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Morphodynamics and controlling mechanisms of subaqueous crescentic dunes in the western offshore region of Hainan Island

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Introduction

Scale applicability remains limited

- Small laboratory-generated dunes cannot adequately represent the morphodynamics of large natural subaqueous dunes because of scale-transfer and local-similarity limitations.

The nonlinear coupling mechanisms remain unclear

- The complex interactions among hydrodynamics, sediment supply, water depth, and dune morphology have not been fully understood, particularly during dune chasing, merging, and splitting.

Long-term field observations are insufficient

- The lack of long-term, repeatable, high-resolution seabed observations limits our understanding of dune migration, growth limits, and the dominant controlling mechanisms.

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R.C. Ewing and G. Kocurek, *Geomorphology* 114, 175 (2010).
K.J.J. van Landeghem et al., *Marine Geology* 263, 108 (2009).

Data and methods

■ Data acquisition and data processing

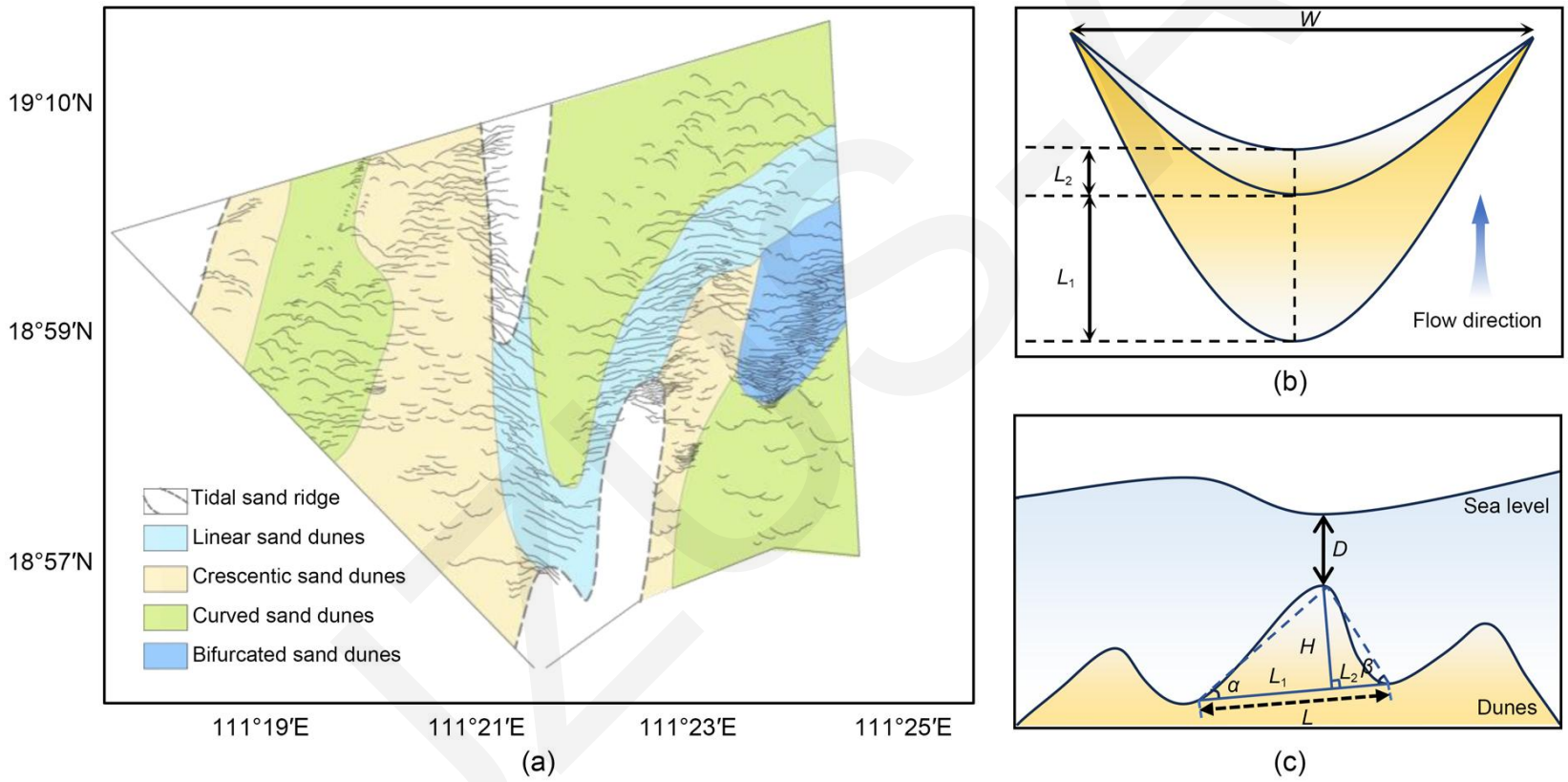


Fig. 1. Distribution of subaqueous dune types and statistical methods for parameter analysis: (a) distribution of dune types in the study area; (b) characteristic parameters of crescentic dunes; (c) statistical analysis of subaqueous dune parameters.

Morphological characteristics analysis

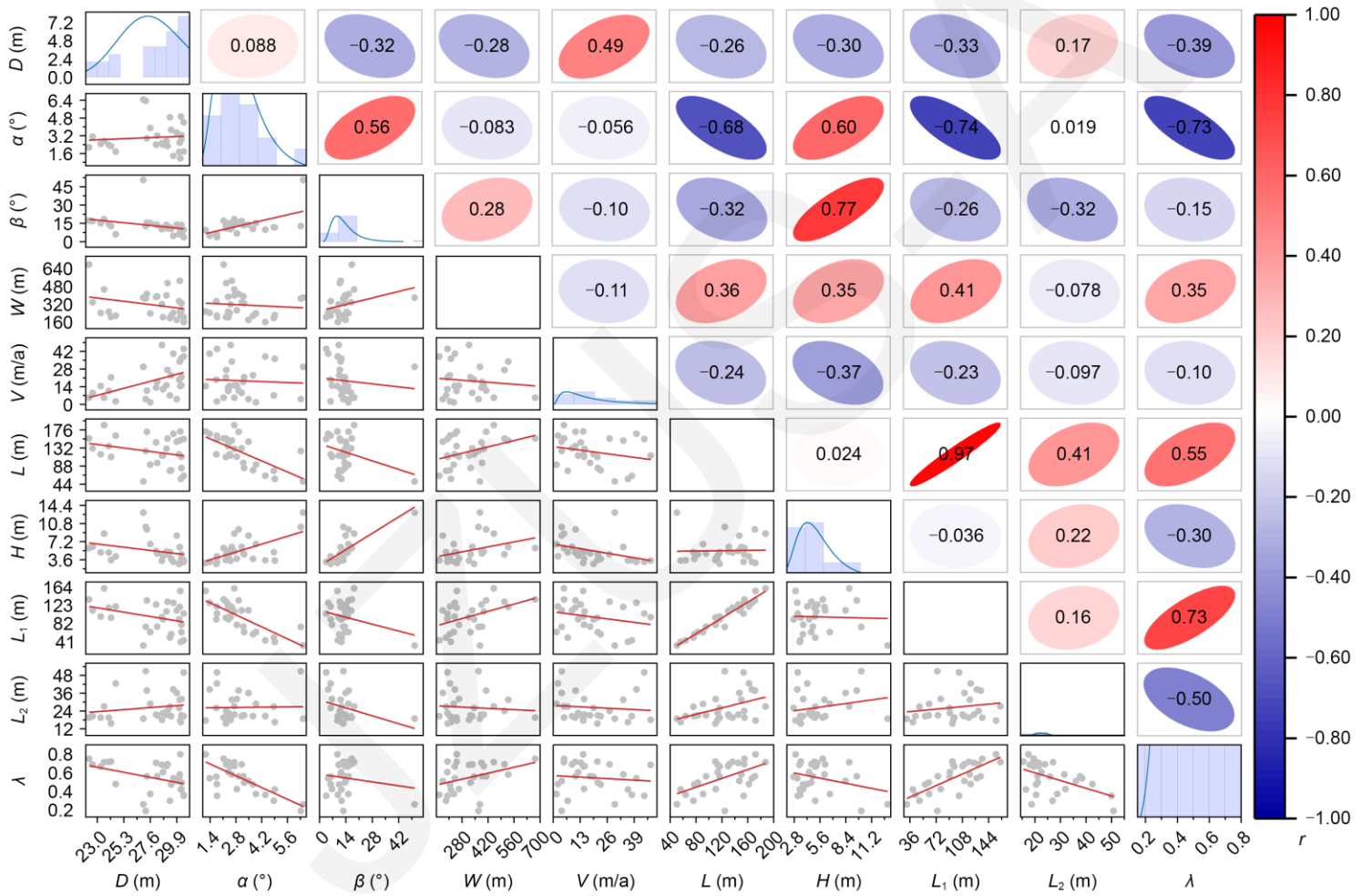
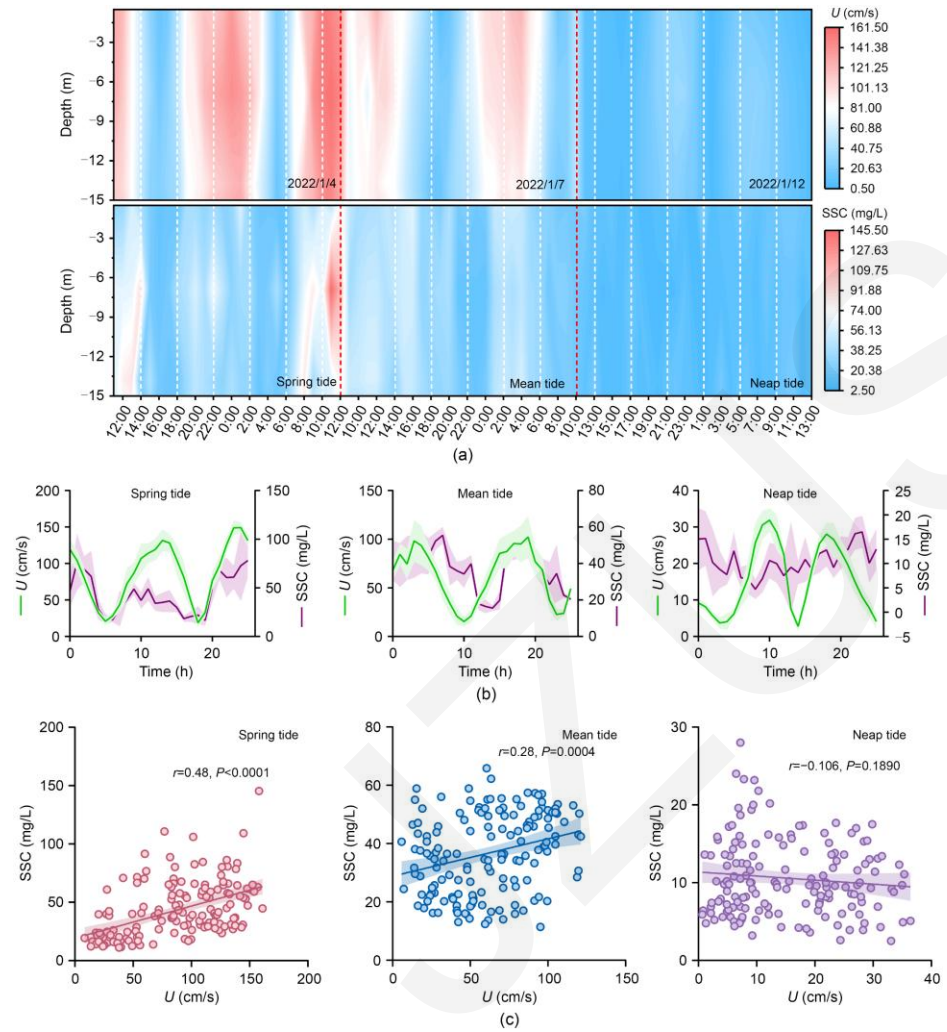


Fig. 2. Correlation analysis among the morphological parameters of crescentic dunes.

Controlling factors of crescentic dunes



- **Tidal currents dominate sediment transport.** Bedload transport, especially during spring tides, drives dune growth and southwestward migration.
- **SSC is controlled by current velocity and shows a lag effect.** SSC generally increases with current velocity, but its peak lags by about **1–2 h**. Spring tides promote resuspension and dune growth, whereas neap tides favor deposition and stabilization.
- **Water depth limits dune development.**

Fig. 3. Time–depth profiles of tidal current velocity (U) and SSC at station C1; (b) temporal variations in current velocity and SSC; (c) linear relationship between current velocity and SSC.

Migration and evolution of crescentic dunes

- Insufficient sediment supply

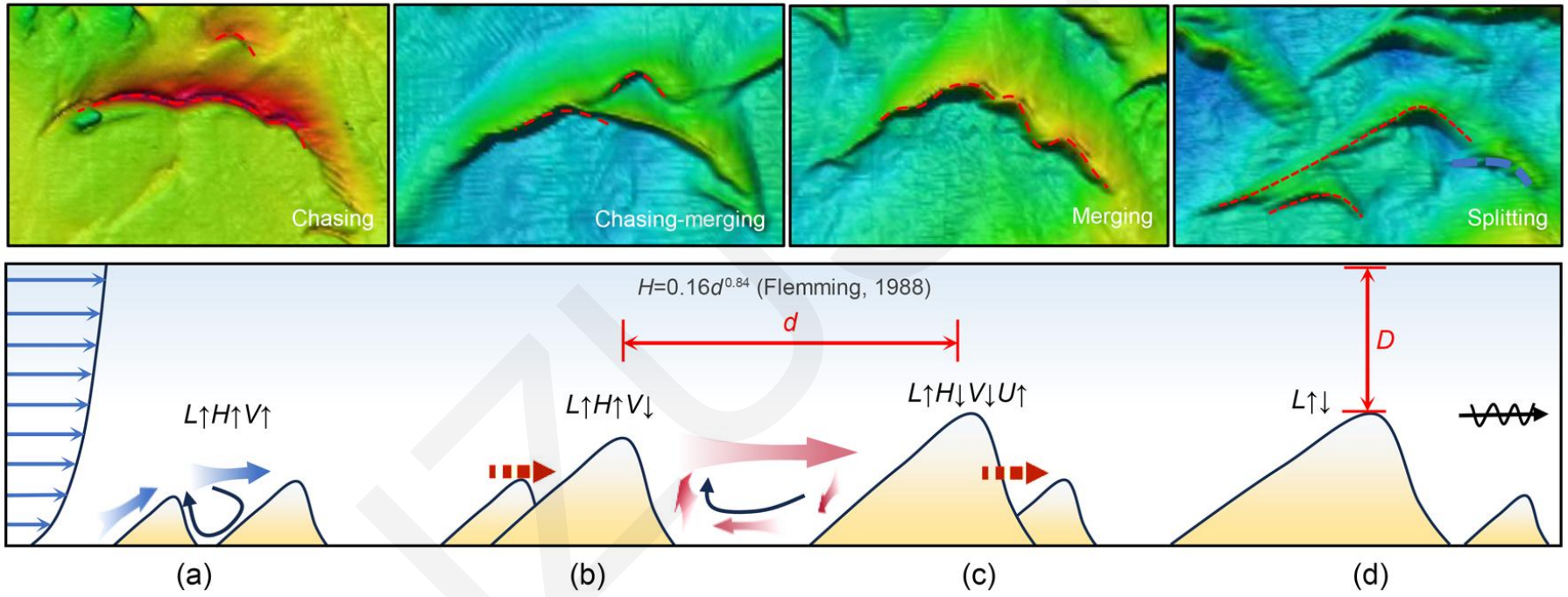


Fig. 4. Schematic diagram of the dynamic growth and evolution process of subaqueous crescentic dunes: (a) chasing; (b) chasing-merging; (c) merging; (d) splitting. Arrows indicate the increase (↑) or decrease (↓) in dune morphological parameters during evolution. d represents the spacing between adjacent dunes.

Migration and evolution of crescentic dunes

- Continuous sediment supply

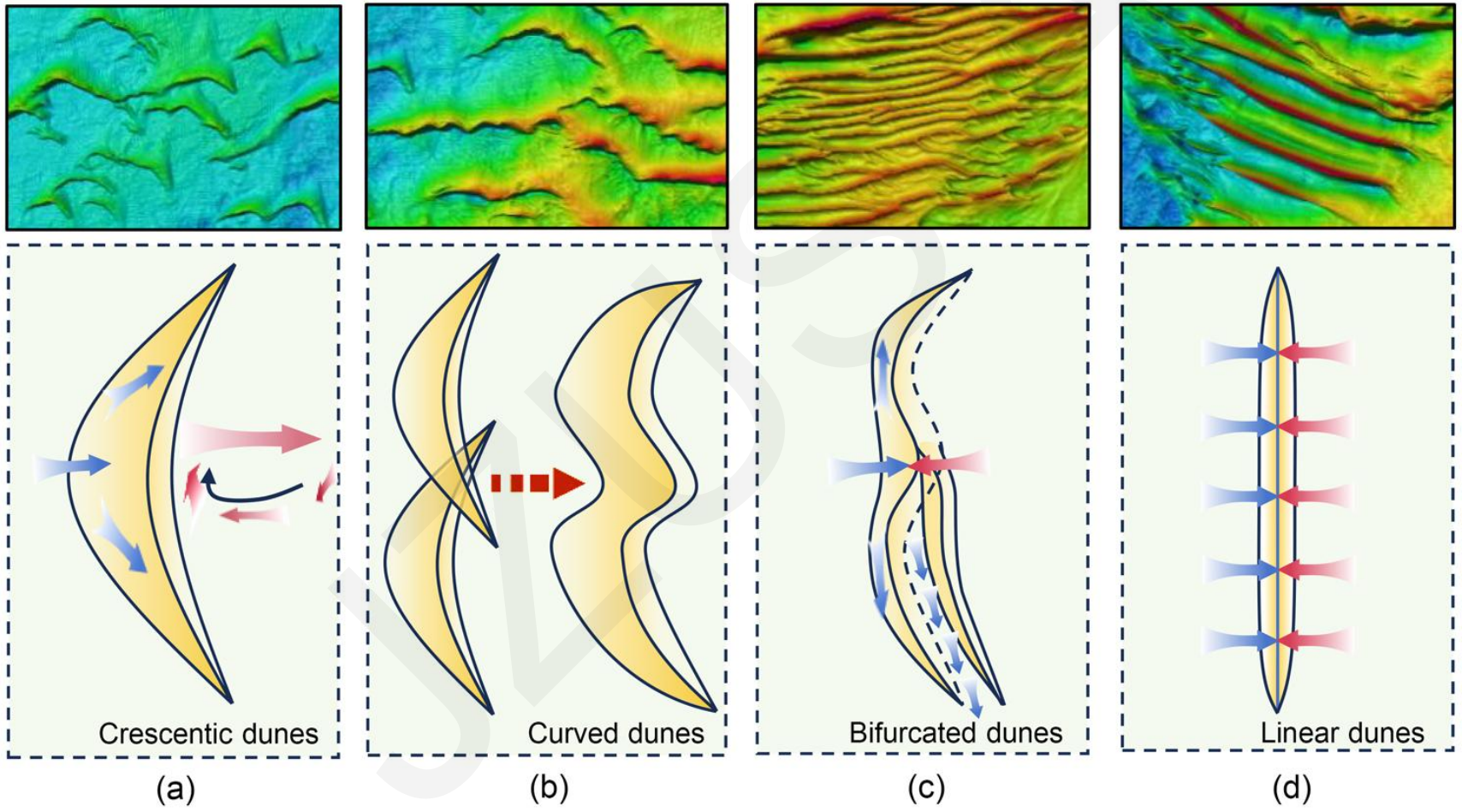
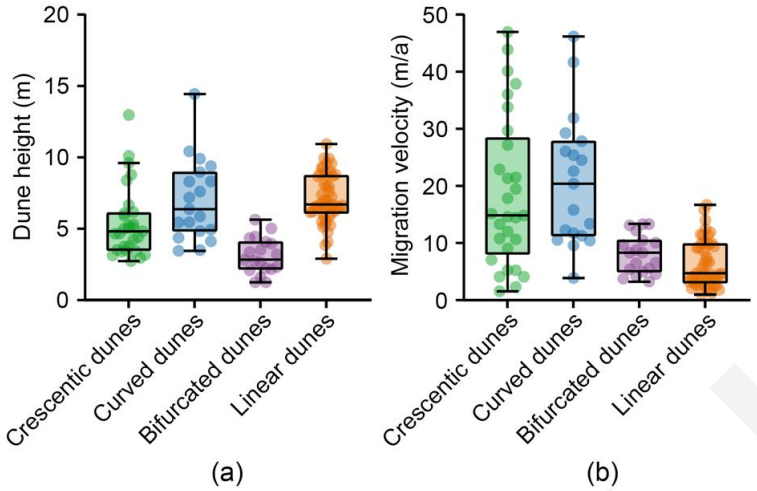
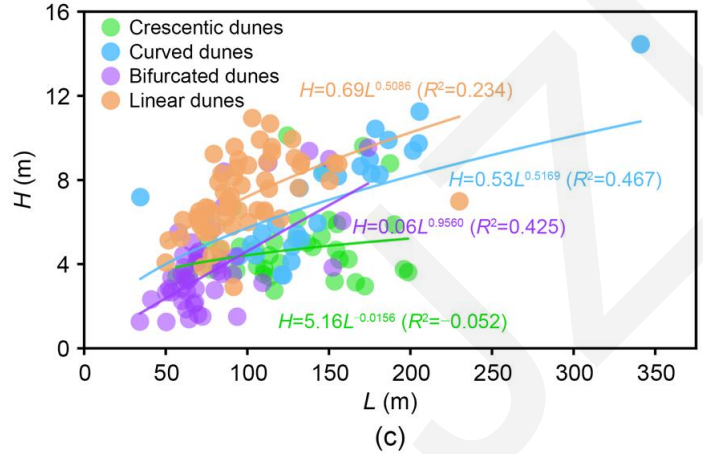


Fig. 5. Four stages in the growth and evolution of subaqueous dunes: (a) crescentic dunes; (b) curved dunes; (c) bifurcated dunes; (d) linear dunes.

Migration and evolution of crescentic dunes





- **Dune migration slows with increasing dune size.**
  Smaller dunes migrate faster, catch up with larger dunes, and eventually merge.
- **Dune evolution reaches a dynamic equilibrium.**
  As dune height approaches its upper limit, crest overtopping and splitting become more frequent, while dune height stabilizes.
- **Morphology evolves progressively.**
  Under continuous sediment supply and tidal forcing, dunes evolve from crescentic→ curved→ bifurcated→ linear forms.

Fig. 5. Morphometric characteristics of different types of subaqueous dunes: (a) distribution of dune heights; (b) distribution of dune migration velocities; (c) fitted relationship between dune wavelength and height.

Conclusions

- **Tidal currents dominate dune development.**
  - Spring-tide bedload transport provides the main driving force for dune formation and growth, while suspended-sediment resuspension, deposition, and lag effects further regulate dune evolution.
- **Dune stability is controlled by morphology and water dept**
  - Dune height determines morphological stability and hydrodynamic response, whereas crest erosion and local water depth constrain the maximum dune height.
- **Dune evolution follows a progressive sequence**
  - The dunes evolve through initiation, chasing, merging, and splitting, accompanied by a morphological transition from crescentic to curved, bifurcated, and linear forms.
- **Sediment supply regulates dune geometry.**
  - Water depth mainly controls the critical dune height, while sediment availability strongly influences dune wavelength and overall morphology.

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