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Offshore-onshore correlation of upper Pleistocene strata, New Jersey Coastal Plain to continental shelf and slope

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Abstract

High-resolution seismic reflection profiles (~1–5 m resolution), including Geopulse™, Uniboom™, minisparker, small air gun, and water gun sources, are used to trace the δ^{18}O stage 5 portion of the outcropping Cape May Formation across the shelf to the continental slope. The δ^{18}O stage 5/6 boundary identified at Ocean Drilling Project (ODP) Site 903 on the continental slope anchors the onshore-offshore seismic correlations. Above the δ^{18}O stage 5 sequence, there are distinguishable lowstand systems tracts (LST), transgressive systems tracts (TST) and highstand systems tracts (HST) that correlate with δ^{18}O stages 4 through 1. Atlantic Margin Coring Project (AMCOR) holes 6009, 6010, 6011, 6020, and 6021C provide age and paleoenvironmental indicators that agree with these correlations. The sub-arctic paleoenvironmental indicators in sequences of δ^{18}O stage 3 agree with the cooler temperatures and lower sea-level highstands of that time. Thicker δ^{18}O stage 3 and 4 sequences are preserved in the Paleo-Hudson River incised valley across the shelf. The expanded ice sheets during stage δ^{18}O 3 compared to δ^{18}O stages 1 and 5 probably increased sediment discharge in the Hudson River drainage system. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Pleistocene; NJ continental shelf; seismic stratigraphy

1. Introduction

The high-resolution seismic reflection database on the New Jersey continental shelf and slope began to accumulate on a regional scale in 1975 with the U.S.G.S. surveys aboard R/V Atlantis II. One of the authors (RES) participated on Atlantis II in the collection of excellent Uniboom™ and minisparker data (Fig. 1). Some of the results of these profiles were discussed by Dillon and Oldale (1978) in their paper on the late Pleistocene shorelines identified in the survey.

Subsequently, detailed nearshore surveys using Geopulse™ profiles correlate the Atlantis II data to the inner continental shelf upper Pleistocene seismic stratigraphy (Ashley et al., 1991; Wellner et al., 1991; Esker et al., 1996). Continuation of these nearshore Geopulse™ surveys by some of the authors (RES, JSW, DWH, and JU) has expanded the knowledge of the upper Pleistocene seismic stratigraphy.

Extending the upper Pleistocene seismic stratigraphy from the shelf to the slope used the surveys for drilling the Ocean Drilling Program (ODP) sites of Leg 150. Water gun profiles in the vicinity of ODP Site 903 on the slope (Mountain et al., 1994a) (Fig. 1) provide the ties extending the upper Pleistocene sequences from the Atlantis II data.

The geological correlations of the upper Pleistocene seismic sequences rely on the data from the 1975 Atlantic Margin Coring (AMCOR) Project of the U.S.G.S. (Hathaway et al., 1979) (Fig. 1). More

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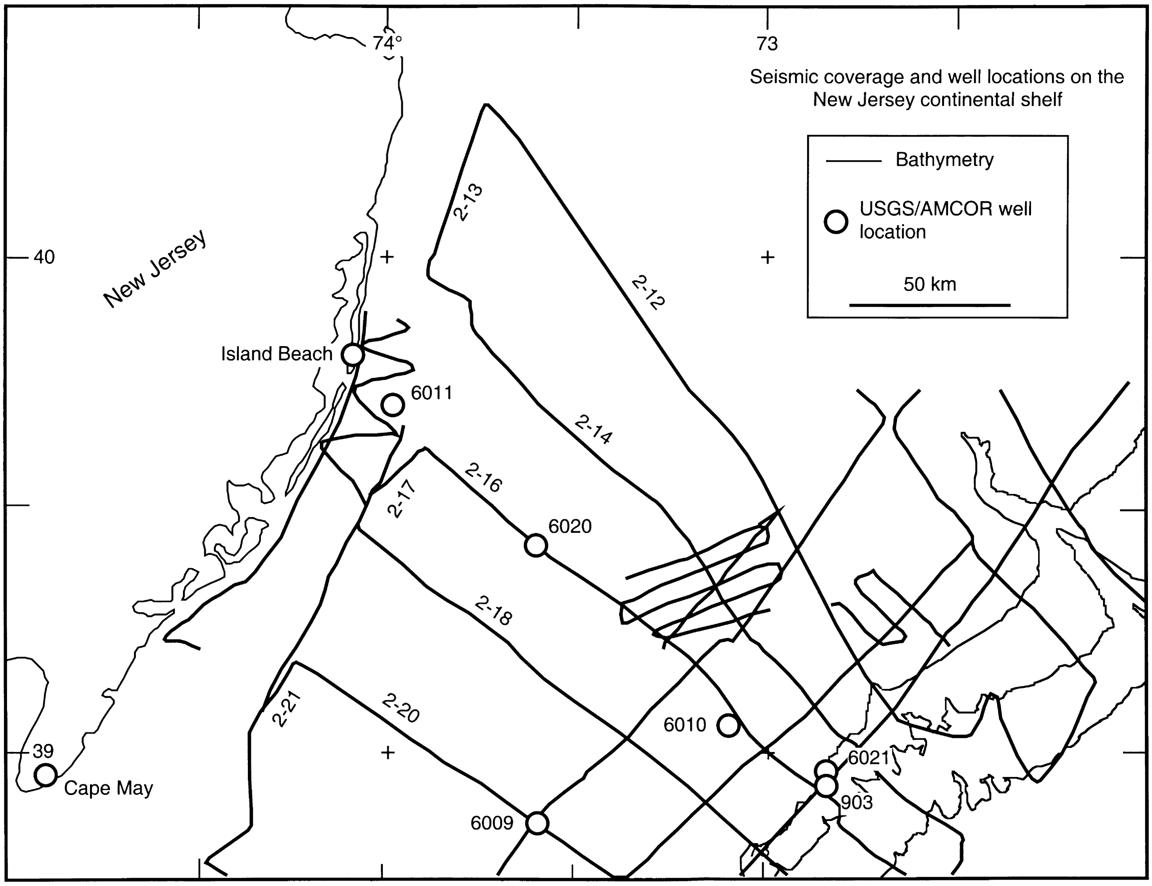

Fig. 1. Location map of regional high-resolution seismic reflection profiles on New Jersey continental shelf. Also shown are Atlantic Margin Coring (AMCOR) Project Sites 6009, 6010, 6011, 6020, and 6021, ODP Site 903, and ODP leg 150X Sites Cape May and Island Beach.

definitive age correlations of the AMCOR holes was provided by the recalibration of AMCOR hole 6021C with ODP hole 903A only 2.5 km to the south (Mountain et al., 1994b). Note that holes at particular AMCOR and ODP sites have letter designations because there are sometimes more than one hole at a site. Also, drilling of onshore New Jersey sites as part of ODP Leg 150X at Cape May and Island Beach (Miller et al., 1994,1996) (Fig. 1), produced definitive tie points for the upper Pleistocene and Holocene seismic sequences.

The objectives of this paper are to correlate the upper Pleistocene strata on the shelf and slope with existing data and to test whether the correlations yield reasonable geologic interpretations given the knowledge of Pleistocene environments and sea-level history.

2. Seismic stratigraphy

A composite cross-section from the Barnegat Inlet area to AMCOR Site 6021 (Fig. 2) is generated by compiling the results of the seismic surveys on the shelf (Fig. 1). Detailed discussion of the seismic stratigraphy and internal reflection patterns, as well as photographs of the seismic data are in Carey et al. (1998). A prominent reflector at depths of 40–100 m is traced across the shelf (labeled ≥6 in Fig. 2). In most places this is the deepest reflector seen on the profiles. In the nearshore region it forms a marked angular unconformity above southeast dipping reflectors (Tertiary and Cretaceous beds). Near the shelf edge and slope this prominent reflector is an unconformity that truncates prograding clinoforms beneath.

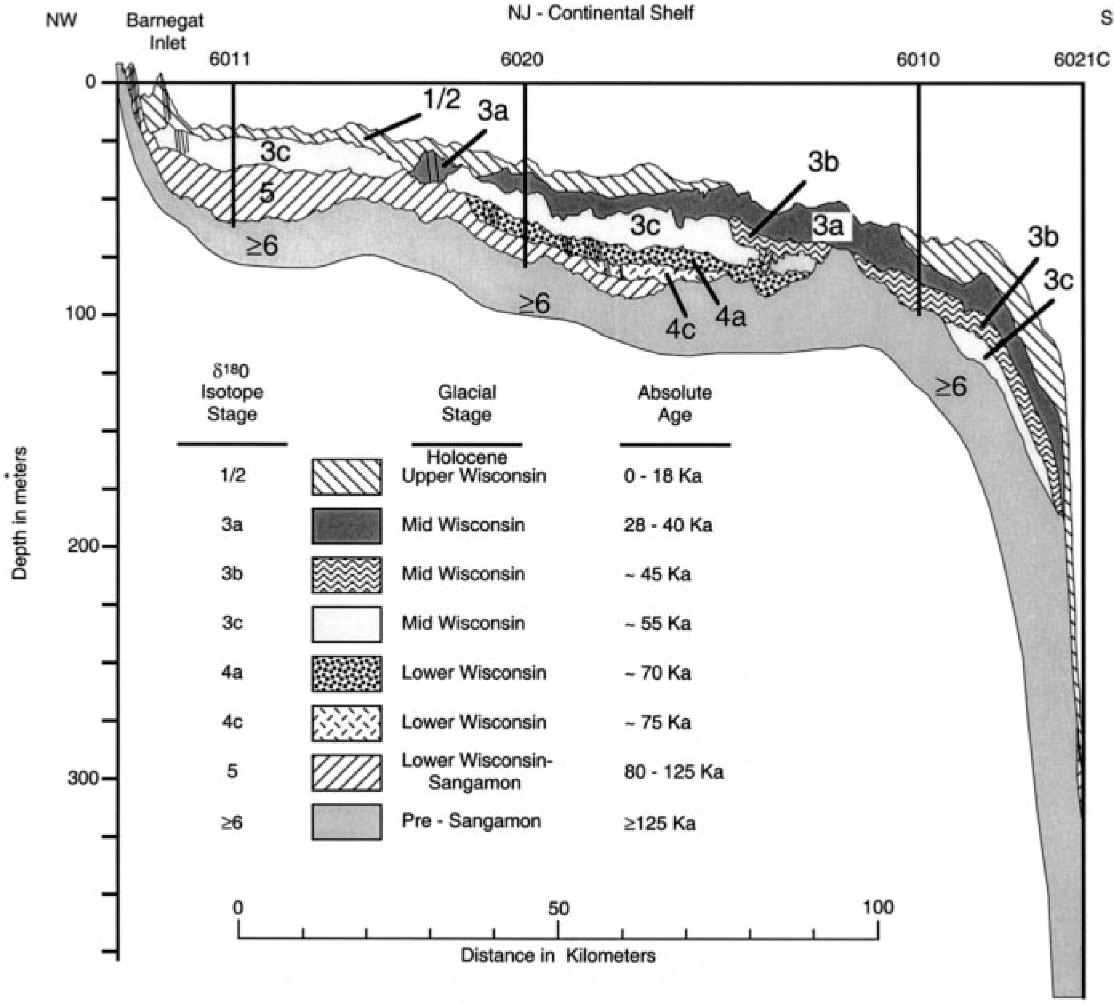

Fig. 2. Composite cross-section paralleling seismic reflection profile 2–16 across New Jersey Continental shelf from near Barnegat Inlet to AMCOR 6021 showing upper Pleistocene seismic stratigraphy.

The relief on the deepest reflector occurs as an apparent swale just southeast of AMCOR 6020 and an outer high just northwest of AMCOR 6010 (Fig. 2). The prominent reflector is traced from the outer high to depths greater than 400 m on the continental slope.

Seven unconformity-bounded seismic units (labeled 1/2; 3a; 3b; 3c; 4a; 4c; and 5 in Fig. 2) are above the deep prominent reflector. By correlating these seismic units and the internal seismic facies indicators (shoreface reflectors, prograding delta reflectors, Carey et al., 1998), the seven units are identified as individual systems tracts of four sequences.

Unit 5 has onlap seismic terminations and is traced landward to the Cape May Formation outcrop containing preserved highstand systems tract facies of δ^{18}O stage 5 (Lacovara, 1997). Lowstand deltaic features are not indicated in this unit on the shelf. It is interpreted as a transgressive to highstand systems tract.

Units 4a and 4c are similarly confined to the apparent swale in the middle of the shelf just southeast of AMCOR 6020 (Fig. 2). Both 4a and 4c show truncated prograding clinoforms (Carey et al., 1998). These units characterize forced-regression lowstand deltas formed by a river drainage terminating in the mid-shelf area controlled by the pre-existing swale topography. The unconformity between 4a and 4c is either a small fluctuation in sea-level with a transgressive surface, or a shift in the location of the deltas during a general sea-level lowstand. In either case, 4a and 4c represent lowstand systems tracts.

Unit 3c is a widespread seismic facies onlapping the outer high and continuing landward terminating in a buried shoreface indicated by seaward prograding reflectors just off Barnegat Inlet (Wellner et al., 1991) (Fig. 2). The 3c unit is therefore a transgressive to highstand systems tract.

Unit 3b is restricted to the outer shelf and slope (Fig. 2). Near its inshore limit it is confined in an incised valley where the internal seismic reflections reveal a prograding delta. The apparent dips of the prograding reflectors are compatible with a longshore infill of an incised valley by a baymouth bar, with the longshore drift to the southwest (Ashley and Sheridan, 1994). Presently, longshore drift on the New Jersey inner shelf is to the southwest (Butman et al., 1979). Controlled by the configuration of the New York Bight, the longshore drift was likely to be southwest during deposition of unit 3b. Unit 3b is a lowstand systems tract when the shoreline and baymouth was between AMCOR 6020 and 6010 (Figs. 1 and 2).

Unit 3a is another widespread seismic unit that onlaps the outer high and outcrops on the sea floor just northwest of AMCOR 6010 (Fig. 2). Unit 3a is traced landward to just northwest of AMCOR 6020 where there are seaward dipping, prograding reflectors (Fig. 2). These prograding reflectors comprise a highstand shoreface representing a transgressive to highstand systems tract.

Unit 1/2 is the youngest seismic facies tract. The unit is widespread on the inner shelf south of Barnegat Inlet and patchy north of Barnegat Inlet where Tertiary and Cretaceous Coastal Plain beds crop out. Unit 1/2 is thickest in the mid-shelf wedge just southeast of AMCOR 6020 (Fig. 2). At this location, seaward prograding piles of sediment seem to be related to the flux through the modern Hudson Shelf Valley (Knebel and Spiker, 1977). Unit 1/2 also thickens on the outer shelf at AMCOR 6010 and seaward (Fig. 2) where it constitutes the outer shelf wedge. Coastal onlap seismic terminations on the shoreline escarpment just northwest of AMCOR 6010 (Fig. 2) show that unit 1/2 is a transgressive systems tract. The seaward prograding, downlap of clinoforms of the mid-shelf wedge indicate a highstand systems tract. Taken together, unit 1/2 is a transgressive to highstand systems tract.

On the continental slope in the vicinity of AMCOR 6021 (Fig. 2), unit 1/2 is largely canyon fill onlapping the truncated surface that terminates units 3a; 3b; 3c, and buries remnants of unit 5. Here unit 1/2 includes some lowstand systems tract facies with some highstand systems tract drape (Carey et al., 1998).

Based on the seismic facies analysis, the seismic stratigraphic units belong to four sequences created by four sea-level cycles (Carey et al., 1998):

	Lowstand (m)	Highstand (m)
Sequence 4—Unit 1/2	~ -120	~ 0
Sequence 3—Units 3b; 3a	~ -60	~ -30
Sequence 2—Units 4c; 4a; 3c	~ -70	~ -20
Sequence 1—Units 5	~ -120	~ 10

3. Geologic correlations

The unit designations in Fig. 2 are associated with specific δ^{18}O isotope stages for the seismic units based on correlations developed below: Unit 1/2 was deposited in δ^{18}O stages 1 and 2; units 3a, 3b, 3c were deposited in δ^{18}O stage 3; units 4a, 4c were deposited in δ^{18}O stage 4; and unit 5 was deposited in δ^{18}O stage 5. All units beneath the prominent unconformity marked ≥6 in Fig. 2 are δ^{18}O stage 6 and older.

Numerous ^{14}C dates from Vibracores$^{\text{TM}}$ that penetrate up to 9 m beneath the sea floor provide geologic correlation of unit 1/2. Ages up to 15–16 ka are reported on the outer shelf and slope (Rine et al., 1991; Davies et al., 1992), and from 2 to 3 ka to 9 to 10 ka on the inner shelf (Ashley et al., 1991; Snedden et al., 1994) and from 2 to 3 ka to 5 to 6 ka in Coastal Plain drill holes (Miller et al., 1994,1996).

Geologic correlation of unit 3a is based on Vibracores into the outcrop of this unit on the mid-shelf (Fig. 2). Ages based on ^{14}C dates range from 28 to 45 ka (Knebel and Spiker, 1977; Davies et al., 1992).

The ages of the units 3b, 3c, 4a, 4c and 5 are based on the biostratigraphy in the AMCOR sites (Figs. 1

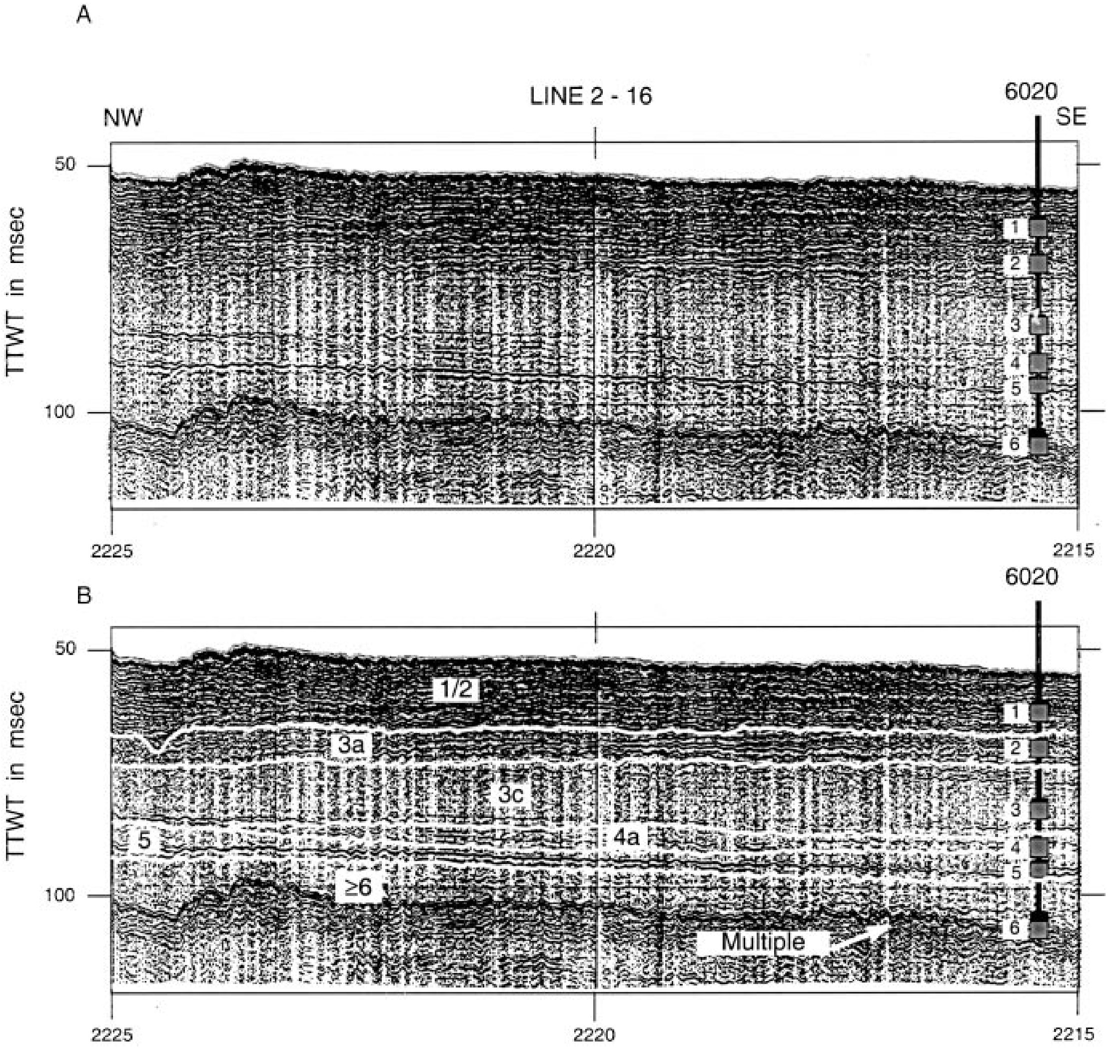

Fig. 3. (A) Uninterpreted portion of seismic reflection profile 2–16 from Atlantis II cruise correlated with AMCOR hole 6020. Numbers 2215–2225 are ship's time representing 1600 m on the horizontal scale. (B) Interpreted seismic reflection profile with seismic units 1/2; 3a; 3c; 4a; 5; and ≥6 identified.

and 2) and ODP Site 903, located 2.5 km south of AMCOR 6021 (Table 1). Sediments of δ^{18}O stage 6 and older were penetrated at AMCOR Sites 6009, 6010, 6011, 6020, and 6021 and at ODP Site 903). The sediments above the δ^{18}O stage 6 unconformity in AMCOR 6011 are reported as barren and, thus, not included in Table 1.

Drilling at AMCOR 6020 was stopped after core 6 recovered a barren fluvial gravel (Hathaway et al., 1979) just beneath the δ^{18}O stage 6 unconformity (Fig. 3). Fortunately, 6020 recovered five cores from the critical seismic units above the unconformity. A benthic Foraminifera fauna characterized by *Elphidium clavatum* exists in the sandy and muddy sediments above the gravel (Hathaway et al., 1979). This benthic fauna is found in Sites 6010, 6009, and 6021 above the δ^{18}O stage 6 unconformity giving a general correlation of the units older than Holocene and younger than δ^{18}O stages 6.

Table 1

NJ continental shelf upper Pleistocene seismic sequences correlations (a: Hathaway et al., 1979; b: Valentine in Harris, 1983; c: Groot et al., 1995; d: Mountain et al., 1994b; e: J. Wehmiller, pers. comm.)

Seismic Sequence O Isotope Age	AMCOR 6020			AMCOR 6010			AMCOR 6009			AMCOR 6021C			ODP 903A	
	Core #			Core #			Core #			Core #			Core #	
1/2	1		*Elphidium clavatum*[a]	1 --- 2	------------------	*E. clavatum*[a]				1 --- 1 --- 2 --- 3 --- 4 --- 5 --- 6	*Islandiella norcrossi* CI = 1.0[c] ---------------- *Elphidium excavatum* CI= 0.0[c] ---------------- *E. excavatum* CI = 0.0[c] ------------------- *E.excavatum* CI=0.0-0.3[c] ------------------- *E. excavatum* CI = 0.0[c] ------------------- *E.excavatum*[c] ------------------- *E. excavatum* CI = 0.0-0.3[c]	*E. clavatum*[a]	1H	
3	2 --- 3	----------------- *Astarte* D/L =0.18[e]		3 --- 4	*Emiliani huxleyi*[b] ------------------		1 --- 2 --- 3	*E. excavatum* CI = 0.4[c] ------------------- *Astarte* D/L = 0.20[e] ------------------- *E. excavatum* *Neoglobiquadrina pachyderma* (dextral) CI = -0.7[c]	*E. clavatum*[a]					
4	4						4	*E. excavatum* *N. pachyderma* (dextral) CI = 0.4-0.6[c]						
5	5	unknown[c] D/L = 0.21								7	CI = 1.0[c]		1H	*E. huxleyi* (ACME)[d]
≥6	6	(barren gravel)		5	*Pseudo-emiliani lacunosa*[b] *Cyclocardia*[c] D/L = 0.27 0.35 (stage 12)		5 --- 6	CI = 0.3[c] -------------------- unknown D/L = 0.66 0.67 0.62 CI = 0.0[c] (stage 17-21?)		8	CI = 0.5[c] *E. clavatum* *Globobulimina ariculata* *Nonionella atlantica* diatoms[a] (stage 6)		2H ------- ------- 10H	*E. huxleyi*[d] (stage 6) ----------------- ----------------- *E. huxleyi* (FAD)[d] (stage 8)

a. Hathaway et al., 1979
b. Valentine in Harris, 1983
c. Groot et al., 1995
d. Mountain et al., 1994b
e. J. Wehmiller, pers. comm.

Work by Groot et al. (1995) on the benthic and planktonic Foraminifera from AMCOR Sites 6009 and 6021, while not age diagnostic, provide paleoenvironmental constraints. The environmentally sensitive Foraminifera in Sites 6009 and 6021 generally agree with climate indices (CI in Table 1) based on pollen (Groot et al., 1995). Correlating climate variations with the δ^{18}O isotope stages of cooling and warming, Groot et al. (1995) assign geologic ages to the cores at 6009 and 6021. We have modified their correlations in Table 1.

The dominance of the benthic Foraminifera *Islandiella norcrossi* with a CI of 1.0 in the upper part of core 1 of 6021C indicates a δ^{18}O stage 1 (Holocene) age. The lower part of core 1 has an *Elphidum excavatum* fauna and a CI of 0.0 indicating the cooling of Pleistocene δ^{18}O stage 2. Cool conditions (*E. excavatum*, CI = 0.0–0.3) are inferred for cores 2 through 6 of 6021C that we correlate with seismic unit 1/2 (Fig. 2, Table 1). Core 7 of 6021C has a CI of 1.0 indicating warm conditions; we interpret this as a remnant of stage 5 sediments. At a depth of core 8, Hathaway et al. (1979) report a change to a deeper water fauna which includes *E. clavatum* along with *Globibulimina ariculata*, *Nonionella atlantica*, and diatoms. This change agrees with the seismic data that show the cores above 8 are from transported canyon fill, with displaced shallow water fauna. Below core 8, prograding reflectors indicate continental slope drape deposits. Core 8 is at the depth of the δ^{18}O stage 6 unconformity traced from the shelf at AMCOR 6010 and from ODP 903. The AMCOR 6021C logs show that bulk density also increases at this depth. Moreover, the CI change to 0.5 indicates a cool environment (Groot et al., 1995) that supports a δ^{18}O stage 6 age for core 8.

The δ^{18}O stage 6 unconformity is traceable to ODP site 903 (Mountain et al., 1994a,b) where it lies between the lower part of core 1H of 903A (*Emiliani huxleyi* (acme)) and core 2H (the δ^{18}O stage 5/6 boundary) (Table 1). The occurrence of *E. huxleyi* from core 2H through core 10H (*E. huxleyi* first appearance datum (FAD), δ^{18}O stage 8) determines a linear sedimentation rate confirming the depth of the δ^{18}O stage 5/6 boundary between core 1H and 2H. The seismic correlation to the faunal change and density increase at core 8 in AMCOR 6021C anchors the δ^{18}O stage 6 unconformity as interpreted on seismic data from the shelf (Figs. 2 and 3).

Another nannofossil constraint is provided at AMCOR 6010 (Fig. 4). The *Pseudoemiliani lacunosa* last appearance datum (LAD) (δ^{18}O stage 12) is found in core 5 beneath the stage 6 unconformity (Valentine in Harris, 1983), while *E. huxleyi* is found in core 3, correlated seismically to δ^{18}O stage 3 (Table 1). Thus, the hiatus at the δ^{18}O stage 6 unconformity is longer at Site 6010 compared to Site 6021. Seaward prograding Pleistocene units are progressively cut out from the slope to the shelf, so older units are penetrated at Site 6010 (Mountain et al., 1994a). This conforms to the seismic observations of truncated clinoforms beneath the δ^{18}O stage 6 unconformity.

Even greater truncation is evident in association with δ^{18}O stage 6 at AMCOR 6009 (Table 1). In core 6 below the δ^{18}O stage 6 unconformity, the amino acid racemization (AAR) D/L ratio for an unknown shell fragment is reported as 0.66, 0.67, 0.62 (Groot et al., 1995). If the racemization is similar to the kinetics of *Mercenaria*, then this indicates a Pleistocene age as old as δ^{18}O stage 17–21. Above the δ^{18}O stage 6 conformity at AMCOR 6009, cores 1 through 4 are correlated seismically with δ^{18}O stages 3 and 4. The *Elphidium excavatum* fauna and the CIs of −0.7 to 0.6 indicate a cool sub-arctic environment, as do the *Neoglobiguadrina pachyderma* (dextral) Foraminifera in cores 3 and 4 (Groot et al., 1995). These cool environments are compatible with δ^{18}O stages 3 and 4 based on correlations to the global δ^{18}O record.

The AAR data for the AMCOR sites supports the correlations in Table 1. Core 5 of 6010, dated as δ^{18}O stage 12 by the nannofossil *P. lacunosa*, has a *Cyclocardia* shell with D/L of 0.27, 0.35. This D/L is compatible with δ^{18}O stage 12 if the kinetics of *Cyclocardia* is like that of *Mercenaria* (Groot et al., 1995). Another AAR D/L ratio of 0.21 on an unknown shell fragment in core 5 of 6020 is comparable to δ^{18}O stage 5 ratios for *Mercenaria*, which fits our seismic correlations (Fig. 3). In core 3 of 6020, an *Astarte* shell has D/L ratio of 0.18 (J. Wehmiller, pers. comm.). We correlate this with the stage 3 seismic sequence (Figs. 2 and 3). Also, another *Astarte* shall fragment from core 2 of 6009 (Table 1) has an AAR D/L of 0.20 (J. Wehmiller, personal communication). Core 2 of 6009 is also seismically correlated to the

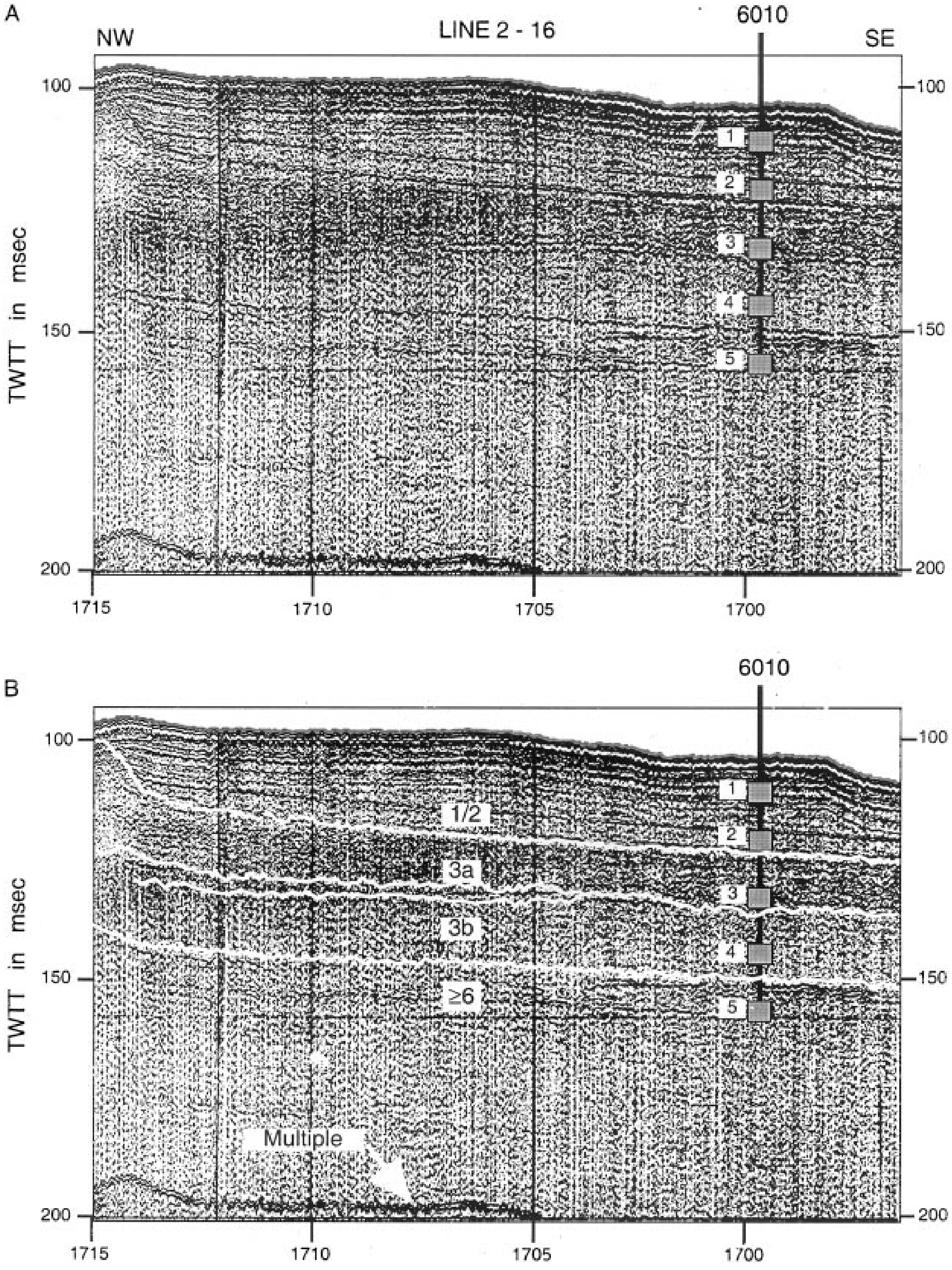

Fig. 4. (A) Uninterpreted portion of seismic reflection profile 2–16 from Atlantis II cruise correlated with AMCOR hole 6010. Numbers 1700–1715 are ship's time representing 2430 m on the horizontal scale. (B) Interpreted seismic reflection profile with seismic units 1/2; 3a; 3b; and ≥6 identified.

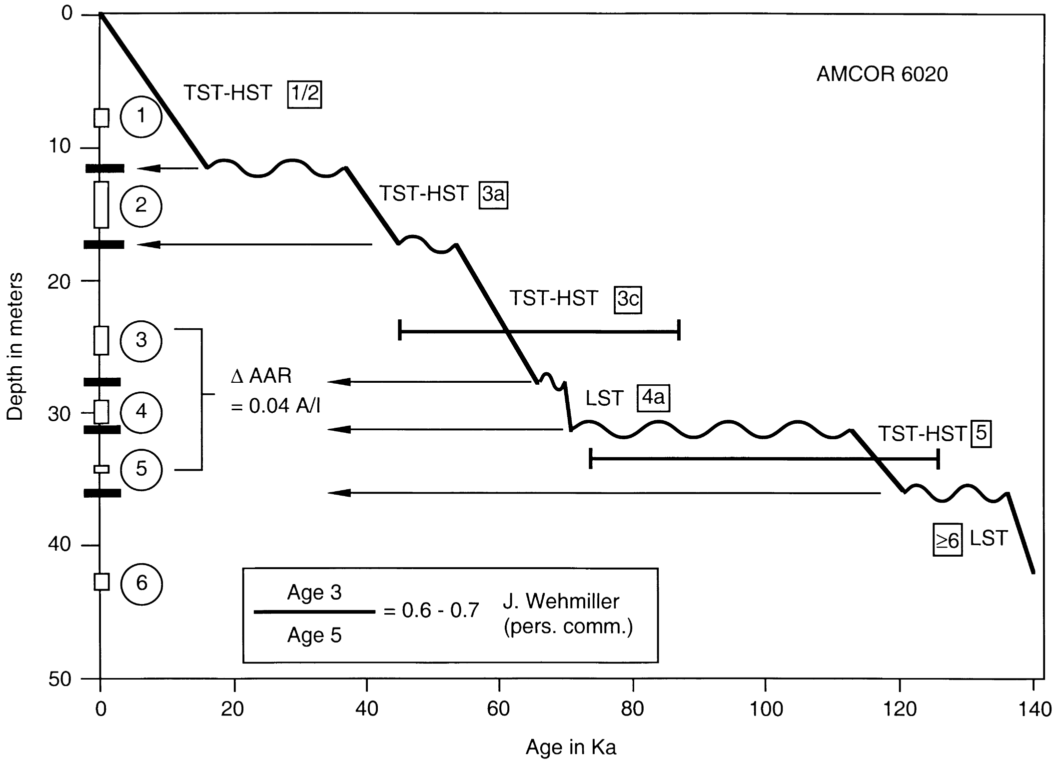

Fig. 5. Age correlations of cores (circled numbers) from AMCOR 6020 showing seismic sequence (boxed numbers) tract designation (LST, TST, HST, lowstand, transgressive and highstand systems tracts, respectively). Differences in amino acid racemization (AAR) ratios and age ranges for cores 5 and 3 shown (J. Wehmiller, pers. comm.).

δ^{18}O stage 3 sequence. The difference in AAR ratios between core 3 and core 5 of AMCOR 6020 indicates that the age of core 3 is 60–70% of the age of core 5 (J. Wehmiller, pers. comm.). If the core 5 AAR of 0.21 is δ^{18}O stage 5 (80–125 ka), then the AAR of core 3 could be δ^{18}O stage 3 or 4 (45–85 ka) (Fig. 5). We correlate core 3 with the lower part of δ^{18}O stage 3 (55–70 ka) which is compatible with the AAR dating.

4. Discussion

Correlations of the seismic sequences (Table 1) yield reasonable sedimentation rates and hiatuses at Site 6020 (Fig. 5). The age range of unit 1/2 is best known because of the numerous ^{14}C dates in Vibracores. Using the unit 1/2 sedimentation rate (~70 cm/kyr) as typical of the transgressive to highstand system tract, and applying that to the older upper Pleistocene sequences, an estimate of the hiatuses is made. The sedimentation rate for the lowstand system tracts (150–300 cm/kyr), taken from the Pleistocene in hole 903A (Mountain et al., 1994a,b), is higher than that for the transgressive to highstand tracts (Fig. 5). Hiatuses range from about 5 to 30 kyr.

One of the longer hiatuses occurred during the δ^{18}O stage 2 lowstand, which is reasonable given the longer duration of that sea-level fall to over the shelf edge at −120 m. Another long hiatus occurred between deposition of the δ^{18}O stage 5 and stage 4 sediments (Fig. 5). This may be due to the long interval (80–125 ka) of sea-level highstand during δ^{18}O stage 5. Entrapment of sediments in highstand estuaries and starvation of the shelf, coupled with a long interval of shelf erosion, can explain this hiatus.

Knebel et al. (1979) discovered a buried incised river valley during mapping of the upper Pleistocene seismic sequences in the mid-shelf area off New Jersey. This occurs in what we call units 3a and 3b deposited in δ^{18}O stage 3 (Fig. 2). The map of this incised valley shows the thalweg trending southeast across the shelf from the general direction of the mouth of the Hudson River. Knebel et al. (1979) named this incised valley the Paleo-Hudson River.

The composite cross-section of the upper Pleistocene seismic sequences across the New Jersey shelf (Fig. 2) is oblique to the southeast trend of the Paleo-Hudson River thalweg. This geometry distorts the view of the valley topography and appears as the swale enclosing units 4a and 4c (Fig. 2). These 4a and 4c forced-regression lowstand deltas formed at the mouth of the Paleo-Hudson River drainage during δ^{18}O stage 4. Thus, the Paleo-Hudson River drainage across the shelf trended southeast during both δ^{18}O stages 3 and 4, and the mouth of the Hudson was in the mid shelf area during that time (Carey et al., 1998).

Carey et al. (1998) noted that what we call units 3a, 3b, 3c, 4a, and 4c are thicker in the Paleo-Hudson River drainage than deposits of units 1/2 and 5 (Fig. 2). These units were deposited in δ^{18}O stages 4 and 3 (75 ka to about 30 ka) in about a 45 kyr interval. This contrasts with the thinner unit 5, deposited during δ^{18}O stage 5 in about 45 kyr, and the thin unit 1/2, deposited in the last 18 kyr. Unit 1/2 should be about 40% of units 3a, 3b, 3c, 4a, and 4c if the sedimentation rates were the same, but this is not the case; the thickness of unit 1/2 is only about 15% of the δ^{18}O stage 3 and 4 unit thickness.

An explanation for these differences lies in the paleoenvironmental indicators in the δ^{18}O stages 3 and 4 deposits (Table 1). The presence of *Neogloboquadrina pachyderma* (dextral) and pollen climate indices of -0.7 to 0.6 indicate sub-arctic conditions in New Jersey and on the continental shelf during δ^{18}O stages 3 and 4. Indeed, the global δ^{18}O record indicates cooler global temperatures and generally lower sea levels during δ^{18}O stage 3 and 4 than today. Sub-arctic conditions in New Jersey are consistent with the δ^{18}O data.

The lower sea-level highstands in δ^{18}O stage 3 (~ -20 to -30 m) indicate that the polar ice sheets did not retreat as far as today, or as far as δ^{18}O stage 5 when sea levels were higher than today. Also, the lower sea levels of the lowstands of stages δ^{18}O 3 and 4 (~ -60 to -70 m) indicate that the polar ice sheets did not advance as far as they did in δ^{18}O stages 2 and 6. Consequently, glacial ice did not reach New Jersey in δ^{18}O stages 3 and 4 as it did in δ^{18}O stages 2 and 6. Thus, δ^{18}O stage 3 and 4 environments in New Jersey were sub-arctic versus arctic in δ^{18}O stages 2 and 6.

During δ^{18}O stages 2 and 6, the ice sheet covered the entire present drainage of the Hudson River, and sediment discharge by braided streams formed a gravel plain on the New Jersey shelf. Erosion of the exposed shelf bypassed sediments to the continental slope and rise. During δ^{18}O stages 3 and 4, the drainage area of the Paleo-Hudson River was different than today, with greater amounts of glacial melt water from closer ice sheets discharging southeast, and soil and vegetation conditions more conducive to erosion. Sub-arctic conifer forests prevailed in δ^{18}O stages 3 and 4 with shallow root systems and thin soils, compared to today's deep rooted deciduous forests. It is reasonable that higher sedimentation rates occurred in δ^{18}O stages 3 and 4 under these conditions. This led to the favorable preservation of the δ^{18}O stage 3 and 4 deposits in the Paleo-Hudson River drainage on the New Jersey continental shelf.

5. Conclusions

1. Upper Pleistocene strata (δ^{18}O stages 5–1) are traced from the Coastal Plain to the continental slope using seismic reflection data.
2. Four sequences are identified with LST, TST, and HST seismic facies tracts.
3. Microfossils from AMCOR Sites 6009, 6010, 6020, 6021, and ODP Site 903 provided age and paleoenvironmental indicators.
4. Sub-Arctic conditions during δ^{18}O stages 3 and 4 favored increased sediment discharge in the Paleo-Hudson River drainage and preferential preservation of these age sediments in the incised river drainage on the New Jersey continental shelf.

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