The maps in this file are from two review papers, summarizing the locations and associated publications for sites included in the University of Delaware database. The 1988 publication (Wehmiller et al., 1988: GSA Special Paper 227) includes an explanation of the regional coverage for the US Atlantic Coastal Plain, as well as the summary data available at the time of publication. The 2013 publication (Wehmiller, 2013: Quaternary Geochronology) shows maps for the US Atlantic and Pacific coasts, with associated references and bibliography.

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A review of the aminostratigraphy of Quaternary mollusks from United States Atlantic Coastal Plain sites

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ABSTRACT

The aminostratigraphic relationships of approximately 150 coastal Quaternary sites from Nova Scotia to Florida and the Bahamas Islands are reviewed. The broad latitudinal range of the sites provides a useful perspective on the relative kinetics of racemization at substantially different temperatures. Local aminostratigraphic sections are presented for five regions in which present mean annual temperatures differ by 3°C or less. Correlation of these individual aminostratigraphies is accomplished by qualitative comparison of results for overlapping sections and by quantitative kinetic modeling. Correlations based on kinetic modeling with local calibration are compared with available U-series data for coastal plain sites. Using basic aminostratigraphic assumptions about the relationship of present and past temperature gradients, the amino acid data from most of the calibration sites follow logical trends. However, significant conflicts between U-series dates and aminostratigraphic age estimates are recognized for sites in South Carolina and for a group of sites in eastern Virginia (central Chesapeake Bay). Reconciliation of the aminostratigraphic data with all of the Atlantic Coastal Plain U-series coral dates is not possible without invoking extreme (and latitudinally variable) thermal effects on the racemization kinetics.

INTRODUCTION

Amino acid racemization (AAR) studies of mollusks from Quaternary marine and nonmarine sites have proven of value in defining relative age relationship and in estimating absolute ages of fossiliferous units (Wehmiller, 1982; G. H. Miller, 1985; Bowen and others, 1985; Miller and Mangerud, 1985; Hearty and others, 1986). The term "aminostratigraphy," first defined by Miller and Hare (1980), involves the direct application of amino acid enantiomeric (D/L) ratios to localities for which identical or similar effective temperatures can be assumed ("effective Quaternary temperatures" or "effective diagenetic temperatures" are the terms most often used to describe these integrated thermal histories). Often such local aminostratigraphies are developed for closely spaced sites with the same current mean annual temperature (CMAT). Ages can be estimated for the different observed groups of D/L values (aminozones) if independent chronologic data are available for calibration or by application of suitable models for the racemization kinetics in the analyzed samples.

In this chapter, we summarize aminostratigraphic studies of mollusks from late Cenozoic marginal marine deposits along the U.S. Atlantic coast. Some of these results have been discussed in previous publications on specific geographic regions. Here we include new data, review analytical methods and interpretive strategies, present several local aminostratigraphic sequences, and provide an overall aminostratigraphic correlation of sites from Nova Scotia (44°N) to Florida (23°N). Our research is part of a large, on-going effort by a number of workers to understand both regional and local stratigraphic sequences in the coastal plain (see Szabo, 1985, and Cronin and others, 1984, for references). This work also has been, and continues to be, an effort to evaluate the reliability of AAR dating methods and to understand the geochemistry, mechanism, and kinetics of diagenetic racemization in mollusks. In a previous paper, Wehmiller and Belknap (1982) noted some serious conflicts between aminostratigraphic age estimates and U-series geochronology. Szabo (1985) has presented some additional isotopic results relevant to these conflicts. These particular issues, which appear to be nearly unique to a few sites on the U.S. Atlantic coast, are discussed in detail in this

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paper. Although the conflicts between aminostratigraphy and independent age estimates occur infrequently, they provide useful perspectives on both the assumptions and geochemistry of aminostratigraphy. Unfortunately, a geochemical resolution for these issues is not yet apparent. Therefore, at this time, we choose only to explain the nature of the conflicts and to quantify them using what we consider to be the most appropriate kinetic model for racemization. We also discuss some constraints that can be placed on the thermal histories that might be invoked to reconcile the amino acid and U-series data.

LOCALITIES AND SAMPLES

The localities from which mollusk samples have been obtained are summarized in Table 1 and in Figures 1 through 5. Most of the localities have been sampled at surface outcrops, but some subsurface sites are also included. Samples from higher latitudes (40° to 44°N) have been affected by glaciation: most of those from the southwest coast of Nova Scotia and from Long Island are transported shell fragments contained in glacial drift; samples from Maine are found in latest Pleistocene glaciomarine silt and clay; other unfragmented (and occasionally articulated) samples from Long Island and from eastern Massachusetts appear to have been transported by ice within large blocks of sediment. South of the limit of glaciation, most of the samples have been collected from sediments deposited in lagoonal, estuarine, or back-barrier environments. Articulated and growth position bivalves have been selected for analysis whenever possible, but the majority of samples available at most sites are disarticulated and/or out of life position, so the results presented here are usually limited by the constraint that nontransported samples are rarely available. Fragmented or otherwise visibly altered shells are avoided wherever possible, but sometimes no other sample types are available.

Figure 1 shows the limits of the study area, from Nova Scotia to Florida and the Bahamas Islands. Figures 2 through 5 are larger-scale maps of the "aminostratigraphic regions" that are discussed in more detail in following sections. Current mean annual temperatures are also shown on these maps. The range of temperatures for each region is significant, but small enough so that, to a first approximation, the aminostratigraphy of each region can be considered independently of the effects of major thermal gradients. However, rigorous application of any kinetic model to long-distance correlation and/or age estimation requires the estimation of effective thermal gradients both within and between the regions shown in Figures 2 through 5.

During the course of our work on the Atlantic Coastal Plain, we have analyzed samples collected by many workers. A locality filing system using microcomputer data-base software was used to standardize the nomenclature of these collections. Each locality was given an informal name, and each collection made at that site was given a specific locality number (UDAMS#, for University of Delaware AMinoStratigraphy). Different collections made at what is considered to be the same location received different UDAMS numbers. Appropriate information about latitude, longitude, elevation, formation name, collector, date of collection, etc. was also recorded in each file. Because effective or ambient temperature (which is a function of latitude) is a major controlling variable in aminostratigraphic correlation, we find it particularly valuable to keep the developing locality file arranged from north to south by latitude.

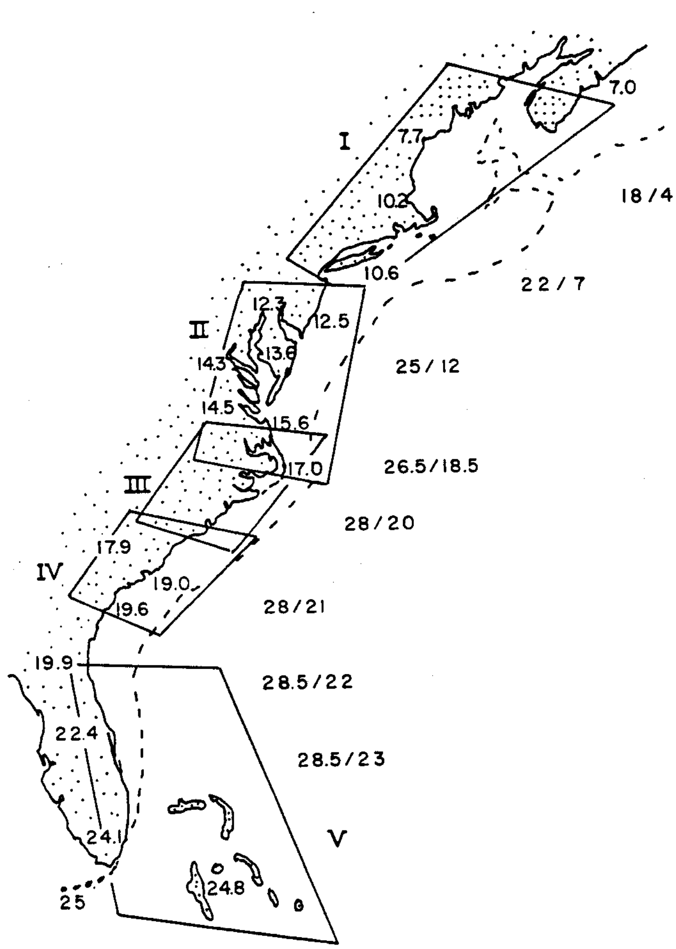

Figure 1. Map of the Atlantic coast of the United States and adjacent regions showing the aminostratigraphic regions discussed in this paper. Regions I through V are shown in Figures 2 through 5. Dashed line is the 200-m isobath. Numerical data shown for coastal sites are mean annual air temperatures (compiled by Belknap, 1979). Numerical data shown for oceanic regions (east of the 200-m isobath) are summer and winter (e.g., 28/20) surface water temperatures (from Imbrie and others, 1983).

Table 1 summarizes the data for the sites discussed here. The abbreviated informal locality names, UDAMS numbers, and locations by latitude/longitude are shown. Figures 2 through 5 show the positions of these collection sites. In the case of subsurface sections with multiple sampling depths (augers, cores, etc.), the site was given one UDAMS number and sample depths were recorded in association with specific data.

Enantiomeric ratios for up to six amino acids in the most

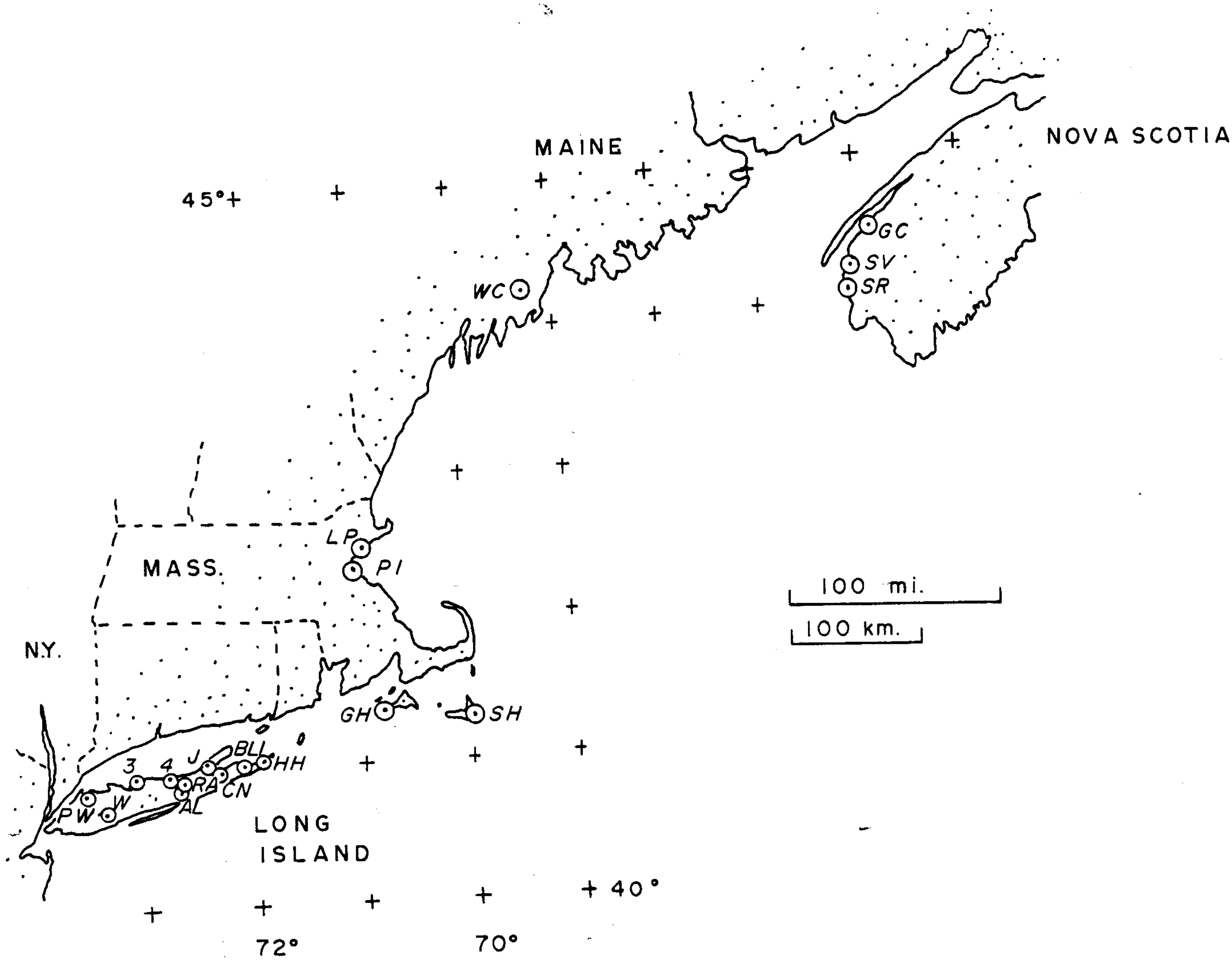

Figure 2. Aminostratigraphic region I, including Nova Scotia, Maine, Massachusetts, and Long Island. Current mean annual temperatures for the region range between 7.5° and 11°C. Locality abbreviations as in Table 1. Holocene localities are Whitney Corner (WC) and Lynn Pit (LP) in Maine and Massachusetts, respectively. Sankaty Head (SH) on Nantucket Island serves as the late Pleistocene calibration locality for this region.

representative genus (genera) for each of the localities considered here are given in Table 1. The number of samples analyzed from each locality is shown in column four of Table 1. Often the number of available samples has been limited. The enantiomeric ratios given in Table 1 are the mean values of multiple sample analyses or, in most of those cases where only one sample was available, the mean of two analyses of that single sample. The chromatographic resolution of alanine, valine, proline, and glutamic acid enantiomers often (roughly 30% of the time) is complicated by interfering peaks, so the mean values for these amino acids shown in Table 1 do not include ratios based on chromatographic peaks with obvious interferences. Data in Table 1 are grouped according to regional aminozone nomenclature, which is described under the heading "Regional Discussions."

The molluscan genera used for aminostratigraphic studies are the bivalves *Mercenaria, Crassostrea, Anadara, Mulinia, Chione, Rangia, Macoma,* and *Spisula,* and the gastropod *Busycon. Mercenaria* was the genus most often used because it is usually a thick-shelled and mechanically robust sample. In some cases we studied the effects of shell alteration on amino acid D/L values by systematically analyzing different portions of the same shell (with variable degrees of alteration) or by analyzing different shells with variable preservation from the same outcrop. Lower D/L values are often observed in the altered portions of these

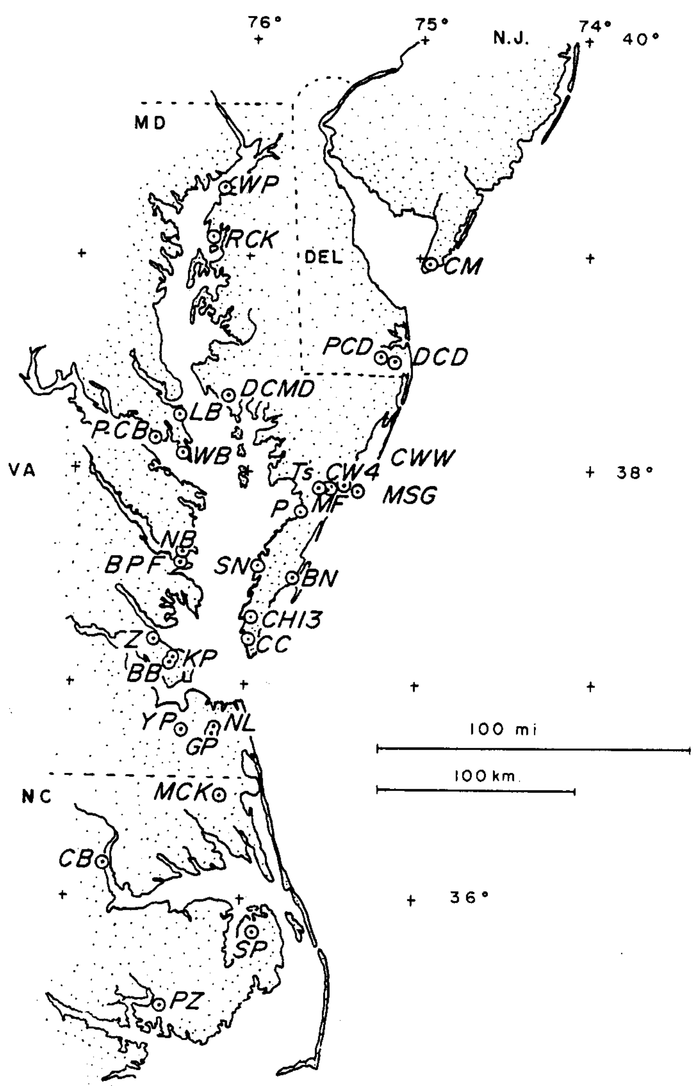

Figure 3. Aminostratigraphic region II, including southern New Jersey, Delaware, Maryland, Virginia, and northeastern North Carolina. Current mean annual temperatures for the region range between 12.5° and 16°C. Locality abbreviations as in Table 1. Sites for which U-series isotopic data are available include Norris Bridge (NB), New Light (NL), Gomez Pit (GP), Moyock (MCK), Stetson Pit (SP), and Ponzer (PZ).

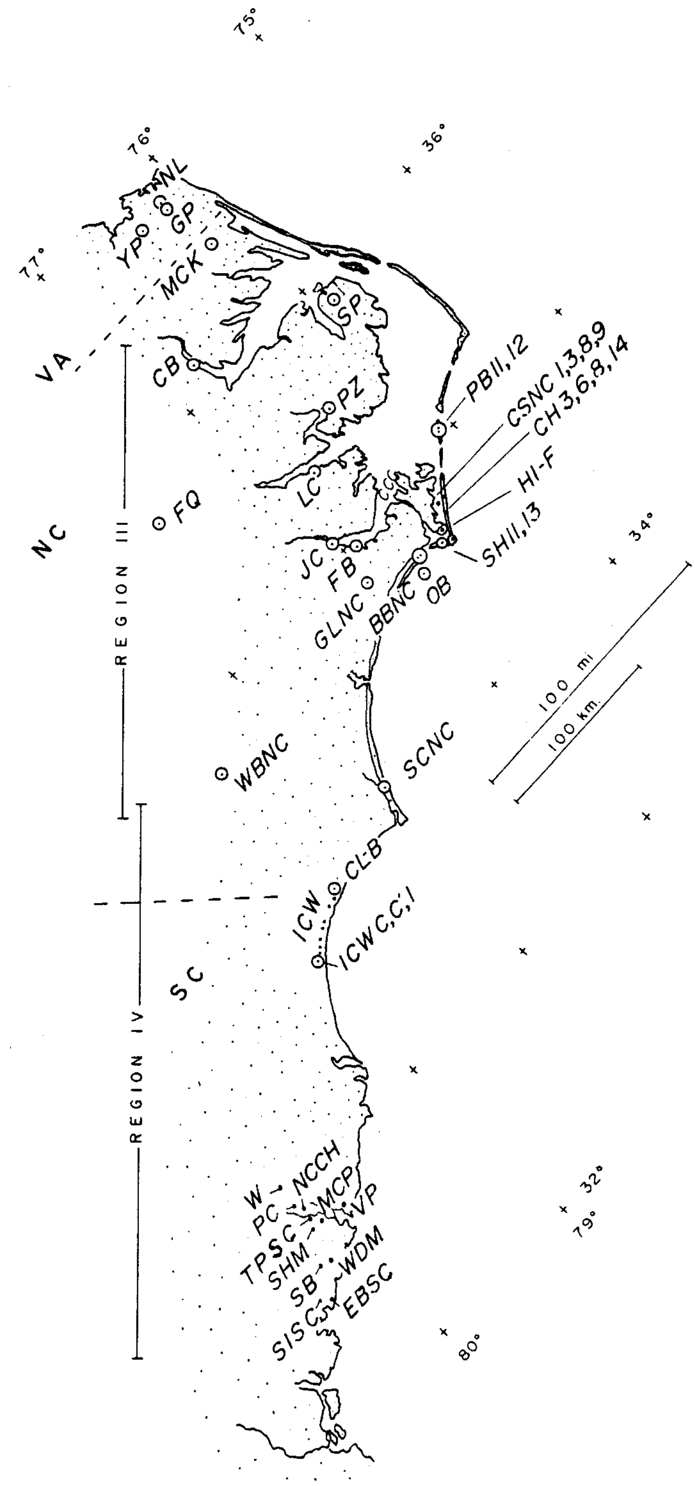

Figure 4. Aminostratigraphic regions III and IV for North Carolina and South Carolina. Current mean annual temperatures for region III range between 16° and 18°C; for region IV, between 18° and 19°C. Locality abbreviations as in Table 1. Region III localities receiving most attention here are Stetson Pit (SP), Ponzer (PZ), and Flanner Beach (FB). Region IV localities of importance include all the Intracoastal Waterway Sites (ICW) near Myrtle Beach, South Carolina, and, in particular, Mark Clark Pit (MCP) and Scanawah Island I (SI), both near Charleston, South Carolina.

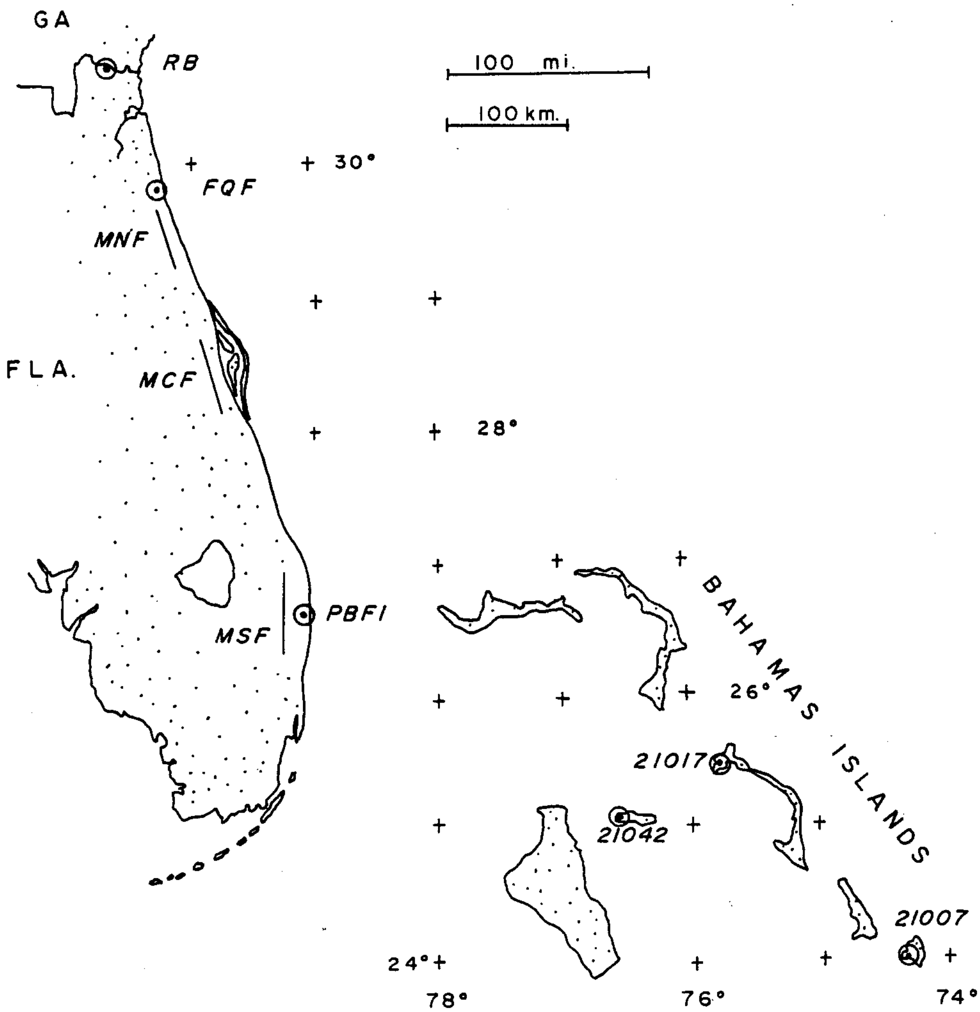

Figure 5. Aminostratigraphic region V for Florida and the Bahamas Islands. Current mean annual temperatures for northern and central Florida range between 20° and 23°C; for southern Florida and the Bahamas, between 23° and 25°C. Locality abbreviations as in Table 1. MNF, MCF, and MSF are abbreviations for "Mitterer North Florida," "Mitterer Central Florida," and "Mitterer Southern Florida," respectively. These regions represent the collections for which amino acid data were published by Mitterer (1975). PBF1 and San Salvador Island (21007) are the two sites in this region at which both mollusks and U-series-dated corals have been collected simultaneously.

shells. In a few cases we analyzed shells that have less than ideal preservation (fragmented, chalky or leached appearance) simply because these were the only samples available. Even in these cases, however, little or no recrystallization (calcite <2 percent) was detected by x-ray diffraction.

Although *Mercenaria* is the preferred sample type, other genera were also studied because: (1) *Mercenaria* is not always present at sites of interest, so the aminostratigraphic value of other genera must be established, and (2) intergeneric relative racemization rates between *Mercenaria* and other common genera must be known so that data for each can be converted into common values for direct aminostratigraphic comparison. In order to accomplish this task with field samples, several sites (with different ages) should be located, each with a large number of samples of different genera. Analyses of co-existing genera then permit documentation of intergeneric relative racemization rates. Alternatively, these relative rates can be modeled using laboratory pyrolysis experiments. Available data show that the relative rates of racemization in different molluscan genera can be duplicated in this manner (Keenan, 1983). From the results obtained from either laboratory experiments or from field sites, we infer the following kinetic groups for the mollusk genera that we studied:

TABLE 1. ATLANTIC COASTAL PLAIN AMINOSTRATIGRAPHY DATA

UDAMSLOC	Locality	Genus	No. of Samples	Latitude	Longitude	Region	Aminozone	D/L Leu	Allo/Iso	D/L Val	D/L Glu	D/L Ala	D/L Pro
	Nova Scotia												
UD00001	GC	Merc	6	44.49	65.91	I	c	0.32			0.25	0.45	0.39
UD00014	SV	Merc	4	44.28	66.14	I	b	0.24			0.20	0.39	0.28
UD01004	WC	Hiat	2	44.16	69.31	I	(a)	0.08		0.05	0.08	0.13	0.12
UD00010	SR	Merc	4	44.03	66.13	I	b	0.24			0.20	0.39	0.28
	Massachusetts												
UD03011	LP	Hiat	2	42.46	70.99	I	(a)	0.08		0.06	0.09	0.15	0.12
UD03012	PI	Merc	2	42.30	70.92	I	b	0.21		0.22	0.20	0.42	0.23
UD03033	GH	Merc	1	41.35	70.83	I	d	0.71		0.79	0.64	0.83	0.73
UD03008 - 10	SH (u & l)	Merc	11	41.25	69.96	I	b	0.24		0.17	0.20	0.43	0.34
	SH (u)	Merc	4	41.25	69.96	I	b		0.16				
	SH (l)	Merc	4	41.25	69.96	I	b		0.15				
	SH (u)	Anad	2	41.25	69.96	I	b		0.18				
	SH (l)	Anad	3	41.25	69.96	I	b		0.13				
	New York												
UD04000	HH	Unkn	4	41.04	72.98	I	(c)	0.31		0.27	0.24	0.38	0.50
UD04002	BLI	Merc	3	40.99	72.31	I	b	0.23		0.20	0.42	0.46	
UD04003	J	Merc	2	40.95	72.58	I	c	0.43		0.26	0.29	0.65	
UD04001	CN	Merc	2	40.93	72.45	I	b	0.21		0.16	0.19	0.38	0.31
UD04009	3	Merc	1	40.92	73.18	I	b	0.18		0.17	0.18	0.25	0.34
UD04005	RA	Merc	3	40.92	72.96	I	c	0.35		0.26	0.30	0.59	
UD04006	AL	Merc	2	40.85	73.03	I	b	0.19		0.15	0.15	0.29	
UD04004	4	Astar	1	40.84	72.82	I	(b)	0.19		0.14	0.15	0.41	
UD04010 - 13	PW	Crass	7	40.83	73.68	I	(c)	0.28		0.18	0.15	0.66	0.35
UD04015	W	Spis	1	40.58	73.38	I	(b)	0.14		0.10	0.14	0.24	0.30
	New Jersey, Maryland, Delaware, Virginia												
UD05009	WP	Rang	3	39.31	76.18	II	(b)	0.35		0.32		0.60	0.48
UD05008	RCK	Rang	1	39.13	76.17	II	(c)	0.44		0.23	0.27	0.68	
UD05003	CM	Merc	3	38.96	75.25	II	a	0.28	0.21	0.20	0.22	0.45	
UD05012	PCD	Merc	3	38.53	75.25	II	b	0.33	0.28	0.25	0.28	0.47	0.48
UD05007	DCD	Merc	8	38.50	75.12	II	d	0.53	0.44	0.39	0.38	0.72	0.60
UD05007	DCMD	Rang	3	38.48	76.25	II	(d)	0.65		0.44	0.45	0.89	0.90
UD05002	LB	Merc	2	38.24	76.39	II	a	0.28		0.31	0.24	0.56	0.36
UD05001	PCB	Rang	1	38.21	76.60	II	(d)	0.59		0.68	0.44	0.73	0.64
UD05000	WB	Merc	12	38.06	76.36	II	a	0.29	0.25	0.27	0.23	0.45	0.39
UD06009	CW4	Merc	2	37.96	75.49	II	d	0.59		0.55	0.47	0.79	0.70
UD06007	CWW	Merc	2	37.95	75.46	II	e	0.88		0.99	0.90	0.99	0.91
UD06004	MF	Merc	3	37.95	75.50	II	d	0.58		0.47	0.46	0.78	0.72
UD06002	T'S	Merc	20	37.95	75.54	II	d	0.54		0.54	0.41	0.70	0.65
UD06006	MSG	Merc	1	37.90	75.36	II	d	0.54		0.39	0.35		0.72
UD06008	P	Merc	2	37.79	75.67	II	d	0.55		0.60	0.44	0.80	0.65
UD06000, 06017	NB	Merc	9	37.63	75.50	II	d	0.55	0.49	0.42	0.39	0.74	0.69
UD06000	NB	Anad	4	37.63	75.50	II	d	0.51		0.39	0.37	0.67	
UD06001	BPF	Merc	1	37.58	75.39	II	e	0.81		0.25	0.23	0.49	0.31
UD06012	SN	Merc	1	37.57	75.90	II	a	0.25		0.25	0.23	0.49	0.31

TABLE 1. (Continued)

UDAMSLOC	Locality	Genus	No. of Samples	Latitude	Longitude	Region	Aminozone	D/L Leu	Allo/Iso	D/L Val	D/L Glu	D/L Ala	D/L Pro
***New Jersey, Maryland, Delaware, Virginia* (continued)**													
UD06000	NB	Anad	4	37.63	75.50	II	d	0.51		0.39	0.37	0.67	
UD06001	BPF	Merc	1	37.58	75.39	II	e	0.81		0.90	0.99	0.90	0.89
UD06012	SN	Merc	1	37.57	75.90	II	a	0.25		0.25	0.23	0.49	0.31
UD06013	BN	Mul	2	37.54	75.77	II	(a)	0.24		0.15	0.16	0.42	
UD06011	CH13	Mul	2	37.30	75.98	II	(a)	0.23		0.16	0.21	0.35	0.25
UD06019	Z	Merc	2	37.24	76.53	II	e	0.89		1.00	0.90	0.99	0.89
UD06014	CC	Merc	2	37.21	76.97	II	a	0.25		0.24	0.24	0.45	0.24
UD06021	KP	Merc	5	37.10	76.43	II	c	0.41		0.35	0.31	0.60	0.51
UD06040, 06020	BB	Merc	4	37.08	76.43	II	c	0.44		0.36	0.29	0.60	0.60
UD06023	NL	Merc	7	36.80	76.19	II	a	0.25		0.21	0.21	0.48	0.37
UD06024	NL	Merc	3	36.80	76.19	II	c	0.42		0.37	0.31	0.65	0.53
UD06029	GP	Merc	4	36.79	76.17	II	d	0.52		0.44	0.37	0.71	0.53
UD06030	GP	Merc	8	36.79	76.17	II	a	0.22		0.15	0.15	0.39	
UD06030	GP	Anad	3	36.79	76.17	II	a	0.26		0.16	0.17	0.41	
UD06056	GP	Merc	11	36.79	76.17	II	c		0.33				
UD06045	GP	Merc	15	36.79	76.17	II	a		0.15				
UD06054	GP	Merc	3	36.79	76.17	II	e		1.08				
UD06027	WP (1)	Merc	2	36.79	76.17	II	c	0.36		0.35	0.26	0.58	0.47
UD06027	WP (1)	Merc	1	36.79	76.17	II	a	0.18		0.15	0.19	0.34	0.21
UD06041	YP	Merc	2	36.76	76.38	II	c	0.37		0.34	0.28	0.50	0.46
UD06034 - 06036	YP	Merc	2	36.76	76.38	II	e	0.88		0.98	0.84	0.94	0.88
North Carolina													
UD07000	MCK	Merc	4	36.52	76.17	II, III	b	0.33		0.23	0.23	0.49	0.39
UD07023	CB	Merc	1	36.19	76.75	II, III	e	0.88		0.95	0.99	0.97	0.95
UD07002	SPIT	Merc	6	35.86	75.86	II, III	b		0.23				
UD07002	SPIT	Merc	1	35.86	75.86	II, III	b	0.33		0.20	0.21	0.50	
UD07002	SPIT	Mul	6	35.86	75.86	III	A (2)	0.28		0.24	0.20	0.41	0.37
UD07002	SPIT	Mul	5	35.86	75.86	III	B (2)	0.51		0.66		0.74	0.65
UD07065	FQNC	Noet	1	35.67	77.64	III	(e)	0.89			0.77	0.89	0.91
UD07006	PZ	Merc	2	35.55	76.44	III	c	0.41	0.33	0.27	0.29	0.60	0.56
UD07007	PZ	Mul	3	35.55	76.44	III	A (2)	0.27		0.26		0.37	0.36
UD07007	PZ	Mul	4	35.55	76.44	III	C (2)	0.63		0.66		0.76	0.74
UD07066	LCNC	Merc	1	35.38	76.79	III	e	0.90		0.93	0.93	0.97	0.94
UD07012	JC	Mul	1	35.08	77.02	III	C (2)	0.69		0.78		0.85	0.85
UD07012	JC	Merc	8	35.08	77.02	III	e	0.88	0.91	0.80	0.85	0.93	0.89
UD07075	PB12	Merc	1	35.05	76.05	III	d	0.78			0.75	0.95	
UD07074	PB11	Merc	1	35.03	76.08	III	c	0.47		0.29	0.34	0.64	
UD07074	PB11	Mul	1	35.03	76.08	III	A (2)	0.21		0.16	0.24	0.41	
UD07008 - 0711	FB	Merc	6	34.98	76.95	III	c	0.46		0.31	0.30	0.62	0.57
UD07026	NRE2	Merc	1	34.98	76.95	III	c	0.43		0.29	0.31	0.56	
UD07026	NRE2	Mul	2	34.98	76.95	III	A (2)	0.27		0.18	0.23	0.44	
UD07008	FB	Mul	6	34.98	76.95	III	A (2)	0.27		0.16	0.17	0.40	0.33
UD07008	FB	Mul	30	34.98	76.95	III	A (2)		0.162 ± 0.028				

TABLE 1. (Continued)

UDAMSLOC	Locality	Genus	No. of Samples	Latitude	Longitude	Region	Aminozone	D/L Leu	Allo/Iso	D/L Val	D/L Glu	D/L Ala	D/L Pro
North Carolina (continued)													
UD07042	CH14	Mul	1	34.86	76.31	III	A (2)	0.19		0.12	0.17	0.35	
UD07034	CSNC1	Merc	1	34.75	76.33	III	c	0.42		0.28	0.33	0.63	
UD07033	CSNC3	Merc	1	34.75	76.33	III	d	0.54		0.40	0.37	0.80	
UD07032	CSNC8	Merc	1	34.75	76.33	III		0.08		0.06	0.09	0.15	
UD07031	CSNC9	Merc	3	34.75	76.33	III	b	0.30		0.21	0.30	0.52	
UD07031	CSNC9	Merc	1	34.75	76.33	III	c	0.47		0.42	0.38	0.71	
UD07031	CSNC9	Merc	1	34.75	76.33	III	d	0.61		0.55	0.41	0.82	
UD07044	CH-8	Merc	1	34.73	76.44	III	d	0.62		0.50	0.49	0.90	
UD07036	GLNC	Mul	1	34.73	77.03	III	B (2)	0.49		0.52	0.50	0.76	
UD07049	HI-F	Merc	1	34.71	76.58	III	b	0.31		0.22	0.24	0.52	
UD07051	BBNC35	Merc	1	34.71	76.78	III	d	0.73		0.54	0.64	0.91	
UD07050	BBNC3	Merc	2	34.70	76.72	III	d	0.59		0.42	0.45	0.82	
UD07045	CH-6	Merc	1	34.68	76.48	III	c	0.38		0.34	0.32	0.61	
UD07057	SH13	Mul	1	34.65	76.56	III	B (2)	0.51		0.48	0.48	0.67	0.62
UD07058	SH11	Merc	2	34.63	76.53	III		0.18		0.17	0.15	0.42	
UD07046	CH-3	Mul	1	34.60	76.53	III	A (2)	0.26		0.19	0.26	0.46	
UD07017	WBNC	Mul	1	34.56	78.48	III	C (2)	0.76		0.73		0.85	0.79
UD07064	OB86	Merc	1	34.50	76.80	III	d	0.66		0.53	0.57	0.85	
UD07064	OB86	Merc	3	34.50	76.80	III	d	0.57		0.49	0.47	0.83	
UD07061	OB84	Merc	3	34.65	76.82	III	d	0.64		0.55	0.54	0.84	
UD07060	OB85	Merc	4	34.65	76.80	III	d	0.58		0.49	0.48	0.83	
UD07059	OB88	Merc	2	34.68	76.80	III	d	0.68		0.60	0.59	0.90	
UD07018	SCNC	Merc	2	34.08	77.92	III	d	0.52		0.35	0.45	0.65	0.67
UD07019	CLB	Merc	4	33.89	78.56	III, IV	e	0.89	0.97	0.90	0.87	0.95	0.87
South Carolina													
UD08011	ICW11	Merc	2	33.86	78.62	IV	a	0.55	0.52	0.41	0.41	0.74	0.64
UD08010	ICW10	Merc	5	33.83	78.69	IV	a	0.57	0.59	0.42	0.38	0.79	0.66
UD08044	MBAP3	Merc	2	33.82	78.75	IV	d	0.88		0.90	0.85	0.96	0.88
UD08009	ICW9	Merc	5	33.82	78.72	IV	b	0.64	0.54	0.47	0.45	0.82	0.73
UD08008	ICW8	Merc	4	33.80	78.76	IV	a	0.54	0.48	0.37	0.40	0.76	0.62
UD08007	ICW7	Merc	3	33.79	78.76	IV	b	0.63	0.52	0.44	0.45	0.80	0.73
UD08024	ICWJ1	Merc	1	33.77	78.81	IV	b	0.66			0.51	0.85	
UD08024	ICWJ2	Merc	2	33.77	78.81	IV	c	0.78		0.70	0.80	0.95	
UD08024	ICWJ4	Merc	1	33.77	78.81	IV	d	0.88		0.84	0.87	0.96	0.87
UD08006	ICW6	Merc	4	33.77	78.81	IV	d	0.93	0.90	0.87	0.85	0.99	0.91
UD08005	ICW5	Merc	3	33.76	78.82	IV	c	0.79	0.86	0.73	0.71	0.96	0.81
UD08019	ICWF'2 - 4	Merc	3	33.76	78.82	IV	c	0.75			0.69	0.95	
UD08019	ICWF'1	Merc	1	33.76	78.82	IV	b	0.66			0.56	0.85	
UD08003	ICW3	Merc	3	33.74	78.87	IV	b	0.66	0.48	0.41	0.46	0.81	0.79
UD08015	ICWC'4	Merc	1	33.71	78.92	IV	a	0.52		0.35	0.37	0.72	
UD08015	ICWC'1, 2	Merc	4	33.71	78.92	IV	b	0.67		0.42	0.44	0.75	0.78
UD08001	ICW1	Merc	1	33.71	78.92	IV	a	0.59	0.54	0.38	0.42	0.78	0.69
UD08014	ICWC	Merc	3	33.71	78.92	IV	a	0.53		0.35	0.35	0.69	
UD08050	W	Merc	1	33.13	80.04	IV	d	0.88		0.92	0.90	0.90	0.90

TABLE 1. (Continued)

UDAMSLOC	Locality	Genus	No. of Samples	Latitude	Longitude	Region	Aminozone	D/L Leu	Allo/Iso	D/L Val	D/L Glu	D/L Ala	D/L Pro
South Carolina (continued)													
UD08001	ICW1	Merc	1	33.71	78.72	IV	a	0.59	0.54	0.68	0.42	0.78	0.69
UD08014	ICWC	Merc	3	33.71	78.92	IV	a	0.53		0.35	0.35	0.69	
UD08050	W	Merc	1	33.13	80.04	IV	d	0.88		0.92	0.90	0.90	0.90
UD08051	PC	Merc	1	32.92	80.08	IV	a	0.57		0.37	0.46	0.79	0.67
UD08030	NCCH	Merc	3	32.88	80.03	IV	a	0.58	0.55	0.49	0.45	0.81	0.68
UD08032	TPSC	Merc	2	32.87	80.05	IV	c	0.78	0.77	0.65	0.65	0.95	0.85
UD08033	TPSC	Merc	1	32.87	80.05	IV	d	0.96	1.05	0.92	0.91	0.99	
UD08031	SHM	Merc	3	32.85	80.08	IV	b	0.67	0.51	0.52	0.52	0.88	0.77
UD08038	MCP	Merc	6	32.83	80.03	IV	a	0.57		0.42	0.42	0.81	0.69
UD08037	VP	Merc	3	32.81	79.84	IV	a	0.55		0.37	0.42	0.78	0.69
UD08052	SB	Merc	1	32.67	80.25	IV	a	0.61		0.60	0.49	0.80	0.71
UD08041	WDM	Merc	1	32.65	80.18	IV	d	0.88			0.88	0.90	0.90
UD08035	SISC	Merc	3	32.56	80.36	IV	a	0.59	0.60	0.45	0.45	0.80	0.70
UD08042	EBSC	Merc	3	32.53	80.27	IV	a	0.51		0.35	0.34	0.72	0.55
Florida													
UD10000	RB	Merc	1	30.72	81.61	V	d	0.82		0.84	0.64	0.84	0.83
UD10076	FQF	Merc	1	29.87	81.25	V	b	0.58		0.36	0.48	0.79	0.69
MNF	MNF(3)	Merc	n/a	29.67	81.25	V	a		0.42				
MNF	MNF(3)	Merc	n/a	29.67	81.25	V	b		0.56				
MNF	MNF(3)	Merc	n/a	29.67	81.25	V	c		0.71				
MNF	MNF(3)	Merc	n/a	29.67	81.25	V	d		0.88				
MCF	MCF(3)	Merc	n/a	28.50	81.00	V	a		0.56				
MCF	MCF(3)	Merc	n/a	28.50	81.00	V	b		0.71				
MCF	MCF(3)	Merc	n/a	28.50	81.00	V	c		0.92				
MSF	MSF(3)	Merc	n/a	26.75	80.25	V	a		0.71				
MSF	MSF(3)	Merc	n/a	26.75	80.25	V	b		0.88				
MSF	MSF(3)	Merc	n/a	26.75	80.25	V	c		0.99				
UD10069	PBF-1	Chione	3	26.71	80.18	V	(a)		0.68				
Bahamas													
UD21017	NELTHRA	Strombus	1	25.47	75.77	V	(a)	0.57		0.52	0.44	0.66	0.56
UD21042	CLFTNPT	Lucina	1	25.00	76.53	V	(a)	0.78			0.73		0.76
UD21007	CKBRNTWN	Chione	3	24.03	74.42	V	(a)	0.62		0.50	0.48	0.89	

Notes:

1. WP samples are poorly documented and ratios are slightly low due to analytical conditions.
2. Capitalized aminozones for Region III Mulinia refer to Figure 12.
3. Localities MNF, MCF, and MSF represent groups of sites from Mitterer (1975); n/a = number of samples not known.
4. A/I data from Regions IV and V from McCartan and others (1982) or Mitterer (1975) unless noted in text.
5. Aminozones are those for Mercenaria; aminozones indicated in parentheses are probable correlative zones derived from other genera.

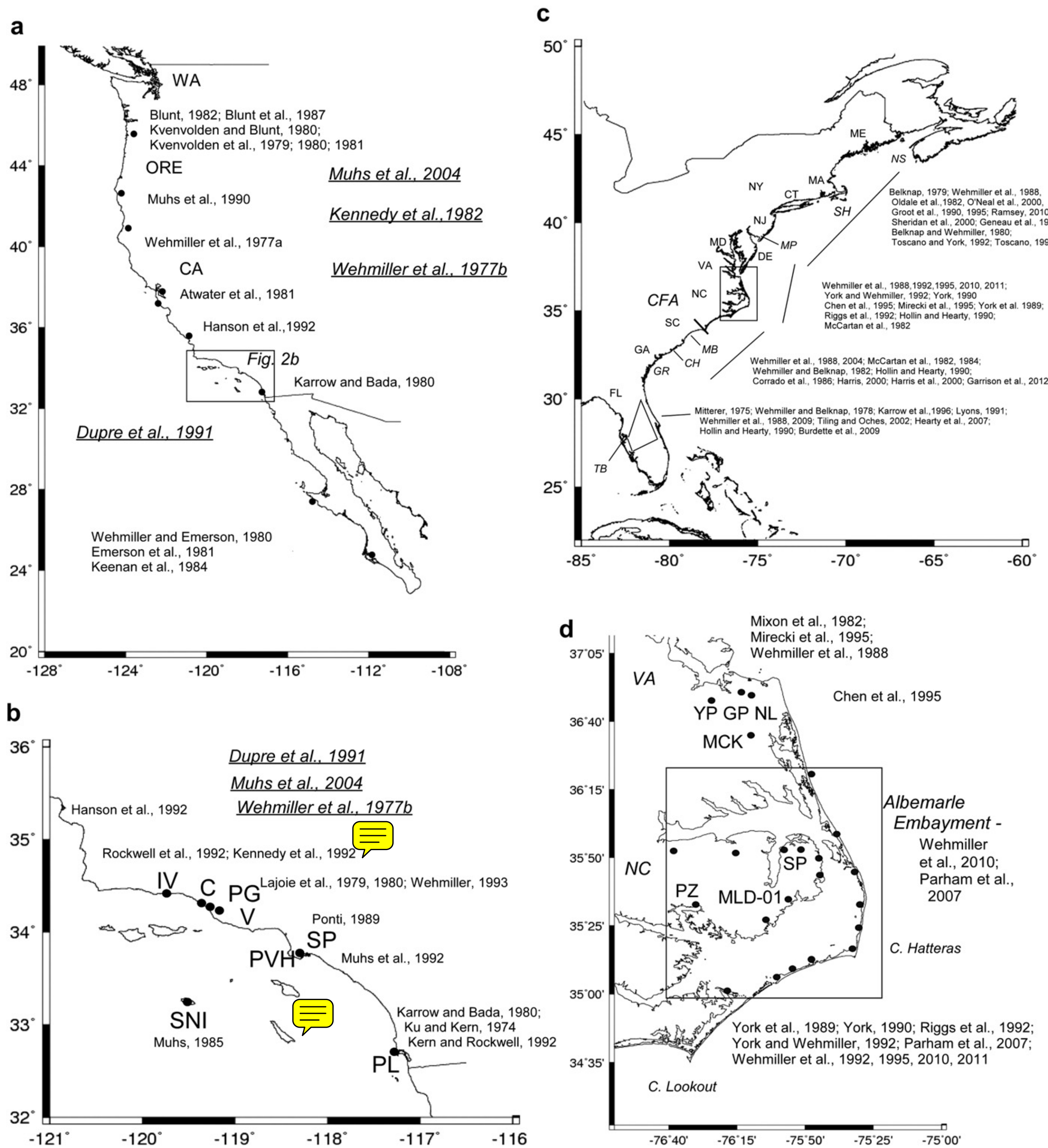

Fig. 2. Study sites on both US coasts. A Google Earth kml file supplements these maps and can be found in online supplementary material (Appendix A). Selected field photographs are available at the stable URL http://dspace.udel.edu:8080/dspace/handle/19716/10390. a: Regional coverage of the US Pacific coast and Baja California Sur, Mexico. Inset shows the area of (b). Dots mark areas where AAR data exist; underlined text identifies references to AAR data from the entire region, other references deal with more local studies. b: Locations of major Southern California AAR studies. Locality identification as follows: IV = Isla Vista; C = Carpinteria; PG = Punta Gorda; V = Ventura; SP = San Pedro; PVH = Palos Verdes Hills; PL = Point Loma; SNI = San Nicolas Island. c: Regional coverage of the US Atlantic coast, showing major references for selected areas. Inset shows the area of (d). Locality identification as follows: NS = Nova Scotia; SH = Sankaty Head; MP = Morie Pit; CFA = Cape Fear Arch; MB = Myrtle Beach; CH = Charleston; GR = Gray's Reef; TB = Tampa Bay. d: North Carolina coastal plain and Albemarle Embayment. Locality identifications as follows: YP = Yadkin Pit; GP = Gomez Pit; NL = New Light Pit; MCK = Moyock; PZ = Ponzer; SP = Stetson Pit. MLD-01 is one of a suite of cores (shown as unlabeled dots) discussed by Wehmiller et al. (2010). The thick (~80 m) section in the Albemarle Embayment likely has the most complete Quaternary section on the US Atlantic Coast. GP, NL, MCK, and SP all have yielded corals dated to MIS 5a (Szabo, 1985; Wehmiller et al., 2004). PZ yielded corals dated to MIS 7 (Szabo, 1985; Thompson and Wehmiller, unpublished).

9) At the present stage of AAR research on North American coastal sequences, there exist many questions that deserve to be studied using the natural laboratory provided by existing samples and those that remain to be collected. The massive nature of many of bivalves permits a variety of "micro-scale" analyses to be conducted on a single sample, such as the study of shell structure alteration (using low- to high-magnification microscopy (Davis-Hartten, 2001), molecular weight distribution (quantitative analysis of free amino acids, and low- and high-molecular weight components (Keenan, 1982; Boutin, 1989), paleobiochemical or immunological analysis (Muyzer et al., 1988), and shell porosity or bleaching studies (Mirecki, 1990). Experiments such as these have the potential to quantify the open-system behavior of the total amino acid system that has been routinely used for geochronological purposes. The development of currently available RPLC methods, now extremely sensitive, will allow for detailed studies of the relation between shell microstructure, amino acid abundance and extent of racemization, ideally using samples with a wide age range (and with extant D/L data for method comparison) such as those from the Quaternary section in the Albemarle Embayment. With the use of RPLC methods to generate large data sets (multiple subsamples from multiple shells) for a single locality, it is quite likely that a much better understanding of natural variability of D/L values within a single unit will evolve. Because RPLC, GC, and IEx methods each yield results for different amino acids, it will be important to conduct good cross-checks between RPLC datasets and earlier results. For the mid-latitude sites discussed in this paper, D/L values for leucine and valine appear most useful, so future studies should assure comparability with the data for these two amino acids.
10) One of the challenging geochronological questions faced by all aminostratigraphers is the issue of the age-resolution capability of the method. Examples from the studies reviewed here include the question whether MIS 3 and MIS 5a samples, or MIS 5a and MIS 5e samples, can be resolved. Although analytical precision may be excellent ($\pm 2\%$) for multiple analyses of a single sample, the range of D/L values observed among multiple samples in a single shell bed can be affected by many factors, including age mixing, local variations in thermal history, and geochemical alteration of analyzed samples. These factors can be assessed only by conducting numerous analyses, far more than have been done for the most of collection sites discussed here. Some of these factors may not be important for certain time scales of interest, but they all must be appreciated during the design of a sampling and analysis plan, assuming that sufficient samples are actually available. As always, AAR methods can contribute great insights into the chronology of fossilifereous units, but the value of these methods is improved when suitable independent calibrations are also available.

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Appendix A. Supplementary material

Supplementary material associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.quageo.2012.05.008.

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