

Geochronology of Quaternary Coastal Plain Deposits, Southeastern Virginia, U.S.A.

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ABSTRACT



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Three clusters of amino acid enantiomeric values (or aminozones) are defined using molluscan fossils from the late Quaternary marine units exposed in Gomez Pit, in the southeastern Virginia coastal plain. Mean alloisoleucine/Isoleucine (A/I) values for two aminozones (IIa: 0.17 ± 0.02 ; IIc: 0.32 ± 0.02) are superposed, show consistent relation to lithologic units, and are used to define local alloformations. A third aminozone (IIb: $A/I = 0.46 \pm 0.04$) cannot be used to define a local alloformation because all IIb mollusks appear to have been reworked into younger (IIc) lithologic units at the Gomez Pit site. U-Th age estimates on corals, and electron spin resonance (ESR) age estimates on fossil mollusks are used to calibrate aminozone IIa. Combined U-Th, ESR, and amino acid enantiomeric data indicate a Stage 5 (80 to 130 ka) age for aminozone IIa. Age estimates for older aminozones IIc and IIb are calculated using aminozone IIa calibration applied to kinetic models describing diagenetic racemization. Using this approach, age range estimates for aminozone IIc (approximately 250 to 400 ka), and aminozone IIb (approximately 500 to 800 ka) are proposed. Aminostratigraphic interpretations are compared with other geomorphic and stratigraphic studies of the southern Chesapeake Bay region. Deposition of the "IIa alloformation" is correlative with parts of the Tabb Formation (Sedgefield Member), or parts of the Norfolk Formation, evolution of the Nassawadox spit (lower Delmarva Peninsula), and filling of the Eastville paleochannel of the ancestral Susquehanna River. The "IIc alloformation" is correlative with the Shirley Formation (on the York-James Peninsula) or Great Bridge Formation. Aminozone IIb (in place elsewhere in the region) is correlative with the Shirley Formation (on the Rappahannock River), evolution of the Omar-Accomack spit, and filling of the Exmore paleochannel of the ancestral Susquehanna River.

ADDITIONAL KEY WORDS: *Stratigraphy, Atlantic coastal plain, sea-level change, amino acid racemization, electron spin resonance.*

INTRODUCTION

Emergent Quaternary units of the U.S. Atlantic coastal plain represent the landward edge of the complex preserved record of multiple marine transgressions associated with ice-volume minima during the last 1.5 to 2 Ma (OAKS *et al.*, 1974; BLACKWELDER, 1981; CRONIN *et al.*, 1981; SZABO, 1985; WEHMILLER *et al.*, 1988; WEHMILLER *et al.*, 1992). These deposits have been particularly well-studied in southeastern Virginia over the past thirty years, primarily because of extensive borrow-pit exposures (OAKS and COCH, 1973; MIXON *et al.*, 1982; DARBY, 1983; PEEBLES, 1984; PEEBLES *et al.*, 1984; SPENCER and CAMPBELL, 1987; COLQUHOUN *et al.*, 1991; TOSCANO and YORK, 1992). These studies have identified up to seven post-Pliocene units based on a combination of

morphostratigraphic, lithostratigraphic, faunal, floral, and geochronological analyses.

In this paper we present aminostratigraphic and electron spin resonance (ESR) data for mollusk samples from an extensive excavated outcrop at Gomez Pit, near Virginia Beach, Virginia (Figure 1A, B). The sequence in Gomez Pit has been exposed for nearly ten years, and results presented here are based on collections made during frequent visits to the site between 1983 and 1990 (Figure 1C). Previous discussions of earlier results from this site have appeared elsewhere (WEHMILLER *et al.*, 1988; MIRECKI, 1990; MIRECKI *et al.*, 1990; GROOT *et al.*, 1990), but this paper presents these and newer data in the context of the detailed lithostratigraphic nomenclature for the site and region. We conclude from these results that a lithostratigraphic record of two transgressive units is preserved in the section at Gomez Pit, overlying the Pliocene (BLACKWELDER, 1981; PEEBLES *et al.*, 1984; KRANTZ, 1991) Chowan Riv-

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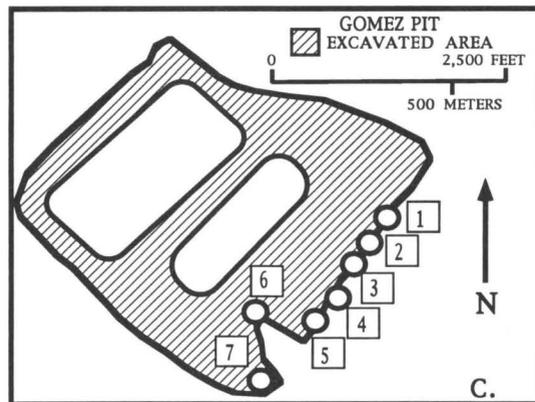
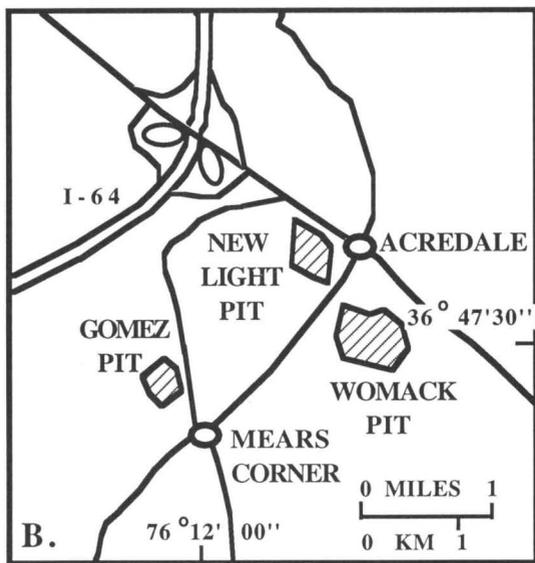
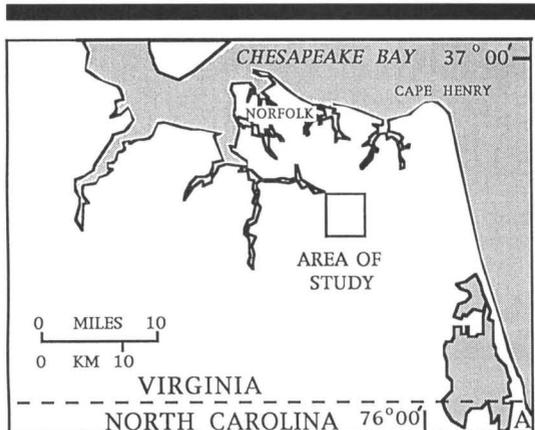


Figure 1. Locality maps. A. Map of the outer coastal plain of southeastern Virginia. B. Map showing locations of borrow pits discussed in the text. C. Map showing locations of stratigraphic sections described in Figure 3.

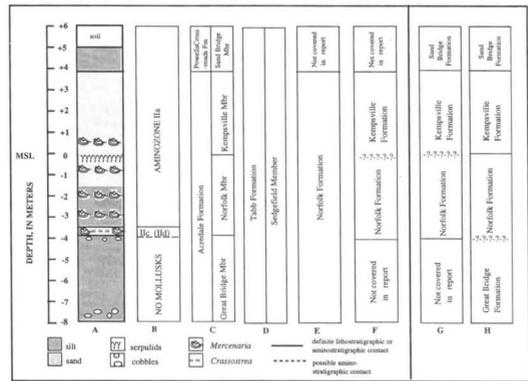


Figure 2. Comparison of stratigraphic frameworks proposed for post-Pliocene units exposed in Gomez Pit and other nearby quarries. Sections C through F are redrawn from published interpretations of Gomez Pit strata. Sections G and H are redrawn from published interpretations of Womack Pit (now flooded) strata, located < 1 km from Gomez Pit. Section A, composite lithologic section from Gomez Pit. Section B, aminostratigraphic interpretation. Section C, from SPENCER and CAMPBELL (1987). Section D, from Peebles (1984). Section E, from DARBY (1983). Section F, from CRONIN *et al.* (1981). Section G, from MIXON *et al.* (1982). Section H, from OAKS and COCH (1973).

er Formation exposed in this borrow pit and elsewhere in the region. Evidence of a third transgression is derived from aminostratigraphic data that imply reworking of older shell material into the units exposed in Gomez Pit. The two transgressive units, which are superposed throughout the exposure, are interpreted to represent portions of marine isotope Stages 5 and 7 (or 9), respectively. These units can be interpreted as "local alloformations" based on their associated aminostratigraphic data. Most previous interpretations of the units at Gomez Pit have not recognized the two transgressive records that are implied by this allostratigraphic interpretation of the Gomez Pit sequence; however, the conclusions presented here are consistent with the general stratigraphic sequence observed on the Delmarva Peninsula (COLMAN and MIXON, 1988; COLMAN *et al.*, 1990; COLQUHOUN *et al.*, 1991).

SITE DESCRIPTION

A summary of different stratigraphic interpretations of Quaternary units at the Gomez Pit area is shown in Figure 2. Although a detailed com-

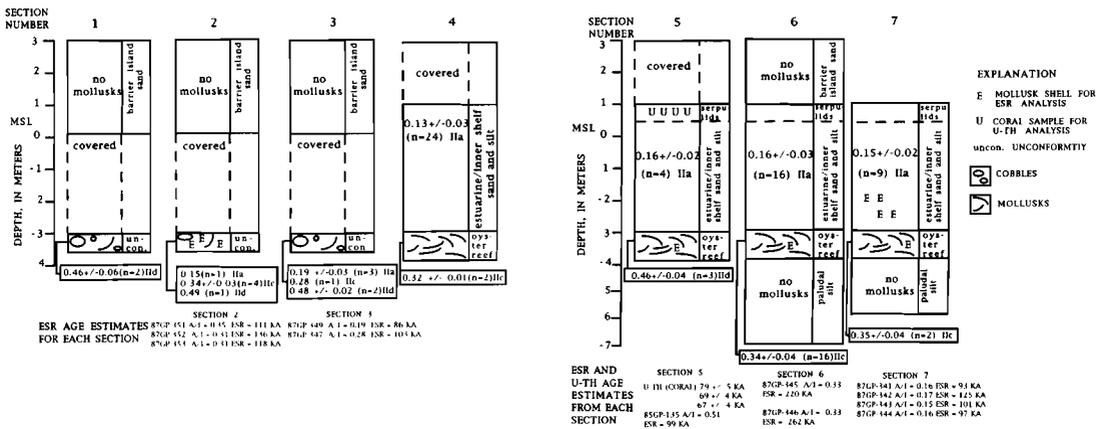


Figure 3. Synthesis of lithologic, aminostratigraphic and chronologic data from Gomez Pit. Locations of Sections 1 through 7 are shown on Figure 1. U-Th coral dates from CRONIN *et al.* (1981) and SZABO (1985). ESR age estimates from SKINNER (1989).

parison of the various stratigraphic frameworks proposed since OAKS and COCH (1973) cannot be considered here, it is important to note that these studies have concluded that most of the units exposed in Gomez Pit (and other nearby borrow pits) represent one transgressive sequence deposited during a single interglacial high stand corresponding to all or part of oxygen isotope Stage 5 (80 ka to 130 ka; OAKS and COCH, 1973; MIXON *et al.*, 1982; DARBY, 1983; CRONIN *et al.*, 1984; PEBBLES *et al.*, 1984; SZABO, 1985; SPENCER and CAMPBELL, 1987; COLQUHOUN *et al.*, 1991).

Seven exposures were described in Gomez Pit, and fossil mollusks from these sections were collected intensively for amino acid racemization and electron spin resonance (ESR) analyses (Figures 1C, 3). The basal Quaternary unit exposed at this site consists of a paludal silt (tree trunks were observed in some sections) overlain by a laterally extensive oyster (*Crassostrea*) reef, which in turn overlain by a fossiliferous estuarine/inner shelf sand. Most mollusk samples for amino acid and ESR analyses were obtained from the oyster reef unit and the overlying fossiliferous sand (Figure 3). A laterally continuous serpulid bed is found in the upper part of the sand unit; the serpulid bed has been used by some workers to define a lithostratigraphic contact in the section (Figure 2).

Coral samples from within the serpulid bed have been analyzed for U-Th geochronology (CRONIN *et al.*, 1981; MIXON *et al.*, 1982; SZABO, 1985). Nine

samples from this unit, collected from several sites in the region, yielded an average age of 71 ± 5 ka (Table A in SZABO, 1985); three samples from Gomez Pit (Mears Corner site of CRONIN *et al.*, 1981; SZABO, 1985) show ages of 79 ± 5 ka, 69 ± 4 ka, and 67 ± 4 ka (SZABO, 1985; Figure 3). No U-Th coral dates are available for other parts of the Gomez Pit section, as the corals are found only within the serpulid unit. Although many corals are found attached to *Mercenaria* in the Gomez serpulid unit, no paired U-series-amino acid analyses have been done on such samples.

U-Th analyses of mollusk (genus *Mercenaria*) shell samples also have been used to estimate age of units in southeastern Virginia (MIXON *et al.*, 1982); however, use of this fossil type is problematic due to uncertainties about the timing and extent of uranium uptake during diagenesis (KAUFMAN *et al.*, 1971). U-Th age estimates from four *Mercenaria* samples collected from the Norfolk or Kempsville Formations have been reported (MIXON *et al.*, 1982), and all age estimates are younger than those obtained on corals from the same locality and unit. U-Th analyses on *Mercenaria* from the Norfolk or Kempsville Formations show ages of 62 ± 5 ka, 51 ± 3 ka, 42 ± 3 ka, and 35 ± 3 ka (MIXON *et al.*, 1982). Because coral and mollusk U-Th age estimates are discordant and mollusk shell is known as an unreliable sample type for U-Th analyses (KAUFMAN *et al.*, 1971), these mollusk shell age estimates have usually been disregarded.

GEOCHEMICAL METHODS AND RESULTS

Aminostratigraphic Methods

Amino acid enantiomeric or diastereomeric values from fossil mollusk shells can be used to define chronostratigraphic units in both marine and terrestrial depositional environments (e.g., MILLER and MANGERUD, 1985; MCCOY, 1987; CLARK *et al.*, 1989; WEHMILLER *et al.*, 1992). Aminostratigraphic methods involve discrimination or correlation of strata at sites where similar temperature history is assumed. Relative ages are inferred from the clusters of D/L values obtained from samples with known racemization rates (or aminozones, as defined by MILLER and HARE, 1980). Ideally, at least some of these clusters of D/L values will be seen in a relative age sequence that is consistent with lithostratigraphic relationships in a single outcrop. If amino acid D/L values are calibrated with independent chronologic data, then numerical ages for other aminozones can be estimated using appropriate kinetic models for racemization (e.g., WEHMILLER *et al.*, 1988; MITTERER and KRIAUSAKUL, 1989; LEONARD and WEHMILLER, 1992). Amino acid enantiomeric data obtained from Gomez Pit samples and others in the region have been obtained by gas-chromatographic (GC) and high-pressure liquid chromatographic (HPLC) methods described elsewhere (FRANK *et al.*, 1977; HARE *et al.*, 1985). GC methods yield D/L data for as many as seven amino acids (D/L leucine values being emphasized here); HPLC methods yield data for D-alloisoleucine/L-isoleucine, hereafter referred to as A/I. Previous summaries of aminostratigraphic data for the Mid-Atlantic region have identified five major aminozones, identified as IIa, IIb, IIc, IIId, and IIe, from youngest to oldest (WEHMILLER *et al.*, 1988; GROOT *et al.*, 1990; WEHMILLER *et al.*, 1992). Aminozones IIa and IIc are represented clearly by Gomez Pit data as demonstrated here.

Aminostratigraphy of Gomez Pit

The aminostratigraphy of Gomez Pit is based on numerous analyses of specimens of the molluscan genus *Mercenaria* obtained from seven measured sections on the southeast and south walls of this excavation (Figures 1C, 3). The abundance of *Mercenaria* at all sections permitted intensive collection of aminostratigraphic data from monogeneric samples showing a variety of textural and geochemical preservation characteristics (MIRECKI, 1990). D/L leucine and A/I values for these

seven sections are summarized, and the corresponding aminozone designations IIa, IIc, and IIId for each of these clusters are shown in Table 1 and Figure 3. The range of D/L or A/I values represented by a "single" aminozone is probably the combined effect of a variety of thermal and diagenetic factors as well as possible age differences for multiple shells within a single aminozone. All of the specimens discussed here were whole valves and several of the IIa and IIc samples were articulated.

Three aminozones are recognized in the Gomez Pit results, and all three have been identified in place at outcrops elsewhere in the region (WEHMILLER *et al.*, 1988). Aminozones IIa and IIc are found superposed at four sections within the pit (Figure 3). The consistent relation of these two aminozones to lithostratigraphy in Gomez Pit sections is used to define informal alloformations that we describe as the "IIa alloformation" and "IIc alloformation," respectively. This interpretation meets three fundamental criteria for aminostratigraphy (MILLER and BRIGHAM-GRETTE, 1989) such that: (1) lowest D/L values occur in the uppermost lithologic unit; (2) there is no overlap of standard deviations for mean D/L values of the IIa and IIc aminozones; and (3) the unconformity between the IIa and IIc aminozones is marked by an abrupt increase in D/L values.

Aminozone IIa (Figure 3) was defined by the largest population of samples ($n = 60$; MIRECKI, 1990); however, only those mollusks that were analyzed by HPLC and GC or ESR methods are reported here (Table 1). The mean A/I value for aminozone IIa is 0.17 ± 0.02 (D/L leucine = 0.26 ± 0.02 ; Table 1). A/I values ranging between 0.09 and 0.20 were measured in the larger IIa sample population (MIRECKI, 1990), the lower values being observed in the uppermost part of the fossiliferous sand where alteration of shells by groundwater is obvious. Amino acid enantiomeric values reported from aminozone IIa are considered correlative with U-Th age estimates of coral samples collected from the serpulid bed in the Gomez section (CRONIN *et al.*, 1981; SZABO, 1985).

Aminozone IIc was defined by a mean A/I value of 0.32 ± 0.02 . No IIc samples from Gomez Pit were analyzed by GC methods, but combined GC/HPLC data from aminozone IIc at other sites in the region (BELKNAP, 1979; WEHMILLER *et al.*, 1988) indicate that the corresponding D/L leucine value for the Gomez IIc aminozone would be 0.42 ± 0.02 . IIc *Mercenaria* samples were always found

Table 1. Amino acid enantiomeric data, and ESR age estimates for fossil *Mercenaria* from Quaternary marine units at Gomez Pit, southeastern Virginia.

Shell Samples	Amino Acid Data*		Electron Spin Resonance Age Estimate (ka)	Uranium Concentration (mg/kg)
	D/L Leucine	A/I		
Aminozone IIA				
87GP-341	—	0.16	93	0.03
87GP-342	—	0.17	125	0.04
87GP-343	—	0.15	101	—
87GP-344	—	0.16	97	—
87GP-349†	—	0.19	86	0.18
83GP-137	0.28	0.13	—	—
83GP-138	0.24	0.20	—	—
83GP-140	0.25	0.17	—	—
Mean values for Aminozone IIA	0.23 ± 0.02 (3)	0.17 ± 0.02 (8)	110 ± 13 (5)	
Aminozone IIC				
87GP-345	—	0.33	220	0.67
87GP-346	—	0.33	262	—
87GP-347†	—	0.28	103	—
87GP-351†	—	0.35	111	0.68
87GP-352†	—	0.31	136	—
87GP-353†	—	0.31	118	—
Mean values for Aminozone IIC		0.32 ± 0.02 (6)	bimodal§	
Aminozone IID				
83GP-135†	0.54	0.50	99	1.88
83GP-136	0.52	0.45	—	—
83GP-139	0.53	0.40	—	—
87GP-327	—	0.47	—	—
Mean values for aminozone IID	0.53 ± 0.01 (3)	0.46 ± 0.04 (4)		

*A/I values are calculated from peak area data, and are not corrected by standard data (MIRECKI, 1990). D/L leucine values are calculated from peak heights on gas chromatograms (MIRECKI, 1985)

†Mollusk valve was collected from the disconformity shown on Figure 2

§Bimodal distribution of age estimates. See discussion in text

— Not determined

within the oyster reef, and were usually (but not always) disarticulated. The contact between aminozones IIA and IIC coincides with the upper surface of the oyster reef (Figure 3).

Aminozone IID, defined by a mean A/I value of 0.46 ± 0.04 (D/L leucine = 0.53 ± 0.01 ; Table 1), is difficult to relate to a specific lithologic unit. All IID shells (whole or partial valves, but none articulated) are found in the middle or lowermost portions of the same oyster reef unit that contains the IIC shells. IID shells were found in one portion of the outcrop (Sections 1, 2, 3, and 5 in Figure 3) and appear to be mixed with IIC shells at Sections 2 and 3. These results most likely indicate that IID shells were reworked into the oyster reef unit during the time of its formation (IIC). It is possible that the unit immediately underlying the IIC oyster reef was formed at the time represented by aminozone IID, but shells with unambiguous

placement in this underlying unit have not been found. The IID aminozone has been found in-place at sites both north and south of Gomez Pit (WEHMILLER *et al.*, 1988), so aminostratigraphic support for a unit with this apparent age is available in the region². Cobbles often found within or below the oyster reef (Figure 3) suggest that this portion of the stratigraphic section represents an erosive record with the creation of a lag deposit and one of more disconformities.

Electron Spin Resonance (ESR) Spectroscopy

The use of ESR to determine age of a fossil mollusk depends on the ability of the aragonitic lattice of mollusk shell to act as a dosimeter, trap-

² In March, 1993 a collection of articulated *Mercenaria* with aminozone IID A/I values was made in a freshly-excavated trench about 100 m NW of Section 6 (Figure 1c), lending further support to the existence of this unit in the area.

ping free electrons in defect sites over time (GRÜN, 1989). The accumulated dose (AD) represents the cumulative effect of all sources of radiation that may interact with a fossil sample. The AD includes radiation from decay of U, Th, and K, both external to the shell and internal, and cosmic radiation. For deeply buried fossils, (> 2 meters), the contribution of cosmic radiation to the AD can be neglected (PRESCOTT and HUTTON, 1988). The AD of the fossil can be calculated from the height of the $g = 2.0012$ peak on an ESR spectra, and the age can be calculated from the AD if U, Th, and K concentrations in shell and enclosing sediment are known. At present, ESR is regarded as a calibrated-age dating method (COLMAN *et al.*, 1987), dependent on assumptions about the depositional environment. Although numerical age estimates are obtained using ESR data, these ages can be regarded as significantly imprecise, because questions regarding the timing and magnitude of diagenetic uranium uptake in calcareous fossils remain. Also, there is uncertainty about the mean life of the electrons in the crystal defect represented by the $g = 2.0012$ peak. Most studies suggest a mean life of approximately 1 Ma at ambient temperatures (RADTKE and GRÜN, 1988); however, further confirmation of the mean life is needed.

Eleven fossil mollusk valves representing aminozones IIa, IIc, and IId at Gomez Pit were analyzed by ESR spectroscopic methods (SKINNER, 1989; Table 1). We sought to provide an independent ESR age estimate on the same mollusk shell fossil used for amino acid analysis. The fossils selected generally were well-preserved aragonitic shells (intact, without borings or chalkiness, and < 2% calcite). U, Th and K concentrations on selected shells (all analyzed for amino acid enantiomeric values) and enclosing sediment were determined by neutron activation analysis (U concentrations in Table 1).

ESR age estimates for aminozone IIa fossils range from 93 ka to 125 ka, correlative with oxygen isotope Stage 5 (Table 1). ESR age estimates are somewhat older than those from U-Th analyses on corals, which suggested deposition during oxygen isotope Substage 5a. Because there is no trend of increasing A/I or D/L value with depth in aminozone IIa, we conclude that only one isotopic substage is represented here, given the resolving ability of the amino acid racemization methods (MIRECKI, 1985; MIRECKI, 1990).

The difficulty of determining unambiguous age

estimates is shown by the examination of ESR results from IIc and IId mollusk valves collected from the oyster reef. The obvious taphonomic evidence of reworking and shell transport preserved within the oyster reef/cobble layer indicates that erosion and reburial of some IIc and IId shells have occurred. Reworking of fossil valves into a new post-depositional sedimentary environment can reduce (or change) the external dose component of the AD. Consequently, a lower AD can result in a significant reduction in age estimate because the primary component of AD in buried fossil mollusks is from decay of sedimentary isotopes, rather than isotope decay within the shell (SKINNER and WEICKER, 1992).

ESR age estimates for aminozone IIc fossils (*i.e.*, those *Mercenaria* valves collected within the oyster reef) are problematic. Even though all aminozone IIc mollusks showed A/I values of *ca.* 0.32, only 2 of 6 IIc samples yielded ESR age estimates that suggest preservation in undisturbed sediment. Four samples yielded ESR ages between approximately 100 and 140 ka, and two others yielded ESR ages of 220–260 ka (Table 1). Considering the transported nature of these IIc shells, the older ages are considered more accurate (and may be just minimum ages), implying that aminozone IIc represents deposition during either Stage 7 or Stage 9 of the marine isotope record.

ESR analysis of a single mollusk valve from aminozone IId (A/I = 0.46) also yielded an age estimate that was younger than expected (99 ka, Table 1). This ESR age estimate does not differ significantly from the range of ages calculated for aminozone IIa. Uranium concentrations in this IId fossil are approximately three times greater (1.88 mg/kg; Table 1) than concentrations measured in aminozone IIc shells, suggesting that post-depositional U-uptake has affected the AD of the IId mollusk valve (SKINNER, 1989).

DISCUSSION

Amino acid enantiomeric data from Gomez Pit support the definition of three aminozones, the youngest two (IIa and IIc) being clearly related to lithostratigraphic units that can be traced along most of the exposure. Based on the extent of the exposures containing these aminozones, and the clarity of the lithologic contact between these aminozones, we refer to these units informally as the IIa and IIc alloformations. The combination of U-Th and ESR data suggest that the youngest of these aminozones (IIa) is correlative with ox-

ygen isotope Stage 5 (ca. 80 to 130 ka). Specific assignment of aminozone IIa to either early or late Stage 5 (substage 5e or Substage 5a, respectively) is not possible, although the abundance of late Stage 5 U-Th coral dates from the region argues for the Substage 5a correlation (SZABO, 1985). In contrast, an early Stage 5 age estimate calculated from ESR data is consistent with the altitude of the IIa alloformation, given probable sea-level elevations during early versus late Stage 5 (RADTKE, 1987; SHACKLETON, 1987), and the tectonic history of the region (CRONIN, 1981). Extrapolation of racemization kinetics from calibration aminozone IIa to older aminozones (higher D/L values) can be accomplished using parabolic or non-linear kinetic models presented elsewhere (WEHMILLER *et al.*, 1988; MITTERER and KRIAUSAKUL, 1989; LEONARD and WEHMILLER, 1992; MURRAY-WALLACE and KIMBER, 1993).

These calculations are presented in Table 2, and suggest that aminozones IIc and IId represent deposition during middle Pleistocene interglacials at approximately 250–400 ka and 500–800 ka, respectively. These age ranges are consequences of the ranges in calibration ages and the many uncertainties inherent to our assumptions regarding kinetic models and relative temperature histories of mollusks from different aminozones (see YORK *et al.* (1989) for similar kinetic model age estimates at nearby sites). The ESR age estimates for aminozone IIc shells only indicate an age greater than Stage 5 and could be consistent with either a Stage 7 or Stage 9 age assignment for this aminozone.

The age estimates derived from the combined amino acid and ESR data can be compared with stratigraphic and geomorphic analyses of the southern Chesapeake Bay region published recently (COLMAN and MIXON, 1988; COLMAN *et al.*, 1990; TOSCANO and YORK, 1992). This comparison is summarized in Figure 5, in which regional aminostratigraphic data are plotted for sites between southern New Jersey and northeastern North Carolina (WEHMILLER *et al.*, 1988; GROOT *et al.*, 1990; TOSCANO and YORK, 1992). The sections at Gomez Pit and Stetson Pit, N.C. (YORK *et al.*, 1989) identified in Figure 5 are particularly important aminostratigraphic reference sections, because these are the only two sites in the entire region where there is a clear relation between superposed aminozones and the lithostratigraphic section. Figure 5 shows that aminozone IIa is found most frequently in the region, as would be ex-

Table 2. Kinetic model age options for aminozones at Gomez Pit, Norfolk, Virginia.

Aminozone	A/I	Age Estimate (ka)			
		Parabolic Kinetic Model*			
IIa	0.17	80	100	125	calibration aminozone
IIc	0.32	283	354	443	
IId	0.46	585	732	915	
		Non-linear Kinetic Model†			
IIa	0.17	80	100	125	calibration aminozone
IIc	0.32	258	323	404	
IId	0.46	547	684	855	

Note: Kinetic model age estimates are presented using early (125 ka), middle (100 ka), or late (80 ka) stage 5 age options as the calibration for aminozone IIa, in either kinetic model. U-Th coral ages support a late stage 5 age for aminozone IIa; ESR age estimates support a middle-to-early stage 5 age for aminozone IIa

*Apparent parabolic kinetic model of KRIAUSAKUL and MITTERER, 1989

†Non-linear kinetic model of WEHMILLER *et al.*, 1988, with appropriate intergeneric conversion

pected for deposits representing the most recent Pleistocene interglacial high stand. IIa sites are found on the southern Delmarva Peninsula (the late Pleistocene Nassawadox spit of COLMAN and MIXON 1988), at Gomez and several nearby borrow pits, and on the eastern margin of a core of older units in central Delmarva (TOSCANO and YORK, 1992). The Nassawadox spit is interpreted to represent the youngest major progradation phase of the Delmarva Peninsula following incision and filling of the Eastville paleochannel that runs beneath southern Delmarva (COLMAN and MIXON, 1988; COLMAN *et al.*, 1990). Aminozone IId values are found at five sites within the Omar-Accomack spit complex (central Delmarva Peninsula) that is interpreted to have filled the Exmore paleochannel (COLMAN and MIXON, 1988; COLMAN *et al.*, 1990). Aminozone IId is also found at the mouth of the Rappahannock River on the west shore of the Chesapeake Bay (Figure 5), at a site known as Norris Bridge (WEHMILLER and BELKNAP, 1982; WEHMILLER *et al.*, 1988). A U-Th coral date of approximately 180 ka from Norris Bridge has proven controversial (WEHMILLER and BELKNAP, 1982; McCARTAN *et al.*, 1982) and is now thought to be suspect (B.J. SZABO, *personal communication* to JFW; June, 1992).

Aminozone IIc is a prominent regional aminozone represented by units found in the Gomez and Womack Pits in southeastern Virginia, a site

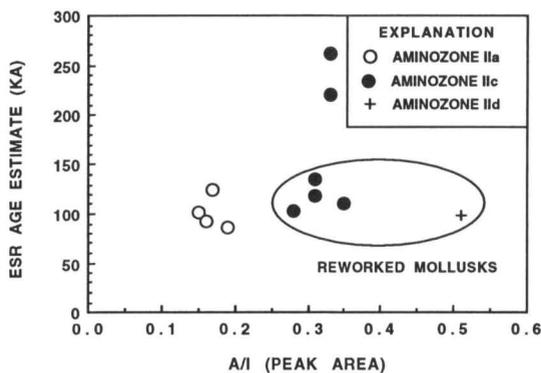


Figure 4. Plot of amino acid enantiomeric values (A/I) versus ESR age estimates from Gomez Pit mollusks. Amino acid and ESR analyses were performed on the same fossil mollusk valve.

known as the Big Bethel Pit on the lower York-James Peninsula (Figure 5), as well as sites near the mouth of Delaware Bay (GROOT *et al.*, 1990). At Gomez Pit, aminozones IIa and IIc are found in lithostratigraphic units that have been interpreted as representing several different lithostratigraphic formations (Figure 2). Aminozone IIc at the Big Bethel Pit is found in a unit mapped as the Shirley Formation (PEEBLES, 1984), a term also applied to the unit at Norris Bridge that yielded the aminozone IIId results (WEHMILLER *et al.*, 1988). IIc samples have also been found in southern Delmarva, perhaps only as reworked fragments (BELKNAP, 1979; GROOT *et al.*, 1990). Recent re-evaluation of the Gomez Pit stratigraphic terminology within the context of the aminostratigraphic results (G. JOHNSON, *personal communication*, 1992) suggests that the IIc unit at Gomez Pit should be re-defined as the Shirley Formation. Because of the major age difference (at least 100 ka) that must be represented by the contact between aminozones IIa and IIc at Gomez Pit, it is suggested that a stratigraphic terminology that emphasizes the significance of the hiatus between IIa and IIc at Gomez Pit be adopted. It is possible that the Norfolk Formation/Great Bridge Formation sequence proposed by MIXON *et al.* (1982) best represents the IIa/IIc relationship, but their placement of the contact between these two units was defined prior to the availability of aminostratigraphic data.

Correlation of the units exposed at Gomez Pit with other deposits in the lower coastal plain can be suggested, although some correlations (and their

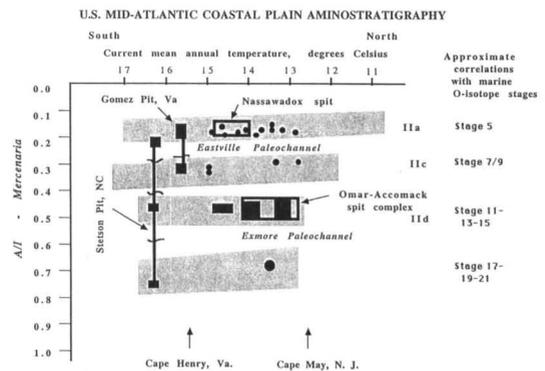


Figure 5. Synthesis of regional formation nomenclature and aminostratigraphy of the mid-Atlantic coastal plain, between approximately 39° and 36° N. latitude, over a range of mean annual temperatures from approximately 12° to 17° C. Cape May is at the mouth of Delaware Bay and Cape Henry is at the mouth of Chesapeake Bay. A/I values plotted are mean peak area ratios for *Mercenaria* from sites between southern New Jersey and northeastern North Carolina. Geomorphic terms (Nassawadox and Omar-Accomack spits, Eastville and Exmore paleochannels) from COLMAN and MIXON (1988). Stetson Pit data from YORK *et al.* (1989). For other site information, see GROOT *et al.* (1990) or WEHMILLER *et al.* (1988).

ages) are controversial. Correlation of the Tabb Formation (PEEBLES *et al.*, 1984) or Norfolk Formation of others is approximately correlative with the Nassawadox Formation, the Wachapreague Formation and the Joynes Neck Sand as exposed on the Delmarva Peninsula and the adjacent shelf (COLQUHOUN *et al.*, 1991; TOSCANO and YORK, 1992). In northern North Carolina, the Tabb Formation and equivalents are correlative to the Core Creek Sand Formation (COLQUHOUN *et al.*, 1991).

Quaternary geochronology of Mid-Atlantic coastal plain units is ambiguous, but the aminostratigraphic sections at Gomez and Stetson Pits help to define important chronostratigraphic reference sections. ESR age estimates at Gomez Pit provide some temporal assignment of aminozone IIc and suggest that aminozone IIa might be of early, rather than late Stage 5 age. Ages of aminozones IIa, IIc, and IIId are important features in the debate over a "long versus short" geochronology for the Atlantic coastal plain, a debate which has been summarized elsewhere (COLMAN and MIXON, 1988). The age options have important consequences for regional tectonic and/or sea-level histories as well as implications for the rate of channel-cutting and filling in the Susquehanna

paleochannel system (COLMAN *et al.*, 1990). Because aminozone IId units are stratigraphically younger than the Exmore paleochannel (the oldest of the three major paleochannels recognized by COLMAN and MIXON [1988]), the age of aminozone IId is an important component of any discussion of the chronology of the evolution of the lower Susquehanna drainage system. COLMAN and MIXON (1988), in reviewing the optional chronologies for this history, suggested that the Exmore paleochannel was cut during sea-level regressions of either Stage 8 or Stage 12 of the marine isotopic record. The older age estimate, or perhaps even one full cycle older, is consistent with the kinetic model age estimate for aminozone IId as presented in this paper. The Eastville paleochannel predates the units containing aminozone IIa samples, hence it was cut prior to Stage 5; the Cape Charles paleochannel post-dates aminozone IIa. Aminozone IIc, although not clearly identified in units that can be stratigraphically related to the Susquehanna paleochannel system, suggests that at least one additional cycle of channel cutting and filling (between the times of the Exmore and Eastville paleochannels) might be preserved in the region.

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Appendix 1. Interlaboratory comparison (ILC) standard data obtained at the University of Delaware Amino Acid Laboratory during period of study.

Standard	A/I Total		D/L Leucine Total	
	Hydrolyzate*	N†	Hydrolyzate	N†
ILC-B	0.44 ± 0.05	25	0.52 ± 0.05	4

Note: To check the analytical precision of amino acid data, ILC standard mollusk shell powders (WEHMILLER, 1984) were run with each batch of fossil samples during HPLC or GC analyses

*A/I values are calculated from peak area data, and are not corrected by any internal standard

†N equals the number of separate ILC-B sample preparations