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Quaternary Geology of the Chesapeake Bay

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INTRODUCTION

The Chesapeake Bay, which is a classic coastal plain estuary, is located on a trailing edge continental margin. It has a surface area of nearly 6,000 km^2 and ranges in width from 8 to 48 km. The morphology of the bay clearly reflects its formation as a response to fluctuating sea level during and following the last major continental glaciation. The shoreline is highly irregular, the tributaries form an intricate dendritic drainage pattern, and a deep axial channel occurs along much of its length (fig. 1). Water depths commonly exceed 30 m in this deep channel, which is flanked by broad shallow benches. Overall, the bay is quite shallow and has an average depth of only 8 m.

The prominent axial channel has been widely viewed as the relict Susquehanna River paleochannel that was incised into the Coastal Plain strata during the last major sea-level lowstand. This channel has been only partially filled with sediments during the Holocene transgression. Ryan (1953), who used borings taken across the bay for the Annapolis-Kent Island Bridge, identified its base at a depth of approximately 61 m. A basal sequence of sands and gravels identified as fluvial deposits partially filled this channel. Overlying these sediments was a sequence of muds deposited when true estuarine conditions were established in the channel. Ryan (1953) projected the longitudinal profile of the channel along the length of the bay and estimated the depth to be 91 and 112 m, respectively, at the bay mouth.

In the early 1960's, borings were obtained in the bay mouth vicinity for the Chesapeake Bay Bridge-Tunnel. On the basis of these borings and the first seismic reflection profiles obtained in the bay, Harrison and others (1965) identified a fluvial channel at a depth of approximately 49 m under the northern end of the present-day bay mouth. They proposed that a minimum of 12 m of uplift had to occur in the bay mouth region relative to the Annapolis region to account for the difference in the channel depths observed at the two bridge crossings, assuming no channel gradient. By using projected channel gradient, Harrison and others (1965) suggested that a maximum of 52 m of relative uplift had occurred at the mouth. Because of the lack of continuity of the axial channel along the length of the bay, the relation between the bay mouth paleochannel and the channel at the Annapolis-Kent Island bridge remained problematic. Harrison and others (1965) argued against the possibility that the late Wisconsinan channel of the Susquehanna River crossed the Delmarva Peninsula north of the bay mouth.

Other channels crossing the peninsula have been identified or postulated, and multiple generations of channels of the Susquehanna River seemed likely, given the cyclic nature of sea level rise and fall over the past 0.75 m.y. Hansen (1966) identified a fluvial channel near Salisbury, Md., and suggested that it represented the course of the Susquehanna River during the low sea level associated with the Illinoian glaciation. However, the full extent of the channel was never adequately defined. Harrison (1972) identified reworked crystalline gravels along the Atlantic shoreline of the Delmarva Peninsula near Metomkin Island and postulated that an ancestral channel of the Potomac River or the combined Susquehanna-Potomac Rivers crossed the peninsula in this vicinity at some point in the past. By using seismic reflection techniques, Schubel and Zabawa (1973) identified a paleochannel in the lower reaches of the Chester River and projected its course through the lower reaches of the Miles and the Choptank Rivers. They postulated an Illinoian age for this channel and suggested that it may connect to the Salisbury paleochannel of Hansen (1966) and cross the peninsula on its way to the Atlantic. In the main portion of the bay, Kerhin and others (1980) identified two paleochannels by using seismic reflection techniques. One extended down the eastern side of the bay from the mouth of Eastern Bay to Taylor's Island. They

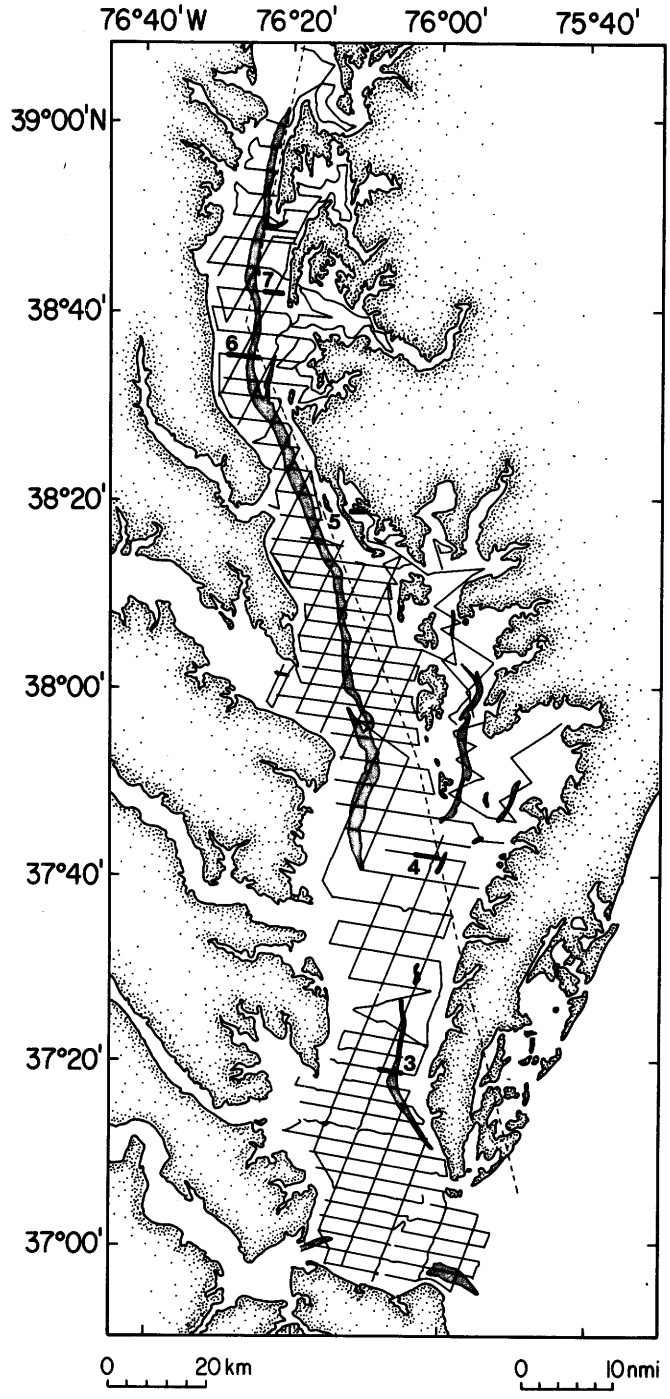

Figure 1. The Chesapeake Bay from the vicinity of Annapolis to the mouth showing tracklines of the seismic reflection profiles. The profile shown in figure 2 is located along section 5. Areas that have water depths of greater than 18.3 m (60 ft) are shaded.

suggested that this channel was the southern extension of the one identified in the Chester River by Schubel and Zabawa (1973), which, therefore, did not turn to the east under the Delmarva Peninsula. They further postulated a connection between this channel and one identified to the south in the Tangier Sound area. Kerhin and others (1980) also placed an Illinoian age on this channel. Because its southern extent was never established in the bay, the location of its exit to the Atlantic shelf remained in doubt. On the Virginia portion of the Delmarva Peninsula, Mixon (1985) identified two major paleochannels by using borehole data. The trend of these channels indicated that they crossed from the bay to the Continental Shelf, and at least one probably connected to the channel identified by Kerhin and others (1980).

In an attempt to reconstruct the late Wisconsinan channel system in the Virginia portion of the bay, Carron (1979) utilized transducer-based seismic reflection techniques. Because the penetration capability of these systems was limited, Carron (1979) suggested that the Susquehanna River flowed down the eastern side of the bay in Virginia and that the western shore tributaries flowed along the western side turning to the east and exiting the bay just north of Cape Henry and eventually joining the Susquehanna on the Continental Shelf.

BACKGROUND OF THE STUDY

Although it was widely recognized that the Chesapeake Bay formed as the lower reaches of the Susquehanna River were flooded during the Holocene transgression, the details of the bay's formation in response to this latest and the Pleistocene sea-level fluctuations remained to be worked out. Several major problems were in need of resolution. The present-day axial channel of the bay was not continuous along its length; the deeper portions of the channels in Virginia were separated from the major portion in Maryland. The disparity in channel depths observed in borings at the Annapolis-Kent Island Bridge and the Chesapeake Bay Bridge-Tunnel appeared to indicate uplift or a lack of continuity of the two channels. The relations between the multiple isolated channel segments identified or postulated under the Delmarva and in the bay and the Susquehanna River drainage system were unclear, as were their historical development. Variations in present-day axial channel bathymetry strongly suggested differences in sediment depositional centers during the Holocene transgression. In addition, it was felt that improved knowledge of the bay's formation and depositional history could assist in understanding the present-day sedimentation processes occurring in the system and, therefore, in addressing some of the management questions arising from the ongoing efforts to improve the health and the productivity of the Chesapeake Bay.

Researchers within the States of Maryland and Virginia were acutely interested in addressing these problems and had made efforts through the studies conducted by Carron (1979) and Kerhin and others (1980). They recognized, however, that they did not have the complete in-house technical capability to adequately solve these problems and that a research program directed at the complete bay system was necessary to tie together the various pieces of subsurface data that had been collected. Through a series of discussions initiated by the Maryland Geological Survey with the the U.S. Geological Survey (USGS), it was agreed that a cooperative effort should be mounted to resolve the Quaternary geology of the Chesapeake Bay. To insure the inclusion of the southern portion of the bay and representation by a Virginia institution, the Virginia Institute of Marine Science was involved early in the planning stages of the study. It was decided that the project would initially involve the collection of high-resolution seismic reflection profiles throughout much of the main portion of the Chesapeake and additional coverage up tributaries where deemed appropriate. Each of the institutions would provide a coprincipal investigator and portions of the profiling equipment. The States would provide vessels to serve as the data-gathering platforms, and the USGS would provide an electronic technician to maintain the equipment in the field. Travel and per diem costs were provided by each institution for their personnel. Except for some funding that passed from the USGS to the Virginia Institute of Marine Sciences to support vessel time, no formal funding mechanisms were established.

METHODOLOGY

Over the course of four field seasons beginning in 1984, almost 2,600 km of high-resolution seismic reflection profiles were collected in the main part of the Chesapeake Bay from the mouth northward to the vicinity of Annapolis, Md. (fig. 1). Data were collected by using a boomer-type system supplied by the USGS and 3.5- to 5.0-kHz transducer-based systems provided by the State institutions. Both types of systems were fired at 0.25- to 0.50-s intervals. The boomer system was run at 280 J, and the data were filtered between 300 Hz and 5.0 kHz. Firing times of the two types of systems were offset to minimize crosstalk. Loran-C was used as the primary navigation system, and all data were recorded on analog tape for archival purposes.

RESULTS

The Chesapeake Bay lies within the Coastal Plain province of the mid-Atlantic region. Uplands surrounding the bay, from its head at the mouth of the Susquehanna River southward 260 km to its mouth at Cape Charles, are composed of unconsolidated sediments deposited during the Cretaceous and later time. These form a series of wedge-shaped deposits that rest on the crystalline basement rocks and dip to the southeast at rates of between 1.9 and 7.5 m/km. The shallow Tertiary seismic stratigraphy prevalent beneath much of the bay consists of a series of long, strong, continuous subhorizontal reflectors that dip slightly to the southeast. These reflectors correlate well with the major unconformities observed in adjacent land-based well records.

Incised into these Tertiary strata are distinct paleochannels that have strong basal reflectors and U-shaped valleys as shown on the seismic records (fig. 2). Characteristically, the sediments that fill these valleys exhibit two forms of seismic reflectors. At the base of each valley, the reflectors are commonly strong, discontinuous, and irregular. Above this basal sequence, the fill sediments either exhibit weak, long, and smooth reflectors or are nearly reflection free. Lithologic data obtained from land-based (Mixon, 1985) and bridge boreholes (Ryan, 1953; Harrison and others, 1965) indicate that the lower channel fill sequence consists of coarse sand and gravels deposited in a fluvial environment. In contrast, the upper sequence is finer grained and was deposited in estuarine environments as the former river valleys were flooded. The environments of deposition of this unit range from narrow river estuary to open bay and nearshore marine near the bay mouth. Lithologies are complex in the estuarine-marginal marine unit, especially near the bay mouth, where boreholes indicate that the sediments consist of interbedded muddy sand, silt, and peat (Mixon, 1985). Further landward, in the central part of the estuary, the unit is likely to be finer grained, as suggested by the character of the seismic reflections (fig. 2); however, no boreholes penetrate this portion of the fill sequence.

Three distinct generations of the paleochannel system have been identified beneath the Chesapeake Bay (fig. 3) and have been informally named the Cape Charles, the Eastville, and the Exmore in order of increasing age. Each has a main trunk channel running approximately parallel to the axis of the present Chesapeake Bay and numerous tributary channels that join the main stem. Seismic reflection and borehole data indicate that the three paleochannel systems are of different ages and that the sediments that fill them are separated by unconformities. The paleochannel systems were incised by the Susquehanna River and its tributaries at times of lowered sea level during the mid- to late Quaternary. Their relative ages can be determined by crosscutting relations on the seismic reflection profiles. Although the geometries, the depths, and the seismic character of the fill sequences are similar in all three channels, which makes distinction in individual seismic reflection profiles difficult, the multiple, closely spaced profile lines (fig. 1) permitted their courses to be traced throughout the length of the bay.

The Cape Charles paleochannel is the youngest and was clearly incised at the time of the last major sea-level lowstand, which was during the late Wisconsinan. Because this channel has been only partially filled with sediment

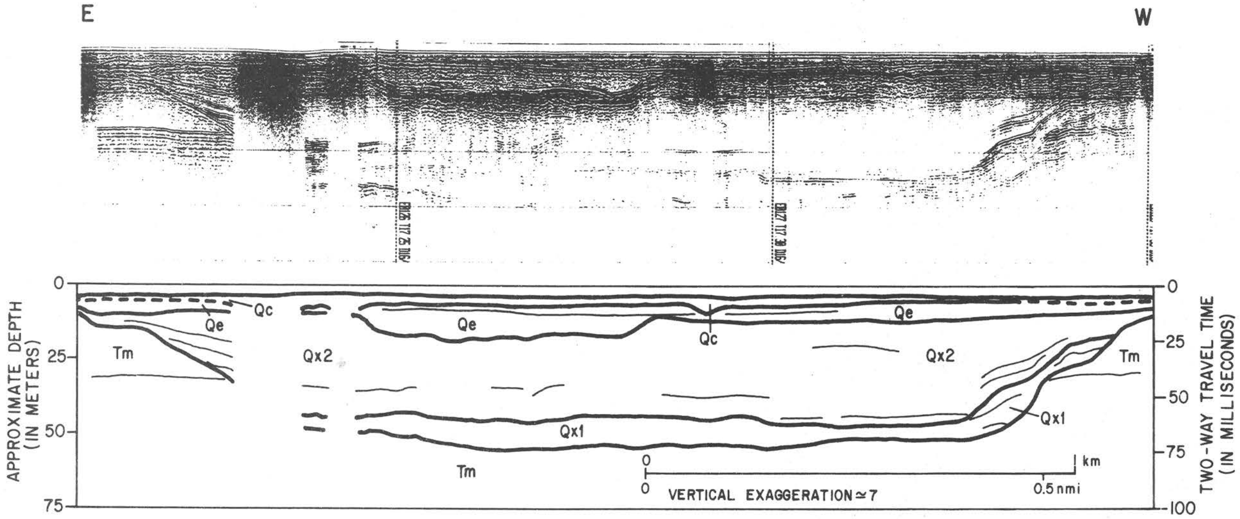

Figure 2. High-resolution seismic reflection profile obtained by using the boomer system and interpretive cross section of the Exmore paleochannel. The location of profile 8 is shown in figure 1. Depth scale assumes a speed of sound in water and sediments of 1,500 m/s. G, record obscured by biogenic gas in the sediments; Tm, late Tertiary marine sediments; Qc, undifferentiated sediments correlative with the fill of the Cape Charles paleochannel; Qe, undifferentiated sediments correlative with the fill of the Eastville paleochannel; Qx1 and Qx2, basal and upper units, respectively, of the fill of the Exmore paleochannel. Note the horizontal reflector in the Tertiary sediments on the left side of the figure.

during the Holocene transgression, it underlies, for the most part, the present bathymetric channel of the bay (compare deep areas outlined on fig. 1 with fig. 3). In a few areas where Holocene spit progradation has occurred, the modern axial channel is offset from the paleochannel; for example, south of the mouth of the Potomac River. In other areas, such as off the mouth of the Rappahannock River, Holocene sedimentation has filled the Cape Charles paleochannel to the extent that there is no present bathymetric expression of the paleochannel location. The most notable change has occurred at the mouth of the Bay where the modern tidal channel is offset by as much as 12 km from the Cape Charles paleochannel (fig. 3). In the vicinity of the mouth, the paleochannel underlies the southern tip of the Delmarva Peninsula (Cape Charles), and Holocene progradation of the peninsula to the south has filled the former paleochannel and forced the tidal channels to the south (Colman and others, 1988).

Under much of the bay, the base of the Cape Charles paleochannel is obscured by the presence of biogenic gas produced by bacterial decomposition of organic matter in the Holocene channel fill sediments (Halka and others, 1988). However, the width can be determined on most of the profiles, and depths are known from profiles where biogenic gas is absent and from bridge borings at the Annapolis-Kent Island Bridge and the Chesapeake Bay Bridge-Tunnel. In general, the main trunk channel is 2 to 4 km wide and is incised into the underlying Tertiary strata to depths of 50 to 70 m. Overall, the channel has only a slight overall gradient.

The Eastville paleochannel crosses the Delmarva Peninsula approximately 40 km north of the present bay mouth (fig. 3) and is filled with estuarine sediments overlain by a barrier-spit complex (Mixon, 1985). This complex appears to have been deposited during the last major interglaciation (the Sangamon) and the paleochannel presumably incised during the preceding major glaciation about 150 ka (Colman and Mixon, 1988). Under the bay, this paleochannel is generally located to the east of the Cape Charles paleochannel, although it crosses that channel and lies to its west off Calvert Cliffs (fig. 3). At the northern end of the study area, the Eastville channel passes under Kent Island and the Poplar Island group. Sediments comprising these islands have been identified as estuarine deposits belonging to the Kent Island formation, which are time equivalent with the barrier-spit complex overlying the channel to the south. The dimensions and depths of the Eastville paleochannel are better known than the Cape Charles because biogenic gas is absent in these older channel fill sediments. The channel has similar widths and depths as the Cape Charles channel, and the gradient, which is very slight, has an overall seaward slope of only 0.038 m/km.

The Exmore paleochannel crosses the Delmarva Peninsula another 40 km north of the Eastville paleochannel (fig. 3). This channel is the oldest of the three and along

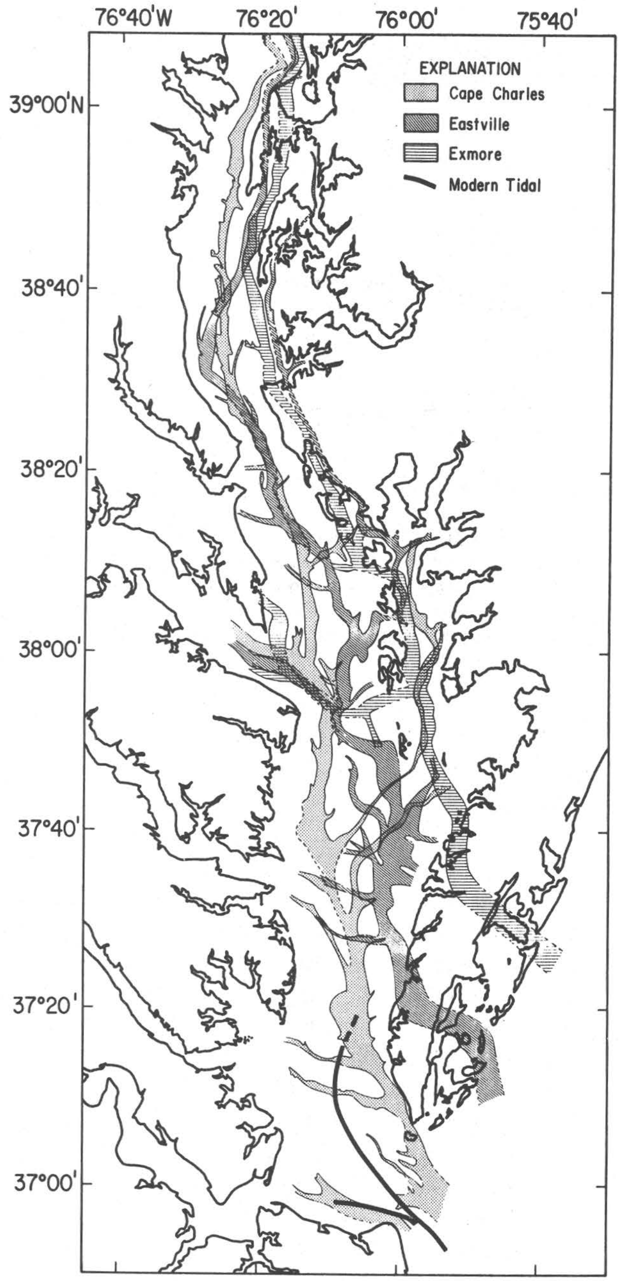

Figure 3. The three major Quaternary paleochannel systems of the Susquehanna River and tributaries beneath the Chesapeake Bay and the Delmarva Peninsula and the location of the modern tidal channels in the bay mouth area.

almost its entire length is located to the east of the Eastville and the Cape Charles paleochannels and passes under Kent Island at the northern end of the study area and the western side of Dorchester County, Md. As with the Cape Charles and the Eastville, the trunk channel has widths of 2 to 4 km and is incised 50 to 70 m into the underlying Tertiary sediments. Linear regression analysis of the channel depths, which is shown on the seismic reflection profiles (fig. 2), indicates a very slight overall landward slope, although the gradient is probably not significantly different from zero. This channel is also overlain by a barrier-spit complex where it crosses under the Delmarva Peninsula (Mixon, 1985); however, the age of this deposit is less certain than that overlying the Eastville (Colman and Mixon, 1988). It has been suggested that the barrier-spit complex was deposited either approximately 200 or 400 ka and that the underlying channel was incised during either of the preceding major sea-level lowstands at about 270 or 430 ka (Colman and Mixon, 1988).

SUMMARY

In what may be a unique case, a cooperative program was established between Federal and State agencies in which each institution contributed programmatic funds toward a research program with little transfer between institutions. The USGS, the Maryland Geological Survey, and the Virginia Institute of Marine Science forged a working relation that resulted in a significant increase in knowledge about the late Quaternary history of the Chesapeake Bay region.

This effort tied together the various paleochannel segments identified in previous studies and showed that a series of at least three fluvial paleochannel systems and their fills dominate the stratigraphy beneath the Chesapeake Bay. Each of the trunk paleochannels identified lies to the west of and, on its way to the Continental Shelf, crosses the Delmarva Peninsula to the south of its predecessor. The southward progression of the channels through time resulted from the southward progradation of the Delmarva Peninsula when interglacial high sea level filled the preceding paleochannel with sediments. This process is continuing at the present time with the displacement of the modern bay mouth tidal channels southward approximately 12 km from the late Wisconsinan paleochannel. The fluvial channels record times of relative low sea levels, the channel fill sediments record the formation and filling of estuaries during the ensuing transgressions, and the subaerial barrier-spit complexes on the Delmarva Peninsula record times of sea-level maxima. As such, the Chesapeake area has preserved a remarkable record of sea-level changes over the past few hundred thousand years and, with it, a record of climatic variations over the same time period. As interest in deciphering the history of climatic changes increases, the record from the Chesapeake area can be expanded to supply data for deciphering that history. The cooperative program established between the Federal and the State agencies has provided a solid base of information that can be utilized to further our understanding of recent climatic changes occurring on Earth. The success of this cooperative program indicates that informal cooperatives can provide significant information without direct transfer of funds and can offer advantages to all the institutions involved. The question remains—how much more could be accomplished with a formal agreement and appropriated funding for similar studies?

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