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The Movement and Stabilization of Beach Sand on Transverse Bars, Assateague Island, Virginia

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ABSTRACT

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Transverse bars on the leeward beaches of Assateague Island were studied to understand the processes responsible for their development. It is thought that they originated by storm activity when sand was eroded from the berm and redeposited in the foreshore. On protected stretches of the beach, low-energy fairweather waves slowly return this sand to the berm by way of transverse bars. Incoming waves are refracted as they approach the coast, and sand moves shoreward in the channels between bars. Along the bar crests, sand also moves shoreward as a result of refraction around the bar and wave interference. Although connected to the upper shoreface, bars seem to be migrating parallel to the shoreline under the influence of slight longshore transport. On even quieter stretches of the beach, transverse bars have been colonized by salt cordgrass, which has effectively stabilized these bars. Cordgrass baffles the waves and binds the sand, thus helping to build the bars upward and retard their migration. With time, the grass stabilizes sediment of the intervening channels and may eventually overgrow the entire beach.

ADDITIONAL INDEX WORDS: *Barrier Island, shoreface, longshore transport, sand bar, ripple marks.*

INTRODUCTION

Transverse bars, that is, sand buildups extending perpendicular to a shoreline, have been recognized for a long time but are little studied (SHEPARD, 1952). Those of the Florida coast described by TANNER (1960) and NEIDORODA and TANNER (1970) serve as the only model for comparison, yet this type of bar is widespread. Intertidal transverse bars, for example, are numerous on the leeward beaches of Assateague Island, Virginia. Moreover, the bars of Assateague display important differences with those of Florida as well as several interesting sedimentary variations among themselves. An examination of these bars, therefore, should expand our understanding of this sedimentary feature and the processes responsible for its development.

Assateague Island is a major barrier island along the Atlantic coast of Maryland and Virginia, and Toms Cove is an embayment into the back side of the island at its southern end (Figure 1). The bars of this study are situated on the northern beach of Toms Cove immediately east of Assateague Point. The cove has existed for little more than a century, forming since 1860 as the Assateague spit built southward. Tidal range in Toms Cove is 90 cm (microtidal), and fairweather waves are generally only a few centimeters high. By the classification scheme of TANNER (1960), waves in the cove are low energy. For example, during the passing of a small storm in October 1987, breaking waves on the ocean side of Assateague Island were 1 m in height, whereas in the cove they were less than 10 cm.

Along a 200-m stretch of beach in Toms Cove, there are 15 well developed transverse bars (Figure 2). They are covered by asymmetrical wave ripples and barren of any vegetation. About 0.5 km farther east is a second set of bars, which are mantled to some degree by grass. The foreshore of the Toms Cove beaches can be divided into three subzones (Figure 3A). (1) The upper foreshore is narrow, 2 to 10 m in width, with a relatively steep slope (6°). The only sedimentary structure consists of a series

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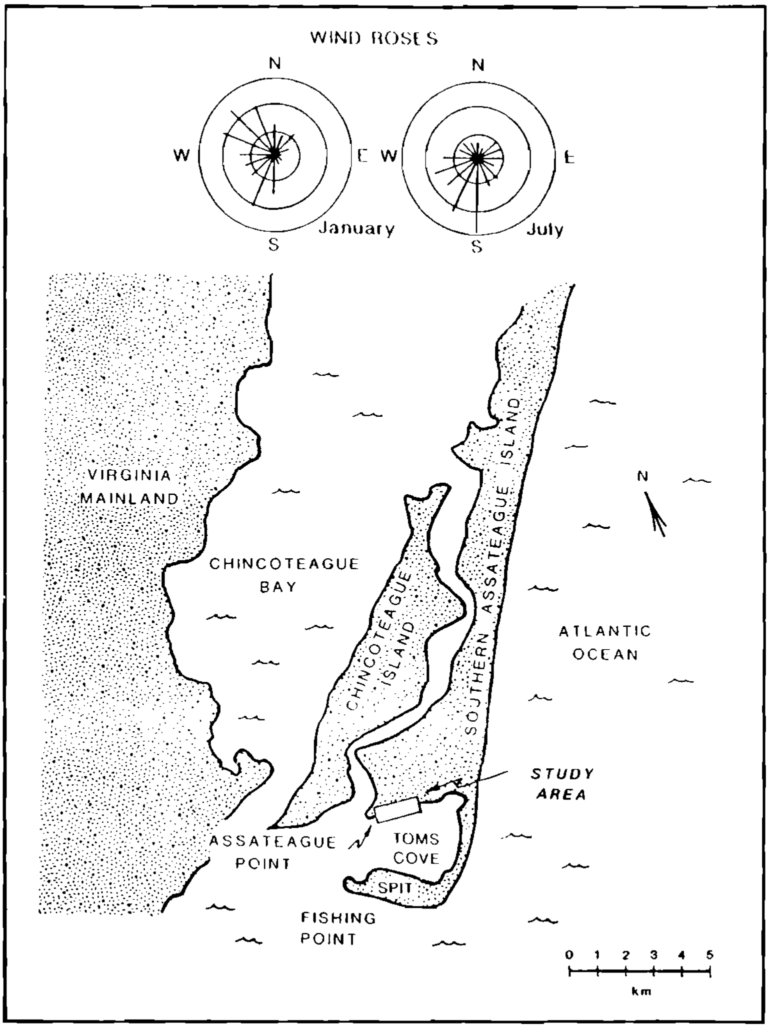


Figure 1. Location of study area in Toms Cove, Assateague Island, Virginia. Wind roses are for the period 1945-1957 (data provided by NASA, Wallops, Virginia).

of horizontal water-level marks which record the rapid but discontinuous fall of the tide. (2) The middle foreshore, 40 to 60 m wide, contains the transverse bars and the shallow channels that separate them. The slope is very gentle, less than 1/2°. Transverse bars have a low relief and are submerged at high tide. (3) The lower foreshore extends seaward from the bar-and-channel zone. The surface sediment is covered by numerous small wave ripples, identical to those that cover the bars. This zone remains submerged during neap low tide, and the seaward boundary is the spring low water line.

TRANSVERSE SAND BARS

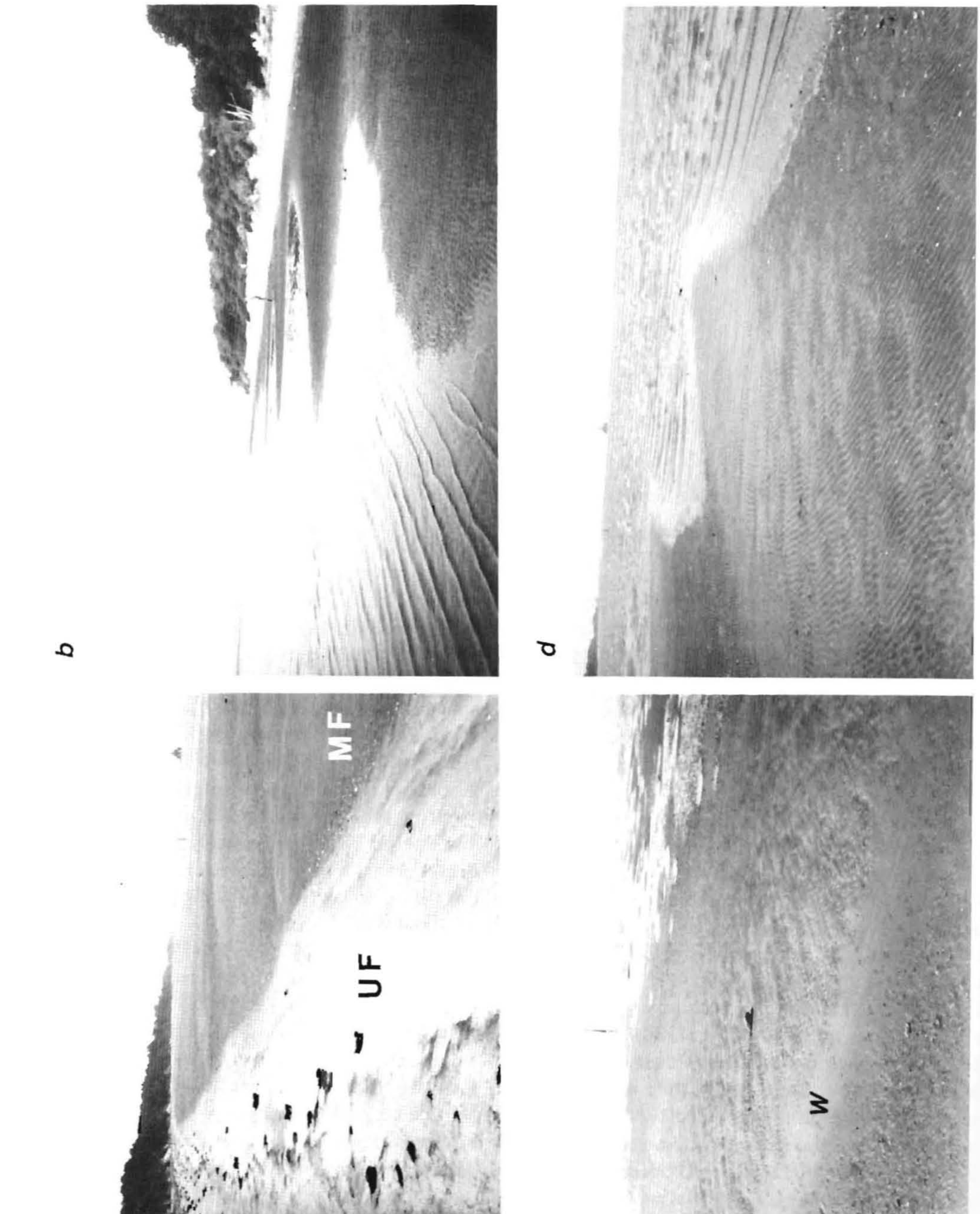
The 15 transverse bars of Assateague Point are attached to the upper foreshore, creating a distinct cusp-like coastline (Figures 3A, B). They vary in length from 45 to 70 m, with a wave length of 13 to 15 m, and a relief of 10 to 15 cm (Figure 3C). The bars are not perpendic-

Figure 2. Series of transverse bars illustrating their overall configuration.

ular to the shoreline; rather, their long axes strike 50 to 65° to the shore. Moreover, several swing around to approximately 40° at their nearshore end. In cross-section larger bars have an asymmetric profile, sloping seaward 1° and landward 3°. Smaller bars are nearly symmetrical, sloping 1° in both directions. Bars are littered with living organisms and skeletal debris: periwinkles, horseshoe crabs, razor clams, scallops, quehogs, worm tubes, snail egg-cases, fish in small isolated pools, and algal mats on the wet sand of low spots. The trails of periwinkles, horseshore crabs (including nests and eggs), and birds are numerous, as are tiny vertical burrows.

In general, transverse bars are thought to form in a similar fashion to coast-parallel ridges of ridge-and-runnel systems. With the passing of a storm, perhaps within a day after the wind abates, sand can be put into suspension and transported seaward by a storm-surge ebb flow (WALKER, 1979). In particular, sand is eroded from the berm and redeposited as bars on the gently sloping foreshore (DAVIS *et al.*, 1972; DAVIS, 1985). TANNER (1960) cited an additional condition for the existence of transverse bars—a predominance of low-energy fairweather waves. Intertidal bars on high-energy beaches may be quickly removed by waves, longshore drift, and rip currents, whereas transverse bars are preserved on beaches subjected to only low-energy waves. Bars of this study are located just behind Assateague Point, and shelter offered by the recurved Assateague spit and the short fetch of the cove are responsible for their preservation. Aerial photoghraphs taken in April 1962 show no bars on Assateague Point (although transverse bars were present elsewhere in Toms Cove). We first discovered them in August 1981; hence, they must have formed within that 19-year period. For the past seven years they have remained relatively unchanged.

Transverse bars are generally oriented perpendicular to the shoreline with a crudely rhythmic spacing. TANNER (1967) and NIEDORODA and TANNER (1970) postulated the existence of a series of current gyres in the shallow, nearshore environment, produced by wave refraction and interference, which is responsible for the perpendicular orientation of these bars. In Toms Cove such a circular current pattern has been observed occasionally, though not consistently, during fairweather conditions. Furthermore, the bars of Toms Cove make an oblique angle to the shoreline, which may reflect a net longshore transport. Longshore currents in the cove are quite weak; breezes of up to 8 knots (average annual wind speed for the period 1966–1980; NASA, Wallops, Vir-


a
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ginia) generate waves 2-3 cm in height and a longshore current of only 6-18 cm/sec. Nevertheless, the seaward ends of the bars apparently migrate eastward under the influence of this drift.

The surface of each bar in this study is covered with wave ripple marks (Figures 3C, D). Ripple length is 4 to 6 cm, height 1 cm or less, and ripple index around 5. The straight, relatively continuous crests generally trend subparallel to the axis of the bar (Figure 4A). Another set of ripple marks (ephemeral) sometimes appears on the transverse bars. They have a wave length of 20 to 45 cm and trend normal to the bar axis. When observed, these larger ripple marks have been partially destroyed by the set of smaller ripples. Trenching reveals that sedimentary structures within the bars have been destroyed by extensive bioturbation.

Figure 3 *(Facing page)*. *a*, Transverse bars at low tide. Backshore (B) and upper foreshore (UF) are littered with dead horseshoe crabs (large numbers of crabs die immediately after mating). Middle foreshore (MF) contains several low-relief bars and intervening channels. Oyster watch house in distance. *b*, Bars and channels at mid-tide. c, Low-relief bar at low tide, covered with small wave ripples and washout structure (W) on steeper landward side. Visible in lower left is channel floor with small wave ripple marks and coarse shell debris. Lower foreshore in distance is pock-marked with the nests of horseshoe crabs. *d*. Though continuous, ripple marks change orientation from channel to bar crests, following the refraction of incoming waves.

At mid-tide waves refract around the seaward end of the bars, thus striking the bars from two directions (Figure 5). Interference ripples develop along the very crest at these times, although normal, symmetric, straight-crested ripple marks occur simultaneously on the lower flanks and into the channels (Figure 4A). At high tide, relief of the bars is too low to impede incoming wave trains, and the interference ripples on the crest are replaced by symmetric, straight-crested ripple marks.

Larger bars are asymmetric in cross-section with a relatively steep landward side. Ripple

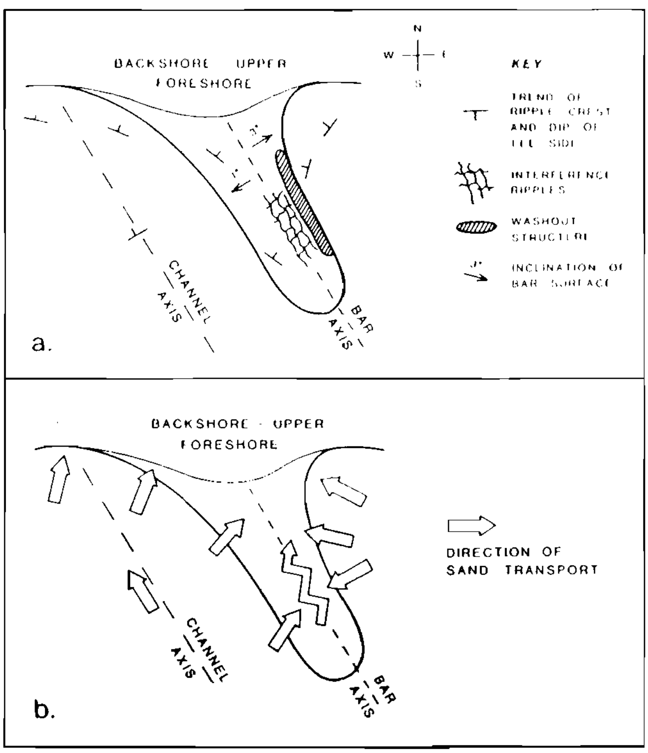


Figure 4. *a*, Sketch of a transverse bar (actually somewhat oblique to the shoreline) and adjacent channel on the middle foreshore portion of the beach. Also shown are the orientation of asymmetric ripple marks, the location of interference ripple marks and washout structure, and the surface inclination of larger bars. *b*, Direction of sand transport during the rise and fall of each tide.

Figure 5. Refraction of waves around the seaward side of a transverse bar.

marks on the lee side of these bars form during each flood tide, but they disappear with the next ebb tide. On such steep slopes the rapidly falling ebb tide as well as small wind-driven waves destroy the ripples (Figures 3C, 4A), leaving a lower-regime plane bed (termed a washout structure, KLEIN, 1977) and horizontal water-level marks on the smooth surface. In contrast, smaller, less steep bars are everywhere covered by ripple marks, even during the ebb tide.

Channels between transverse bars are not completely exposed at low tide. Scattered pools exist during spring low tide, and the seaward portions retain considerable water during neap low tide. Periwinkles and algal mats are abundant. Sieving of the sand shows it to be identical in texture and composition to that of the bars: well sorted fine sand ($M = 2.54 - 2.62\phi$, $\sigma = 0.41 - 0.44\phi$), composed of quartz with a large admixture of whole and fragmented bivalves, and a concentration of heavy minerals in the very fine fraction (Figure 6). However, coarse shell debris is concentrated along the shoreward terminus of the channels. Wave ripple marks are of the same size as ripples on the adjacent bars; their straight crests have an orientation that is perpendicular or oblique to the channel axis and subparallel to the shoreline. Overall, ripple crests are generally continuous from channel to bar, but they do change direction, following the refraction of incoming waves (Figures 3D, 4A).

The asymmetry of ripple marks and their orientation provide clues to sediment movement along the Toms Cove bars. At any one time ripple marks are symmetric on the seaward portions of bars and channels, but they become slightly asymmetric in shallower water close to shore. Conversely, at any one place ripple marks are slightly asymmetric with the approach of each flood tide, becoming symmetric as the water deepens. The symmetric, oscillation ripple marks indicate no net sediment movement at high tide, when water is deep relative to the small, low-energy waves. On the other hand, the slightly asymmetric ripples indicate minor shoreward transport of sediment during each rise (and fall) of the tide. The ori-

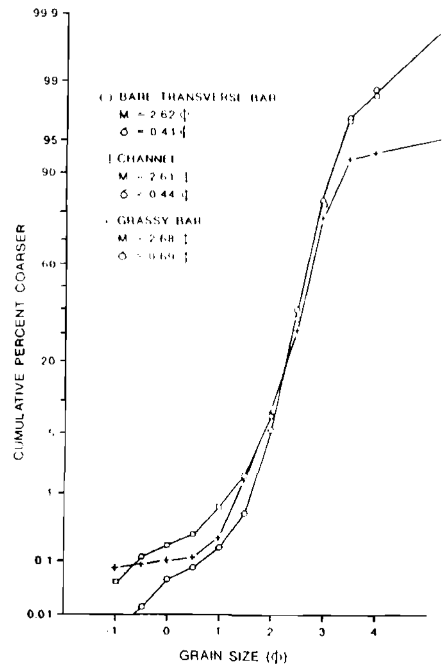


Figure 6. Grain-size distributions of representative sands from bare transverse bars, intervening channels, and grass-covered bars.

entation of ripple crests illustrates that sand moves shoreward within the channels, up the flanks of the bars, and shoreward along the bar crests (Figure 4B). In this way sand that was eroded from the berm by storm activity is eventually returned to the upper foreshore and backshore (NIEDORODA AND TANNER, 1970; DAVIS, 1985). With time the bar apparently lengthens and attaches itself to the upper shoreface. The dominant summer winds are from the southwest (Figure 1), and waves from that direction generate a weak longshore transport to the east along Assateague Point, which in turn deflects the bars from a perpendicular orientation. The asymmetry of larger bars, with a steep lee side to the northeast (landward), also argues that the bars are slowly shifting.

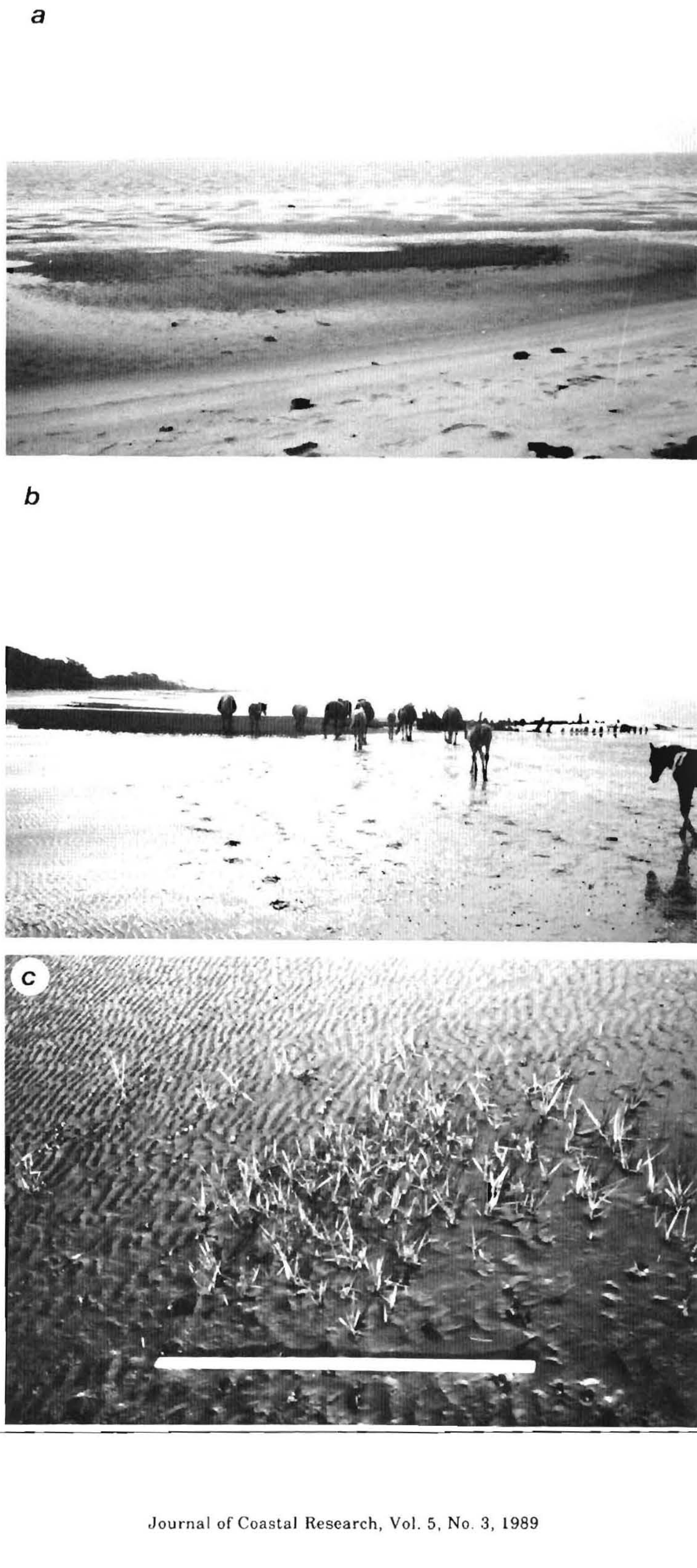
Finally, the set of ephemeral ripple marks is thought to be produced by larger-than-usual waves. Their longer wave length may be related to higher velocity waves in deeper water, when water is piled against the shoreline by strong winds. The low-relief transverse bars do not affect the orientation of these larger ripples; they have the same trend on beaches of Toms Cove lacking bars as on the bars themselves. And during periods of low-energy waves, the ripple crests of this ephemeral set are superimposed, planed, and partially destroyed by the set of smaller ripples, which forms with the return of fair weather.

GRASS-COVERED BARS

The second group of bars is smaller and more irregular in shape than the bare transverse bars. They are 20 to 30 m long, having a width of 5 to 13 m and a relief of 20 cm. In plan view they vary from elongate to bean-shaped to circular to bifurcating to cresent-shaped (Figure 7A). Elongate bars make an angle of 45 to 90° with the shoreline, but other types have no preferred orientation. Elongate bars are also asymmetric in cross-section with a steep side landward and a gentle seaward slope. Bar crests are inhabited by salt-tolerant cordgrass, *Spartina alterniflora,* as well as crabs (including their burrows and piles of fecal pellets), clams, and mussels. Grass cover ranges from slight, in which patches of *Spartina* are just beginning to develop, to extensive thickets (Figure 7B), and in general the grass cover progressively increases on bars to the east.

These bars undoubtedly originated in the same manner as the bare transverse bars, but *Spartina* was able to colonize those of the quieter environs deeper into Toms Cove. The first plants to occupy a bar establish themselves mid-way along the bar's length (Figure 7C), that is, at some distance out from the upper foreshore and where sediment movement is minimal. Once established, the grass thickets modify water movement over and around the bars and thus alter their size, shape, and constitution. Grass blades baffle incoming waves, slowing and diverting them and accentuating sand deposition, and the extensive root system binds the sand, retarding its erosion and movement once deposited. Thus, grassy bars stand taller (5 to 10 cm higher), sorting of the sand is slightly poorer (moderately well sorted, $\sigma = 0.47 - 0.69\phi$, Figure 6), mud content is greater

Figure 7 (Next page). *a*, Bean-shaped bar mantled by salt cordgrass. *b*, Series of grass-covered bars extending along the beach of Toms Cove. Wild ponies graze on *Spartina alterniflora* in the middle foreshore. *c*, Thin patch of cordgrass beginning to develop on bar crest. Note lack of ripple marks in area stabilized by grass. Ruler is 30 cm long.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(2 – 7% versus 1 – 2%), and a small tombolo of sand and coarse shell debris, littered by dead grass and foam, connects each bar to the upper shoreface. Stabilization of the sediment also allows the immigration of sessile mussels. Those areas of the bars not populated by salt cordgrass are covered by small ripple marks (Figure 7C), further underscoring the stabilizing effects of *Spartina*, and the asymmetric profile of elongate bars hints that they were migrating before the grasses became established.

Incoming waves are deflected away from the seaward face of a grassy bar and around to its sides. The presence of asymmetric ripple marks indicates that sand is likewise moving slowly in these same directions. The bar thus grows sideways taking a circular or bean shape. With time these new areas of the bar are inhabited by cordgrass, and water movement is diverted further. Eventually, as this process continues, a bar can assume quite irregular shapes.

Channels between the grassy bars are covered by symmetric ripple marks. Like ripple marks elsewhere along the beach of Assateague Point, these have a ripple length of 4 to 5 cm, a height of 1 cm, and a ripple index of 5. In several areas, however, cordgrass from adjacent bars has overgrown the channels, forming large patches of *Spartina* that span as many as three bars and the intervening channels. These bars, therefore, have coalesced into a relatively large grass-covered structure.

Farther to the east bars disappear from the foreshore zone, and the entire beach is overgrown by a spacious meadow of cordgrass. Sediment movement here is essentially nonexistent.

SUMMARY

Transverse bars of Toms Cove develop on shorelines where the beach is protected from incoming waves. At mid-tide, waves refract around the seaward end of these bars, thus striking them from two directions. Analysis of surface ripple marks indicates that sand is slowly moving landward during each rise and fall of the tide. In particular, sand moves shoreward within the channels, up the flanks of the bars, and shoreward along their crests. Larger bars are asymmetric in profile and oriented at an oblique angle to the shoreline, suggesting that these bars are migrating due to a slight longshore transport.

On quieter regions of the beach, salt cordgrass (*Spartina alterniflora*) has stabilized the transverse bars. Blades of this grass baffle incoming waves, which accentuates sand deposition, whereas roots bind the sand, retarding its movement once deposited. Stabilized bars deflect waves around to the sides, and in this way grassy bars expand laterally into quite irregular shapes.

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