Chapter 3
COASTAL MORPHODYNAMICS

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Chapter IV-3
Coastal Morphodynamics

IV-3-1. Introduction

a. This chapter discusses the morphodynamics of three coastal environments: deltas, inlets, and sandy shores. The divisions are somewhat arbitrary because, in many circumstances, the environments are found together in limited areas. For example, within a major river delta like the Mississippi, there are sandy beaches, bays where cohesive sediments accumulate, and inlets which funnel water in and out of the bays. Coastal features and environments are also not constant over time. For example, as we discussed in Part IV-2, estuaries, deltas, and beach ridge shores are elements of a landform continuum that extends over time. Which particular environment or shore type is found at any one time depends on sea level rise, sediment supply, wave and tide energy, underlying geology, climate, rainfall, runoff, and biological productivity.

b. Based on the fact that physical conditions along the coast are constantly changing, it can be argued that there is no such thing as an "equilibrium" state for any coastal form. This is true not only for shoreface profiles but also for deltas, which continue to shift over time in response to varying wave and meteorologic conditions. In addition, man continues to profoundly influence the coastal environment throughout the world, changing natural patterns of runoff and littoral sediment supply and constantly rebuilding and modifying engineering works. This is true even along undeveloped coastlines because of environmental damage such as deforestation, which causes drastic erosion and increased sediment load in rivers. The reader is urged to remember that coastal landforms are the result of the interactions of a myriad of physical processes, man-made influences, global tectonics, local underlying geology, and biology.

c. Cohesive shores, another one of the primary geologic terrains found around the world, have been discussed in Part III-5, "Erosion, Transport, and Deposition of Cohesive Shores."

IV-3-2. Introduction to Bed Forms

a. Introduction. When sediment is moved by flowing water, the individual grains are usually organized into morphological elements called *bed forms.* These occur in a baffling variety of shapes and scales. Some bed forms are stable only between certain values of flow strength. Often, small bed forms (ripples) are found superimposed on larger forms (dunes), suggesting that the flow field may vary dramatically over time. Bed forms may move in the same direction as the current flow, may move against the current (antidunes), or may not move at all except under specific circumstances. The study of bed form shape and size is of great value because it can assist in making quantitative estimates of the strength of currents in modern and ancient sediments (Harms 1969, Jopling 1966). Bed form orientations are indicators of flow pathways. This introduction to a complex subject is by necessity greatly condensed. For details on interpretation of surface structures and sediment laminae, readers are referred to textbooks on sedimentology such as Allen (1968, 1984, 1985); Komar (1998); Leeder (1982); Lewis (1984); Middleton (1965); Middleton and Southard (1984); and Reineck and Singh (1980).

b. Environments. In nature, bed forms are found in three environments with greatly differing characteristics:

(1) Rivers - unidirectional and channelized; large variety of grain sizes.

(2) Sandy coasts and bays - semi-channelized, unsteady, reversing (tidal) flows.

(3) Continental shelves - deep, unchannelized; dominated by geostrophic flows, storms, tidal currents, wave-generated currents.

c. Classification. Because of the diverse natural settings and the differing disciplines of researchers who have studied sedimentology, the classification and nomenclature of bed forms have been confusing and contradictory. The following classification scheme, proposed by the Society for Sedimentary Geology (SEPM) Bed forms and Bedding Structures Research Group in 1987 (Ashley 1990) is suitable for all subaqueous bed forms:

(1) Ripples. These are small bed forms with crest-to-crest spacing less than about 0.6 m and height less than about 0.03 m. It is generally agreed that ripples occur as assemblages of individuals similar in shape and scale. On the basis of crestline trace, Allen (1968) distinguished five basic patterns of ripples: straight, sinuous, catenary, linguoid, and lunate (Figure IV-3-1). The straight and sinuous forms may be symmetrical in cross section if subject to primarily oscillatory motion (waves) or may be asymmetrical if influenced by unidirectional flow (rivers or tidal currents). Ripples form a population distinct from larger-scale dunes, although the two forms share a similar geometry (Figure IV-3-2). The division between the two populations is caused by the interaction of ripple morphology and bed, and possibly shear stress. At low shear stresses, ripples are formed. As shear stress increases above a certain threshold, a "jump" in behavior occurs, resulting in the appearance of the larger dunes (Allen 1968).

(2) Dunes. Dunes are flow-transverse bed forms with spacings from under 1 m to over 1,000 m that develop on a sediment bed under unidirectional currents. These large bed forms are ubiquitous in sandy environments where water depths are greater than about 1 m, sand size coarser than 0.15 mm (very fine sand), and current velocities are greater than about 0.4 m/sec. In nature, these flow-transverse forms exist as a continuum of sizes without natural breaks or groupings (Ashley 1990). For this reason, "dune" replaces terms such as megaripple or sand wave, which were defined on the basis of arbitrary or perceived size distributions. Unfortunately, the term "sand wave" is still used in the literature, often with only the vaguest indication of what size feature is being described. For descriptive purposes, dunes can be subdivided as small (0.6- to 5-m wavelength), medium (5-10 m), large (10-100 m), and very large (> 100 m). In addition, the variation in pattern across the flow must be specified. If the flow pattern is relatively unchanged perpendicular to its overall direction and there are no eddies or vortices, the resulting bed form will be straight-crested and can be termed two-dimensional (Figures IV-3-3a and IV-3-4). If the flow structure varies significantly across the predominant direction and vortices capable of scouring the bed are present, a three-dimensional bed form is produced (Figure IV-3-5).

(3) Plane beds. A plane bed is a horizontal bed without elevations or depressions larger than the maximum size of the exposed sediment. The resistance to flow is small, resulting from grain roughness, which is a function of grain size. Plane beds occur under two hydraulic conditions:

(a) The transition zone between the region of no movement and the initiation of dunes (Figure IV-3-6).

(b) The transition zone between ripples and antidunes, at mean flow velocities between about 1 and 2 m/sec (Figure IV-3-6).

(4) Antidunes. Antidunes are bed forms that are in phase with water-surface gravity waves. Height and wavelength of these bedforms depend on the scale of the system and characteristics of the fluid and bed material (Reineck and Singh 1980). Trains of antidunes gradually build up from a plane bed as water velocity increases. As the antidunes increase in size, the water surface changes from planar to wave-like. The water waves may grow until they are unstable and break. As the sediment antidunes grow, they may

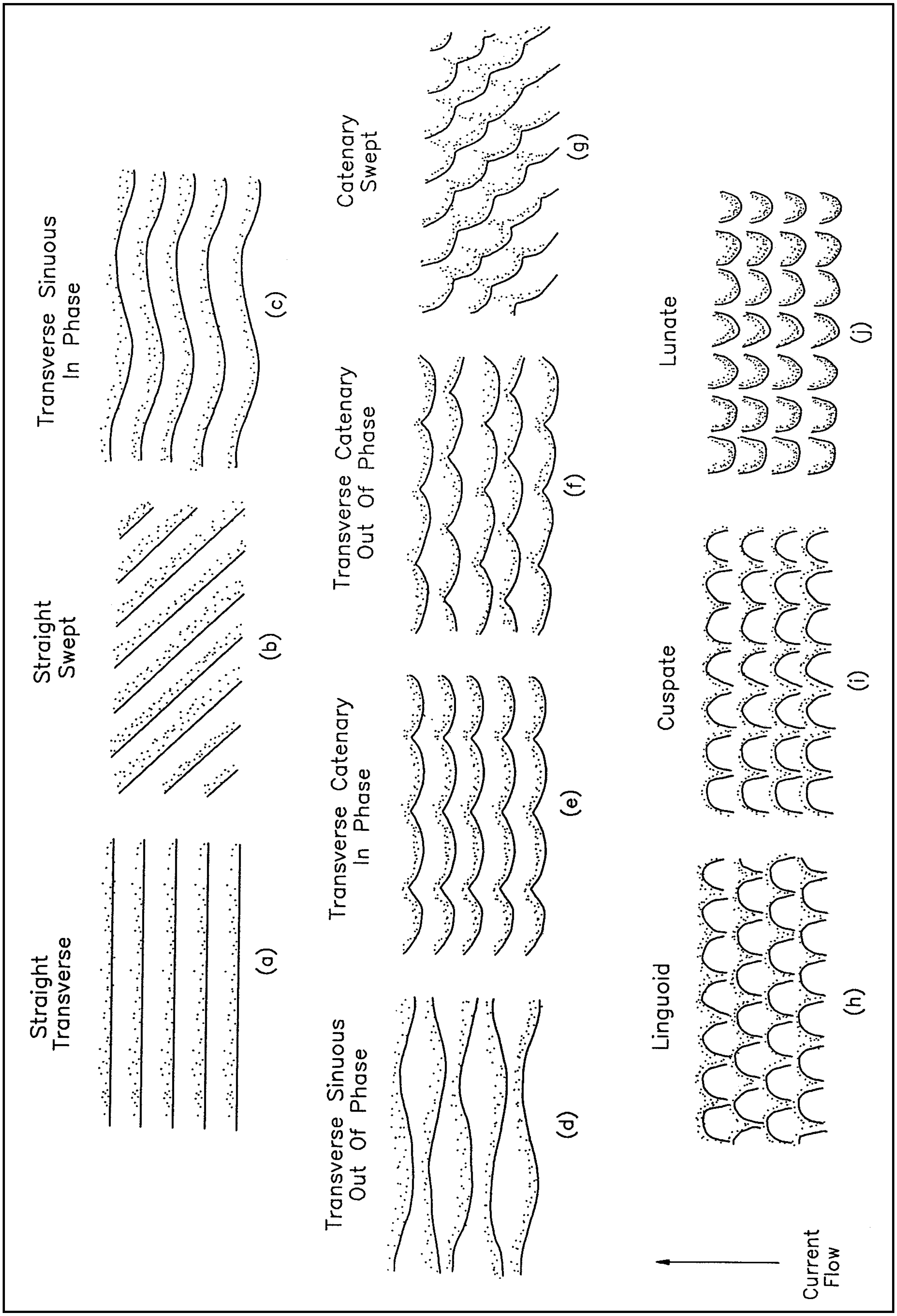

Figure IV-3-1. Sediment ripples. Water flow is from bottom to top, and lee sides and spurs are stippled (modified from Allen (1968))

Figure IV-3-2. Ripples in a runnel, now exposed during low tide. Flow was from upper left to lower right. Complicated pattern is best classified as transverse sinuous out of phase (type d) in Figure IV-3-1. Photographed at Bon Secour Wildlife Refuge, near Gulf Shores, Alabama

migrate upstream or downstream, or may remain stationary (the name "antidune" is based on early observations of upstream migration).

d. Velocity - grain size relationships. Figure IV-3-6 (from Ashley (1990)) illustrates the zones where ripples, dunes, planar beds, and antidunes are found. The figure summarizes laboratory studies conducted by various researchers. These experiments support the common belief that large flow-transverse bed forms (dunes) are a distinct entity separate from smaller current ripples. This plot is very similar to Figure 11.4 in Graf's (1984) hydraulics text, although Graf uses different axis units.

IV-3-3. Deltaic Processes[1]

a. Introduction. River deltas, which are found throughout the world, result from the interaction of fluvial and marine (or lacustrine) forces. According to Wright (1985), "deltas are defined more broadly as coastal accumulations, both subaqueous and subaerial, of river-derived sediments adjacent to, or in close proximity to, the source stream, including the deposits that have been secondarily molded by waves, currents, or tides." The processes that control delta development vary greatly in intensity around the world. As a result, delta-plain landforms span the spectrum of coastal features and include:

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[1] Material in this section adapted from Wright (1985).

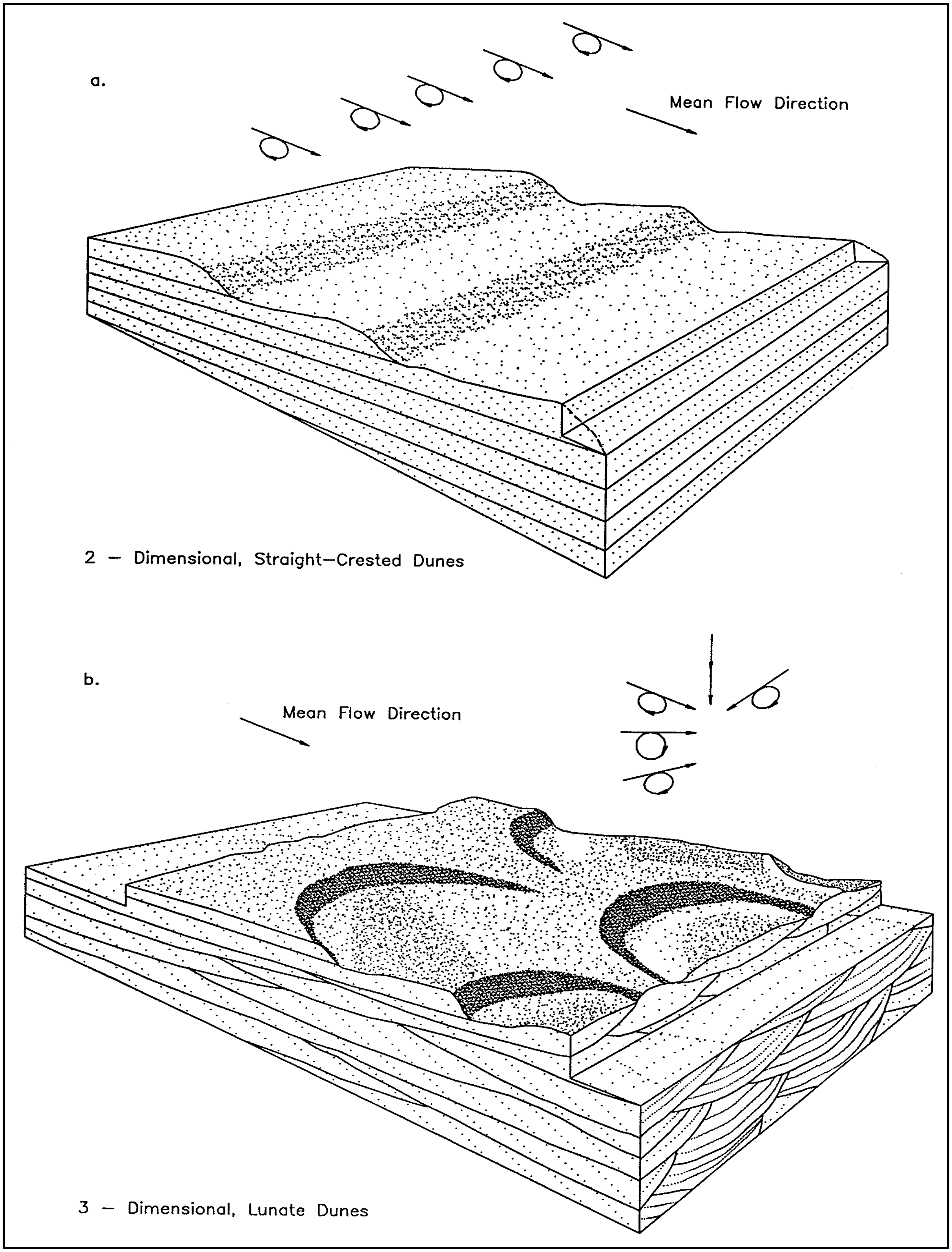

Figure IV-3-3. Two-dimensional and three-dimensional dunes. Vortices and flow patterns are shown by arrows above dunes. Adapted from Reineck and Singh (1980)