2. LITHOLOGY AND CLAY MINERALOGY OF THE SEDIMENTS FROM SITE 336, DSDP LEG 38

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INTRODUCTION

Site 336 was drilled through a series of Cenozoic deposits and penetrated basalt (Figure 1). The total penetration was 515 meters. The sedimentary series to a depth of 463 meters was studied. Available were 122 samples from sedimentary series and six samples from the al-tered basalt zone. Basically the purpose of the study did not include the basalt, therefore, the following section is a very brief characterization of the samples from this zone. However, we would like to note that redeposited disintegration products of the altered basalts are present in the sedimentary series.[1]

ALTERED EXTRUSIVE ROCKS

Altered basalt was recovered from the 472-482 meter interval (Cores 39, 40). The lower 4 meters (Samples 1113, 1112) are composed of a dark, greenish-black, friable rock, in which the relict primary structure is clearly seen. The matrix consists of diversely oriented small plagioclase laths with the spaces between them being filled with glasses, ore minerals, and pyroxene. Nearly all the plagioclases are entirely replaced by montmorillonite, and there appears to be segregations of crystalline zeolite aggregates (clinoptilolite). Two meters above, a rock of a similar character is present (Sample 1111), but with less of a distinctly preserved primary structure, due to shapeless, diffuse areas of new montmorillonite units. Even higher (~2.0 m), the rock is mottled (dark green with brown spots) due to the presence of iron hydroxides and green montmorillonite areas (Sample 1110). The primary structure of the parent rock is no longer traceable. The upper 2 meters of the interval contain rocks (Samples 1109, 1108) with an intense red-brown color from iron hydroxides. Petrographic examination indicates that, for the most part, these areas represent montmorillonites permeated with iron hydroxides.

X-Ray Mineralogy

These samples were subjected to investigation by X-ray. The <0.001 mm fraction was decanted and analyzed (Table 1). Zeolite was isolated and identified by X-ray.

In Samples 113-110, which characterize the lower 7.5-8 meters of the basalt section, the predominant (more than 90%) component is montmorillonite, which has an increased content of iron in octahedral positions. The high iron content is emphasized by the absence of reflection with d = 4.8Å in the diffraction patterns of preheated preparations, and by a complete dissolution of the mineral in muriatic acid. Another feature of the montmorillonite is a good crystallization, recorded in diffraction patterns by an integer series of distinct sharp reflection with $d_{(001)}$=17.6-17.8Å in a glycerine-saturated preparation. In samples from the upper part of the basalt section (Samples 1109, 1108), montmorillonite remains ferruginous, but is badly crystallized, and has an abnormally high d value of 19.2 to 18.9Å in the diffraction pattern of the glycerine-saturated preparation.

Analyses of the <0.001 mm fraction and, particularly, the 0.010-0.001 mm fraction, isolated from the above samples, indicate the presence of zeolite of the clinoptilolite group. The zeolite yields a distinct series of reflections with d = 8.9Å, 7.97Å, 3.96Å, and 3.20Å.

It appears that the section under consideration consists of an extensively altered alkaline basalt. The overlying red clay, which does not exhibit features of the primary structure of the parent rock, may be a subaerial weathering crust. For the montmorillonitized and zeolitized basalt with a relict primary structure, it is uncertain whether it represents a deeper weathering zone or postvolcanic, hydrothermal transformation of the extrusive body.

SEDIMENTARY SERIES

The sedimentary section penetrated by Site 336 ranges in age from middle or late Eocene through Pleistocene. A study of samples from this section indicates that a number of features, such as external appearance, and color (in dry state), permit subdivision of the section into three main series (units), each of which can be further subdivided into subseries (subunits). In some parts of the section, it is possible to further single out characteristic packets and groups of layers.

Series 3 (Cores 20-37)

Series 3 (Samples 1044-1107) represents the lower part of the Cenozoic (Oligocene-Eocene, 220-454 m). It is 234 meters thick and differs considerably from the two overlying series. It is also possible to distinguish four lithologic subseries (subunits) with some common features justifying their interpretation as belonging to one series.

[1]For the purposes of this paper, the sediments have been grouped into "series" (Figure 2). The "series" do not necessarily correspond to "units" as defined by shipboard sedimentologists (see Site Report chapter, this volume). Also, the sediment terminology is that of the authors, and may not correspond to shipboard designations. Sample numbers are those assigned by the authors for the investigations.

AGE	DEPTH SERIES, SUBSERIES (m)	LITHOLOGIC COLUMN	CORE	SECTION, INTERVAL (cm) AND SAMPLE NO. (GIN)	THICKNESS OF SERIES (m)	LITHOLOGIC DESCRIPTION OF SERIES
PLIO. to PLIO.-PLEISTOCENE	I		1	20, 70-72 (1001)[a]; 2, 140-142 (1001); 3, 80-82 (1002); 4, 100-102 (1003); 5, 120-122 (1004)		Mostly dark, bluish-gray unsorted sandy-silty-clayey tuffaceous rocks; in interbeds in crystalline and vitroclastic tuffs; subordinate interbeds make up silty clays with spots of brown colloidal organic matter, with dispersed pelitomorphic carbonate; in interbeds and accumulations of foraminifera shells; many fragments of brown volcanic glass, basalt; in a heavy fraction are grains of pyroxene, magnetite, leucoxenized ilmenite; there are also grains of zircon, pink garnet; especially characteristic is the detrital material: it is purely polymictic, terrigenous: fragments of quartzites, quartzite sandstones, metamorphic shales, limestone; terrigenous material was supplied into sediments during ice-rafting.
			2	1, 110-112 (1005); 2, 60-62 (1006)[a]; 2, 80-82 (1006); 4, 110-112 (1007)		
			3	1, 80-82 (1008); 2, 80-82 (1009)		
			4	2, 46-48 (1010)		
			5	1, 120-123 (1011); 2, 55-57 (1012); 3, 89-81 (1013); 4, 103-105 (1015); 5, 44-46 (1015); 6, 74-76 (1016)		
			6	1, 14-16 (1017)[a]; 1, 84-88 (1017); 2, 85-88 (1017)5; 2, 113-114 (1017)[b]; 3, 62-64 (1018); 4, 73-75 (1019); 5, 126-128 (1020); 6, 58-60 (1021)		
			7			
			8	1, 79-81 (1022); 2, 58-62 (1023); 4, 90-92 (1025); 6, 47-49 (1026)[a]; 6, 84-86 (1026)		
			9	1, 139-141 (1027); 3, 89-91 (1028); 5, 87-89 (1029)		
			10	1, 81-83 (1030)		
			11	2, 68-70 (1031); 3, 68-70 (1032); 4, 68-70 (1033)		
			12	1, 87-84 (1034); 2, 58-60 (1035)		
	~159		13			
OLIGOCENE	II		14		~58	Light, pale yellow gray below, greenish-gray tuffaceous clayey silts and silty sands above; abundant fragments of volcanic glass (0.10-0.20 mm sized), skeletal remains of siliceous sponges, presence of authigenic glauconitic grains (sand size); rocks are carbonate-free, poor in plant remains; in the heavy fraction pyroxene prevails over ore and other grains; clay matter is monomineral-montmorillonite ferruginous, poorly crystallized, authigenic.
			15	1, 56-58 (1036)		
			16	1, 119-125 (1037); 4, 80-84 (1038); 6, 40-44 (1038)[a]		
			17			
			18	3, 70-72 (1039); 4, 100-110 (1040)		
	~216		19	2, 90-82 (1041)		
	III_1		20	1, 80-82 (1042); 2, 75-77 (1043); 3, 75-77 (1044); 4, 75-77 (1045); 5, 75-77 (1046); 6, 75-77 (1047)	~40	
			21	1, 75-71 (1048)[a]; 1, 118-120 (1048); 2, 75-77 (1049); 3, 75-77 (1050);4,75-77(1051);5,75-77(1052);6,75-77(1053)		
			22	1, 64-66 (1054); 2, 94-96 (1055); 3, 96-98 (1056); 4, 96-98 (1057); 5, 96-98 (1058); 6, 86-88 (1059)		
			23	1, 79-81 (1060); 2, 79-81 (1061); 3, 79-81 (1062)		
EOCENE	III; III_2		24	1, 79-81 (1063); 2, 79-81 (1064); 3, 79-81 (1065); 4, 79-81 (1066); 5, 79-81 (1067); 6, 79-81 (1068)	~50	Dark gray with a greenish-brown clay rocks; a small admixture of arenaceous-silty material (mostly fragments of basalt rocks, montmorillonitized tuffs); coal particles, colloidal humus, pyrite are constant. The heavy fraction contains ore grains, zircon, pyroxene, amphibole, apatite, garnet, chloritoid, epidote; presence of authigenic zeolite is characteristic.
			25	1, 109-111 (1068)[a]; 3, 109-111 (1069); 6, 109-111 (1070)		
			26	1, 99-101 (1071); 3, 109-111 (1072); 6, 109-111 (1073)		
			27	1, 27-29 (1074); 3, 27-29 (1075); 6, 27-29 (1076)		
			28	1, 86-90 (1077); 3, 110-114 (1078); 6, 111-116 (1079)		
	III_3				~56	
			29	2, 111-118 (1080)		
			30	1, 120-122 (1081); 2, 110-112 (1082); 3, 99-101 (1082); 5, 58-60 (1084); 6, 109-111 (1085)		
			31	1, 111-113 (1086); 2, 75-77 (1087); 3, 75-77 (1088)		
	III_4					
			32	1, 120-122 (1089)		
				1, 100-102 (1090); 2, 81-83 (1091); 3, 78-80 (1092); 4, 75-77 (1093); 5, 75-77 (1094); 6, 75-77 (1095)		
			33			
			34			
			35	1, 74-76 (1096); 2, 86-88 (1097); 3, 62-66 (1098); 4, 74-77 (1099); 5, 122-125 (1106)		
			36	1, 136-138 (1101); 2, 64-65 (1102); 3, 52-53 (1103); 4,122-124 (1104): 5, 34-36 (1105); 6, 38-40 (1106); 6, 123-125 (1106)[a]		
				1, 83-85 (1107)		
	~464		37			
			38			
	BASALT		39	1, 99-103 (1108); 2, 103-105 (1109); 3, 84-86 (1110); 4, 88-90 (1111); 5, 124-126 (1112)		
			40	1, 133-135 (1113)		
			41			
			42			
			43			
			44			

Figure 1. *Lithologic-mineralogic summary, Site 336.*

LITHOLOGIC-PETROGRAPHIC DESCRIPTION OF SUBSERIES	LAYERS	DESCRIPTION OF CLAY AND AUTHIGENIC MINERALS	ASSOCIATIONS OF CLAY AND AUTHIGENIC MINERALS
	Foraminiferas	Characteristic polymineral composition. The main component in montmorillonite of various degree of ferruginicity (50-60%); middle part of the member contains "montmorillonite-hydromica" with 20% micaceous beds; in the lower part of the member the montmorillonitic mineral is poorly crystallized; chlorites differ in degree of imperfection; hydromicas (20-35%) yield up to 20% of labile montmorillonitic beds; kaolinite content 10-20%.	Kaolinite-chlorite-hydromica-montmorillonite.
	Accumulations of authigenic glauconite.	Composition of a clay fraction is monomineral, represented by a very badly crystallized montmorillonitic mineral (100%); traces of terrigenous minerals.	Siliceous-montmorillonite
An admixture of sandy particles (basalt fragments, altered tuffs, clay balls) increases upwards; in interbeds in sedimentation breccia; clay excretions are typical.	Phillipsite	Persistent presence of clinoptilolite combined with montmorillonitic mineral (85-90%), very poorly crystallized. Presence of hydromica, kaolinite and chlorite from 0-5-10%. Hydromica contains up to 20% of labile montmorillonitic beds. Chlorites differ in degree of imperfection.	Clinoptilolite-montmorillonite (admixture of hydromica, chlorite, and kaolinite).
Pelitomorphic homogeneous clays with authigenic pyrite and irregular accumulation of phillipsite.		The main component (75-80%) in mixed-layered mineral montmorillonite-hydromica containing from 10-30% micaceous beds; considerable amounts of hydromica (5-15%) from 20-25% of montmorillonitic beds. Phillipsite is peculiar to some samples; chlorite content (imperfect and perfect) is insignificant.	Mixed-layered montmorillonite-hydromicaceous (admixture of hydromica, chlorite, kaolinite, sometimes phillipsite).
Clastic texture of clay mass; authigenic phillipsite characterized by presence of dark green glauconite consisting of the mixed-layered phase "hydromica-montmorillonite" (20% montmorillonite packets) and pure ferruginous montmorillonite.	Accumulations of authigenic glauconite.		
Clastic texture of clay mass, abundance of plant organic matter pyrite; there is gypsum in interbeds in accumulations of sandy material, ferruginous concretions, abundance of phillipsite.	Tuff with phillipsite.	The main component in mixed-layered mineral montmorillonite-hydromica (90%); characteristic is constant presence (5-10%) of phillipsite, its amount increasing in the 0.01 fraction; a hydromica admixture is insignificant; no chlorite and kaolinite.	Phillipsite-mixed-layered-montmorillonite-hydromicaceous.
		The main component in montmorillonite (90%), well crystallized in the lower part, but poorly crystallized in the upper part, clinoptilolite is representative.	Clinoptilolite-montmorillonite.

Figure 1. *(Continued)*.

TABLE 1
Data of the X-Ray Analysis of Clay Minerals (Fraction: <1 and <10 mk), Site 336

Depth (m)	Sample (Interval in cm)	No. of Sample "Gin"	Size of Fraction (mm)	Zeolites	Montmorillonitic Minerals	Micaceous Mineral	Chlorite	Kaolinite	Association of Clay and Authegenic Minerals	Age
290-292	1-2, 140-142	1001	<0.001	Absent	Ferruginous and aluminic	Al-hydromica 1 Md with 20% montmorillonite beds	Perfect	Contained as an admixture (10-20%)	Kaolinite (10-20%)-chlorite (10-25%)-hydromica (20-30%)-montmorillonite (50-60%)	Pliocene and Plio-Pleistocene
7.20-7.22	1-5, 120-122	1004								
10.10-10.12	2-1, 110-112	1005	0.01			Illite without montmorillonitic beds				
11.30-11.32	2-2, 80-82	1006	<0.001		Aluminic, mixed-layer, with 10-15% micaceous beds	Al-hydromica 1 Md with 20% montmorillonite layers	Imperfect			
17.30-17.32	3-1, 80-82	1008			Ferruginous, mixed layer with 10-15% micaceous beds	The same	Perfect			
27.96-27.98	4-2, 46-48	1010			Aluminic-ferruginous		Imperfect			
36.70-36.73	5-1, 120-123	1011			Almunic-ferruginous mixed layer with 20-25% micaceous beds					
41.03-41.05	5-4, 103-105	1014					Perfect			
52.26-52.28	6-5, 126-128	1020								
64.79-64.81	8-1, 79-81	1022	<0.001	Absent	Ferruginous, poorly crystallized with abnormally high value of *d*-reflec on diffractogram of a specimen saturated with glycerine	Al-hydromica 1 Md with 20% montmorillonite beds	Perfect	Contained as an admixture (10%)		
74.89-74.91	9-1, 139-141	1027			Ferruginous		Imperfect			
93.31-93.33	10-1, 81-83	1030			Ferruginous, poorly crystallized with abnormally high value of *d*-reflec on diffractogram of a specimen saturated with glycerine		Perfect			
113.68-113.70	11-2, 68-70	1031				Illite				
132.08-132.10	12-2, 58-60	1035	<0.001	Absent		Illite (traces)	Perfect (traces)	Not found	Siliceous-montmorillonitic (100%)	Oligocene (late?) and Pliocene
169.06-169.08	15-1, 56-58	1036								
183.30-183.34	16-4, 80-84	1038	<0.01			Not found	Not found			
185.90-185.94	16-6, 40-44	1038a	<0.001							
		1040b	<0.01			Al-hydromica 1 Md with 20% montmorillonite beds				
208.40-208.42	19-2, 90-92	1041	<0.001			Not found				
216.8-216.82	20-1, 80-82	1042								
221.25-221.27	20-4, 75-77	1045	<0.01	Clinoptilolite	Aluminic-ferruginous	Illite	Not found	Traces	Clinoptilolitic montmorillonitic (~85-90%); admixture of hydromica, chlorite, and kaolinite (~0-5-10%)	
224.25-224.27	20-6, 75-77	1047	<0.001		Aluminic-ferruginous, poorly crystallized, with abnormally high *d*-reflec on diffractogram of a specimen saturated with glycerin	Al-hydromica 1 Md with 20% montmorillonite beds				
233.27-233.25	21-6, 77-75	1053		Not found			Perfect (traces)			
237.44-237.46	22-2, 94-96	1055		Clinoptilolite						
243.36-243.38	22-6, 86-88	1059					Not found			
244.79-244.81	231, 79-81	1060	0.01							
247.79-247.82	23-3, 79-82	1062	<0.001	Not found			Imperfect			
252.29-259.31	24-4, 79-81	1066	<0.01	Not found	Ferruginous, mixed layer with 10-15% micaceous beds	Al-hydromica with 20% montmorillonite beds	Imperfect			Late Eocene
260.79-260.81	24-5, 79-81	1067	<0.001		Ferruginous, mixed layer, with 30% micaceous beds	Al-hydromica 1 Md with 25% montmorillonite beds				
267.09-267.11	25-3, 106	1069		Clinoptilolite						
273.99-274.01	26-1, 99-10	1071		Phillipsite						

TABLE 1 – *Continued*

Depth (m)	Sample (Interval in cm)	No. of Sample "Gin"	Size of Fraction (mm)	Zeolites	Montmorillonitic Minerals	Micaceous Minerals	Chlorite	Kaolinite	Association of Clay and Authegenic Minerals	Age
282.27-282.29	27-1, 27-29	1074		Not found	Ferruginous, mixed layer with 10-15% micaceous beds	Al-hydromica 1 Md with 20% montmorillonite beds	Perfect	Traces	Mixed-layered montmorillonite-hydromicaceous (admixture of hydromica 5-20%, chlorite, kaolinite 5-10%, sometimes phillipsite)	Late Eocene
285.27-285.29	27-3, 27-29	1075			Ferruginous, mixed layer with 30% micaceous beds	Al-hydromica 1 Md with 25% montmorillonite beds				
292.86-292.90	28-1, 86-90	1077	<0.01	Phillipsite	The same as sample 1074	The same as sample 1074				
298.61-298.66	28-6, 111-116	1079	<0.001	Not found	Ferruginous, poorly crystallized, with abnormally high value of *d*-reflec on diffractogram of a specimen saturated with glycerine	Al-hydromica 1 Md with 20% montmorillonite beds				Middle or late Eocene
331.20-331.22	30-1, 120-122	1081			Ferruginous, mixed layer with 10-15% micaceous beds					
336.58-336.60	30-5, 58-60	1084	<0.01	Phillipsite						
350.11-350.13	31-1, 111-113	1086	<0.001		Ferruginous, mixed layer, with 20% micaceous beds		Not found	(5-10%)		
352.75-352.77	31-3, 75-77	1088								
369.20-369.22	32-1, 120-122	1089	<0.001	Not found	Ferruginous, mixed layer with 10-15% micaceous beds	Al-hydromica 1 Md with 20% montmorillonite beds	Not found	Not found	Phyllipsite mixed-layer montmorillonite-hydromicaceous (90%)	Middle or late Eocene
388-388.02	33-1, 100-102	1090	<0.01	Phillipsite	Mixture of ferruginous and alumnic-ferruginous	Illite				
393.77-393.75	33-5, 77-75	1094	<0.001 <0.01	Not found	Ferruginous, with an admixture of mixed layer, with 10-15% micaceous beds	Not found Al-hydromica 1 Md with 20% montmorillonite beds	Not found	Not found		
425.74-425.76	35-1, 74-76	1096	<0.001 0.01	Phillipsite	Ferruginous, mixed layer with 10-15% micaceous beds	Not found				
435.86-435.88	36-1, 136-138	1101	<0.001 0.01		Ferruginous, mixed layer with 30% micaceous beds					
440.22-440.24	364-122-124	1104	<0.001		Ferruginous, poorly crystallized, with abnormally high value of *d*-reflec on a diffractogram of a specimen saturated with glycerin			Present 10%		
443.23-443.25	36-6, 123-125	1106a			The same as Sample 1101					
453.83-453.85	37-1, 83-85	1107	<0.001	Clinoptilolite	Ferruginous, poorly crystallized, with abnormally high value of *d*-reflec on a diffractogram of a specimen saturated with glycerin					
472.99-473.03	39-1, 99-103	1108	<0.001	Clinoptilolite		Not found	Not found	Present (5-10%)	Clinoptilolite-montmorillonite (90%)	Basalt
474.53-474.55	39-2, 103-105	1109								
475.84-475.86	39-3, 84-86	1110	<0.001		Ferruginous	Al-hydromica 1 Md with 20% montmorillonite beds (traces)	Not found	Not found		
477.38-477.40	39-4, 88-90	1111								
479.24-479.26	39-5, 124-126	1112								
483.33-483.35	40-1, 133-135	1113	0.01							

Deposits of this series consist of sandy silty clays. They are dark gray with a greenish-brown tinge. The brownish color is a particular characteristic for the lowest part of the series (Subseries 3_4). The dark color is largely attributable to scattered organic (vegetable) matter. For the most part, it consists of a fine carbonaceous detritus and colloidal humus. Shreds of higher plant tissues with a preserved cellular structure are present. Pyrite is regularly present in the form of spherical grains and irregular aggregates, and pyritization of vegetable remains is often noticeable. Siliceous skeletal remains and fragments of sponge spicules are nearly absent, and calcareous shells are very rare.

A very uniform composition is present for the heavy mineral fraction. The 0.10-0.05 mm fraction has a marked predominance of ore components (up to 100%) consisting of pyrite, or (in a variable quantity) pyrite with magnetite, leucoxenized ilmenite, and iron hydroxides. There are also single grains (rarely more than 5%-10%) of zircon, monoclinic pyroxene, hornblende, apatite, chloritoid, garnet, and minerals of the epidote group. Generally, the rocks are free of any constant admixture of a considerable amount of pyroclastic material, however rare single fragments of transparent acid volcanic glass are present. However, the series has three distinct thin ash tuff layers (montmorillonitized and zeolitized), containing authigenic zeolite (phillipsite and clinoptilolite).

Subseries 3_4 (Cores 32-27)

It has a thickness of about 75.7 meters (368.0-453.5 m) (Samples 1107-1089). Grain size analyses indicate they are sandy silty clays, however petrographic analysis shows that the clay matrix is composed of clastic material. It appears to be a mixture of clay detritus, coal microparticles, and iron hydroxides. Fragments of the clay aggregates differ in microstructure, color shades, and iron content. Among the clay aggregates, one can distinguish fragments of brownish montmorillonite and ochreous basic basalt, light green nodular pieces (usually smooth-contoured) of montmorillonitized tuffaceous rocks (Figure 2), and fragments of sedimentary claystones (with scattered carbon dust). Also present are clay pellets aggregated in situ by organic activity.

Immersed in this nonuniform, microbreccia clay mass are sand and silt-sized particles of feldspars, quartz, altered basalt fragments, and rounded, acid extrusive fragments. Often the fragments enrich individual clay layers (e.g., Samples 1106, 1105, 1100), or appear as randomly scattered rare inclusions.

Rocks of this subseries contain a great deal of pyrite, crystalline gypsum, and carbonaceous detritus including colloidal humus matter and shreds of tissues from dry land vegetation. The deposits, especially in the lower horizons (Cores 36, 37), are typically characterized by a presence of oval and isometric ferruginous concretions (0.5 and 0.15 mm). These are brown and massive, with polished glossy or fissured opaque surfaces. Usually these ferruginous units are accompanied by sand size quartz grains and rock fragments covered by a glossy iron-bearing crust (Figure 3). Some biogenic clay pellets and rounded clay pieces are covered with thin iron films, as well as by a network of fissures.

Finally, a characteristic feature of the subseries is an abundance of authigenic zeolite segregations. Aggregates of very small (0.2-0.01 mm) well-formed monoclinic zeolite crystals permeate the clay matrix filling the pores and developing around clastic grains. The mineral has a low birefringence and, therefore, appears isotropic in very small crystals. X-ray data indicate the zeolite belongs to the phillipsite group, and at the base of the subseries (Sample 1107), to clinoptilolite.

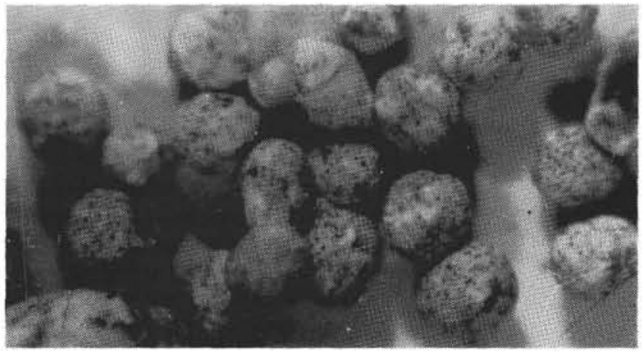

Figure 2. *Light green nodular pieces of montmorillonitized tuffaceous rock. ×46.*

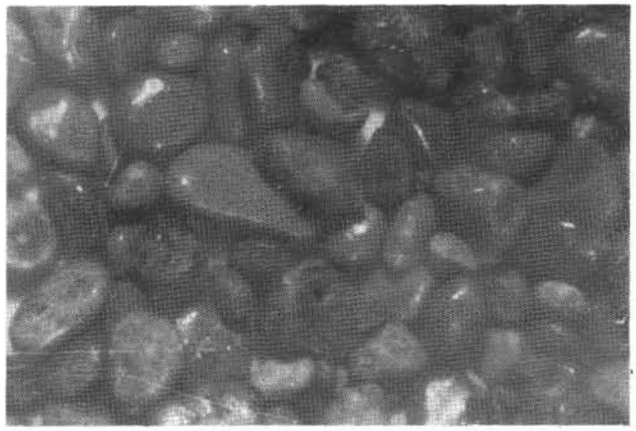

Figure 3. *Rock fragments covered by a glossy iron-bearing crust. ×45.*

Fractions (<0.001 mm) separated from rocks of subseries 3_4 were subjected to X-ray investigation. Despite the fact that the clay component is obviously clastic and includes variously shaped clay fragments, the mineral composition is not particularly varied. There is a predominance of an iron-bearing mixed-layer mineral (montmorillonite-hydromica) which contains from 10%-15% to 30% of randomly distributed mica layers. The mixed-layer character of the mineral is recorded in diffraction patterns of glycerine-saturated preparations. The patterns merge into a wide diffuse reflection of a continuous spectrum from d = 8.8Å to 9.8Å.

In the clay fraction (<0.001 mm) of the upper part of Subseries 3_4 (Samples 1089, 1090, 1096), traces of hydromica containing up to 20% montmorillonite layers are present. In the 0.010-0.001 mm fraction (Sample 1094), illite was present without expandable layers and, therefore, retaining in the diffraction patterns of glycerine-saturated preparations an integer series of reflections with $d_{(001)}$ = 10Å.

Another characteristic feature of the <0.001 mm fraction is a presence of phillipsite, a zeolite with strong sharp reflections of d = 7.0Å and d = 3.17Å on the diffraction patterns of the untreated sample. In Core 37, Sample 1107 contains, in the <0.001 mm fraction, a zeolite of the clinoptilolite group, which is typical of rocks of the underlying basalt series.

Thus, the rocks of Subseries 3_4 are characterized by the association: mixed-layer phase of montmorillonite-hydromica with phillipsite. The variation of features lower in the section suggests a basis for subdividing the subseries into two packets.

Lower Packet

The lower packet (Samples 1107-1102) has a thickness of 19 meters (434.5-453.5 m). Sandy clays dominate (with a sand content up to 40%) and contain iron ooids. The content of the iron ooids in the 0.5-0.25 mm fraction attains 50%. In several, extremely clayey layers (Samples 1104, 1102), there is a great deal of scattered organic matter (C_{org} is within the limits 1.26%) and some humusified clay aggregates, which give the deposits a micronodular texture. Near the upper boundary of the packet there is a layer of montmorillonitized and zeolitized ash tuff almost without any preservation of its primary ash structure (Sample 1101, 435.9 m).

Upper Packet

The upper packet (Samples 1100-1089), with a thickness of 56.5 meters (368.0-434.5 m), is characterized by a gradual decrease down section in the amount of vegetable detritus, iron concretions, and an increase in clastic clays and pieces of light green montmorillonitized tuffaceous rocks (with relics of ash structure).

Subseries 3_3 (Cores 29 to 31)

The subseries is 47 meters thick and is present in the interval from 311.0 to 358.5 meters (Samples 1088-1081). It is composed of deposits largely similar to those of the underlying subseries (3_4). The sediments are dark gray greenish-brown-tinged clays with a non-uniform admixture of sandy particles of feldspars, quartz, basalt fragments, and acid vitroclasts. The rocks have abundant authigenic zeolite, the clay matrix has a clastic texture. Iron concretions, characteristic of the lower subseries, are absent, and among the clastic clay fragments of light green montmorillonitized tuffs are present. Rare basalt fragments are present, and the content of scattered carbonaceous detritus is lower. A principal and characteristic feature of subseries 3_3, are concretions of dense green glauconite-like matter (Samples 1086, 1084). The concretions (0.50-0.20 mm) have an isometric and irregular shape, but with rounded surfaces. Many concretions are coated with iron oxides on their surfaces and, as a rule, covered by a network of fine shrinkage fissures (Figure 4). This may indicate a colloidal nature for the primary matrix of these concretions.

Petrographically, the concretions resemble glauconite. The concretions (in thin sections) have smooth and bay-like outlines because of syneresis fissures. Under crossed nicols, an aggregate polarization is seen, and the interference color is the tinged green mineral color. According to X-ray data, however, the concretions consist of mixed-layer montmorillonite-hydromicaceous phase (20% mont.), and iron montmorillonite.

The composition of the clay fraction of the subseries is identical to that of the lower subseries (3_4). The main component (80%) is an iron mixed-layer mineral

Figure 4. *Grains of glauconite covered by a network of fine drying (shrinkage) fissures.* ×25.

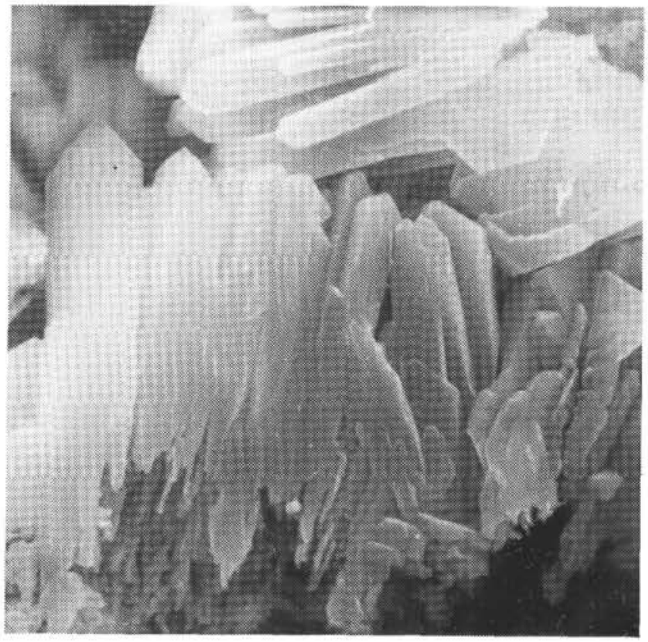

Figure 5. *Phillipsite crystals.* ×2850.

(montmorillonite-hydromica). It contains 10% or 15%, and frequently as much as 30%, micaceous nonexpandable layers. Phillipsite is present in the clay fraction of many samples (Figure 5).

Subseries 3_2 (Cores 24 to 28)

The subseries is 44 meters thick (254.8-298.7 m) and consists of deposits (Samples 1079-1063) substantially differing from those of the lower two subseries. The subseries consists of dark gray greenish-tinged clays, which are no longer characterized by a clastic texture of clay matrix. The sediments are composed of a pelitomorphous clay material, generally rather uniform, with uniformly scattered fine carbonaceous detritus. In most cases, the clay shows a secondary micronodular texture (Figure 6) associated with bioturbation. However, in some places relics of a primary texture are preserved thin, horizontal lamination, emphasized by an optically

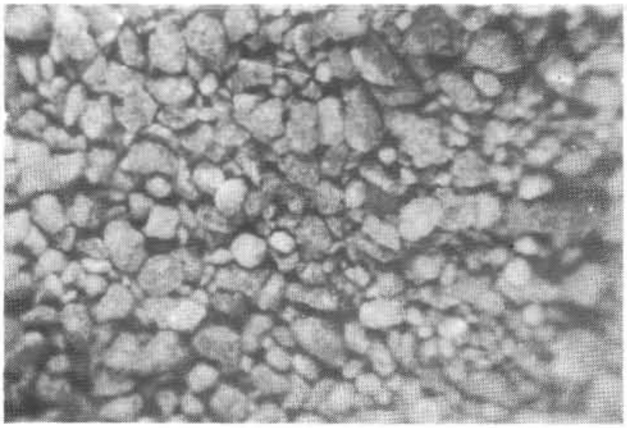

Figure 6. *Secondary micronodular texture of the clay mass.* X23.

oriented arrangement of clay and coal particles. This may be an indication of rather quiet sedimentation conditions for the pelitomorphous material. Silt and sand grains are present in the clays. They form sparse inclusions, but more often accumulate in separate thin layers. Amid the clastic material is a large amount of pieces of light greenish montmorillonitic tuffs, basalt fragments, acid vitroclasts, grains of plagioclases and quartz, and rounded clay pellets. At times, the clays are so enriched by these clay clots that they acquire a microbreccia-like texture (Sample 1074). At a depth of 267.1 meters, the layer is especially saturated with sandy material and includes scattered, small pebbles.

In the heavy mineral fraction of the subseries ore grains still prevail, among which are pyrite, magnetite, and leucoxenized ilmenite. Also present are: monoclinic pyroxene, hornblende (from single grains to 5%), zircon, apatite, garnet, and chloritoid grains.

Authigenic phillipsite is constantly present in forming small isolated aggregates. The main component of the thin clay fraction of this subseries is an iron mixed-layer montmorillonite-hydromica, containing from 10%-15% to 30% nonexpandable mica layers. In some samples, a very poorly crystallized Fe-montmorillonite is found. In the diffraction patterns of glycerine-saturated preparations (Sample 1079), it is identified by an abnormally high value of the first small-angle basal reflection of 19.4Å. Hydromica, in whose structure up to 20%-25% montmorillonite layers are present, is regularly present (5%-15%). In some samples, the hydromica content is 20%-25%. Minor admixtures of kaolinite and chlorite (traces, 5%-10%) were noted. Chlorite, in most samples, has crystallochemical features indicating that it is recent and well crystallized. It is resistant to thermal treatment, and in the diffraction patterns of preparation preheated to 550°C, it retains the chlorite peak (d = 14Å-14.3Å). In the upper part of the subseries, a defective chlorite is present. In the diffraction patterns of preheated preparations, it is indicated by a reflection in the range of d = 13.5Å.

Subseries 3_1 (Cores 20 to 23)

The thickness of the subseries is 38 meters (216-254 m). Its main component is clay, which is dark gray and slightly greenish. Fine carbonaceous detritus is scattered uniformly through it, and shapeless pyrite segregations as well as single fragments of sponge spicules and small nests of zeolite are present.

The subseries contains two distinct ash layers. One is present at a depth of 248.3 meters. The second, between 235.6 and 237.4 meters, is a montmorillonitized and zeolitized tuff with a clear vitroclastic structure. Only the outer outlines of some glass fragments have been preserved, with crystalline aggregates of zeolite segregated inside them as microdruses.

Spaces between the glass fragments are filled with cryptocrystalline montmorillonite. X-ray data indicate that the montmorillonite is iron containing and well crystallized, with a reflection of 17.6Å (in glycerine-saturated preparation) (Figure 7).

In the lower part of the subseries up to the tuff, the clays are very homogeneous with a small content of silty particles and sparsely scattered sand grains. The clay matter is pelitomorphous and fine scaled; in some places, a similar optical orientation of clay particles is observed, which together with the corresponding position of coal particles, underscores a fine horizontal lamination of the initial sediment. This primary texture is usually bioturbated. The deposits contain aggregate inclusions of zeolite and pyrite segregations with an irregular shape. X-ray data indicate that the <0.001 mm fraction largely consists (up to 90%) of a ferruginous, poorly crystallized montmorillonite mineral, whose crystal features are evident in diffraction patterns of glycerine-saturated preparations. These are characterized by a low-contrast broad reflection in the low-angle region with abnormally high spacings of the order of 18.2-19.0Å. The reflection is often recorded in the diffraction pattern as a "plateau" with a constant intensity. After processing the fraction with soda, repeated X-ray studies indicated a normal montmorillonitic reflection

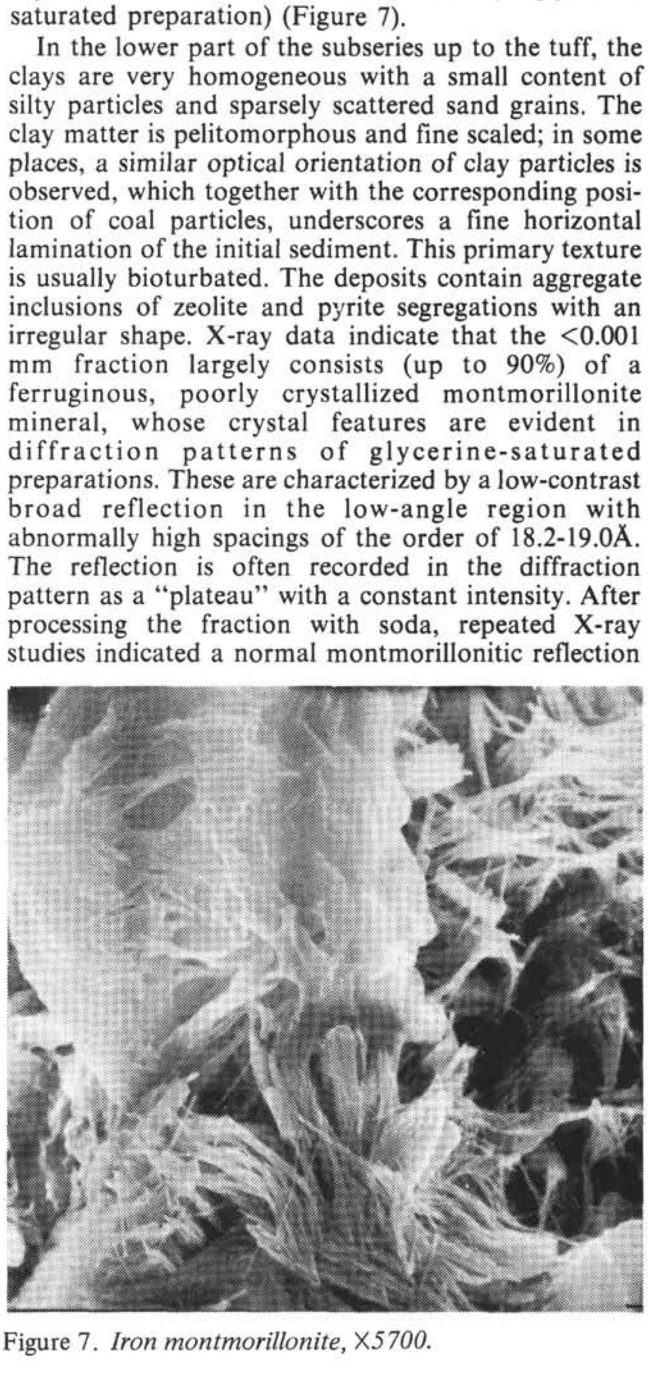

Figure 7. *Iron montmorillonite,* X5700.

in the low angle region. It is presumed that the abnormally high spacing values (d =19.0Å) are due to the presence of absorbed amorphous silica. Besides montmorillonite, the clay fractions contained hydromica in 20%-25% of the montmorillonite layers; its quantity normally was not greater than 5%, reaching 10% only at the base of the subseries. Diffraction patterns also show traces of kaolinite and chlorite (perfect and defective).

The second ash layer gives way to overlying clays of the same nature—pelitomorphous, fine scaled, with scattered coal powder, zeolite nodes, and noticeable (Samples 1045, 1046, 1049, 1050, 1052) admixtures of sandy and coarse-grained material. Pieces of basalt, pale green montmorillonitized tuffaceous rocks, acid extrusives, quartzites, grains of quartz and feldspars with clay rounded pellets (of a local origin) are so abundant in some clay layers that they give rise to a microbreccia-like rock texture. In some samples there are single, but very large, fissured, light green glauconite grains.

Typical of all rocks of the subseries is a low content of the heavy fraction and a uniform mineral composition. Ore minerals present include pyrite, magnetite, and leucoxenized ilmenite. Other minerals, as single grains, are: pyroxene, hornblende, zircon, garnet, chloritoid, apatite, and epidote with censite. Among the accessory admixtures of vitroclastic tuff, grains of leucoxenized ilmenite prevail (85%), as well as pyrite (5%-10%) and, in single grains, magnetite, zircon, monoclinic pyroxene, and sphene.

Series 2 (Cores 14 to 19)

Series 2, in the interval from 159 to 216 meters, has a thickness of 57 meters. The upper boundary of this series has been somewhat nominally determined as no samples are available from the interval with its contact with Series 1 (Cores 13 and 14). However, the deposits of Core 14 are classified with Series 2, as they contain up to 30% glauconite. This is a very characteristic mineral of the deposits of Series 2. The sediments of this series have a light color: in the lower part of the section, they are predominantly yellowish-gray and in the upper part, gray with olive-green shades. By size designation, the deposits are clay siltstones and fine-grained silty clayey sands. All sediments are tuffaceous.

The main characteristics of the series are as follows: there is a characteristic content of pyroclastics (fragments of acid, less frequently, basic glasses, hornblende, pieces of basalt, fragments of prismatic pyroxene crystals, and plates of fresh brown biotite); an increased siliceous content due primarily to the presence of remains of siliceous organisms (sponges, diatoms, and Radiolaria) and to a partial decomposition of vitroclastic material; and authigenic glauconite, either in situ or slightly redeposited. The characteristics of the clay component are very specific. The clay matter is monomineralic, represented by iron montmorillonite and largely authigenic. The lower 19.8 meters of the section are composed of sediments (Samples 1040-1043), which can be described as tuffaceous spongolites, because of their content of vitroclastic material and sponge spicules.

Beginning at a depth of 195.7 meters and above, glauconite is a very dominant component. The grains are bright green and have a rounded irregular (but smoothly contoured) shape; open syneresis fissures are noticeable. Under crossed nicols, the glauconite has an aggregate polarization. The glauconite grains are usually larger than the average sizes of the quartz, feldspar, and other grains. The glauconite mass fills the channels in some sponge spicules.

In the vitroclastics, acid glasses predominate. There are also achromatic smooth and opaque-white, fibrous fragments and smaller amounts of fragments of vesicular brown basic glasses (n = 1.608-1.610). However, in the heavy fraction, which doubtlessly reflects the character of the pyroclastic material, the predominant mineral is monoclinic pyroxene (70%-85%); also present is magnetite, pyrite, single grains of zircon, rutile, chloritoid. It is possible that, initially, the quantity of basic glasses in primary sediments might have been larger, but during diagenesis part became altered thus relatively increasing the content of acid glasses.

The clay material of this series appears homogeneous, finely dispersed and point-polarizing. According to X-ray data, the <0.001 mm fraction consists almost entirely (more than 90%) of iron-containing, poorly crystallized montmorillonite with low-contrast, wide, often "plateau"-shaped reflections in the low-angle region with abnormally large spacings (d of the order 18.7Å and more than 19.2Å). This diffraction pattern of the mineral may be attributed to the presence of absorbed amorphous silica in the interlayers of the structure. After elimination of silica by soda treatment, spacing of low-angle montmorillonite reflection becomes normal.

The clay fraction in the middle part of the series (Samples 1038, 1038a) is represented by pure montmorillonite. In its upper part, this fraction contains a slight admixture of illite and perfect chlorite. In the lower part of the series, traces of mixed-layer hydromica-montmorillonite phase are present. The 0.010-0.001 mm fraction has the same composition as the <0.001 mm fraction.

Series 1 (Cores 1 to 13)

Series 1, about 159 meters thick (0-159 m), consists of a variety of lithologies (Samples 1000-1033). For the most part, these are bluish-gray, unsorted, sand-silt-clay tuffaceous rocks, replaced in thin interbeds by crystal-vitroclastic tuffs (Samples 1022, 1023, 1025). A subordinate role is played here by silt-clay sediments with a small sandy admixture, permeated by organic substance (Samples 1007, 1009). This series has three major distinctive features as compared with the two lower series. First, it contains sometimes rather abundant (Samples 1001, 1006a) well-preserved foraminifera shells (usually planktonic forms). In some thin layers, the clay matter is permeated with pelitomorphous carbonate (sometimes with coccolith relics). Second, the sediments are rich in basic (alkaline) pyroclastics, and contain basalt fragments, pieces of an opaque basic mass of hyalobasalts, angular fragments of brown basic glasses, feldspars, quartz, monoclinic pyroxene, fragments of acid extrusive, and achromatic glasses. Finally, the sediments contain a clastic material, which is present in varying proportions with pyroclastic material.

The clastics are polymictic, transported to the basin by ice-rafting. This terrigenous material includes fragments of quartzite, quartzitoid sandstones with regenerated quartz grains, microcline grains, and grains of acid plagioclases, cataclastic quartz, fragments of hornblende metamorphic schists, and limestones. In the heavy mineral fraction are garnet, amphibole, pyroxene, and epidote. Locally derived clastic material includes fragments of basalts (rounded), green montmorillonitized tuffaceous rocks (with glauconite grains and sponge spicules), and clay pellets.

The characteristics of Series 1 are very pronounced in the nature of their clay component. The clay is extremely polymictic, and represented by a kaolinite-chlorite-hydromica-montmorillonite association. The predominant mineral of the association is montmorillonite (~50%-60%) whose structural diversity is determined by variation in iron content of octahedral positions of 2:1 layers, the appearance (in some cases) of mixed-layer montmorillonite-hydromica phases (10%-15% of hydromica layers), and the degree of crystallization. An alternation of layers is observed in the series, with layers whose clay fraction contains more ferruginous montmorillonite alternating with those containing aluminum-rich ones. In the upper part of the series (Samples 1001-1004), two crystallochemical modifications of montmorillonite are present in the clay fraction: one rich in iron, the other, in aluminum. In the middle part of the series (Samples 1008-1014), generally mixed-layer phases of montmorillonite-hydromica are present. In the clay fraction of the lower part of the series (Samples 1022-1031), an iron montmorillonite mineral is present with an abnormally high reflection (18.2-18.9Å) in the diffraction pattern of the saturated sample.

Thus, a major feature of the clay composition of Series 1 is the constant, considerable (20%-35%) presence of mixed-layer hydromica-montmorillonite mineral of the modification 1 Md with 20% montmorillonite layers, and a relatively increased quantity of chlorite (10%-20%) and kaolinite (10%-20%). Chlorite is either perfect with d = 14.0-14.2Å, or defective, contracting during heating to 550°C to 13.6, 13.4, 13.2Å. Perfect chlorite generally dominates. Kaolinite is indicated by reflection with d = 7.14 and 3.56Å in the diffraction patterns of HCl-treated samples. Chlorite-kaolinite is present as a terrigenous component.

CONCLUSIONS

In summing up the lithologic-mineralogic studies of the sediments from Site 336, some generalizations can be given and some specific conclusions made.

1) The Eocene-Pleistocene deposits (greater than 460 m), deposited on a basaltic series are easily subdivided into three sharply differing series. Differences in the sequence reflect the corresponding changes in the timing of tectonic events, the characteristics of volcanic phenomena, and climatic conditions prevalent on the land masses. Within each series, separate subseries and groups of layers are defined, which emphasize details of the series.

Series 3 (lower) is represented by clay deposits with variable admixture of silt and sand. The clay matrix is pelitomorphic and contains a thin mixture of carbonaceous particles and brown colloidal humus. In the sandy silts are basalt fragments altered to varying degrees, grains of quartz, feldspars, fragments of montmorillonitized tuffaceous rocks, acid effusives, and claystones. Occasional pieces of limestone are noted. In the lower part of the series (Subseries 3_4), in individual layers, clay is particularly enriched by humus matter and displays a microclotted texture.

For the series as a whole authigenic zeolites (clinoptilolite and phillipsite) are very characteristic. In the interval from 311.0 to 358.5 meters the clay often contains aggregate grains of glauconite, either formed in situ or having undergone only a small amount of redeposition.

Series 2 (middle) has a thickness of 57 meters. It is essentially different compared with Series 3. The series is composed of light colored tuffaceous clay silts and sandy silts. The grain size characteristics are not a result of mechanical differentiation of the disintegrated material, but a result of the abundance of pyroclastic fragments of basalt and volcanic glass (silt-size), skeletal remains of siliceous sponges, and authigenic grains (sand-size) of glauconite.

These characteristics, plus the nature of the clay material define Series 2. The clay material is monomineral, ferruginous, badly crystallized, montmorillonite. Rocks of Series 2 are noncarbonaceous and do not contain an admixture of vegetable detritus. Deposits of this series are considered pelagic sediments.

Series 1 (upper) is about 159 meters thick. It is composed of blue-gray unsorted sandy silt-clay tuffaceous rocks, and contains crystal and vitroclastic tuff. Subordinate strata are composed of clay with spots of brown colloidal matter, with scattered pelitomorphic carbonate, and in places accumulations of foraminifera shells. Fragments of brown volcanic glass and of basalt are ubiquitous. In the heavy fraction are pyroxene, magnetite, leucoxenized ilmenite grains, as well as grains of zircon and pink garnet. The detrital material is particularly characteristic. It is very polymictic, terrigenous, with fragments of quartz, quartzite, metamorphic slate, and limestone. The terrigenous material was derived by ice-rafting. A second, no less important peculiarity of the upper series, is the presence of layers of primarily claystones with pelitomorphic carbonate, and coccolith tests. The latter are present throughout.

2) We suggest that the accumulation of the Cenozoic sediments was associated with tectonic activity since middle Eocene.

The impression seems to be that the lower series was formed in conditions of gradual deepening and that deposition began in shallow water. In this first period of sedimentation (the lower two subseries), periodic swampy conditions may have been present, which led to the accumulation of silt, rich in humus, pyrite, and gypsum. The damp and relatively warm climate favored the development on dry land of a thick vegetable covering, which insured the gradual influx of vegetable material into the depositional environment during the time of deposition.

The next series, as noted earlier, accumulated in a deep-water zone, where very little vegetable detritus and pelitomorphic, clastic clay material was deposited.

However, at this time there was the accumulation of pyroclastic, and in particular vitroclastic, material, as well as the remains of siliceous organisms.

As a result the tempo of sedimentation was increased, deposits accumulated which on the basis of grain size did not correspond to those which were usual for the facies. The abundance of fresh, siliceous volcanogenic material led to the active development of diagenetic processes. Fragments of nonstable basic (perhaps alkaline?) volcanic glass were dissolved, ferruginous montmorillonite formed (badly crystallized), and glauconite formed.

Towards the beginning of the formation of Series 1, drastic changes took place in the general climatic condition of the environs of the Norwegian Sea with the appearance of continental glaciers.

Therefore for the upper series of the section described there are two sharply distinguished lithologic rock types: unsorted sand-silt-clay and primarily clay, which are to a varying degree calcareous. An alternation of even more contrasting rock types analogous in age, is observed in the section from Site 337. There, unsorted sandy silty claystones alternate not only with claystones, but also with coccolith marls. Therefore, it seems that the calcareous containing deposits could have formed in an interglacial period when normal conditions for the accumulation of deposits were renewed for each facies. On this basis it is important to note that the calcareous rocks are found only in the upper series of Cenozoic age. They are observed in all sections studied from Sites 336, 337, 346, and 350).

In the case of Site 336 some rocks contain carbonate originally deposited. It is biogenous and consists of coccolith skeletons. In other rocks authigenic carbonate is present, which results from the diagenetic transformations of the coccoliths.

We share the opinion of the previous researchers that towards the beginning of the Pleistocene period the barrier between the Atlantic and Norwegian Sea waters ceased to exist. The warm current of the Gulf Stream began to exert a favorable influence on the development of nannoplankton and foraminifera.

3) Several authigenic components were noted particularly zeolites and glauconite. Zeolites are characteristic of the lower series (3). It is important to note that they are not only coincidental with layers of ashy tuff, but also widely developed in claystones without a visible admixture of pyroclastic material. Clay material (a mixed-layer phase of montmorillonite-hydromica) is pelitomorphic, is found associated with colloidal humus, and does not display postsedimentation changes. Therefore there is no basis for assuming that the appearance of zeolites was associated with the transformation of the clay. It is asserted that in such cases the formation of zeolites requires the presence of slightly dissolved alumosilicate pyroclastics.

The presence in the heavy fraction of the clays of semidissolved (with teeth-like edges) fragments of prismatic crystals of fresh monoclinic pyroxene also testifies to a former admixture of pyroclastic material.

In the claystone series studied phillipsite and clinoptilolite are present. Phillipsite is distributed through almost the entire series of Eocene clay, and only the upper part of the series (3_1) contains clinoptilolite. It is interesting to note that up to now it has been considered that the Miocene is the lower age boundary of distribution of phillipsite in oceanic rocks (Atlantic, Pacific, and Indian oceans). Thus, at least for the Norwegian Sea, this boundary goes down to the Eocene.

Authigenic glauconite exists in two stratigraphic horizons: in the Eocene (Subseries 3_3) and in the Miocene (Series 2). X-ray characterizations of these glauconites are diverse. Eocene glauconite consists, for the most part, of a mixed-layer phase of hydromica montmorillonite (about 20% montmorillonite layers) and has only an admixture of pure, ferruginous montmorillonite. In the Miocene glauconite ferruginous montmorillonite is prevalent, and the mixed-layer phase of hydromica montmorillonite has a subordinate role.