23. X-RAY MINERALOGY STUDY OF TERTIARY DEPOSITS, LEG 81, SITES 552–555[1]

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ABSTRACT

This X-ray mineralogy study of Tertiary samples recovered from Rockall sites permitted the definition of four mineralogical units and the tracing of the paleoenvironmental evolution in this region.

INTRODUCTION

The following mineralogical units were defined on the basis of our study:

Unit I (upper Paleocene) is characterized by the occurrence of quartz and feldspars as well as by that of clay minerals, namely smectite, illite, kaolinite, and chlorite. Deposits are of a quite marked detrital nature.

Unit II (lower Eocene) consists of sediments represented by plagioclase feldspars and zeolites; the major clay mineral components are smectites. These deposits suggest a sedimentation influenced by a basic volcanic environment. The presence of layers rich in kaolinite (Site 555) probably indicates terrigenous inputs developed under leaching warm climates.

Unit III (middle Eocene to middle Miocene) is marked by a high carbonate content and dominantly smectite clay minerals: zeolites persist. Sedimentation is of pelagic type attesting to the impact of basic volcanism and/or that of fine-grained terrigenous inputs developed under warm climates with contrasting seasons.

Unit IV (from middle/upper Miocene) is also characterized by high carbonate contents. Clay minerals are highly variable (smectite, illite, kaolinite, chlorite). This change in mineralogical composition suggests climatic cooling linked to a change in the hydrological exchanges between the Norwegian Sea and North Atlantic.

METHODS

Analyses

X-ray diffraction was used on a total of 167 Paleocene and Miocene samples. The diffractometer used was a Philips 1310 and operating conditions were as follows: nickle-filtered copper Kα radiation at 40 kv, 20 mA.

Total Sediments

Dried and pulverized samples of total sediments were analyzed according to the powder diffractogram method. Semiquantitative values of quartz, calcite, and feldspars (K and plagioclase) were estimated from peak heights by comparison with mixed synthetic reference samples. Zeolites were estimated by relative frequencies as abundant, present, or trace on the basis of height of characteristic reflections.

Clay Fraction (<2 μm)

Total sediments were dispersed in pure water using mechanical agitation. Samples with high carbonate contents were first treated with HCl N10. After several (two or three) washings in pure water, <2 μm subfractions were separated by gravity settling. After centrifuging the <2 μm portion of the suspensions, the resulting thick paste was spread across two slides; the amount of clay per square centimeter transferred to the slide was always the same. The first slide was saturated with ethylene glycol before analysis. The second was scanned untreated and then heated at 550° for 1 hr. before a second analysis.

Identification of minerals was made according to the classical methods (Brown, 1961; Thorez, 1975). Semiquantitative estimations of the different minerals were made from diagrams of the glycolated slides. Abundance was estimated relative to total clay minerals on the basis of the height of their characteristic reflections.

INTERPRETATION

Interpretation of mineralogical results was based first on the mineral associations. In order to simplify the description of the interpretative methods used, a reminder of the most probable significance attributed to the different minerals encountered is briefly given.

Nonclay Minerals

Quartz and feldspars are assumed to be of detrital origin. Their relative abundance in bulk sediments is considered an indicator of continental inputs delivered to the sea and of variation of either erosional factors (e.g., climatic conditions and orogenetic effects) or of the transport mode (e.g., currents, ice rafting, wind). The feldspar nature may to a certain extent be regarded as a petrographic source marker.

1. Plagioclase associated with smectites and certain zeolites (see later) for basic rocks;

2. K feldspars associated with quartz and primary clay minerals (illite and chlorite) for acidic rocks.

In general, the occurrence of carbonates in marine deposits is dependent on numerous factors, particularly: biogenic productivity (Hays and Perruza, 1972) with respect to the terrigenous flux dissolution rate as a function of depth (Berger, 1971a, b), and CO_2 partial pressure (Li et al., 1969). As in many marine deposits the carbonate contents in the Leg 81 samples (essentially calcite) clearly appear to be correlated to the abundance of calcareous microfauna, and for this reason they are considered open ocean markers. Furthermore, the abundance of carbonates could also indicate the temperature of water masses. This abundance could indicate, as

[1] Roberts, D.G., Schnitker, D. et al., *Init. Repts. DSDP*, 81: Washington (U.S. Govt. Printing Office).

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shown by Sancetta et al. (1973) in the N. Atlantic for Quaternary deposits, warm climatic conditions.

Several uncommon components were often encountered in Leg 81 early Tertiary deposits, occurring in low quantities: zeolites (clinoptilolite and analcime or wairakite), and opal C.T. These minerals were frequently observed in the fine-grained fraction, particularly in the smectite-rich clay fraction (see later). From the Nayudu (1964), Bonatti (1967), Griffin et al. (1972), Kastner and Stonecipher (1976), and Latouche et al. (1981) observations, these minerals and associations could be regarded as indicative of a reworking of weathered volcanic basic rocks (smectite–zeolite association), of hydrothermal alterations (wairakite), or eruptions or rich silica lavas (opal C.T.). Nevertheless, Mélières (1979) also described the development of clinoptilolite crystals which grow through infilling and replacement of radiolarian tests.

Clay Minerals

Many studies dealt with the significance of clay minerals in marine deposits. From the present-day Atlantic model, it appears (Biscaye, 1965; Griffin et al., 1968; Rateev et al. 1969; Chamley, 1979) that detritism from lands and soils is the dominant mechanism responsible for the clay-fraction composition. For this reason the latitudinal distribution of Atlantic marine clay fraction is closely related to climatic zones and corresponding soil clay fractions (Paquet, 1969; Tardy, 1969; Latouche, 1971). Kaolinite is predominant in the equatorial domain whereas smectite predominates in the tropical one; illite and chlorite characterize the intermediate and high latitudes.

A nonlatitudinal distribution of smectites was observed in deposits surrounding Iceland, the Azores, and the Canary islands (Yerashev-Shak, 1964; Rateev et al., 1969). These smectites could result from high temperature reactions of volcanic glasses and basaltic detritus with seawater. Such evolution processes were described by Bonatti (1967) and experimentally reproduced by Seyfried and Bischoff (1977). These smectites, however, may also be partially detrital as suggested by the occurrence of smectite in the present-day near-shore deposits investigated in the vicinity of basaltic Faeroe Islands (Latouche, 1975) and in early Tertiary deposits of the Rockall region (Courtois and Chamley, 1978). Regardless of the procedure involved, it appears that the basic volcanic environment favors the genesis of smectites.

RESULTS

Site 552

This site is located at the base of Hatton Bank, Hole 552 (Fig. 1, Table 1). The samples studied come from the lower Eocene, middle Eocene, middle Miocene, and

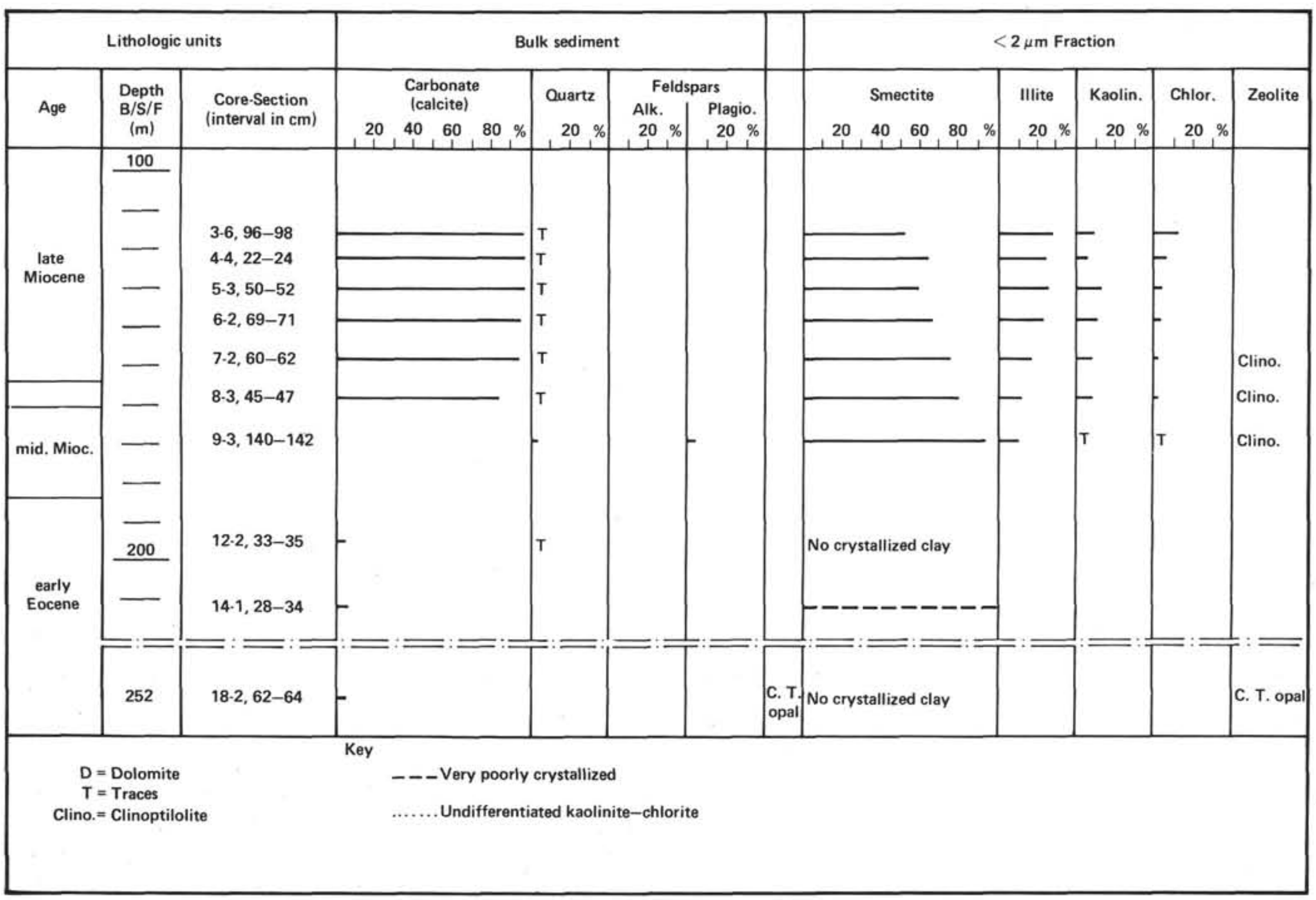

Figure 1. Mineralogical log, Hole 552.

Table 1. X-ray diffractometry mineralogical results.

	Bulk sample						<2 μm Fraction				
Sample (interval in cm)	Quartz (%)	Calcite (%)	Dolomite (%)	Alkaline feldspars (%)	Plagioclase feldspars (%)	Other mineral	Smectite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)	Other mineral
Hole 552											
3-6, 96–98	Traces	96					50	28	9	13	
4-4, 22–24	Traces	96					63	24	6	7	
5-3, 50–52	Traces	96					57	26	13	4	
6-2, 69–71	Traces	94					64	22	11	3	
7-2, 60–62	Traces	93					74	16	8	2	Clinoptilolite
8-3, 45–47	Traces	83					78	12	8	2	Clinoptilolite
9-3, 140–142	2				4		91	9	Traces	Traces	Clinoptilolite
12-2, 33–35	Traces	3						No crystallized clay			
14-1, 28–34		5					100				
18-2, 62–64		3		C.T. opal and zeolite				No crystallized clay			C.T. opal
Hole 552A											
25-1, 104		96					53	27	10	10	
26-2, 69–70		96					61	27	6	6	
27-2, 130–131		91					59	19	11	11	
28-2, 130–131		94					61	23	7	9	
29-1, 97–98		91					64	20	8	8	
30-1, 76–77		95					60	25	5	10	
31-2, 100–101		95	Traces				61	21	7	11	
32-2, 54–55		93	Traces				59	21	9	11	Clinoptilolite
33-3, 83–84	Traces	93	Traces				63	21	10	6	
34-1, 80–81	1	94					60	24	8	8	Clinoptilolite
35-3, 30–31		93					67	13	[K.+Ch.] = 20		Clinoptilolite
36-2, 50–51		84					78	10	[K.+Ch.] = 12		
37-1, 15–16	2	65	Traces				100				Clinoptilolite
37-1, 106–107		3					100				Clinoptilolite
37-2, 51–52	3	25			4		100 Poorly crystallized				
37-2, 92–93	3	20			6		100 Poorly crystallized				
38-1, 130–131	2	24			4		100 Poorly crystallized				
Hole 553A											
3-1, 110–111		91					76	14	5	5	
4-2, 80	1	90					72	15	[K.+Ch.] = 13		
6-1, 140–142		91			2		80	14	3	3	
7-4, 132–134		94					76	15	[K.+Ch.] = 9		Clinoptilolite
8-3, 28–30		83					85	8	[K.+Ch.] = 7		Clinoptilolite
8, CC (77)	1	77			2		100 Poorly crystallized				
9-2, 20	1	79			Traces		100 Poorly crystallized				
9-3, 77	1	84			2		100 Poorly crystallized				
9-4, 112		75					100 Poorly crystallized				
9-5, 97	1	79					100 Poorly crystallized				
9, CC	1	76			Traces		100 Poorly crystallized				
10-1, 127–129		76					100 Poorly crystallized				
10-3, 38–40		70					100 Poorly crystallized				
10-4, 92–94		25					96	4			Clinoptilolite
10-6, 66–68	2	12			3		91	8			
11-2, 90		7					100				Clinoptilolite
11-4, 148	2	8			3		100 Poorly crystallized				Clinoptilolite
11-5, 78		6			6		100 Poorly crystallized				
11, CC		39			10		100 Poorly crystallized				Clinoptilolite
12-1, 57		22			7		100 Poorly crystallized				Clinoptilolite
12-4, 64	2	4			4		100 Poorly crystallized				Clinoptilolite
13-1, 140		1					100 Poorly crystallized				
13-3, 7		2					100 Poorly crystallized				Clinoptilolite
14-5, 43	3	2			10		84 Poorly crystal.		[K.+Ch.] = 16		
15-1, 36	6	3			10		75 Poorly crystal.		[K.+Ch.] = 25		Clinoptilolite
15-3, 50		2					100 Poorly crystallized				
16-1, 39	8	2			10		67 Poorly crystal.	33			
17-1, 30	3	2			15		83 Poorly crystal.		[K.+Ch.] = 17		
18-2, 123	3	2			9		75 Poorly crystal.	25			
19-2, 118	4	7			15		67 Poorly crystal.	33			Clinoptilolite
20-6, 78	8	2			7		100				Clinoptilolite
21-3, 136	10	2			20		94	6			Clinoptilolite
22-3, 90	4	2			7		93	7			
23-1, 84	5	2			15		100	Traces			

Table 1. (Continued).

	Bulk sample						<2 μm Fraction				
Sample (interval in cm)	Quartz (%)	Calcite (%)	Dolomite (%)	Alkaline feldspars (%)	Plagioclase feldspars (%)	Other mineral	Smectite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)	Other mineral
Hole 553A (Cont.)											
23-4, 59	3	7			15		100	Traces			Clinoptilolite
24-2, 31		4					100				
25-1, 66–69		3					100 Poorly crystal.	Traces			
26-1, 94–96	20	2			25		100 Poorly crystal.	Traces			
27-5, 70–72	14	1			20		74	13	[K. + Ch.] = 13		
34-1, 40–42		2					100				
35-1, 102–104		3					100				Analcime
36-3, 20–22		2			7		100				
37-1, 31	18	7					100				
37-4, 65	6	3					100				
Hole 554											
6-5, 53–55		94					30	42	18	10	
7-3, 49–51		93					57	23	10	10	
8-3, 62–64		90					51	25	12	12	
Hole 554A											
1-1, 78–80	1	93					56	28	8	8	
2-2, 20–22		90					51	29	10	10	
3-3, 110–112		91					51	25	16	8	
4-3, 63–65		71					81	11	4	4	Clinoptilolite
5-2, 28–30		78					82		8	10	Clinoptilolite
5-3, 40–42		96					37	28	21	14	
6-2, 77–78		33			12		62	13	[K. + Ch.] = 19		
Hole 555											
3-6, 15		94					47	32	14	7	
4-6, 80		96					51	33	8	8	
5-5, 60		96					49	31	11	9	
6-4, 23		96					49	35	7	9	
7-6, 10		94					51	29	10	10	
8-2, 70		96					54	26	10	10	
9-1, 90–92		96					61	25	7	7	
10-5, 20		93					67	19	7	7	
11-3, 13		94					61	24	9	6	
12-2, 70		94					60	20	10	10	
13-1, 26		94					72	16	6	6	
14-1, 34		93					65	21	7	7	
15-1, 110		93					74	16	5	5	
16-5, 60		93					52	24	16	8	
17-2, 75		93					62	26	6	6	Clinoptilolite
18-2, 4–6		94					59	21	10	10	
19-1, 87	1	96					75	17	4	4	
20-1, 110	1	94					73	20	4	3	
21-2, 140	1	93					100	Traces	Traces	Traces	
22-2, 37		94					84	16	Traces	Traces	Clinoptilolite
24-1, 20		93					84	15	Traces	Traces	Clinoptilolite
24-6, 20		93					100 Poorly crystal.		Traces	Traces	Clinoptilolite
25-4, 50		93					100	Traces	Traces	Traces	Clinoptilolite
26-3, 86		88					84	16			Clinoptilolite
26-6, 105		73					82	18			Clinoptilolite
27-2, 78		5				Zeolite	91	9			Clinoptilolite
28-1, 32	10	12			10		100				Clinoptilolite
31-1, 124	14	3			15		100				Clinoptilolite
31-2, 11	3	4			7		100 Poorly crystallized				Clinoptilolite
32-2, 52	4	4			15		100 Poorly crystallized				
32-6, 35	1	4			7		100 Poorly crystallized				
33-2, 40		7			7		100 Poorly crystallized				
33-6, 6	4	4			5		91	9			
34-3, 40	5	1			7		100				
34-4, 25	12	1			25		100 Poorly crystallized				
36-1, 115		1					38		62		
37-2, 80	5	1			15		46		54		
38-2, 57	5	2			7		77		23		
38-2, 97		3					100				
39-3, 28	5	1			5		84		16		
39-4, 125	2	5			11		82		[K. + Ch.] = 18		

Table 1. (Continued).

Sample (interval in cm)	Bulk sample Quartz (%)	Calcite (%)	Dolomite (%)	Alkaline feldspars (%)	Plagioclase feldspars (%)	Other mineral	<2 μm Fraction Smectite (%)	Illite (%)	Kaolinite (%)	Chlorite (%)	Other mineral
Hole 555 (Cont.)											
40-5, 32	4	1			3		85	8	[K. + Ch.] = 7		
40-7, 22	2	1			6		75	9	9	7	
41-2, 37	2	4			7		100				
41-4, 64	1	2			7		92		4	4	
42-1, 34		30			15		100 Poorly crystallized				
42-2, 2	1	2			5		100				
43-3, 13	2	4			5		97		3		
44-3, 71	2	4			7		95	5			
45-2, 114	1	3			5		100	Traces			
46-3, 37		5			4		63	17		20	
46-5, 20	4	13			10		85		6	9	Clinoptilolite
47-3, 25	3	3			9		100				Clinoptilolite
48-2, 112–113	3	1			5		84	8	4	4	Clinoptilolite
48-4, 12–14	2	2			5		86		7	7	Clinoptilolite
49-1, 5–10	3	4			10		97			3	Clinoptilolite
51-1, 13	8	40			7		50		20	30	
52-2, 76	7	1			15		82	8	5	5	
53-5, 39	3	2			11		79	5	4	12	
54-6, 55	6	2			7		80	4	8	8	
55-2, 51	3	2			5		90	Traces	5	5	
56-1, 105	3	3			10		85	3	4	8	
57-1, 58	4	3			10		90	4	2	4	
58-2, 80	5	6			7		96		[K. + Ch.] = 4		Clinoptilolite
59-5, 90	5	4			10		95		2	3	Clinoptilolite
60-4, 35	6	4			10		95		[K. + Ch.] = 5		
60-6, 18	6	3			11		88	6	[K. + Ch.] = 6		
61-1, 66	11	3			15		92		[K. + Ch.] = 8		
61-2, 45	6	5			9		89	4	[K. + Ch.] = 7		
62-3, 75	5	2			7		92	4	[K. + Ch.] = 4		
62-4, 63	5	3			7		86	7	[K. + Ch.] = 7		
63-1, 35	7	2			5		90		[K. + Ch.] = 10		
63-1, 130		96			5		Traces				
64-2, 60	11	3			13		94		[K. + Ch.] = 6		Clinoptilolite
64-4, 34		2					Traces				
65-1, 53		3					100 Poorly crystallized				
65-2, 142		2			10		55 Poorly crystal.		[K. + Ch.] = 45		Clinoptilolite
67-1, 104		4					100 Poorly crystallized				
67-4, 68	8	2			12		94	3	3		
84-1, 93	19	2			15		58	42	Traces	Traces	
86-3, 32	19	2			12		43	27	10	20	
87-2, 68	19	5			10		80	12	4	4	
87-5, 65	20	4			12		50	14	20	16	
88-3, 50–54	20	3			10		60	17	10	13	
92-2, 93–96	14	3			10		49	33	9	9	
93-2, 57–60	19	4			20		60	20	10	10	

upper Miocene. A considerable hiatus exists throughout the upper Eocene, Oligocene, and lower Miocene.

Lower Eocene

Sediments in Samples 552-18-2, 62–64 cm to 552-12-2, 33–35 cm are very little carbonated (0–5% of calcite). Silica occurs in the form of opal C.T. at only one level (Sample 552-18-2, 62–64 cm) in which zeolites (clinoptilolite) also appear. Quartz is absent from these sediments. Clay minerals are very badly represented; only poorly crystallized smectites may be detected.

Middle Eocene

Only one level was studied: Sample 552-9-3, 140–142 cm. Sediments are free of carbonates; some quartz and plagioclase feldspar traces were observed. Clay minerals are represented by highly dominant smectites (few illites and some kaolinite and chlorite traces). Some rare zeolites (clinoptilolite) are associated with the fine-grained fractions.

Middle and Upper Miocene

The principal mineral components in Samples 552-8-3, 45–47 cm to 552-3-6, 96–98 cm are carbonates (83–96% represented by calcite); quartz traces are observable at certain levels. Clays are represented mostly by abundant smectites associated with illites, kaolinites, and chlorites which increase progressively from the base to the top of the Miocene. Zeolite traces (clinoptilolite) were observed at the middle Miocene level (Sample 552-8-3, 45–47 cm) and at the upper Miocene level (Sample 552-7-2, 60–62 cm).

Sediments examined from Hole 552A (Fig. 2, Table 1) belong to the middle and upper Eocene, lower Oligo-

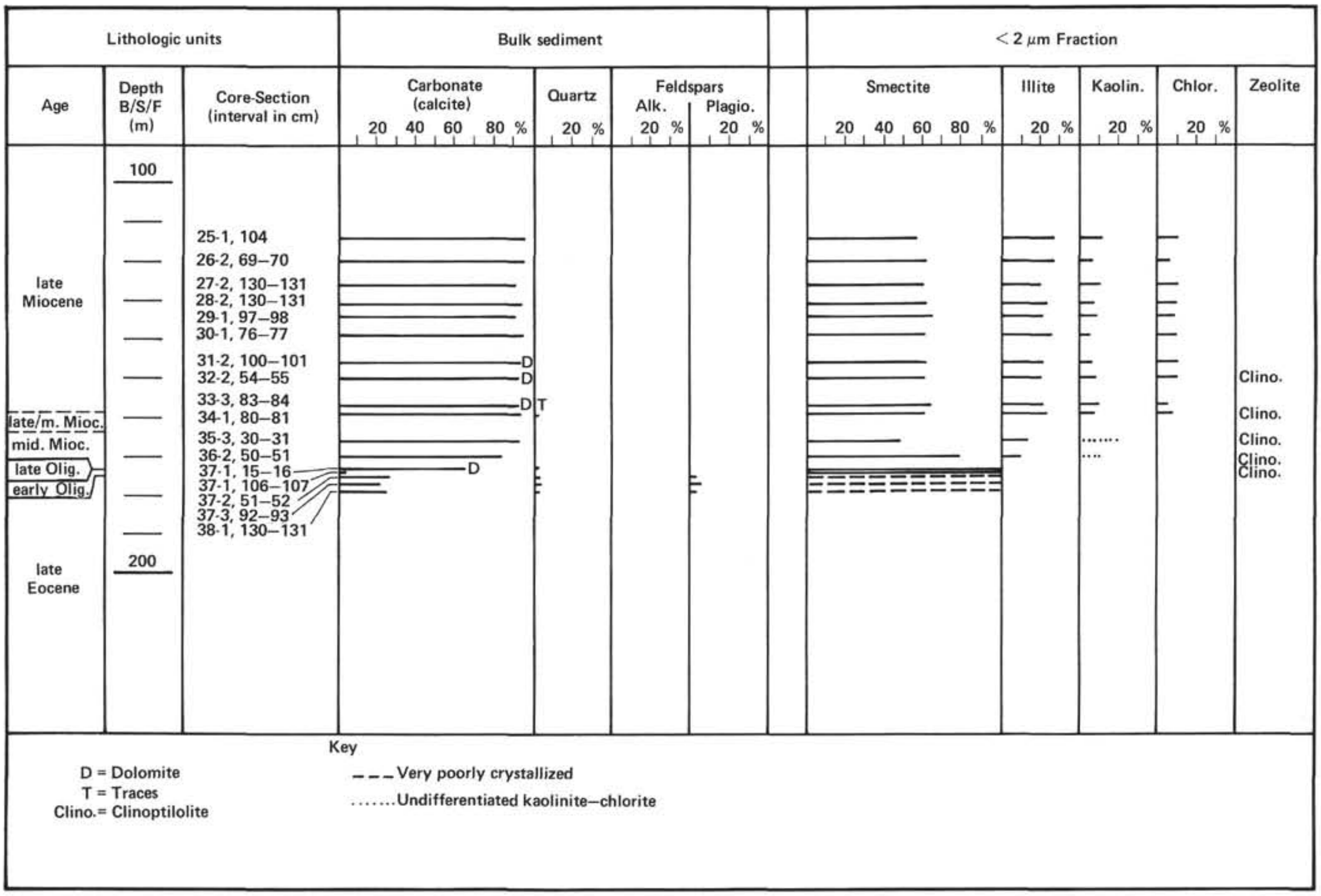

Figure 2. Mineralogical log, Hole 552A.

cene, and middle and upper Miocene. A considerable gap exists between the Oligocene and middle Miocene. Only one Oligocene level was investigated.

Eocene and Oligocene

Sediments in Samples 552A-38-1, 130–131 cm to 552A-37-1, 15–16 cm are slightly carbonated (3–25%). Only the Oligocene level contains calcite (65%). Quartz occurs in limited proportions while plagioclase feldspars are occasionally detectable (Samples 552A-38-1, 130–131 cm to 552-37-2, 51–52 cm). Clays are often badly crystallized: only smectites can be distinguished. Some rare zeolites (clinoptilolite) were observed.

Middle and Upper Miocene

Sediments in Samples 552A-36-2, 50–51 cm to 552A-25-1,104 cm are highly carbonated (84–96% of calcite; some dolomite traces were observed in Cores 33 and 31); quartz and feldspars are wanting.

Here clay assemblages are of higher diversity than in the previous formation. Smectites remain dominant but illites, kaolinites, and chlorites are very well represented. Some zeolites were detected (clinoptilolite) in the first Miocene levels investigated (Cores 35, 34, and 32).

Site 553

This site is also located at the base of the Hatton Edoras Bank. The deposits studied from Hole 553A (Fig. 3, Table 1) belong to the lower Eocene, middle Eocene, upper Oligocene, and lower, middle, and upper Miocene. Many gaps were observed, one of which (the most wide) covered the upper Eocene and lower Oligocene. Furthermore, it must be noted that Oligocene sediments are very rare.

Lower Eocene

Sediments in Samples 553A-37-4, 65 cm to 553A11-2, 90 cm are very little carbonated (exclusively calcite) and are characterized by a quite significant occurrence of quartz, often associated with plagioclase feldspars.

Clay minerals consist mainly of smectites; some rare levels contain illite traces. Zeolites are present (clinoptilolite); only one level (Sample 553A-35-1, 102–104 cm) is marked by the presence of analcime.

Middle Eocene, Upper Oligocene, and Early Miocene

The sediments in Samples 553A-10-6, 66–68 cm to 553A-8,CC (77 cm) are characterized by a mineralogical assemblage of low diversity. They are rich in carbonates except at the first two middle Eocene levels (Samples 553A-10-6, 66–68 cm and 553A-10-4, 92–94 cm) which contain 25 and 12% of calcite. Quartz and feldspars appear sporadically and only in the form of traces. The main clay mineral components are smectites, generally poorly crystallized.

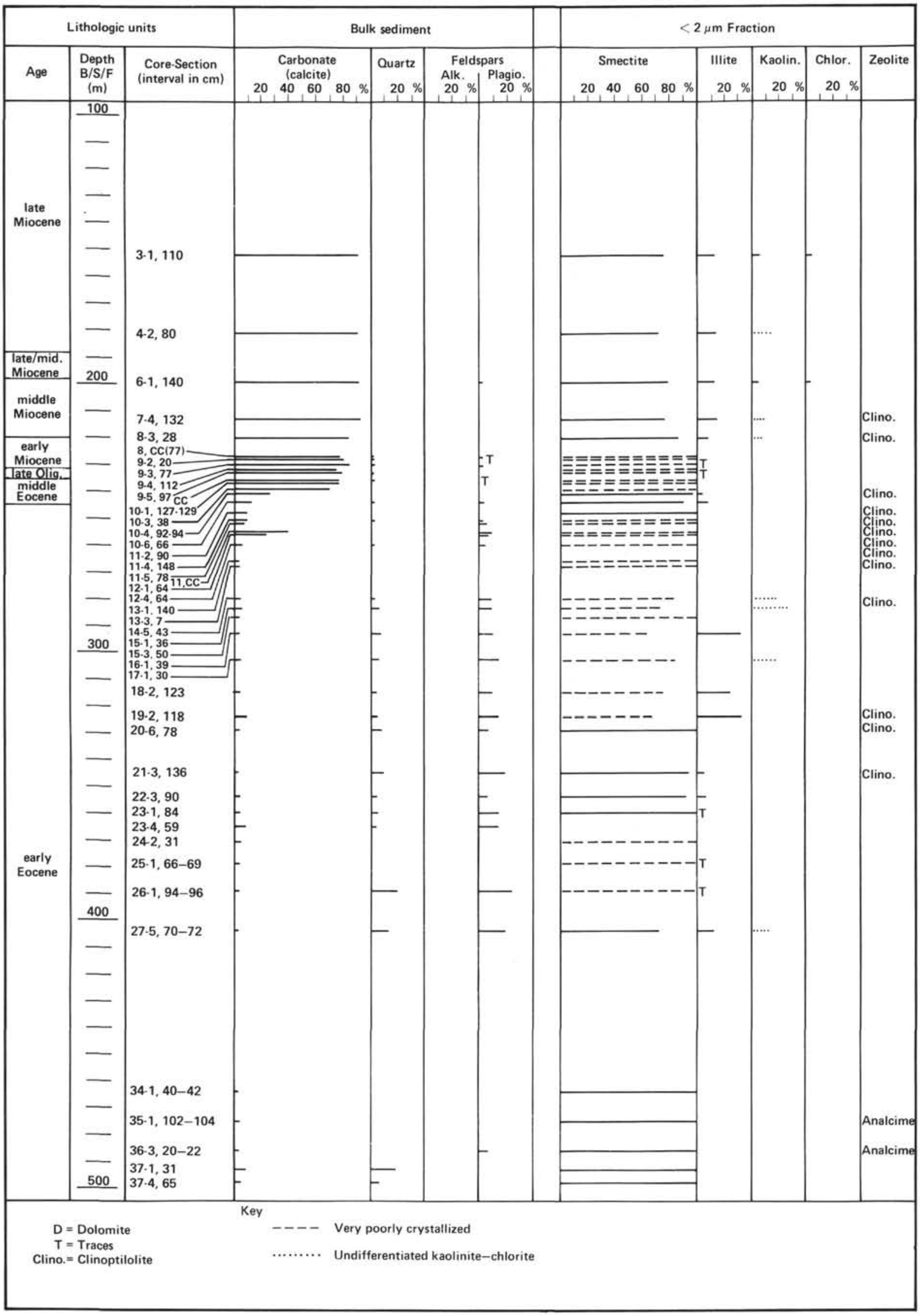

Figure 3. Mineralogical log, Hole 553A.

Middle and Upper Miocene

Sediments in Samples 553A-8-3, 28–30 cm to 553A-3-1, 110–111 cm are more carbonated than in the previous underlying formations. Quartz and feldspars are abundant.

Clay fractions are very diversified: smectites are always very abundant (80–74%, respectively from the middle to upper Miocene) but illites, kaolinites, and chlorites (often badly differentiated) are present.

Site 554

This site is also located at the base of the Hatton Edoras Bank but further to the ocean than the previous sites. Very few samples were examined.

Sediments from Hole 554 (Fig. 4, Table 1) that were investigated belong entirely to the upper Miocene (Samples 554-8-3, 62–64 cm to 554-6-5, 53–55 cm) They are carbonated (calcite). Quartz and feldspars are absent.

The clay assemblage is a mixture of smectites, illites, kaolinites, and chlorites. Smectites prevail at the base whereas illites are most abundant in the last level studied (Samples 554-6-5, 53–55 cm).

Deposits from Hole 554A (Fig. 5, Table 1) that were studied belong to the lower Eocene, lower and upper Oligocene, and middle and upper Miocene. Middle Eocene and lower Miocene are very poorly represented.

Lower Eocene

Sediments from Sample 554A-6-2, 77–78 cm are very little carbonated (33% calcite); plagioclase feldspars (12%) are observed and quartz is absent. Clay minerals are very rich in smectites, while illite, undifferentiated kaolinites, and chlorites occur in very limited quantities and are poorly crystallized.

Oligocene

Sediments from Samples 554A-5-3, 40–42 cm to 554A-4-3, 63–65 cm are carbonated (71–96% of calcite); quartz and feldspars are absent. Clay minerals are very badly crystallized especially in the first level (Sample 554A-5-30, 40–42 cm). The two other levels investigated show a clear predominance of smectites; these are better crystallized and associated with zeolite traces (clinoptilolite).

Middle and Upper Miocene

Sediments from Samples 554A-3-3, 110–112 cm to 554A-1-1, 78–80 cm are very carbonated (90–93% of calcite). Quartz traces are rare whereas feldspars are absent altogether. Clay minerals are very diversified; the dominant mineralogical characteristic is the abundance of smectites. Illites, kaolinites, and chlorites are present and well crystallized.

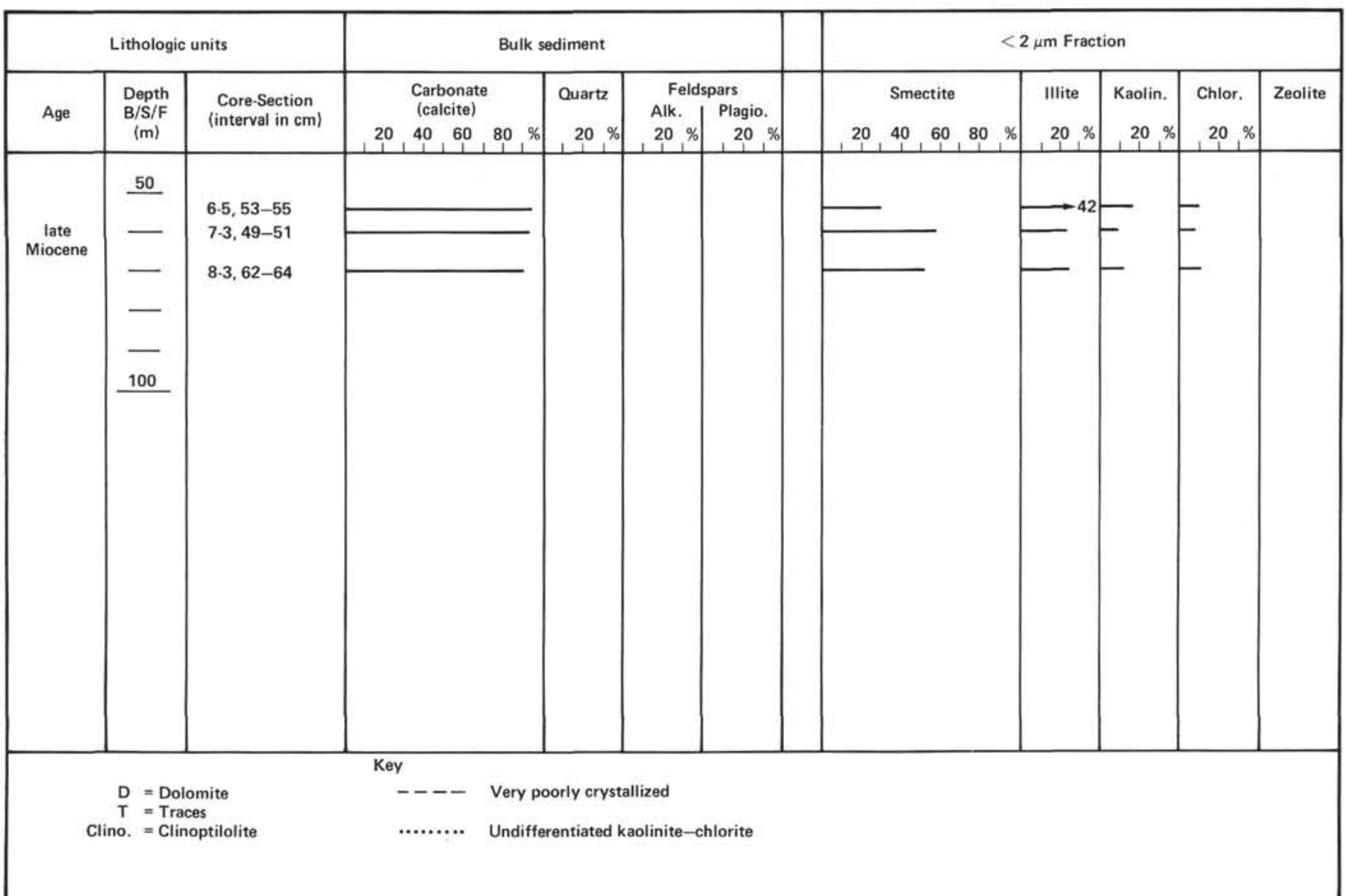

Figure 4. Mineralogical log Hole 554.

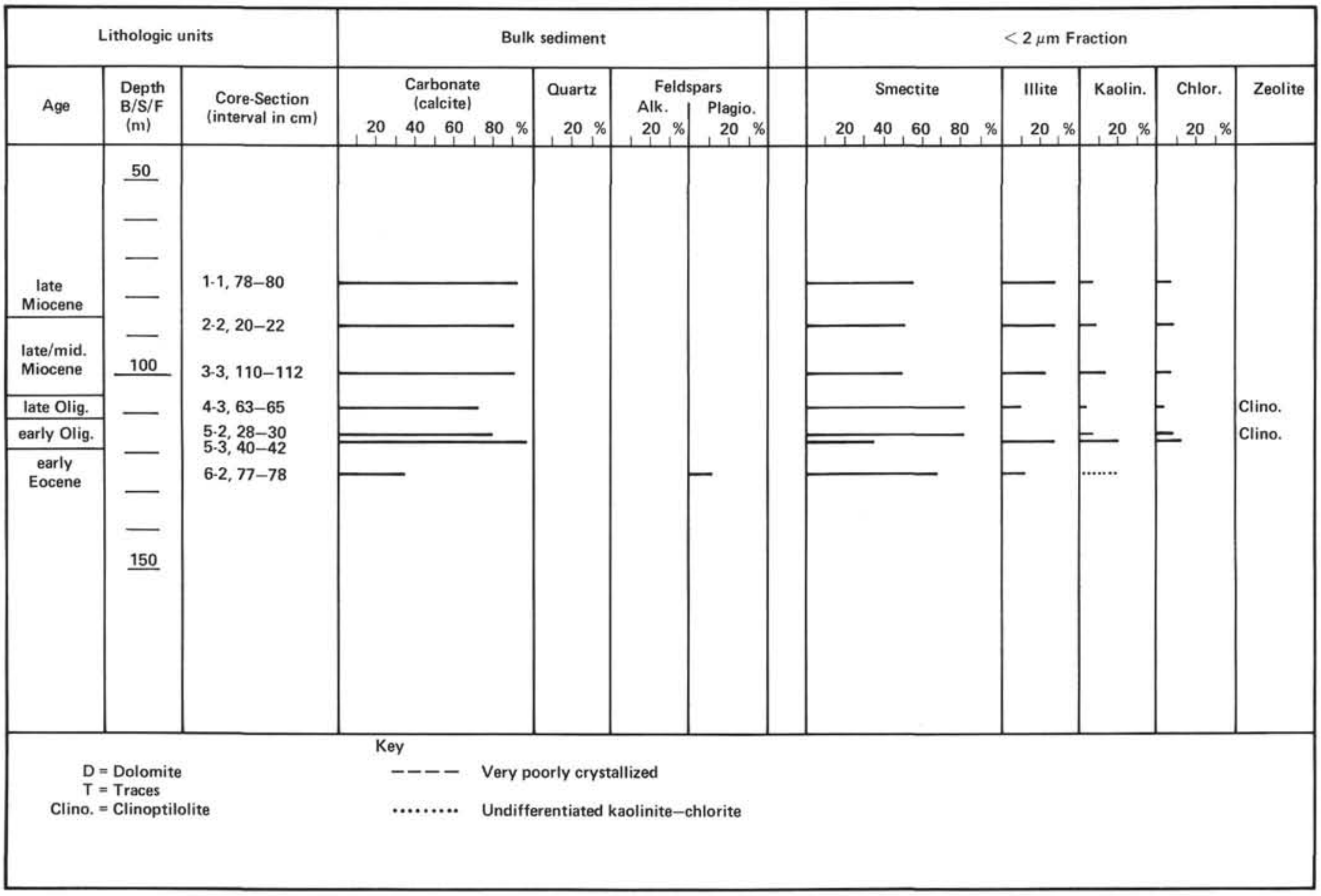

Figure 5. Mineralogical log Hole 554A.

Site 555

This site (Fig. 6, Table 1) is located halfway between Hatton Bank and Edoras Bank. The sediments examined belong to the upper Paleocene, lower Eocene, and lower, middle, and upper Miocene. A considerable sedimentary gap exists between the middle Eocene and middle Oligocene. Other numerous but minor gaps were also observed.

Upper Paleocene

Sediments in Samples 555-93-2, 57–60 cm to 555-84-1, 93 cm are very little carbonated (calcite). Quartz, plagioclase feldspars are fairly abundant. The clay assemblage is formed of smectites, illites , kaolinites, and chlorites. Smectites are dominant, illites quite well represented, and kaolinites nonabundant.

Lower Eocene (approximately 390 m)

A series of basaltic deposits (Samples 555-67-4, 68 cm to 554-27-2, 78 cm) separates the lower Eocene sediments from the upper Paleocene sediments. Here deposits are very little carbonated (on average 6% of calcite). Quartz and feldspars continue to be present but occur in less important quantities than in the Paleocene levels.

Clay minerals are chiefly represented by smectites. Some illite, kaolinite, and chlorite (the latter not always differentiated) traces were sometimes observed. At certain levels, however (Samples 555-39-3, 28 cm, 555-28-2, 57 cm, 555-37-2, 80 cm, and 555-36-1, 115 cm), smectites and kaolinites were detected, the latter being largely dominant (62–54%). All the levels investigated represented a quite well-individualized layer. From Sample 555-31-2, 11 cm to the top of lower Eocene there may be observed large amounts of zeolite (clinoptilolite) associated with clays.

Lower, Middle, and Upper Miocene

The dominant characteristic of the Miocene sediments (Samples 555-26-6, 105 cm to 555-3-6, 15 cm) is their carbonate nature (73–94% of calcite). Quartz and feldspars are absent. Important variations of the clay fraction composition were noted from the base to the top. In the first Miocene levels (Samples 555-26-6, 105 cm to 555-21-2, 140 cm), clays are almost exclusively represented by smectites. Some illite, kaolinite, and chlorite traces are occasionally observable.

From Sample 555-20-1, 110 cm to the top (Sample 555-3-6, 15 cm), clay assemblages are more diversified: smectites remain dominant but begin to decrease gradually towards the Miocene top. Conversely, illites which

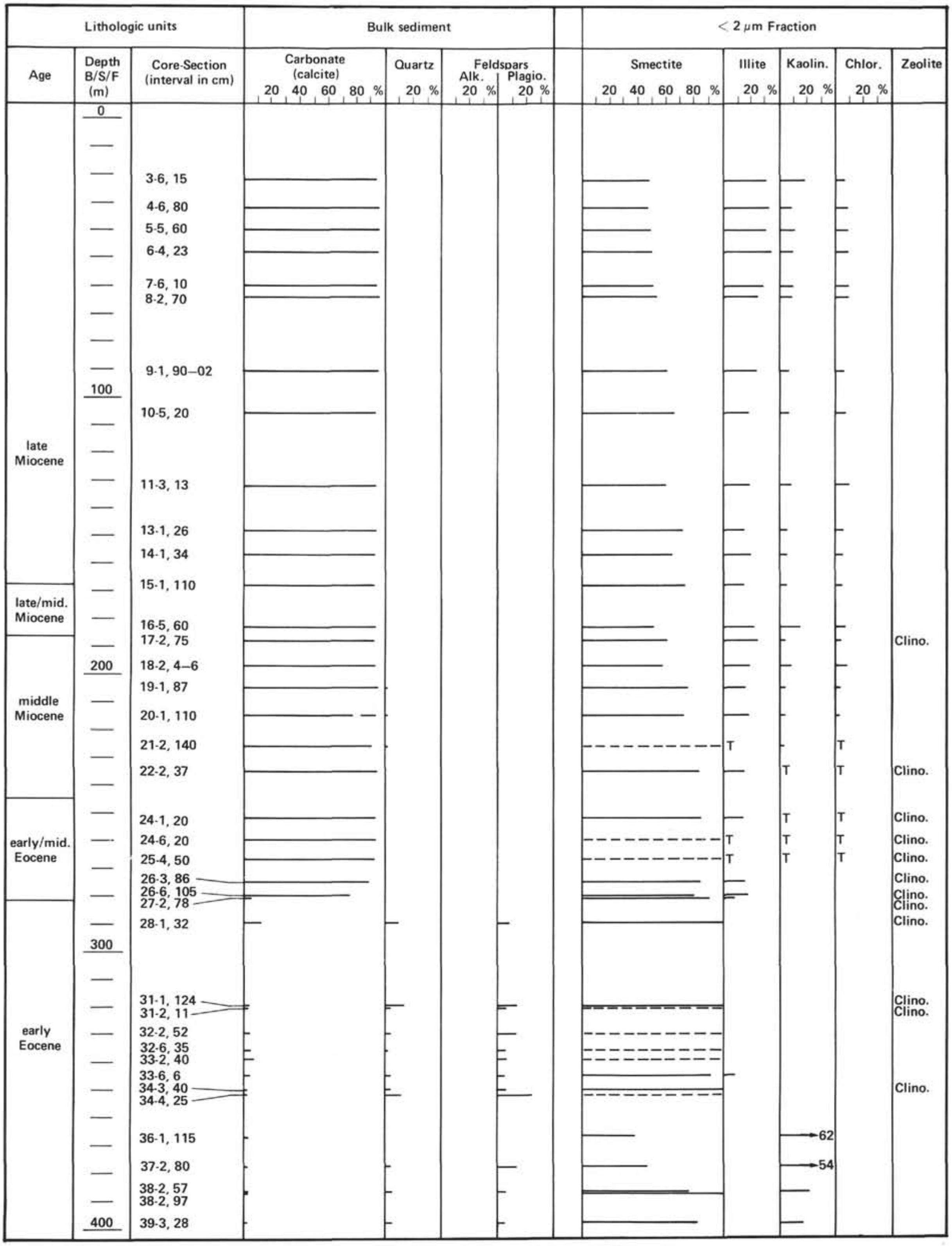

Figure 6. Mineralogical log Hole 555 (0–910 m).

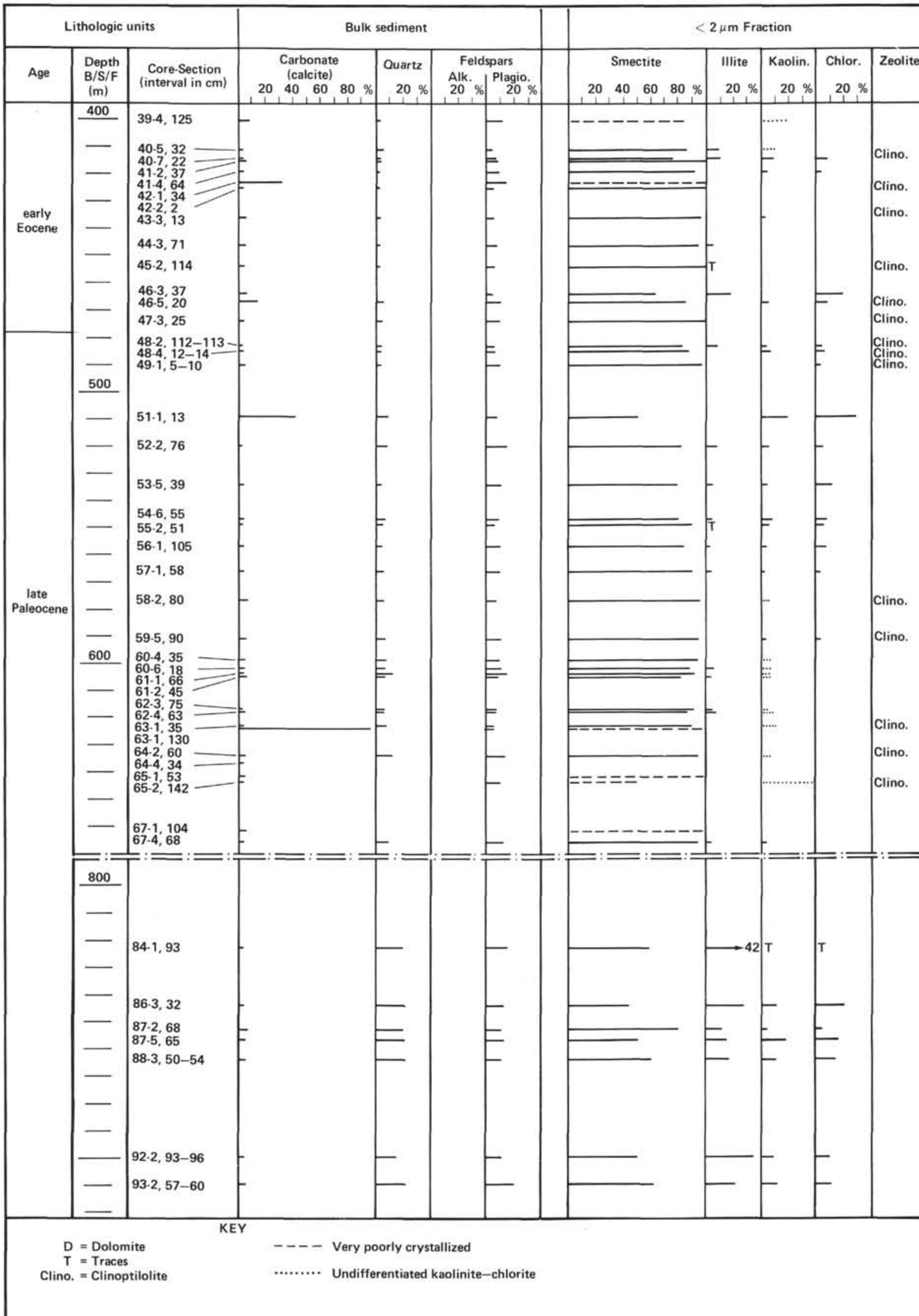

Figure 6. (Continued).

are well represented, increase toward the top. Kaolinites and chlorites are well differentiated. Zeolites (clinoptilolite) observed in the lower Eocene occur until the middle Miocene levels (Samples 555-7-2, 75 cm).

SYNTHESIS AND CONCLUSIONS

Four mineralogical assemblages (Table 2) were distinguished. The characteristics and vertical extension of which, in each site, will now be discussed.

Mineralogical Unit 1

This unit consists of upper Paleocene deposits which are only found at Site 555 and correspond to the first half (Samples 555-93-2, 57–60 cm to 555-67-1, 104 cm) of the sedimentary episode encountered within the volcanic complex between 672 and 822 m of depth.

This unit is characterized by the abundance of quartz and plagioclase feldspars, by the scarcity of carbonates, and by diversified clay fractions (smectites, illites, kaolinites, and chlorites). It reveals sedimentation of terrigenous nature with deposits rich in primary clay minerals (illite, and chlorite) and quartz, which suggests the existence of petrographic acidic sources. However, smectites, which represent the principal mineral component, and plagioclase feldspars also suggest a marked impact of basic sources.

Mineralogical Unit 2

This unit is mainly represented by lower Eocene sediments found at all sites, in particular in Holes 553A (Samples 553A-37-4, 65 cm to 553A-11-2, 90 cm) and 555 (Samples 555-67-1, 104 cm to 27-2-78). At the latter site, it is a long sedimentary episode (390 m vertically) that displays numerous and varied characteristics. The most dominant characteristics, however, are the following: extreme predominance of smectites—often badly crystallized—good representation of plagioclase feldspars, scarcity of quartz and carbonates, and quite constant occurrence of zeolites (clinoptilolite). These features reflect a sedimentation highly influenced by a basic volcanic environment. In contrast to the previous unit, mineralogical Unit 2 is marked by the decreasing impact of acidic sources reflected in the lowering of primary clay mineral amounts (illite and chlorite) and of quartz.

Table 2. Schematic diagram of the mineralogical assemblages of the lithological units.

Samples	Mineralogical assemblages
552A-25-1, 104 cm to 36-2, 50–51 cm 552-3-6, 96–98 cm to 8-3, 45–47 cm 553A-3-1, 110–111 cm to 8-3, 28–30 cm 554A-1-1, 78–80 cm to 3-3, 110–112 cm	Unit 4 Smectite, illite, kaolinite, chlorite, calcite
553A-8,CC (77 cm) to 10-3, 38–40 cm 555-21-2, 110 cm to 26-6, 105 cm	Unit 3 Smectite, calcite, traces of zeolite
552A-37-1, 15–16 cm to 38-1, 130–131 cm 552-9-3, 140–142 cm to 18-2, 62–64 cm 553A-11-2, 90 cm to 37-4, 65 cm 555-27-2, 78 cm to 67-1, 104 cm	Unit 2 Smectite, feldspars, plagioclases, zeolite
555-67-1, 104 cm to 93-2, 57–60 cm	Unit 1 Smectite, illite, kaolinite, chlorite, quartz, feldspars

Among the particularities that account for the sporadic interruption of this unit, special mention must be made of the relatively high kaolinite contents found in Samples 555-38-2, 57 cm to 555-36-1, 115 cm. Although less sharp, an increase of kaolinite contents occurs at Site 553 between Samples 553-17-1, 30 cm and 553-14-5, 43 cm. This kaolinite occurrence could indicate a terrigenous inflow developed during the alteration of leaching and warm climates (Millot, 1964).

The analysis of the samples available did not permit an accurate definition of the stratigraphic uppermost limit of Unit 2. Middle Eocene deposits from Hole 552A (between Samples 552A-38-1, 130–131 cm and 552A-37-1, 106–107 cm) show good affinity with mineralogical Unit 2. The sole Oligocene sample studied (Sample 552A-37-1, 15-16 cm) also shows similar features despite its more abundant carbonate contents. The mineralogical features of Unit 2 are clearly identifiable at Site 552 within lower and middle Eocene deposits, between Samples 552-18-2, 62–64 cm and 552-9-3, 140–142 cm and in Hole 553A within the thick lower Eocene layers investigated, between Samples 553A-37-4, 65 cm and 553A-10-4, 92–94 cm. Unit 2 features are not, however, as distinct as at Site 554, where only a small number of samples were studied.

Mineralogical Unit 3

This unit is clearly distinguished at Site 555 within the lower and middle Miocene deposits, between Samples 555-26-6, 105 cm and 555-21-2, 110 cm. Identical characteristics were observed in Hole 553A within middle Eocene, upper Oligocene, and lower Miocene sediments, between Samples 553A-10-3, 38–40 cm and 553A-8,CC (77 cm). Unit 3 was not identified at Sites 552, 552A, and 554.

Unlike the previous unit, Unit 3 is characterized by a sudden increase of carbonate contents and the quasi-disappearance of quartz and feldspars. The principal clay mineral components continue, even to a greater extent, to be smectites. They may occasionally be the only mineral components. Zeolites (clinoptilolite) are associated with the fine-grained fraction, namely at Site 555.

The sudden occurrence of considerable carbonate contents may be explained by the more pelagic nature of deposits. The disappearance of coarse terrigenous material suggests that the impact of continental sources wears off or, at least, that considerable dilution of eventual terrigenous inputs takes place in biogeneous materials. However, the abundance of smectites emphasizes certain affinities with Unit 2. This abundance is either the result of the basic volcanic impact and/or very fine grained terrigenous inputs which develop in soils under warm climates with contrasting seasons (Paquet, 1969).

Mineralogical Unit 4

This unit was recognized at all sites within the following intervals:

1. Hole 552A: between Samples 552A-36-2, 50–51 cm and 552A-25-1, 104 cm;

2. Hole 552: between Samples 552-8-3, 45–47 cm and 552-3-6, 96–98 cm;

3. Hole 553A: between Samples 553A-8-3, 28–30 cm and 553A-3-1, 110–111 cm;

4. Hole 554A: between Samples 554A-3-3, 110–112 cm and 554A-1-1, 78–80 cm;

5. Hole 555: between Samples 555-20-1, 110 cm and 555-3-6, 15 cm.

All these deposits belong to middle and upper Miocene.

In contrast to the underlying unit, this unit is mainly differentiated by an increase in appearance of illite, kaolinite, and chlorite. Smectite, which is the quasi-exclusive clay mineral in Unit 3, does not represent more than 75% of the clay fraction at the base of Unit 4. Toward the top, these contents decrease below 50%. As in Unit 3 carbonates are very abundant, representing most often 90% of the total sediments. Mainly biogenous, these carbonates reflect the pelagic nature of deposits, which is also emphasized by the extreme scarcity of quartz. In this type of environment, the appearance or increase of primary clay minerals is striking. It could suggest resumption of the acidic petrographic source impact already observed during the Paleocene (Unit 1). Such an assumption, however, suggests tectonic readjustments and consequently a parallel increase of coarse terrigenous inputs. But the absence of quartz rules out this possibility.

The change in the mineralogical composition of clays, namely, the replacement of smectites by illites and chlorites, has often been observed in deposits of the second half of the Tertiary in the northeastern Atlantic: Leg 47 (Chamley et al., 1979) and Leg 48 (Cassat, 1979; Latouche and Maillet, 1979). Although it is difficult to give an accurate stratigraphic age to this event (because of numerous sedimentary gaps that exist between middle Eocene and middle Miocene) the most recent data obtained during Leg 80 (Chennaux et al., unpublished) locate the major mineralogical change in clays at the middle/upper Miocene boundary. The stratigraphic age of this important limit may be related to the period Roberts and Montadert (1979) considered that of a sharp increase of deep-sea flux from the Norwegian Sea towards the Atlantic. This flux increase also corresponds to hydrologic and climatic changes throughout the world (Shackleton and Kennett, 1975). In Northern Europe the occurrence of primary clay minerals (characteristic of alteration of cold climates and high latitude) in marine sediments (Biscaye, 1965; Rateev et al., 1969) has already been regarded as a probable marker of cooling linked to modifications of exchange between the Norwegian Sea and North Atlantic (Latouche and Maillet, 1980). Since the nature and age of the mineralogical changes observed during the end of middle Miocene are identical throughout Leg 81 sites, it is assumed that these changes were set off by the same factors.

TERTIARY SEDIMENTATION: COMPARISON WITH LEG 48 RESULTS

The Tertiary deposits examined during Leg 81 are more complete than those sampled during Leg 48. Careful observation of these sediments led to a better understanding of the evolution of mineralogical assemblages as well as to a sharper separation between the major episodes (Table 3).

Leg 48 includes only one association: Paleocene to Oligocene sediments interrupted by numerous gaps (Latouche and Maillet, 1979). This association was composed of smectites associated either with quartz and feldspars (Sites 403, 404) or with carbonates (Sites 505, 506). Conversely, Leg 81 treated three mineralogical associations:

1. A very characteristic detrital episode (Association 1) covering the upper Paleocene and part of the lower Eocene.

2. An episode still detrital but the clays of which were mostly represented by smectites (Association 2) during the lower Eocene.

3. An episode of pelagic sedimention: smectite and carbonate (Association 3) during middle Miocene.

Association 2 of Leg 48 and Association 4 of Leg 81 may be readily correlated, for they consist of oceanic sediments, the clay inputs of which (represented by smectite, illite, kaolinite, and chlorite) were deposited within a carbonated environment. The appearance of illite and chlorite which marked a major renewal of sedimentation may be accurately dated as upper Miocene. The numerous hiatuses in Leg 48 rendered, of course, similar accurate dating impossible.

Table 3. Comparison of Leg 81 (Sites 552–555) and Leg 48 (Sites 403–406).

	Leg 81		Leg 48		
Assemblage	Age	Mineralogical association	Mineralogical association	Age	Assemblage
4	late Miocene	Sm.-I.-K.-Ch. Carbonate	Sm-I-K-Ch Carbonate	early Pliocene Miocene	2
3	middle Miocene middle Eocene	Sm. Carbonate	?	Hiatus	
2	early Eocene	Sm. Quartz	Sm. Carbonate or Quartz	?	1
1	early Eocene late Paleocene	Sm.-I.-K.-Ch. Quartz		early Eocene late Paleocene	

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REFERENCES

Berger, W. H., 1971a. Calcite solution profile from faunal analysis. Ores Sediments, *Int. Sedimentol. Congr.*, 8th 1971. (Abstracts)

________, 1971b. Sedimentation of planktonic foraminifers. *Mar. Geol.*, 11:325–358.

Biscaye, P. E., 1965. Mineralogy and sedimentation of recent deep-sea clay in the Atlantic Ocean and adjacent seas and oceans. *Geol. Soc. Am. Bull.*, 76:803–832.

Bonatti, E., 1976. Mechanisms of deep-sea volcanism in the South Pacific. *Res. Geochem.*, 2:453–491.

Brown, G., 1961. *The X-ray Identification and Crystal Structures of Clay Minerals*: London (Mineralogical Society).

Cassat, G., 1979. X-ray mineralogy from Holes 339, 400, 400A, 401, 402 and 402A of Bay of Biscay. *In* Montadert, L., Roberts, D. G. et al., *Init. Repts. DSDP*, 48: Washington (U. S. Govt. Printing Office), 649–663.

Chamley, H., 1979. North Atlantic clay sedimentation and paleoenvironment since the late Jurassic. *In* Talwani, M., Hay, W., and Ryan, W. B. F. (Eds.), *Deep Drilling Results in the Atlantic Ocean.* Continental Margins and Paleoenvironmental., pp. 342–361.

Chamley, H., Debrabant, P., Foulon, J., Girourd d'Argoud, G., Latouche, C., Maillet, N., Maillot, H., and Sommer, F., 1979. Mineralogy and geochemistry of Cretaceous and Cenozoic Atlantic sediments off the Iberian Peninsula (Site 398, DSDP Leg 47B). *In* Sibuet, J.-C., Ryan, W. B. F. et al., *Init. Reps. DSDP*, 47, Pt. 2: Washington (U. S. Govt. Printing Office), 429–449

Courtois, C. and Chamley, H., 1978. Terres rares et minéraux argileux dans le Crétacé et le Cénozoïque de la marge atlantique orientale. *C. R. Hebd. Seances Acad. Sci.*, Paris, 286, Série D.,: 671–674.

Griffin , J. J., Windom H., Goldberg, E. D., 1968. The distribution of clay minerals in the world ocean. *Deep-Sea Res.*, 15:433–459.

Griffin, J. J., Koide, M., Hohndorf, A., Hawkins, J. W., and Goldberg, E. D., 1972. Sediments of the Lau Basin, rapidly accumulating volcanic deposits. *Deep-Sea Res.*, 19:139–148.

Hays, J. D., and Perruza, A., 1972. The significance of calcium carbonate oscillations in eastern Equatorial Atlantic deep sea sediments for the end of the Holocene warm interval. *Quat. Res.*, 2: 335–362.

Kastner, M., and Stonecipher, S. A., 1976. Zeolites in pelagic sediments of the Atlantic, Pacific and Indian Oceans. *In* Sand, L. B., and Mumpton, F. A. (Eds.), *Natural Zeolites, Occurrence, Properties, Use*, pp. 199–220.

Latouche, C., 1971. Les argiles des bassins alluvionnaires aquitains et des dépendances océaniques. Contribution à l'étude d'un environnement [Thèse Sc. Nat.]. Univ. Bordeaux.

________, 1976. Les minéraux argileux des sédiments actuels de l' Atlantique nord-oriental et du sud de la mer de Norvège. *Proc. Int. Clay Conf.*, 1975, pp. 45–54.

Latouche, C., and Maillet, N., 1979. X-ray mineralogy studies. Leg 48. Rockall Region (Sites 403, 404, 405, and 406). *In* Montadert, L., Roberts, D. G., et al., *Init. Repts. DSDP*, 48: Washington (U. S. Govt. Printing Office), 665–676.

Latouche, C., and Maillet, N., 1980. Minéraux argileux et évolution des environnements sédimentaires du domaine atlantique nord-oriental durant le Paléogène. *Bull. Soc. Geol. Fr.*, 7, (4):757–761.

Latouche, C., Maillet, N., and Blanchet, R., 1982. X-ray mineralogy studies, Deep Sea Drilling Project Leg 60. *In* Hussong, D. M., Uyeda, S., et al., *Init. Repts. DSDP*, 60: Washington (U.S. Govt. Printing Office), 437–453.

Li. Y. H., Takahashi, T., and Broecker, W. S., 1969. Degree of saturation of $CaCo_3$ in the oceans. *J. Geophys. Res.*, 74:5507–5525.

Mélières, F., 1979. Mineralogy and geochemistry of selected Albian sediments from the Bay of Biscay, Deep Sea Drilling Project Leg 48. *In* Montadert, L., Roberts. D. G., et al., *Init. Repts. DSDP*, 48: Washington (U. S. Govt. Printing Office), 855–876.

Millot, G., 1964. *Géologie des argiles*: Paris (Masson Ed.).

Nayudu, Y. R., 1964. Palagonite tuffs (hyaloclastites) and the products of post-eruptive processes. *Bull. Volcanol. Napoli*, 27:391–410.

Paquet, H., 1969. Evolution géochimique des minéraux argileux dans les alterations et les sols des climats méditarrannées et tropicaux à saisons contrastées. *Mem. Serv. Carte. Geol. Alsace Lorraine*, 30: 1–212.

Rateev, M. A., Gorbunova, Z. N., Lisitzyn, A. P., and Nosov, G. L., 1969. The distribution of clay minerals in the oceans. *Sedimentology*, 13:21–43.

Roberts, D. G., and Montadert, L., 1979. Margin paleoenvironments of the Northeast Atlantic. *In* Montadert, L., Roberts, D. G., et al. *Init. Repts. DSDP*, 48: Washington (U.S. Govt. Printing Office), 1099–1118.

Sancetta C., Imbric, J., and Kipp, N. G., 1973. Climatic record of the past 130,000 years in North Atlantic Deep Sea Core. V. 23-82, correlation with the terrestrial record. *Quat. Res.*, 3:110–116.

Seyfried, W., and Bischoff, J. L., 1977. Hydrothermal transport of heavy metals by sea water: the role of sea water, basalt ratio. *Earth Planet. Sci. Lett.*, 34:71–77.

Shackleton, N. J., and Kennett, J. P., 1975. Late Cenozoic oxygen and carbon isotopic changes at D.S.D.P. Sites 284. Implications for the glacial history of the northern hemisphere and Antartica. *In* Kennett, J. P., Houtz, R. E., et al., *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office), 801–807.

Tardy J. 1969. Géochimie des alterations. Études des arènes et des eaux de quelques massifs cristallins d'Europe et d'Afrique. *Mem. Serv. Carte. Geol. Alsace Lorraine*, 31:1–199.

Thorez, J., 1975. *Phyllosilicates and Clay Minerals. A Laboratory Handbook for their X-ray Diffraction Analysis*: Dison, Belgivm (Lelotte, G., Ed.).

Trichet, J., 1970. Contribution à l'étude de l'altération expérimentale des verres volcaniques. *Trav. Lab. Geol. Ec. Norm. Super. Paris*: 1–152.

Yeroschev-Shak, V, A., 1964. Clay minerals of the Atlantic Ocean. *Sov. Oceanogr.*, 30-2:90–106.

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