Figure IV-3-29. Shinnecock Inlet, New York, 24 October 1996. The inlet has been stabilized with stone jetties 800 ft apart. The beach east of the inlet has advanced to the end of the east jetty. To the west, the shore has suffered chronic erosion, requiring frequent emergency repair by the highway department to prevent the road from being breached. The ebb shoal (only partially shown in this photograph) is an unsymmetric oval that attaches to the downdrift beach about 1,200 m west of the west jetty (Photograph courtesy of USAED, New York)

(b) Beaches are critical buffer zones protecting wetlands and coastal plains from wave attack.

(c) Beaches are habitat or nesting ground for many animal species, some of which are endangered (e.g., turtles).

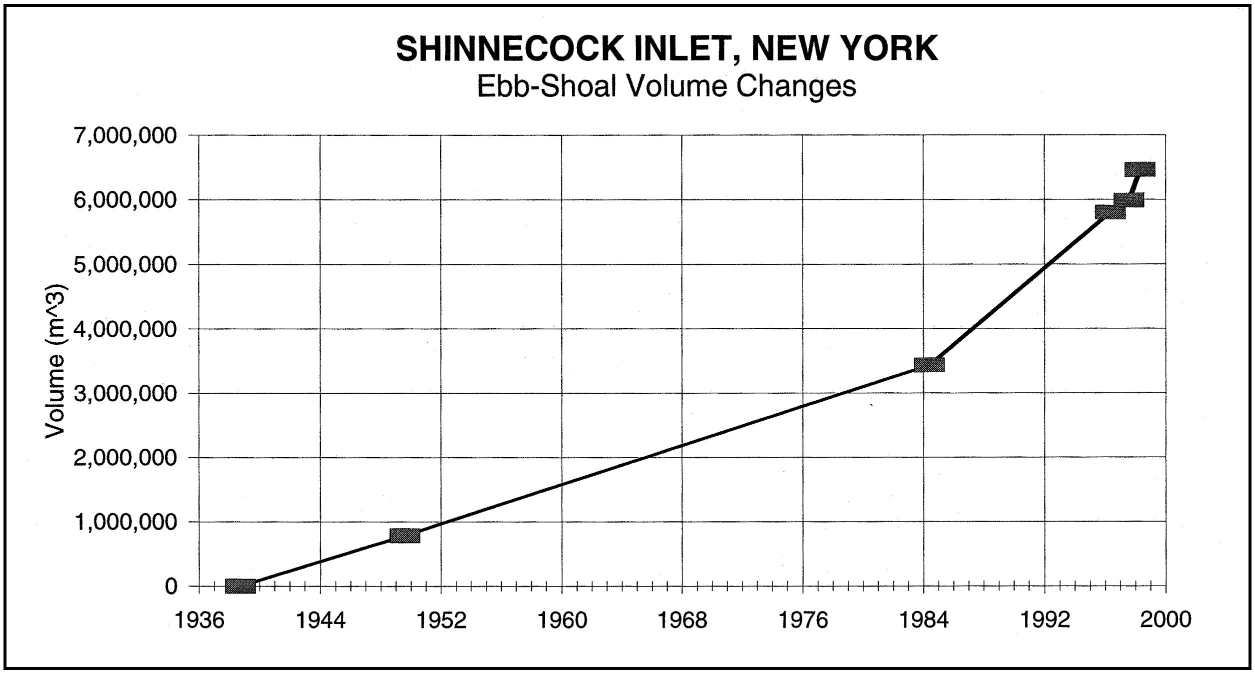

Figure IV-3-30. Ebb-shoal volume changes, Shinnecock Inlet, New York. Volumes were based on subtracting the 1933 U.S. Coast and Geodetic Survey data (pre-inlet) from more recent surveys: 1949, 1985, 1996, 1997, and 1998. The ebb shoal is still growing, indicating that it is a sediment trap, although some of the littoral drift probably bypasses. Hydrographic data courtesy of U.S. Army Engineer District, New York

(d) Much engineering effort and large amounts of funding are expended on planning and conducting beach renourishment.

(e) Sediment supply and, therefore, beach stability, are often adversely affected by the construction of navigation and shore-protection structures.

(f) Sand is a valuable and increasingly rare mineral resource in most of the coastal United States.

(4) Range of coastal environments. Around the world, coasts vary greatly in steepness, sediment composition, and morphology. The most dynamic shores may well be those composed of unconsolidated clastic sediment because they change their form and state rapidly. Clastic coasts are part of a geologic continuum that extends from consolidated (rocky) to loose clastic to cohesive material (Figure IV-3-31). Waves are the primary mechanisms that shape the morphology and move sediment, but geological setting imposes overall constraints by controlling sediment supply and underlying rock or sediment type. For example, waves have little effect on rocky cliffs; erosion does occur over years, but the response time is so long that many rocky shores can be treated as being geologically controlled. At the other end of the continuum, cohesive shores respond very differently to wave action because of the electrochemical nature of the sediment (see Part III-5).

b. Tide range and overall beach morphology.

Most studies of beach morphology and processes have concentrated on microtidal (< 1 m) or low-mesotidal coasts (1-2 m). To date, many details concerning the processes that shape high-meso- and macrotidal beaches (tide range > 2 m) are still unknown. Based on a review of the literature, Short (1991) concluded that

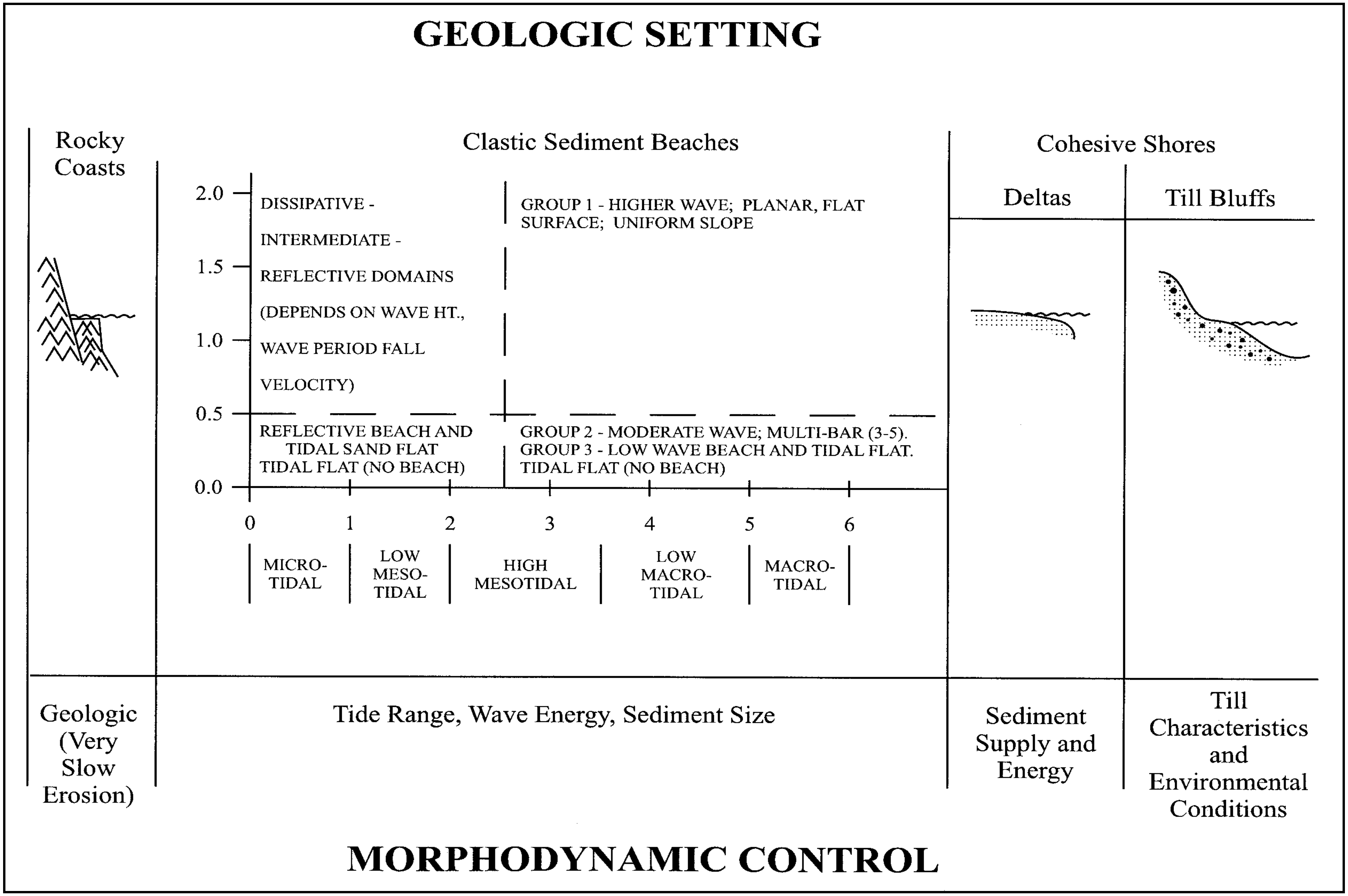

Figure IV-3-31. Summary of factors controlling morphodynamics along a range of coastal environments. Clastic shore processes are detailed in Figure IV-3-26 and discussed in the text

wave-dominated beaches where tide range is greater than about 2 m behave differently than their lower-tide counterparts. Short underscored that high-tide beaches are also molded by wave and sediment interactions. The difference is the increasing impact of tidal range on wave dynamics, shoreface morphodynamics, and shoreline mobility. Short developed a tentative grouping of various beach types (Figure IV-3-32). Discussion of the various shoreface morphologies follows.

c. High tidal range (> 2 m) beach morphodynamics.

(1) Review. Based on a review of research on macrotidal beaches, Short (1991) summarized several points regarding their morphology:

(a) They are widespread globally, occurring in both sea and swell environments.

(b) Incident waves dominate the intertidal zone.

(c) Low-frequency (infragravity) standing waves may be present and may be responsible for multiple bars.

(d) The intertidal zone can be segregated into a coarser, steeper, wave-dominated high tide zone, an intermediate zone of finer sediment and decreasing gradient, and a low-gradient, low-tide zone. The highest zone is dominated by breaking waves, the lower two by shoaling waves.

(e) The cellular rip circulation and rhythmic topography that are so characteristic of microtidal beaches have not been reported for beaches with tide range greater than 3 m.

(2) Macrotidal beach groups. Using published studies and field data from Australia, Short (1991) divided macrotidal beaches into three groups based on gradient, topography, and relative sea-swell energy:

(a) GROUP 1 - High wave, planar, uniform slope. Beaches exposed to persistently high waves ($H_b > 0.5$ m) display a planar, flat, uniform surface. Shorefaces are steep, ranging from 1 to 3 deg, and have a flat surface without ripples, bed forms, or bars. The upper high tide beach is often relatively steep and cuspid and contains the coarsest sediment of the system. On both sand and gravel beaches, the high tide, upper foreshore zone is exposed to the highest waves. Plunging and surging breakers produce asymmetric swash flows, which maintain the coarse sediment and steep gradient. Further seaward, wave shoaling becomes a more important factor than wave breaking because waves are attenuated at low tide (due to shallower water and greater friction). Tidal currents also increase in dominance seaward. Wright (1981) found that tidal currents left no bed forms visible at low tide but were an important factor in longshore sediment transport.

(b) GROUP 2 - Moderate wave, multi-bar. Multi-bar, macrotidal beaches are formed in fetch-limited environments with high tide range and abundant fine sand (King 1972b). The common characteristic of these beaches is a relatively uniform 0.5- to 0.6-deg intertidal gradient and the occurrence of multiple bars (two to five sets) between msl and mlw (Short 1991). Bar amplitude is usually below 1 m and spacing ranges from 50 to 150 m, with spacing increasing offshore. Field observations indicate that the bars are formed by a wave mechanism, particularly during low wave, post-storm conditions. The bars appear to build up onsite rather than migrate into position. These multi-bar beaches probably cause dissipative conditions during most wave regimes, possibly resulting in the development of infragravity standing waves. This would account for the spacing of the bars; however, this hypothesis has not been tested with rigorous field measurements (Short 1991).

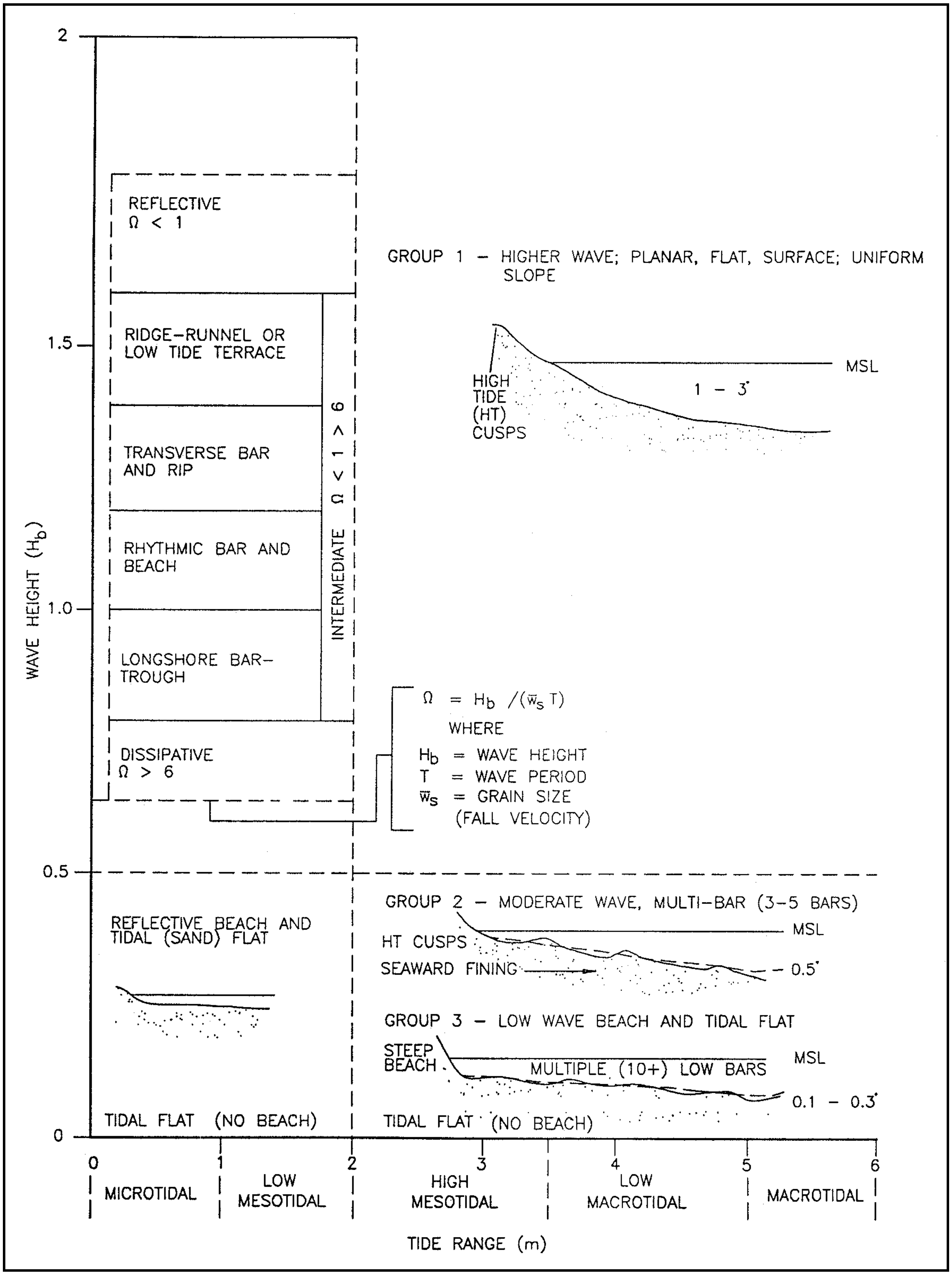

Figure IV-3-32. Micro- to macrotidal beach and tidal flat systems (adapted from Short (1991)). Dimensionless parameter Ω discussed in the text

(c) GROUP 3 - Low wave beach and tidal flat. As wave energy decreases, macrotidal beaches eventually grade into tide-dominated tidal flats. Between the two regimes, there is a transition stage that contains elements of both morphologies. These beach-tidal flat systems are usually characterized by a steep, coarse-grained reflective beach (no cusps usually present) which grades abruptly at some depth below msl into a fine-grained, very low gradient (0.1 deg), rippled tidal flat (Figure IV-3-33). The tidal flat may be uniform or may contain low, multiple bars. Beach-tidal flat shores are found in low-energy environments that are only infrequently exposed to wave attack, but the energy must be sufficient to produce the morphologic zonation.

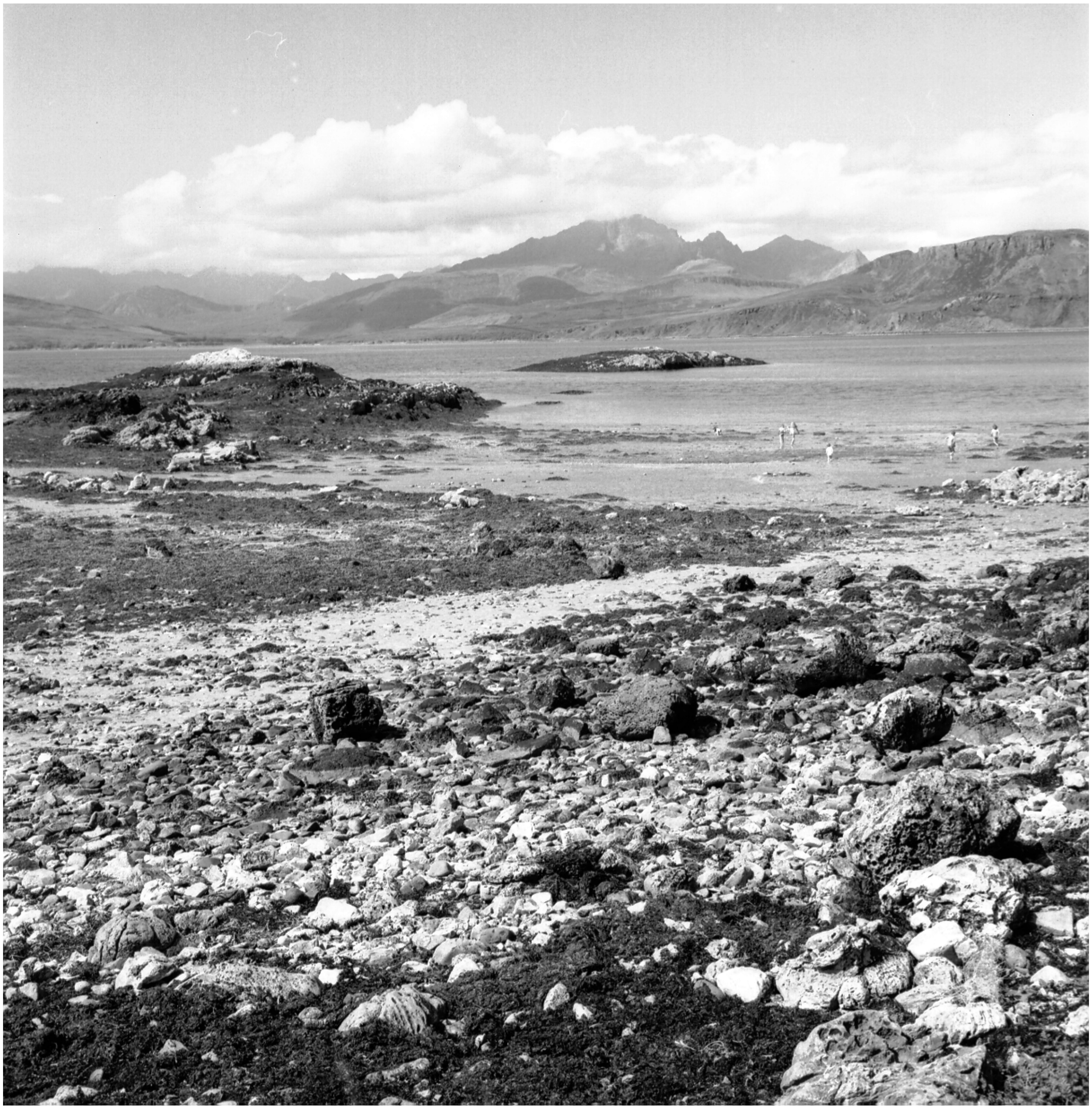

Figure IV-3-33. View west from Tarskavaig, Isle of Skye, Scotland, August 1983. Photograph taken at low tide. At this macrotidal beach, facing the Sea of the Hebrides, the upper shoreface consists of coarse cobble, while the low foreshore is low gradient and almost featureless

(3) Spatial and temporal variations. Beaches on macro-tidal coasts vary morphologically as important environmental parameters change. Short (1991) cites one setting where the shoreface varies from high-energy, uniform steep beach (Group 1) to beach-tidal flat (Group 3) within 2 km. He suggests that the changes in morphology are due to variations in wave energy: as energy changes alongshore, important thresholds are crossed which result in different ratios of wave versus tide domination. In addition, there may be temporal variations throughout the lunar cycle. As tide range varies during the month, the transitions where one morphologic group merges into another may migrate cyclically along the coast. More field studies are needed to document this phenomenon.

(4) Summary. On tideless beaches, morphology is determined by waves and sediment character. On microtidal beaches, waves still dominate the morphodynamics, but tide exerts a greater influence. As tide range increases beyond 2-3 m, the shape of beaches becomes a function of waves coupled with tides. On the higher tide coasts, as water depth changes rapidly throughout the day, the shoreline and zone of wave breaking move horizontally across the foreshore and tidal currents move considerable sediment.

d. Morphodynamics of micro- and low-mesotidal coasts.

(1) Morphodynamic variability of microtidal beaches and surf zones. Based on field experiments in Australia, Wright and Short (1984) have presented a model of shoreface morphology as a function of wave parameters and sediment grain size. This model is a subset of Figure IV-3-31 that occupies the zone where tide range is between 0 and 2 m and H_b (breaker height) is greater than about 0.5 m.

(a) Wright and Short (1984) determined that the morphodynamic state of sandy beaches could be classified on the basis of assemblages of depositional forms and the signatures of associated hydrodynamic processes. They identified two end members of the morphodynamic continuum:

- Fully dissipative.
- Highly reflective.

Between the extremes were four intermediate states, each of which possessed both reflective and dissipative elements (Figure IV-3-32).

(b) The most apparent differences between the beach states are morphological, but distinct process signatures, representing the relative velocities of different modes of fluid motion, accompany the characteristic morphology. As stated by Wright and Short (1984):

> Although wind-generated waves are the main source of the energy which drives beach changes, the complex processes, which operate in natural surf zones and involve various combinations of dissipation and reflection, can lead to the transfer of incident wave energy to other modes of fluid motion, some of which may become dominant over the waves themselves.

(c) Wright and Short grouped fluid motion into four categories (Table IV-3-1):

- Oscillatory flows.
- Oscillatory or quasi-oscillatory flows.
- Net circulations.
- Non-wave-generated currents.

Table IV-3-1
Modes of Fluid Motion Affecting Clastic Shorelines

Modes	Notes	Frequencies of flows	Examples
Oscillatory	Corresponds directly to incident waves	Frequency band of deep-water incident waves	Sediment-agitating oscillations
Oscillatory or quasi-oscillatory	Shore-normal oriented standing and edge waves	Wide range of frequencies	Trapped edge waves, "leaky" mode standing waves
Net circulations	Generated by wave energy dissipation	Minutes to days	Longshore currents, rip currents, rip feeder currents
Non-wave-generated currents	Generated by tides and wind shear	Minutes to hours (?)	Tidal currents

(Based on Wright and Short (1984))

(d) From repeated observations and surveys of beaches, Wright and Short (1984) concluded that beach state is clearly a function of breaker height and period and sediment size. Over time, a given beach tends to exhibit a *modal* or most frequent recurrent state, which depends on environmental conditions. Variations in shoreline position and profile are associated with temporal variations of beach state around the modal state. Wright and Short found that a dimensionless parameter Ω could be used to describe the modal state of the beach:

$$\Omega = \frac{H_b}{\overline{w_s} T} \qquad \text{(IV-3-3)}$$

where H_b is breaker height, $\overline{w_s}$ is sediment fall velocity, and T is wave period. For the following values of Ω (Figure IV-3-32):

- Ω about 1: defines the reflective/intermediate threshold
- $1 < \Omega < 6$: intermediate beaches
- $\Omega \cong 6$: marks the threshold between intermediate and dissipative conditions

(e) Beaches take time to adjust their state, and a change of Ω across a threshold boundary does not immediately result in a transformation from reflective to intermediate or from intermediate to dissipative. On the Pacific coasts of Australia and the United States, storms can cause a shift of beach state from reflective or intermediate to dissipative in a few days because the energy is high. The return to reflective conditions under low energy may require weeks or months or longer (the sequence of beach recovery is illustrated in stages *a* through *f* in Figure IV-3-34). In environments where the dominant variation in wave energy occurs on an annual cycle (e.g., high storm waves in winter and low swell in summer), the full range from a dissipative winter profile to a reflective summer profile may be expected.

(f) Wright and Short (1984) concluded that large temporal variations in Ω are accompanied by large changes in state. However, when the variations in Ω take place in the domains of $\Omega < 1$ or $\Omega > 6$, no corresponding changes in *state* result. Intermediate beaches, where Ω is between 1 and 6, are spatially and temporally the most dynamic. They can undergo rapid changes as wave height fluctuates, causing reversals in onshore/offshore and alongshore sediment transport.

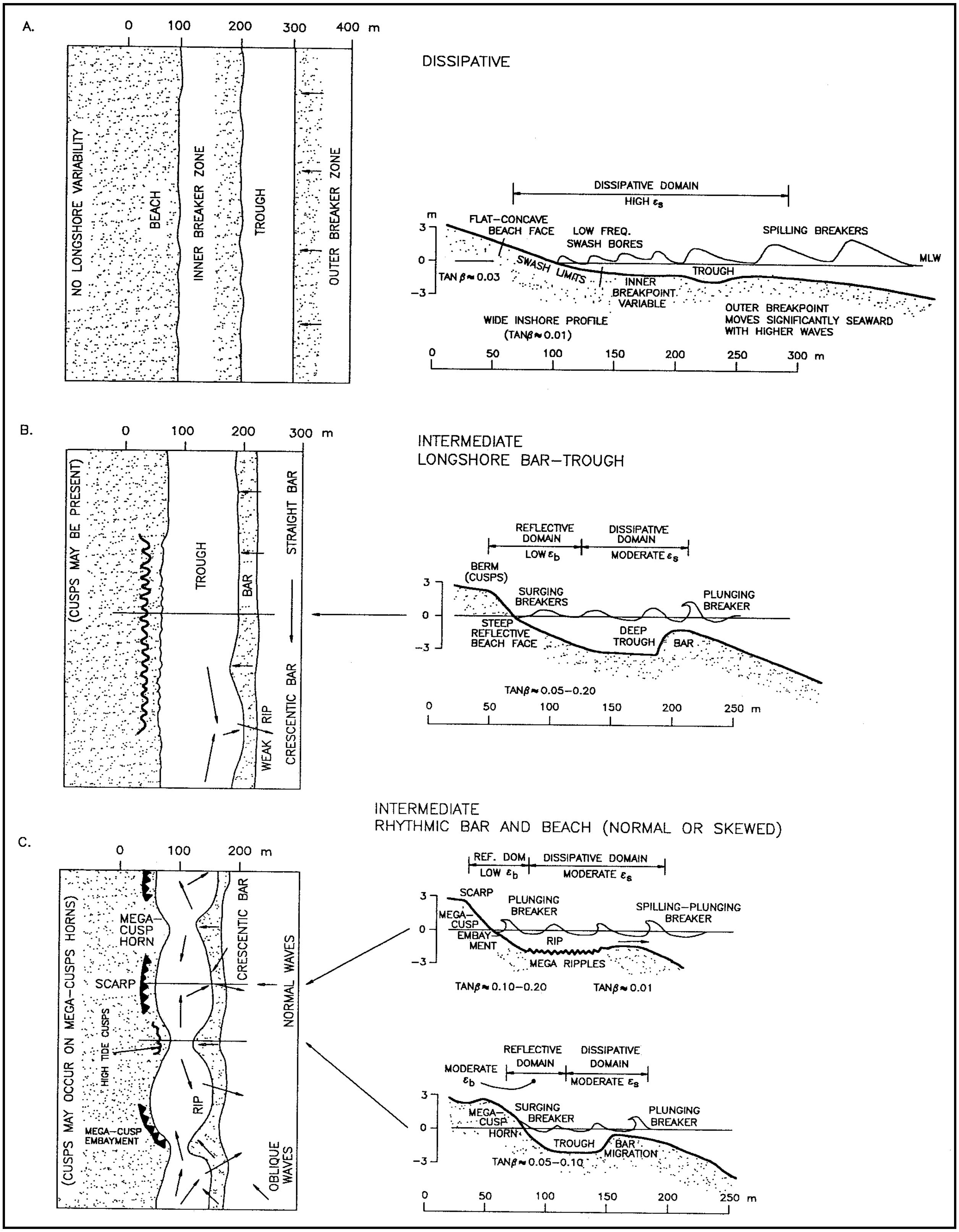

Figure IV-3-34. Plan and profile views of six major beach stages (adapted from Wright and Short (1984)). Surf-scaling parameter ε is discussed in the text; β represents beach gradient. Dimensions are based on Australian beaches, but morphologic configurations are applicable to other coastlines (Continued)

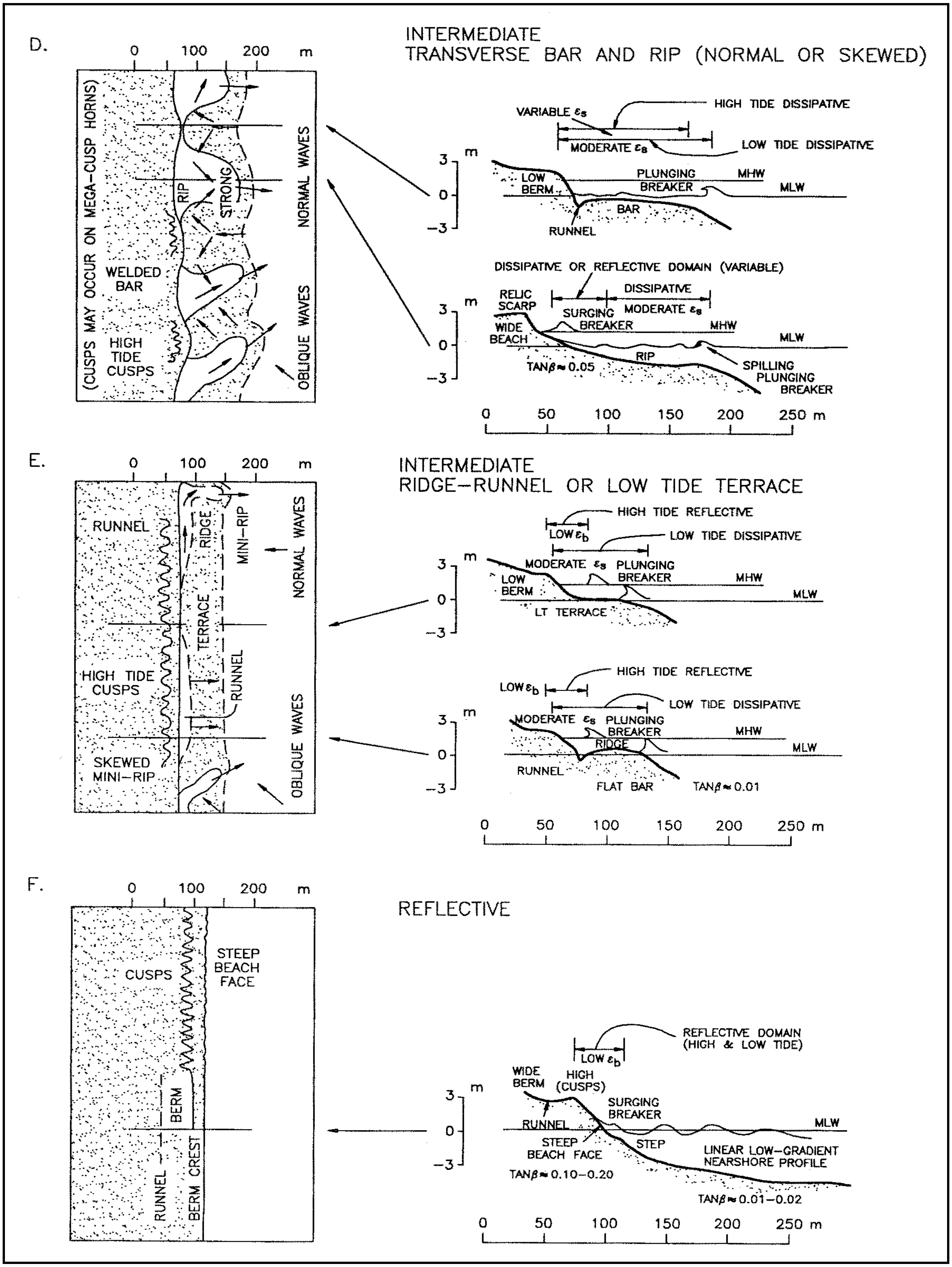

Figure IV-3-34. (Concluded)