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4. CLAY MINERALOGY OF CENOZOIC SEDIMENTS OF THE ATLANTIC CITY BOREHOLE, NEW JERSEY[1]

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ABSTRACT

A great diversity of clay mineral assemblages are identified in sediments from the Atlantic City borehole. Detrital as well as authigenic clays are identified. The first group characterizes clayey intervals and includes chlorite, illite, randomly interstratified minerals, and kaolinite, whereas authigenic minerals, which are comprised of smectite, kaolinite, halloysite, and glauconite, occur mainly in Oligocene and middle Miocene sands and sandy sediments.

Detrital clay minerals are similar to those deposited off New Jersey, and a similar trend in the composition of clay assemblages is observed from Eocene to Pleistocene. A major change in clay mineralogy occurs within the middle Eocene from sediments rich in illite/smectite mixed layers at the base to kaolinite-dominated sediments in the upper part. Dominant detrital clay minerals characterize the middle part of the Kirkwood Formation. The three sequences, Kw1b, Kw2, and Kw3, which are separated by unconformities, show distinct clay assemblages. From Kw2 to Kw3, increasing proportions of illite, also recorded in coeval sediments from offshore sites, reflect the intensification of erosion following a tectonic uplift in the Appalachians. Chlorite and illite/vermiculite mixed layers are typical of Pleistocene sediments.

INTRODUCTION

Three continuously cored boreholes were drilled at Island Beach, Atlantic City, and Cape May, New Jersey (Leg 150X, Miller et al., 1994; Fig. 1). The Atlantic City borehole shows sediments from middle Eocene to Holocene. From top to base, Miller et al. (1994) and Owens et al. (1995) distinguish the following seven units.

1. Cape May Formation (0–53 ft [0–16.1 m]; uppermost Pleistocene–Holocene) contains nearshore gravelly sands and clays at the top and fluvial deposits at the base.
2. Cohansey Formation (53–293 ft [16.1–89.3 m]; middle (?) Miocene) comprises fluvial deposits represented by sands and sandy clays.
3. Kirkwood Formation (293–914 ft [89.3–278.6 m]; lower Miocene–middle Miocene) is composed of sands, silts, and clays. These facies represent diverse fluvial, nearshore, and neritic environments. It is the thickest unit of the Neogene.
4. Atlantic City Formation (914–1010 ft [278.6–307.9 m]; upper Oligocene) is dominated by clayey glauconite sands and silts at the base shoaling upward to silty clays and medium- to coarse-grain glauconitic quartz sands. This formation was deposited in a middle to inner neritic environment.
5. Sewell Point Formation (1010–1181 ft [307.9–360.1 m]; lower Oligocene) consists of clayey glauconite sand and silts and fine-grained quartzose sand that characterize middle to outer neritic environment.
6. Abescon Inlet Formation (1181–1352 ft [360.1–412.2 m]; upper Eocene) corresponds to glauconitic silts and silty clays with benthic foraminifers that characterize middle to outer neritic environment.
7. Shark River Formation (1352–1452 ft [412.2–442.7 m]; middle Eocene) is composed of marls to clayey chalk at base, overlain by clayey glauconite sands and glauconite sandy clays. Foraminifers characterize middle to outer neritic environment.

The aim of the study is to document variations in the nature of terrigenous supply related to environmental changes from the middle Eocene to the Holocene at Atlantic City and to compare data with those collected at offshore Sites 903 and 905 (Deconinck and Vanderaveroet, 1996).

METHODS

Clay mineral associations of 158 samples have been studied using X-ray diffraction (XRD) on oriented mounts. Deflocculation of clays was done by successive washing with distilled water after decarbonation of the crushed rock using 0.2 HCl. The clay fraction (less than 2-µm particles) was separated by sedimentation and centrifugation (Brown and Brindley, 1980; Holtzapffel, 1985). X-ray diagrams were obtained using a Philips PW 1730 diffractometer with CuK_α radiation and a Ni filter. A tube voltage of 40 KV and a tube current of 25 mA were utilized. Three X-ray diagrams were obtained after air-drying, ethylene-glycol solvation, and heating at 490°C for 2 hr.

The goniometer scanned from 2.5° to 28.5° 2θ for air-dried and glycol-solvated conditions, and from 2.5° to 14.5° 2θ for heating conditions. The identification of clay minerals was made according to the position of the (001) series of basal reflections on the three X-ray diagrams (Brown and Brindley, 1980; Reynolds, 1980; Moore and Reynolds, 1989). Semi-quantitative estimations of the clay minerals are based on the intensity and on the area of the main diffraction peak of each mineral (Holtzapffel, 1985). The clay fraction also contains quartz, feldspars, opal-CT, amphibole, gibbsite, and clinoptilolite. These minerals are not quantified, but their occurrence is mentioned as rare or common according to the intensity of their diffraction peaks.

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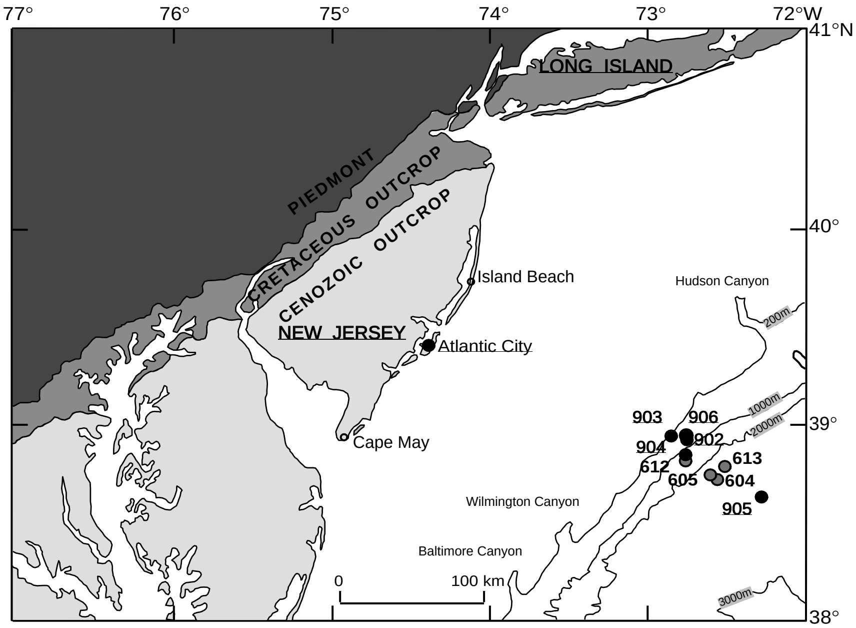

Figure 1. Location of ODP sites from Leg 150 and 150X, and most DSDP sites drilled in the western North Atlantic.

In addition, clay minerals were observed by transmission electron microscopy (TEM) using a JEOL 100 CX.

RESULTS

The clay mineral assemblages identified at Atlantic City are composed of chlorite (0%–27%), illite (2%–84%), smectite (0%–98%), kaolinite (0%–82%), and randomly interstratified minerals including illite/smectite (I/S, 0%–89%) and illite/vermiculite (I/V, 0%–20%; Fig. 2). In sandy intervals, kaolinite is commonly associated with another mineral, tentatively interpreted as halloysite (hydrated kaolinite) on the basis of TEM observations (see below). Kaolinite and halloysite display almost the same diffraction peaks; therefore it was not possible to quantify separately both minerals (Fig. 2). Quartz occurs throughout; feldspars and amphibole are restricted to the topmost part of the borehole, whereas opal C–T is identified in the deepest formations. Clinoptilolite and gibbsite occur occasionally (Table 1).

According to the appearance or disappearance of clay minerals and their relative percentages, six distinct clay mineralogical zones (CMZ) are identified and described in stratigraphic order.

CMZ 6, middle Eocene. CMZ 6 corresponds to the Shark River Formation from the bottom of the borehole to 1380 ft (420.6 m). The clay fraction is dominantly composed of I/S (79%–89%) occurring with illite (11%–21%) and traces of kaolinite (Fig. 2). Quartz is present throughout this zone and opal-CT, together with clinoptilolite, commonly occur at the base (Fig. 3A; Table 1). Observations by transmission electron microscopy show that I/S display a fleecy shape (Plate 1) similar to I/S identified in the Eocene nannofossil clayey chalk cored offshore (Deconinck and Vanderaveroet, 1996).

CMZ 5: 1380–1138 ft (420.7–347 m), middle upper Eocene–lower Oligocene. CMZ 5 includes the top of the Shark River Formation (from 1380 to 1352 ft [420.7–412.2 m]), the Abescon Inlet Formation (from 1352 to 1181 ft [412.2–360.1 m]), and the base of the Sewell Point Formation (from 1181 to 1138 ft [360.1–347 m]; Fig. 2). At the base of this interval, percentages of kaolinite increase sharply from 13% to 53% relative to I/S. The maximum of kaolinite is recorded around 1273 ft (388.1 m). Upsection, percentages of kaolinite decrease, whereas percentages of I/S increase. The amounts of illite are almost constant, with an higher average proportion than in CMZ 6. Chlorite is in traces, quartz is common, and gibbsite occurs occasionally (Fig. 3B; Table 1).

CMZ 4: 1138–741 ft (347–225.9 m), upper Oligocene–lower Miocene. This interval includes the top of the Sewell Point Formation (from 1138 to 1010 ft [347–307.9 m]), the Atlantic City Formation (from 1010 to 914 ft [307.9–278.6 m]), and the base of the Kirkwood Formation (Kw0 and Kw1a; Miller and Sugarman, 1995). At the top, glauconite becomes rare to absent (Miller et al., 1994). The clay mineralogy, which is much more variable than in CMZ 5 and 6, is characterized by two distinct clay mineral assemblages. Sandy intervals show either abundant glauconite, which is identified on X-ray diagrams by a well-developed reflection at 10 Å and a weak reflection at 5 Å (Fig. 3C), or almost pure well-crystallized smectite (Fig 3D). Smectite particles show relatively well-outlined and occasionally curled edges (Plate 1). In the clayey interval from 882 to 802 ft (268.9–244.5 m), the proportion of kaolinite reaches 50% and the composition of the clay fraction is rather homogeneous (Fig. 2).

CMZ 3: 741–388 ft (225.9–118.3 m), lower Miocene–middle Miocene. CMZ 3 comprises the upper Kirkwood Formation (Kw1b, Kw2a, Kw2b, and Kw3; Miller and Sugarman, 1995). The clay mineral assemblages are more homogeneous than in the underlying CMZ, with average percentages of 2% for chlorite, 20% for illite, 57% for I/S, and 21% for kaolinite (Figs. 2, 3E). However, according to clay mineralogy, three packages of sediments separated by unconformities are distinguished within CMZ 3 (Fig. 2). The lowermost part (CMZ 3A), corresponding to Kw1b sequence (Miller and Sugarman, 1995), is characterized by a variable proportion of I/S and kaolinite. The second interval (CMZ 3B), corresponding to Kw2, is much more homogeneous and is separated from the first one by a sequence boundary, which is associated with a 2-m.y. hiatus (Miller et al., 1994). This hiatus corresponds to the shelf/slope reflector m5.2 (Miller et al., in press). CMZ3B shows, at the base, a slight increase of illite occurring above the unconformity. The third interval (CMZ 3C), corresponding to Kw3 sequence, is characterized by increasing illite relative to I/S and kaolinite. CMZ 3C is separated from the CMZ 3B by an unconformity and a 3.5-m.y. hiatus corresponding to m3 shelf/slope reflector (Miller et al., 1994).

CMZ 2: 293–53 ft (89.3–16.1 m), middle Miocene–Pleistocene. From 388 to 293 ft (118.3–89.3 m), there is no recovery. This CMZ 2 corresponds to the Cohansey Sand Formation (from 293 to 53 ft [89.3–16.1 m]). Upper Miocene and Pliocene intervals are missing from the Atlantic City borehole. The clay assemblages are either composed of dominant well-crystallized smectite (Fig. 3F), similar to smectite identified in CMZ 4, or of kaolinite and halloysite (Fig. 2).

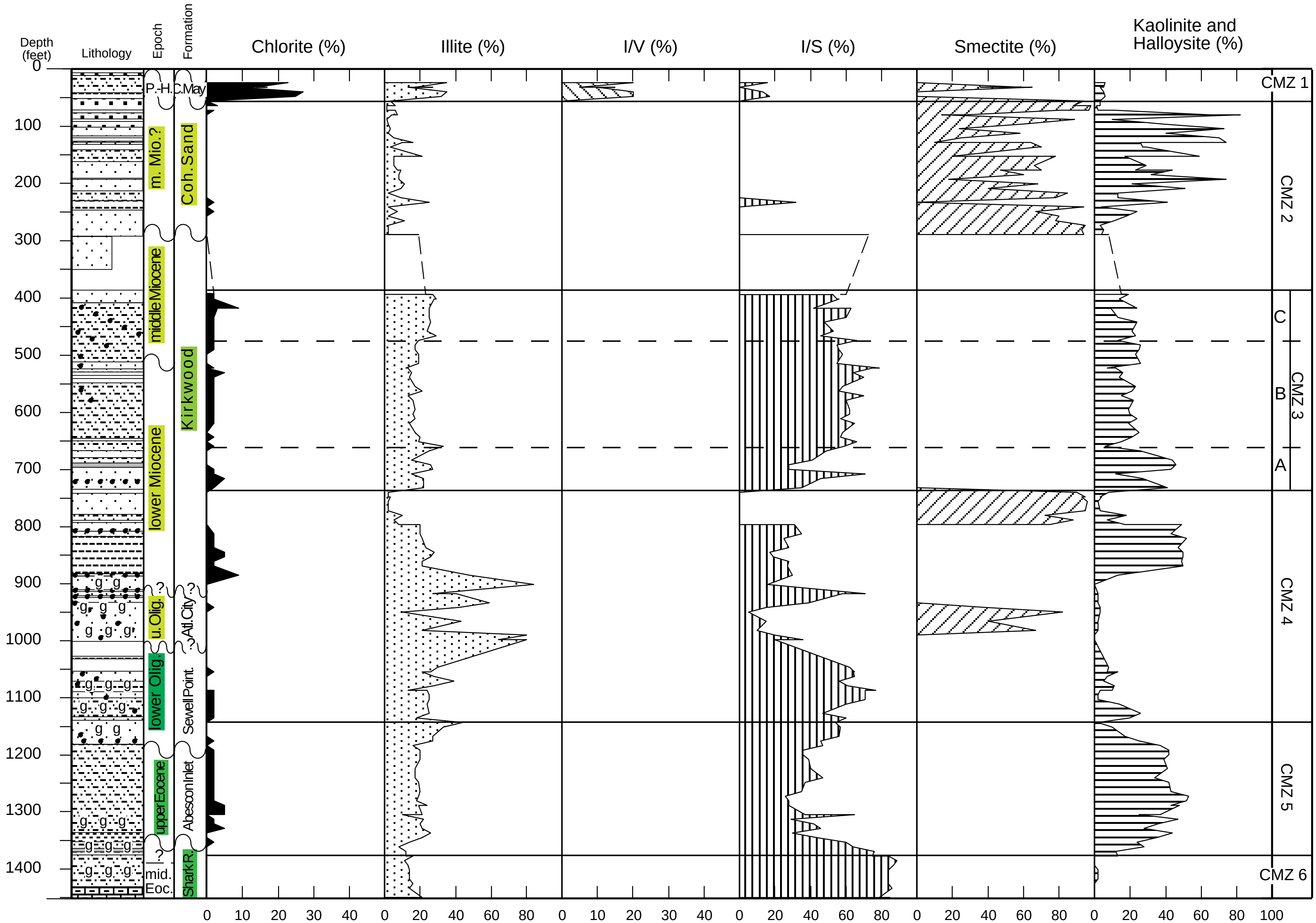

Figure 2. Clay mineralogy of sediments cored at Atlantic City borehole.

Table 1. X-ray diffractometry mineralogical results from the Atlantic City borehole.

Core-depth (ft)	Chlorite	Illite	I/V	I/S	Smectite	Kaolinite	Quartz	Feldspar	Amphibole	Clinoptilolite	Gibbsite	Opal C-T
150X-AC-												
3-19	23	35	20	16	0	6	++	++	++			
4-26	14	17	5	0	59	5	++	++	++			
5-29	17	27	15	0	36	5	++	++	++			
6-33	9	13	10	0	65	3	++	+	+			
8-43	27	35	20	13	0	5	++	++	++			
9-51	25	32	20	17	0	6	++	++	++			
10-56	0	3	0	0	94	3	++					
11-61	3	6	0	0	88	3	++					
12-66	0	1	0	0	98	1	++					
13-71	0	1	0	0	97	2	++					
14-72.3	2	6	0	0	81	11	++					
15-76.8	0	7	0	0	28	65	++					
16-83	0	4	0	0	14	82	++					
17-87	0	1	0	0	88	11	++					
18-89.5	0	1	0	0	89	10	++					
19-93	0	2	0	0	60	38	++					
22-103	0	3	0	0	24	73	++					
24-113	0	2	0	0	58	40	++					
25-118	0	5	0	0	25	70	++					
26-123.5	0	16	0	0	10	74	++					
27-128	0	10	0	0	64	26	++					
28-132.5	0	3	0	0	70	27	++					
29-137	0	3	0	0	68	29	++					
31-152.1	0	21	0	0	20	59	++					
32-154.8	0	5	0	0	78	17	++					
33-165	0	5	0	0	66	29	++					
34-173	0	7	0	0	70	23	++					
34-177	0	9	0	0	47	44	++					
35-183	0	8	0	0	60	32	++					
36-193	0	8	0	0	18	74	++					
37-200	0	11	0	0	68	21	++					
38-207.5	0	9	0	0	40	51	++					
39-213.3	0	2	0	0	85	13	++					
40-226	0	9	0	0	78	13	++					
41-236	2	25	0	32	0	41	++					
42-244	0	2	0	0	94	4	++					
44-248.7	2	7	0	0	67	24	++				+	
45-253.7	0	2	0	0	80	18	++				++	
46-266	0	11	0	0	78	11	++				+	
47-276	0	2	0	0	95	3	++					
48-282	0	2	0	0	93	5	++				+	
49-287	0	2	0	0	94	4	++					
50-292	0	19	0	73	0	8	++					
51-391	2	23	0	60	0	15	++					
52-395	2	27	0	52	0	19	++					
53-400	2	29	0	55	0	14	++					
54-404	2	28	0	56	0	14	++					
55-414	9	25	0	42	0	24	++					
56-422	3	25	0	63	0	9	++					
57-432	2	25	0	60	0	13	++					
58-444	2	26	0	48	0	24	++					
59-454	2	24	0	53	0	21	++					
60-462	2	29	0	46	0	23	++					
61-473	2	19	0	66	0	13	++					
62-483	2	17	0	55	0	26	++					
63-494	2	17	0	56	0	25	++					
64-500	0	19	0	58	0	23	++					
65-510	0	19	0	55	0	26	++					
66-523	2	12	0	79	0	7	++					
67-525	0	13	0	75	0	12	++					
68-532	5	15	0	64	0	16	++					
69-541	2	14	0	70	0	14	++					
70-552	2	17	0	58	0	23	++					
71-562.7	2	21	0	56	0	21	++					
72-572	2	13	0	70	0	15	++					
73-582	2	16	0	60	0	22	++					
74-592	2	17	0	62	0	19	++					
75-604	2	16	0	62	0	20	++					
76-612	2	17	0	57	0	24	++					
77-622	2	14	0	65	0	19	++					
78-634	0	17	0	58	0	25	++					
79-643	2	20	0	57	0	21	++					
80-652	0	19	0	66	0	15	++					
81-662	2	33	0	59	0	6	++			+++		
82-672	0	25	0	49	0	26	++			++	+	
84-683	0	15	0	41	0	44	++				+	
85-692	0	26	0	28	0	46	++				++	
86-700	2	27	0	28	0	43	++			+	+	
87-710.5	2	15	0	71	0	12	++				+	
88-720	5	22	0	46	0	27	++				+	
89-734	2	22	0	35	0	41	++				+	
90-740	0	2	0	0	90	8	++					
91-745	0	2	0	0	95	3	++					
92-749.5	0	3	0	0	93	4	++					
93-755	0	2	0	0	96	2	++					
96-772.5	0	2	0	0	95	3	++					
97-782	0	10	0	0	72	18	++				++	
98-789.5	0	5	0	0	88	7	++				+	
99-794	0	8	0	0	75	17	++				++	

Table 1 (continued).

Core-depth (ft)	Chlorite	Illite	I/V	I/S	Smectite	Kaolinite	Quartz	Feldspar	Amphibole	Clinoptilolite	Gibbsite	Opal C-T
100-802	0	20	0	31	0	49	++				+	
101-812	2	20	0	35	0	43	++				+	
102-822	2	21	0	25	0	52	++				+	
103-834	2	23	0	28	0	47	++				+	
104-842	5	28	0	17	0	50	++				+	
105-852	5	26	0	19	0	50	++				+	
106-864	2	21	0	28	0	49	++				+	
107-872	2	21	0	27	0	50	++					
108-882	9	48	0	30	0	13	++					
112-902	0	84	0	16	0	0	++					
113-916	0	27	0	71	0	2	++					
114-920	0	40	0	58	0	2	++					
117-935	0	59	0	39	0	2	++					
119-941.5	2	42	0	15	38	3	++					
121-950	0	10	0	5	82	3	++					
123-970	0	43	0	15	40	2	++					
124-980	0	21	0	10	67	2	++					
125-989	0	80	0	20	0	0	++					
126-999	0	64	0	36	0	0	++					
127-1000.5	0	80	0	20	0	0	++					
133-1053.4	2	26	0	65	0	7	++					
134-1057	2	21	0	64	0	13	++					
135-1062.2	0	28	0	65	0	7	++					
136-1071	0	39	0	56	0	5	++					
137-1075.5	0	28	0	61	0	11	++					
138-1083	0	13	0	77	0	10	++			+		
139-1087	2	24	0	71	0	3	++			+		
140-1093	2	25	0	71	0	2	++			+		
141-1104	2	25	0	71	0	2	++			+		
142-1112	2	24	0	60	0	14	++			+		
143-1124	2	25	0	47	0	26	++			++		
144-1134.5	2	18	0	60	0	20	++					
145-1145	0	44	0	54	0	2	++					
146-1148	0	30	0	62	0	8	++					
147-1155.5	0	33	0	57	0	10	++					
148-1164	0	27	0	56	0	17	++					
149-1172.8	2	27	0	46	0	25	++					
150-1183	0	16	0	47	0	37	++				+	
151-1189.5	2	20	0	36	0	42	++				+	
152-1200	2	20	0	36	0	42	++				+	
153-1210	2	20	0	39	0	39	++				+	
154-1220	2	17	0	40	0	41	++				+	
156-1240	2	17	0	47	0	34	++				+	
157-1252	2	19	0	37	0	42	++				+	
158-1262	2	20	0	35	0	43	++				+	
159-1273	2	19	0	26	0	53	++				+	
160-1282	2	18	0	28	0	52	++				+	
161-1290	5	24	0	28	0	43	++				+	
162-1293	5	19	0	28	0	48	++				+	
163-1302	5	21	0	37	0	37	++					
164-1306	0	10	0	65	0	25	++					
165-1314	2	22	0	29	0	47	++					
166-1320	2	20	0	42	0	36	++					
167-1330	5	21	0	46	0	28	++					
168-1339	0	26	0	30	0	44	++					
169-1344	0	21	0	44	0	35	++					
170-1350	2	14	0	60	0	24	+					
171-1360	0	8	0	64	0	28	+			+		
172-1370	0	12	0	76	0	12	+					
173-1375.5	0	12	0	75	0	13	+			+		
174-1380	0	16	0	84	0	0	+			+		
175-1387	0	11	0	89	0	0	+			+		
176-1394	0	13	0	87	0	0	+			++		+
177-1404.3	0	14	0	84	0	2	+			++		
178-1414	0	14	0	84	0	2	+			+		
179-1425	0	16	0	84	0	0	+			++		+
180-1434	0	14	0	86	0	0	+			++		+
181-1446.5	0	21	0	79	0	0	+			+++	++	
182-451	0	15	0	85	0	0	+			++		++

Notes: I/V = illite/vermiculite; I/S = illite/smectite. + = rare, ++ = common, +++ = abundant.

Kaolinite may occur alone or may be associated with halloysite (Plate 1), but according to XRD (Fig. 3G), it is not possible to separately quantify these minerals.

CMZ 1: 53 feet (16.1 m) to the top, upper Pleistocene–Recent. The topmost part of the borehole, consisting of clays, is correlated with the Cape May Formation. It is characterized by the occurrence of chlorite (up to 27%), random illite/vermiculite mixed layers and the common occurrence of feldspar and amphibole (Fig. 3H; Table 1). Therefore, the clay assemblages are very distinct from those identified in the underlying formations (Fig. 2).

To summarize, CMZ 6, 5, 3, and 1 show a common clay assemblage composed of chlorite, illite, I/S, and kaolinite, previously identified in offshore sediments (Deconinck and Vanderaveroet, 1996). Sediments from CMZ 4 and 2 contain particular clay species represented either by well-crystallized, almost pure smectite or by kaolinite/halloysite. The occurrence of these minerals is closely associated with sandier intervals.

DISCUSSION

Diagenetic Influences

Development of Authigenic Kaolinite/Halloysite and Smectite

The detrital origin of clay minerals and the absence of sedimentary and post-sedimentary authigenesis is one of the conditions for the

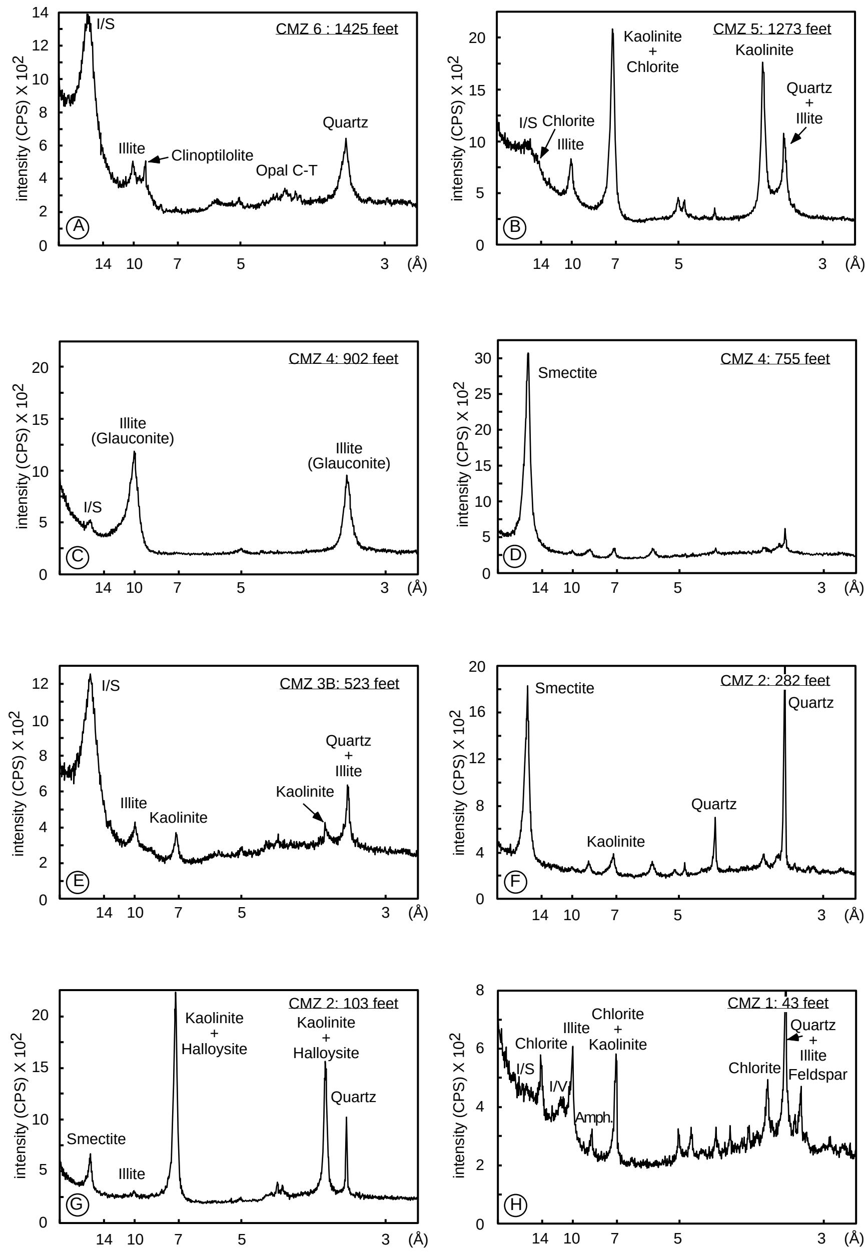

Figure 3. Typical X-ray diffractograms (glycolated) from each Clay Mineral Zone (CMZ): I/S = random illite/smectite mixed layers; I/V = random illite/vermiculite mixed layers; Amph = Amphibole.

interpretation of clay assemblages in terms of paleoenvironments. The occurrence of diagenetic clays in sands and sandstones is common, with kaolinite, illite, and chlorite being the most frequent authigenic species (Chamley, 1989). Sandy sediments represent particularly suitable environments for the formation of secondary minerals because of the high porosity and permeability, allowing migration of fluids (Wilson and Pittman, 1977; Huggett, 1984). At the Atlantic City borehole, three main features suggest the authigenic development of clays in sandy intervals:

1. the close relationship between the clay mineralogy and the lithology,
2. the important fluctuations from one sample to another, particularly in CMZ 2, and
3. the sharpness of diffraction peaks, which indicate a rather good crystallinity of clay minerals.

This latter argument is confirmed by TEM observations showing euhedral hexagonal particles of kaolinite and relatively well-outlined smectite particles (Plate 1). The secondary formation of smectite is less commonly reported in the literature. Smectites occurring in sands of various ages are typical of CMZ 4 and 2 and commonly compose the entire clay fraction. Smectite probably formed after deposition of clean sands, because the amount of clay minerals is very low in the samples. For this reason, it was unfortunately not possible to separate enough clays for additional geochemical analyses and scanning observations.

Glauconitization

The percentages of illite are generally lower than 40%, except in CMZ 4, where percentages reach 80%. According to XRD diagrams, illite corresponds to glauconite. This mineral is clearly associated with glauconitic intervals identified by visual description. Consequently, illite is not considered as detrital.

To summarize, the authigenic development of smectite, kaolinite/halloysite, and glauconite have modified the original detrital assemblages, particularly in CMZ 4 and 2. In these intervals, fluctuations in the relative proportions of clay minerals are related to postdepositional features rather than to environmental changes.

Environmental Interpretation—Comparison with Offshore Sites

The clay assemblages predominantly composed of I/S identified in middle Eocene sediments (CMZ 6) are similar to those identified in the Eocene clayey chalk drilled on the slope off New Jersey. I/S are interpreted as detrital (see discussion in Deconinck and Vanderaveroet, 1996) and reflect a warm and seasonally humid climate.

The transition to CMZ 5, which is characterized by a sharp increase in kaolinite (Fig. 2), occurs between 1375.5 and 1380 ft in a lithologically homogeneous interval composed of bioturbated laminated glauconite silty clay belonging to the upper Shark River Formation. The increase in kaolinite could be explained by three hypothesis:

1. a shallower environment than during middle Eocene (Owens et al., 1988),
2. a warm and wet climate (Van Valkenburg et al., Chapter 5, this volume), or
3. the higher sea level during the Sequence E10 (Browning et al., Chapter 18, this volume) in which a maximum of kaolinite corresponds to the maximum flooding surface at 1273 ft (388.1 m).

This correlation was already noticed by Deconinck (1993). At Site 903, a similar increase in kaolinite is recorded between Eocene chalk and upper Oligocene silty clays across the major unconformity O1 (Deconinck and Vanderaveroet, 1996). Upper Eocene chalks (NP19–20) are rich in I/S at Site 903, whereas coeval sediments (Abescon Inlet Formation, Fig. 2) contain high percentages of illite and kaolinite.

In CMZ 4, except in the clayey interval (prodelta silty clays, Miller and Sugarman, 1995) between 808 and 880 ft (lower part of the Kw1a sequence), the environmental interpretation of clay minerals is impeded by glauconitization and authigenesis of smectite occurring in sands. In the clayey interval, the clay mineral association that is composed of dominant kaolinite (average proportion 49%), illite, and I/S seems mainly detrital. This association also characterizes lower Miocene sediments from Site 903. However, at Site 903, I/S are dominant (55%), whereas kaolinite represents only 25% of the clay fraction. Differential settling processes of clays favoring the deposition of kaolinite nearshore relative to I/S are probably responsible for this difference.

The interval corresponding to CMZ 3 is composed predominantly of clayey sediments displaying mostly detrital minerals, except at the base (CMZ 3A), where kaolinite/halloysite is possibly authigenic in sandy intervals. Lower Miocene clayey sediments of CMZ 3B show clay assemblages almost similar to the coeval sediments deposited on the slope off New Jersey (Deconinck and Vanderaveroet, 1996). The base of Kw3 (CMZ 3C) corresponds to the shelf/slope reflector m3-Blue (Miller et al., 1996). Increasing proportions of illite are recorded at the Atlantic City borehole and above m3 at Site 903, where illite is interpreted as the result of erosion following a tectonic uplift occurring in the Appalachians highlands (Poag and Sevon, 1989; Poag, 1992; Deconinck and Vanderaveroet, 1996). The erosion of crystalline rocks yielded a large quantity of micas. This interpretation is consistent with sedimentation rates that were as high as 40 m/m.y. during deposition of the Kirkwood Formation (Sugarman et al., 1993).

In CMZ 2, it is not possible to separate detrital and authigenic influences, the latter being obviously dominant. Detrital influences prevail again in CMZ 1. The abundance of chlorite, illite, I/V, feldspars and amphibole recorded in the Atlantic City borehole is also characteristic of Pleistocene sediments cored at offshore Sites 903 and 905 (Deconinck and Vanderaveroet, 1996).These minerals are primarily inherited from the North American crystalline basement and transported by ice sheets and marine currents (Hathaway, 1980; Dunn et al., 1987; Cremer et al., 1989; Thiébault et al., 1989).

CONCLUSIONS

The clay mineral associations of sediments cored at Atlantic City are much more diverse than those identified at offshore sites. The diversity results from the authigenic development of clay minerals superimposed on detrital associations. Authigenic clays, including smectite, kaolinite, and halloysite, have developed in sands, and therefore a close relationship between the lithology and the clay mineralogy is observed in the Atlantic City borehole. Clayey intervals contain mostly detrital clay minerals. From Eocene to Pleistocene, the long-term trend in clay sedimentation is similar at Atlantic City and off New Jersey. A renewal of clays from smectite to kaolinite and illite is recorded within the Eocene, increasing proportions of illite occur in the middle Miocene, and chlorite characterizes Pleistocene sediments.

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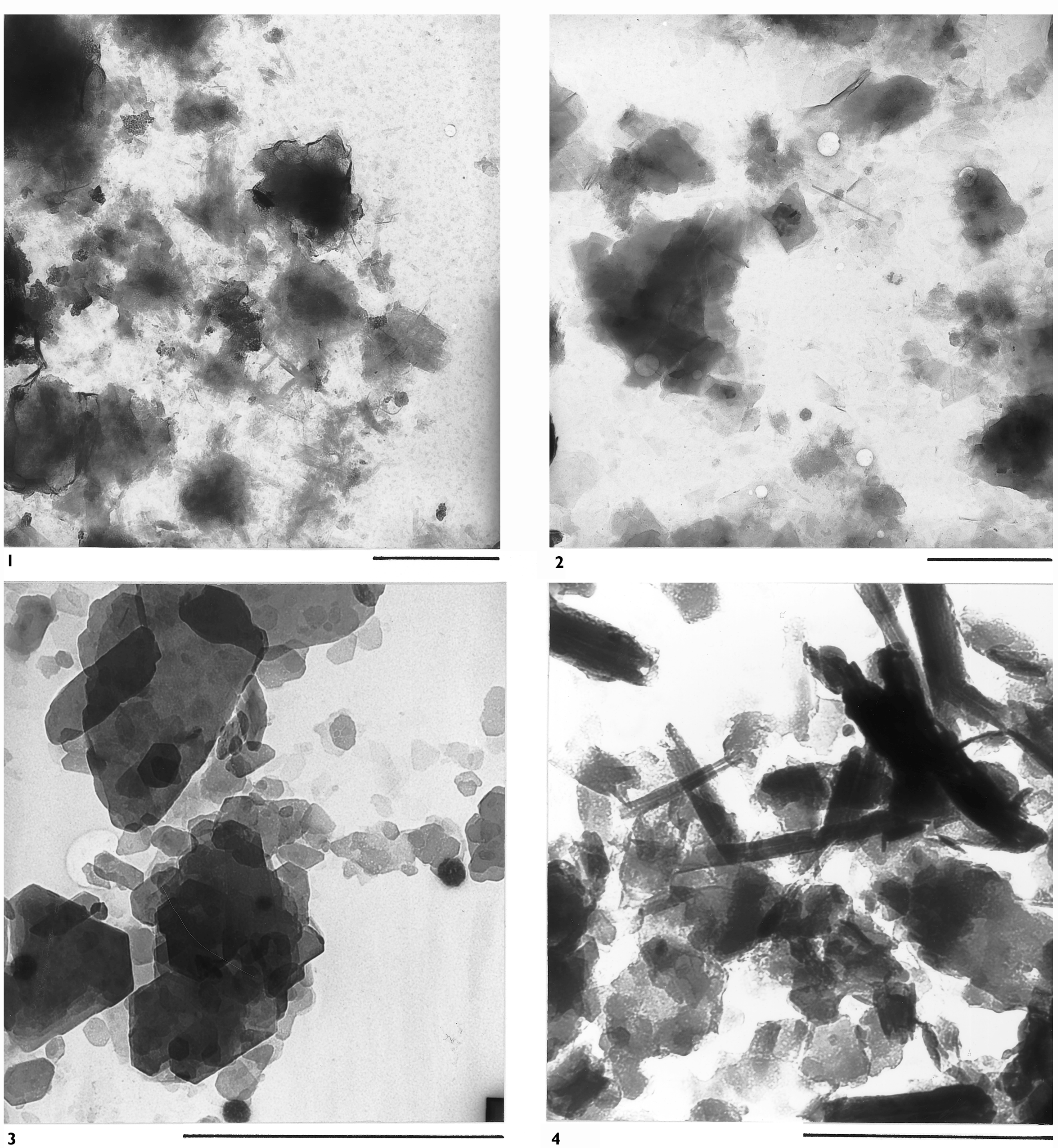

Plate 1. TEM pictures of clay fraction of samples from Atlantic City borehole, scale bar = 1 µm. **1.** Sample 150X-AC-173-1394 (CMZ 6) showing abundant fleecy particles of I/S. **2.** Sample 150XAC-93-755 (CMZ 4), authigenic smectite from sandy intervals. **3.** Sample 150X-AC-36-193 (CMZ 2) euhedral, hexagonal particles of kaolinite. **4.** Sample 150X-AC-16-83 (CMZ 2) mixture of kaolinite and tubular particles of halloysite.

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