

Presentations

4-15-2011

Lecture 9: Morphodynamics of coastal systems

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Colin Woodroffe (2002) "Coasts: Form, Process and Evolution", Outline of Chapter 9:

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NOTE – No "Historical Perspective" Section

Only 40 pages total (vs. 72 for Beaches/Barriers), 11 figures (vs. 32 for Beaches/Barriers)

Chapter 9 Morphodynamics of coastal systems

Opens with quote from Gilbert (1885) (p.435):

In order that a particular portion of shore shall be the scene of littoral transportation, it is essential, first, that there be a supply of shore drift; second, that there be shore action by waves and currents; and in order that the local process be transportation simply, and involve neither erosion nor deposition, a certain equilibrium must exist between the quantity of the shore drift on the one hand and the power of the waves and currents on the other. On the whole this equilibrium is a delicate one, but within certain narrow limits it is stable. That is to say, there are certain slight variations of the individual conditions of equilibrium, which disturb the equilibrium only in a manner tending to its immediate readjustment. For example, if the shore drift receives locally a small increment from stream drift, this increment, by adding to the shore contour, encroaches on the margin of the littoral current and produces a local acceleration, which acceleration leads to the removal of the obstruction. Similarly, if from some temporary cause there is a local defect of shore drift, the resulting indentation of the shore contour slackens the littoral current and causes deposition, whereby the equilibrium is restored. (Gilbert, 1885)

9.1. Models in Coastal Geomorphology, 9.1.1. Models and Hypothesis Generation

“Models include physical models, conceptual models and computer models. They are not predictors of future conditions, but are frameworks within which various scenarios can be simulated and hypotheses tested.”

“The best models are simple models that ignore much of the detail of individual systems, but embody most of the variation that is observed... A model is particularly useful if it suggests hypotheses that can then be tested.”

“It is often the case that models can be manipulated to produce almost any behaviour, and the validity of the assumptions and hypotheses on which a model is based must be continually and rigorously reassessed.”

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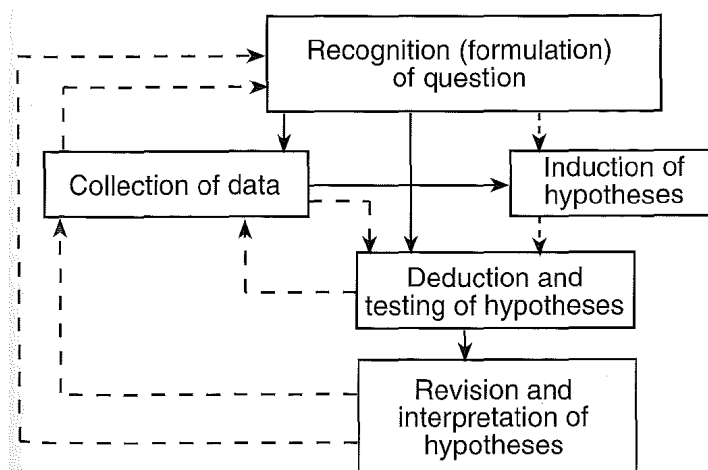
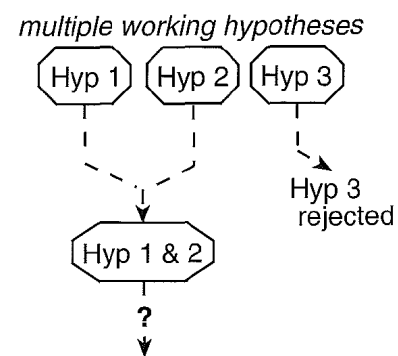


Figure 9.1. Generation and testing of hypotheses and



Scientific method:

- (i) Recognition/formulation of question, (ii) Collection of data, (iii) Induction of hypotheses,
- (iv) Deduction and testing of original hypotheses, (v) revision and interpretation of hypotheses.

Note – above path recognizes that research can start with a question rather than a hypothesis. The initial step can be “discovery-driven” rather than “hypothesis-driven” science.

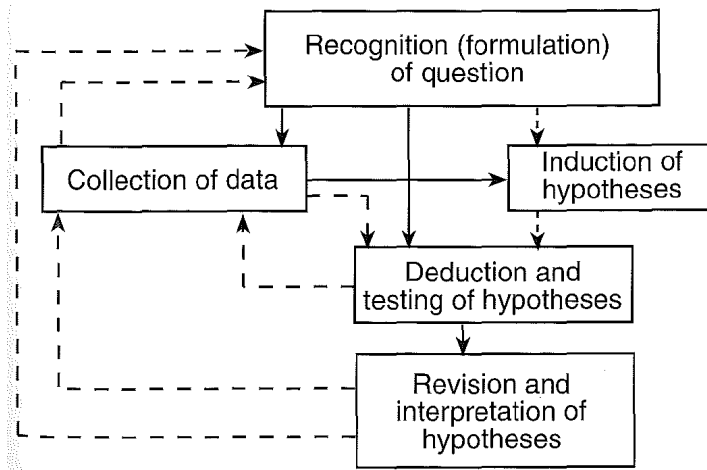
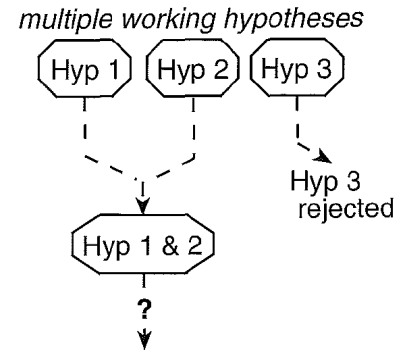


Figure 9.1. Generation and testing of hypotheses and refinement of multiple working hypotheses.



A single “ruling hypothesis” is sensitive to bias that may lead to collection of only confirming data (Gilbert, 1886).

Multiple working hypotheses enable more objective evaluation. Scientific knowledge expands by identifying and dismissing incorrect hypotheses (falsification).

Often more than one competing hypotheses remain which can’t (yet) be disproven. Or different hypotheses work better for slightly different scenarios. (e.g., Holocene sea level.)

9.1.2. Types of Models

A model is a framework within which relationships between variables can be represented.

Descriptive model – sensible recognition based on an association of anecdotal observations (e.g., “flat beaches have larger waves”). Large, unquantified uncertainty. Not very predictive beyond a trend. Does not explain underlying relationship.

Empirical model – quantitative relationship statistically based on many observations (e.g., observed value of average beach steepness as a function of sand grain size). Predictive with statistically derived uncertainty. Still does not explain underlying relationship.

Theoretical model – quantitative relationship or trend derived from theoretically expected behavior of a system (e.g., theoretical rate water should percolate through a beach as function of beach steepness based on hydrology). Provides insight into underlying relationship. May or may not be more predictive than an empirical model.

Conceptual model – based on logical, often intuitive relationships between variables (e.g., Darwin’s model for atoll formation). Often based on sophisticated understanding of system behavior. But generally not quantitatively predictive beyond general trends unless combined with theoretical and/or empirical models.

9.1.2. Types of Models (cont.)

Physical model – scaled representation of a system (e.g., wave tank). Scaling issues can be a major limitation (e.g., can small lab waves represent large ocean waves?).

Computational model – (a) mathematical (or “analytical”) model based on equations, (b) logical (or “behavioral”) model based on heuristic rules, (c) computer (or “computational”) model based requiring intensive calculations to provide significant insight.

Sensitivity analysis – holding some variables constant while changing others in a quantitative model to explore the response of system to an isolated change.

Model uncertainty – no model can precisely predict future outcomes. All model predictions have associated uncertainties/probabilities, although sometimes they are hard to define.

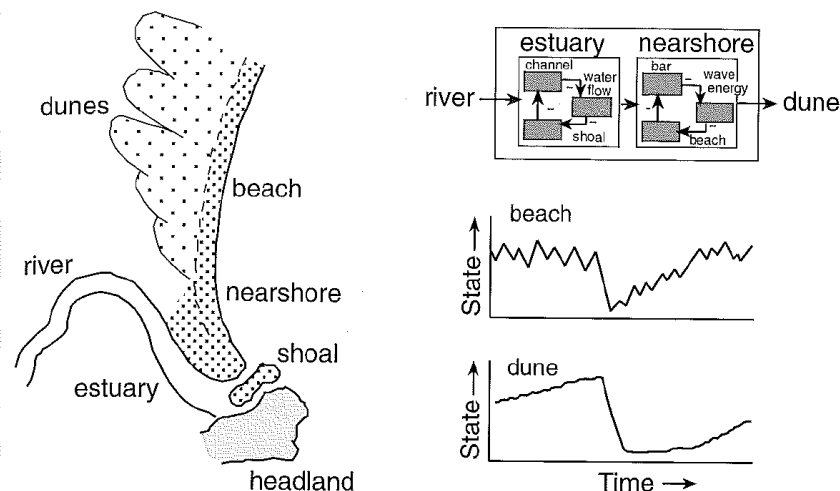
Static models – most parameters are fixed in time (e.g., short-term sed transport model).

Dynamic models – feedbacks are possible (e.g., morphodynamic model)

Lumped vs. distributed parameter models (e.g., box model vs. 3D model)

Deterministic vs. stochastic model (e.g., Newtonian vs. quantum mechanics)

9.2. Coastal Systems – “The complexity of coastal systems makes complete descriptions difficult and accurate predictions improbable.”



-- Beach and dune are subsystems within example coastal system.

-- During fair weather they evolve separately (linearly, decoupled).

-- During/immediately after storm they evolve together (non-linearly coupled w/feedbacks).

-- Reductionist approach could work during fair weather.

-- Holistic morphodynamic approach (with non-linear feedbacks) required to address change of states in response to storms.

Figure 9.2. Subsystems within a coastal system can be interrelated but operate at different time scales in response to forcing events. In this example a schematic coastal embayment, like that shown in Figure 1.11, is shown. The beach and dune are likely to respond differently. They may be closely coupled in response to an extreme event, such as a storm that erodes both the beach and the dune. However, at other times they appear to be decoupled and operate in response to different factors; the beach responds to incident wave energy, whereas the dune responds to wind winnowing of the subaerial beach.

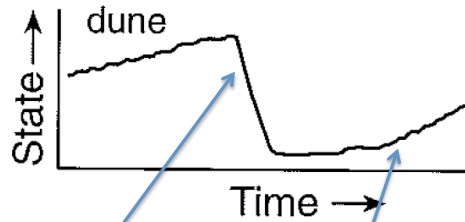
9.2.1. Feedbacks and Thresholds

Negative feedback – Perturbations are damped, returning system to previous condition.

Positive feedback – Perturbations grow, moving system away from previous condition.

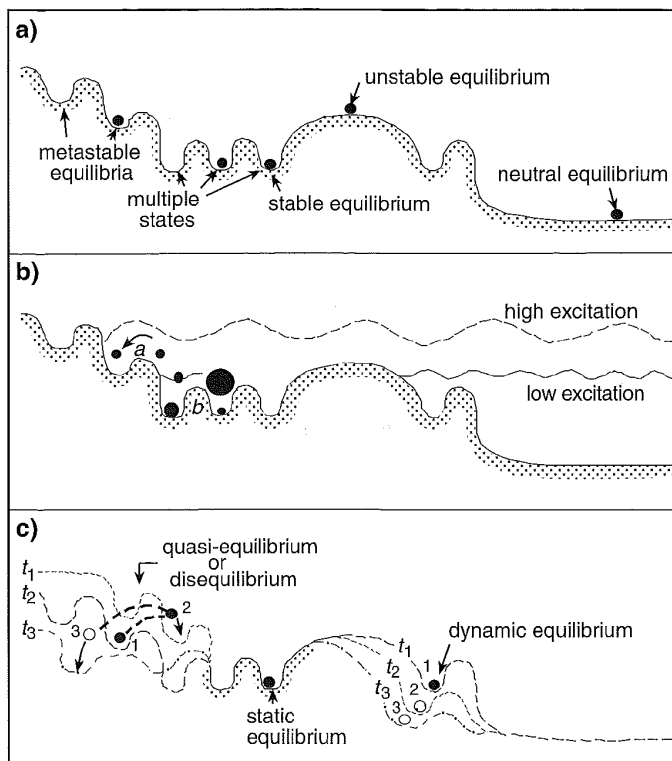
Threshold – Critical response level for a system at which system jumps rapidly to a distinctly different state (markedly different from previous condition). E.g., critical stress for sediment erosion or suspension, overbank flow in the flooding of a marsh.

Self-organization – response of a system to exceeding of internal thresholds, leading to highly non-linear changes in state which are not strongly coupled to external forcing.



Threshold exceeded due to external forcing.

Threshold exceeded due to self-organization.



9.2.2. Equilibrium – Figure 9.3(a)-(b) analogy to pebbles in rock pools.

Static equilibrium – state does not change at all over time.

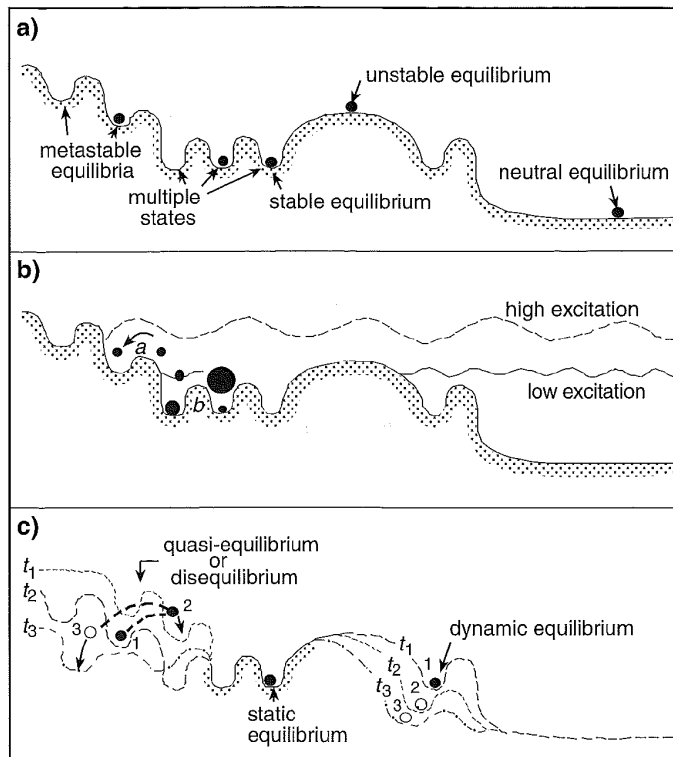
Stable equilibrium – a minor disturbance (e.g., small wave) will not significantly change state and system returns to previous condition via negative feedback.

Unstable equilibrium – a minor disturbance will move system (e.g., pebble on top of round rock) via positive feedback to different, eventually more stable state.

Multiple states – several states with similar thresholds for stability (e.g., neighboring rock pools).

Metastable equilibrium – a major disturbance can place system in a new state that is only rarely seen after major events (e.g., pebble in perched pool).

Figure 9.3. Schematic representation of the concept of equilibrium. The system may be thought of as a series of rock pools within which pebbles adjust to equilibrium, or as a pinball table (see text for discussion).



9.2.2. Dynamic Equilibrium – Figure 9.3(c)

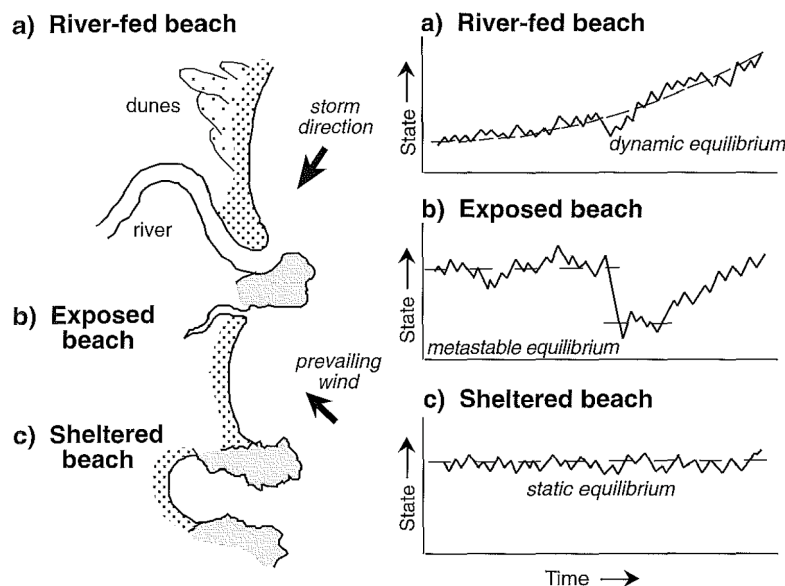
Dynamic equilibrium -- the available equilibrium states change with time as a function of the external boundary conditions.

Pebble example is that the pools are no longer carved in rock but in sediment instead. The troughs and crests are bedforms, and the pebble can move from one trough to another in response to “events”.

But the locations of the crests and troughs (the dynamic equilibria) also slowly change in time.

Quasi-equilibrium – Large scale morphology evolves slowly, and is often “catching up” with changing forcing, and final equilibrium may not be reached.

Figure 9.3. Schematic representation of the concept of equilibrium. The system may be thought of as a series of rock pools within which pebbles adjust to equilibrium, or as a pinball table (see text for discussion).



Equilibrium also depends on scale and energy regime:

Large (buffered), high energy, systems may continually evolve slowly, leading to dynamic or quasi-equilibrium.

Small, high energy systems are more likely to jump between metastable states.

Small-scale, low energy systems are more likely to be in static equilibrium for extended periods.

Figure 9.4. Three different beaches exhibiting three different types of equilibrium. (a) The river-fed beach receives new sediment from the river and it shows a long-term dynamic equilibrium with increase in volume. (b) The exposed beach varies from accreted to eroded, as the result of storm cut; these alternative states represent a metastable equilibrium. (c) The sheltered beach is not disturbed by major storms and does not receive new sediment; it is in a static equilibrium.

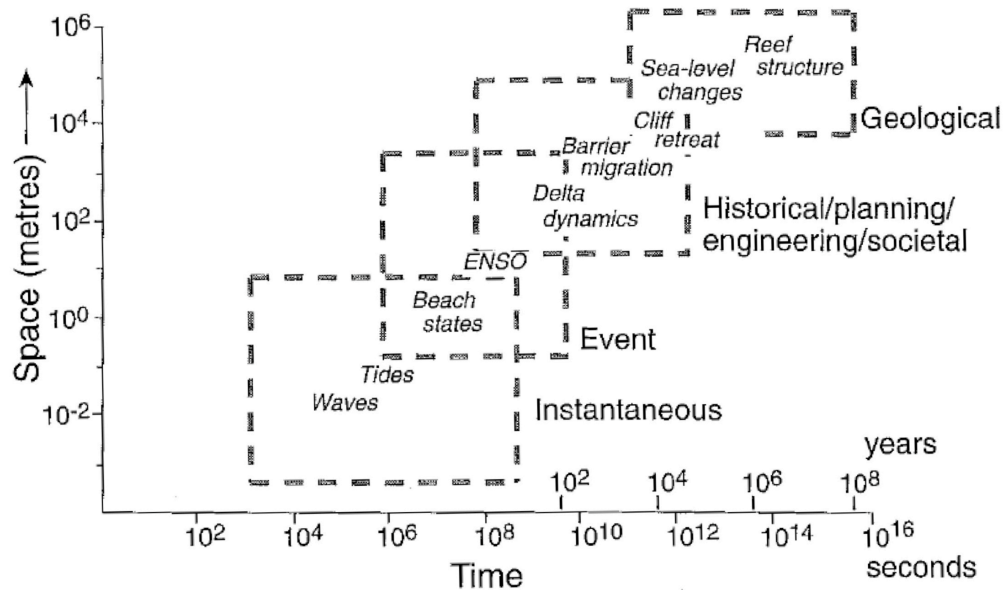


Figure 1.9. The representation of space and time scales appropriate for the study of coastal morphodynamics and the schematic representation of examples of coastal systems or patterns of variation and their general position in terms of space–time scales (based on Cowell and Thom, 1994).

9.3.1. Inheritance, Convergence and Polygenetic Landforms

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Inheritance – “The unerasable and determining signature of history”. Past events are unique. Thus evolution in response to known present forcing may still vary as a function of early conditions, from previous morphodynamic states (“hysteresis”) to antecedent geology.

Convergence/Polygenetic Landforms – When similar coastal landforms result from operation of different sets of processes or sequence of events. (e.g., sand-peat-sand can be due to large scale sea level fluctuations or local tectonics).

Divergence – Highly non-linear or chaotic behavior can cause different outcomes from very external similar forcing conditions. (e.g., the “butterfly effect”).

9.3.2. Response to Changes Over Time

Perturbation – Sudden small or large change in some independent factor affecting a system state.

Reaction Time – Time over which the perturbation occurs and the disequilibrium – relative to longer-term conditions -- morphology forms.

Relaxation/Recovery Time – Time for system to reach equilibrium again after a perturbation.

a) Event sequencing

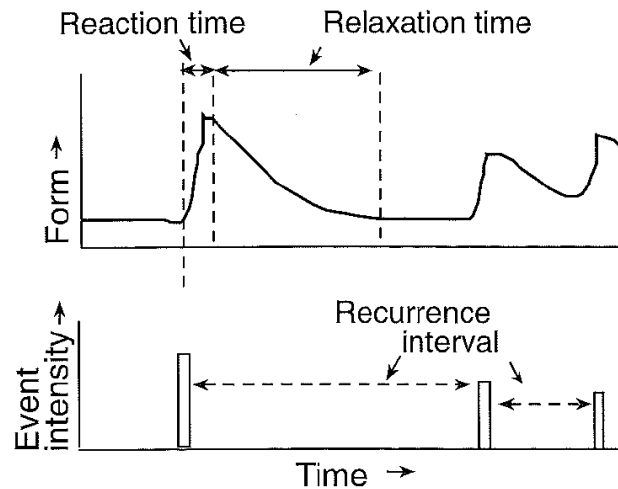


Figure 9.6. Change in coastal systems. (a) Response to a perturbation. The sequencing of events is shown in terms of event intensity. Response of coastal form to each event is a function of reaction and relaxation time, and the relationship between this response and recurrence interval.

b) Boundary conditions

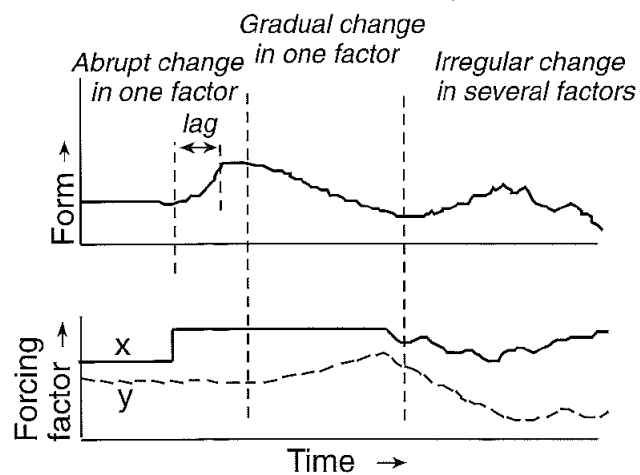
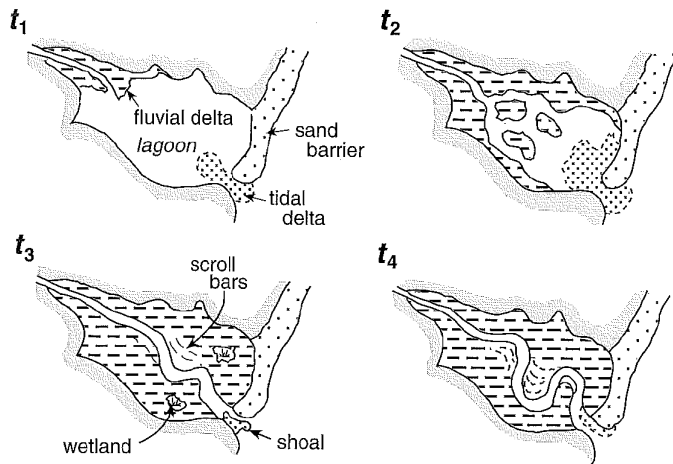


Figure 9.6.

(b) Response to a change of boundary conditions. Response may be lagged or gradual, and where several forcing factors are involved change is likely to be irregular.

Intrinsic Changes – Abrupt adjustments to systems that come about as a result of accumulated change without specific external stimuli.

a) Estuarine stages



b) Estuarine sedimentation

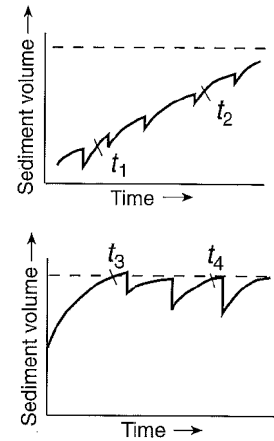


Figure 9.7. Conceptual model of stages of infill of estuarine system on a wave-dominated coast such as southern Australia or southern Africa. During the early phases (t_1 and t_2) the estuary infills progressively in response to fluvial delta progradation and barrier formation and tidal inlet dynamics. The system changes to river domination when the estuarine basin has totally infilled, which is an intrinsic threshold. In the later river-dominated phases (t_3 and t_4), the system ceases to accumulate more sediment, but is cyclical, characterised by channel mobility with sediment bypassing, and phases of erosion associated with large flood events (based on Cooper, 1993; Cooper *et al.*, 1999b).

9.3.3. The Role of Extreme Events

“Mega-events” are too extreme for morphodynamic processes to “relax”, e.g., tsunamis, rapid uplift or landsliding from an earthquake, rapid flooding from a dam release, etc.

Figure 9.8. Boulders scattered across reefs at Agari-Hen’na Cape on the eastern side of Miyako Island, southern Ryukyu Islands. These have been attributed to tsunami (photograph T. Kawana).



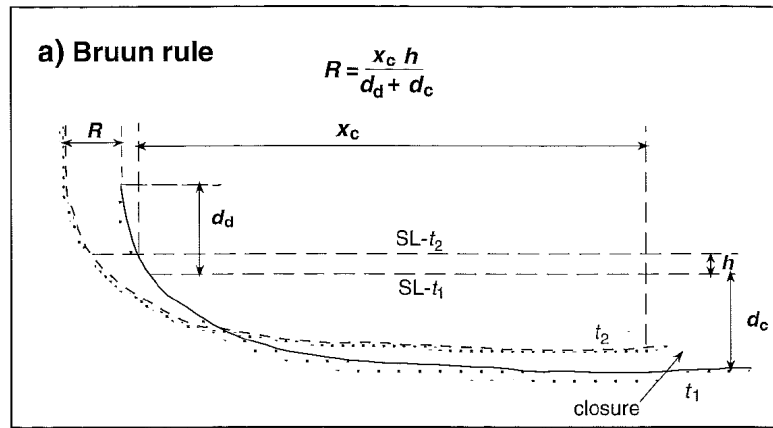
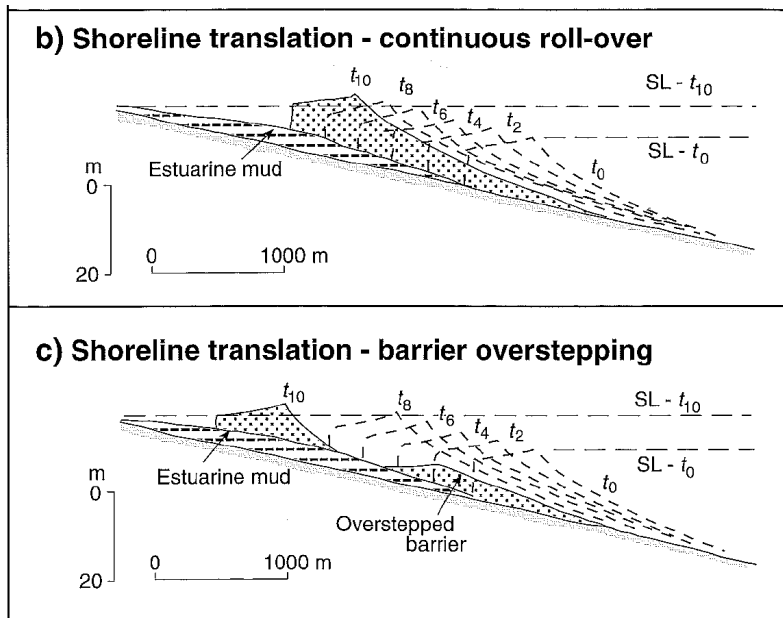


Figure 9.9. Simulation modelling of sandy shoreface response to rising sea-level. (a) The Bruun rule, showing the definition of variables and the response to a rise in sea level.

- Based on conservation of mass (a very solid concept!)
- Assumes an equilibrium shape for the profile during sea level rise/regression (also reasonable)
- Predictions are sensitive to “closure” depth (problem).
- Assumes all offshore transport (problem – barrier rollover involves landward transport)
- Assumes no net convergence/divergence of along-shore transport (potential problem).
- Transport direction and along-shore transport can be dealt with using sources/sinks.
- Closure depth can be dealt with if lower shoreface slopes offshore.



- Based on conservation of mass, including sources and sinks.
- Allows seaward transport For barrier roll-over.
- Sloping lower shoreface solves closure depth problem.
- Can assume an equilibrium shape for the profile during sea level rise/regression.
- Also allows rule-based changes in profile (e.g., barrier overstepping).

Figure 9.9. The shoreline translation model in continuous roll-over mode, and (c) the shoreline translation model in barrier overstepping mode (based on Cowell and Thom, 1994).

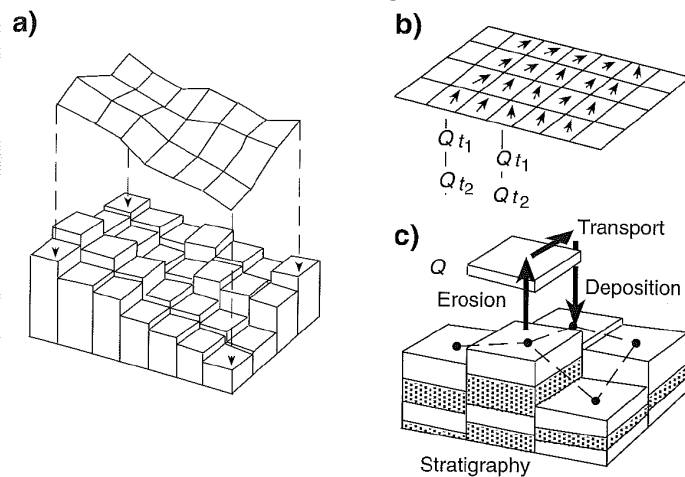


Figure 9.10. Grid cell modelling. (a) Schematic representation of the topography in the coastal zone as a 2-dimensional array of fishnet grid (upper) and 3-dimensional (often termed 2.5D) block diagram (lower). (b) Example of the derivation of subsequent grids, such as vectors for current speed and direction and consequently sediment transport volumes over a series of discrete time steps. (c) Models offer the potential to compute 4-dimensional (or more) arrays, as in this enlargement of several sediment cells, with calculation of erosion, transport, and deposition on a cell-by-cell basis. Where different grain sizes behave differently it may be possible to simulate stratigraphic development through time (based on WAVE/SEDSIM model of Martinez and Harbaugh, 1993).

-- "2.5D" models use 2D x-y hydrodynamics, but track morphological evolution in z

-- "Sediment transport" models keep morphology fixed during hydrodynamic time steps and then update morphology based on predicted deposition/erosion.

-- Dynamic morphological models model bathymetry directly without separate hydrodynamic time-step.

-- Multidimensional morphodynamic models ("large-scale coastal behavior models") are computationally constrained.

(-- Specific multidimensional models mentioned in text, circa 2000 and earlier, are mostly out-of-date today.)