05

E76-10266
CR-146567

Special

ABSTRACT

SHORELINE CONFIGURATION AND SHORELINE DYNAMICS: A MESO-SCALE ANALYSIS

Atlantic coast barrier-island shorelines are seldom straight, but rather sinuous in plan view. These shoreline curvatures range in size from cusps to capes. Significant relationships exist between the orientation of shoreline segments within the larger of these sinuous features (10 to 15 km between apexes) and shoreline dynamics, with coefficients ranging up to .9.

Orientation of the shoreline segments of Assateague Island (60 km) and the Outer Banks of North Carolina (130 km) was measured from Landsat II imagery (1:80,000) and high-altitude aerial photography (1:120,000). Long-term trends in shoreline dynamics were established by mapping shoreline and storm-surge penetration changes from historical aerial photography spanning four decades.

NAS 5-20999

21240

(E76-10266) SHORELINE CONFIGURATION AND SHORELINE DYNAMICS: A MESOSCALE ANALYSIS (Virginia Univ.) 22 p HC $3.50 CSCL 08J

N76-21633

Unclas

G3/43 00266

SHORELINE CONFIGURATION AND SHORELINE DYNAMICS: A MESOSCALE ANALYSIS

R. Dolan

B.P. Hayden

J.E. Heywood

Department of Environmental Sciences

University of Virginia

Charlottesville, Va., 22903

INTRODUCTION

Sand beaches and barrier islands are seldom long and straight over extensive reaches, as described at one time by Professor R.J. Russell (1958), but rather sinuous when viewed in plan. These longshore variations in shoreline form occur as organized patterns with features or curvatures ranging in size from beach cusps to very large shoreline meanders.

Crescentic coastal landforms are dynamic and respond readily to varying sea state, tides, and sea level. The smaller ones appear, disappear, and migrate along the shoreline, and the large features establish the spatial context for along-the-shore distribution of erosion and storm overwash processes. Although efforts are underway to formulate a theoretical framework for the processes responsible for longshore topographic variation, empirical research is needed to characterize shoreline features in terms of their distribution in time and space.

We have developed a monitoring system based on Landsat II imagery and high-altitude aerial photography that provides

---

This research is being conducted under sponsorship of the National Aeronautics and Space Administration, Landsat II, Follow-on Investigation 21240, Contract No. NAS5-20999.

excellent spatial and temporal data on large-scale crescentic shoreline features. The test site for this investigation includes the barrier islands of the mid-Atlantic coast (Fig. 1).

BACKGROUND

Since the 1960's there has been a rapid increase of interest among coastal investigators in longshore variations in inshore processes and their relationship to rhythmic and crescentic beach morphology, shoreline erosion, and overwash processes (Bruun 1954, Hom-ma and Sonu 1962, Dolan and Ferm 1968, Dolan 1971, Komar 1971, Bowen and Inman 1971, Sonu 1972, Dolan, Vincent, and Hayden 1974, Guza and Inman 1975, and Dolan and Vincent 1976). In 1954 Bruun's analysis of coastal bathymetry of the Danish North Sea exhibited a meandering pattern of offshore contours. He interpreted this to signify that the nearshore zone was not planar but had transverse and longitudinal bars which migrated much like those found in river channels. These rhythmic or meanderlike patterns occurred in the shoreline as well. Hom-ma and Sonu's (1962) investigation of the inshore zone in Japan indicated that the bar patterns were often crescentic with horns pointing to or joining the shoreline. The beach areas where the horns reached the shore had a rhythmic pattern.

Dolan and Ferm (1968) indicated that rhythmic longshore variations in the sandy shorelines occurred in a hierarchical pattern, the elements of which were often superimposed. The elements included (1) small cusps, or cusplets, only a meter across, (2) beach cusps which were up to tens of meters in length, (3) giant beach cusps, or shoreline sand waves, from 100 to 3,000 meters in length, (4) secondary capes 25 to 50 kilometers apart, and (5) capes 100 to 200 kilometers apart (Fig. 2). Larger crescentic coastal landforms are important in determining where the maximum power of storm surges and storm erosion occurs (Dolan 1971).

Recent research has described processes responsible for features of the size classified as shoreline sand waves or shoreline meanders. Komar (1971) hypothesized that sediment transport by rip currents was a possible mechanism. Bowen and Inman (1971) suggested that edge waves in the surf zone were the cause of crescentic bars and possible giant beach cusps. Sonu (1972) studied the circulation within one sand-wave cell and indicated that the topography might cause the circulation rather than the reverse.

Of the wide range of rhythmic and crescentic shoreline forms, those classified by Dolan (1971) as shoreline sand waves and secondary capes are the most significant in determining where the rapid environmental changes occur along sand beaches and barrier islands.

THE HYPOTHESIS

If large scale crescentic coastal landforms are associated in time and space with inshore processes of similar scale, then it is reasonable to assume that there should be a measurable relationship between the spatial distribution of shoreline forms and manifestations of shoreline dynamics (Fig. 3). This investigation was designed to test whether or not a significant correlation exists between orientation of shoreline segments (up to 10 km. in length) within larger sinuous features and shoreline dynamics. Orientation of shoreline segments along Assateague Island (60 km) and the Outer Banks of North Carolina (130 km) was measured from Landsat II imagery (1:80,000 and 1:250,000) and high-altitude aerial photography (1:120,000). Long-term trends in shoreline dynamics were established by mapping shoreline and storm-surge penetration changes from historical aerial photography spanning four decades.

Our investigation is based on the interpretation of imagery of three different scales: low-altitude metric photography at scales ranging from 1:5,000 to 1:40,000; high-altitude metric photography at 1:120,000; and Landsat II imagery enlarged to 1:80,000 and 1:250,000.

MEASURING HISTORICAL CHANGE

Since our concern is with monitoring change in coastal landforms and establishing shoreline dynamics through time, we developed a method which enables rapid comparison of photographs taken of the same area at different times.

With varying scales of historical aerial photography and the need to measure relatively straight segments of otherwise curved shoreline, base maps at the scale of 1:5,000 were produced that divided the coastline into segments of 3.6 km. The base maps were drawn from enlarged sections of the most recent 7.5-minute series USGS topographic maps. The frame of each map is oriented with the long side parallel to the coastline and positioned over the barrier island so that the shoreline and vegetation line fit within the frame. The long side of the frame, lying entirely over the ocean, then becomes the base line from which all measurements are made (Fig. 4).

For each base map, aerial photographs are enlarged until the best possible fit of natural and cultural features between photo and base map is obtained. The shoreline and storm-overwash penetration line or vegetation line are then drawn on an overlay map. This process is repeated for each historical photograph of the same area.

The shoreline was defined as the high-water mark. The storm-overwash penetration line was defined by a smoothed line that separates the beach and dune sand or lightly vegetated sand flats from the relatively contiguous stands of dense vegetation. Alternatively, the grass line closest to the beach may be defined as the vegetation line.

Using an orthogonal grid system with transects spaced at 100-meter intervals along the coast, the points at which the shoreline and the vegetation line intersected each across-the-shore transect were recorded to the nearest 5 meters.

A computer program has been written which lists the following information for every base map (statistics include mean, variance, standard deviation, number of transects over which mean is calculated, maximum value, and mininum value).

1. Location of vegetation line (VL), shoreline (SL), and overwash-penetration distance (OP = VL - SL) for each of the 36 transects along the coast.
2. Line-printer graphs of VL, SL, and OP.
3. Changes and rates of change in VL, SL, and OP between selected dates (erosion and accretion statistics).
4. Line-printer graphs of rates of change in VL, SL, and OP.
5. Line-printer graphs of the mean + one standard deviation of rate of change in VL, SL, and OP (Fig. 5).

In addition, the following information is provided for sections of the coast of any desired length:

1. Statistics on OP for each year and statistics on changes and rates of change in VL, SL, and OP between any two years.
2. Frequency distributions of OP for each year and of rates of change of VL, SL, and OP between any two years.

MEASURING SHORELINE FORM

To answer questions concerning the angularity of the shoreline segments within the larger crescentic forms images

250,000 are needed. Landsat II imagery is ideal for this purpose. Since concern is with long stretches of coastline and large crescentic landforms, the relatively low resolution of the Landsat imagery is acceptable. The orthogonal accuracy of Landsat imagery is important and difficult to achieve with aerial photography.

By experimenting with enlargements of the 70-mm Landsat negatives, we are able to control the amount of "noise" one perceives in angular orientation along the coast. The method we are now using is simple, and it does not call for sophisticated equipment or digital processing of raw Landsat data. The steps are:

1. A photographic print is made from a 70-mm negative of Band 7 of a cloud-free Landsat image of the coastal area under study at a scale from 1:250,000 to 1:80,000.
2. A straight edge is placed along each straight-line segment of the coast as perceived by the mapper, and a line is drawn on an overlay. The point of intersection of adjacent lines is called a "node" and marks the location of change in angularity of the coastline (Fig. 3).
3. Lengths of these line segments are measured and their angular orientations with respect to the north/south line are recorded.

4. Each node is located to the nearest 100-meter transect previously defined in the discussion on historical data collection. The nodes then define the location of each straight-line segment along the coast.

A certain amount of subjectivity and user judgment is incorporated into this method; therefore, steps 2 through 4 are repeated at least 5 times. Different people perform the same operation to reduce mapper bias. These data are then put into digital format compatible with the computer program written for the historical analysis. The length and angularity of each straight-line segment is assigned to each transect within that segment.

ANALYSIS AND RESULTS

Figure 6-A illustrates the magnitude of shoreline erosion along Assateague Island from Chincoteague Inlet to Ocean City Inlet. The mean rate of erosion plus one standard deviation measured from low-altitude aerial photography spanning the last three decades is shown. Peaks represent sections of the coast where extremes in erosion and storm-surge penetration have taken place at some point in time and therefore indicate points of high vulnerability to future storm-surge penetration.

Figure 6-B shows shoreline form, or angular orientation, as determined from Landsat imagery. These data were taken from a single image of a Landsat pass on 31 May 1975, No. 2129-15021, Band 7, enlarged to 1:250,000. Each break in the line

represents a point on the coast where a relatively straight trend of the shoreline changes direction.

Visual comparison of the distribution of shoreline erosion and coastal angularity indicates that the major erosional and storm-overwash areas are associated with changes in angular orientation. Furthermore, in most cases, the closer the shoreline trends approach a north/south orientation, the greater the recession rates. This result was expected since the maximum energy gradient for the mid-Atlantic coast is north/northeast.

We are currently in the process of refining our computer programs to run scatter plots, regression analyses, and tests of variances and residuals for correlation statistics between various expressions of shoreline form and coastal erosion. Results obtained from the initial program are promising. Correlation between the angular orientation of a straight-line segment of coast and the recession of that entire segment is tested for each sample. For example, when a Landsat image of Assateague Island enlarged to 1:80,000 was used for analysis, 15 straight-line segments of the coast were defined in one sample. The correlation coefficient (r) between coastal orientation (degrees north of east) and shoreline recession (mean + one standard deviation, meters/year) was .44. When a smaller enlargement of 1:250,000 was used, 9 segments were defined and r increased to .94 (Fig. 7). Thus by increasing the scale of a Landsat enlargement, smaller crescentic features appear which are not related to the mesoscale processes and the correlation coefficient is reduced.

of New Jersey to better determine the effect of man's presence on the naturally changing coatline. We will also investigate questions concerning the rotation of angular orientation of relatively straight segments within the crescentic landforms and shifts in the location (north or south) of those nodes where the straight segments change direction or intersect. If these changes can be detected, we may be able to predict the shifting of vulnerability zones.

We are convinced that the combination of historical data and shoreline-form analysis from the three levels of remotely sensed imagery utilized in this investigation can provide a powerful tool for coastal zone managers.

REFERENCES

BOWEN, A.J., and INMAN, D.L., 1971, Edgewaves and crescentic bars: Journal of Geophysical Research, v. 76, n. 36, p. 8667-8671.

BRUUN, P., 1954, Migrating sand waves or sand humps, with special reference to investigations carried out on Danish north seacoast: Proceedings 5th Conference on Coastal Engineering, p. 460-468.

DOLAN, R., 1971, Coastal landforms; crescentic and rhythmic: Geologic Society of America Bulletin, v. 82, p. 177-180.

DOLAN, R., and FERM, J.C., 1968, Crescentic landforms along the Atlantic coast of the United States: Science, v. 159, p. 627-729.

DOLAN, R., VINCENT, C.L., and HAYDEN, B.P., 1974, Crescentic coastal landforms: Zietschrift fur Geomorphologie, v. 18, n. 1, p. 1-12.

GUZA, R.T., and INMAN, D.L., 1975, Edge waves and beach cusps: Journal of Geophysical Research, v. 80, n. 21, p. 2997-3012.

HOM-MA, M., and SONU, C., 1962, Rhythmic pattern of longshore bars related to sediment characteristics: Proceedings 8th Conference on Coastal Engineering, p. 248-278.

KOMAR, P.D., 1971, Nearshore cell circulation and the formation of giant cusps: Geologic Society of America Bulletin, v. 82, p. 2643-2650.

______, 1971, The mechanics of sand transport on beaches: Journal of Geophysical Research, v. 76, n. 3, p. 713-721.

RUSSELL, R.J., 1958, Long, straight beaches: Ecologae Geologicae Helvetiae, v. 51, p. 592-98.

SONU, C.J., 1972, Field observation of nearshore circulation and meandering currents: Journal of Geophysical Research, v. 77, n. 18, p. 3232-3247.

VINCENT, C.L., and DOLAN, R., 1976, Shoreline meandering; Hatteras Island, North Carolina: Geologic Society of America Bulletin, in press.

FIGURE CAPTIONS

Fig. 1. Barrier islands of the mid-Atlantic coast.

Fig. 2. Large-scale shoreline meanders.

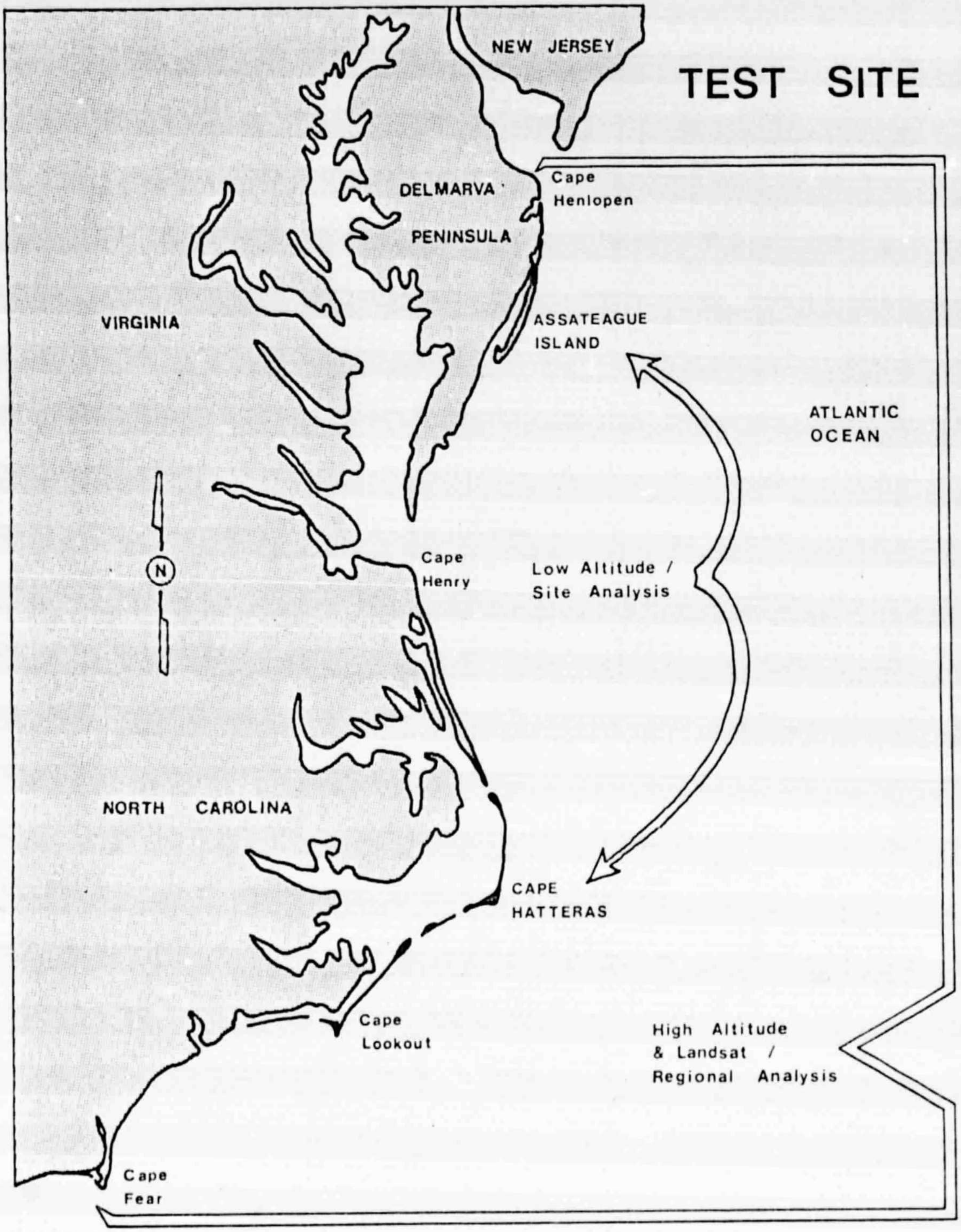
Fig. 3. Shoreline form and shoreline dynamics.

Fig. 4. Method for utilizing historical photography, base maps, and a grid-address system.

Fig. 5. Computer output of historical shoreline change.

Fig. 6 Areas of high erosion and storm-surge penetration are closely associated with changes in shoreline orientation.

Fig. 7. Correlation of coastal erosion and shoreline orientation for Assateague Island.



ORIGINAL PAGE IS
OF POOR QUALITY

Fig 1

METHOD OF DATA COLLECTION

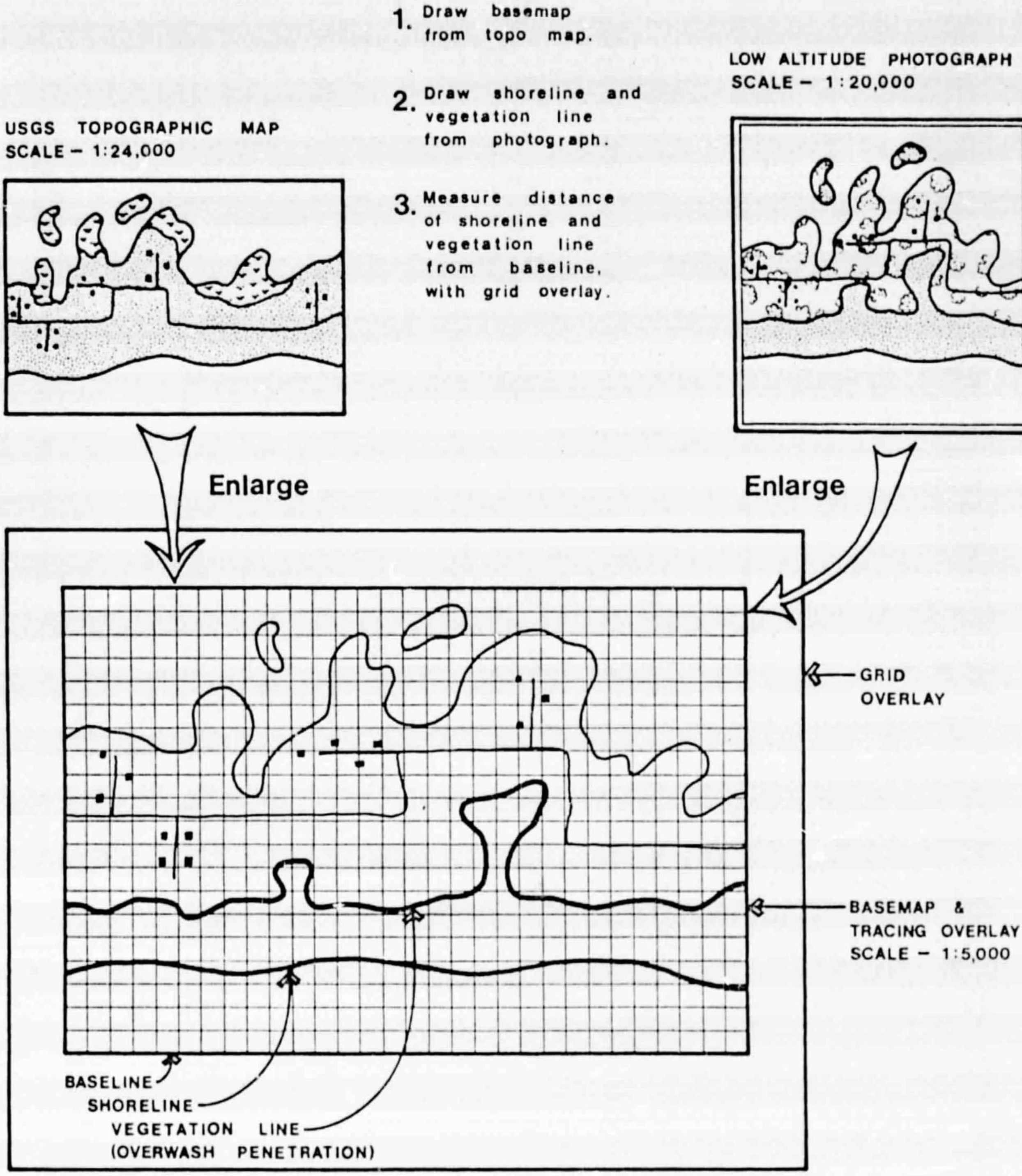
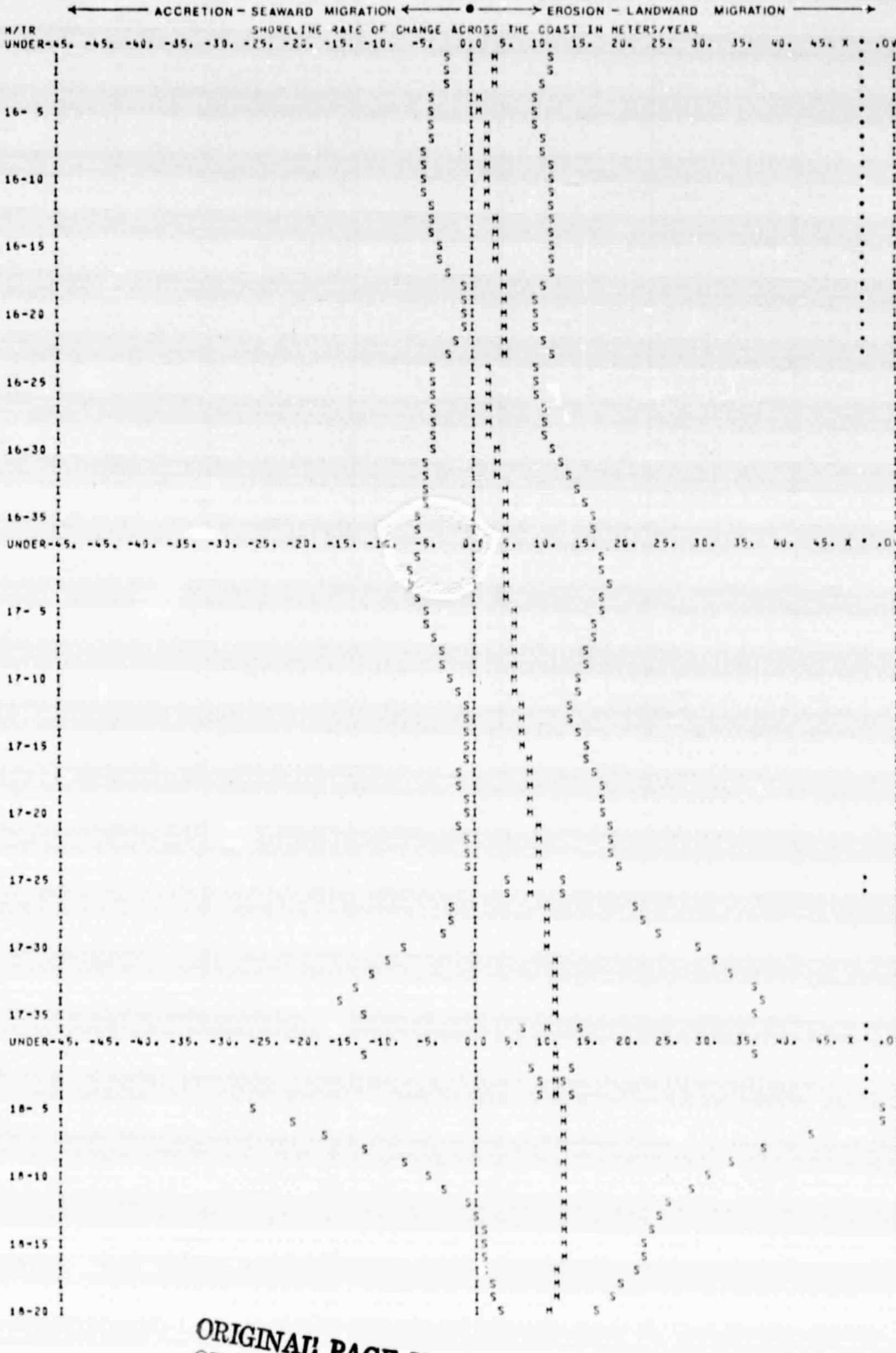


Fig 4

M = MEAN RATE OF CHANGE, FROM 02JUN38 TO 04JUN74 (36.00 YEARS).
S = ONE STANDARD DEVIATION FROM THE MEAN.
* = MEAN AND STANDARD DEVIATION WERE CALCULATED OVER A TOTAL TIME PERIOD LESS THAN 36.00 YEARS DUE TO ABSENCE OF DATA.
M/TR = MAP AND TRANSECT NUMBER. EACH TRANSECT REPRESENTS A DISTANCE OF 100 METERS ALONG THE COAST.



M/TR	MEAN	S.D.
	3.3	6.2
	3.3	6.4
	3.2	6.2
	1.2	6.6
16- 5	1.4	6.5
	1.5	6.9
	1.8	7.0
	1.9	7.5
	2.0	8.0
16-10	2.1	8.3
	2.2	8.1
	2.4	7.7
	2.6	7.6
	2.9	7.4
16-15	3.1	6.9
	3.3	6.9
	3.5	6.1
	3.7	5.0
	3.7	4.4
16-20	3.7	4.5
	3.7	4.5
	3.7	5.5
	3.7	6.3
	1.5	6.6
16-25	1.6	6.6
	1.7	6.6
	1.8	6.8
	2.1	7.2
	2.3	7.1
16-30	2.6	7.8
	2.8	8.4
	3.2	8.8
	3.6	9.5
	3.9	9.9
16-35	4.1	10.6
	4.2	11.2
.OVER 45		
	4.2	11.5
	4.2	12.1
	4.2	12.5
	4.4	11.6
17- 5	4.7	11.0
	4.9	10.6
	5.1	9.7
	5.2	9.1
	5.3	8.8
17-10	5.3	8.0
	5.4	7.2
	5.6	6.4
	5.8	6.6
	6.1	7.1
17-15	6.3	7.3
	6.5	7.6
	6.8	8.6
	6.9	8.8
	7.1	8.6
17-20	7.3	8.7
	7.6	9.2
	7.7	9.2
	7.9	9.2
	8.2	9.5
17-25	7.3	3.4
	7.4	3.5
	8.8	11.3
	8.9	11.9
	9.1	13.4
17-30	9.3	18.4
	9.5	20.6
	9.7	22.3
	9.8	25.2
	9.9	26.4
17-35	10.1	24.5
	9.4	3.4
.OVER 45		
	10.4	24.7
	9.5	2.3
	9.5	1.5
	9.9	1.8
18- 5	11.0	33.3
	11.1	34.5
	11.2	30.6
	11.4	25.0
	11.4	20.6
18-10	11.4	17.8
	11.4	15.3
	11.4	12.8
	11.3	11.4
	11.2	10.6
18-15	11.0	10.2
	10.7	10.1
	10.3	9.5
	10.0	8.2
	9.5	7.4
18-20	8.9	6.3

Fig 5

SHORELINE FORM VS. EROSION FOR ASSATEAGUE ISLAND

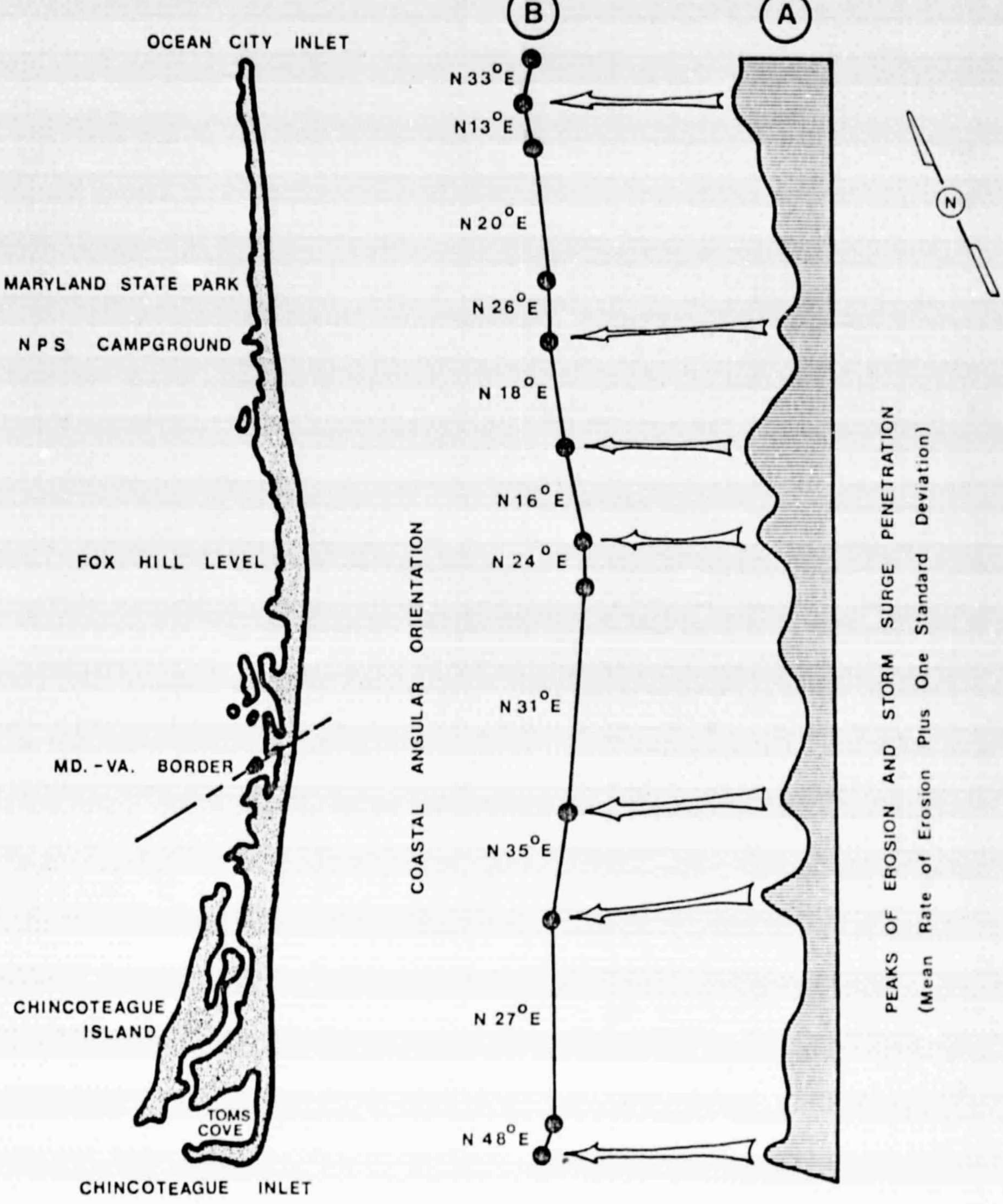


Fig 6