Late Quaternary Paleochannel Systems on the Continental Shelf, South of the Chesapeake Bay Entrance

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ABSTRACT


Analyses of an extensive network of high-resolution seismic-reflection records and borehole samples outlined three distinct paleochannel systems beneath the continental shelf south of the entrance to Chesapeake Bay. Amino acid racemization analyses of mollusks from the fill sequences are used for estimation of the ages of channel cutting and filling. The principal periods of channel cutting appear to be during the sea-level minima associated with marine oxygen isotope Stages 2 and 6. An older channel-filling phase (Stage 13 or 15) is also recognized based on aminostratigraphic results. These aminostratigraphic results are consistent with the results of previous studies on the mid-Atlantic coastal plain.

ADDITIONAL INDEX WORDS: Seismic reflection, paleogeography, aminostratigraphy, channel-fill sequences, sea-level change.

INTRODUCTION

Recent work on the inner continental shelf south of the entrance to Chesapeake Bay, coupled with earlier studies of the Quaternary paleochannel systems underlying Chesapeake Bay and the Virginia inner shelf, allows correlation of the Quaternary history of the two areas. Among the strongest of the several lines of evidence is the occurrence of three independent paleochannel systems in each area with similar apparent ages for each member of the successive pairs. The paleochannel pairs represent major sea-level lowstand events during the Quaternary and demonstrate the controlling effect of sea-level fluctuations on the geological development of the coastal zone.

This study utilizes a network of very-high-resolution seismic-reflection profiles extending from the entrance of Chesapeake Bay nearly to the Virginia/North Carolina border. Samples were taken from a limited set of cores (Figure 1) in order to: (1) determine the geographic distribution and morphologic character of the paleochannel systems beneath the shelf, (2) develop a geochronology of the paleochannel systems, (3) document and describe the sedimentary features of the channel-fill sequences, and (4) attempt to correlate features in the geological history of the inner shelf with those of Chesapeake Bay and other nearby areas.

METHODS

The seismic-reflection profiles were obtained during earlier investigations of the inner continental shelf directed toward identifying potential resources of beach-quality sand (KIMBALL and DAME, 1989; DAME, 1990; HOBBS, 1990; KIMBALL et al., 1991). Several surveys were performed aboard the Virginia Institute of Marine Science's (VIMS) R/V BayEagle and using a LORAN-C positioning system.

The seismic data were developed with a
Datasonics' Model SBT-220 sub-bottom transceiver coupled to a Datasonics TTV-120 transducer tow vehicle and an EPC graphics recorder. The sub-bottom system operated simultaneously on two frequencies, 3.5 kHz for bottom penetration and 200 kHz for bottom tracking. Two-way travel time was reduced to vertical distance using a constant acoustic velocity of 1500 m s\(^{-1}\). Vertical resolution is at least as fine as 0.5 m.

Cores collected by the Norfolk District of the U.S. Army Corps of Engineers (Williams, 1987) and from earlier studies at VIMS were incorporated into the study to provide lithostratigraphic control. Five cores, selected for their locations relative to the sub-bottom profiles (Figure 1), were sampled and studied in detail. The split cores were described visually (logged) and representative sediment samples were taken from each lithological segment. The samples were processed to determine sand: silt: clay ratios and the grain-size distributions of the sand portions. Additionally, we collected a set of shells from the cores for amino acid racemization analysis to estimate the ages of the strata from which the shells were removed.

All fourteen samples selected for amino acid racemization analysis were disarticulated and out of life position, some were fragmented. The fossils were identified to genus by R.J. Diaz and L.C. Schaffner (personal communication). The amino acid analyses were performed by one of us (J.F.W.) following methods described in Belknap and Wehmiiller (1980) and subsequent works (Wehmiiller and Belknap, 1982; Wehmiiller et al., 1988, 1992; Wehmiiller, 1992).

**PREVIOUS WORK**

This study builds upon work published beginning in the early 1970s (Shideker and Swift, 1972; Shideker et al., 1972; Swift et al., 1972; Swift, 1975; Swift et al., 1977) and continuing through those noted above. The studies of the major paleochannel systems underlying the modern Chesapeake Bay (Colman and Hobbs, 1987; Colman et al., 1988, 1990; and Colman and Mixon, 1988), especially when allied with Mixon's (1985) study of the southern Delmarva Peninsula, collectively document a complex history of channel incision and infill associated with Pleistocene transgressive-regressive cycles.

\(^1\) The use of trade names is for descriptive purposes only and should not be taken as product endorsements.

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**Figure 1.** A map of the study area indicating the network of sub-bottom profiles and the locations of the five cores. Line A-A' is a projected cross section. Two perpendicular heavy-line segments represent the profiles depicted in Figures 4 and 5.

Toscano et al. (1989), Toscano and Kerhin (1990), Toscano (1992), and Toscano and York (1992) discuss the Quaternary history of the inner continental shelf of Maryland. The history and timing of major variations in sea level and general transgressive-regressive processes should be similar for both Maryland and southern Virginia. Immediately north of the study area, Shideker et al. (1984), Finkelstein and Kearney (1988), and Foyle and Oertel (1992) have worked with the upper sedimentary sequences associated with the southernmost portions of the Delmarva Peninsula. Riggs et al. (1992) address the Quaternary marine units of northeastern North Carolina.
The Quaternary geology of the inner continental shelf is intimately linked to that of the outer coastal plain. OAKS and COCH (1973 and other dates), PEEBLES et al. (1984), JOHNSON et al. (1985), and CHEN (1992), among others, describe and interpret the geologic history of the Virginia coastal plain.

RESULTS

The seismic records indicate the existence of three paleochannel systems. These filled drainage systems are depicted in Figure 2. Systems I and II are approximately coast-parallel, whereas system III has more coast-normal components. Figures 3 and 4 present portions of sub-bottom profiles that image the paleochannels. Analysis of the records demonstrates that the three systems are of different relative ages, System I being both the oldest and physically lowest, and System III being the youngest and uppermost.

The fluvial-erosion surfaces marking the limit of incision of channel systems are relatively strong reflectors on the seismic records and the channels themselves are distinct (Figure 3). The youngest system is not as well developed as the older systems (Figure 4). Bank-to-bank relief in System I commonly is between 9 and 14 m with a maximum of 14 m. In System II the relief ranges between 4 and 7 m and in System III, the youngest, the range is from 2 to 5 m. Channel widths follow a similar pattern of magnitude increasing with age. Table 1 summarizes the geometry of the three systems.

Table 1. Geometry of the paleochannel systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Relative Relief</th>
<th>Axial Depth</th>
<th>Main Stem Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>2 to 4</td>
<td>-14 to -20</td>
<td>50 to 80</td>
</tr>
<tr>
<td></td>
<td>(&lt;1 to 5)</td>
<td>(-12 to -24)</td>
<td>(max 200)</td>
</tr>
<tr>
<td>II</td>
<td>4 to 6</td>
<td>-18 to -22</td>
<td>100 to 400</td>
</tr>
<tr>
<td></td>
<td>(&lt;1 to 8)</td>
<td>(-15 to -24)</td>
<td>(max 600)</td>
</tr>
<tr>
<td>I</td>
<td>9 to 12</td>
<td>-24 to -30</td>
<td>200 to 600</td>
</tr>
<tr>
<td></td>
<td>(&lt;1 to 14)</td>
<td>(-15 to -31)</td>
<td>(max 1000)</td>
</tr>
</tbody>
</table>

All values are meters
Parenthetical values ( ) indicate extreme values
Axial depth is (approximate) distance below sea level.

Figure 5 displays graphic logs of the five cores used in this study, including locations of the fossils that were analyzed for amino acid racemization. Lithologic breaks observed in the cores were correlated with prominent reflectors on the seismic profiles. The more distinct acoustic reflectors appear to coincide with the abrupt transition from silts to coarse sands at the top of the fining-upward sequences.

Table 2 presents the results of the amino acid enantiomeric ratio analyses. The data shown are the ratios of peak areas for D-alloisoleucine and L-isoleucine, or A/I values. *Mulinia* and *Spisula* A/I values are converted to “equivalent Merce-
Figure 3. A portion of the sub-bottom profile from Line 5 (the E-to-W oriented heavy line, see figure 1) and an interpretation (of the top panel). The record shows filled paleochannels from both Systems II and III. System III is cut into the underlying strata whereas System II is probably cut into the sediment filling the System I channel. The sequence is capped by a still-younger sediment blanket.

Table 2. Results of amino acid analyses.

<table>
<thead>
<tr>
<th>Core</th>
<th>Sample No.</th>
<th>Fossil Type</th>
<th>Depth (below seafloor) (m)</th>
<th>A/I Ratio</th>
<th>Aminozone</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-39</td>
<td>V-39-1</td>
<td>Solenidae Ensis</td>
<td>1.54</td>
<td>0.01</td>
<td>II-a</td>
</tr>
<tr>
<td>V-39</td>
<td>V-39-3</td>
<td>Mactridae Spisula</td>
<td>3.24</td>
<td>0.11</td>
<td>II-a</td>
</tr>
<tr>
<td>V-39</td>
<td>V-39-4</td>
<td>Mactridae Spisula</td>
<td>4.15</td>
<td>0.14</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-3</td>
<td>Mulinia cf. lateralis</td>
<td>3.08</td>
<td>0.10</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-4</td>
<td>Mulinia cf. lateralis</td>
<td>3.08</td>
<td>0.11</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-3</td>
<td>Mulinia cf. lateralis</td>
<td>3.46</td>
<td>0.14</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-4</td>
<td>Mulinia cf. lateralis</td>
<td>3.46</td>
<td>0.15</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-5</td>
<td>Veneridae Mercenaria</td>
<td>4.26</td>
<td>0.18</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-5</td>
<td>Veneridae Mercenaria</td>
<td>4.26</td>
<td>0.20</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-5</td>
<td>Veneridae Mercenaria</td>
<td>4.26</td>
<td>0.15</td>
<td>II-a</td>
</tr>
<tr>
<td>V-44</td>
<td>V-44-5</td>
<td>Veneridae Mercenaria</td>
<td>4.26</td>
<td>0.21</td>
<td>II-a</td>
</tr>
<tr>
<td>A-37</td>
<td>A-37-5</td>
<td>Mactridae Rangia</td>
<td>4.34</td>
<td>0.51</td>
<td>II-d</td>
</tr>
<tr>
<td>A-37</td>
<td>A-37-5</td>
<td>Mactridae Rangia</td>
<td>4.34</td>
<td>0.55</td>
<td>II-d</td>
</tr>
<tr>
<td>A-37</td>
<td>A-37-5</td>
<td>Mactridae Rangia</td>
<td>4.34</td>
<td>0.61</td>
<td>II-d</td>
</tr>
</tbody>
</table>
DISCUSSION

The three sequences of channel fill follow the general pattern of fining-upward documented by PEEBLES (1984) and PEEBLES et al. (1984) in the outer coastal plain. In their model, coarse, basal fluvial deposits grade upward into finer paludal and estuarine deposits as a consequence of the decrease in stream gradient accompanying a marine transgression. The same sequence is observed in the filled channels seen in the inner continental shelf. The coarse layers separating the strata not cut by channels are likely the lag atop the regional erosion surfaces created in the subsequent transgressions. The coarse lag materials may be the remnants both of the last stages of the transgression when the high-energy shore zone crossed the area and of the regression, when the shore zone again crossed the area and left the surficial sediments exposed to subaerial erosion.

The three channel systems show some distinct differences in morphology. The northern elements of the youngest sequence, the fill of the topmost channel System III, are generally shore normal with the fill sequence overlain by only a thin blanket of somewhat coarser sediment. The three primarily east-west trending channels in the vicinity of 36°50 N appear related to the modern Rudee Inlet and the Lake Rudee-Lake Wesley drainage. Similarly, the single northeast-southwest channel at about 36°47 N appears related to a smaller, upland drainage that has been flooded to create the present-day Lake Tecumseh. This
history of drowned and filled valleys is much the same as that observed by GAMMISCH et al. (1988) in the Potomac River where upland streams were subsequently infilled during the Holocene transgression.

The older, more shore-parallel paleochannels present a more complex picture. Perhaps they represent an orientation or environment similar to the modern Currituck, Roanoke, and Croatan Sounds, and in northeastern North Carolina, and Back Bay in southeastern Virginia, which are bounded by Pleistocene shorelines. Portions of the sounds are linear and shore-parallel and have the potential to contain deeper, filled channels or themselves to be drowned tributaries (RIGGS et al., 1992). The older channel systems are insufficiently defined to verify the specific drainage patterns, but it is not unreasonable to consider that the southeastern portions of the older channels, System I, drained toward the south.

The amino acid data provide age estimates for the channel cut and fill sequences. Figure 6 summarizes this chronology. The sample from V-39-1, with an A/I value of 0.01, is Holocene and indicates that paleochannel System III has been filled during isotope Stage 1. Samples from deeper in core V-39, and samples from core V-44, all fall into aminozone IIa (after intergeneric conversion), and have age estimates between 80 and 130 ka based on the kinetic and correction models discussed in WEHMILLER et al. (1988) and WEH­MILLER (1992). This conclusion indicates that paleochannel Systems I and II were filled during isotope Stage 5. The super-position of two clusters

Figure 5. Simplified graphic logs of the five cores indicating the A/I ratios of 14 fossil mollusks. The stratigraphic correlations were outlined based on the sediment characters and the A/I ratios.
Figure 6. A composite correlation chart modified from Colman and Mixon (1988) which relates oxygen isotope stages and aminostratigraphic zones to the major stratigraphic elements in the Quaternary history of Chesapeake Bay and the Virginia inner shelf. Aminozone III includes most of northeastern North Carolina; aminozone II encompasses Virginia, Maryland, Delaware and New Jersey (from Wehmiller et al., 1988).

of Mulinia A/I values in core V-44 suggests units of two ages in this core, possibly representing two erosion events within Stage 6.

According to Toscano (1992) Stage 5 on the Maryland continental shelf can be interpreted as follows: Substage 5e (130–120 ka BP), rapid transgression to a high Pleistocene sea stand of 6 m higher than present; Substage 5d, sea level approximately –10 m, perhaps as low as –23 m; Substage 5c, sea level rose to approximately today’s level; Substage 5b perhaps similar to and continuing conditions of 5c; and Substage 5a, sea level approximately –7 m. These variations in sea level and the associated horizontal movements of depositional environments are reflected in the complexity of the infill sequence of the lower paleochannel systems (Figure 5).

Rangia specimens from core C-37 yielded A/I
values of approximately $0.56 \pm 0.04$. Similar values have been observed in other *Rangia* specimens in the region (Wehmiller et al., 1988) and have been assigned to aminozone IId, estimated to be correlative with isotope stages 11, 13, or 15 (Wehmiller et al., 1988; Groot et al., 1990). The warmest and the next warmest periods in Quaternary are considered to be oxygen-isotope Stages 12 and 14 respectively (L. Burckle, Lamont-Doherty Earth Observatory, personal communication). We think that the infill sequence associated with the old *Rangia* is correlative to Stage 13 (and/or 15), and possibly equivalent in age to the oldest (Exmore) paleochannel system in the Chesapeake Bay (Colman and Mixon, 1988).

**CONCLUSIONS**

The three separate filled paleochannels under the inner continental shelf of southern Virginia are correlative with the regional setting as described by Colman and Hobbs (1987), Colman and Mixon (1988), Toscano (1992), and Riggs et al. (1992), among others. The channels likely were cut during the sea-level lowstands of oxygen isotope Stages 12 (14?), 6 and 2, and filled during the subsequent transgressions. This is similar to the history proposed for the Exmore, Eastville, and Cape Charles paleochannels in the Chesapeake Bay (Colman and Mixon, 1988). Aminostratigraphic analyses of 14 samples permit estimation of the age of the infilling. The channel fills indicate a flooding and transgression with sedimentary environments shifting from the coarse-grained materials of fluvial channels to progressively finer materials of paludal, estuarine or lagoonal systems and, possibly, to barrier-island, and inner-shelf environments. The interchannel areas show a similar history with the three periods of sedimentation being separated by periods of erosion as evidenced by erosional surfaces which are seen in both the cores and the high-resolution seismic reflection profiles.

The complexity of the sedimentary sequences, in both temporal and spatial scales, reflects the complex variations of sea level and processes of erosion and deposition during Stage 5 (Toscano, 1992). Finally, there is a suggestion of a change in the orientation of the channel systems through time: the older systems, I and II, being somewhat more parallel to the shoreline, and the youngest system, III, having elements that are more shore-normal and probably associated with features of today's shoreline. The more shore-parallel systems suggest the possibility of the physical palaeoenvironment being similar to that of the modern Currituck Sound in northeastern North Carolina.

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**LITERATURE CITED**


Finkelstein, K. and Kearney, M.S., 1988. Late Pleistocene barrier-island sequence along the southern
Delmarva Peninsula: implications for middle Wisconsin sea levels. *Geology*, 16, 41–45.


