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22. MAGNETOSTRATIGRAPHY OF LOWER EOCENE TO LOWER MIOCENE SEDIMENTS IN CORES FROM THE NEW JERSEY COASTAL PLAIN[1]

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ABSTRACT

This paper describes the magnetostratigraphy of lower and middle Eocene, lower and upper Oligocene, and lower Miocene terrigenous sediments recovered in three on shore borecores on the New Jersey coastal plain (Island Beach, Atlantic City, Cape May Sites; Ocean Drilling Program Leg 150X). Near-shore, terrigenous sediments are quite often very weakly magnetized. Thus, to improve the practical measuring sensitivity of the magnetometer, I have taken high-volume (120 cm^3), whole-round samples from these cores. Most samples were alternating-field (AF) demagnetized to 50 mT in a large-diameter solenoid, and pilot samples from Island Beach were thermally demagnetized. At two of the three Leg 150X sites (Island Beach and Atlantic City), magnetic field polarity reversals are found in Oligocene and Eocene passive margin sequences bounded by disconformities (sequence boundaries). There are also two short, lower Miocene sections at the Cape May Site that have a series of polarity reversals. In limited stratigraphic sections, where biostratigraphic (planktonic foraminifers, calcareous nannofossils) and Sr-isotope data are available, correlations are made to the geomagnetic polarity time scale. These data help to date sediments at discrete stratigraphic levels in the cores and to estimate the duration of hiatuses at sequence boundaries.

INTRODUCTION

As part of the New Jersey Transect (Miller and Mountain, 1994), the overall goal of Ocean Drilling Program (ODP) onshore Leg 150X is to examine the response of sedimentation on the passive margin to glacioeustatic changes. Magnetostratigraphic studies at ODP Leg 150 Sites 903 and 904 have provided useful age data for Miocene sediments on the New Jersey upper slope (Van Fossen and Urbat, 1996). In this study, I extend the magnetostratigraphy of terrigenous sediments landward into upper shelf paleoenvironments. The integrated biostratigraphy, Sr-isotope stratigraphy, and magnetostratigraphy of Leg 150X helps set the stage for future offshore drilling on the middle and outer shelf (e.g., ODP Leg 174A), which will then give a more complete series of dated sections on the New Jersey passive margin (Miller and Mountain, 1994).

A difficulty facing magnetostratigraphy in the passive margin setting is that near-shore marine deposition is very often interrupted by relatively abrupt breaks in sedimentation (disconformities) brought on by changes in sea level and/or sediment influx from the continent. Consequently, one must extract magnetostratigraphic records from relatively short sections of sediments (sequences) bounded by major breaks in lithology (sequence boundaries). In addition, rapidly varying sedimentation rates will hinder attempts at the simple matching of polarity reversal patterns to the geomagnetic polarity time scale (GPTS). Thus, the key to making age assignments based on the GPTS is to perform "integrated stratigraphy" by incorporating all available methods of characterizing and dating sediments (i.e., physical stratigraphy, biostratigraphy, and Sr-isotope stratigraphy). The Berggren et al. (1995) GPTS is used in this study, and, where identified, reversal boundaries are referenced to onsets or terminations of magnetochrons using the suffixes "O" or "T," respectively.

The intensity of remanent magnetism in terrigenous sediments is often very weak owing to the high energy of deposition of the paleoenvironment. However, recent magnetostratigraphic studies have improved on the success rate in this environment by simply increasing the volume of material per sample, and thereby increasing the magnetic signal-to-noise ratio (Miller et al., 1990, 1993; Van Fossen and Urbat, 1996). Another strategy in these studies has been to sample the passive margin by way of continental or deep-sea drilling, which eliminates problems apparently related to weathering in outcrops (Ellwood et al., 1986). In this study, these methods are extended to three onshore sites of Leg 150X (Island Beach, Atlantic City, and Cape May). By way of large-volume sampling, I have been able to recover magnetostratigraphies from weakly magnetized lower and middle Eocene, lower and upper Oligocene, and lower Miocene terrigenous sediments.

MAGNETOSTRATIGRAPHY

Paleomagnetic samples from cores of Leg 150X are mainly whole-round samples (4.32-cm diameter) with a nominal volume of 120 cm^3, i.e., twenty times that of the conventional ODP paleomagnetic sample. This amounts to a twenty-fold increase in signal-to-noise ratio on the cryogenic magnetometer, and I estimate that such an increase improves the practical sensitivity of magnetization intensity to better than 0.01 mA/m. Similarly, at Sites 903 and 904 of Leg 150, quarter-core samples 42 cm^3 in volume were used to improve the measurement sensitivity level (Van Fossen and Urbat, 1996). The data from those samples formed the basis of the magnetostratigraphy, replacing virtually all of the shipboard pass-through data, which was marred by a core liner magnetization and spurious magnetizations attributed to drilling slurry. Terrigenous sediments are often coarsely grained and the detrital and chemical sources of the iron-oxide grains can be mixed. Thus depositional processes in the near-shore paleoenvironment can result in a very "inefficient" remanent magnetization. A large-volume sample can also help overcome this problem by providing a more representative sample of the magnetization in the sediment. The magnetizations in the terrigenous sediments of Leg 150X were in general very weak, and the success of measurement indeed depended on a greater sample size. There were, however, limited sections at the Island Beach (IB) and Cape May (CM) sites where intensities were strong enough to be sampled with the conventional 6-cm^3 sample.

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The paleomagnetism laboratory at the Lamont-Doherty Earth Observatory (LDEO) is equipped with a large-volume alternating-field (AF) demagnetization coil in which samples up to ~300 cm^3 can be demagnetized to 50 mT. Two large-access ovens with internal fields <10 nT are also available for thermal demagnetization. These apparatus enable the decomposition of the natural remanent magnetization (NRM) to reveal the most stable component of magnetization in individual samples. All measurements of magnetic remanence were made on a 2G cryogenic three-axis magnetometer. Measurement and demagnetization experiments were conducted within a shielded room with a nominal field of ~200 nT. In each sample, the most stable magnetization vector was identified through analysis of demagnetization data in orthographic projection. The method of least-squares analysis (Kirschvink, 1980) was applied to the demagnetization trajectories to calculate least-squares best-fitting vectors, with inclination forming the basis of polarity determination. An estimate of the percentage of total variance in the selected data and an intensity of the best-fit magnetization vector are also provided by the least-squares analysis. These parameters are used in evaluating the data.

Island Beach Site (Site IB)

Site IB is located at 39°48′N, 74°05′W in Island Beach State Park, New Jersey, at a mean elevation of 3.7 m (Fig. 1). Drilling to 1223 ft (372.8 m) recovered 1060 ft (323.1 m) of core. The lower Miocene Kirkwood Formation could not be sampled, because it was generally unconsolidated at Site IB, and drilling with the Christensen small-diameter system did not begin until 453 ft (138.1 m; Miller et al., 1994b). Paleomagnetic work begins in the upper Oligocene Atlantic City Formation (505–693 ft [153.9–211.2 m]) where the sediments are more lithified and suitable for sampling. At Site IB, a portion of the sample collection was subjected to thermal demagnetization as a check on AF treatments. The sample chosen for thermal demagnetization in most cases has a nearby AF-treated sample (usually within 2 ft [0.6 m]) for a better comparison of the two methods. In all cases, thermal demagnetization confirmed the AF results, although treatments beyond about 500°C induced spurious magnetizations in the samples, probably the result of magnetochemical alteration during heating.

Magnetization intensities are fairly strong (1–10 mA/m) in the dark green, glauconitic clayey sands of the lower Oligocene (Sewell Point Formation, 602–697 ft [183.5–212.4 m]), but reduce to 0.01 mA/m at the base of the section, where the sediments become dark gray to black and more lignite-rich (656–697 ft [199.9–212.4 m]). AF-demagnetization experiments suggest a single component of magnetization throughout the Oligocene section (Fig. 2), and only three samples were rejected owing to non-interpretable demagnetization profiles. The data suggest three polarity zones in the Oligocene section between depths of 523.1 and 658.5 ft (159.4 and 200.7 m).

The lowermost Oligocene (Sewell Point Formation) and middle to upper Eocene (Absecon Inlet Formation) at Site IB were sampled from 693.5 to 789.9 ft (211.4–240.7 m). These glauconitic clays, silty clays, and clayey sands are generally weakly magnetized (~0.01 mA/m; Table 1). A number of samples were either too weak to measure or gave inconsistent directions of magnetization during progressive demagnetization; however, the data from seven samples were salvaged and indicate a relatively thick zone of reversely magnetized sediments (Table 1). In the upper part of this zone, the inclination of remanence is relatively shallow, usually less than 25°. The primary reversed component of magnetization may be contaminated by a normal polarity overprint that is often incompletely removed from the total magnetization in samples from this section.

Demagnetization of sandy glauconite clay from the middle Eocene Shark River Formation (800–862 ft [243.8–262.7 m]) yields a relatively weak (0.01 mA/m), but very consistent magnetization. I eliminated data from the four samples that were taken in the upper, more glauconitic part of the Shark River Formation (800–825 ft [243.8–251.5 m]) where the direction of magnetization behaved very erratically during laboratory treatment. Below a disconformity at 862 ft (262.7 m), greenish gray clay and sandy clay of the lower Eocene Manasquan Formation are also relatively weakly magnetized, yet yield very consistent and straightforward demagnetization profiles (Fig. 3; Table 1). Sample B870.0 demonstrates thermal demagnetization of a fine sandy clay (Fig. 3). In the Manasquan Formation and Shark River Formation above, zones of reversed and normal polarity magnetization are present throughout, and there is little evidence for contamination by any secondary magnetization.

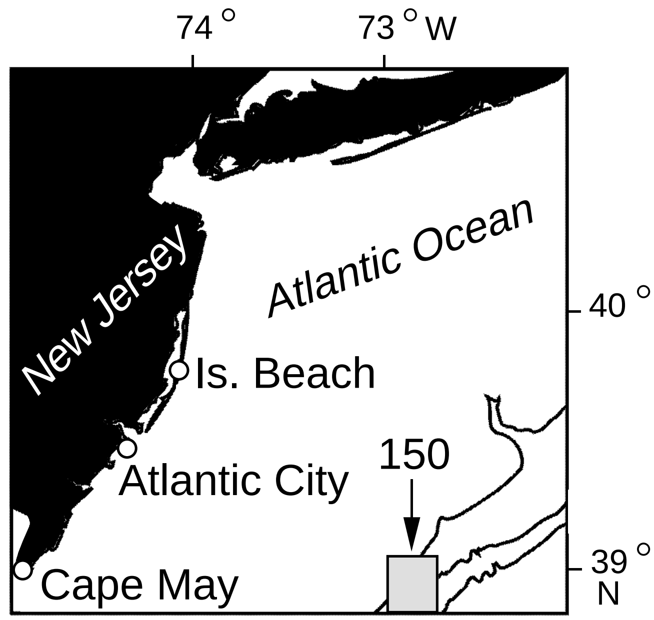

Figure 1. Location map of the New Jersey Coastal Plain and Leg 150X sites at Island Beach, Atlantic City, and Cape May. Square indicates ODP Leg 150 study area.

Below the contact at 1076 ft (328.0 m), sampling was possible only in scattered sections where the core material was not disturbed by drilling. Samples from upper Paleocene sediments (1076–1167 ft [328.0–355.7 m]) are mainly normal in polarity, but two samples at 1119.0 ft (341.1 m) and 1128.6 ft (344.0 m) are reversely magnetized (Table 1). I have also measured a reversed polarity magnetization in two samples from the upper Cretaceous Navesink Formation (1197.6 and 1219.5 ft [365.0 and 371.7 m]). Although it was not possible to develop a magnetostratigraphy in these sediments, the data suggest that these pre-Eocene New Jersey Coastal Plain formations have the potential to record an ancient magnetization.

In summary, at Site IB I have progressively AF demagnetized and analyzed 118 whole-round and standard 6-cm^3 samples, 29 of which were omitted from magnetostratigraphic analysis owing to a weak and/or non-interpretable magnetization. Based on the data from the remaining 89 samples, I incorporated the biostratigraphic and Sr-isotope data from Site IB to make correlations to the GPTS.

A polarity transition occurs at 549.95 ft (167.6 m), roughly in the middle of the upper Oligocene Atlantic City Formation at Site IB (Fig. 2). In their reexamination of the planktonic foraminifers, Pekar et al. (Chapter 15, this volume) judge this section as reworked and note the Sr-isotope date of 24.3 Ma at 520 ft (158.5 m; Sugarman et al., Chapter 12, this volume). Thus the previous age assignment of these sediments to Zone P20–P21a (Miller et al., 1994b) is probably too old. In addition, Pekar et al. (Chapter 15, this volume) have made a cross correlation to Zone P22 sediments at Site CM by way of gamma-ray logs, suggesting the Atlantic City Formation at Island Beach is also latest Oligocene in age. Unfortunately, there is no subdivision of Zone P22

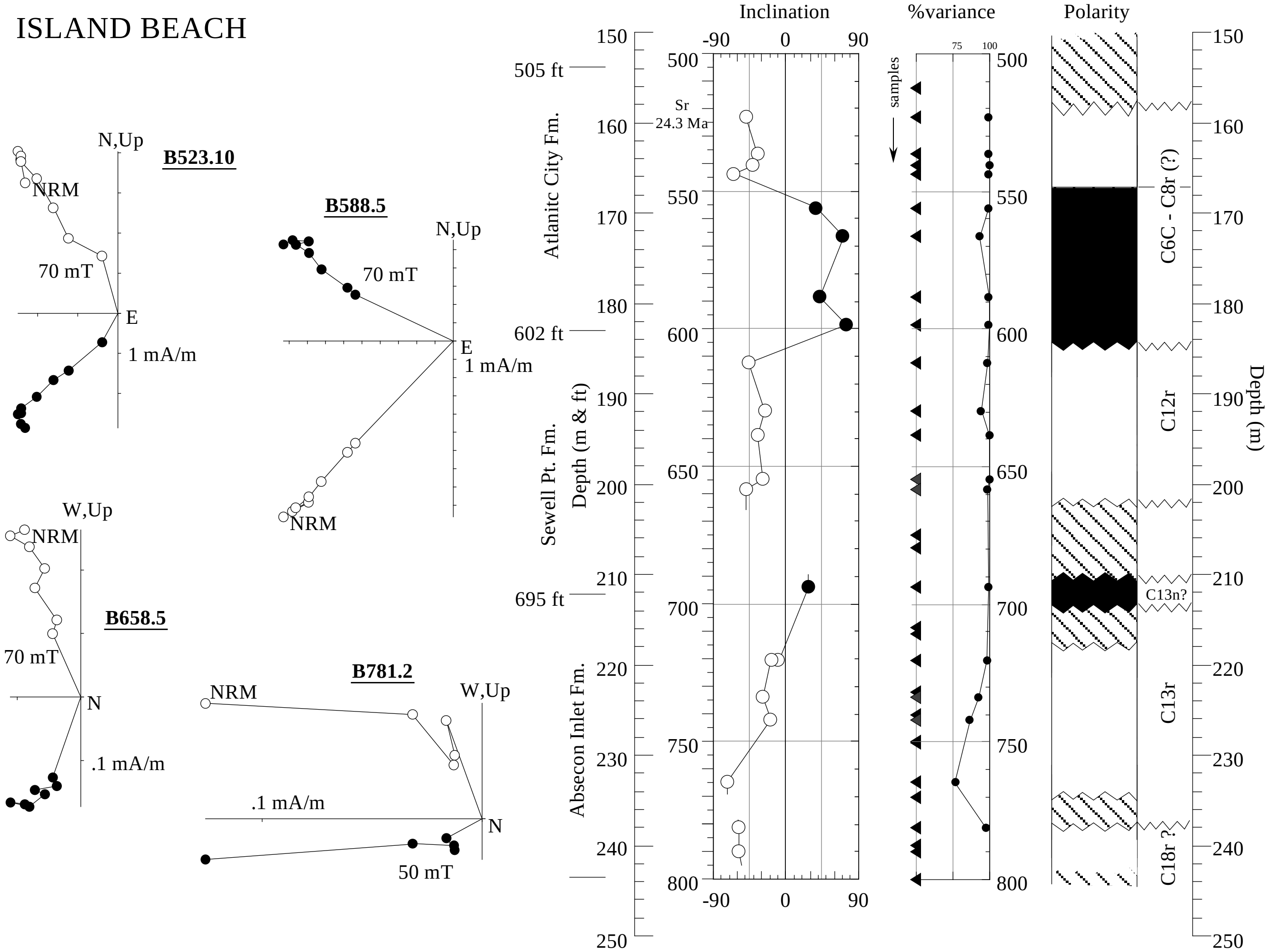

Figure 2. Progressive AF demagnetization and magnetostratigraphy of samples from Site IB (500–800 ft [152.4–243.8 m]). Demagnetization profiles in orthographic projection are shown at left (closed/open symbols = horizontal/vertical projection, mT = millitesla). Inclination of remanence vs. depth shown on right along with percent variance (triangles give location of discrete samples). Polarity interpretation (black = normal, white = reverse, hatch = uninterpretable).

or available nannofossil data from this section. Also, the simple polarity zonation of reverse (523.10–549.95 ft [159.4–167.6 m]) and normal (549.95–598.30 ft [167.6–182.4 m]) is insufficient to venture a precise correlation to the GPTS. These polarity zones can correlate to any late Oligocene chron from C6C to C8r.

Below the disconformity at 602 ft (183.5 m), the lower Oligocene Sewell Point Formation has been assigned to planktonic foraminifer Zone P19 (Miller et al, 1994b, Pekar et al., Chapter 15, this volume). Therefore, the thick zone of reversed polarity between 612 and 659 ft (186.5 and 200.8 m) at Site IB is likely to correlate to Chron C12r, a relatively lengthy period of reversed magnetic field polarity (~2 m.y.) in the early Oligocene, according to the GPTS. Sr-isotope dates from this section range from 32.7 to 33.1 Ma (Sugarman et al., Chapter 12, this volume) and agree with an assignment to Chron C12r. Thus, given the Oligocene chronology at Site IB, it is suggested that the disconformity at 602 ft (183.5 m) between the Atlantic City and Sewell Point Formations represents a hiatus of roughly 6 m.y.

A precise planktonic foraminiferal zonation is not available for the upper Eocene Absecon Inlet Formation due to the absence of *Cribrohantkenina inflata* (Miller et al., 1994b). However, M.-P. Aubry (pers. comm., 1995) has assigned the glauconitic silty clay section between 710 and 752 ft (216.4 and 229.2 m) to calcareous nannoplankton Zone NP19/20. It is therefore suggested that the reversed polarity zone between 720.5 and 764.5 ft (219.6 and 233.0 m) correlates to the older half of Chron C13r (although a correlation to C15r is also possible).

Between the depths of 800 and 900 ft (243.8 and 274.3 m), sediments within the lower Shark River Formation (middle Eocene) and upper Manasquan Formation (lower Eocene) were deposited in a rapid series of five passive margin sequences (E4 through E8, Browning et al., Chapter 16, this volume). These sequences are identified primarily through lithostratigraphy and benthic foraminiferal biofacies. The identification of five polarity intervals between 835 and 930 ft (254.5 and 283.5 m) and nannofossil data (M.-P.Aubry, pers. comm., 1995) help in determining precise ages of sediments and durations of hiatuses represented by the sequence boundaries (see Table 2; Fig. 3). Nannofossils at 840 ft (256.0 m) indicate Zone NP15c (M.-P. Aubry, pers. comm., 1995), and therefore the normal polarity interval above sequence Boundary E5/6 (846 ft [257.9 m]) is probably Chron C20n. Below 851 ft (259.4 m), down to the disconformity at 857 ft (261.2 m; Miller et al., 1994a; M.-P.Aubry, pers. comm., 1995), three samples define Chron C21n partim (Table 2; Fig. 3). Based on the GPTS, an age of 46.3 Ma is assigned to the sediments at a depth of 851.00 ft (C21n termination) and 49.6 Ma to the sediments at 867.75 ft (264.5 m; C22n onset; see Table 2). Chron 21r is missing from this section; thus, the sequence boundaries at 857 and 862 ft (261.2 and

Table 1. Progressive demagnetization data used in constructing Site IB (Island Beach) magnetostratigraphy.

Sample name	Depth (m)	N	Var (%)	Dec (°)	Inc (°)	First (mT)	Last (mT)	Jcomp (mA/m)
150X-IB-								
B523.10	159.44	5	99.7	223.8	–48.7	20.0	70.0	5.0783
B536.50	163.53	5	98.9	105.4	–34.2	20.0	70.0	2.5750
B540.30	164.68	7	99.9	305.1	–41.4	100.0	400.0	9.9070
B543.60	165.69	7	99.4	317.7	–64.8	20.0	80.0	3.8917
B556.30	169.56	5	99.4	216.5	37.0	20.0	70.0	3.2417
B566.20	172.58	5	93.0	198.9	69.6	20.0	70.0	1.8767
B588.50	179.37	4	99.7	310.8	41.0	20.0	50.0	4.5200
B598.30	182.36	4	99.2	291.3	74.2	20.0	50.0	6.5067
B612.15	186.58	7	98.7	95.2	–45.6	20.0	80.0	14.5383
B629.90	191.99	7	93.8	211.7	–25.0	100.0	400.0	1.9017
B638.30	194.55	7	99.9	159.9	–34.3	20.0	80.0	5.3083
B654.80	199.58	6	99.8	316.6	–29.0	5.0	70.0	0.2321
B658.50	200.71	6	98.8	115.1	–48.7	5.0	70.0	0.0268
B693.50	211.38	4	99.1	133.3	27.9	35.0	50.0	0.0158
B720.50	219.61	3	98.3	98.4	–10.0	30.0	50.0	0.0263
B733.60	223.60	6	91.9	110.3	–28.3	7.5	40.0	0.0435
B742.00	226.16	5	86.6	230.2	–18.8	30.0	50.0	0.0368
B764.50	233.02	6	76.4	329.9	–72.4	20.0	50.0	0.0404
B781.20	238.11	4	97.9	150.6	–59.2	20.0	50.0	0.0576
B789.90	240.76	1	-	165.0	–58.6	40.0	40.0	0.0103
B840.50	256.18	5	93.0	177.7	62.1	10.0	50.0	0.0164
B844.40	257.37	4	98.8	145.3	48.7	20.0	50.0	0.0303
B844.80	257.50	6	93.6	156.2	22.2	5.0	50.0	0.0321
B848.00	258.47	5	97.1	197.4	–10.6	5.0	40.0	0.0159
B850.00	259.08	7	84.8	117.4	–57.5	200.0	480.0	0.0852
B852.00	259.69	6	84.1	247.5	32.9	5.0	40.0	0.0097
B855.00	260.60	5	99.4	97.6	34.4	5.0	40.0	0.0238
B857.15	261.26	5	98.1	137.7	52.6	5.0	40.0	0.0208
B859.85	262.08	5	96.2	243.4	38.6	5.0	40.0	0.0159
B864.30	263.44	4	99.3	213.8	50.8	20.0	50.0	1.1191
B866.30	264.05	5	98.3	292.8	52.9	5.0	40.0	0.0355
B869.20	264.93	4	97.7	217.7	–40.0	20.0	50.0	0.0562
B870.00	265.18	7	65.5	18.2	–52.0	200.0	480.0	0.0071
B871.30	265.57	4	81.8	267.4	8.6	30.0	50.0	0.0052
B871.90	265.76	6	99.8	276.3	16.9	15.0	50.0	1.6674
B873.45	266.23	6	97.8	238.6	–1.3	10.0	50.0	0.0162
B875.40	266.82	4	99.8	69.3	–18.5	30.0	50.0	0.0095
B876.75	267.23	5	96.3	177.1	55.7	7.5	50.0	0.0317
B885.30	269.84	5	98.0	77.6	10.8	7.5	50.0	0.0179
B888.25	270.74	5	96.0	160.8	12.2	7.5	50.0	0.0273
B889.50	271.12	6	62.6	228.7	18.8	250.0	480.0	0.0037
B907.00	276.45	5	96.6	215.6	25.1	10.0	50.0	0.0230
B922.60	281.21	4	88.3	282.6	54.0	20.0	50.0	0.0197
B934.30	284.77	1	-	43.3	–54.4	50.0	50.0	0.0142
B940.80	286.76	4	86.0	234.3	9.1	20.0	50.0	0.0554
B944.10	287.76	3	91.5	270.5	–58.0	40.0	50.0	0.0113
B947.20	288.71	3	99.4	192.8	68.7	30.0	50.0	0.0570
B955.50	291.24	4	90.3	214.6	–31.9	20.0	50.0	0.0323
B963.00	293.52	7	99.2	347.7	–37.9	300.0	480.0	0.6910
B969.50	295.50	4	94.8	218.7	–12.8	20.0	50.0	0.0177
B972.00	296.27	5	95.8	187.6	–53.0	10.0	50.0	0.0353
B974.00	296.88	4	94.7	68.9	62.1	20.0	50.0	0.0145
B976.00	297.48	5	79.6	120.1	38.2	10.0	50.0	0.0188
B978.60	298.28	4	97.9	335.6	74.4	20.0	50.0	0.0164
B982.40	299.44	4	97.3	211.4	21.2	20.0	50.0	0.0235
B982.90	299.59	5	94.7	336.4	–48.4	330.0	450.0	0.0032
B983.40	299.74	6	95.9	337.4	–18.0	30.0	50.0	0.0093
B984.60	300.11	5	88.8	315.0	45.3	10.0	50.0	0.0455
B986.60	300.72	5	74.2	67.3	69.1	10.0	50.0	0.0203
B991.00	302.06	4	95.6	228.9	77.2	20.0	50.0	0.0492
B994.75	303.20	5	94.3	332.2	63.9	20.0	50.0	0.0253
B1000.80	305.04	6	62.1	163.9	34.5	300.0	450.0	0.0160
B1006.25	306.70	4	99.1	143.6	29.7	10.0	50.0	0.0521
B1010.30	307.94	4	83.5	356.0	73.8	20.0	50.0	0.0126
B1012.50	308.61	4	98.7	124.1	39.4	20.0	50.0	0.0268
B1017.60	310.16	4	99.4	205.7	28.0	10.0	50.0	0.0403

262.7 m) form a concatenated normal interval of C21n partim and C22n partim (Fig. 3). Based on the GPTS, these breaks in sedimentation represent a cumulative hiatus of at least 1 m.y., but no greater than 3 m.y. M.-P. Aubry (pers. comm., 1995) has also identified Zone NP12 (879–955 ft [267.9–291.1 m]), and therefore I identify the thick normal polarity interval down to 930 ft (283.5 m) as Chron C23n. The top of C23n is unfortunately truncated by sequence Boundary E3/E4 at 876 ft (267.0 m).

Following a 20-ft (6.1 m) zone of uncertain polarity zonation, the series of early Eocene magnetochrons continues with Chron C23r (partim) from 955 to 973.0 ft (291.1–296.6 m; Fig. 3). I have made this assignment based on planktonic foraminifers that suggest the sediments above 975 ft (297.2 m) are no older than Zone P7 (Miller et al., 1994b) and the calcareous nannofossils (M.-P.Aubry, pers. comm., 1995), which extend Zone NP12 down to a depth of 955 ft (291.1 m). I also identify Chron C24n between 973.0 and 1018.8 ft (296.6 and 310.5 m; Fig. 3), based on the nannofossil evidence that indicates that Zone NP10 does not begin until the depth of 1022 ft (311.5 m). The thin reversed polarity zone (982.65–984.00 ft [299.5–299.9 m]) is assigned to a composite of Subchrons C24n.1r and C24n.2 (52.54–52.79 Ma; see Table 2).

Atlantic City Site (Site AC)

The Atlantic City Site (Site AC) is located at 39°22′N, 74°25′W in the Atlantic City Coast Guard Station at a mean elevation of 1.5 m (Fig. 1). Drilling to 1452 ft (442.6 m) recovered 977 ft (297.8 m) of core, and paleomagnetic sampling began at 808 ft (246.3 m). Howev-

Table 1 (continued).

Sample name	Depth (m)	N	Var (%)	Dec (°)	Inc (°)	First (mT)	Last (mT)	Jcomp (mA/m)
B1020.40	311.02	3	99.3	288.6	–42.9	30.0	50.0	0.0290
B1024.65	312.31	4	99.6	304.4	–45.4	20.0	50.0	0.1633
B1027.00	313.03	6	95.0	172.4	–18.6	20.0	50.0	0.0437
B1028.80	313.58	4	95.8	108.4	–28.5	20.0	50.0	0.0406
B1032.60	314.74	4	68.7	296.1	76.6	20.0	50.0	0.0278
B1034.90	315.44	4	87.5	184.7	–58.8	20.0	50.0	0.0408
B1038.40	316.50	4	85.4	191.7	42.8	20.0	50.0	0.0284
B1042.50	317.75	5	92.0	299.3	–50.0	200.0	360.0	0.0075
B1043.20	317.97	4	96.0	160.7	32.2	20.0	50.0	0.0469
B1062.90	323.97	6	97.1	25.6	12.0	10.0	50.0	0.0244
B1069.50	325.98	4	99.4	221.1	–66.2	20.0	50.0	0.0567
B1090.50	332.38	4	98.2	146.3	51.8	20.0	50.0	0.0616
B1110.50	338.48	4	95.4	174.5	61.8	20.0	50.0	0.0443
B1119.00	341.07	4	93.3	192.2	–11.1	250.0	360.0	0.0537
B1128.60	344.00	4	93.4	223.3	–38.1	20.0	50.0	0.0245
B1132.40	345.16	5	83.7	194.7	24.9	10.0	50.0	0.0408
B1148.90	350.18	5	95.5	180.8	63.3	10.0	50.0	0.0581
B1150.30	350.61	4	88.9	259.1	36.5	20.0	50.0	0.0303
B1158.50	353.11	6	93.6	227.6	21.3	200.0	390.0	0.0421
B1170.20	356.68	4	90.7	223.6	60.7	20.0	50.0	0.1338
B1188.70	362.32	4	99.0	37.3	25.9	20.0	50.0	0.0698
B1197.60	365.03	7	95.7	110.0	–45.9	150.0	390.0	0.1239
B1219.50	371.70	6	96.9	322.4	–61.1	150.0	360.0	0.0491

Note: N = number of data used in each least–squares analysis; Var = percentage of the total variance in the selected data accounted for by the least–squares vector (dash indicates variance calculation not applicable); Dec, Inc = declination and inclination of the magnetization vector; First, Last = first and last demagnetization step in millitesla; Jcomp = intensity of least-squares magnetization.

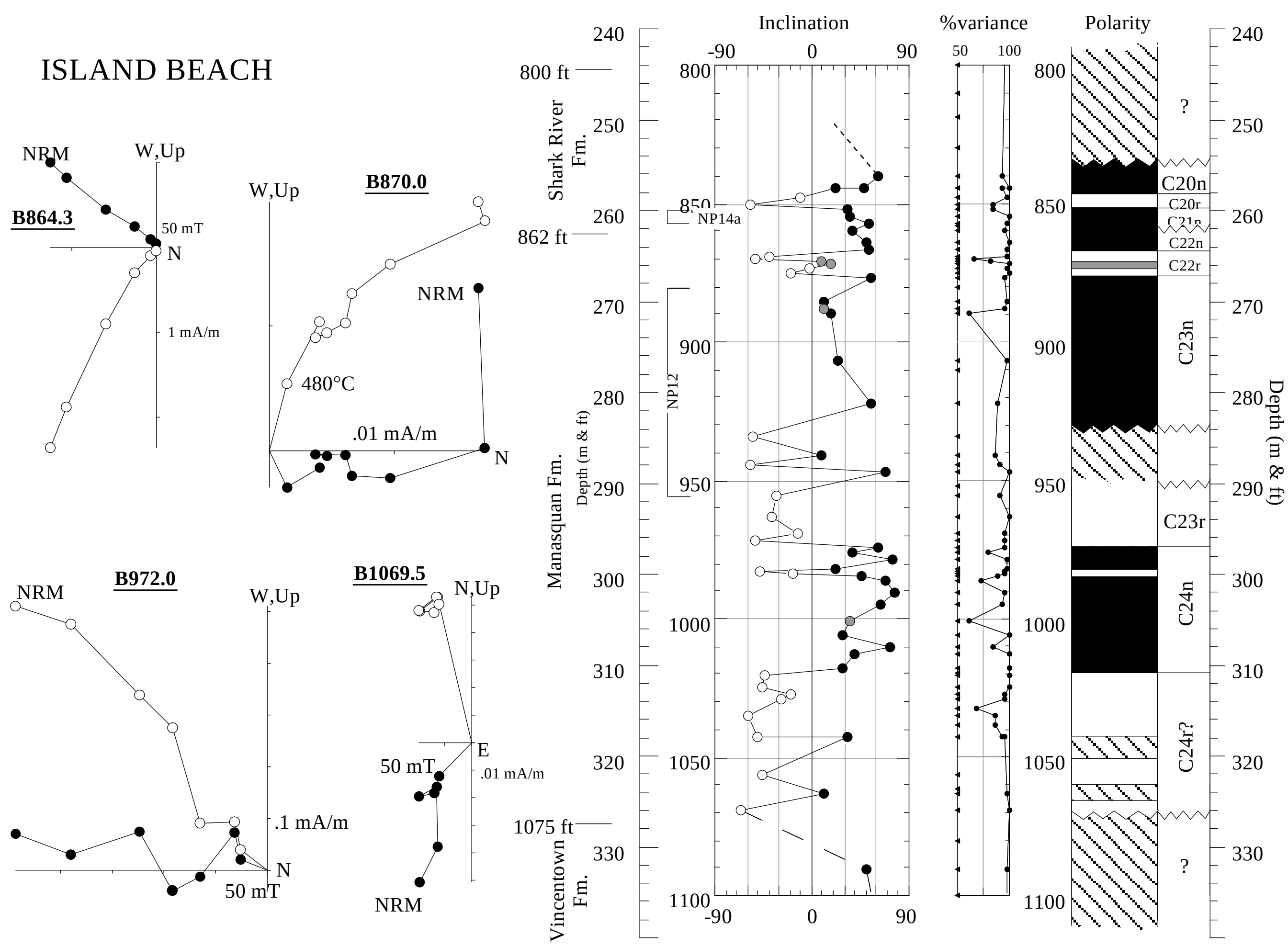

Figure 3. Progressive AF demagnetization and magnetostratigraphy of samples from Site IB (800–1100 ft [243.8–335.3 m]). Demagnetization profiles in orthographic projection are shown at left (closed/open symbols = horizontal/vertical projection, mT = millitesla). Inclination of remanence vs. depth shown on right along with percent variance (triangles give location of discrete samples). Polarity interpretation (black = normal, white = reverse, hatch = uninterpretable).

Table 2. Progressive demagnetization data used in constructing Site AC (Atlantic City) magnetostratigraphy.

Sample name	Depth (m)	N	Var (%)	Dec (°)	Inc (%)	First (mT)	Last (mT)	Jcomp (mA/m)
150X–AC–								
A808.50	246.43	4	99.1	299.8	–62.5	20.0	50.0	0.1054
A919.00	280.11	4	99.9	122.8	–42.1	20.0	50.0	1.9957
A1000.50	304.95	4	99.9	203.3	51.3	20.0	50.0	7.1105
A1054.60	321.44	4	99.9	216.8	55.0	20.0	50.0	0.6413
A1079.40	329.00	4	100.0	217.3	–19.8	20.0	50.0	1.4224
A1148.30	350.00	3	93.4	212.3	57.0	30.0	50.0	0.0608
A1177.00	358.75	3	87.5	55.6	–14.1	30.0	50.0	0.0106
A1202.40	366.49	5	97.4	160.8	30.5	10.0	50.0	0.1132
A1207.00	367.89	2	96.8	115.9	31.3	40.0	50.0	0.0567
A1212.50	369.57	6	97.4	147.6	43.4	10.0	50.0	0.0814
A1216.45	370.77	6	95.7	146.8	36.9	10.0	50.0	0.0797
A1221.60	372.34	5	98.5	208.4	55.5	10.0	50.0	0.0641
A1225.20	373.44	6	97.4	85.2	20.2	10.0	50.0	0.0836
A1236.50	376.89	6	97.0	193.7	29.4	10.0	50.0	0.0851
A1239.00	377.65	4	95.2	273.6	65.2	20.0	50.0	0.0247
A1244.50	379.32	6	96.2	153.6	45.3	10.0	50.0	0.0603
A1249.00	380.70	6	92.7	184.1	26.6	10.0	50.0	0.0628
A1254.50	382.37	6	94.1	229.2	41.9	10.0	50.0	0.0622
A1260.45	384.19	5	98.3	159.3	43.3	10.0	50.0	0.1093
A1267.75	386.41	5	92.4	317.2	–34.2	10.0	50.0	0.1187
A1270.65	387.29	5	97.5	178.3	43.1	10.0	50.0	0.0892
A1275.20	388.68	5	97.6	222.3	30.7	10.0	50.0	0.0775
A1280.20	390.20	5	98.3	213.2	38.7	10.0	50.0	0.1118
A1285.45	391.81	5	97.4	268.8	62.0	10.0	50.0	0.0850
A1289.80	393.13	6	96.4	153.3	43.8	10.0	50.0	0.0584
A1296.65	395.22	4	98.0	252.0	41.7	20.0	50.0	0.0244
A1300.40	396.36	6	95.0	20.5	64.1	10.0	50.0	0.0549
A1305.10	397.79	5	96.1	293.6	66.5	10.0	50.0	0.0320
A1310.85	399.55	5	99.4	127.1	–41.4	10.0	50.0	0.0812
A1316.50	401.27	5	96.9	233.8	50.9	10.0	50.0	0.0594
A1319.40	402.15	4	96.7	134.0	48.6	20.0	50.0	0.0279
A1320.40	402.46	5	87.6	71.2	46.6	10.0	50.0	0.0472
A1324.60	403.74	5	97.3	219.9	54.6	10.0	50.0	0.0547
A1330.90	405.66	5	89.6	159.8	62.8	10.0	50.0	0.0310
A1337.35	407.62	5	99.2	67.7	45.2	10.0	50.0	0.0304
A1344.20	409.71	5	99.1	120.5	50.3	10.0	50.0	0.0270
A1349.10	411.21	5	98.9	168.4	55.4	10.0	50.0	0.0322
A1350.10	411.51	5	97.8	124.2	84.0	10.0	50.0	0.0284
A1356.40	413.43	5	96.9	145.1	50.5	10.0	50.0	0.0198
A1360.20	414.59	5	93.9	174.9	63.7	10.0	50.0	0.0136
A1365.50	416.20	5	96.3	266.6	9.6	10.0	50.0	0.0257
A1372.90	418.46	5	64.7	269.7	73.7	10.0	50.0	0.0151
A1378.80	420.26	3	82.9	155.8	–17.6	30.0	50.0	0.0200
A1383.35	421.65	5	99.5	241.4	–63.6	10.0	50.0	0.1402
A1387.40	422.88	5	96.1	22.8	58.7	10.0	50.0	0.0365
A1394.30	424.98	5	82.9	92.4	58.4	10.0	50.0	0.0247
A1400.30	426.81	5	95.5	171.9	64.1	10.0	50.0	0.0263
A1405.50	428.40	5	79.2	128.9	67.1	10.0	50.0	0.0198
A1410.70	429.98	5	97.6	282.7	52.1	10.0	50.0	0.0322
A1416.70	431.81	5	91.6	260.8	52.4	10.0	50.0	0.0312
A1420.40	432.94	2	71.7	253.8	–12.1	30.0	50.0	0.0089
A1424.60	434.22	1	?	56.8	–19.1	40.0	50.0	0.0069
A1430.60	436.05	1	?	91.7	–5.5	40.0	50.0	0.0302
A1436.90	437.97	5	98.7	117.0	50.3	10.0	50.0	0.0184
A1440.44	439.05	5	96.9	136.7	66.4	10.0	50.0	0.0128

Note: N = number of data used in each least–squares analysis; Var = percentage of the total variance in the selected data accounted for by the least–squares vector (dash indicates variance calculation not applicable); Dec, Inc = declination and inclination of the magnetization vector; First, Last = first and last demagnetization step in millitesla; Jcomp = intensity of least-squares magnetization.

er, because of the poor recovery rate down to 1050 ft (320.0 m) at Site AC, I could only sample the lowermost Kirkwood and uppermost Atlantic City Formations in limited locations. Although there are relatively strong and stable magnetizations present in the various sediment types within these sections, the wide distribution of samples makes it difficult to make any assessment in terms of magnetostratigraphy.

Below the disconformity at 1181 ft (360.0 m), silty clays of the Absecon Inlet Formation yield very consistent directions during progressive AF demagnetization (Fig. 4). None of the samples from this interval were rejected on the grounds of poor data quality. The intensity of magnetization ranges from 0.01 to 0.1 mA/m, and although this 130-ft (39.6 m) section is almost entirely normal in polarity, two reversed polarity magnetizations at 1267.75 and 1310.85 ft (386.4 and 399.5 m) suggest that these sediments record an ancient magnetization.

From the disconformity at 1333 ft (406.3 m) to the bottom of the Site AC core (1452 ft [442.6 m]) in shelly clays of the middle Eocene Shark River Formation, the intensity of magnetization hardly varies and is on the order of 0.01 mA/m (Table 3). Most of the 21 samples from this section yield straightforward demagnetization profiles (Fig. 4), although in a few samples secondary overprints were found. One part of this section, in particular from 1422 to 1431 ft (433.4–436.2 m), appears to contain a primary magnetization of reversed polarity that has been significantly contaminated by a steep normal downward overprint perhaps related to drilling (Fig. 4). In such samples, the net magnetization moves from the lower to upper hemisphere during progressive AF treatment from NRM to the limit of 50 mT. I interpret these data as indirect evidence for a reversed magnetization.

In summary, at Site AC, 59 whole-round samples have been progressively AF demagnetized and analyzed. Correlations to the GPTS were made based on the data from the 48 samples below the disconformity at 1181 ft (360.0 m) and the biostratigraphic data from Site AC. It is very difficult to assign a magnetochronology to the thick, predominantly normal polarity interval within the upper Eocene Absecon Inlet Formation (1200 ft [365.8 m] to disconformity at 1325 ft [403.9 m], Fig. 4) and Shark River Formation below. In general, the sediments at a depth of 1181 ft (360.0 m) are no younger than Zone P17, as suggested by the planktonic foraminifer data (Miller et al., 1994a). Calcareous nannofossils indicate that Zone NP19/20 extends

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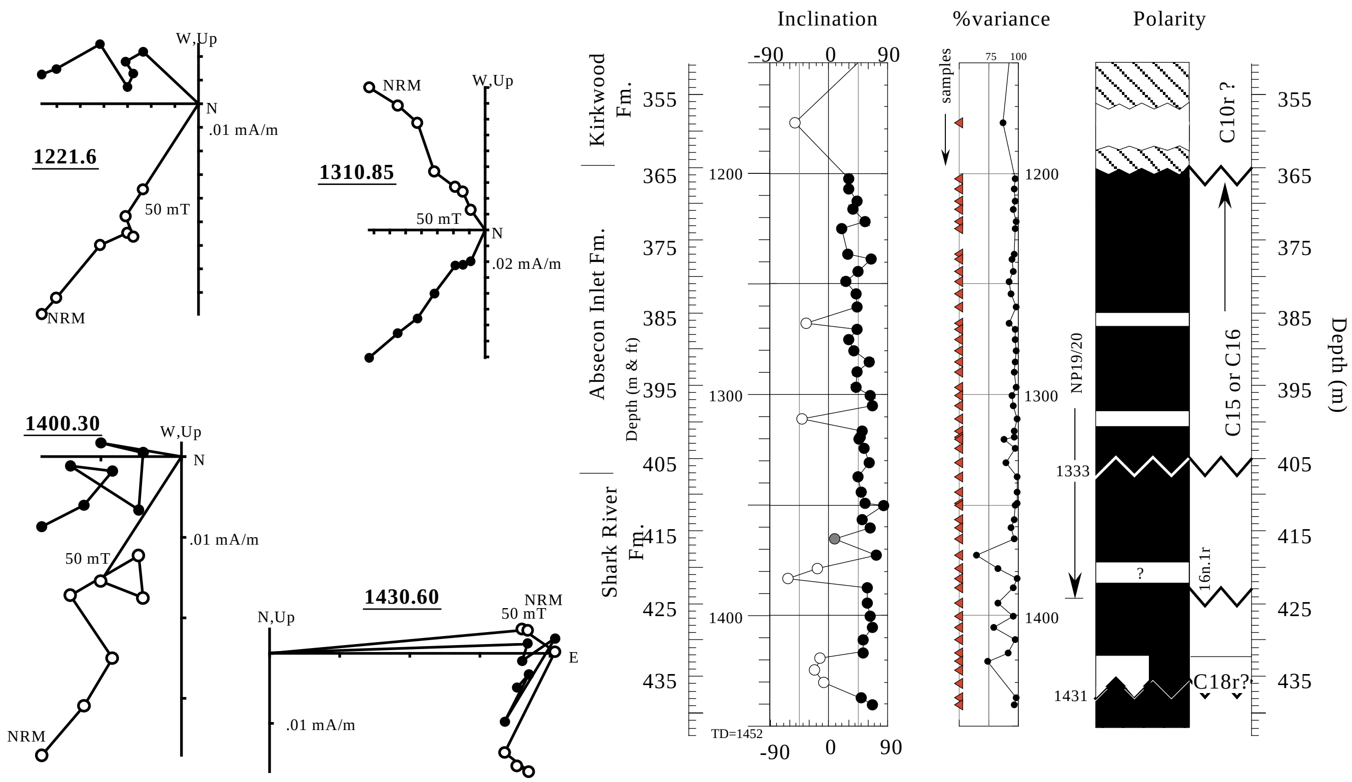

Figure 4. Progressive AF demagnetization and magnetostratigraphy of samples from Site AC (1150–1452 ft [350.5–442.6 m]). Demagnetization profiles in orthographic projection are shown at left (closed/open symbols = horizontal/vertical projection, mT = millitesla). Inclination of remanence vs. depth shown on right along with percent variance (triangles give location of discrete samples). Polarity interpretation (black = normal, white = reverse, hatch = uninterpretable).

down to 1390 ft (423.7 m; M.-P.Aubry, pers. comm., 1995), which, given the GPTS, means that the upper Eocene sediments at Site AC should be no older than Chron C16. Therefore, the best magnetostratigraphic age that can be assigned to the interval between 1181 and 1390 ft (360.0 and 423.7 m) is Chron C15n/r or C16n/r (Fig. 4). Such an assignment predicts much more reversed polarity magnetizations than is observed in these sediments. Whereas the thin reversed zone between 1375.85 and 1385.40 ft (419.4 and 422.3 m) may represent C16n.1r (35.55–35.72 Ma; Table 4), the predominance of normal polarity magnetization at Site AC remains a mystery.

The lowest occurrence of *Porticulasphaera semiinvoluta* is at a depth of 1348 ft (410.9 m) and marks the base of planktonic foraminifer Zone P15 (Miller et al., 1994a). I therefore correlate the polarity reversals within the upper Shark River Formation (1325 and 1431 ft [403.9 and 436.2 m)] to Chron C18n and C18r (Fig. 4). The thin reversed zone between 1375.85 and 1385.40 ft (419.4 and 422.3 m) may represent C18n.1r (39.64–39.72 Ma; see Table 2). The field reversal at 1422.25 ft (433.5 m), which I infer from three overprinted but reversely magnetized samples, may represent the termination of Chron C18r (40.22 Ma).

Cape May Site (Site CM)

Site CM is located at 38°56′N, 74°53′W in the Coast Guard Training Center at a mean elevation of 1.5 m (Fig. 1). Drilling to 1500 ft (457.2 m) recovered about 1129 ft (344.1 m) of core. Our study of this site is focused on the lower to middle Miocene Kirkwood Formation. Samples were taken from the more consolidated silty clay and sandy mud intervals below roughly 650 ft (198.1 m), which forms the aquifer confining units of this formation (Miller, et al., 1996). In addition, the unnamed upper and lower Oligocene glauconitic sands were sampled in two sections.

Silts and silty sands of lower Miocene Kirkwood Unit 2a (615–710 ft [187.5–216.4 m]) are relatively strongly magnetized, but yield rather erratic demagnetization profiles. A consistent and stable magnetization in four samples was from in this unit (Fig. 5; Table 4), however these were too widely distributed stratigraphically to make any useful interpretation in terms of polarity history. The base of Kirkwood Unit 1b was suitable for sampling between 905 and 927 ft (275.8 and 282.5 m). Here a strong (0.1–1.0 mA/m) and stable magnetization is found that is normal in polarity throughout, with the exception of one reversed sample at 917.20 ft (279.6 m).

Between about 942 and 1062 ft (287.1 and 323.7 m), the gray silty clays of Kirkwood Unit 1a sequence contain a magnetization that is relatively weak in intensity (~0.01 mA/m), but very consistent in direction during demagnetization. This unit features a thick normal polarity zone from 966 to 994 ft (294.4–303.0 m) in which magnetizations decay to the origin virtually unchanged in direction from the NRM (Fig. 5). It is conceivable that these sediments contain only a recent secondary magnetization. Continuing down through Unit 1a, the magnetizations remain weak and predominantly normal in polarity. However, near a lithological change to glauconitic clay (~1020 ft [310.9 m]), there is a thin zone of reversed polarity (between 1018.0 and 1024.9 ft [310.3 and 312.4 m]; Table 4).

The Kirkwood equivalent, Kw0 sequence (1062–1180 ft [323.7–359.7 m]), may be the only lower Miocene section at Cape May con-

Table 3. Progressive demagnetization data used in constructing Site CM (Cape May) magnetostratigraphy.

Sample name	Depth (m)	N	Var (%)	Dec (°)	Inc (°)	First (mT)	Last (mT)	Jcomp (mA/m)
150X-CM-								
C625.50	190.65	6	87.5	141.3	−46.6	20.0	70.0	0.6600
C649.60	198.00	4	87.1	209.9	31.0	20.0	50.0	0.3883
C669.75	204.14	6	88.8	342.9	−21.2	20.0	70.0	0.7100
C693.65	211.42	6	97.6	130.0	−56.3	20.0	70.0	0.0883
C906.40	276.27	6	91.4	154.1	29.2	10.0	70.0	0.8567
C916.40	279.32	7	96.2	137.0	59.2	15.0	90.0	2.8333
C917.20	279.56	6	75.2	26.3	−22.0	30.0	90.0	0.1750
C926.50	282.40	6	98.8	202.2	73.7	25.0	90.0	2.8533
C966.10	294.47	5	98.8	172.0	43.5	20.0	50.0	0.3175
C971.30	296.05	5	96.1	278.3	43.8	20.0	50.0	0.0453
C974.10	296.91	5	95.4	306.5	63.9	20.0	50.0	0.0658
C976.10	297.52	5	95.9	183.4	18.9	20.0	50.0	0.0970
C980.30	298.80	5	87.3	307.2	53.9	20.0	50.0	0.0387
C982.90	299.59	5	93.0	1.7	63.9	20.0	50.0	0.0279
C984.60	300.11	6	97.8	279.3	−5.8	20.0	50.0	0.0282
C987.10	300.87	6	96.1	150.9	61.1	20.0	50.0	0.0367
C988.50	301.29	5	99.2	295.2	53.8	20.0	50.0	0.0516
C994.60	303.15	5	92.0	14.7	27.4	20.0	50.0	0.0536
C1013.45	308.90	5	91.7	245.0	30.0	20.0	50.0	0.0169
C1014.90	309.34	5	97.7	238.1	28.9	20.0	50.0	0.0323
C1021.10	311.23	5	88.9	353.0	−29.8	20.0	50.0	0.0243
C1024.25	312.19	5	86.3	107.8	−23.7	20.0	50.0	0.0307
C1025.60	312.60	5	71.8	269.9	20.8	20.0	50.0	0.0263
C1030.80	314.19	5	85.4	279.8	26.4	20.0	50.0	0.0529
C1032.15	314.60	5	93.2	171.4	32.6	20.0	50.0	0.0300
C1037.75	316.31	5	90.0	155.0	27.3	20.0	50.0	0.0448
C1042.75	317.83	5	95.3	254.7	3.2	20.0	50.0	0.0967
C1046.50	318.97	5	86.4	185.7	5.3	20.0	50.0	0.0253
C1051.10	320.38	7	59.9	124.8	49.4	20.0	90.0	0.0983
C1060.50	323.24	8	98.4	41.1	19.3	20.0	90.0	0.5617
C1071.40	326.56	6	87.0	34.8	−38.2	15.0	70.0	0.0101
C1092.90	333.12	8	95.9	219.6	62.3	20.0	90.0	0.6300
C1096.80	334.30	8	98.9	1.0	−51.1	20.0	90.0	0.5233
C1114.35	339.65	7	98.6	352.1	−57.9	20.0	90.0	2.9650
C1120.65	341.57	6	99.5	176.6	29.3	30.0	90.0	6.2583
C1121.30	341.77	6	99.8	147.8	−35.2	20.0	50.0	150.2783
C1122.40	342.11	6	99.3	167.3	−28.1	30.0	90.0	5.5167
C1126.10	343.24	5	99.2	188.9	69.1	30.0	90.0	6.7467
C1140.10	347.50	5	90.2	253.1	18.5	30.0	90.0	0.7150
C1144.10	348.72	6	85.0	131.3	−5.7	15.0	70.0	0.2283
C1144.80	348.94	5	64.1	274.6	46.2	30.0	50.0	0.0873
C1154.20	351.80	7	73.5	29.7	−26.3	25.0	85.0	0.2633
C1162.30	354.27	7	93.7	111.4	−60.8	35.0	95.0	0.5783
C1200.70	365.97	4	100.0	141.9	85.5	10.0	48.0	14.0491
C1204.70	367.19	4	100.0	182.9	85.6	10.0	48.0	27.6805
C1208.70	368.41	5	100.0	233.5	84.7	10.0	48.0	15.7326
C1283.45	391.20	6	96.5	152.7	−12.2	40.0	50.0	0.0133
C1306.50	398.22	7	99.3	163.0	−27.8	20.0	50.0	0.1041
C1317.10	401.45	7	86.4	212.7	61.9	20.0	49.0	0.0595
C1323.00	403.25	7	94.0	256.3	39.1	20.0	49.0	0.0772
C1328.50	404.93	7	87.0	277.1	68.1	20.0	48.0	0.0381
C1332.50	406.15	6	95.5	134.0	−56.6	20.0	48.0	0.0570
C1343.30	409.44	4	87.3	153.6	−35.1	44.0	50.0	0.0232
C1436.60	437.88	5	98.2	275.7	47.0	20.0	50.0	0.0520

Notes: N = number of data used in each least-squares analysis; Var = percentage of the total variance in the selected data accounted for by the least-squares vector (dash indicates variance calculation not applicable); Dec, Inc = declination and inclination of the magnetization vector; First, Last = first and last demagnetization step in millitesla; Jcomp = intensity of least-squares magnetization.

taining what might be considered a continuous series of polarity reversals. Six of the 13 samples from this interval that yielded interpretable magnetizations are reversed in polarity. Glauconite sands at the top of this unit range in intensity from 1 to 100 mA/m and yield very consistent demagnetization profiles. A reversed magnetization at 1121.30 ft (341.7 m) clearly demonstrates overprinting by a normal field (perhaps the present-day field), which is resolved between the NRM and applied field of 15 mT (Fig. 5). Where the sands of this unit become more clay-rich below about 1140 ft (347.5 m), the magnetizations become less consistent during AF demagnetization. Two samples, at 1154.20 and 1162.30 ft (351.8 and 354.3 m), suggest a zone of reversed polarity that closes out our lower Miocene sample set at Site CM.

There were a few isolated sections of upper Oligocene unnamed sediments at Site CM where paleomagnetic sampling was possible. Unfortunately, these green glauconitic sands between 1180 and 1270 ft (360 and 387.1 m) yielded very inconsistent demagnetization profiles and are difficult to interpret. Three samples at the base of this unit contain a very strong magnetization pointed virtually straight down (Table 4) suggesting a drilling-related contamination. For the remainder of the upper Oligocene, quartz sands and glauconitic silty sands between 1220 and 1270 ft (371.9 and 387.1 m) yielded erratic magnetizations during analysis and could not be interpreted.

Magnetizations from the lower Oligocene (unnamed) at Site CM can be characterized as weak in intensity, but nonetheless consistent during AF treatment. Most yield normal polarity magnetizations (Table 4), but scattered through this section are samples that contain indirect evidence for reversed polarity magnetization. In these samples, for instance at 1283.45 ft (391.2 m; Fig. 5), the direction of the net magnetization swings from the lower to upper hemisphere during progressive AF treatment, suggesting the existence of a reversed polarity magnetization with relatively high coercivity.

In summary, 97 whole-round and standard 6-cm^3 samples have been progressively demagnetized and analyzed at Site CM. There were many weak and/or spurious magnetizations at this site, leaving only 54 useful samples and many gaps in the overall stratigraphic coverage. However, the occurrence of reversed polarity magnetizations within the Kirkwood Formation and the unnamed Oligocene sediments suggest that secondary magnetizations have not totally contaminated the site, and therefore, the Cape May sediments have the potential to record an ancient magnetization. Using the planktonic foraminifer data and Sr-isotopes analyses at this site, there are two sections in which one can make reasonable correlations to the GPTS.

Within the Kw sequence of the Kirkwood Formation, there is a relatively thick section of normal polarity magnetizations from 966.10 to 1018.0 ft (294.5–310.3 m; with sampling gap 995.0–1013.0 ft [303.3–308.8 m]). This is followed by a thin reversed polarity section between 1018.0 and 1024.9 ft (310.3 and 312.4 m) followed by normal polarity magnetizations down to the disconformity at 1062 ft (323.7 m), marking the base of the Kirkwood sequence (Fig. 5). Sr-isotope dates from this interval average ~20.7 Ma (Sugarman et al., Chapter 12, this volume) and, together with the last occurrence of *Globigerina angulisuturalis* (Miller, et al., 1996; Liu et al., Chapter 10, this volume), suggest this polarity sequence may be correlative to Chrons C6n through C6An.1 (partim) (Table 2).

The polarity reversal sequence between 1062 and 1126 ft (323.7 and 343.2 m) may correlate to Chrons 6An–6Ar. Given our age estimate of the overlying sediments (Kw 1a), and the planktonic foraminiferal data that suggest that lower Miocene Kirkwood Kw 0 is younger than Zone N4 (Liu et al., Chapter 10, this volume), the sediments in this unit cannot correlate to magnetozones older than Chron 6Ar. Between depths of 1094 and 1124 ft (333.5 and 342.6 m), Sr-isotope age dates range from 22.24 to 22.59 Ma (Sugarman et al., Chapter 12, this volume). These data suggest that this predominantly reversed polarity zone correlates to the older half of Chron C6Ar (Fig. 5). Given the age estimates of Kirkwood Units 1a and 0, it would appear that the hiatus represented by the disconformity at 1062 ft (323.7 m) is on the order of 1 m.y.

CONCLUSION

At the three Leg 150X onshore sites, I have used a large-sample method to extract a record of paleomagnetic field polarity from the weakly magnetized sediments on the New Jersey coastal plain. From these data, field polarity reversals in lower Miocene, Oligocene, and Eocene sections were identified. Unfortunately, the many gaps in the physical and magnetostratigraphic coverage within the cores do not allow correlation between Sites IB, AC, and CM. However, at discrete stratigraphic levels within the cores, by incorporating biostratigraphic and Sr-isotope data, ages of sediments were determined based on a correlation to the GPTS.

At Site IB, a series of polarity intervals from Chron C20n through C24r was found (C21r missing). Middle Eocene sediments at depths of 851.00 and 867.75 ft (259.4 and 264.5 m) are dated as 46.28 and 49.60 Ma, respectively (C21n termination, C22n onset, ages referred to GPTS of Berggren et al., 1995). Two sequence boundaries at this site at 857 and 862 ft (261.2 and 262.7 m) were found to be straddled by Chron C22n, suggesting the overall interruption of sedimentation at these levels was relatively brief (<0.5 m.y.). In the lower Eocene

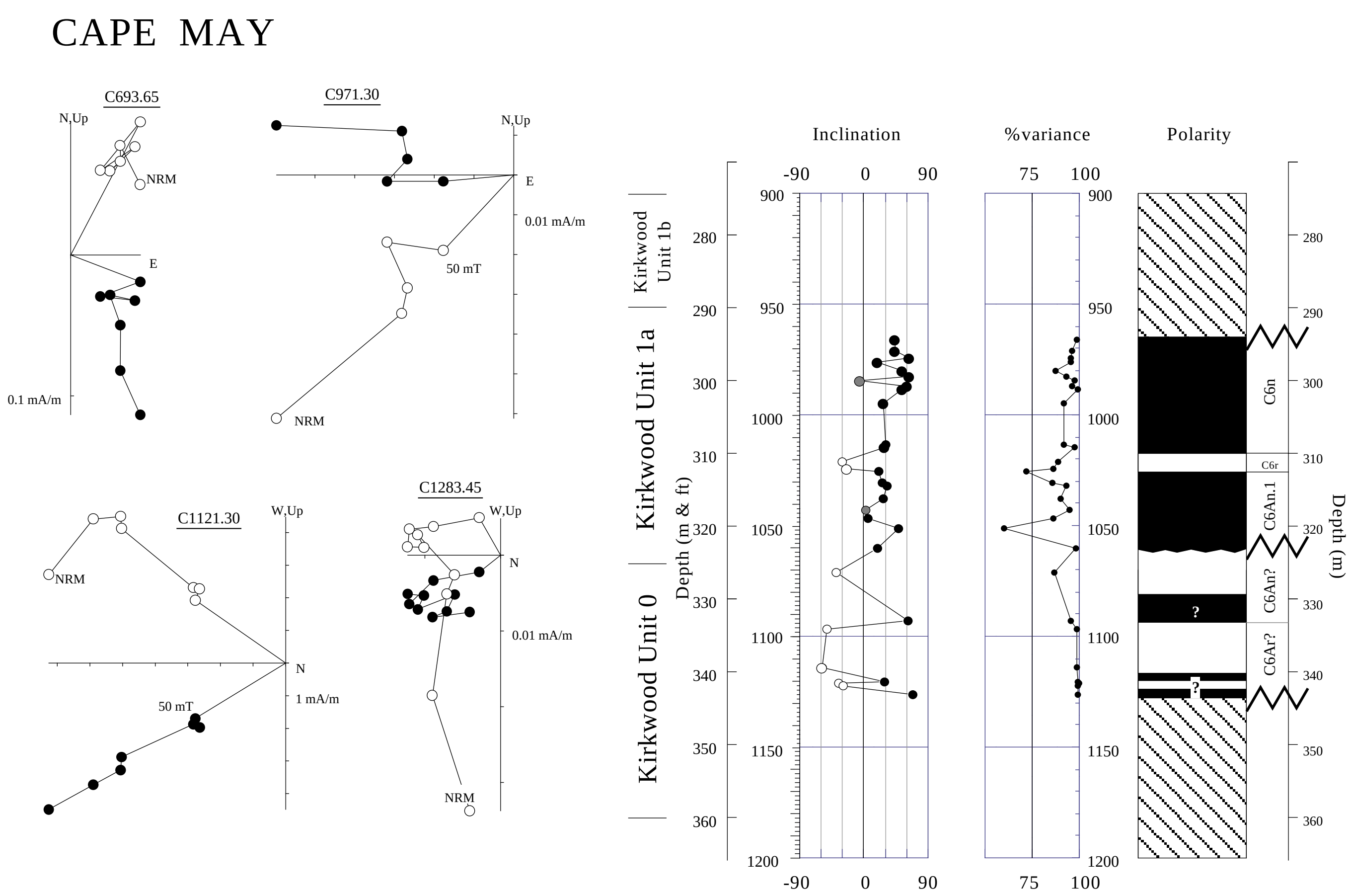

Figure 5. Progressive AF demagnetization and magnetostratigraphy of samples from Site CM (900–1200 ft [274.3–365.8 m]). Demagnetization profiles in orthographic projection are shown at left (closed/open symbols = horizontal/vertical projection, mT = millitesla). Inclination of remanence vs. depth shown on right along with percent variance (triangles give location of discrete samples). Polarity interpretation (black = normal, white = reverse, hatch = uninterpretable).

Table 4. Polarity zonations and reversal boundary depths for Sites IB, AC, and CM.

Depth (ft)	Depth (m)	Sense	Interpretation	Age (Ma)
Site IB (Island Beach)				
851.00	259.4	N-R	C21n(T)	46.28
867.75	264.5	R-N	C22n(O)	49.60
982.65	299.5	R-N	C24n.1r(T)	52.54
984.00	299.9	N-R	C24n.2(O)	52.79
Site AC (Atlantic City)				
1375.85	419.4	R-N	C16n.1r(T)	35.55
1385.40	422.3	N-R	C16n.1r(O)	35.72
Site CM (Cape May)				
1018.00	310.3	R-N	C6n(O)	20.45
1024.90	312.4	N-R	C6An.1(T)	20.88

Notes: Ages from Berggren et al. (1995); chronostratigraphic notation from Cande and Kent (1992). O = onset, T = termination, N = normal, and R = reverse

section, sediments at 982.65 and 984.00 ft (299.5 and 299.9 m) are dated as 52.54 and 52.79 Ma, respectively. Middle Eocene sediments between 1375.85 and 1385.40 ft (419.4 and 422.3 m) at Site AC are correlated to Chron C16n.1r (35.55–35.72 Ma). A portion of the lower Miocene Kirkwood Formation at Site CM contained a record of Chrons C6n through C6Ar. Sediments at depths of 1018.00 and 1024.90 ft (310.3 and 312.4 m) are dated as 20.45 and 20.88 Ma, respectively.

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