Reports

Virginia Barrier Island Configuration: A Reappraisal

Abstract. *The 12 Virginia barrier islands are divided into three groups on the basis of historical retreat rates and characteristics. The growth and reversal of inlet offsets is a long-term event that results from the operation of known coastal processes. Both geomorphic evidence and wave refraction analyses indicate that shoreline irregularity will diminish with time. There is no basis for the prediction (or expectation) that cape-like features will evolve along this shoreline.*

In an earlier report Dolan *et al.* (*1*) postulated that two capes will develop within 100 years along the barrier island chain on the eastern shore of Virginia in response to a theoretically trapped standing edge wave. The data base for these conclusions appears to have been derived from map illustrations prepared by Rice *et al.* (*2*). In this report we record the historical shoreline changes from 1852 to 1974 to demonstrate that the geomorphic responses to a southerly longshore transport of sediments, to shoreline retreat patterns, and to known coastal processes are sufficient to explain island behavior and the observed trends in shoreline configuration.

The Virginia barrier island chain may be divided into three groups of islands according to shoreline response (Fig. 1). Net shoreline changes and significant events during the past 122 years are schematically summarized opposite each of the island silhouettes. These representative data sets and recorded events were derived from sequential maps of shoreline change constructed from the Coast and Geodetic Survey and other federal government records (*2*).

Islands in the northern group have been experiencing parallel beach retreat during historical times. This sector of the barrier chain has been sediment-starved, while Fishing Point spit at the southern end of Assateague Island, updrift of this group, has served as a sediment trap and has grown at the rate of 6.5 km per century (*3*). Lack of sediment supply is reflected in the marked shoreline concavity or erosional arc of the northern group of islands. This configuration has remained essentially unchanged for the past 122 years, while the islands have retreated landward.

The retreat characteristics of the middle group of islands may be described as rotational instability. The term rotation is used to describe the effects of erosion and deposition in changing the shape and orientation of an island rather than an actual physical rotation of the island. This group of islands has pronounced offsets and inlets with large ebb-tidal deltas. Reversals in inlet offset, noted at both ends of Hog Island (Fig. 1), have been shown to be related to changing ebb-channel directions across the large ebb-tidal deltas (*2*).

Each of the islands in the southern group has experienced varied amounts of shoreline change. These islands have undergone changes in shape, and all, except Fishermans Island at the southern end of the longshore transport system, have been retreating toward the mainland. Retreat in this group of islands has been termed nonparallel because each island has exhibited a different response, due to variable causes (*2*). However, the general trend for the southern group of islands during historical times has been a steady reduction of their seaward convexity, leading to shoreline straightening.

The reasons for these shoreline retreat patterns along the barrier islands are generally understood and involve sediment supply, the underlying Pleistocene topography, tectonic movements, and wave refraction effects. Sediment supply, regulated by the net southward littoral drift as well as by local events, such as the opening of ephemeral inlets, has played a prominent part in individual island adjustments and in the response of the three island groups in general. The buried late Pleistocene topography beneath the barrier islands also influences inlet position and stability (*4*). These factors are discussed in (*5*).

Differential subsidence, ranging from 1.2 mm/year at Fishermans Island to 2.0 mm/year at the southern end of Assateague Island (*6*), indicates that tectonic movements have much potential to influence island development. Subsidence has had the same effect as a rise in sea level such that the northern barrier islands have been migrating landward at a more rapid rate than the southern islands. This pattern of retreat is also influenced by wave refraction over the inner continental shelf (*7*). There has been little focusing of wave energy on the northern group of islands and thus less change in island orientation in comparison to the other two island groups. The close proximity of the northern group of islands to the mainland (Fig. 1) indicates that the combination of diminished sediment supply, differential subsidence, and uniform wave attack has promoted steady retreat.

The middle and southern groups of islands are most affected by wave focusing; the results are clearly demonstrated in the middle group where large ebb-tidal deltas occur. Nearshore wave refraction (*8*) and attendant bar-bypassing of sediment (*2, 9*) around ebb-tidal deltas at inlets have contributed to pronounced modern downdrift offsets, at least one of which (Parramore Island) has been regarded as an evolving embryonic cape (*1*). In fact, similar downdrift offset inlets have been described for a number of different coastal environments including the Copper River delta in Alaska, the Massachusetts coast, the drumstick islands of South Carolina, and the eastern shore of Virginia (*2, 8–10*). There is a voluminous amount of data that indicates that wave refraction around ebb-tidal deltas results in downdrift offsets by creating a local reversal in drift direction, just downdrift of the inlet. This process leads to the accumulation of sediment that has been bypassed around the ebb-tidal delta. Operation of these processes at a major, stable inlet can, with sufficient time, cause the downdrift barrier to grow seaward adjacent to the inlet, thus producing an offset. Wachapreague Inlet at the north end of Parramore Island exhibits these characteristics, and Parramore displays the most pronounced offset in this barrier island chain.

Increases in island offset do not proceed uniformly or continue ad infinitum. Indeed, the reversal of offsets, or the growth of offsets, appears to be a normal, although long-term, phenomenon associated with dynamic adjustments of ebb channels, ebb-tidal deltas, and the two islands adjacent to the inlet. Offset reversals, such as those noted at both ends of Hog Island, took place after abrupt major changes in the location and direction of the ebb channel across the

 0036-8075/82/0115-0285$01.00/0

ebb-tidal delta. Adjustments that produced the modern reversed offsets of Hog and Cobb islands began in the late 1800's and have continued at a declining rate to the present (*2*). Similar reversals of island offsets have been reported for the Georgia barrier islands (*10*), the vicinity of Chatham Inlet on Cape Cod (*11*), and the Massachusetts and New Hampshire barrier beaches (*12*).

Geomorphic evidence indicates that the shoreline before the 1600's was more irregular than is evidenced in historical records since that time (*2, 5*). Pronounced, truncated beach ridges meet the modern shoreline at marked angles, particularly on Parramore and Smith islands. Italian Ridge on Parramore Island, a heavily forested ridge with as much as 6 m of relief, joins the modern shoreline at a 12° angle. Similar truncated beach ridges that meet modern coastlines at large angles are known from the barrier islands of the Florida panhandle and South Carolina. Island restorations extrapolated from ridges in the Virginia barrier islands indicate that past coastlines were more irregular than the present configuration (*2*).

True capes, such as Cape Hatteras, Cape Lookout, and Cape Fear in North Carolina, Cape Romain–Santee Point in South Carolina, and lesser capes at Tybee and Little St. Simons islands in Georgia, correspond to the discharge areas of ancient or present-day rivers (*13*). The concurrence of capes and rivers is too prevalent to be fortuitous. Hoyt and Henry (*13*) showed that capes did not develop under present conditions; instead, capes originated as river deltas on the continental shelf during the late Wisconsin stage of glaciation when sea level stood much lower than at present. During sea level rise, which accompanied glacial melting, deltas became the loci of prominent capes and associated barrier island systems. The present coastal configuration of these well-known capes can therefore be explained in terms of normal coastal processes and the erosion and retreat of formerly more extensive seaward-projecting capes (*13*).

It is clearly unnecessary to draw upon edge wave theory to explain cape development, as envisioned by Dolan *et al.* (*1*). In fact, Inman and his co-workers have not shown (*14*) that edge waves are a primary factor in shaping shorelines. The Virginia barrier islands are located along the open mid-Atlantic coast; it is highly unlikely that Assateague Island and Cape Charles could serve as effective headlands to trap a standing edge wave. Even if such edge waves were shown to exist, it is very difficult to conceive that the amplitudes of such postulated edge waves, which would be on the order of centimeters, would have much of an impact on the shoreline, given the other, much higher energy fac-

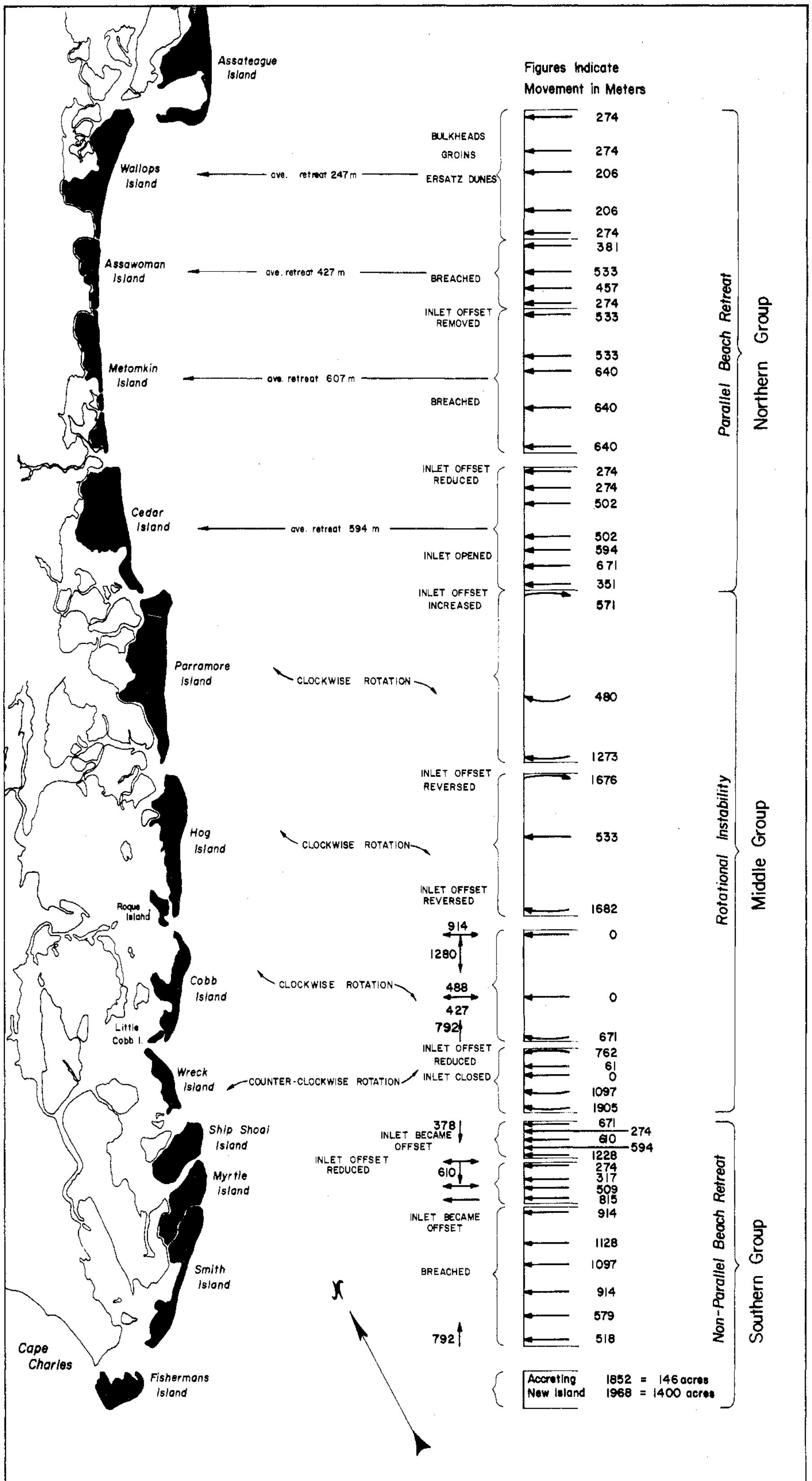

Fig. 1. The Virginia barrier islands may be divided into three groups. The rates of shoreline retreat and reorientation as well as significant geomorphic changes during the past 122 years are indicated (*2*).

tors. Finally, it is possible to match any spacing of edge waves with the scale of some feature (from 3-m beach cusps to 30-km capes) by picking a certain wave period and mode. Therefore, the choice of edge wave modal number 3 by Dolan *et al.* (*1*) has no special meaning and would have extremely low energy relative to lower number modes. In order to invoke edge waves to explain this kind of shoreline response, it is necessary to demonstrate how such long waves were caused and how they can persist at the same wavelength through highly variable infragravity wave input.

We must conclude that the present configuration of the eastern shore of Virginia is the result of a regime of shoreline retreat responding to temporal and spatial variations in well-understood and documented coastal processes. Process variations result from reduced sediment supply, vertical tectonic movements, long-term changes in wave refraction over the continental shelf, and an apparent influence of late Pleistocene drainage systems, all operating in the ubiquitous presence of a rising sea level. More localized geomorphic responses within the system can be related to their time of onset and prevailing weather, local episodes of erosion and rapid retreat, local variations in sediment supply, and changes in inlet morphology and dynamics. The published works of many investigators establish the importance of these factors and influences to the coastal processes maintaining barrier shorelines during retreat. The recorded changes in the configuration of the eastern shore of Virginia suggest that a smoother shoreline configuration, rather than emerging cape-like features, can be anticipated in the future.

STEPHEN P. LEATHERMAN
Department of Geography, University of Maryland, College Park 20742

THOMAS E. RICE
Department of Geology, University of Massachusetts, Amherst 01003

VICTOR GOLDSMITH
Earth Sciences and Resources Institute, University of South Carolina, Columbia 29208, and *Israel National Oceanographic Institute, Haifa*

References and Notes

1. R. Dolan, B. Hayden, C. Jones, *Science* **204**, 401 (1979).
2. T. Rice, A. Niedoroda, A. Pratt, in *The Virginia Coast Reserve Study* (Nature Conservancy, Arlington, Va., 1976), pp. 117–279.
3. M. Field and D. Duane, *Geol. Soc. Am. Bull.* **87**, 691 (1976).
4. J. C. Kraft, *ibid.* **82**, 2131 (1971); S. Halsey, in *Barrier Islands*, S. Leatherman, Ed. (Academic Press, New York 1979), pp. 184–210.
5. T. Rice and S. Leatherman, manuscript in preparation.
6. S. Holdahl and N. Morrison, *Tectonophysics* **23**, 373 (1974).
7. V. Goldsmith, W. Morris, R. Byrne, C. Whitlock, Report No. 38 (Virginia Institute of Marine Science, Gloucester Point, 1974) (NASA Report 358).
8. M. Hayes, V. Goldsmith, C. Hobbs, in *Proceedings of the 12th Coastal Engineering Conference* (American Society of Civil Engineers, New York, 1970), pp. 1187–1200; V. Goldsmith, R. Byrne, A. Sallenger, D. Drucker, in *Estuarine Research*, L. Cronin, Ed. (Academic Press, New York 1957), pp. 183–200.
9. D. FitzGerald, K. Hubbard, D. Nummedal, in *Proceedings of Coastal Zone 78* (American Society of Civil Engineers, New York, 1978), pp. 1973–1974.
10. G. Oertel, *J. Sediment. Petrol.* **47**, 1121 (1977).
11. V. Goldsmith, thesis, University of Massachusetts, Amherst (1972).
12. D. Hubbard, thesis, University of South Carolina (1974).
13. J. H. Hoyt and V. J. Henry, *Geol. Soc. Am. Bull.* **82**, 59 (1971).
14. D. Inman, C. Nordstrom, R. Flick, *Annu. Rev. Fluid Mech.* **8**, 275 (1976); R. Guza and D. Inman, *J. Geophys. Res.* **80**, 2997 (1975).
15. We acknowledge critical reviews by G. Oertel, R. T. Guza, J. M. Demarest, R. W. G. Carter, and D. FitzGerald.

13 June 1980; revised 20 October 1981

The Rise of Global Mean Sea Level as an Indication of Climate Change

Abstract. *Rising mean sea level, it is proposed, is a significant indicator of global climate change. The principal factors that can have contributed to the observed increases of global mean sea level in recent decades are thermal expansion of the oceans and the discharge of polar ice sheets. Calculations indicate that thermal expansion cannot be the sole factor responsible for the observed rise in sea level over the last 40 years; significant discharges of polar ice must also be occurring. Global warming, due in some degree presumably to increasing atmospheric carbon dioxide, has been opposed by the extraction of heat necessary to melt the discharged ice. During the past 40 years more than 50,000 cubic kilometers of ice has been discharged and has melted, reducing the surface warming that might otherwise have occurred by as much as a factor of 2. The transfer of mass from the polar regions to a thin spherical shell covering all the oceans should have increased the earth's moment of inertia and correspondingly reduced the speed of rotation by about 1.5 parts in 10^8. This accounts for about three quarters of the observed fractional reduction in the earth's angular velocity since 1940. Monitoring of global mean sea level, ocean surface temperatures, and the earth's speed of rotation should be complemented by monitoring of the polar ice sheets, as is now possible by satellite altimetry. All parts of the puzzle need to be examined in order that a consistent picture emerge.*

The ocean is a logical domain in which to search for evidence of climate change such as may be caused by increasing concentrations of atmospheric CO_2. Because the oceans are so closely coupled to the atmosphere and because of the very large heat capacity of the oceans, any climate change of global proportions will necessarily be reflected in oceanic conditions.

The two most readily identifiable measures of globally integrated oceanic conditions are the mean temperature and the volume of the oceans as reflected by the global mean sea level. It is not now feasible to monitor closely the mean temperature of the oceans. Even mean surface temperatures cannot now be determined with sufficient accuracy to detect unambiguously interannual or decadal variations. Improvements in satellite measurements of ocean surface temperature may, in time, remedy the major sampling problems of obtaining valid mean surface temperatures, but for the moment only conjectures about variations in the mean temperature of the oceans are possible. On the other hand, evidence of changes in the mean thermal state of the oceans can be found in changes of global mean sea level and may also be inferred from changes in mean atmospheric surface temperatures. Modeling experiments (*1*) strongly indicate that, in the absence of any changes in the mean ocean surface temperature, global mean surface air temperatures would not vary either.

There is consensus (*2*) that during the period between 1890 and 1940 the mean surface air temperature of the Northern Hemisphere rose between about 0.3° and 0.6°C (Fig. 1A). One cannot be certain that these estimates applied to the entire globe, since the Southern Hemisphere is only poorly represented in available data. For the sake of argument, however, we will assume that the lowest of these values (0.3°C) applies to the entire earth and also is representative of the upper mixed layer of the ocean. Because the upper waters of the ocean are not wholly uncoupled from the deeper layers, we will also assume that any slowly

0036-8075/82/0115-0287$01.00/0