4.1 COMPARISON OF APPROACHES TO DATING ATLANTIC COASTAL PLAIN SEDIMENTS, VIRGINIA BEACH, VIRGINIA

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INTRODUCTION

In this study we characterized and dated a stratified section of middle to late Pleistocene strata exposed in a borrow pit in Virginia Beach, Virginia (Fig. 4.1-1). We collected sediment, coral, and mollusk samples for the intercomparison of infrared stimulated luminescence (IRSL), uranium-series (U-series), and amino acid racemization (AAR) geochronologic methods. This intercomparison is important for independently testing and validating these methods for dating middle and late Pleistocene sediments of the Atlantic Coastal Plain.

The borrow pit site locally is known as Gomez Pit, owned and operated by the E. V. Williams Co. of Virginia Beach. It is one of several borrow pits that have yielded a large amount of Quaternary litho- and chrono-stratigraphic information for the region the last 30 years. A recent paper by Mirecki and others (1995) summarizes the geochronologic framework for the current intercomparison study, and Wehmiller and others (1989) provide an overview of relevant literature and the geomorphology, stratigraphy, and geochronology of Gomez Pit and nearby sites. Other recent publications that discuss the geochronology at Gomez Pit in a broader regional context include Groot and others (1990), Toscano and York (1992), and Wehmiller and others (1992; 1995). The site was chosen for this intercomparison study because of the extensive background knowledge that was already available. Because Gomez Pit is an active borrow pit, the exposures are always changing and we were fortunate in having access to some fresh outcrops (less than one year of exposure) for sampling during the present study.

New geochronologic results are presented here for IRSL dating of host sediments, U-series dating of corals, and AAR dating of mollusks, obtained on samples collected from Gomez Pit in August and September, 1995. Samples from previously obtained collections at Gomez Pit were also analyzed. The spacing and timing of the collections of different outcrops at a single site is an important part of the interpretation of results as weathering and diagenesis can play important roles in AAR dating.

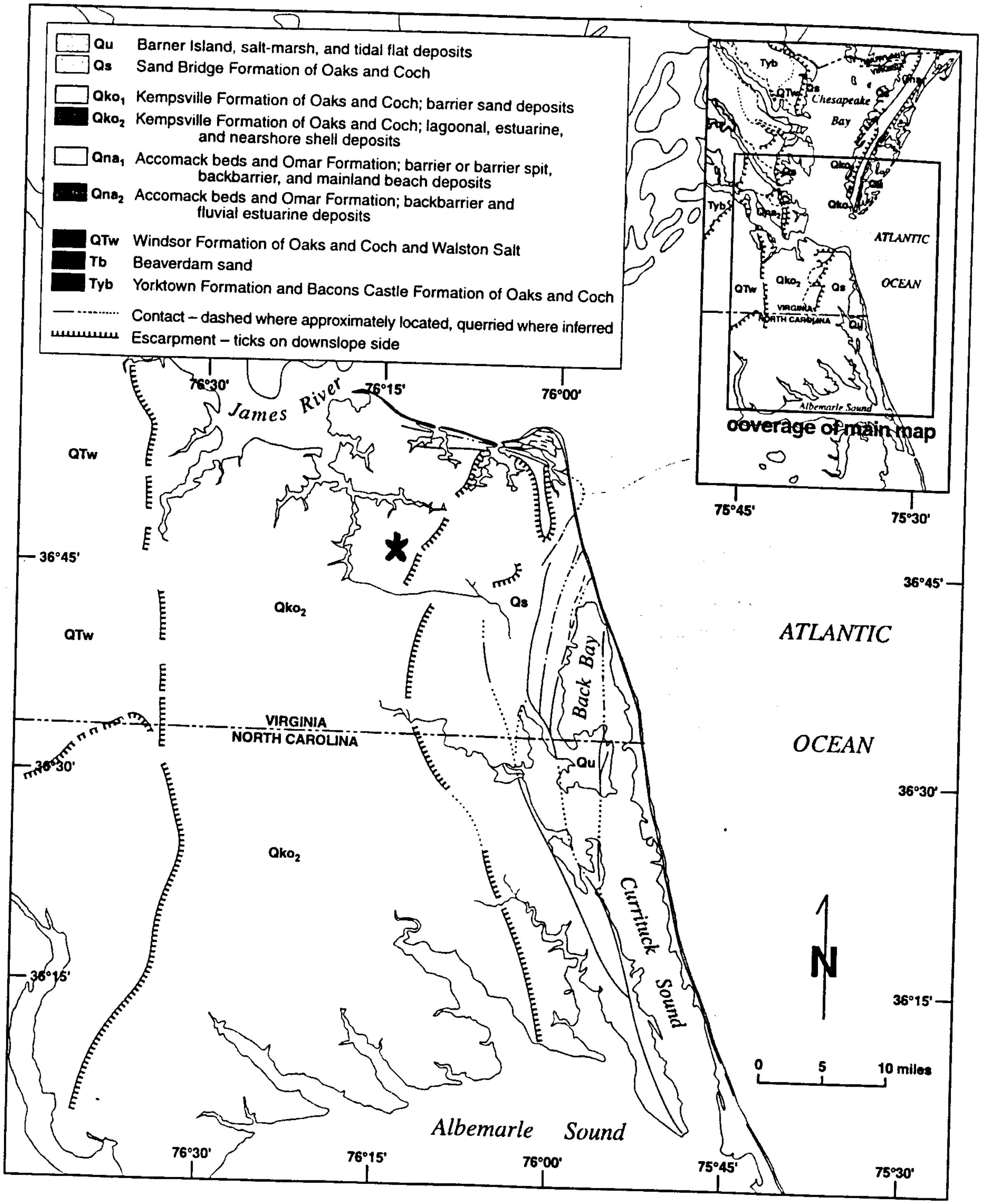


Figure 4.1-1. Regional map of the mid-Atlantic coastal plain and expanded view of the area of southeastern Virginia and northeastern North Carolina. See Mirecki and others (1995) (see Appendix I and II for further locality information). GP= Gomez Pit; Mck = Moyock; NL = New Light Pit; YP = Yadkin Pit.

FIELD STUDY AND SAMPLING EFFORT

The perennially changing working faces of Gomez Pit have been visited and sampled over the past 15 years by geologists from numerous institutions (Fig. 4.1-2). Previous investigations involved aspects of sedimentologic, paleoenvironmental reconstruction and/or geochronology. Recent collections of geochronologic data were made by Mirecki (1990) and Wehmiller (unpublished data). Sites used by Mirecki for her Ph.D. research (1982-1987;

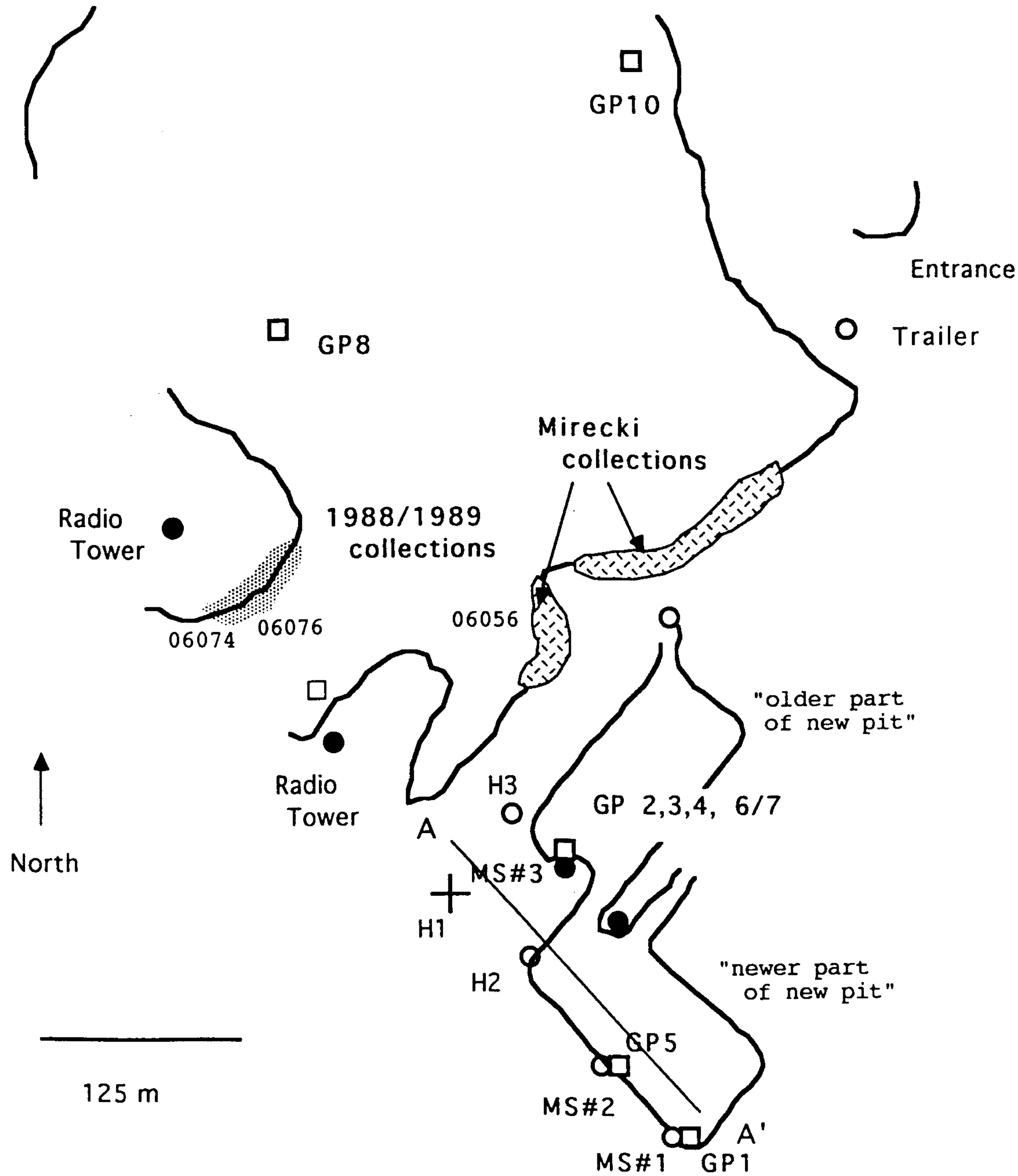


Figure 4.1-2. Sketch map with survey points for sites discussed in text. Detailed information from Sept. 1995 survey is in Appendix III. Line A-A' is the line of projection for the survey shown in Figure 4.1-8.

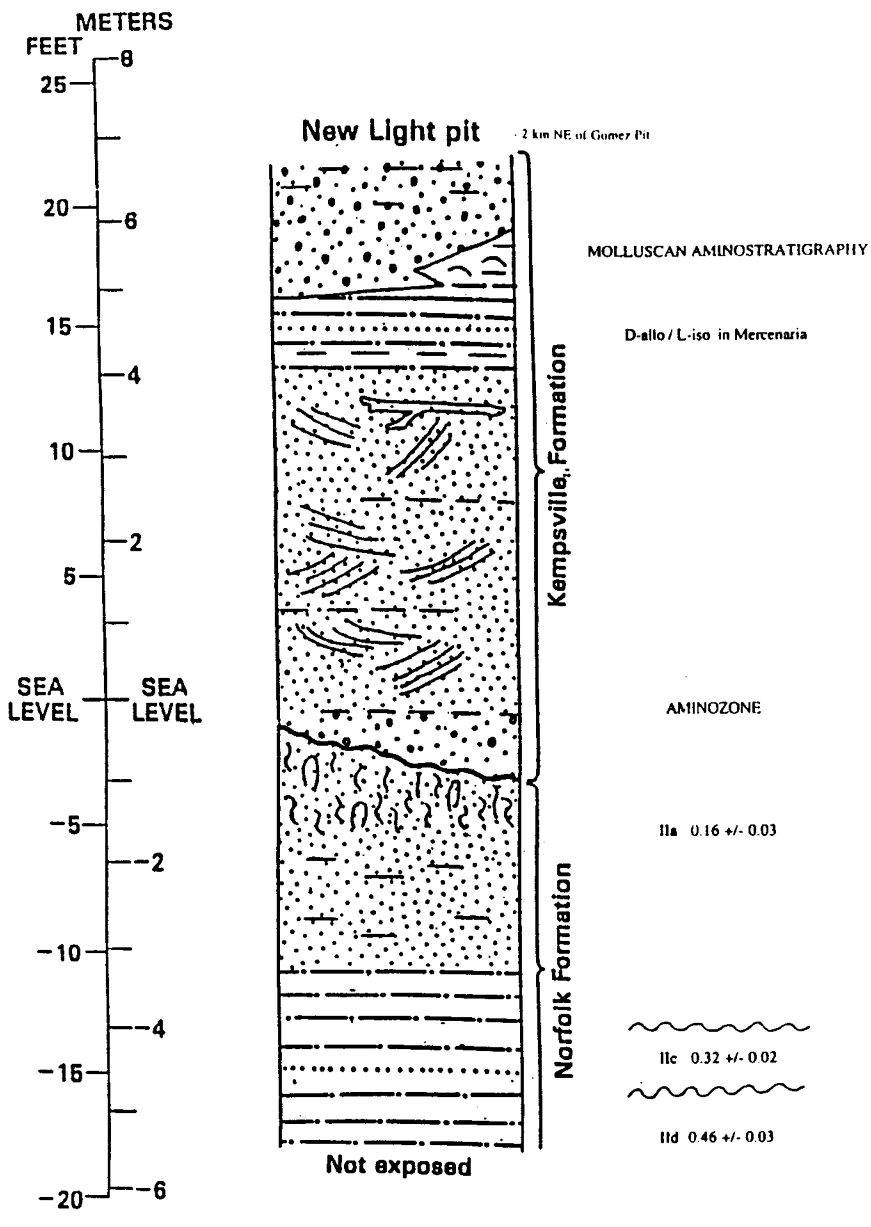
Mirecki, 1990) were sampled as the face was excavated. Coral and sediment samples were collected for the purposes of U-series and luminescence dating by Wehmiller in 1988 and 1989 at some of these sites (Fig. 4.1-2). For this study, exposures in the southeastern portion of the mapped area (Fig. 4.1-2) were sampled extensively in August and September, 1995. Two measured sections (MS#1 and MS#2) in the newer portions of the "new pit" were studied in September, 1995, and a third section (MS#3), in the older part of the new pit, was stratigraphically tied to these measured sections by walking out all of the lithologic contacts. Seven of the nine luminescence samples were taken from MS#1, MS#2, and MS#3 in August, 1995.

The 1995 sampling program was initiated specifically for this project. In June, 1995, we visited Gomez Pit for one day to determine the feasibility of conducting the research. Plans were made to collect samples for dating. Samples for luminescence dating were acquired on August 17-19, 1995. We also collected some mollusk samples at this time, being particularly interested to collect shells with clear stratigraphic relation to the IRSL samples. Photographic documentation of collection sites was also conducted.

After the August collection trip, plans were made for a return to Gomez Pit for additional sampling and a "field conference" involving all interested parties. This work was conducted between September 22 and 25, 1995. Mollusk sampling, surveying, general mapping, and stratigraphic section description were conducted, along with additional photography. Gerald Johnson, of the Geology Department at the College of William and Mary, along with a large group from the University of Delaware (Delaware), participated in this September field work. The U-series geochronologist in this project, Ken Ludwig of the U.S. Geological Survey (USGS) Denver, also was not able to participate in this September visit. Because of Ludwig's time constraints, it was agreed that the U-series results that would be incorporated into this study would be from samples previously collected by J. Wehmiller and recently (1994-1995) analyzed by Ludwig in the context of some independent collaborative research between Delaware and the USGS.

STRATIGRAPHIC DESCRIPTION OF THE UNITS EXPOSED IN GOMEZ PIT

The nomenclature and interpretation of the general stratigraphic sequence at Gomez Pit is summarized in Mirecki and others (1995) and illustrated in Figures 4.1-3 and -4, from Mixon and others (1982) and Peebles and others (1984), respectively. Measured sections MS#1, MS#2, and MS#3 (Figs. 4.1-5, -6 and -7) provide further lithostratigraphic detail of the section exposed at Gomez Pit and show the positions of several of the luminescence and mollusk samples collected in this study. The emphasis in our sampling was to obtain geochronologic samples from the "upper" or serpulid unit and the "lower" or oyster biostrome unit (see Fig. 4.1-4) because previous aminostratigraphic results (Mirecki and others, 1995) indicate that there is a substantial difference in age between these two units. Mollusks and luminescence sample GP10 were also collected from the Chowan River Formation, which is exposed in trenches near the center of the pit. Corals were sampled from the serpulid unit only.



(Stratigraphic column adapted from Mixon et al., 1982)

Figure 4.1-3. Stratigraphic diagram from Mixon and others (1982) for units in the region, including those of Gomez Pit.

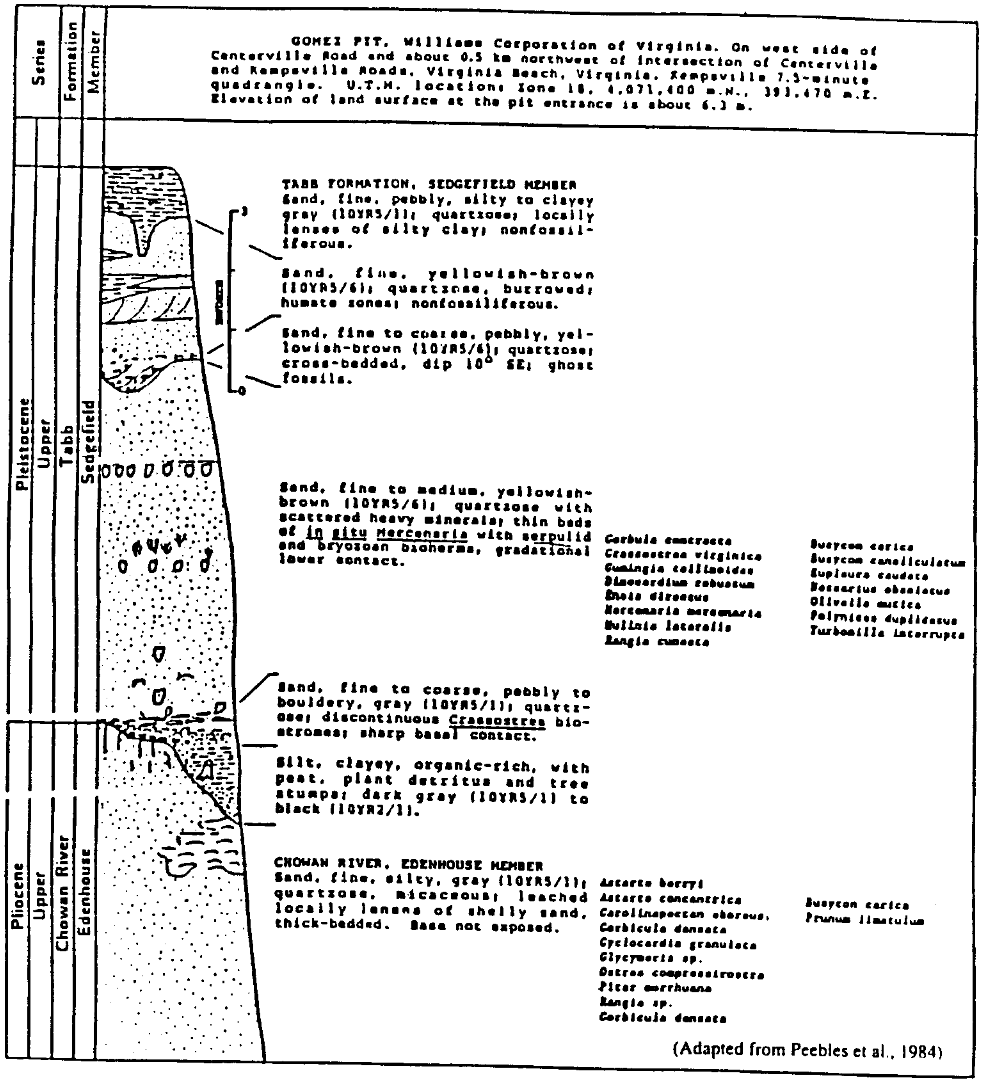


Figure 4.1-4 Stratigraphic diagram for Gomez Pit, from Peebles and others (1984).

SAMPLES AND ANALYTICAL METHODS

Geochronologic sample numbers and data for this study are presented in Tables 4.1-1 (IRSL), -2 (U-series) and -3 (AAR). Samples locations are shown in Figures 4.1-2 and 4.1-8. Sample preparation and analytical methods followed normal practices employed in each of the participating laboratories, and are described briefly below. More information on these dating methods, including principles and methodology, is presented by Forman and others (this volume) on luminescence geochronology, Ku (this volume) on U-series, and Wehmiller and Miller (this volume) on AAR.

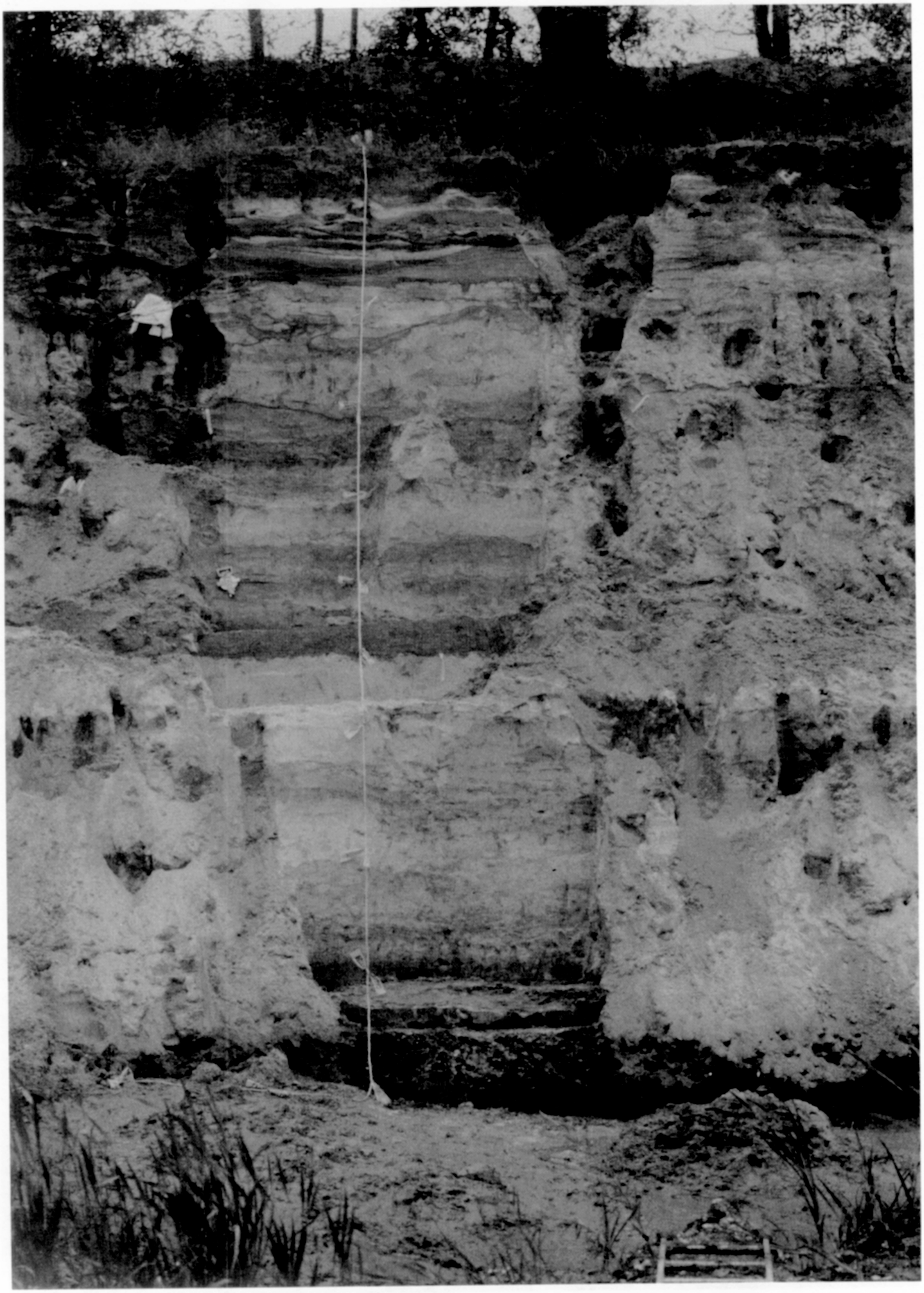


Figure 4.1-5 Measured section #1, Sept. 1995. See Figure 4.1-2 for location.

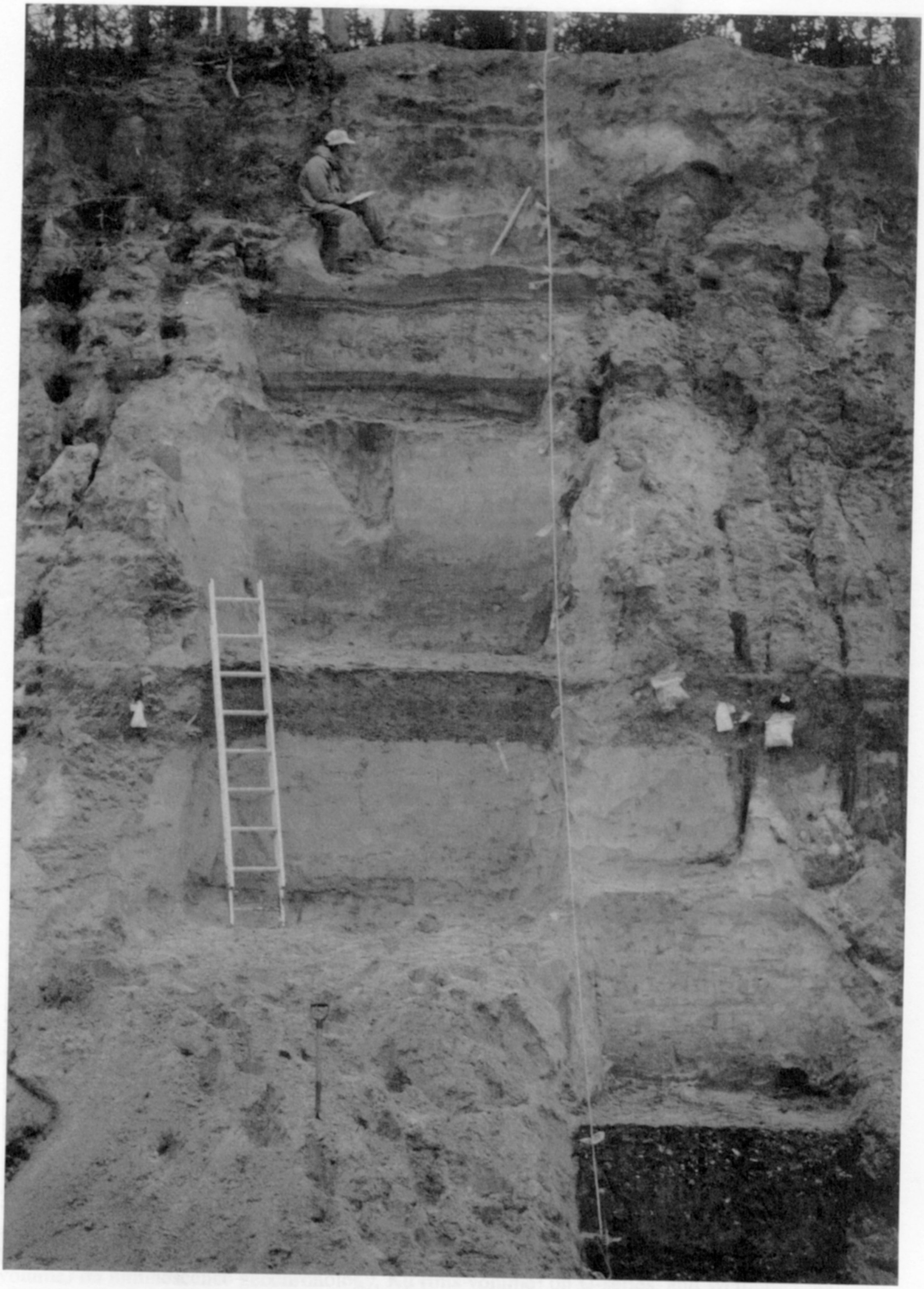


Figure 4.1-6. Measured section #2, Sept. 1995. See Figure 4.1-2 for location.

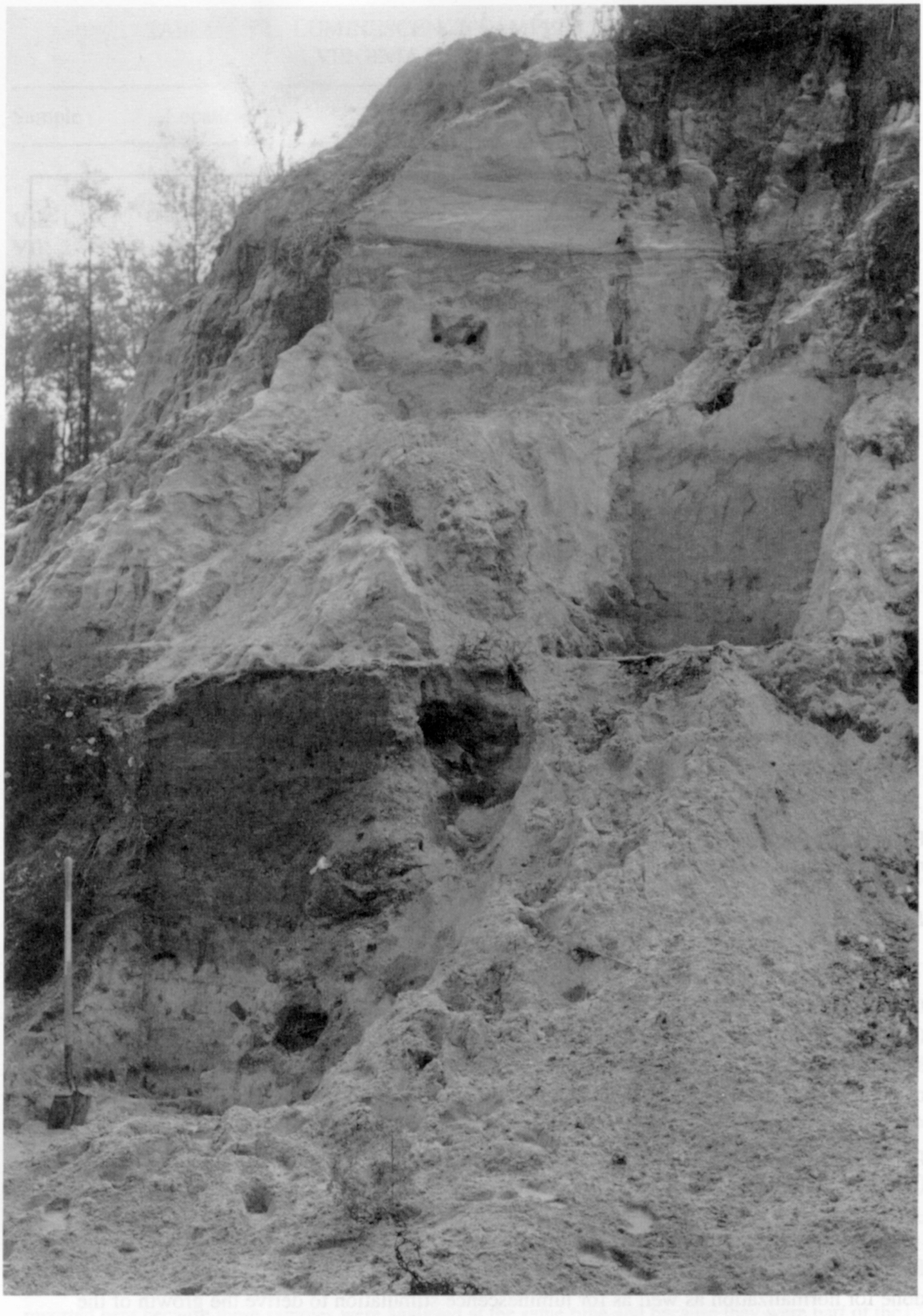


Figure 4.1-7. Measured section #3, Sept. 1995. No detailed description done for this section, but survey markers (blue and pink flags) can be used to match this section to sections #1 and #2.

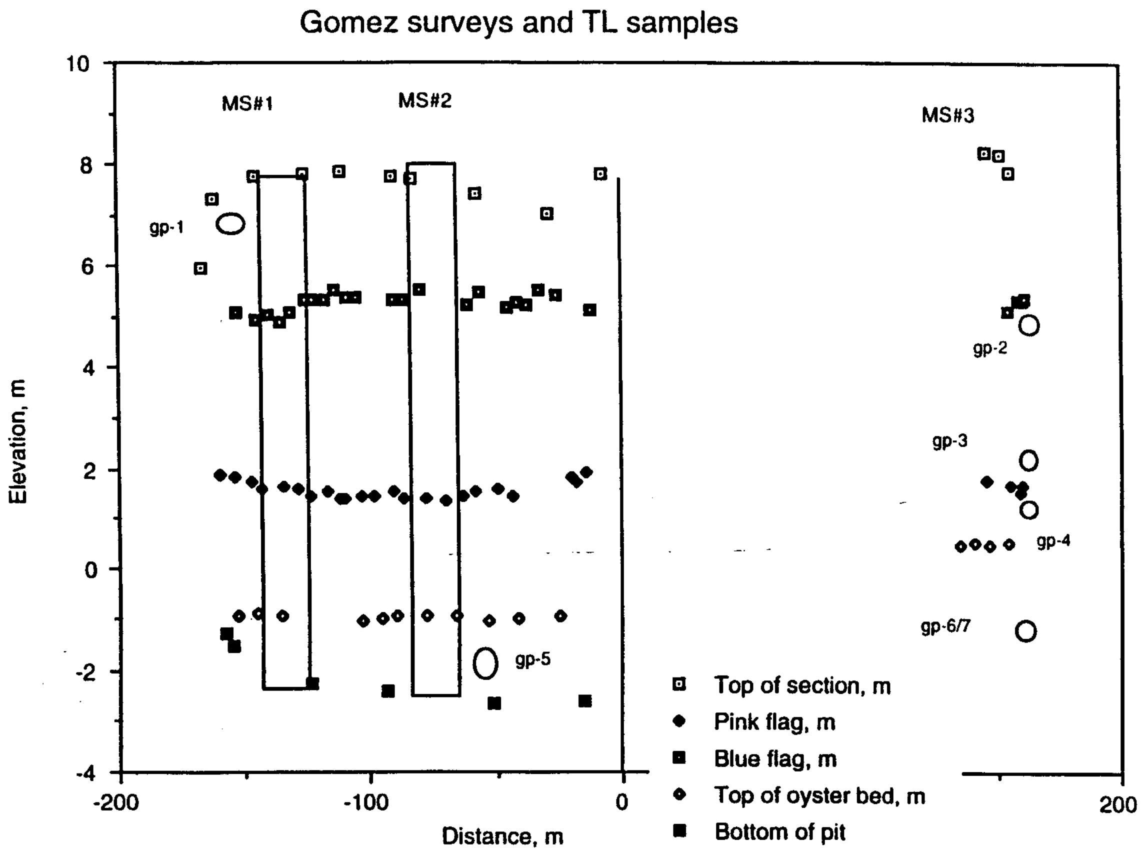


Figure 4.1-8 Surveys of marker beds in sections identified in Figure 4.1-2, including locations of measured sections #1-3. Sections are projected onto line A-A' as shown in Figure 4.1-2.

Luminescence Geochronology

Luminescence analysis was carried out at the University of Quebec in Montreal under the direction of M. Lamothe, primarily on samples of the sand beds, except two samples of mud (GP6 and GP8). From the sands, the 150-200 µm size fraction of feldspar was separated using sieve and densimetric methods. Sample GP7 yielded little of this grain size and a second split of 300-500 µm size fraction was prepared. GP6 and GP8 samples are fine-grained mud and the 4-8 µm size fraction was selected for analysis. Although no mineralogical separation was possible on these samples, it is expected that they contain feldspar which is sensitive to IRSL (880 nm photons).

Multiple aliquots of sample were mounted on aluminum planchets (if sand) or discs (if fine silt). All samples were subsequently illuminated using an 880 nm infrared source. This is done for normalization as well as for luminescence stimulation to derive the growth of the luminescence signal upon dosing. The choice of this stimulation wavelength is based on a resonance effect for feldspar as shown by Hutt and Jaek (1989) and Spooner (1993).

TABLE 4.1-1. LUMINESCENCE SAMPLES FROM GOMEZ PIT, VIRGINIA BEACH, VIRGINIA

Sample	Location
	Sampled by J.Wehmiller, May 1989, from site 06076(B)[1]
VIR-1	ca. 50 cm below oyster bed
VIR-2	ca. 20 cm above oyster bed, below *Mulina* bed
VIR-3	Serpulid bed, lower part
VIR-4	Serpulid bed, upper part
	Sampled by Lamothe and Wehmiller, August 1995
GP1	Upper sand unit, MS#1
GP2	Above serpulid bed, below blue flag, MS#3
GP3	Within serpulid bed, MS#3
GP4	Below serpulid bed, below pink flag, MS#3
GP5	Below oyster bed, MS#2
GP6/7	Below oyster bed, MS#3
GP8	Below oyster bed
GP9	No sample[2]
GP10	Chowan River[3]
GP0	Beach sand, Cape Henry[4]

[1]VIR-1 through 4 were collected by "coring" into a freshly exposed surface on the outcrop with a 2-lb coffee can. This sampling was done while the outcrop was in shadow and the actual sampling position was further shaded with a black plastic garbage bag. These samples were taken with no specific plan for luminescence analyses, but were later (1991) sent to M. Lamothe for some preliminary analysis.

[2]Number assigned for sample that would be taken in time permitted.

[3]Sampled to determine "infinite" TL signal for site, and to evaluate local fading effects.

[4]Sampled to determine "time zero" TL signal for local sediments.

TABLE 4.1-2. CORAL SAMPLES ANALYZED FOR U-SERIES ISOTOPE GEOCHRONOLOGY

Sample	Identification
	Sampled by J.Wehmiller, July 1989, from site 06076 serpulid bed[1]
JW89-117	*Septastrea*[2]
JW89-118	*Astrangia*
JW89-124B	*Septastrea*V

[1]Analyzed by Ludwig at USGS, 1994-1995.

[2]Coral specimens (*Septastrea*) from a nearby site (Moyock, North Carolina - see Fig. 4.1-1) are also reported here because these samples were analyzed at the same time and because they were part of the development of a sample preparation scheme that was employed on the Gomez samples. Number assigned for sample that would be taken in time permitted.

TABLE 4.1-3. MOLLUSK SAMPLES ANALYZED FOR AMINO ACID RACEMIZATION AS PART OF THIS STUDY

Sample	Identification	Date Collected
	Gomez Pit Collections	
JW95-035	*Mercenaria* within oyster bed at MS#3	8/95
JW95-037	*Mercenaria* within oyster bed at GP8	8/95
JW95-038	*Mercenaria* within Chowan River Fm. at GP10	8/95
JW95-043	*Mercenaria* within serpulid zone, MS#2	9/95
JW95-044	*Mercenaria* within serpulid zone, MS#3	9/95
JW95-046	*Mercenaria* within upper part of oyster bed, MS#2	9/95
JW95-048	*Mercenaria* within lower part of oyster bed, 50 m northeast of MS#2	9/95
	Earlier collections: serpulid zone, Mercenaria samples, Gomez Pit	
JW89-104	Locality 06076A	
JW89-106	Locality 06076A	
JW89-121	Locality 06076A	
JW89-133	Locality 06076A	
JW89-139	Locality 06076A	
JW89-141	Locality 06076A	
JW89-148	Locality 06076A	
GP278	Locality 06056	
	Earlier collections: oyster bed Mercenaria samples	
JW88-46	Locality 06074	
JW89-162	Locality 06076A	
JW89-163	Locality 06076A	
JW89-170	Locality 06076B	
JW89-173	Locality 06076B	
	Moyock, North Carolina[1]	
JW93-61-1, -2, -3, -4		

[1]Analyzed during this study for intrashell comparison and evaluation of internal consistency.

U-Series Geochronology

The analysis of U-series isotopic systematics followed standard laboratory procedures employed by the USGS. However, the actual physical preparation of the coral samples was different from that employed in previous coral U-series studies of Atlantic coastal plain sites (Szabo, 1985). Because the thermal ionization mass spectrometry (TIMS) U-series method permits analysis of carbonate samples weighing as little as 100 mg, it was possible to clean large (ca. 3000 mg) coral samples to the most robust (least contaminated) fragments prior to analysis. This strategy has now been employed on approximately 10 coastal plain samples (J. Wehmiller, unpublished data) including the samples listed in Table 4.1-2. The actual sample reduction, which has been done at the University of Delaware under the direction of J. Wehmiller, consists of drilling and grinding of the coral while it is held in a dish of distilled water and viewed under a binocular microscope. Tungsten carbide dental drill tips (generally < 0.25 mm) are used for this purpose. As drilling proceeds, coral samples disintegrate leaving a residue of polyp wall material (fragments usually weighing about 10 mg each) and pulverized material that remains in suspension. The TIMS U-series analysis is usually done on a collection of about 15 of these individual fragments. The entire mechanical sample reduction process usually requires about 10 hours for each sample.

AAR Geochronologic Methods

The amino acid racemization analyses reported here involved both gas chromatographic (GC) and high-pressure liquid chromatographic (HPLC) methods routinely reported in the literature (Wehmiller and Miller, this volume). As part of current research at Delaware, we are making a concerted effort to analyze the same sample extract by both of these procedures, rather than doing separate analyses of a single shell by different methods at different times. Consequently, we are able to report here both GC and HPLC results obtained simultaneously on a specific sample hydrolyzate. Additionally, because of ongoing research at Delaware, we have been analyzing (by both GC and HPLC) individual layers of *Mercenaria* (see Fig. 4.1-9) to

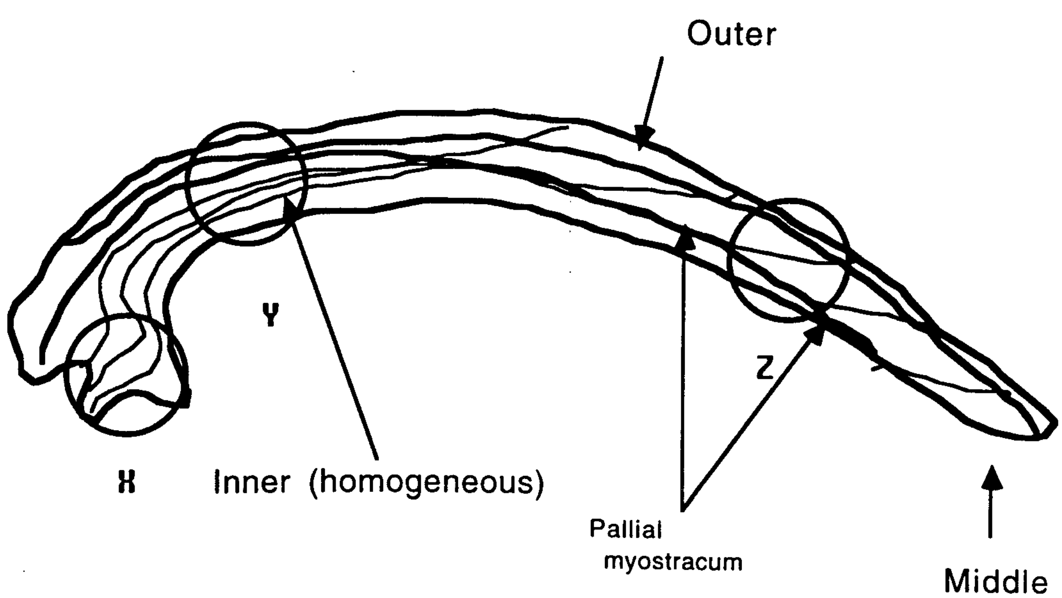


Figure 4.1-9. Cross-section of the shell of *Mercenaria*, showing typical shell structure. Areas of sampling are identified. From Panella and McLintock (1968).

evaluate possible shell structural effects on racemization (because of intrinsic mineral/organic effects on racemization kinetics or extrinsic differences in diagenetic alteration of different shell layers) and to use these intra-shell differences in apparent racemization as aminostratigraphic tools. Some, but not all, of the shells analyzed here were sampled for intra-shell analysis. Interlaboratory comparison samples (Wehmiller, 1984) were analyzed routinely (at least one ILC sample with each batch of ten shells) during the course of the amino acid analyses reported here.

DISCUSSION OF RESULTS

Apparent IRSL Age Estimates

Luminescence geochronology on Gomez Pit samples yielded age estimates that are significantly younger than expected and as determined by U-series and AAR methods. The dosimetric and luminescence data are shown on Tables 4.1-4, -5, and -6. The histogram from the single grain analyses, after prompt measurement and a waiting period, are shown on Figure 4.1-10. This type of test is designed to assess the datability of a sample (Lamothe and Auclair, 1997). Growth curves are presented in Figure 4.1-11. As presented in Table 4.1-6, reported age estimates range from 32 to 87 ka, if only the prompt measurements are considered. Even the GP10 sample, from the Pliocene Yorktown Formation yielded an anomalously young age of 342 ka. Age estimates for the lower and upper Norfolk Formation cluster at around 70-90 ka and 30-40 ka, respectively. These results indeed confirm that there are at least two high sea level stands represented at the Gomez Pit. A stage 7 correlation is suggested for sample VIR-1, although its ca. 160 ka age is a minimum.

The distribution of R_l values for sample GP3 (Fig. 4.1-10a) and the fact that the growth curve data are mostly reproducible (lower reproducibility for GP7 and GP10), are a clear indication that the samples were properly bleached before deposition. In that sense, the set of samples from Gomez Pit constitutes an ideal group of samples to study the second postulate in luminescence geochronology: the stability of luminescence for the constituent feldspar grains. Inasmuch as the geochronologic control at Gomez Pit is not well established, one can nevertheless recognize that the ages reported here are too young on the basis of paleo-sea level reconstruction. Wehmiller and others (1989) have shown that the periods of high sea level in the area correspond to unique isotopic stages, i.e., the ones that represent periods characterized by a return of oxygen isotopic ratios close to the modern value. These periods are isotopic stages 5a (according to Ludwig and others, 1996), 5e, 7, 9 and so on. None of these periods are younger than ca. 75 ka so that it can confidently be assessed that the IRSL ages are too young. The processes through which underestimation of ages can result is discussed below.

As discussed above, the second assumption in luminescence geochronology is that the electrons in the dated traps are bound tightly at electron sites. It has been known for several years that at least feldspar from volcanic terranes is prone to anomalous fading, which is defined here as the loss of luminescence signal with time from presumably stable deep traps (Wintle, 1973). Even though Wintle and Huntley (1982) had required that anomalous fading tests be carried out in any dating program, the advent of preheating in the laboratory procedures has had the malign effect of reducing the possibility of monitoring such effect since most of the component that is unstable over the period of observation in the laboratory is eradicated by the thermal treatment. Recently, Spooner (1993) demonstrated that specimens of feldspar minerals

TABLE 4.1-4. GEOCHEMISTRY AND WATER CONTENT OF THE IRSL SAMPLES

Sample	Fraction	U (ppm)	Th (ppm)	K (percent)	Water content *in situ*	Laboratory saturation
GP1	wc	0.2	0.4	0.82	0.030	0.301
GP1	kut A	0.3	0.5	0.51	0.013	---
GP1	kut B	0.6	1.2	0.73	0.063	---
GP1	feldspath	0.1	<0.1	13.16	---	---
GP2	wc	0.6	2.0	1.10	0.039	0.300
GP2	kut A	0.8	1.8	1.09	0.067	---
GP2	kut B	0.7	1.4	1.28	0.043	---
GP2	feldspath	0.1	0.2	13.95	---	---
GP3	wc	1.2	1.6	1.12	0.116	0.136
GP3	kut A	1.0	1.2	0.94	0.049	---
GP3	kut B	1.4	2.1	1.36	0.052	---
GP3	feldspath	0.4	0.2	13.78	---	---
GP4	wc	0.8	2.0	0.48	0.046	0.287
GP4	kut A	0.8	1.6	0.56	0.029	---
GP4	kut B	0.7	1.7	0.43	0.029	---
GP4	feldspath	0.2	0.4	13.37	---	---
GP5	wc	1.2	2.0	0.75	0.208	0.240
GP5	kut A	1.8	3.4	0.88	0.210	---
GP5	kut B	1.8	3.1	0.75	0.174	---
GP5	feldspath	1.4	1.6	14.86	---	---
GP6	wc	4.0	8.7	1.95	0.521	0.694
GP7	wc	0.4	0.6	0.45	0.244	---
GP7	kut A	1.9	5.6	1.27	---	0.360
GP7	kut B	1.7	3.7	1.03	0.100	---
GP7	feldspath	<0.1	1.1	14.54	---	---
GP8	wc	2.9	8.9	2.09	0.608	0.650
GP8	kut	4.2	12.6	2.30	---	---
GP10	wc	1.3	2.3	0.84	---	---
GP10	feldspath	0.4	0.8	12.12	---	---

K, U and Th analyzed by instrumental neutron activation (INAA)
Water content = water mass/dry mass

from museum collections were prone to fading, whatever their composition. In this Ph.D. study, he monitored the luminescence signal from several types of feldspar over time periods in excess of one year and most of his specimens did fade. As a follow up of this study, the monitoring of several feldspar grains from different geological contexts and ages has been carried out in our laboratory. In most of the cases, there were several grains in the samples investigated that were shown to lose some 10-20 percent of their luminescence signal over time periods of less than 2 months. Moreover, the aliquots used for the construction of the growth curves also have been

TABLE 4.1-5. DOSE RATE DATA

Sample	Grain size	Alpha dose (Gy/ka)	External Beta dose (Gy/ka)	Internal Beta dose (Gy/ka)	Gamma dose (Gy/ka)	Dose rate (Gy/ka)
GP1	150-250 μm	---	0.535	0.752	0.207	1.644
GP2	150-250 μm	---	0.778	0.797	0.373	2.098
GP3	150-250 μm	---	0.885	0.787	0.430	2.252
GP4	150-250 μm	---	0.416	0.764	0.252	1.582
GP5	150-250 μm	---	0.588	0.849	0.408	1.995
GP6	4-8 μm	0.518	1.298	---	0.771	2.737
GP7	300-500 μm	---	0.257	1.659	0.385	2.451
GP8	4-8 μm	0.446	1.314	---	0.860	2.770
GP10	150-250 μm	---	0.583	0.693	0.330	1.756

Notes 1- a value for samples GP6 and GP8 = 0.06
2- External Beta dose corrected for attenuation, Internal Bata dose rate corrected for absorption
3- Cosmic dose estimated at 0.15 Gy/ka

TABLE 4.1-6. APPARENT IRSL AGES OF GOMEZ PIT SAMPLES

Sample	Dose rate (Gy/ka)	Paleodose (Gy)	IRSL age (ka)
VIR 1	1.89	73 ± 4	38.6
VIR 2	2.76	95 ± 5	34.4
VIR 3	1.61	259 ± 23	161

Sample	Dose rate	Paleodoses (Gy)			IRSL ages (ka)		
	(Gy/ka)	De (0)	De (1)	De (2)	Age (0)	Age (1)	Age (2)
GP1	1.64	58.4 ± 1.9	63.9 ± 1.4	64.1 ± 2.5	35.5	38.9	39.0
GP2	2.10	70.4 ± 2.7	---	90.3 ± 4.2	33.6	---	43.0
GP3	2.25	71.7 ± 3.2	77.7 ± 3.4	85.8 ± 3.4	31.8	34.5	38.1
GP4	1.58	65.1 ± 2.4	---	68.6 ± 2.7	41.2	---	43.4
GP5	1.99	142 ± 11	---	175 ± 6	71.2	---	87.7
GP6	2.74	167 ± 10	---	195 ± 10	61.0	---	71.2
GP7	2.45	213 ± 20	231 ± 49	239 ± 25	86.9	94.3	97.5
GP8	2.77	193 ± 19	---	237 ± 19	69.7	---	85.6
GP10	1.76	600 ± 55	826 ± 70	---	342	470	---

Notes De (0) = prompt measurement; De (1) and De (2) = delayed measurements
De (1) : delay = 45 to 50 days, except for GP10 where delay = 25 days
De (2) : delay = 127 to 137 days
Error for age around 10 percent

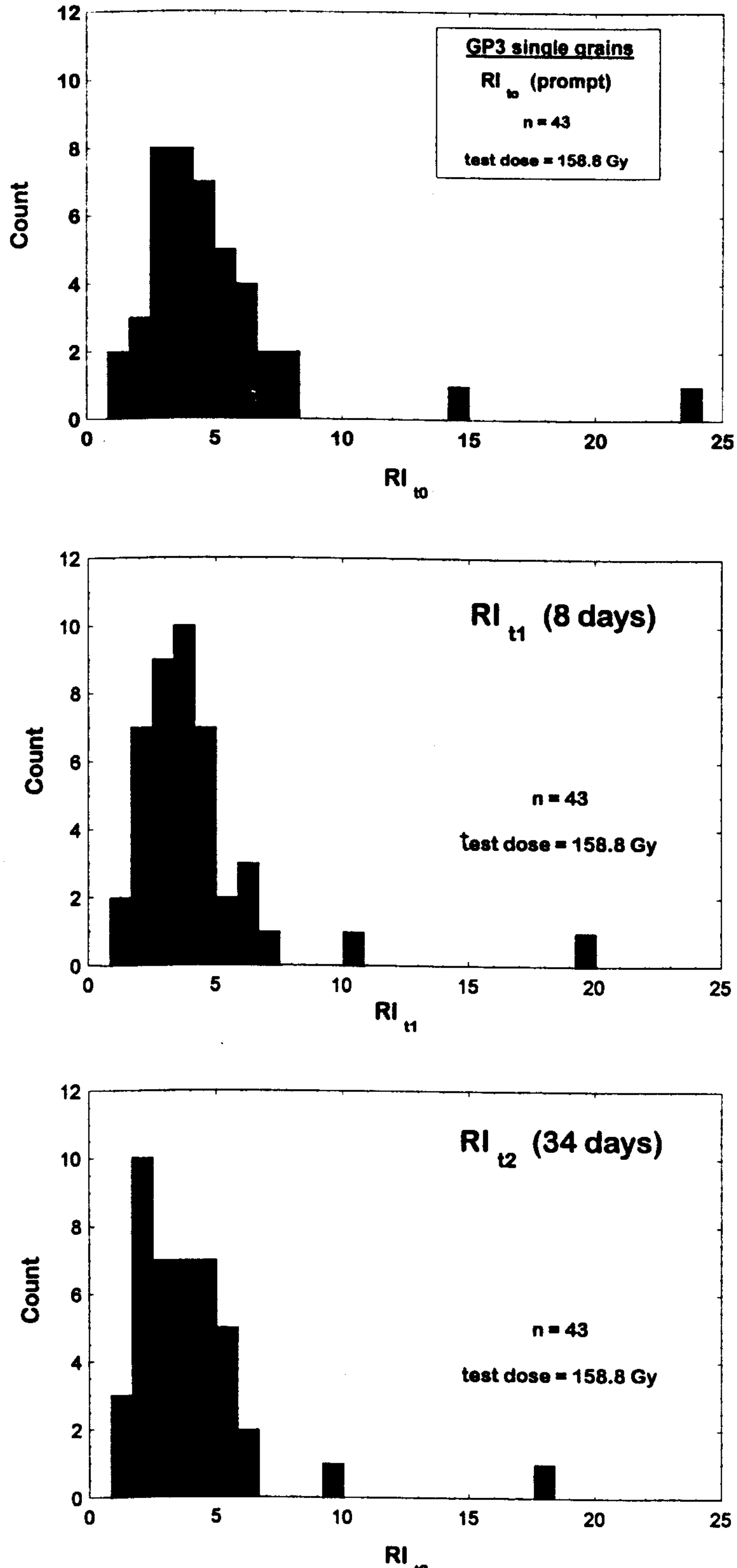


Figure 4.1-10. Histograms of R_I for GP3 single grains after prompt measurement (a), and delays after 8 and 34 days (b and c, respectively).

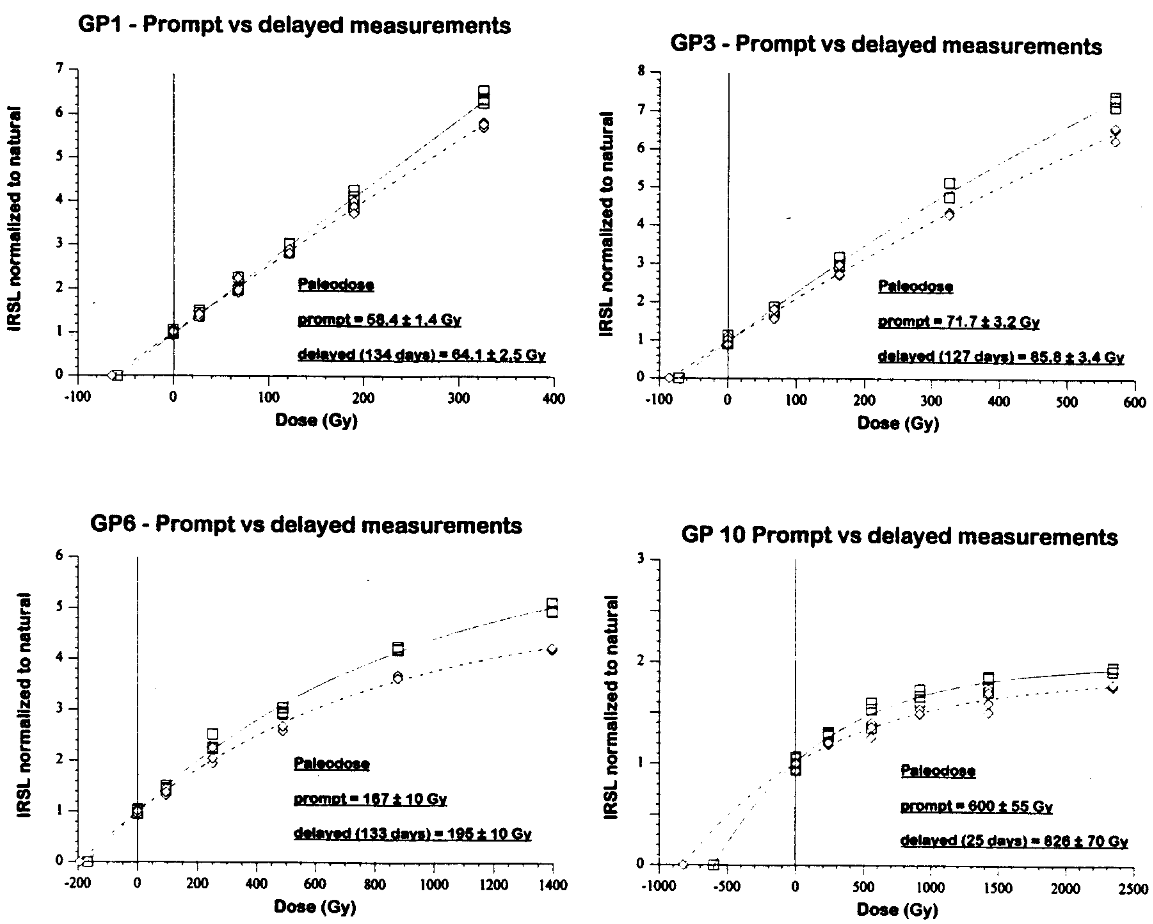


Figure 4.1-11. Growth curves for for samples GP1, GP3, GP6 and GP10, after prompt and delayed measurements (a, b, c, and d, respectively).

remeasured some time after irradiation and these showed a decrease of signal, particularly for those with high doses.

For several samples from Gomez Pit, the same delayed measurements were performed after periods of between 25 to 137 days. They all showed a decrease of luminescence signal. The same is observed for the R_l values measured from single grains (Fig. 4.1-10b) over a period of 34 days. Such samples and methods are therefore not suited for dating the depositional age for these samples. Consequently, these estimates are considered to be minimum ages.

Anomalous Fading in Feldspar

The stability of electrons trapped in defects of feldspathic minerals is a matter of strong debate. Ever since Wintle (1973) discovered the problem of anomalous fading, this malign behavior of feldspars has escaped thorough understanding of its fundamental physical basis. In brief, electrons trapped in minerals are believed to be tightly preserved from untrapping because of the need for an external energy source to excite them (see Forman and others, this volume). Upon glowing a sample, heat can provide enough energy to excite the electron so that it may escape from the trap, go through the conduction band, and undergo recombination, some of which is radiative and leads to thermoluminescence. Optical stimulation from, for example, 2 eV photons can provide enough energy to the electron so that it may escape and recombine. However it is known that, provided a small amount of thermal energy (a few tens of °C), recombination can take place through the so-called localized transitions (Templer, 1986) without the need for the electron to reach the conduction band (Fig. 4.1-12). On the other hand,

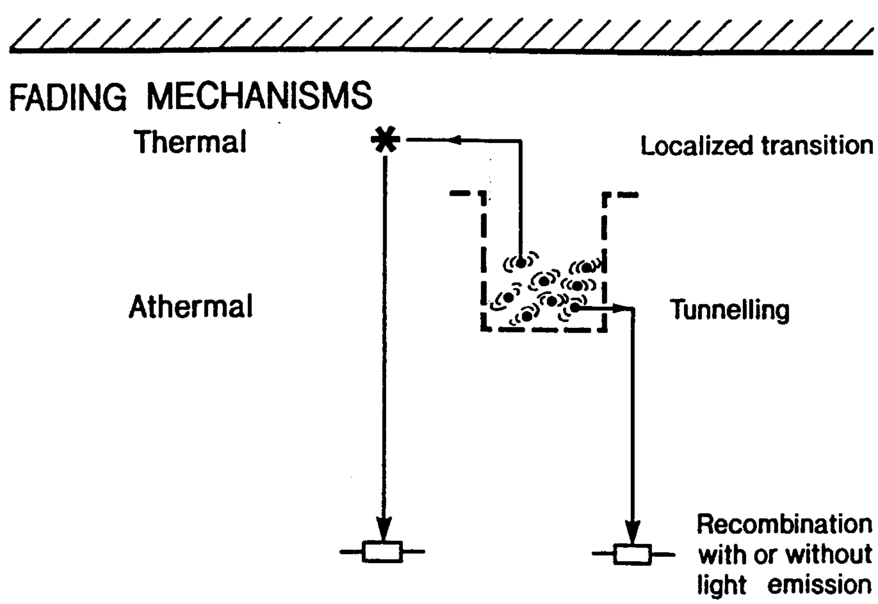


Figure 4.1-12. The physics of trapped electrons and the fading mechanisms invoked for explaining the unstability of the luminescence signal with time.

theoretical calculation suggests that a crystal held at room temperature should keep constant its trapped electron density. Nevertheless, Spooner (1993) has demonstrated that even at 10°C, some electrons can escape the dated trap through athermal tunneling, a phenomenon for which an explanation would go beyond the scope of this report. The main point here is that, after some time, there could be a decrease in electron density in any trap that suffers from anomalous fading. This process takes some time and can be unnoticed by the TL/OSL practitioner in routine dating procedures.

In the case of the Gomez Pit samples, the first test for stability was the remeasurement of the aliquots used for IRSL dating a few weeks to a few months after the prompt measurements. As shown on Figure 4.1-11, there is a significant decrease in luminescence of the irradiated aliquots compared to the natural ones. The latter, by definition, is a stable luminescence signal. A second experiment was based on the monitoring of individual grains at different times after dosing. Again, for some grains, the decrease was severe, and it demonstrated that the samples are badly fading so that the ages should be considered as minimal.

U-series Results

U-series results presented here (Table 4.1-7) confirm previous U-series results for samples from the serpulid unit of Gomez Pit (Szabo, 1985). All previous U-series results were obtained by the alpha-spectrometric method. New data presented here provide the first application of the TIMS method to U.S. Atlantic coastal plain corals. Alpha-spectrometry age estimates of between 70 and 80 ka (substage 5a) were obtained on several coral samples from Gomez, Moyock, and other nearby borrow pits in the region. Although the new results do not change any of the conclusions related to the previous results, they do constitute a significant "challenge" to oxygen-isotope-based sea-level curves, which would predict sea levels during substage 5a to be 10 m or more lower than the current elevation of the serpulid unit. The

TABLE 4.1-7. GOMEZ PIT U-SERIES TIMS DATA

Sample	U, ppm	$^{230}Th/^{232}Th$	$^{230}Th/U$ age, ky	Age error, ky	$^{234}U/^{238}U$, initial	Initial error
JW89-117[1]	2.3	98	79.8	1.0	1.150	0.02
JW89-118[1]	2.1	430	74.2	0.9	1.142	0.03
JW89-124B[1]	1.9	236	75.8	6.9	1.140	0.04
JW92-48D[2]	2.6	11	78.7	2.8	1.154	0.07
JW92-48C[2]	2.4	98	79.8	1.0	1.150	0.02

[1] Calcite/aragonite determinations have been made on these samples; there is no more than a "trace" of calcite (<3 percent).

[2] Samples JW92-48D and C are "dirty" and "clean" splits of the same coral sample, from Moyock, North Carolina. The cleaned sample was prepared in the drilling/reduction manner described in the text, as were the three Gomez samples (89-117, 89-118, and 89-124B). Note that the cleaning of JW92-48 reduced the ^{232}Th content and improved the age and initial $^{234}U/^{238}U$ errors.

serpulid unit was deposited below mean sea level. The implications of these substage 5a age estimates for coastal plain corals have been debated extensively over the past 15 years (Cronin and others, 1981; Szabo, 1985; Wehmiller and others, 1988) and are the subject of continuing investigation. Some possible diagenetic issues related to these dates will be discussed below. We conclude also that the cleaning procedures used (mechanical reduction to eliminate the most porous portions of the corals) and the use of TIMS technology do improve the analytical results (evidenced in the reduction in ^{232}Th and the improved precision) but they did not significantly vary from the original age estimate.

AAR Results

As with previous AAR results (Mirecki, 1990, 1995; J. Wehmiller, unpublished data), the Gomez Pit section consists of two distinct aminozones. Figure 4.1-13 shows the D/L leucine and D/L alanine values for *Mercenaria* samples from previous collections (1985-1989) in the

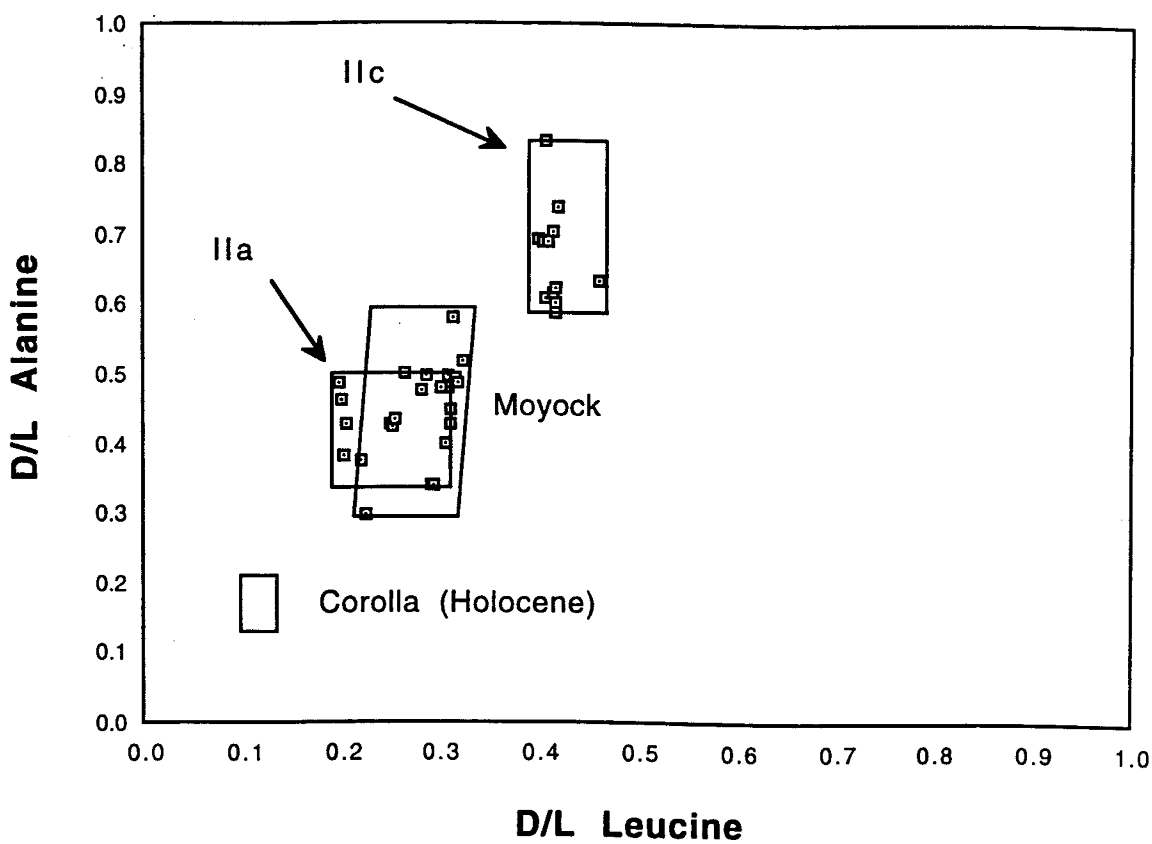


Figure 4.1-13. D/L leucine and D/L alanine values for *Mercenaria* samples from previously-collected Gomez pit sites (aminozones IIa and IIc - see appendices I and II), from Moyock, North Carolina , and from Holocene samples (^{14}C-dated) collected at Corolla, North Carolina (Fig.4.1-1).

serpulid and oyster units of Gomez Pit. The aminostratigraphic data from these two units cluster into two aminozones "IIa" and "IIc" that are recognized regionally (Wehmiller and others, 1988). Mirecki and others (1995) show the distribution of these aminozones based on D-alloisoleucine/L-isoleucine data obtained by HPLC, with mean A/I values for these two aminozones of 0.16 and 0.32, respectively. In the present study we have employed not only A/I values (obtained by both GC and HPLC) but D/L values for at least four other amino acids (alanine, valine, leucine, and aspartic acid). Because of redesign of the HPLC detection system and modification of detection reagent concentrations, A/I values currently are about 10 percent greater than those obtained on our HPLC between 1985 and 1990 (including all those obtained by Mirecki). Figure 4.1-13 shows that leucine D/L values in "IIa shells" range between 0.22 and 0.32 and alanine D/L values range between 0.38 and 0.50. The lower D/L values are usually (but not always) observed in fragments cut from the edges of the shells (hinge or growth edge, as well as the middle layer in the central portion of the shell), while the higher D/L values in any aminozone are almost always obtained from fragments cut from the inner homogeneous layer (see Fig. 4.1-9 for shell sampling positions and structural terminology). The leucine and alanine values cluster around 0.42 and 0.65, respectively, for aminozone IIc shells.

Leucine and alanine D/L values for *Mercenaria* from Moyock, NC, overlap those for the Gomez IIa aminozone. This nearby site (Fig. 4.1-2) has yielded U-series data overlapping those from Gomez Pit. Figure 4.1-13 also shows leucine and alanine D/L values for Holocene (^{14}C-dated) *Mercenaria* collected at Corolla, NC (Wehmiller and others, 1995). These data help define the regional Holocene aminozone.

Newly obtained data from locations MS#2 (95-043), MS#3 (95-044), GP6/7 (95-035), GP8 (95-037), and GP10 (95-038), and samples 95-046 and 95-048, overlap ranges for the IIa and IIc aminozones from previous work (Figs. 4.1-13 and -14). These results represent *Mercenaria* collected from upper part of the oyster unit in the immediate vicinity of MS#2 (95-046) and *Mercenaria* collected from the lower oyster unit 50 m northeast of MS#2 (95-048). Figure 4.1-14 shows that 95-035 and 95-037 fall within the range of IIc shells from previous collections, confirming the aminostratigraphic correlation that was expected at the time of collection. 95-038 shells plot at or near equilibrium D/L values, also as expected from the known age of these shells (Pliocene/early Pleistocene Chowan River Fm). Sample 95-048 appears to plot with higher D/L values than those from IIc or 95-035 and 95-037, suggesting a greater age for the 95-048 shells. 95-046 shells spread over a wide range of D/L values that barely overlap with the lowest part of the 95-048 range (Fig. 4.1-19). 95-046 shells actual range so widely that they overlap with some of the 95-043 and 95-044 shells, all of which were collected from within the serpulid unit and were therefore expected to have IIa aminozone D/L values.

Results for samples 95-043 and 95-044 are enigmatic. Their A/I and D/L leucine values are generally higher than the same ratios in serpulid unit shells collected from elsewhere in the pit (Appendix II). The serpulid unit shells from Gomez Pit have yielded a large range of A/I and leucine D/L values that was also observed by Mirecki (1990). This range can usually be explained in terms of shell preservation characteristics. Furthermore, it appears that most (if not all) of this range can be duplicated in a single shell by analysis of single shell layers. This intra-shell variation appears to diminish in relative significance as the shells become more racemized.

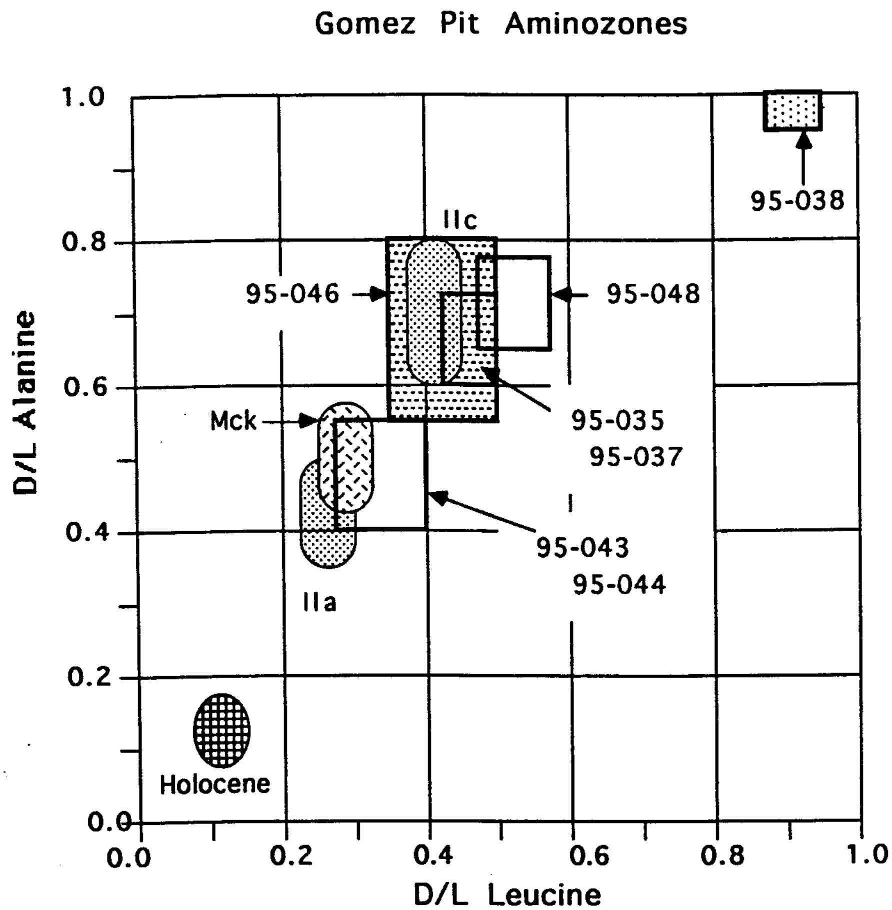


Figure 4.1-14. Gomez Pit Aminozones: Leucine and Alanine D/L values from the IIa, IIc, Moyock and Holocene aminozones (Fig. 4.1-10) compared with those from MS#2 (95-043, 95-046, and 95-048), MS#2 (95-044 and 95-035), GP8 (95-037), and GP10 (95-038). Similar clusters of D/L values have been observed by Mirecki (1990).

Belknap (1979) and Wehmiller and Belknap (1982) also noted these ranges of D/L values for the different units, but the number of analyses obtained for the earlier studies was small enough to preclude any firm conclusions regarding diagenetic effects.

The results for 95-046 and 95-048 are important because of their value in understanding the stratigraphy, taphonomy, and geochemical diagenetic processes of the oyster unit that is so prominent throughout Gomez Pit. Previous aminostratigraphic results for *Mercenaria* from the oyster unit have been confusing, with two aminozones being inferred, one representing reworked shells (Mirecki, 1990; Mirecki and others, 1995). The new results for 95-046 and 95-048 reinforce these original conclusions. Furthermore, occasional *Mercenaria* samples from the uppermost part of the oyster unit have yielded aminozone IIa values, indicating that shells of this age burrowed into the underlying oyster unit during the time (i.e., IIa time) of deposition of the overlying sand and serpulid units. Some of the shells from the top of the oyster unit (95-046) also confirm this observation, and at least one of these shells was noted as probably being of this young age at the time of its collection. The consistently higher D/L values for the 95-048 samples, collected from lower in the oyster unit (see MS#1 and MS#2 descriptions; 95-048 collected 50 meters from MS#2 where the lower oyster unit was very distinctive in outcrop) suggest that the "older aminozone from the oyster unit" has been found "in place" (rather than being represented by reworked shells).

The spread of D/L values in the oyster unit could also be a consequence of groundwater flow and diagenetic alteration, which could also have affected shells in the overlying sand and serpulid units. Alteration fronts are visible in the measured sections, particularly at the boundary about 0.5 to 1.0 meter above the pink flag in MS#1, MS#2, and MS#3. The presence of shell ghosts throughout the upper part of the section (see MS#1 and MS#2 descriptions) indicates that there has been substantial loss of carbonate from the section. The contrast in porosity and lithology across the upper contact of the oyster unit results in perched ground water. Leaching and iron staining of shells in the oyster unit is common. High uranium content of both the shells and the sediment in the oyster unit has been noted (Mirecki and others, 1995; Kaufman and others manuscript; M. Lamothe, unpublished). Collectively, these features imply that some material was selectively released and translocated from the porous, upper sandy units to the tight underlying oyster unit. It is not clear how much of the alteration, leaching and translocation of material is related to the regional drawdown of the watertable in the last 30+ years (G. Johnson, pers. comm., 1995) and how much is a natural part of the subsurface geochemical system for the region. Nevertheless, in spite of the preliminary and speculative nature of these observations, it is important to emphasize that these processes, which clearly have affected the molluscan material in the section, have probably also affected the corals (and the U-series system) and the luminescence systematics (e.g., consistency of dose-rate). The spread of D/L values in the IIa, 95-043, and 95-044 samples also must be related to these diagenetic leaching effects.

AAR Kinetic Modeling

Because AAR requires direct or indirect calibration for its use as a dating method, any interpretation of the D/L values in terms of time will depend on the accuracy of the calibration as well as the accuracy of the AAR results. The AAR data from Gomez Pit can be interpreted in both regional and local contexts. The regional context has been reviewed extensively (Wehmiller and Belknap, 1982; Wehmiller and others, 1988, 1992) and will not be addressed here. The local interpretation, in this case, will emphasize the difference between sample ages for the oyster and serpulid units, inferred from different kinetic models for racemization and different options for the ages of the calibration samples. This approach follows that given in Mirecki and others (1995: Table 4.1-2).

We use two kinetic models to provide model age estimates. Table 4.1-8 lists six D/L leucine values that span the range observed in the present study (with the exception of the Chowan River 95-038 samples). The different columns list age assignments for different choices of calibration ratios (either 80 ka or 125 ka calibrations are use) for two kinetic models: "B" for "Boutin non-linear model", presented in Wehmiller and others (1988); and "PB" for parabolic model, presented first by Mitterer and Kriausakul (1989). The Boutin model is applied directly to leucine D/L values; the parabolic model is applied to A/I values, converted from the appropriate leucine D/L value using the intrageneric conversion equations in Wehmiller and others (1988). Model runs B/1, B/2 and B/3 use a D/L leucine value of 0.25, 0.30, and 0.30,

TABLE 4.1-8. KINETIC MODEL OPTIONS - LEUCINE[1]

D/L Leu.	B/1 80	B/1 125	B/2 80	B/2 125	B/3 80	B/3 125	PB1/ 80	PB1/ 125	PB2/ 80	PB2/ 125	PB3/ 80	PB3/ 125
0.25	80	125					80	125	~~47~~	~~73~~	~~30~~	47
0.30	126	197	80	125	~~52~~	~~81~~	136	213	80	125	~~51~~	80
0.35	192	300	122	190	80	125	213	334	125	196	80	125
0.40	284	445	180	182	118	184	316	494	186	289	118	184
0.45	410	640	260	406	170	266	447	699	262	410	167	261
0.50	576	900	365	571	239	374	609	952	357	558	228	356

[1]Ages in ky for different D/L leucine values, as predicted by different kinetic models: B = Boutin non-linear (see Wehmiller and others, 1988); PB = parabolic.

respectively, for the 80 and 125 ka calibrations. Model runs PB1, PB2, and PB3 use these same values for the two calibrations, respectively.

The results of the comparisons of the Boutin and parabolic kinetic models are shown in Figure 4.1-15. The difference in age estimates is much more dependent on the choice of calibration sample than on the choice of kinetic model. For example, if a D/L leucine value of 0.25 is used as either the 80 or 125 ka calibration, then a D/L leucine value of 0.40 would be interpreted to represent an age of either 300 ka or 475 ka, respectively, by either model (within ca. ± 5 percent, a range much smaller than the analytical range on an aminozone). Consequently, the following qualitative age estimates can be presented for the leucine aminozones observed in this study:

Using leucine D/L of 0.25 (the "best minimum value" for the serpulid unit) as an 80 ka calibration (the inferred age based on the U-Th dates of corals associated with the serpulid unit at 06076) predicts:

0.30 = ca. 125 ka
0.35 = ca. 200 ka (the mean value of 95-043 and 95-044?)
0.40 = ca. 300 ka
0.45 = ca. 425 ka ("best value" for IIc?)
0.50 = ca. 600 ka (95-048?)

If a leucine value of 0.35 (the mean of 95-043 and 95-044) is used as the 80 ka calibration, then it is possible to reach a leucine D/L of 0.50 by about 240 ka. Note that no corals from the sites of collection of 95-043 and 95-044 have been dated. Using the same D/L leucine value options with a 125 ka calibration will increase all of these age estimates by about 55-60 percent (a factor of 125/80).

Using conservative estimates of the "best" mean value for each of the Gomez Pit leucine aminozones, and assuming that there is as much as 15 percent variation (due to shell preservation effects), it seems appropriate to assume a mean leucine D/L of ca. 0.33 for 100 ka and to project the kinetics of Figure 4.1-15 to age estimates of ca. 220 ka (stage 7?) and ca. 300 ka

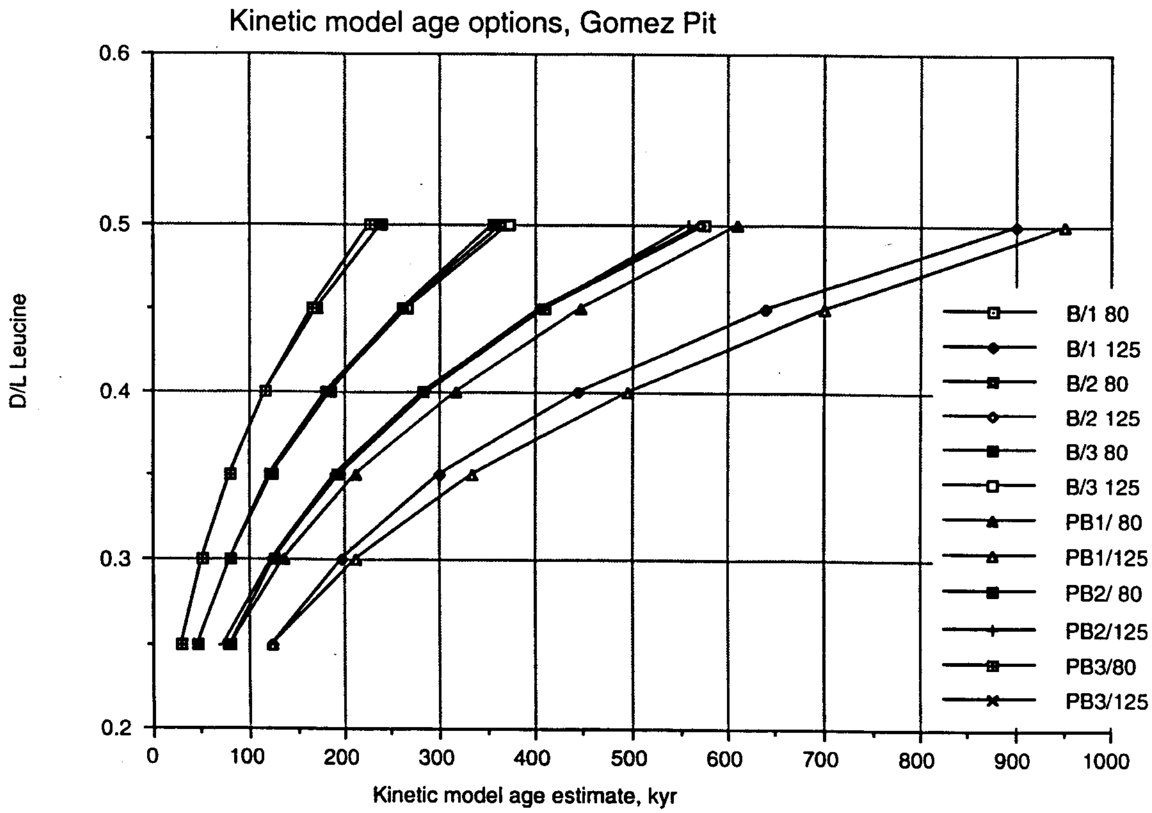


Figure 4.1-15. Kinetic model age estimates from Table 4.1-5. Models labelled "B" are for "Boutin non-linear" (Wehmiller and others, 1988). Models labelled "PB" are for "parabolic kinetics" (see Mitterer and Kriausakuk, 1989). Three pairs of curves are shown for each model category - those with leucine values of 0.25, 0.30, and 0.35 "fixed" to calibration points of either 80 kyr or 125 kyr.

(stage 9?) for the leucine values of ca. 0.42 and 0.50, respectively. Although these age estimates for the older aminozones are slightly younger than those presented in Mirecki and others (1995), it must be emphasized that, at the present state of knowledge, the combination of analytical and kinetic model uncertainties for AAR methods, combined with unknown diagenetic variables, could easily result in any age estimate being "off" by 100 ka, even though the relative age differences for different aminozones might remain stable.

SUMMARY AND CONCLUSIONS

Results of this study add to our understanding of the relative reliability and comparability of the IRSL, U-series, and AAR geochronologic methods, and highlight specific problems. Comparability was enhanced because these methods were applied on the same measured sections, and because geologists and geochronologists worked side-by-side throughout the project, both in the field and in the lab. Results of this study also improve the geochronologic control on the Gomez Pit section of the U.S. Atlantic coastal plain sediments by significantly adding to the available age estimates on samples from this section.

The U-series and amino acid data obtained in this study duplicated most of the previous results. Although, some subtle differences in amino acid D/L values were encountered Some of the differences in AAR results can be ascribed to different sampling and analytical methods compared with the earlier work we have done at Gomez Pit (Mirecki, 1990), but some of these new results may be indicative of diagenetic effects that remain to be evaluated.

The twelve samples dated by the IRSL method are thought to have the same feldspar composition and their luminescence unstability would suggest that the ages reported should be considered as minimum ages, until a solution to anomalous fading can be found. The differences in ages between the different marine units is however significant.

Collectively the three dating methods indicate that there are at least two Pleistocene fossiliferous marine units preserved in the Gomez Pit section, one representing all or part of marine isotope stage 5, the other representing all or part of marine isotope stage 7 and/or perhaps stage 9. The apparent IRSL ages for the samples show three clusters: one at ca. 40-45 ka, one at 70-100 ka, and a single sample (VIR-1) yielded an older age of 160 ka. U-series results confirm earlier reports of ca. 70-80 ka ages on coral in fossiliferous units exposed at Gomez Pit and nearby pits. The AAR results indicate that the units above the oyster unit span from ca. 130 ka to 80 ka and younger, with the age of the serpulid unit at least 80 ka. Shells from the oyster unit(s) provide two age estimates that may correspond to deposition during marine-oxygen-isotope stages 7 and 9, but the effects of diagenetic alteration on these shells remains to be more fully evaluated.

Carbonate leaching and shell alteration are clearly evident in the section at Gomez Pit, despite the many "well-preserved" shells. The preservation quality of most of the specimens in the oyster unit indicates active water flow, staining, dissolution and possible precipitation, making this unit very complex both geochemically AND chronostratigraphically. The implications of these diagenetic processes for the accuracy of the U-series age estimates from Gomez Pit need to be fully evaluated, as it seems reasonable that the corals have not been "immune" from these processes.

The three most important things to getting a good age estimate are context, context and context, and these were supported by the results of this study. By having geologist and geochronologist present at the time of field reconnaissance and sampling, and in communication during lab analysis , the results have lower uncertainty by virtue of the fact that each participant witnessed the actions of the others.

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Appendix ~~#~~ II

Amino acid racemization data, 1995-1996 analyses , Gomez Pit collection

Date	Lab No	Run	Sample	A/I hplc	comments	Ala	Val	A/I gc	Leu	Asp	Phe	Glu
3/5/96	960143	20	jw95-043-1a	0.335		0.483	0.204	0.390	0.404	0.632	0.359	0.177
3/5/96	960143	22	jw95-043-1a	0.335		0.497	0.200	0.369	0.408	0.627	0.365	0.197
2/15/96	960062	86	jw95-043-1b outer c	0.150	small				0.235	0.499		
2/16/96	960062	91	jw95-043-1b outer c	0.150	split for hplc and gc	0.439	0.130	0.207	0.245		0.262	0.159
2/15/96	960063	85	jw95-043-1b middle	0.290	split for hplc and gc	0.420	0.171	0.369	0.371	0.608	0.493	0.215
2/21/96	960063	99	jw95-043-1b middle	0.290			0.172	0.344	0.368	0.598	0.267	0.214
2/26/96	960063	1	jw95-043-1b middle	0.290	ɔgram modifications	0.411	0.172	0.361	0.362	0.587		
2/26/96	960063	2	jw95-043-1b middle	0.290	ɔgram modifications	0.436	0.177	0.378	0.364	0.601		
2/26/96	960063	3	jw95-043-1b middle	0.290	ɔgram modifications	0.431	0.173	0.354	0.368	0.610	0.269	0.196
2/22/96	960064	104	jw95-043-1b outer	0.130	awlful gc run							
12/7/95	950511	67	jw95-043-1c	0.295	CAUTION	0.483	0.201	0.348	0.397	0.625	0.409	0.278
12/12/95	950511	3	jw95-043-1c	0.295	CAUTION	0.501	0.192	0.385	0.393	0.640		
2/20/96	960086	96	jw95-043-1c-x	0.155	small hplc/gc	0.390			0.283	0.532	0.220	0.170
2/29/96	960086	13	jw95-043-1c-x	0.155	failed no inj!							
2/29/96	960086	14	jw95-043-1c-x	0.155		0.420	0.126	0.215	0.288	0.575	0.270	0.181
2/20/96	960087	97	jw95-043-1c-y inner	0.340	small hplc/gc	0.450	0.150		0.380	0.614		
2/28/96	960087	7	jw95-043-1c-y inner	0.340		0.495	0.215	0.358	0.392			0.220
2/21/96	960088	101	jw95-043-1c-y middle	0.280	small hplc/gc		0.234	0.283	0.372	0.539	0.237	0.222
3/1/96	960088	15	jw95-043-1c-y middle	0.280		0.606	0.208	0.303	0.369	0.593	0.355	0.245
2/20/96	960089	98	jw95-043-1c-z	0.230	small hplc/gc	0.462	0.161	0.238	0.296	0.537	0.254	0.181
3/6/96	960089	23	jw95-043-1c-z	0.230	too big for asp-glu	0.457	0.161	0.235	0.296			
3/1/96	960144	18	jw95-043-8-1-x	0.190		0.430	0.132	0.216	0.246	0.540	0.197	0.163
3/5/96	960144	21	jw95-043-8-1-x	0.190			0.143	0.225	0.261	0.547	0.203	0.150
3/1/96	960145	16	jw95-043-8-1-y	0.270		0.513	0.197	0.317	0.351	0.602	0.282	0.203
3/12/96	960145	46	jw95-043-8-1-y	0.270	small peaks	0.456	0.206	0.330	0.346	0.583		0.210
3/8/96	960146	37	jw95-043-8-2-x	0.201	aux He not on!	0.461	0.137	0.193	0.242			
3/9/96	960146	38	jw95-043-8-2-x	0.201	ın with aux he on!!!!	0.453	0.142	0.216	0.244	0.572		
3/9/96	960147	39	jw95-043-8-2-y	0.285		0.521	0.226	0.328	0.354		0.342	0.191
3/11/96	960147	44	jw95-043-8-2-y	0.285		0.485	0.200	0.347	0.364	0.579	0.378	0.238
12/4/95	950502	60	jw95-044-4	0.340	CAUTION	0.563	0.197	0.381	0.407	0.559		0.240
12/4/95	950502	62	jw95-044-4	0.340	CAUTION	0.556	0.209	0.346	0.398	0.586	0.396	0.240
12/19/95	950528	14	jw95-044-3	0.280	split for hplc and gc				0.360	0.574		
12/19/95	950528	15	jw95-044-3	0.280	split for hplc and gc	0.516	0.207	0.301	0.376	0.622		0.257
12/7/95	950509	66	jw95-044-6	0.235	CAUTION	0.431	0.154	0.287	0.306	0.582	0.329	0.220
12/11/95	950509	71	jw95-044-6	0.235	CAUTION	0.432	0.139	0.275	0.304	0.563	0.328	0.227

	Date	Lab No	Run	Sample	A/I hplc	comments	Ala	Val	A/I gc	Leu	Asp	Phe	Glu
58	1/28/96	960055	66	jw95-044-6	0.240		0.444	0.202	0.306	0.345	0.600	0.356	0.227
59	1/29/96	960055	67	jw95-044-6	0.240	BASELINE DROPPE	0.386	0.208	0.308	0.353	0.591	0.326	0.216
60	1/31/96	960055	74	jw95-044-6	0.240		0.440	0.197	0.343	0.346	0.595	0.315	0.218
61	2/1/96	960055	78	jw95-044-6	0.240		0.454	0.205	0.316	0.348	0.602	0.334	0.229
62													
63													
64													
65	9/15/95	950439	19	jw95-035-1	0.435	›mez nrc oyster bed	0.661		0.496	0.455	0.654		0.290
66	9/19/95	950439	24	jw95-035-1	0.435	›mez nrc oyster bed	0.618	0.302	0.496	0.445			
67	9/20/95	950439	28	jw95-035-1	0.435	›mez nrc oyster bed	0.638	0.303	0.503	0.446	0.696	0.512	0.321
68	9/18/95	950440	22	jw95-035-2	0.430	›mez nrc oyster bed	0.612	0.325	0.484	0.463			
69	9/19/95	950440	25	jw95-035-2	0.430	›mez nrc oyster bed	0.609	0.320	0.496	0.472	0.733	0.548	0.422
70	9/19/95	950440	26	jw95-035-2	0.430	›mez nrc oyster bed	0.613	0.311	0.473	0.483	0.690	0.565	0.380
71	10/3/95	950440	31	jw95-035-2	0.430	›mez nrc oyster bed	0.621	0.319	0.483	0.477	0.743	0.554	0.345
72													
73	9/15/95	950441	20	jw95-037-1	0.390	›mez nrc oyster bed	0.692	0.255	0.530	0.454	0.654	0.395	0.345
74	9/18/95	950441	21	jw95-037-1	0.390	›mez nrc oyster bed		0.251	0.320	0.463	0.672	0.411	0.305
75	9/20/95	950441	27	jw95-037-1	0.390	›mez nrc oyster bed	0.643	0.333	0.436	0.445		0.507	0.303
76	10/10/95	950442	41	jw95-037-2	0.360	›mez nrc oyster bed	0.631	0.282	0.419	0.434	0.670	0.439	0.324
77	10/12/95	950442	42	jw95-037-2	0.360	›mez nrc oyster bed	0.724	0.284	0.421	0.423	0.672	0.441	0.320
78	10/12/95	950442	43	jw95-037-2	0.360	›mez nrc oyster bed				0.439	0.645		0.307
79	11/28/95	950442	50	jw95-037-2	0.360	›mez nrc oyster bed	0.646			0.434	0.646	0.458	0.332
80	11/29/95	950442	51	jw95-037-2	0.360	›mez nrc oyster bed	0.678			0.434	0.662		
81	11/29/95	950442	52	jw95-037-2	0.360	›mez nrc oyster bed				0.432	0.652		
82													
83													
84													
85													
86	10/4/95	950443a	32	jw95-038-1	1.300	gomez nrc Chowan	0.887	0.786	1.260	0.857	0.907	0.849	0.815
87	10/4/95	950443b	33	jw95-038-1	1.300	gomez nrc Chowan	0.890	0.698	1.143	0.885	0.919	0.891	0.860
88	10/5/95	950443b	35	jw95-038-1	1.300	gomez nrc Chowan	0.991	0.832		0.914	0.902	0.838	0.840
89	10/9/95	950443b	36	jw95-038-1	1.300	gomez nrc Chowan	0.991	0.836		0.898	0.906	0.866	0.857
90	10/9/95	950444b	37	jw95-038-2	1.300	gomez nrc Chowan	0.956	0.859		0.896			
91	10/9/95	950444b	38	jw95-038-2	1.300	gomez nrc Chowan	0.955	0.841	1.260	0.899	0.914		
92	9/15/95	950444a	18	jw95-038-2	1.300	gomez nrc Chowan							
93	9/18/95	950444a	23	jw95-038-2	1.300	gomez nrc Chowan	0.895	0.800	1.140	0.869	0.902	0.814	0.699
94	9/20/95	950444a	29	jw95-038-2	1.300	gomez nrc Chowan	0.971	0.827	1.022	0.879	0.910	0.903	0.793
95	10/5/95	950444b	34	jw95-038-2	1.300	gomez nrc Chowan							
96													
97													
98													
99	1/28/96	960057	65	jw95-046-1a articulated	0.460			0.327	0.473	0.519	0.690	0.468	0.333
100	1/30/96	960057	68	jw95-046-1a articulated	0.460	NOISY BASELINE	0.685	0.376	0.452	0.509	0.687	0.538	0.357
101	2/1/96	960057	76	jw95-046-1a articulated	0.460			0.364	0.444	0.514	0.700	0.514	0.346
102	2/1/96	960057	77	jw95-046-1a articulated	0.460		0.741	0.358	0.463	0.502	0.691	0.459	0.337
103	2/13/96	960057	81	jw95-046-1a articulated	0.460		0.695	0.356	0.452	0.511	0.691	0.449	0.333
104													
105													
106	12/4/95	950503	61	jw95-046-13	0.270	pilt for hplc suspect	0.659	0.191	0.267	0.339	0.541	0.315	0.237
107	12/6/95	950503	64	jw95-046-13	0.270	pilt for hplc suspect	0.619	0.176	0.262	0.344	0.542		
108	12/11/95	950503	72	jw95-046-13	0.270	pilt for hplc suspect		0.191	0.243	0.332	0.619	0.330	0.233
109	12/12/95	950503	2	jw95-046-13	0.270	pilt for hplc suspect	0.767	0.189		0.342	0.604		
110													
111	3/11/96	960148	43	jw95-046-13a	0.340		0.610	0.218	0.405	0.428	0.616	0.396	0.246
112	3/12/96	960148	48	jw95-046-13a	0.340		0.623	0.206	0.415	0.426	0.608	0.368	0.246
113													
114	3/7/96	960149	28	jw95-046-13b	0.300	‹s big some overload		0.188	0.321	0.365		0.490	0.239

	Date	Lab No	Run	Sample	A/I hplc	comments	Ala	Val	A/I gc	Leu	Asp	Phe	Glu
115	3/12/96	960149	45	jw95-046-13b	0.300		0.519	0.187	0.348	0.363	0.573		
116													
117													
118	1/30/96	960056	70	jw95-046-17	0.370	small peaks				0.429	0.602		
119	1/30/96	960056	71	jw95-046-17	0.370		0.783	0.282	0.338	0.437	0.628	0.468	0.322
120	1/31/96	960056	75	jw95-046-17	0.370		0.635	0.286		0.447	0.653	0.544	0.309
121													
122													
123													
124	12/7/95	950512	68	jw95-046-21	0.322	pilt for hplc suspect				0.415	0.589		
125	12/8/95	950512	69	jw95-046-21	0.322	pilt for hplc suspect		0.236		0.400	0.636	0.445	0.306
126	12/8/95	950512	70	jw95-046-21	0.322	pilt for hplc suspect		0.227		0.390	0.676	0.410	0.337
127													
128													
129	3/9/96	960150	40	jw95-046-21a inner	0.490	›rload of later peaks	0.611	0.289	0.495	0.481			
130	3/11/96	960150	41	jw95-046-21a inner	0.490		0.546	0.303	0.535	0.484	0.665	0.398	0.285
131	3/7/96	960151	29	jw95-046-21a middle	0.450		0.679	0.298	0.473	0.483	0.639		
132	3/6/96	960152	25	jw95-046-21b	0.440	small				0.450	0.625		
133	3/11/96	960152	42	jw95-046-21b	0.440		0.605	0.282	0.441	0.445			0.288
134													
135													
136	12/1/95	950504	59	jw95-048-7	0.440	pilt for hplc suspect	0.768	0.315	0.551	0.492	0.633		
137	12/6/95	950504	63	jw95-048-7	0.440	pilt for hplc suspect	0.730	0.320	0.467	0.486		0.504	0.321
138													
139	12/14/95	950527	5	jw95-048-4a	0.460	split for hplc and gc					0.693	0.477	0.339
140	12/14/95	950527	6	jw95-048-4a	0.460	split for hplc and gc	0.726	0.321	0.433	0.544			
141	1/25/96	950529	57	jw95-048 4b	0.480	le mix with 960057	0.681	0.328	0.563	0.568	0.742		
142	1/25/96	950529	58	jw95-048 4b	0.480	le mix with 960057	0.638	0.321	0.513	0.552		0.529	0.348
143	1/26/96	950529	63	jw95-048 4b	0.480	le mix with 960057	0.728	0.332	0.537	0.537	0.702	0.541	0.363
144	1/26/96	950529	64	jw95-048 4b	0.480	le mix with 960057	0.720	0.313	0.540	0.547	0.690	0.495	0.315
145													
146		960058		jw95-048 5a	0.525	no gc data							
147		950526		jw95-048 6	0.470	no gc data							

	Date	Lab no	Run no	Sample	A/I hplc	Comments	Ala	Val	A/I gc	Leu	Asp	Phe	Glu
1													
2	2/28/96	960076	8	gp278 x	0.165	olit for hplc and gc	0.393	0.121	0.193	0.203			
3	2/19/96	960076	93	gp278 x small pks	0.165	olit for hplc and gc	0.438	0.124	0.179	0.206	0.512	0.207	0.159
4	2/19/96	960077	92	gp278 y inner	0.225	olit for hplc and gc	0.490		0.296	0.302	0.538	0.240	0.160
5	2/27/96	960077	5	gp278 y inner	0.225	nice run	0.409	0.175	0.293	0.306	0.536	0.291	0.189
6	2/21/96	960078	100	gp278 y middle		small hplc/gc	0.472			0.202	0.476		
7	2/27/96	960078	6	gp278 y middle		nice run	0.496	0.122	0.175	0.198		0.249	0.162
8	2/19/96	960079	94	gp278 z		olit for hplc and gc	0.507	0.154	0.234	0.287	0.504		
9	2/19/96	960079	95	gp278 z		olit for hplc and gc	0.485	0.155	0.252	0.283	0.473		
10													
11													
12													
13													
14	1993	930172		jw89-104	0.190	done with sp, mck							
15	1993	930173		jw89-106	0.130	done with sp, mck							
16													
17													
18													
19	2/15/96	960080	87	jw89-121-b inner	0.240	olit for hplc and gc	0.348	0.148	0.262	0.294	0.595		0.172
20	2/16/96	960080	90	jw89-121-b inner	0.240	olit for hplc and gc	0.350	0.133	0.262	0.291	0.563	0.269	0.185
21	2/15/96	960081	88	jw89-121-b outer	0.200	small				0.268	0.494	0.241	0.183
22	2/16/96	960081	89	jw89-121-b outer	0.200	olit for hplc and gc	0.443	0.142	0.217	0.256		0.357	0.166
23		890027		JW89-121A	0.160								
24		890028		JW89-121B	0.180								
25													
26	7/19/95	950337	7	jw89-139-a1	0.203	M ONeal Gomez							
27	7/19/95	950337	8	jw89-139-a1	0.203	M ONeal Gomez	0.434	0.144	0.204	0.252	0.534	0.233	0.198
28	7/19/95	950337	9	jw89-139-a1	0.203	M ONeal Gomez	0.438	0.156	0.234	0.251		0.240	0.190
29		950338		jw89-139-a2	0.160	M ONeal Gomez							
30		960069		jw89-139-a3	0.210	pollard							
31		950334		jw89-133A 1	0.130	M ONeal Gomez							
32		950335		jw89-133A 1	0.235	M ONeal Gomez							
33		950336		jw89-133A 2	0.160	M ONeal Gomez							
34													
35													
36		950339		jw89-141a-1	0.200	M ONeal Gomez							
37		950340		jw89-141a-2	0.160	M ONeal Gomez							
38													
39													
40		960070		jw89-141a-3	0.175	pollard							
41													
42		950341		jw89-148A-1	0.230	M ONeal Gomez							
43		950342		jw89-148A-2	0.190	M ONeal Gomez							
44													
45													
46	7/20/95	950393	10	jw88-46-1-1	0.369	M ONeal Gomez	0.738	0.286	0.439	0.419	0.634	0.363	0.293
47	7/20/95	950393	11	jw88-46-1-1	0.369	M ONeal Gomez	0.831	0.309	0.399	0.407		0.423	0.276
48	7/20/95	950393	12	jw88-46-1-1	0.369	M ONeal Gomez	0.688	0.287	0.437	0.410	0.650	0.384	0.262
49		950394		jw88-46-1-2	0.380	M ONeal Gomez							
50		890005		jw88-46-1		GTF 1989							
51													
52													
53													
54	3/1/96	960142	17	jw89-163	0.447	LARGE PEAKS	0.632	0.306	0.479	0.461			
55		890040		jw89-163	0.310	39 gtf opa effects							
56													
57		890039		jw89-162	0.360	39 gtf opa effects							

	Date	Lab no	Run no	Sample	A/I hplc	Comments	Ala	Val	A/I gc	Leu	Asp	Phe	Glu
58													
59													
60	12/14/95	950515	4	jw89-170	0.385	ɔlit for hplc and gc	0.609	0.269	0.404	0.407	0.634		0.291
61	12/18/95	950515	13	jw89-170	0.385	ɔlit for hplc and gc				0.413	0.621	0.416	0.289
62	12/22/95	950515	23	jw89-170	0.385	ɔlit for hplc and gc	0.589	0.241	0.440	0.416	0.632	0.505	0.289
63	1/25/96	960060	59	jw89-170	0.370		0.614	0.271	0.377	0.413	0.629	0.453	0.320
64	1/25/96	960060	60	jw89-170	0.370		0.602	0.277	0.414	0.417	0.652		
65	1/26/96	960060	61	jw89-170	0.370		0.622	0.265	0.424	0.417	0.616		
66	1/26/96	960060	62	jw89-170	0.370			0.282	0.408	0.408	0.618	0.439	0.318
67													
68													
69													
70	1/31/96	960061	72	JW89-173	0.370		0.690	0.300	0.374	0.404	0.637	0.468	0.281
71	1/31/96	960061	73	JW89-173	0.370		0.691	0.287	0.381	0.401	0.619	0.385	0.270
72	2/14/96	960061	84	JW89-173	0.370		0.702	0.282	0.368	0.414	0.622	0.417	0.280
73		950416		JW89-173	0.360	12/95 run							
74													
75													
76													
77	5/4/95	950234	19	JW93-61-4	0.260	:ko split - moyock	0.494	0.187	0.305	0.317	[.72]	-	-
78	5/5/95	950234	21	JW93-61-4	0.260	:ko split - moyock	0.518	0.191	0.300	0.323	0.549	0.289	0.241
79	5/9/95	950234	25	JW93-61-4	0.260	:ko split - moyock	0.582	0.164	0.305	0.314	0.548	0.272	0.2695
80	5/9/95	950234	26	JW93-61-4	0.260	:ko split - moyock	0.485	0.192	0.296	0.318	0.5507	0.294	[.219]
81	5/10/95	950234	27	JW93-61-4	0.260	:ko split - moyock	0.496	0.186	0.302	0.309	oload	oload	oload
82	5/10/95	950234	28	JW93-61-4	0.260	:ko split - moyock	0.480	0.166	0.316	0.309	0.5422	0.2498	0.2053
83	2/28/96	960082	9	jw93-61-4x	0.160	ɔlit for hplc and gc	0.297	0.117	0.202	0.224	0.5356	0.174	0.1123
84	2/28/96	960083	10	jw93-61-4y inner	0.235	ɔlit for hplc and gc	0.446	0.149	0.274	0.311	0.5526	[.2064]	[.1186]
85	3/12/96	960083	47	jw93-61-4y inner	0.235	ɔlit for hplc and gc	0.427	0.159	0.244	0.312	oload	oload	.1634]
86	2/29/96	960084	11	jw93-61-4y middle		ɔlit for hplc and gc	0.373		0.185	0.220	0.4917	0.2412	0.1613
87	2/29/96	960085	12	jw93-61-4z		large peaks	0.502	0.134	0.214	0.265	oload	0.2908	0.1422
88													
89	1993	930177		jw93-61-1	0.191								
90	1993	930178		jw93-61-2	0.251								
91	1993	930179		jw93-61-3	0.229								
92	1993	930180		jw93-61-4	0.223								

Appendix III

Gomez Pit survey data, Sept. 1995

Gomez Pit Survey 9/95

Short Exposure

Bottom of Section (ref'd to H^3 on map - 2 pts on corners of outcrop)

D (m)	Elev (m MSL)
70.1	-1.16
46.6	-1.16

Top of Oyster Bed

D	Elev
45.5	0.51
53.2	0.46
59.8	0.54
65.1	0.46

TL Sites

D	Elev	
45.7	-1.03	in plane of outcrop
39.5	1.49	in cross plane ⊥
40.0	2.38	in cross plane ⊥
42.2	4.80	in cross plane ⊥

Pink Section

D	Elev
54.2	1.79
45.2	1.69
41.3	1.56
39.8	1.69

Blue Section

D	Elev
42.2	5.13
48.1	5.36
55.2	5.34
62.7	5.32

Top of Outcrop

D	Elev
54.4	8.25
48.4	8.19
44.6	7.86

Gomez Pit Survey 9/95

Long Exposure - Top of Section

D (m)	Elev (m MSL)
8.1	7.79
29.3	7.04
57.3	7.42
83.4	7.72
90.8	7.75
111.3	7.84
126.1	7.83
145.2	7.77
161.9	7.32
166.5	5.95

Pink Section

D	Elev
15.1	1.91
18.8	1.75
20.6	1.81
43.5	1.43
50.0	1.59
58.2	1.56
63.2	1.43
69.8	1.34
78.4	1.38
86.6	1.40
90.9	1.53
99.0	1.46
103.0	1.43
110.5	1.40
112.3	1.39
116.9	1.52
123.9	1.46
129.1	1.57
134.4	1.64
143.3	1.61
147.4	1.76
153.9	1.83
157.7	1.86

Blue Section

D	Elev
153.3	5.08
145.1	4.96
140.1	5.03
135.5	4.91
131.3	5.08
125.9	5.33
122.6	5.33
118.5	5.32
114.2	5.55
108.9	5.40
105.6	5.39
90.7	5.31
87.3	5.34
79.7	5.53
61.1	5.23
56.3	5.49
46.3	5.20
41.9	5.27
37.7	5.26
32.9	5.52
26.6	5.42
12.5	5.14

Green Section

D	Elev
161.7	4.16
160.6	4.14
158.6	4.06
157.9	4.09
156.1	4.09
152.3	3.67
149.5	3.93

Orange Section

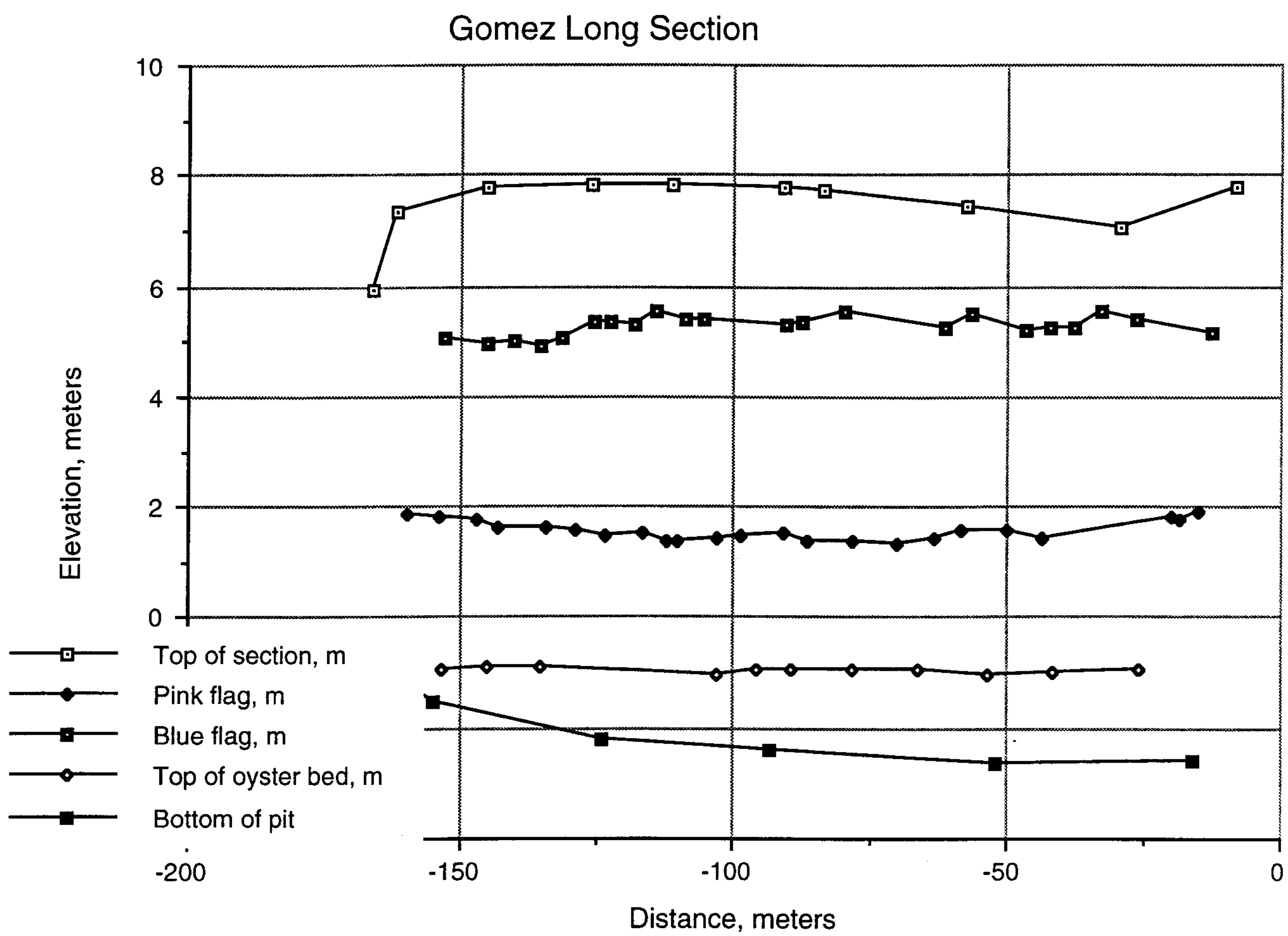
D	Elev
163.6	4.37
161.9	4.31
160.7	4.22
159.2	4.33
158.1	4.67
155.9	4.96
153.0	5.58
152.5	5.89
151.9	6.15

Top of Oyster Bed

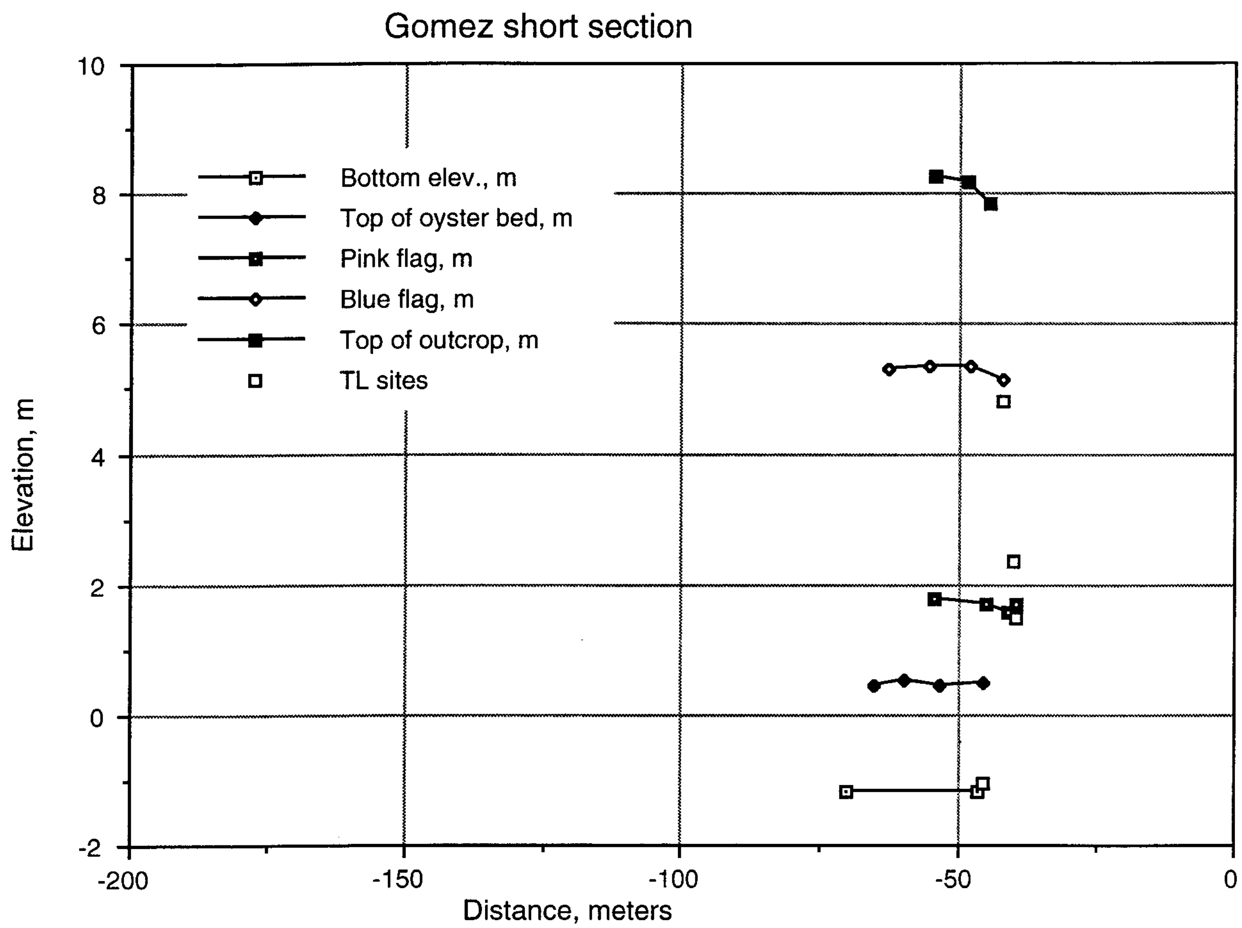
D	Elev	
153.6	-0.96	
145.2	-0.88	
135.6	-0.92	
115.8	-1.03	
103.3	-0.97	
95.8	-0.93	
89.5	-0.95	
78.2	-0.96	
66.0	-0.93	
53.3	-1.03	} JFW yel flags
41.6	-1.00	
25.8	-0.94	- corner of pit

Bottom of Pit

D	Elev
15.9	-2.58
51.7	-2.64
93.3	-2.42
124.0	-2.23
154.9	-1.54
158.4	-1.29



Gomez Long Section
10
8
6
4
2
0
Elevation, meters
Top of section, m
Pink flag, m
Blue flag, m
Top of oyster bed, m
Bottom of pit
-200
-150
-100
-50
0
Distance, meters


Gomez short section
Bottom elev., m
Top of oyster bed, m
Pink flag, m
Blue flag, m
Top of outcrop, m
TL sites
Elevation, m
10
8
6
4
2
0
-2
-200
-150
-100
-50
0
Distance, meters

Appendix IV

Thermoluminescence data, 1989 sampling, Gomez Pit

2 1 cm

0 TL 2 cm

0 TL 1 cm

0 TL 3 cm

Lux

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Fax #302-831-4158 # pages incluant celle-ci 2

Dr John Wehmiller
Dept. Geology
University of Delaware

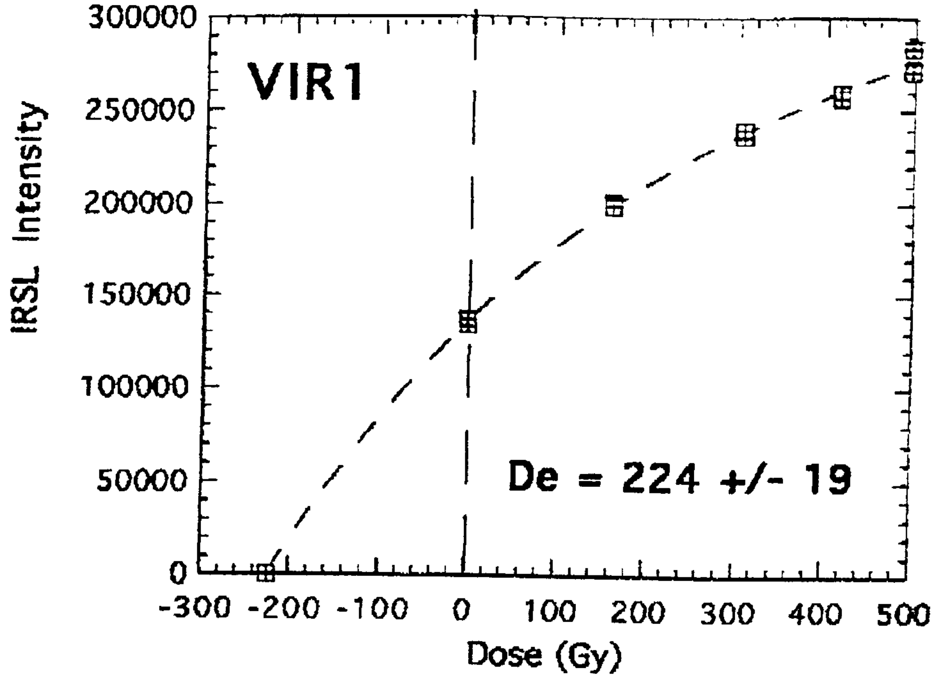
Dear John,

Thank you for your last letter and reprints. It was a good thing that you renewed contact recently since it gave me the opportunity to look at the Virginia data again. As I mentioned to you last year, the preliminary ages we obtained were a bit younger that expected. This might be due to downward percolation of fines from the top since we analyzed the so-called 4-8 µm"fine grains". I am annexing here the preliminary Infrared Stimulated Luminescence integrated growth curves. The numbers are based on several approximations, such as the alpha efficiency, the cosmic dose (~ 15 mGy/ka), and the water content (~ 25%). For VIR-2, the reproducibility was not great and also this sample has much higher U and Th abundances than the other two. Could you tell me why this is? I think that the best thing to do now is to isolate the feldspar and qaurtz sand sized grains, which we do here in routine, and measure ages on them in order to confirm or refine the data. I have realized that in our business, we have to measure ages on several types of minerals of different grain sizes in order to get the best age estimate. I will send you some of my reprints in which you will see how, I believe, we could date samples in which are evidence of "intrusion" of older or younger grains.

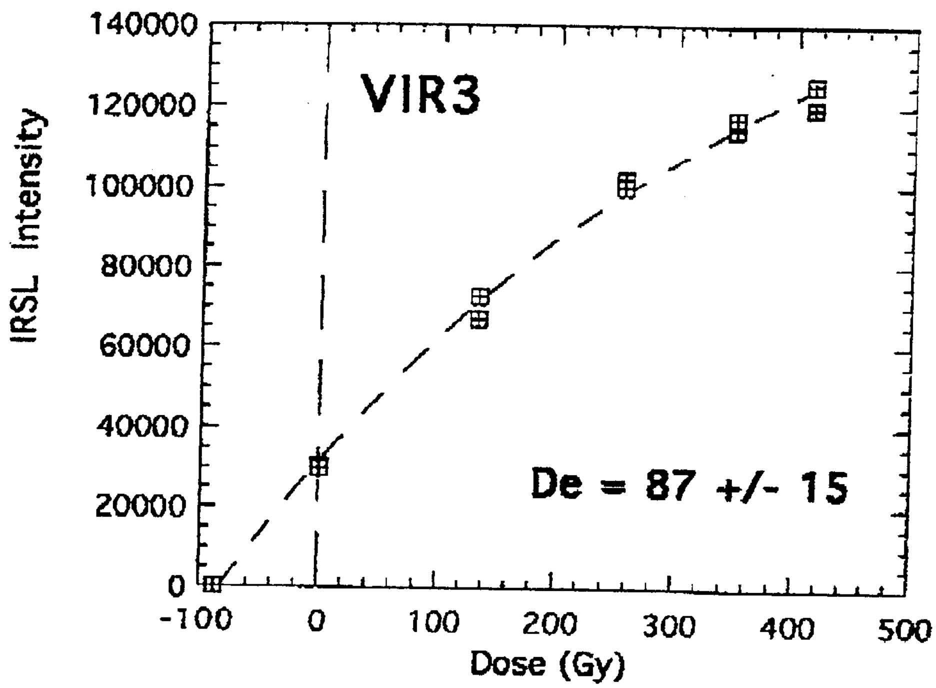
I have only a "small" problem: I do not have any money. Do you think you could participate financially in the project, for an amount of ~ CDN$ 500-1000? I could then pay one of my student assistant who would do the mineral separation and the mounting and irradiation of the sample. I am sure we could have something really solid for next spring. This project is actually very interesting in the OSL point of view since there is quite a dispute about the underestimation of ages from older interglacial sediments, this being particularly raging in Europe. Your project is a great supply of material to test the technique.

Best regards.

Michel Lamothe
Professeur



Annual Dose = 1.1 OSL Age ≈ 200ka ± 50



Annual Dose = 1.6 Age ≈ 60 ka

Reproducibility here is so and so.