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Coastal Processes

High-altitude aerial photographs aid in investigations.

ABSTRACT: *Along sandy coasts the configuration of the shoreline is seldom straight, but rather crescentic in plan view. Crescentic forms can serve as indicators of beach and inshore bar-trough relationships, as well as places along the coast where surge and overwash may focus during storms. The increased availability of high-altitude aerial photographs offers, for the first time, a data source for the investigation of crescentic features of sandy coasts.*

INTRODUCTION

THE INCREASED availability of high-altitude aerial photographs provide an excellent opportunity for the coastal investigator to monitor changes in shoreline features at scales that were previously only occasionally used. If combined with the low-altitude photographs and ground surveillance, high-altitude imagery provides a valuable tool for engineering design and resource planning, as well as for studies of beach processes.[2] This paper considers a specific application—the measurement of crescentic shoreline features.

Shorelines have long been considered by geomorphologists and engineers in terms of straight lines, or along rocky coasts, forms which eventually develop into straight lines. Erosion clearly leads to straighter shorelines; however, sufficient data have now accumulated from aerial photographic studies to indicate that sand beaches are seldom straight, but consist of sinuous curves, with spits and bars protruding out into the inshore zone.[3] The crescentic forms have acquired the descriptive names *sand waves* and *shoreline rhythms* (Bruun, 1954; Hom-ma and Sonu, 1962; Bakker, 1968; Sonu and Russell, 1966; Dolan and Ferm, 1968; Zenkovich, 1967; Dolan, 1971; Komar, 1971, and Sonu, 1972), and generally occur as fields of en echelon points and embayments (Figure 1). The seaward projections and landward embayments are subaerial manifestations of transverse bars-and-troughs. The crescentic configuration, coupled with the uniform sizes and dynamics of the sand waves, confirms that sandy coastlines respond to a system of interrelated processes, and are not always randomly distributed irregularities which depend on local conditions. Therefore, it is essential to have a data source, such as high-altitude photographs, which provides a regional integrated view of these complex systems.

Crescentic coastal landforms are of more than academic importance. Many of the morphologic and sedimentologic characteristics of sand beaches are associated directly with the rhythmic configuration. Research near Cape Hatteras, North Carolina, shows that

[1] Assistance of the Geographic Applications Program, U.S. Geological Survey, and the National Aeronautics and Space Administration, Chesapeake Bay Ecological Program, Wallops Island, Virginia is gratefully acknowledged.

[2] High-altitude photographs have been used extensively to survey the geomorphology and hydrology of large areas. Recent examples of detecting and interpreting selected features in North Carolina and Arizona include the works of Sapp (1970) and Mairs (1970).

[3] For an excellent review of the application of large-scale aerial photography in coastal research, reference is made to: C. J. Sonu, "Study of Shore Processes with Aid of Aerial Photogrammetry," Photogrammetric Engineering, Vol. 30, No. 6, pp. 932–941, 1964.

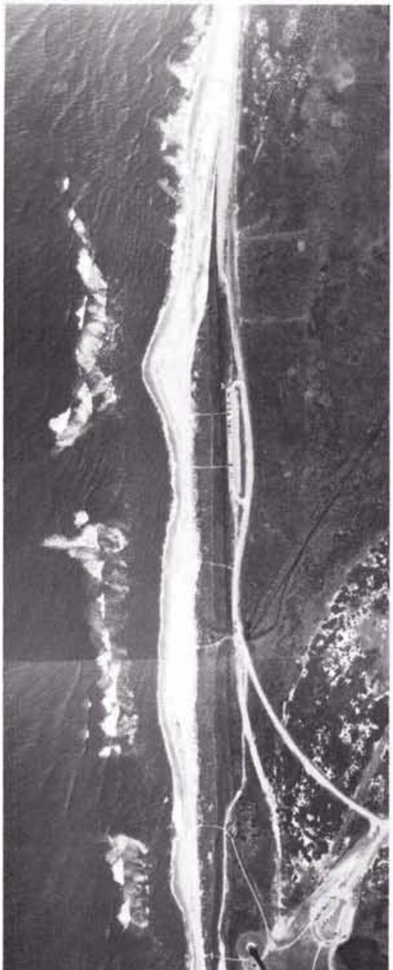

FIG. 1. Sand wave field near Cape Hatteras, North Carolina.

the width, slope, and even the sediment size of the beach all vary in relation to positions within individual crescentic forms. This relationship explains much of the hitherto unexplained variance that investigators have found in correlation between wave action, as measured offshore, and beach characteristics.

Submarine bars associated with the sand waves have deep-water channels immediately offshore from embayments. Depressions in the bars allow higher waves to penetrate closer inshore, breaking on the beach face rather than on the bar. These channels and the offshore bar system can be seen on aerial photographs by comparing the shoaling of the incoming breakers with the sand wave field (Figure 2). Thus, the focus of destructive storm surge and overwash along barrier islands is related to the field position rather than by chance variation in the submarine bars or low places in the barrier dunes (Dolan, 1971).

THE PHOTOGRAPHS

Several sets of high-altitude photographs have been taken of the middle Atlantic coastal region. Five sets are now available of the Cape Hatteras area since 1968, and most of the barrier islands of Virginia and North Carolina are scheduled to be photographed by U-2 aircraft every 18 days under the NASA-USGS CARETS program. Commencing in 1972, space imagery of ERTS-I will provide regular coverage of the mid-Atlantic coast.

Although the types of imagery available to secondary users depend on the agency and the objectives of the original NASA- and USGS-funded projects, color-infrared is available from most of the NASA-USGS aircraft missions.[4] The high-altitude photographs are taken by reconnaissance aircraft, RB-57's and U-2's. Although the aircraft program is presently considered experimental, it is expected to continue in a complementary role to the ERTS and *Skylab* satellite platforms. The scales most frequently requested by investigators are 1:60,000 and 1:120,000.

On photographs at a scale of 1:60,000, one inch represents slightly less than one mile, or approximately the scale of standard USGS quadrangle maps. At a scale of 1:120,000, one inch represents two miles, so the standard 9 × 9-inch negative covers an area of 324 square miles (18 by 18 miles) as compared to 81 square miles for 1:60,000. The same area with lower-altitude photographs

[4] Three recent papers published in *Photogrammetric Engineering* discuss the use of color aerial photography: "Color for Metric Photogrammetry" (Vol. 34, No. 3, pp. 265–272, 1968); "Coastal Hydrography" (Vol. 34, No. 1, pp. 44–42, 1968); and "Color Photography for Water Resources Studies" (Vol. 34, No. 3, pp. 246–265, 1968).

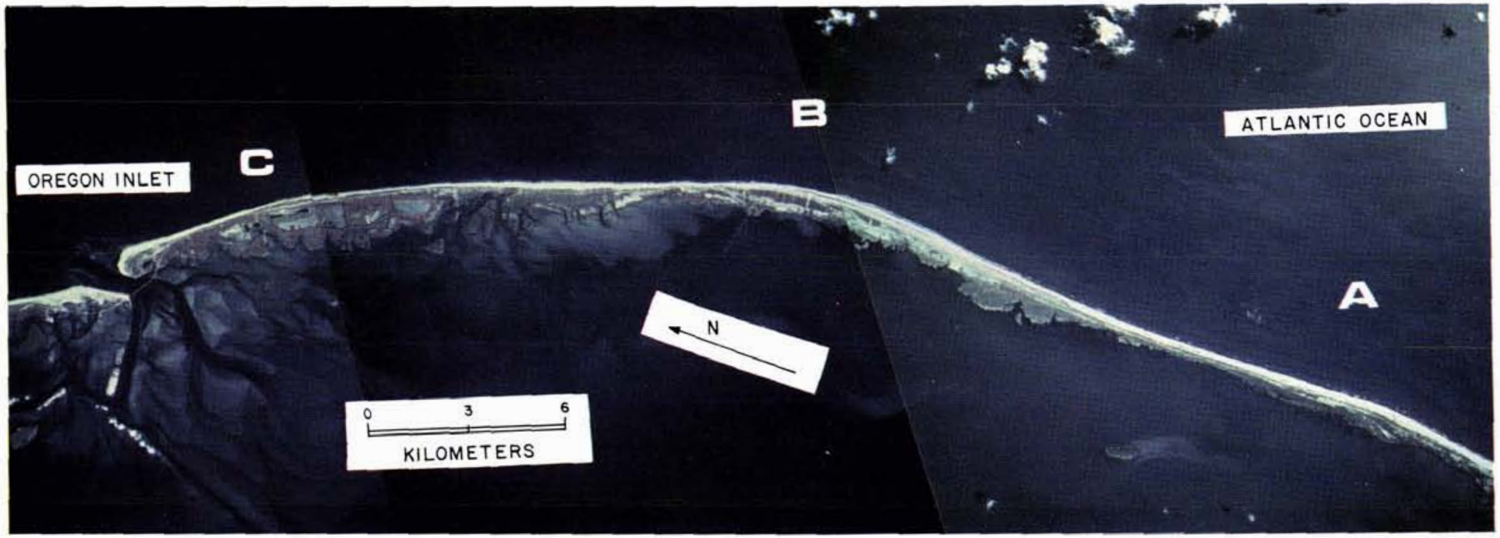

PLATE 1. High-altitude photographs at a scale of 1:120,000 provide a base for investigation of large-size crescentic landforms. Near Oregon Inlet, North Carolina, crescentic features, both concave and convex, of size 15 to 20 kilometers are recognizable from the photographs (*AB* and *BC*). Under magnification smaller scale features are evident at *B*.

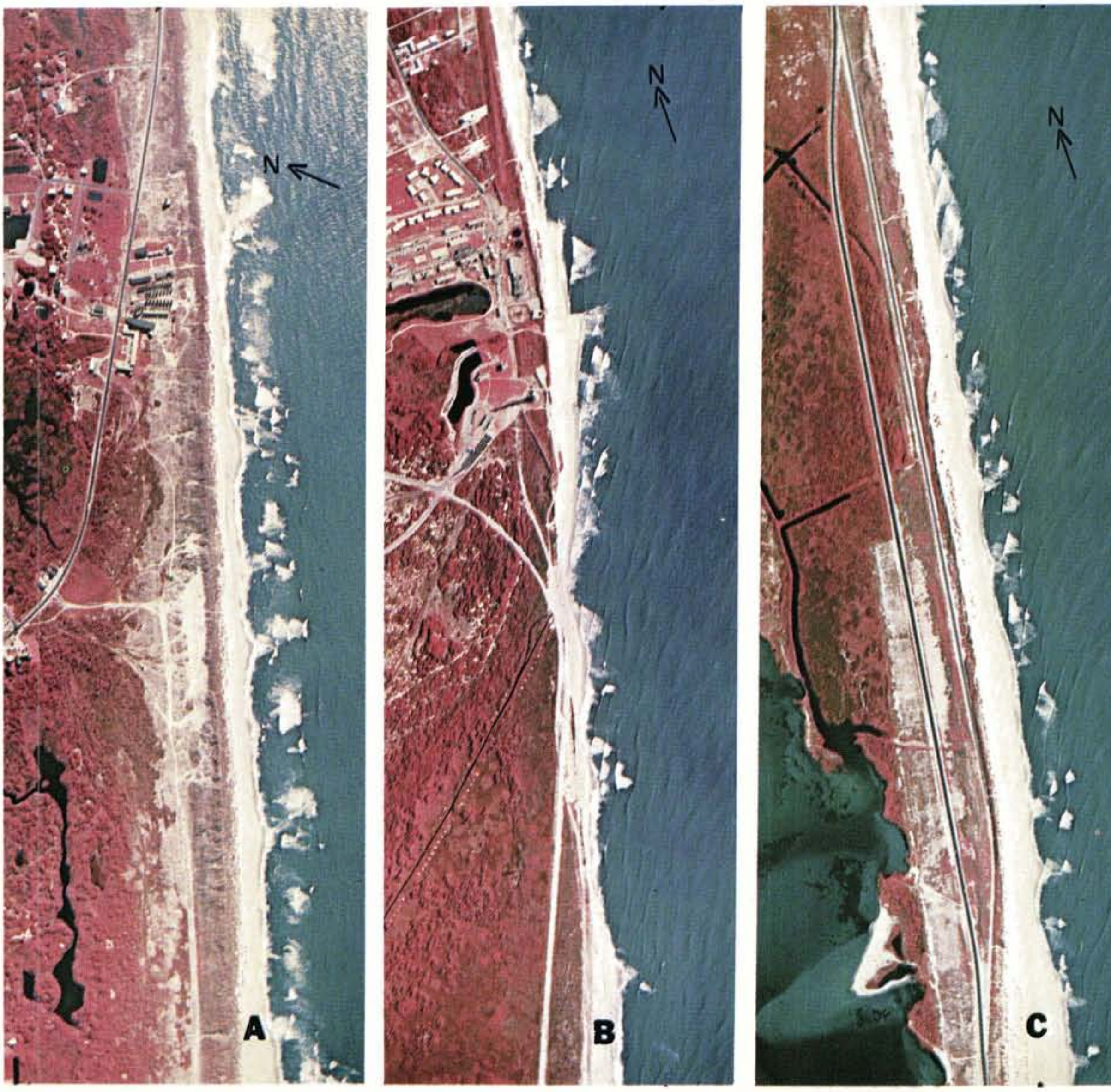

PLATE 2. Aerial photographs at a scale (original) of 1:10,000 provides sufficient resolution for measurement of shoreline sand waves. The spacing of the crescentic forms near Hatteras Village, North Carolina, *A* is 1,500 feet. Near the Cape Hatteras Lighthouse *B*, the spacing ranges from 508 to 1,500 feet. The combination of large- and small-scale aerial photography provides the coastal investigator with an excellent range of resolution for measurement of crescentic ladnforms.

FIG. 2. Concern about erosion may depend upon the relation between the structure location and the sand wave position. The Cape Hatteras Lighthouse is vulnerable at the time of this photo, but the large mass of sand in the foreground will migrate toward the point and the Lighthouse will then be secure for a time.

(1:20,000) would require 36 9×9-inch negatives.

The quality photographic films used in the NASA high-altitude photographs provide amazing degrees of resolution. Magnification in excess of $10\times$ can be used for detailed measurements. The range of measurement possible on the photography is well within the error, due to distortion, inherent in the photograph.

THE ANALYSIS

Sequential measurements of the rhythmic features in the Cape Hatteras and Cape Lookout National Seashore areas indicate the following attributes. (1) Sand wave lengths range from 150 to 1000 meters, with most between 500 and 600 meters. (2) Wave amplitudes average about 15 to 25 meters and may reach amplitudes of 40 meters. (3) Although the question of movement of the sand wave field along the beach is still under investigation, the rate of change is clearly a function of wave energy, and thus greatest during the stormy winter season along the mid-Atlantic.

Crescentic coastal landforms, as described by their wave lengths and amplitudes, occur throughout the world. Their dimensional range also seems to be consistent, not only along the Atlantic, but for all coasts. Thus, the sand shorelines should not be viewed as straight lines but rather as a sinuous rhythmic line which may be nonstationary, tending to migrate along the coast. Dolan (1970) has shown that stable shoreline conditions may change rapidly toward less stable conditions as the crescentic forms advance along the shore. As long as the wide part of the form is positioned seaward of the structure, the structure may seem secure from erosion. However, as the crescentic forms move along the coast the same structure may become vulnerable to wave forces if positioned near the embayment where waves break at the beach. The Cape Hatteras Lighthouse, shown in Figure 2, is an excellent example. This change in stability can occur without significant changes in wave or tidal conditions.

Therefore, positions of the shoreline, relative to any development, are not only determined by processes responsible for along-the-shore shoreline change. This variation is best determined from aerial photographs, ranging in scale from 1:30,000 to 1:100,000. The smaller scales provide the coastal investigator with a clear view of regional relationships between crescentic segments of the shoreline.

In some areas a distinct hierarchical nesting of sand features seems to occur, with smaller crescentic features grouped within larger ones (Dolan and Ferm, 1968). Plate 1 illustrates this nested relationship. The 1:60,000 NASA color-infrared photo shows several large crescentic trends which, if magnified, show smaller crescentic forms. Figures 1 and 2 show examples of the intermediate sized sand waves.

In addition to the high-altitude photographs, the National Aeronautics and Space Administration, through regional centers along the Florida and Mississippi coasts, and at Wallops Island, Virginia, do provide high-quality, low-altitude photographs at scales of about 1:10,000 to 1:20,000 for selected investigations. Low-altitude color-infrared photographs of the barrier islands of Virginia and North Carolina have been used for examination of the hierarchical nesting of crescentic forms at different scales (Plate 2). Although the high-altitude imagery provides the large, regional overview, photographs at lower altitudes permits a finer analysis of the hierarchical nesting of smaller features, such as beach cusps, found within the crescentic features.

Conclusions

A significant amount of information concerning the state of the coastal environment can be obtained from high-altitude aerial photographs. By comparing photographic sequences, averaged conditions as well as rates of changes can be established. In addition, regional relationships provide an integration of the processes and sand responses occurring along the coast. For the most effective use of remote sensing, these data should be carefully coupled with lower-altitude photographs and ground-truth systems (Front Cover); however, remote sensing is the only method currently available for investigating the aerial and temporal distributions of crescentic coastal features.

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