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Evolution of Tidal Inlet - Drainage Basin Systems

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ABSTRACT

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As well as causing estuarine shorelines to move landward, rising sea level modifies the small tidal inlet - drainage basin systems that fringe estuaries. The small tidal inlet - drainage basins on the Potomac River and nearby Chesapeake Bay are examples of an evolutionary sequence that progresses from larger, generally free flowing inlets, through smaller inlets which significantly modify the estuary's tidal characteristics, to ephemeral inlets associated with enclosed ponds. Shallow seismic data and vibracores demonstrate that a rising sea level drowns a drainage basin and reduces the basin's area. Consequently the tidal prism is decreased and the associated inlet moves toward the next evolutionary type.

ADDITIONAL INDEX WORDS: *Inlet, estuary, coastal marsh, sea-level rise, seismic data, tidal prism, vibracore.*

INTRODUCTION

There are numerous studies of tidal inlets relating the cross-sectional area of the inlet to the tidal prism (ESCOFFIER, 1940; BRUNN, 1967, 1978; O'BRIEN, 1969; O'BRIEN and DEAN, 1972; BYRNE *et al.*, 1974; JARRETT, 1976; and many others). Many of the researchers have found and reported upon variations in the throat-cross-sectional-area to tidal prism relationship with decreasing, usually less than 500 m^2, cross sectional area. In their Chesapeake-Potomac study area BYRNE *et al.* (1980a, b) distinguished three distinct types of small, tidal inlet - drainage basins.

Hack Creek and Black Pond, two small drainage basins that feed into the Potomac River estuary from Hack Neck, and Dividing Creek, a small tributary estuary of Chesapeake Bay, (Figure 1)(GAMMISCH, 1986) exemplify the three types of small, tidal-inlet, drainage systems found in non-oceanic, tidal environments. Furthermore, this group of surficially independent systems depicts the structural interrelationships and evolution of the three types. The intent of this study is to describe the three inlet-basin types and to demonstrate that the three are but evolutionary stages of the edges of an estuary.

Classified as the first type of tidal inlet - drainage basin are small tributaries of the major estuaries. There being little or no restriction to the flow at the inlet and the tidal range being the same inside and outside of the inlet. This type or class of basin is relatively large, in excess of 400 hectares, and exhibits a distinct channel or thalweg suggestive of active tidal currents. Dividing Creek (Figure 2) is such a system.

The second type of tidal inlet - drainage basin, exemplified by Hack Creek (Figure 3), is smaller and has a restricted inlet. The restriction, which frequently results from a tidal delta, causes a reduced tidal range within the inlet and a retardation of the tide (BYRNE *et al.*, 1980a, b)(Figure 4). As with the first type, the drainage pattern usually is dendritic, however there exists no active channel or thalweg.

Black Pond (Figure 3), Conduit Pond, and Flag Pond (Figure 3) are examples of the third group of tidal inlet - drainage basin. Each basin's area is so small, usually less than 40 hectares, that the tidal prism and fluvial runoff are insufficient to prevent longshore drift from closing the inlet. The enclosed system floods during

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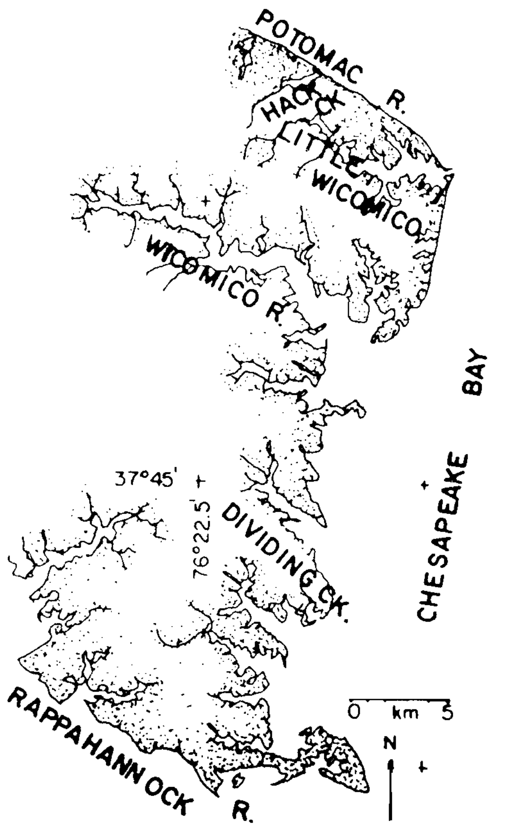


Figure 1. General location map showing the Hack Creek and Dividing Creek. Black, Conduit, and Flag Ponds are adjacent to Hack Creek.

periods of high rainfall and runoff or as the result of a storm surge. When the hydraulic head is sufficient, an inlet breaks open and a channel cuts through the barrier beach. The system remains tidal until longshore drift closes the inlet again forming a pond.

METHODS

The primary new data acquired for this study are two sets of shallow, subbottom, seismic reflection profiles (Figure 5), a series of probes through the bottom sediments of the tributary estuaries, and three vibratory cores. Separate seismic profiles were made with a 7.0 kHz, 2.0 kW Raytheon RTT-1000 instrument and a variable frequency, 3.5, 5.0, and 7.5 kHz, 12 kW Datasonics SBP-5000 system. Both operate at 200 kHz simultaneously with the lower frequency in order to assure proper determination of the present bottom. We also obtained three vibracores (Figure 5) from the flanks of the Potomac River adjacent to Hack Creek and a series of auger samples taken within each of the tributaries. Navigation was by LORAN-C supplemented with visual fixes.

RESULTS AND DISCUSSION

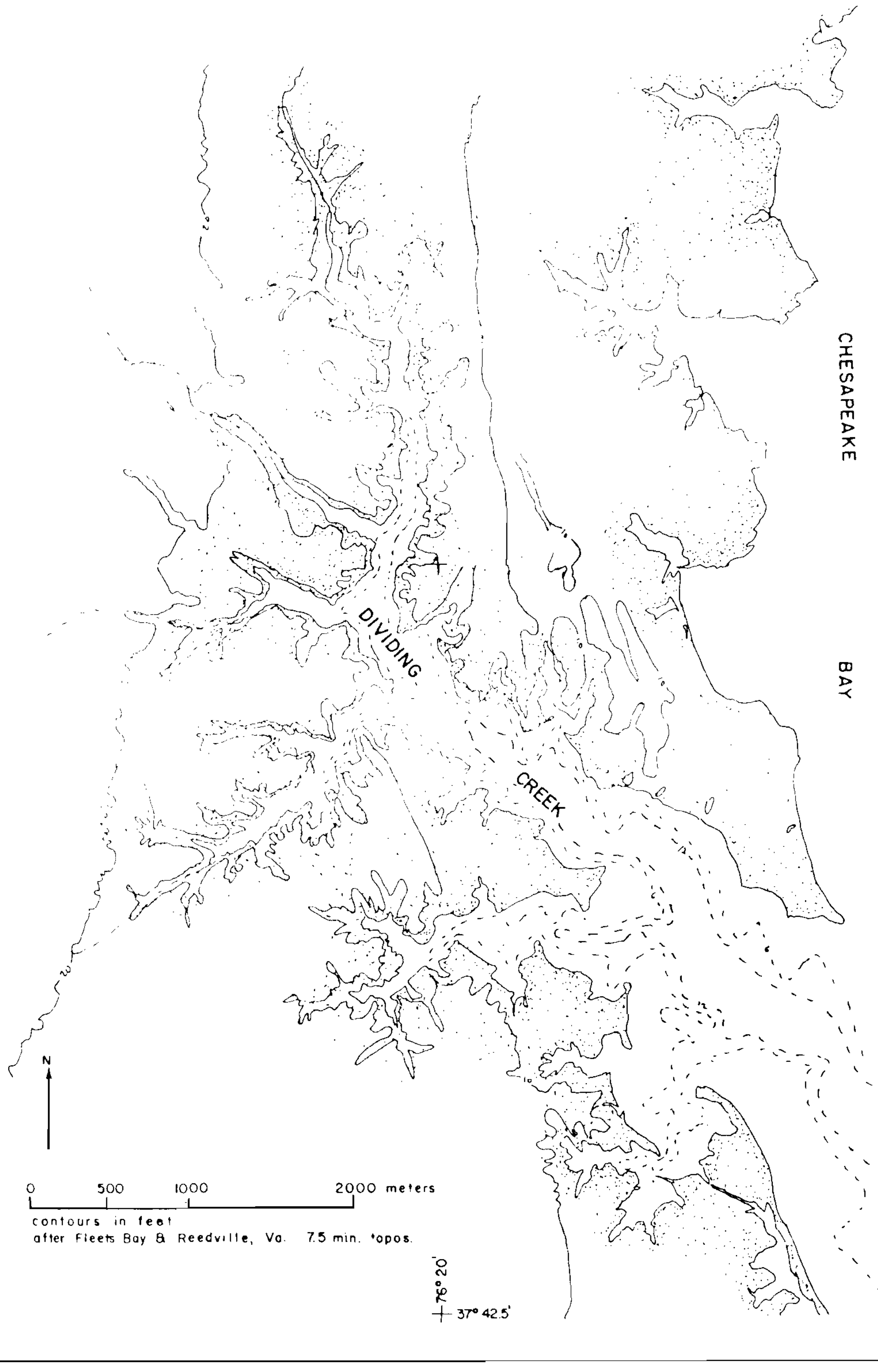
In terms of cross sectional area of the inlet and tidal prism Hack Creek is typical of many of the inlet-basin drainage systems along the fringes of Chesapeake Bay (BYRNE *et al.*, 1980a). Hack Creek's inlet has been stabilized with jetties so that it will be of more use to boaters and to prevent migration of the inlet along the beach. The impedance of the long inlet-channel and the flood-tidal delta diminishes the Potomac River's tide of approximately 0.9 m range to approximately 0.36 m inside the creek and causes a retardation of tidal phase (Figure 4). A marsh consisting primarily of *Spartina alterniflora* is growing on the older lobes of the tidal delta and at the site of an abandoned inlet.

Hack Creek's mainstem does not have a channel, but the seismic surveys and probe profiles reveal a discrete paleochannel under the present flat bottom. Deposits of up to 6 m of estuarine clays, silts, and fine sands fill the creek. Each branch of the system terminates in a small pocket marsh that is cut by an ephemeral stream.

In the vicinity of Hack Creek the cross section of the Potomac River estuary conforms with the morphological scheme of KNEBEL *et al.* (1981) in that there are three units, shoreline flats with a width of about 100 m, a transitional slope that is roughly 3 km wide and ends at about 10 m water depth, and the main channel below 10 m depth. The sediments follow the morphology changing from sand to silty sand to mud with increasing depth. The transitional slope is laterally smooth, conveying no indication of remnant drainage from Hack Creek and its neighbors.

Analysis of the seismic profiles supplemented with the core data reveals three acoustic or seismostratigraphic units in the upper section of the record. The surface unit is reworked sand derived from shoreline erosion and longshore

Figure 2. A map of Dividing Creek. (Facing Page).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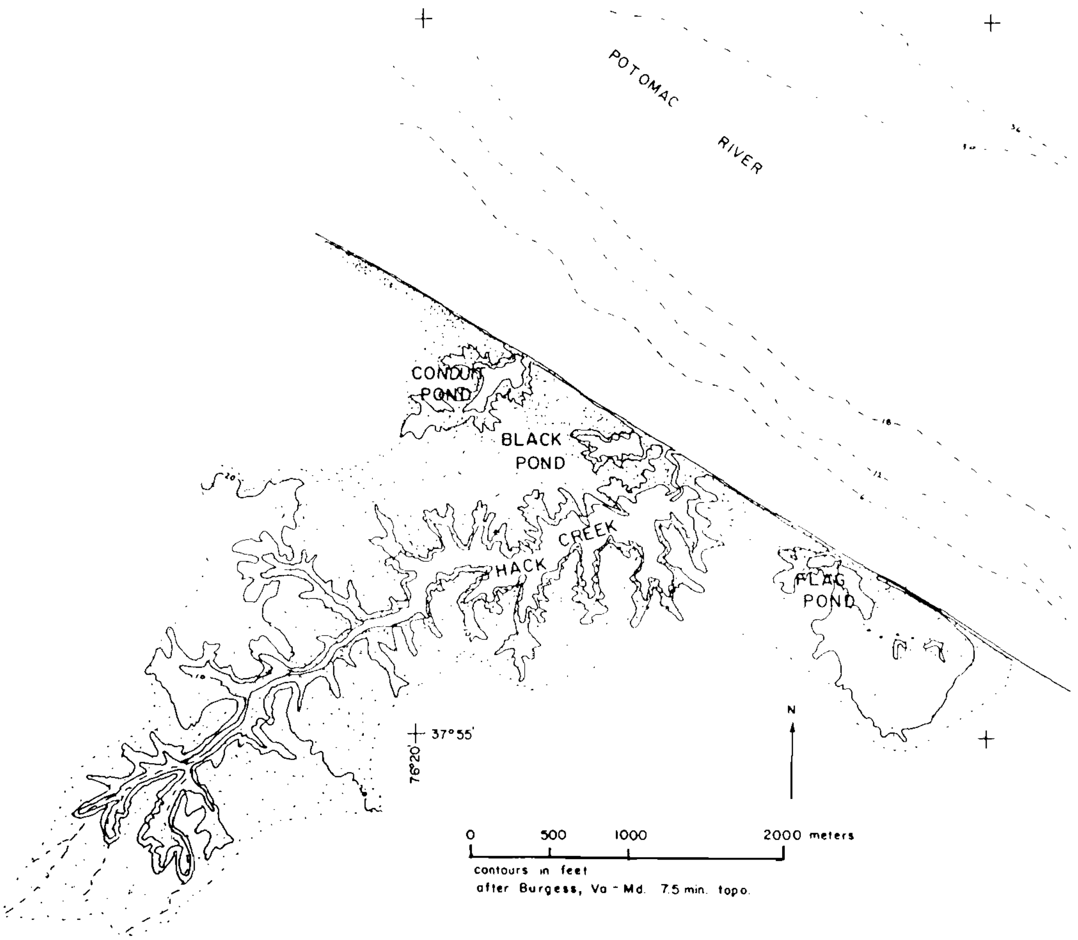


Figure 3. A map of Hack Creek, Black, Flag, and Conduit Ponds.

transport. From the beach to approximately 3 m water depth this unit is a shell rich, medium to coarse grained sand that forms a series of shore parallel bars. A line of sediment samples normal to shore shows that the sand fines with increasing depth grading to a muddy sand at the edge of the Potomac River's channel.

The second unit appears to represent a continuous layer that extends from the beach or fastlands to where it is truncated by the major river channel. The surface of this unit is both undulatory and highly dissected and is incised with a complex system of filled paleochannels.

The third major unit is the material filling these channels. This stratigraphic unit is composed of sediments indicative of a transition from a fluvial channel to estuarine fill. This sequence seen in the vibracores conforms with the model of PEEBLES (1984) whereby during a marine transgression, coastal streams evolve from free flowing, primarily coarse grained, fluvial environments to finer grained, filled estuaries.

A contour map of the surface of the second unit (Figure 6) reveals a complex, dendritic drainage pattern. The several minor channels merge into one deep channel with an axial depth of about 30 m. This one channel is the system's only connection with the paleochannel of the Potomac. The probe profiles and seismic records obtained from within Hack Creek indicate that the paleochannel underlying Hack Creek

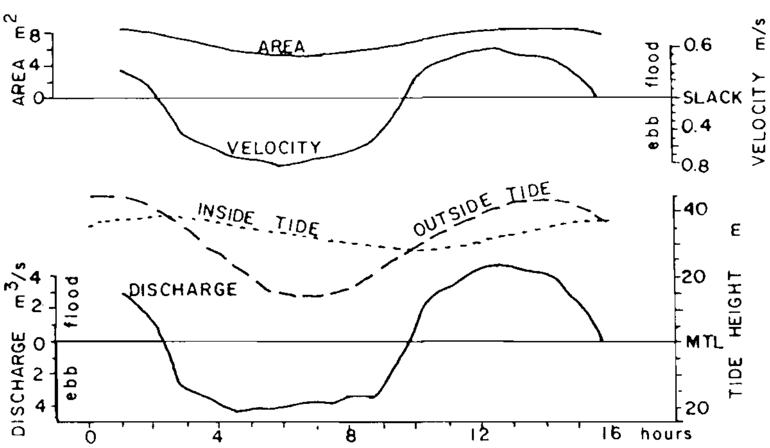


Figure 4. The cross-sectional area, average velocity, discharge, and tide-height of Hack Creek through a tidal cycle.

is on grade with the major limb of the (paleo-) dendritic pattern extending offshore from Hack Neck. The three other smaller drainage systems near Hack Creek, Black, and Conduit Ponds to the west and Flag Pond to the east, also appear to be extensions of the offshore, buried dendritic pattern. Also the eastern arm of Flag Pond and the smaller, unnamed ponds to its east (Figure 3) might be the last, upland remnants of the southeastern-most limb of the paleodrainage system depicted in Figure 6.

Samples from cores taken in the interiors of the pond systems, with the exception of Black Pond, exhibit the same sedimentary sequence as found in Hack Creek. The uppermost sediments of Black Pond represent a fresh water pond environment.

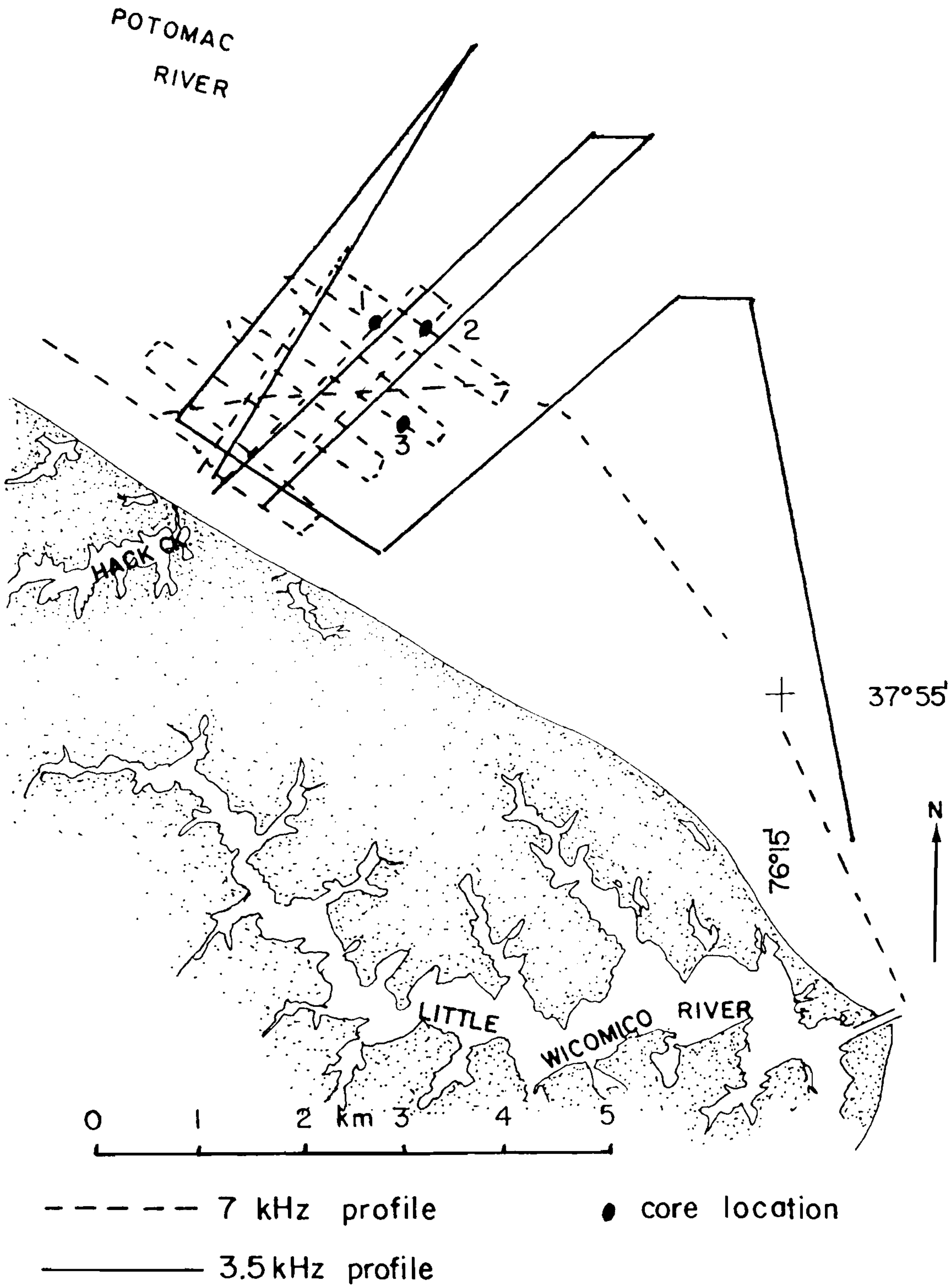
Similarly, an analysis of the gradients of the channels from the upland scarp at about 15 m above sea level through the shoreline and under the Potomac's nearshore flats indicates the depth of the channel bottoms continually increases offshore. A distinct increase in the slope of the thalweg approximately 4 km offshore where the tributary channel joins the Potomac River's paleodrainage suggests that the basin was perched above salt water or tidal intrusion until fairly recently when sea level reached the uppermost parts of the Potomac River's channel. This intermediate, stream base-level would allow the system to mature from V-shaped, narrow, relatively linear valleys to larger, meandering streams with wider valleys, and flat valley floors, again following the scheme of PEEBLES (1984).

CONCLUSIONS

Seismic reflection data and geomorphic and stratigraphic evidence indicate the existence of a complex, dendritic, paleodrainage system under the flanks of the Potomac River estuary in the vicinity of Hack Creek. This drainage system interconnects Hack Creek with three adjacent, smaller creek systems. The mainstem of this system intersects the Potomac River.

Since the slowing of the rate of sea-level rise approximately 3,000 years ago, erosion, primarily wave action, has modified the shore flanking the Potomac River (ROSEN, 1976). As a result, the successive branches of the dendritic system were isolated from the main stem. Tidal channels, inlets, and marshes were drowned and, in some cases, buried or filled. With continued transgression of the shoreline, the various branches became shorter and shorter enclosing successively smaller and smaller basins. As basins decreased in size, the combined volumes of the fluvial outflow and the tidal prism also diminished until they were no longer able to maintain an inlet. As the inlets closed, the small ponds, such as Flag, Black, and Conduit Ponds, formed.

The temporal end-members of the evolutionary scheme can be seen in the small ponds and in Dividing Creek (Figure 2). The ancestral Hack Creek as shown by the paleodrainage very


POTOMAC RIVER
2
3
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7 kHz profile
core location
3.5 kHz profile

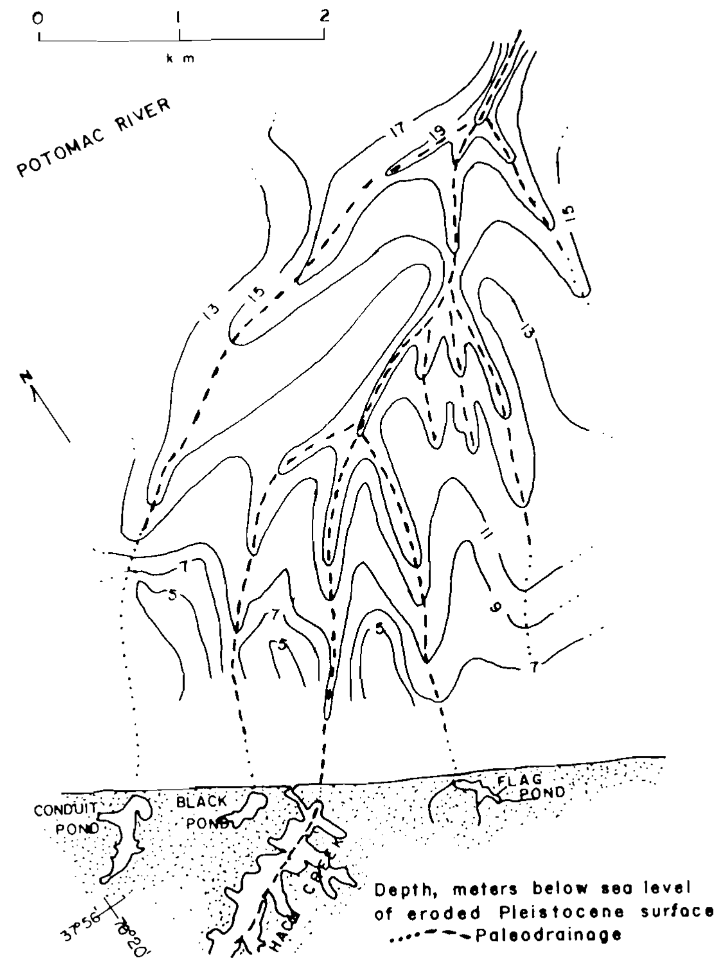

Figure 6. A contour map on the eroded Pleistocene surface depicting the paleodrainage of the Hack Creek system.

closely resembles Dividing Creek as it is today. Thus with the continued retreat of the shoreline that accompanies a moderately slowly increasing sea level (BRUUN, 1962), one would expect to see the progressive evolution of one relatively small tributary estuary type to the next until the tributary's inlet closes forming a pond, which itself eventually is consumed by the transgressing shore.

LITERATURE CITED

BRUUN, P., 1962. Sea level rise as a cause of shore erosion. *American Society Civil Engineers Proceedings, Journal Waterways and Harbors Division*, 88, 117–130.

BRUUN, P., 1967. *Tidal Inlets and Littoral Drift; Stability of Tidal Inlets.* Vol. 2, 193p.

BRUUN, P., 1978. *Stability of Tidal Inlets.* Amsterdam: Elsevier. 506p.

BYRNE, R.J.; DeALTERIS, J.T., and BULLOCK, P.A., 1974. Channel Stability in Tidal Inlets: A Case Study. *Proceedings, 14th Coastal Engineering Conference, American Society of Civil Engineers,* (New York), pp. 1585–1604.

BYRNE, R.J.; THOMAS, G.R., and GAMMISCH, R.A., 1980a. Tidal prism-inlet area relations for small tidal inlets. *Proceedings, 21st Coastal Engineering Conference, American Society of Civil Engineers, (New York)*, pp. 2517–2533.

BYRNE, R.J.; THOMAS, G.R., and GAMMISCH, R.A., 1980b. Chesapeake Bay Inlets; *Special Report*

Figure 5. Map showing the location of the seismic lines and vibracores. (Facing Page).

in Applied Marine Science and Ocean Engineering No. 238, Virginia Institute of Marine Science, Gloucester Point, Virginia.
ESCOFFIER, F., 1940. The Stability of tidal inlets. *Shore and Beach,* 8(4), 14–115.
GAMMISCH, R.A., 1986. Geological History of a Holocene Drainage System, Hack Creek, Virginia. Unpublished master's thesis, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 70p.
JARRETT, J.T., 1976. Tidal Prism - Inlet Area Relationships, *G.I.T.I. Report No. 3.* U. S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, Virginia and U. S. Army Waterways Experiment Station, Vicksburg, Mississippi.
KNEBEL, H.J.; MARTIN, E.A., GLENN, J.L., and NEEDEL, S.W., 1981. Sedimentary framework of the Potomac Estuary, Maryland. *Bulletin Geological Society America,* 92(1), 578–589.
O'BRIEN, M.P., 1969. Equilibrium flow areas of tidal inlets on sandy coasts. *Journal Waterways and Harbors Division, American Society of Civil Engineers,* 95, No. WW1, Proceedings Paper 6405, pp. 43–52.
O'BRIEN, M.P. and DEAN, R.G., 1972. Hydraulics and sedimentary stability of coastal inlets. *Proceedings, 13th Coastal Engineering Conference, American Society of Civil Engineers (New York),* pp. 761–780.
PEEBLES, P.C., 1984. Late Cenozoic Landforms, Stratigraphy and History of Sea Level Oscillations of Southeastern Virginia and Northeastern North Carolina. Ph.D. dissertation, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 127p.
ROSEN, P.S., 1976. The Morphology and Processes of the Virginia Chesapeake Bay Shoreline. Ph.D. dissertation, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia, 313p.

□ RESUMEN □

Además de ser la causa del retroceso de la linea de costa, el ascenso del nivel del mar modifica las pequeñas desembocaduras de drenaje mareal de los estuarios. Los pequeños canales de drenaje del rio Potomac y en las cercanias de la bahia de Chesapeake son ejemplos de la secuencia evolutiva desde desembocaduras amplias y de flujo libre pasando por pequeños canales de desembocadura que modifican de una manera importante las caracteristicas del flujo mareal en el estuario hacia canales efimeros asociados con albuferas cerradas. Datos sismicos superficiales y de vibracores demuestran que el ascenso del nivel del mar anega el sistema de drenaje y reduce el área de la bahia. Como consecuencia, el prisma de marea disminuye y los canales de desagüe asociados evolucionan hacia el siguiente tipo.—*Department of Water Sciences, University of Cantabria, Santander, Spain.*

□ RÉSUMÉ □

De même que la montée du niveau de la mer provoque le recul vers la terre de la ligne de rivage des estuaires, elle modifie les petits goulets associés aux bassins de draînage qui les frangent. Le bassin de draînage et le petit goulet associé de la Potomac, ou la baie de Chesapeake voisine sont des exemples d'une séquence d'évolution qui progresse à partir de goulets plus larges et à écoulement libre, vers des goulets plus petits qui modifient d'une manière significative les caractéristiques tidales de l'estuaire, pour évoluer ensuite en goulets ephémères associés à des lagunes fermées.—*Catherine Bressolier, U.A. 910, Montrouge, France.*

□ ZUSAMMENFASSUNG □

Ein steigender Meeresspiegel verschiebt nicht nur die Küstenlinien der Ästuare insgesamt landwärts, sondern verändert auch die kleinen Gezeitenbecken - Entwässerungssysteme an ihrem Rande. Diejenigen am Potomac und der nahegelegenen Chesapeake Bay sind Beispiele für eine Entwicklungssequenz, die von größeren i.a. frei durchspülten Buchten über kleinere mit bereits deutlich verändertem Gezeitencharakter zu rasch vergänglichen mit geschlossenen Tümpeln übergeht. Bohrergebnisse und solche oberflächennaher Seismik belegen, daß ein steigender Meeresspiegel ein Entwässerungsbecken überflutet und dabei seine Fläche reduziert. Infolgedessen wird auch der Tidenhub beim Übergang zum nächsten Entwicklungstyp verändert.—*Dieter Kelletat, Universität Gesamthochschule Essen, Essen, FRG.*