5. CLAY MINERALOGY OF THE CAPE MAY, ATLANTIC CITY, AND ISLAND BEACH BOREHOLES, NEW JERSEY[1]

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ABSTRACT

Three boreholes on the New Jersey coast drilled by Ocean Drilling Program Leg 150X have been analyzed mineralogically. The dominance of kaolinite in the clay fraction of upper Eocene, lower Miocene, and lower middle Miocene strata indicates a warm, wet terrestrial climate at those times. Lack of kaolinite in Oligocene strata suggests a cool, dry climate.

INTRODUCTION

Mineralogy has been useful in the ongoing investigations of the stratigraphy, paleoenvironment, and tectonic history of the New Jersey Coastal Plain (Owens and Sohl, 1969; Owens and Gohn, 1985; Owens et al., 1988). In this paper, we present new clay fraction X-ray diffraction analyses for three boreholes from sites on the New Jersey shoreline at Cape May, Atlantic City, and Island Beach (Figs. 1, 2). Owens et al. (1995b) and Owens et al., (1995a) informally divided the Kirkwood Formation into the Belleplain, Wildwood, Shiloh Marl and Kirkwood Formations. Miller et al. (Chapter 14, this volume) retained the Kirkwood Formation in its original sense and applied the terms Belleplain, Wildwood, Shiloh Marl, and Brigantine Members to the formations of Owens et al. (1995a, 1995b). We follow the nomenclature of this volume to be consistent. We discuss the effects of hydraulic sorting and climatic variations on the clay mineralogy of deposits of Eocene through Miocene age, and we conclude that climate had by far the greater effect. We also present clay mineral analyses for Upper Cretaceous, Paleocene, and Holocene units.

METHODS

Clay mineral analyses were performed on a Diano Series 2000 X-ray diffractometer using Cu K-alpha radiation and a monochromator. (The use of any trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.) Sediment samples were centrifuged in deionized water to obtain the <2-µm clay fraction; the supernatant was concentrated and allowed to dry on glass slides, thereby subhorizontally orienting the clay minerals. The nontreated clay slides were run on the X-ray diffractometer from 2° to 14°2θ, and then run from 2° to 40°2θ if no peak was present at 6°. Slides that showed a peak at 6° were saturated in ethylene glycol vapor for 24 hr, and then run on the diffractometer from 2° to 40°2θ. Samples containing illite/smectite mixed-layer clay (a range of mixtures of inseparable clay layers with swelling and X-ray diffraction characteristics intermediate between illite and smectite) or montmorillonite will show a shift in peak position to approximately 5°2θ after glycolation. Samples that retained a peak at 6°2θ after glycolation were then heated to 350°C for 1 hr, and then rerun on the X-ray diffractometer. This treatment destroys soil dioctahedral vermiculite peaks. If the peak remained at 6°2θ, then the slide was reheated to 550°C for 1 hr, and rerun on the X-ray diffractometer. If the peak at 6°2θ remained, the mineral was inferred to be chlorite.

Another method of slide preparation was necessary for samples that did not readily disaggregate in water (typically carbonates). These samples were ground in an agate mortar and passed through a number 200 sieve; the resulting powder was smeared on a glass slide

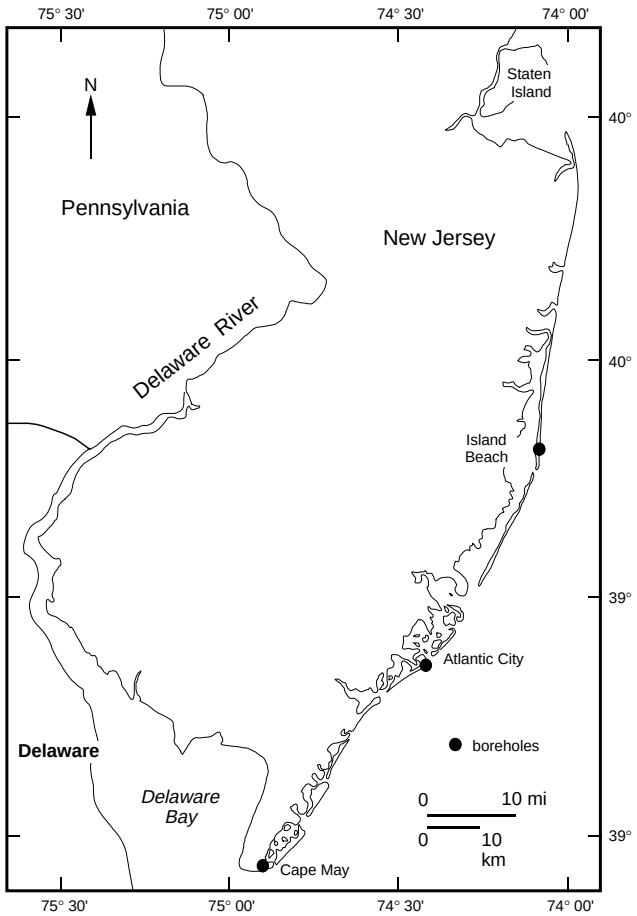

Figure 1. Location of boreholes used in this study.

[1]Miller, K.G., and Snyder, S.W. (Eds.), 1997. *Proc. ODP, Sci. Results*, 150X: College Station, TX (Ocean Drilling Program).

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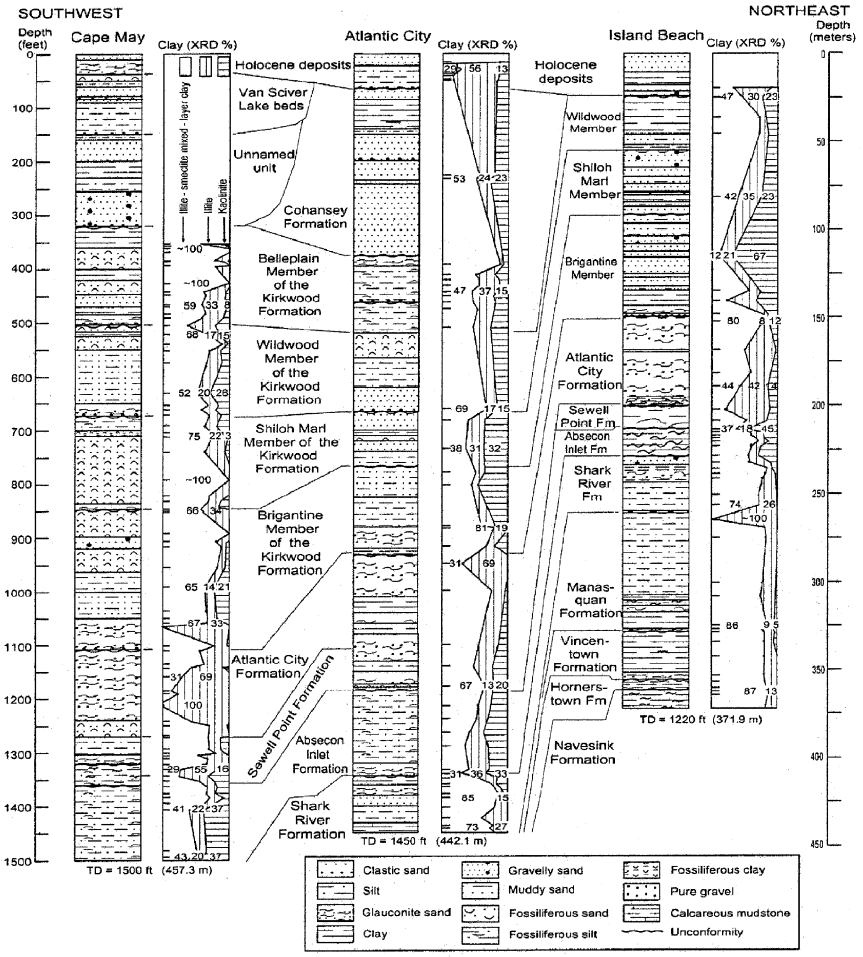

Figure 2. Lithology, stratigraphy, and clay mineralogy for the three cores. Sample depths shown by short horizontal lines along the left side of the Clay (XRD%) columns. Blanks in the columns indicate that a mineral was not detected; it is not likely to be present as more than 3% of the sample on the slide. The Absecon Inlet Formation is synonymous with the "ACGS Alpha unit" of Owens et al. (1988); the Atlantic City Formation is synonymous with "ACGS Beta unit" of Owens et al. (1988).

using a mixture of amyl acetate and cellulose nitrate cement. These randomly oriented "whole-rock" slides were run from 2° to 40°2θ on the X-ray diffractometer.

The X-ray diffractograms were first qualitatively analyzed to determine their mineralogy with reference to laboratory standards and the Mineral Powder Diffraction File. Approximate percentages of clay minerals were estimated on the X-ray traces using the method of Soller and Owens (1991).

RESULTS

Cape May Borehole

The Cape May borehole (Fig. 1) was sampled from a depth of 107.9–455.6 m (353.9–1494.4 ft). Quantification of X-ray traces from the borehole reveals marked variations in relative proportions of illite/smectite, illite, and kaolinite (Table 1). Included with illite/smectite mixed-layer clay is some relatively pure montmorillonite.

The uppermost unit examined in the Cape May borehole is the Belleplain Member of the Kirkwood Formation (Kw3 sequence) (107.9–149.9 m; 353.9–491.7 ft). This unit is characterized by a predominance of illite/smectite (~60%–80%), illite at about 20%–35%, and a relatively small amount of kaolinite (2%–15%).

The Wildwood Member of the Kirkwood Formation (Kw2a, Kw2b, and Kw2c sequences) underlies the Belleplain Member; the Wildwood was sampled from 154.1 to 204.6 m (505.4–671.1 ft). This unit generally has less illite/smectite and montmorillonite than the Belleplain (about 40%–70%), variable amounts of illite (15%–35%), and significantly more kaolinite (12%–28%).

The Shiloh Marl Member of the Kirkwood Formation(Kw1b) was sampled from 210.7 to 279.5 m (691.1–916.8 ft). The proportion of illite/smectite varies between 60% and 90%, illite varies between 0% and 30%, and kaolinite from 0% to 20%. In addition, the minerals clinoptilolite and aragonite are found in the Shiloh Marl. An indurated layer of rock at 217.2 m (712.4 ft) consists mainly of dolomite and quartz. The dolomite was probably precipitated between detrital quartz grains; the ions were probably derived by solution of the magnesium-bearing illite/smectite mixed-layer clay and calcareous shell fragments. Clinoptilolite may have been recrystallized from airborne or waterborne glassy volcanic ash.

The Brigantine Member of the Kirkwood Formation (Kw1a and Kw0 sequences) was sampled from 291.3 to 335.9 m (955.5–1101.8 ft). This unit is also predominantly illite/smectite (65%–85%), with illite making up roughly 10%–20% of the clay mineral fraction. Kaolinite increases from 5% at the top of the Brigantine to around 20% from 301.8 to 320.1 m (989.9–1049.9 ft), before dropping to an insignificant level below this depth. An indurated layer sampled at 324.8 m (1065.3 ft), similar to the one in the overlying Shiloh Marl, consists mostly of dolomite and quartz.

The Atlantic City Formation (ACGS Beta unit of Owens et al., 1988) was sampled from 338.4 to 387.2 m (1109.9–1270 ft). The most notable feature of this formation is the high proportion of illite, which appears to exceed 50% from 347.6 to 381.1 m (1140.1–1250.0 ft), and reaches a calculated maximum of 97% at 370.4 m (1214.9 ft). Illite/smectite decreases in an irregular fashion from about 60% to a trace at 367.9 m (1206.7 ft), and increases in a similar manner to ~70% at the bottom of the formation. There is very little kaolinite in the Atlantic City Formation in this borehole, as the relative proportion of this mineral never rises above 13%. A significant amount of calcite, aragonite, and clinoptilolite also occurs at 380.9 m (1249.4 ft).

The bottom two units of the Cape May borehole are the lower Oligocene Sewell Point Formation and the underlying upper Eocene Ab-

Table 1. New Jersey Cape May core.

Depth (m)	Relative %					
	I/S	I	K	Q	C	D
107.9	61	24	15	☒		
108.8	73	24	3	☒		
110.2	<100(M)	T	T	☒		
112.3	<100(M)	T	T	☒		
116.9	78	20	2			
117.4	91(M)	7	1	T		
120.1	<100(M)	T	T	T		
120.6	77	20	3			
130.1	<100(M)	T	T	☒		
134.5	62	33	4	☒		
136.4	64	30	5			
142.1	59	33	8	☒		
143.4	62	33	6	?		
147.6	65	28	7			
149.9	61	30	9			
154.1	42	36	22	T		
159.4	68	17	15			
164.7	91(M)	6	3	☒		
168.3	70(M)	16	13	☒		
174	67	21	12	☒		
192.2	52	20	28	☒		
199.1	69	16	15	☒		
201.5	60	18	21			
204.6	71	17	12			
210.7	64	18	19	T		
214.6	75	13	12			
217.2	75	22	3	☒	☒	☒
225.8	64	29	7	☒	☒	
241.3	<100(M)			☒		
250.4	72	27	1	☒		
253.4	71	17	12			
258.1	59	25	16	☒		
259.4	64	36		☒	☒	☒
259.5	66	34		☒	☒	
271.6	~100(M)			☒		☒
276.5	82	14	4	☒		
279.5	89	7	4	☒		
291.3	83	12	5			
291.7	76	17	7			
302.0	65	14	21	☒		
315.9	66	17	18			
320.4	70	12	18			
322.6	67	33	?			
324.8		~100		T	☒☒	
335.9	79	17	3		T	
338.4	57	43	?		T	
346.3	64(M)	26	?	☒		
348.4	43	51	6			
353.2	31	69				
361.3	15	85			☒	
363.0	25	75				
367.9	T	<100				
370.4	3	97				
378.4	45	55			☒	
380.9	72	26	2		☒☒	
386.6	71	29	T			
387.5	69	19	13	☒	☒	
393.9	71	18	11	☒		
396.3	81	14	5		☒	
398.1	56	44				
399.5	70	30				
402.4	68	15	17			
405.5	29	55	16			
409.2	26	43	31			
411.9	56	22	22		☒	
415.2	69	14	17		☒	
419.2	68	13	20	☒	☒	
421.6	73	11	6			
425.0	64	13	23			
428.7	41	22	37		☒	
451.8	53	15	33		☒	
455.6	43	20	37			

Notes: I/S = illite/smectite mixed-layer clay; I = illite; K = kaolinite; Q = quartz; C = calcite; D = dolomite. ☒ = mineral present; blank cell = mineral not detected; M = montmorillonite; T = trace; ? = possible occurrence; and ☒☒ = dominant peak.

secon Inlet Formation. The major trend for these two units is the marked (although uneven) increase in kaolinite from 15% at the top of the Sewell Point Formation to 37% at the bottom of the Absecon Inlet Formation. Illite/smectite and illite proportions fluctuate widely from 25% to 70% and 10% to 55%, respectively. Pyrophyllite is also present at 409.2 m (1342.2 ft) within the Sewell Point Formation.

Atlantic City Borehole

The Atlantic City borehole (Fig. 1) was sampled from 5.2 to 442.1 m (17–1450 ft; Table 2; Miller et al., 1994a). The uppermost unit examined is the Holocene sediment that was sampled from 5.2 to 15 m (17–49 ft). This unit is rich in illite (55%–90%), followed in abundance by illite/smectite (15%–30%) and kaolinite (10%–20%). Chlorite and plagioclase feldspar are also present throughout this unit.

The Cohansey Formation was sampled at 68.9 and 70.7 m (226.0 and 231.9 ft). Relative to the Holocene sediments, this formation shows an increase in illite/smectite (50%–60%), a decrease in illite (20%–25%), and a slight increase in kaolinite (19%–23%).

The Belleplain Member of the Kirkwood Formation (Kw3 sequence) was sampled from 119.3 to 141.0 m (393.3–462.5 ft). The uppermost sample is rich in montmorillonite. The rest of the unit has levels of illite/smectite (45%–60%) similar to those in the overlying Cohansey Formation. Illite (30%–40%) and kaolinite (10%–20%) make up the rest of the clay fraction.

The Wildwood Member of the Kirkwood Formation was sampled from 144.9 to 201.5 m (475.3–660.9 ft). The upper two samples contain 54% and 48% illite/smectite, 32% and 27% illite, and 14% and 25% kaolinite. The lowest of the three samples is mostly aragonite.

The Shiloh Marl Member of the Kirkwood Formation was sampled at 207.9 and 224.1 m (681.9 and 735.0 ft). Proportions of illite/smectite range from 40% to 70%, followed by illite (15%–30%) and kaolinite (15%–35%). Gibbsite is also present.

The Brigantine Member of the Kirkwood Formation (Kw0 and Kw1a sequences), was sampled from 237.5 to 279.5 m (779–916.8 ft). The most conspicuous trend in clay mineralogy is the increase in kaolinite from 32% at the top of the unit to a maximum of 45% at 267.9 m (878.7 ft), followed by a rapid decrease to an insignificant level at the bottom of the unit. A small amount of gibbsite is also present at 267.9 m (878.7 ft). Illite/smectite increases from 38% to 81% of the clay mineral fraction from top to bottom, whereas illite decreases from 31% to 9% at 267.9 m (878.7 ft), before increasing to around 20% at the bottom of the unit.

The Atlantic City (upper Oligocene) and Sewell Point (lower Oligocene) Formations were sampled from 289.2 to 359.2 m (948.6–1178.2 ft). Illite/smectite fluctuates in the range of 30%–70%, whereas illite and kaolinite vary from 15% to 70% and 0% to 20%, respectively. A significant amount of clinoptilolite was found at 335.3 m (1099.8 ft).

The Absecon Inlet Formation was sampled from 360.4 to 406.2 m (1180.1–1332.3 ft). Kaolinite increases from 20% to 35% of the clay mineral fraction at 385.1 m (1263.1 ft) before decreasing somewhat to 25%–30% toward the bottom of the unit. Illite/smectite decreases within the range of 70%–40%, where illite increases in an irregular fashion within the range of 10%–40%. Calcite is also present below 370.1 m (1213.9 ft).

The Shark River Formation is the lowest unit examined in the Atlantic City borehole, and was sampled from 406.5 to 428.4 m (1333.3–1405.1 ft). This unit is characterized by a decrease in the relative proportion of kaolinite from 25% to 35% at the top of the formation to an insignificant level below 422.3 m (1385.1 ft). In contrast, illite/smectite increases from 30% to 40% to a level of 70%–80% at the bottom of the unit, whereas illite fluctuates within the range of 10%–40%. Small amounts of aragonite are found at 419.9 m (1377.3 m) and at 438.0–442.1 m (1436.6–1450.1 ft), whereas clinoptilolite is present from 433.6 to 442.1 m (1422.2–1450.1 ft). Calcite is found throughout the Shark River Formation.

Island Beach Borehole

The Island Beach borehole was sampled from 19.7 to 364.6 m (64.6–1195.9 ft; Table 3; Miller et al., 1994b). A single sample was examined from the uppermost unit, the Holocene, at a depth of 19.7 m (64.6 ft). It is rich in illite (58%) followed in abundance by illite/

Table 2. New Jersey Atlantic City core.

Depth (m)	Relative %						
	I/S	I	K	Q	C	Ch	F
5.2		87	13	☒		☒	☒
6.5	18	69	13	☒		☒	☒
8.8	29	56	15	☒		☒	☒
12.6	17	69	14	☒		☒	☒
14.5	19	66	15	☒		☒	☒
15.2	18	65	17	☒		☒	☒
68.9	57	23	19	☒			
70.7	53	24	23	☒			
119.3	90(M)	5	5	☒			
125.3	52	30	18	☒			
128.1	58	31	11	☒			
131.5	56	31	12	☒			
134.9	47	37	15	☒			
137.4	47	32	21	☒			
141.0	48	31	20	☒			
144.9	54	32	14	☒			
155.4	48	27	25	☒			
207.9	69	17	15	☒			
224.1	41	26	34	☒			
237.5	38	31	32	☒			
224.4	44	23	33	☒			
267.9	46	9	45	☒			
268.8	61	22	17	☒			
279.5	81	19		☒	☒		
289.2	68	14	19				
304.5	31	69		☒			
335.3	77	21	2	☒			
348.1	58	28	13	☒			
359.2	49	31	21	☒			
360.4	67	13	20	☒			
370.1	57	19	24	☒	☒		
377.1	54	18	28	☒	☒		
385.1	43	22	35	☒	☒		
392.7	38	38	25	☒	T		
406.2	43	28	28	☒	☒		
406.5	41	33	26	☒	☒		
408.8	31	36	33	☒	☒		
411.2	58	27	15	☒	☒		
414.0	75	11	15	☒	☒		
416.0	81	9	11	☒	☒		
419.9	87	10	3	☒	☒		
422.3	85	15		☒	☒		
427.4	81	19		☒	☒		
433.6	62	39		☒	☒		
438.0	80	21		☒	☒		
439.8	73	27			☒		
442.1	83	17			☒		

Notes: I/S = illite/smectite mixed-layer clay; I = illite; K = kaolinite; Q = quartz; C = calcite; Ch = chlorite; and F = plagioclase-feldspar. Blank cell = mineral not detected; ☒ = mineral present; M = montmorillonite; and T = trace.

Table 3. New Jersey Island Beach State Park #3 core.

Depth (m)	Relative %						
	I/S	I	K	Q	C	Ch	F
19.7	33	58	9	☒		☒	☒
24.8	47	30	23				
36.1	74	10	16	☒			
45.5	74	12	14				
81.3	42	35	23	☒			
114.8	12	21	67	?			
134.4	58	18	24	T			
137.5	51	25	4	T			
148.4	78	9	13	?			
151.9	80	8	12	?			
168.8	52	47	1	?			
181.1	61	31	8				
188.7	44	42	14	?			
202.4	23	66	11				
208.4	53	32	15	?			
213.6	37	18	45		☒		
214.6	61	19	20	?			
216.6	61	19	20		T		
217.8	68	12	20	T			
223.2	72	16	12	☒			
223.0	62	14	24		T		
228.2	58	16	26	☒	☒		
232.1	58	32	10	?	☒		
235.2	86	8	7	☒	☒		
238.2	84	14	2	?			
241.2	78	22	T		☒		
250.4	75	25	T		☒		
256.0	74	26	?		☒		
261.0	T	~100			☒		
267.2	81	19	?	?	☒		
268.3	85	15	?	?	☒		
274.4	80	20		T	☒		
300.3	77	23		T	☒		
307.6	83	17	?	T	T		
324.8	86	9	5	☒	☒		
327.0	78	16	6	☒	☒		
328.2	81	17	2	T	☒		
334.3	82	15	3	☒	?		
342.7	82	17	1	T	T		
356.2	82	18	T		☒		
360.6	84	16	T	?	☒		
362.4	87	13	T		☒		
364.6	87	13	T		☒		

Notes: I/S = illite/smectite mixed-layer clay; I = illite; K = kaolinite; Q = quartz; C = calcite; Ch = chlorite; and F = plagioclase-feldspar. ☒ = mineral present; blank cell = mineral not detected; ? = possible occurrence; and T = trace.

smectite and kaolinite (33% and 9%, respectively). Chlorite, plagioclase feldspar, and salt (introduced during processing) are also present.

The Wildwood Member of the Kirkwood Formation (Kw2a sequence) was sampled from 24.8 to 45.5 m (81.3–149.2 ft). This unit is characterized by increasing illite/smectite (45%–75%), decreasing illite (30%–12%), and a higher but decreasing level of kaolinite (23%–14%). Salt is present at 24.8 m (81.3 ft).

The Shiloh Marl Member of the Kirkwood Formation (Kw1b sequence) is represented by a single sample at 81.3 m (266.6 ft). This sample is 42% illite/smectite, 35% illite, and 23% kaolinite. Vermiculilte is also present.

The Brigantine Member of the Kirkwood Formation (Kw1a sequence) was sampled from 114.8 to 148.4 m (376.5–486.8 ft). There is a very high level of kaolinite at the top of this unit (67%), which declines rapidly to a variable level (5%–25%) with increasing depth. Illite/smectite increases from 12% to 78%, and illite is variable at 10%–25%.

The Atlantic City Formation was sampled from 151.9 to 188.7 m (498.2–618.9 ft). Illite/smectite decreases from 80% to 44%, illite increases in an irregular fashion from 8% to 42%, and kaolinite decreased from 12% to 1% before increasing to 14%. Small amounts of goethite are also present at 168.8 and 181.1 m (553.7 and 594.0 ft).

The Sewell Point Formation was sampled at 202.4 and 208.4 m (663.9 and 683.5 ft). This formation shows an increase in illite/smectite from 23% to 56%, a decrease in illite from 66% to 32%, and kaolinite in the range of 10%–15%.

The Absecon Inlet Formation was sampled from 213.6 to 223.0 m (700.6–731 ft). The uppermost part of this formation has a large amount of kaolinite (45%), which remains in the range of 12%–24% throughout the rest of the formation. Illite/smectite increases from 37% at the top of the formation to a range of 60%–75%, and illite fluctuates in the range of 10%–20%. Trace amounts of gibbsite and calcite are also present at 213.6 m (700.6 ft).

The Shark River Formation was sampled from 228.2 to 256.0 m (748.5–839.7 ft). Kaolinite decreases from 26% at the top of the formation to a trace below 241.2 m (791.1 ft), whereas illite/smectite appears to increase and then decrease in the range of 55%–85%. Illite varies between 8% and 32% of the clay mineral fraction. Trace amounts of clinoptilolite are present at 250.4 and 256.0 m (821.3 and 839.7 ft), whereas calcite is present throughout much of the Shark River Formation.

The four lowest formations (in ascending order) are the Manasquan, Vincentown, Hornerstown, and Navesink Formations, which were sampled from 261.0 to 364.6 m (856.1–1195.9 ft). There appears to be little significant variation in clay mineralogy throughout these four units, with the exception of the uppermost sample in the Manasquan Formation, which is mostly illite. Below 264.5 m (867.6 ft), illite/smectite varies within the range 75%–90%, illite from 10% to 25%, and kaolinite from 0% to 6%. Traces of clinoptilo-

lite appear from 264.5 to 300.3 m (867.6–985.0 ft) and 342.7 to 360.6 m (1124.1 –1182.8 ft). Calcite is found throughout most of these four formations.

DISCUSSION

The Effect of Climate

The influence of climate on clay mineralogy has been noted by many researchers (Robert and Kennett, 1994; Weaver, 1989; Millot, 1970). Illite/smectite and kaolinite tend to form in soils as a result of chemical weathering in tropical to subtropical areas with abundant precipitation. In contrast, illite (and related minerals such as chlorite) typically form in soils with little chemical weathering in cold and/or dry climates, and areas of high relief where mechanical erosion is predominant. It follows that climatic changes in a given region will be reflected by changes in clay mineralogy in the soils of that region, and that the erosion of these soils and their subsequent deposition as sediments in adjacent oceanic areas will preserve a record of climatic changes in the stratigraphic sequence.

Hydraulic Sorting

The relative proportions of illite/smectite, illite, and kaolinite deposited offshore are also influenced by distance from shore. Snowden and Forsthoff (1976) observed that in the Pearl River delta in Louisiana/Mississippi, the mineral kaolinite is first deposited in the greatest proportions where the fresh water begins to mix with the saline Gulf of Mexico water. However, after this the relative proportion of kaolinite deposited decreases steadily seaward, whereas illite/smectite tends to increase (Parham, 1966). Snowden and Forsthoff (1976) believe this effect is a result of the more rapid flocculation in salt water of kaolinite compared with illite/smectite. The tendency of kaolinite to be deposited closer to shore relative to illite/smectite may also be related to the larger original particle size of kaolinite.

A southwestward increase in unit thickness may be indicative of a downdip position for the Cape May borehole relative to the Atlantic City borehole, which in turn may be farther downdip than the Island Beach borehole. If this is true, the effect of hydraulic sorting would be expected to increase the amount of kaolinite in the Island Beach borehole relative to the Cape May borehole, for example. Our studies of the New Jersey boreholes suggest that the effect of hydraulic sorting has been masked by the effect of climate.

Lateral Trends in Clay Mineralogy of Selected Units in New Jersey

The Absecon Inlet Formation, Sewell Point Formation, Atlantic City Formation, and most of the Kirkwood Formation (Brigantine, Shiloh Marl, and Wildwood Members) are present in the Cape May, Atlantic City, and Island Beach boreholes in New Jersey, and this enables a general description of lateral changes in clay mineralogy to be made from southwest to northeast.

The lowest unit described here is the Absecon Inlet Formation, which is late Eocene in age. The overlying lower Oligocene Sewell Point Formation is only present in the Cape May and Island Beach boreholes, but because of its mineralogic similarity is here included with the Absecon Inlet Formation. The most notable feature of the Absecon Inlet Formation is the relatively high proportion of kaolinite, which reaches maximum levels of 35%–45% consistently across the formation in all three cores. We believe that this high level of kaolinite may be caused, at least in part, by a warmer and/or wetter climate during this time interval (Robert and Kennett, 1994).

The Absecon Inlet and Sewell Point Formations are overlain unconformably by the upper Oligocene Atlantic City Formation. In contrast to the lower formations, the Atlantic City Formation has significantly higher levels of illite (typically 50%–100%), and an unusually low amount of kaolinite. This trend is particularly prominent in the Cape May borehole. We speculate that this pattern may result from a relatively cooler and/or drier climate during the late Oligocene.

The Atlantic City Formation is unconformably overlain by the lower Miocene Brigantine Member of the Kirkwood Formation. This unit is characterized by a lateral increase in kaolinite from a moderate level in the Cape May borehole (up to 20%), to a high of 67% in the Island Beach borehole. As with the Absecon Inlet Formation, the high level of kaolinite in the Brigantine Member may be caused by a warmer and/or wetter climate on the adjacent landmass when this unit was being deposited (see Sugarman et al., in press, for further discussion of Miocene climatic transition).

The Brigantine Member is unconformably overlain by the middle Miocene Shiloh Marl, which in turn is unconformably overlain by the middle Miocene Wildwood Member, the latter being the uppermost unit described in this section. Kaolinite proportions in these two formations appear to be in the moderate to high range (15%–35%), except for in the Cape May borehole, where the proportion of kaolinite is somewhat lower (0%–28%). We infer that the moderately high levels of kaolinite found in these two units may result in part from continued warm/wet climatic conditions through this part of the Miocene.

SUMMARY AND CONCLUSIONS

The presence of a significant proportion of kaolinite in the Absecon Inlet and Sewell Point Formations probably reflects a warm, wet terrestrial climate during the late Eocene and early Oligocene in the northern Atlantic Coastal Plain. Kaolinite is also dominant in part of the Kirkwood Formation (Brigantine, Shiloh Marl, and Wildwood), again suggesting warm and wet conditions during the early and early middle Miocene. Because the Atlantic City Formation has very little kaolinite, the Oligocene appears to have been a relatively cool and dry time.

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