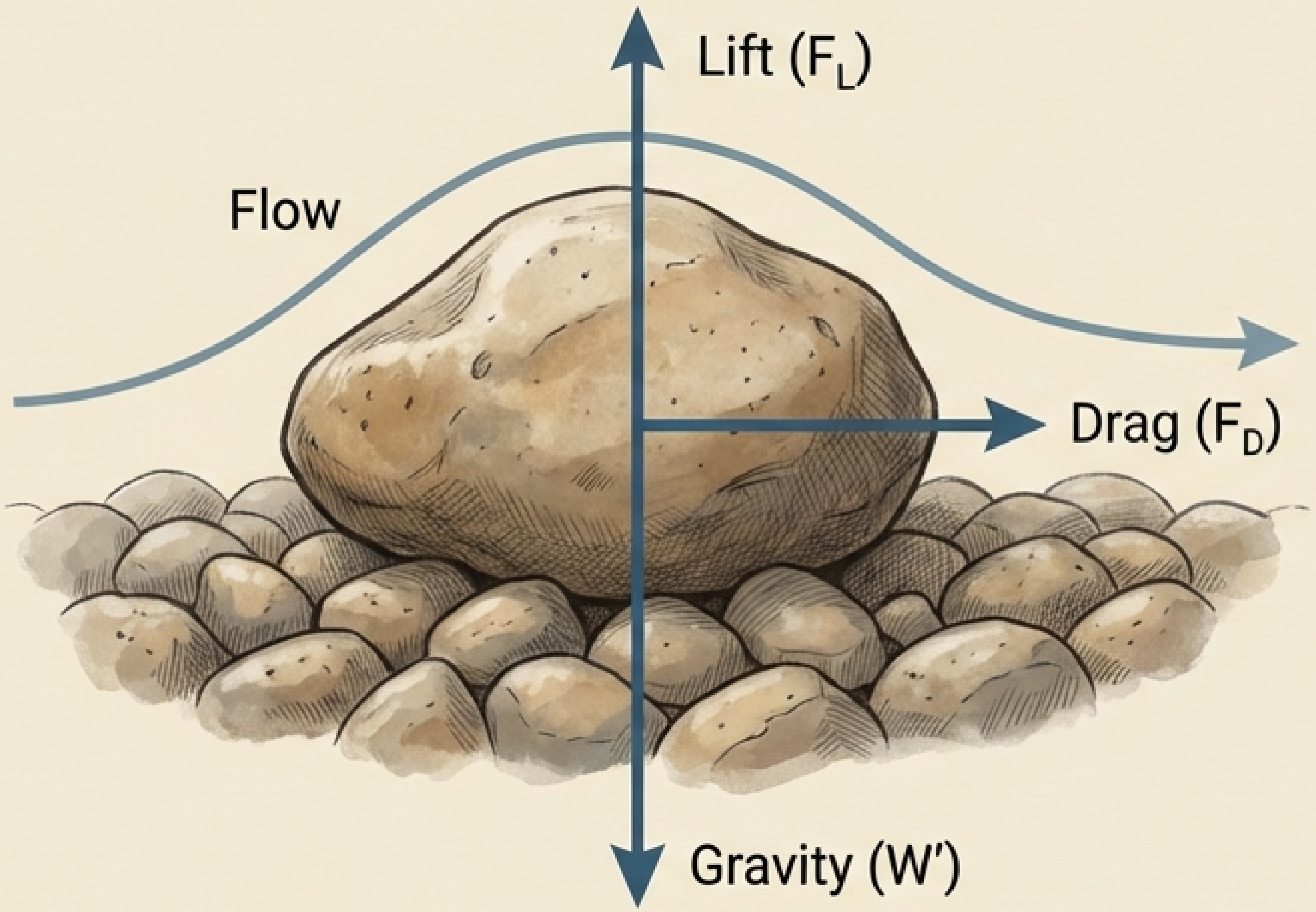


$$\Phi = -\log_2(D)$$

Key Insight: The beach slope is a direct direct function of the sediment type (D_{50}).

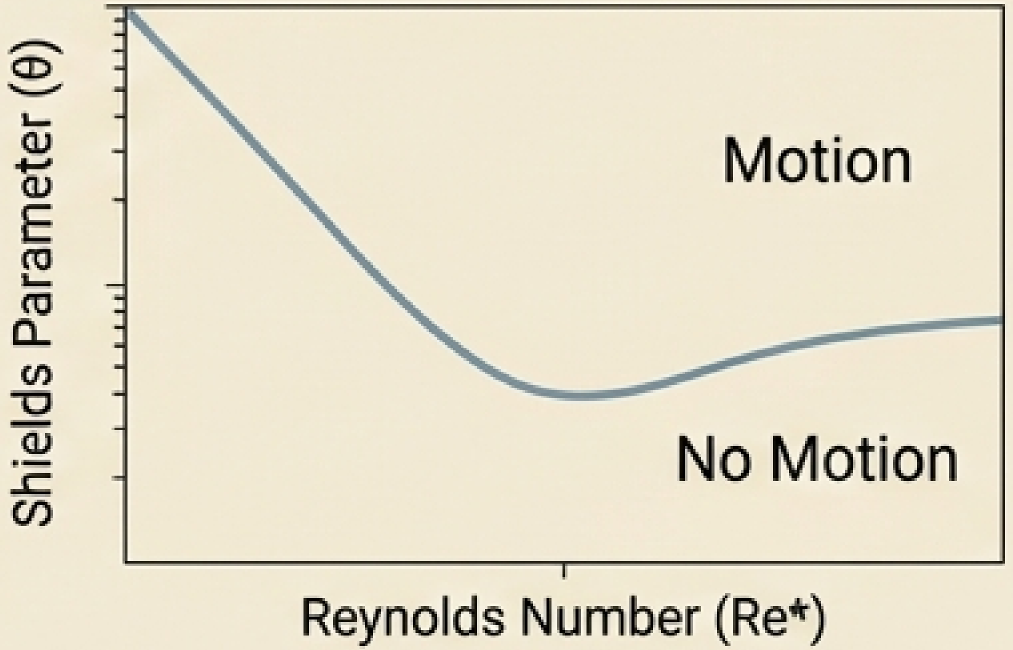
The Threshold of Motion

The Physics of the Spark



$$\tau_c = \theta_c(\rho_s - \rho)gD$$

Translation: Sediment moves only when the bed shear stress (τ) exerted by the water exceeds the critical value (τ_c). **Essentially:** Does the water push harder than the grain weighs?

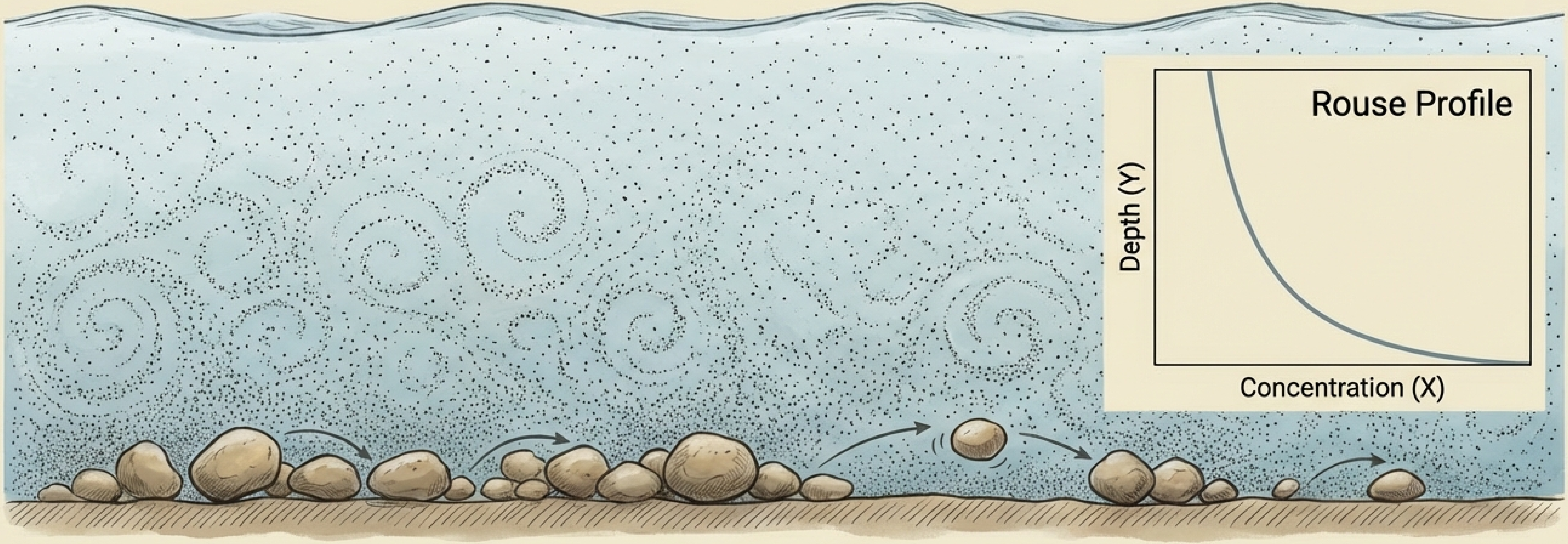


Modes of Transport: Bed Load vs. Suspended Load

Suspended Load (Q_s)

Turbulence-supported. Concentration decreases with height.

Total Load $Q_t = Q_b + Q_s$

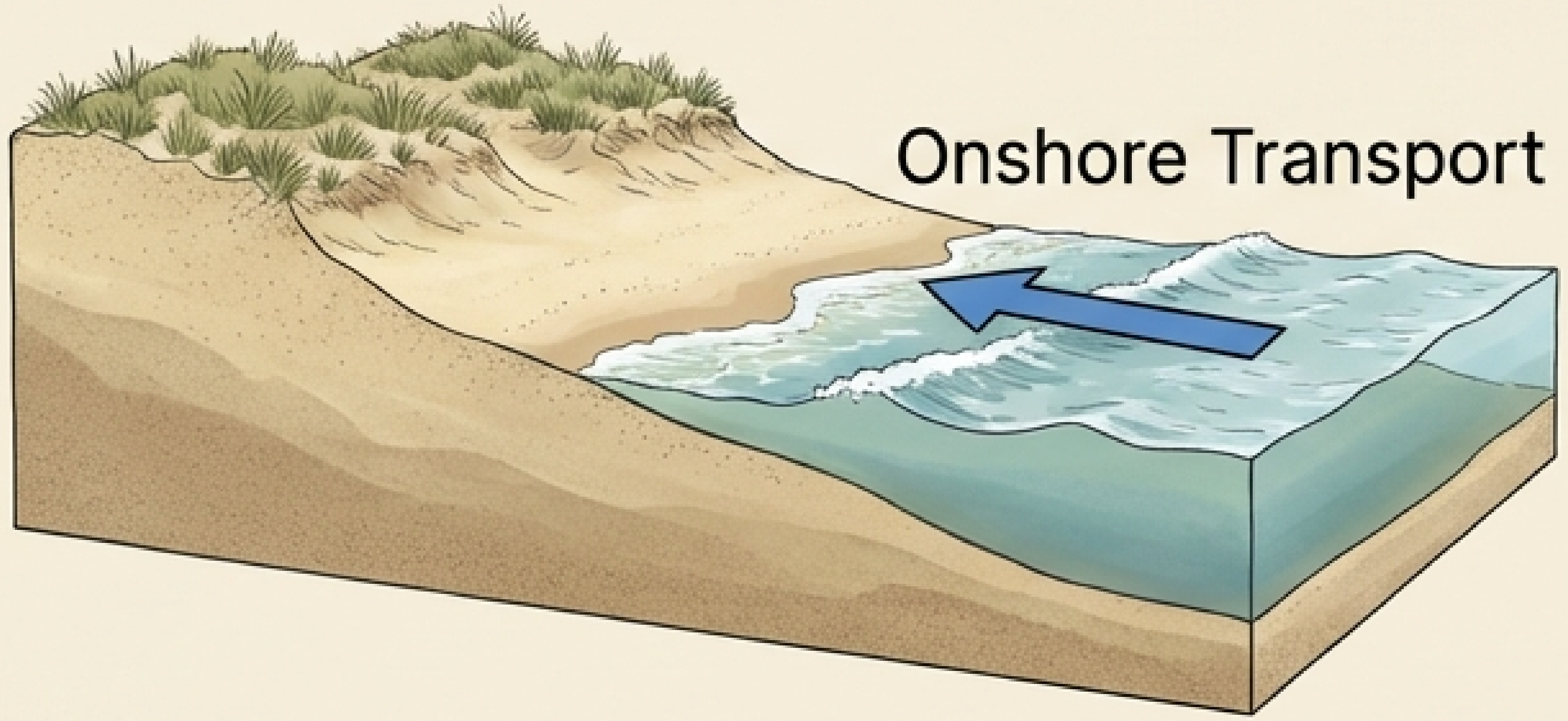


Bed Load (Q_b)

Rolling/sliding friction. Governed by shear stress.

The Breathing Coast: Cross-Shore Dynamics

Fair-Weather / Summer Profile



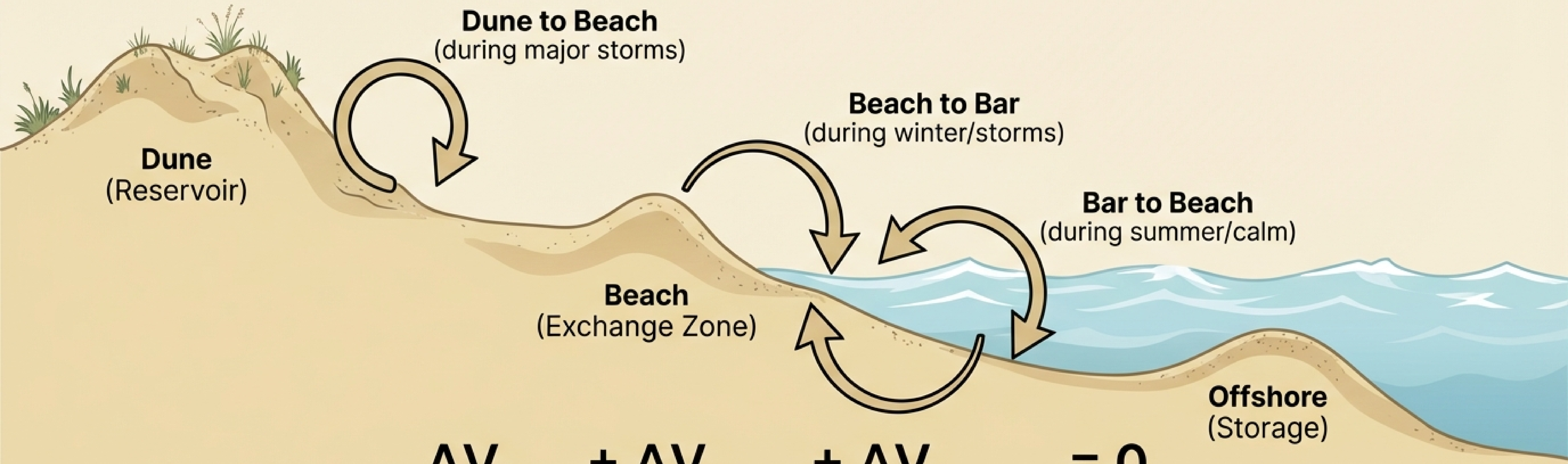
Wave Asymmetry moves sand onshore. Constructive phase.

Storm / Winter Profile

Undertow and turbulence move sand offshore. Destructive phase.

Key Insight: The beach isn't disappearing; it is redistributing. The offshore bar is a temporary storage locker for beach sand.

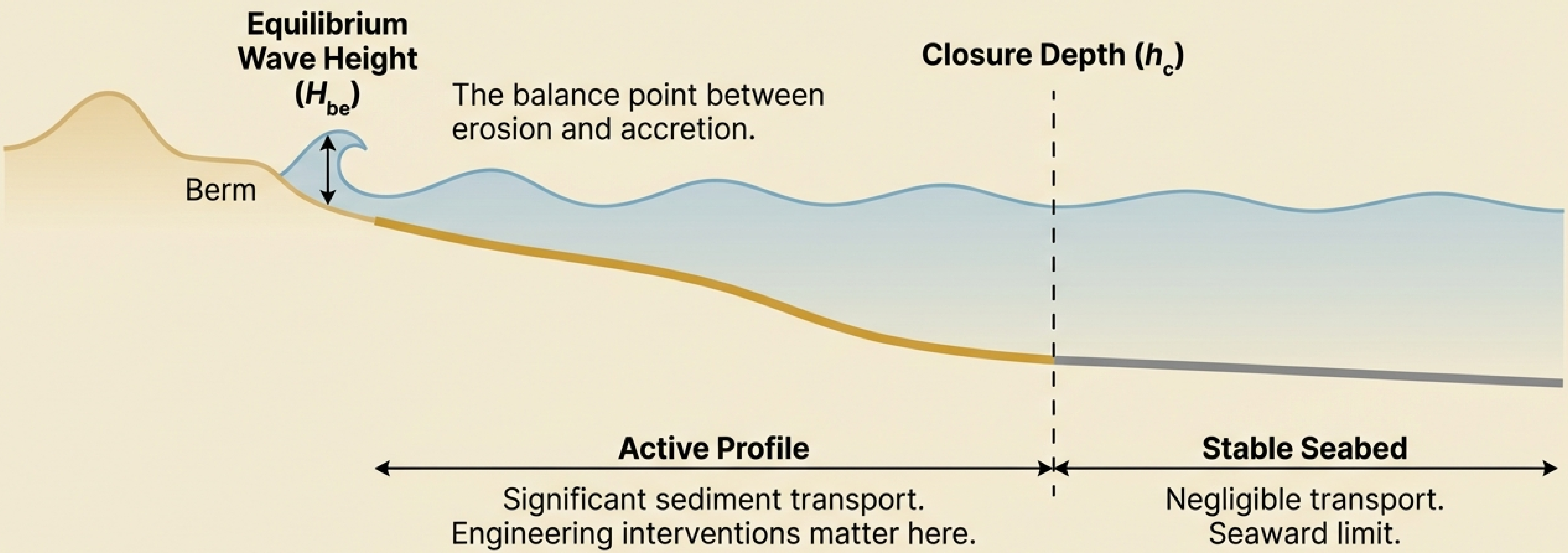
The Closed System: Dune, Beach, and Offshore



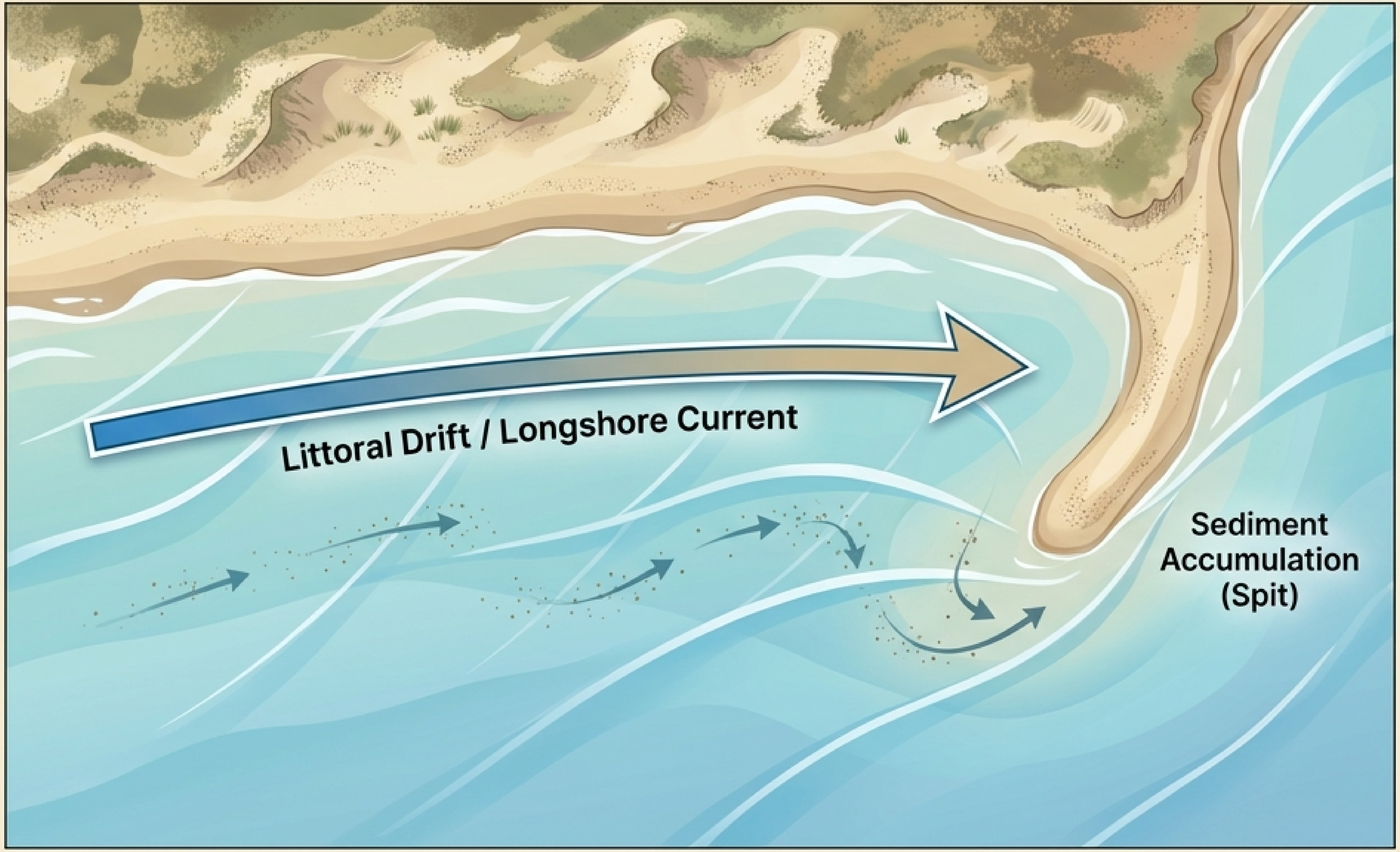
$$\Delta V_{dune} + \Delta V_{beach} + \Delta V_{offshore} = 0$$

Matter is neither created nor destroyed. A loss in the dune must equal a gain in the offshore bar.

Defining the Limits: Equilibrium and Closure



The River of Sand: Longshore Transport



$$Q \propto H_b^{2.5} \sin(2\alpha_b)$$

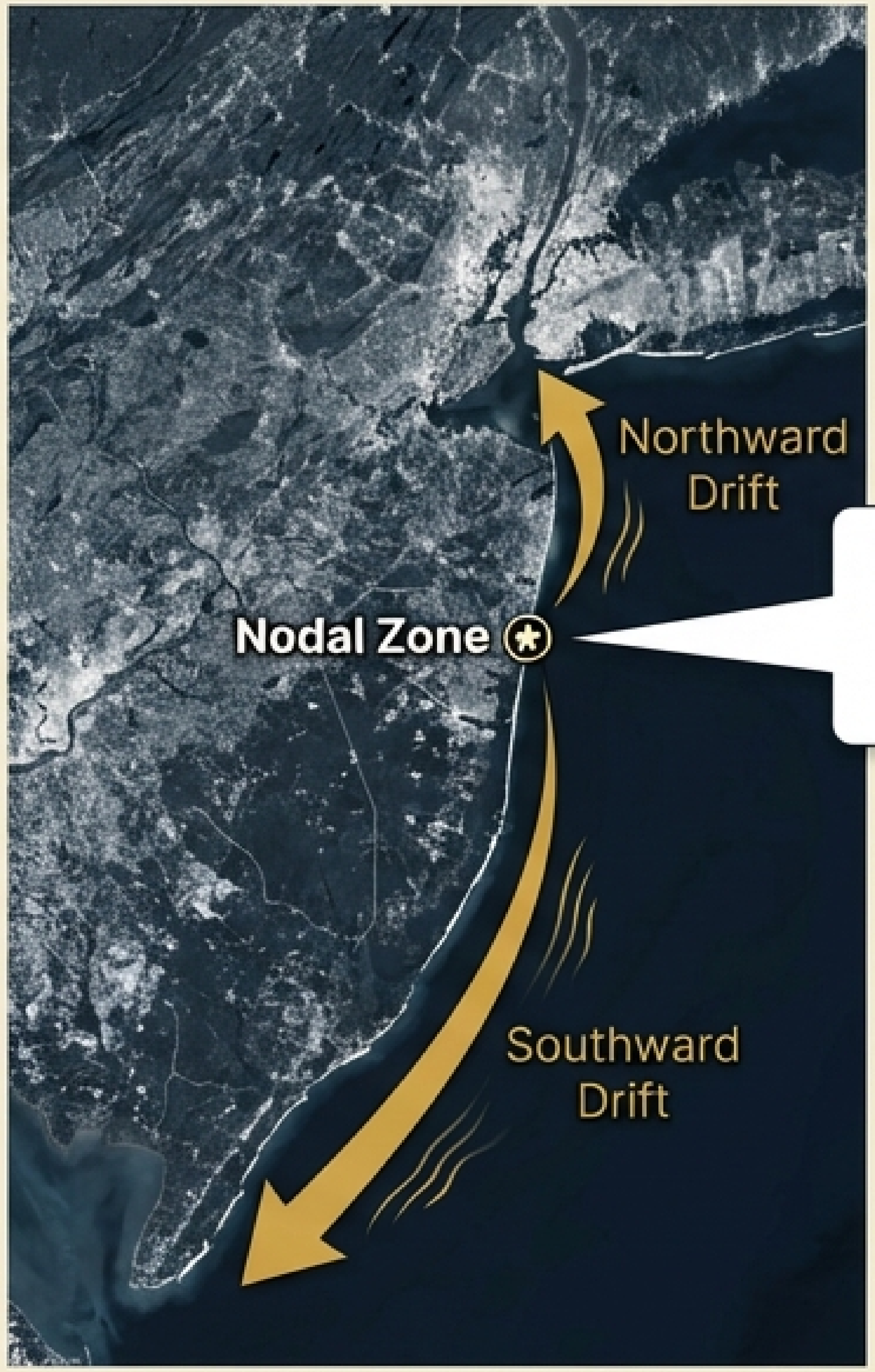
H_b = Breaker Height
α_b = Breaker Angle

Mechanism: Oblique breaking waves generate a continuous current that acts like a conveyor belt, moving vast quantities of sand along the coast. This process is quantified by the transport rate equation, where sediment transport Q is proportional to the breaker height and the sine of twice the breaker angle.

Comparing Transport Regimes

	Longshore Transport	**Cross-Shore Transport**
Driver	Wave energy flux alongshore (Steady)	Oscillatory flow & wave breaking (Time-varying)
Direction	One-way (Net Littoral Drift)	Two-way (Onshore/Offshore "Breathing")
Resulting Feature	Spits, Inlets, Barrier elongation	Bars, Berms, Dune scarps
Modeling	Easier to predict (CERC formula)	Difficult, non-linear, event-dependent

Case Study: New Jersey's Nodal Zone

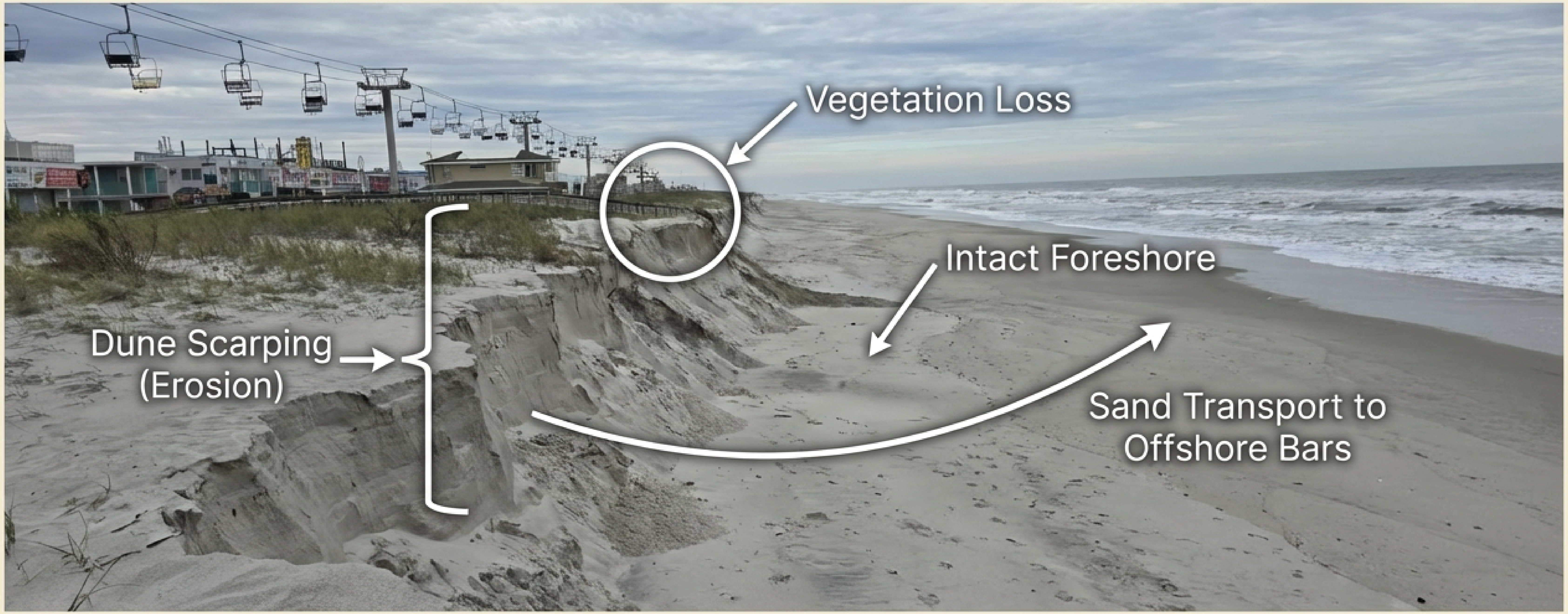


The Parting of the Waters. Divergence caused by wave refraction and inlet shoals.

North NJ: Groins trap sand on their South side.

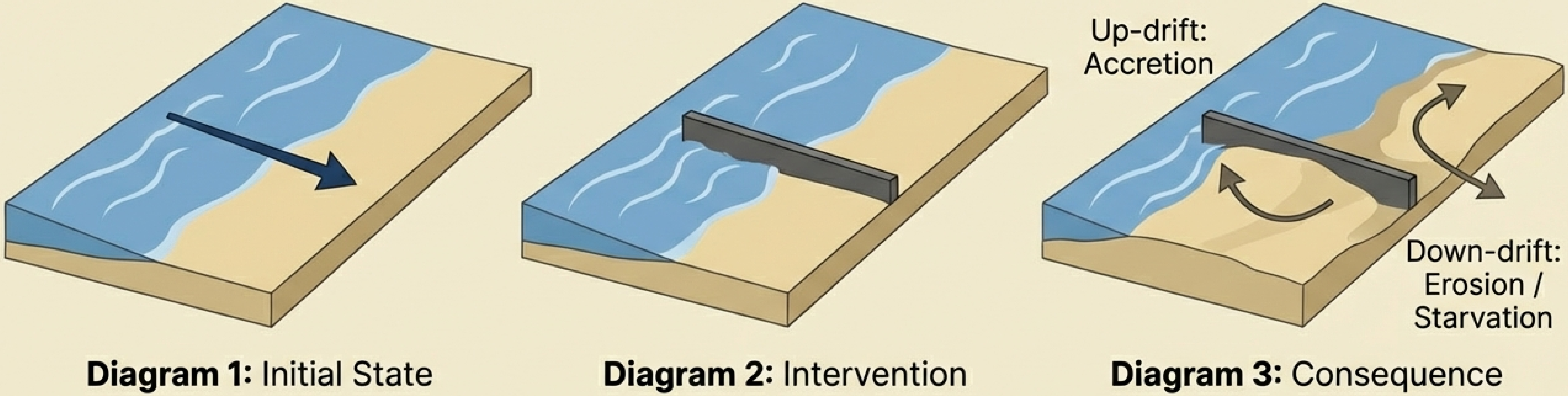
South NJ: Sand moves toward Delaware Bay.

Event Analysis: Seaside Heights, October 2025



Process: High wave runup attacked the dune base. The sand was not lost, but relocated to the nearshore bar system to dissipate wave energy.

Human Influence and Morphodynamics



The **Feedback Loop**: Morphology changes waves → Waves change morphology.

Hard Structures: Groins, Jetties, Seawalls
Soft Engineering: Dredging, Nourishment

Essential Mathematical Relationships

Phi Scale (Grain Size)

$$\Phi = -\log_2(D)$$

Shields Parameter (Threshold of Motion)

$$\tau_c = \theta_c(\rho_s - \rho)gD$$

Sediment Budget (Conservation of Mass)

$$\Delta V_{\text{dune}} + \Delta V_{\text{beach}} + \Delta V_{\text{offshore}} = 0$$

Longshore Transport Rate (CERC)

$$Q \propto H_b^{2.5} \sin(2\alpha_b)$$

Settling Velocity (for coarse sand)

$$w_s = \sqrt{(s-1)gD}$$

s = specific gravity, g = gravity, D = diameter, H = wave height

Achieving Dynamic Equilibrium

Coastal stability is not stillness; it is a state of dynamic exchange. Understanding the balance of Energy, Sediment, and Morphology allows us to design with the cycle of nature, rather than against it.