35. ORGANIC FACIES VARIATIONS IN THE MESOZOIC SOUTH ATLANTIC[1]

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ABSTRACT

Visual kerogen and total organic carbon determinations indicate that there are two periods of organic enrichment events in the Mesozoic sediments of the South Atlantic. The first period, from the Late Jurassic through the late Aptian, is recorded in sediments from the Falkland Plateau, the Cape Basin, and the Angola Basin. Apparently, salinity stratification in the restricted basin, coupled with rising sea level, led to bottom water anoxia and organic enrichment. The second event, from the late Albian to the Santonian period, is recorded in sediments from the Angola Basin and the Sao Paulo Plateau. It appears to have been caused by development of an anoxic oxygen minimum zone at midwater depths. Organic matter sedimentation in the Mesozoic South Atlantic is controlled by geologic, climatic, eustatic, and oceanographic factors.

INTRODUCTION

The purpose of this chapter is to document variations in the types of organic matter in Mesozoic sediments of the South Atlantic and to describe the controls on organic matter distribution (Fig. 1). The Mesozoic sediments recovered from the South Atlantic by the Deep Sea Drilling Project (DSDP) fall into two categories: (1) organic-rich Cretaceous and Jurassic black shales, and (2) organic-poor (TOC less than 1%) nannofossil oozes, chalks, and clays. Samples were analyzed for total organic carbon (TOC) and, by transmitted light microscopy, for organic matter types (OMT); selected samples were pyrolyzed using a Chromalytics MP-3 instrument. The organic matter was identified using criteria established by Masran and Pocock (1981).

Most of the samples analyzed in this study were collected by the author from the DSDP core repository at Lamont Doherty Geological Observatory in New York. The samples from Site 511 on the Falkland Plateau were collected by Dr. F. M. Weaver during DSDP Leg 71. Dr. P. A. Meyers collected the samples from Hole 530A on DSDP Leg 75. Original sample locations include the Falkland Plateau, the Angola Basin, the Cape Basin, the São Paulo Plateau, the Rio Grande Rise, and the Walvis Ridge.

Falkland Plateau (Sites 327, 330, 511)

These sites, located only about 10 km apart, were drilled on the northern edge of the Falkland Plateau (see Tables 1-3 and Figs. 1, 2). Drilling here penetrated the oldest sediments recovered in the South Atlantic and helped to document the transition of the area from a coastal plain to an open ocean environment.

The oldest sediments, Mid-Jurassic from Site 330, are olive green limestones deposited in a fluvial coastal plain environment (Barker and Dalziel, 1977). The sediments appear to have been deposited under oxidizing conditions (Barker and Dalziel, 1977) judging from the low amount of organic carbon and the abundance of terrestrial organic material (Table 1, Fig. 2). These sediments are overlain by variously colored Late Jurassic limestones deposited in a continental shelf environment, at depths less than 400 m, on the subsiding plateau. TOC values in these sediments vary from 0.36 to 2.01%, and although the organic matter is dominantly terrestrial (woody and coaly), samples with the higher TOC values have higher amounts of amorphous kerogen (Table 1, Fig. 2).

Organic-rich sediments were deposited from Late Jurassic through Aptian times at all three sites, although the exact lithology and organic facies vary slightly between the sites. Black, massive, thinly laminated mudstones were probably deposited under reducing conditions in the basinal region of the plateau at Site 511. These are the richest sediments sampled on the Falkland Plateau. TOC values average 3.8%, and the kerogen is predominantly amorphous (Table 2, Fig. 2). The equivalent units at Sites 327 and 330 are olive gray and black carbonaceous claystones with some interbedded micritic limestones. Site 327 averages 2.88% TOC and has slightly more amorphous kerogen than does Site 330, which has an average TOC content of 1.96% (Table 3, Fig. 2). Pyrolysis results indicate that the amorphous material at all three sites is hydrogen rich and oil prone (Table 4), suggesting a marine origin for the organic material.

At all three sites, this organic interval is capped by a late Aptian–Albian sequence of variously colored nannofossil clays, chalks, and mudstones. These sediments are rich in terrestrial organic matter and low in organic carbon (Tables 1-3; Fig. 2). This may reflect a return to more oxidizing conditions associated with an Aptian–Albian regression (Fig. 3).

Cape Basin (Site 361)

A lower to upper Aptian organic-rich sequence was deposited in the Cape Basin (see Table 5 and Fig. 4). It consists of dark gray to black sapropelic shales, greenish gray to greenish black sandy mudstones, and bluish gray to greenish gray sandstones (Bolli and Ryan, 1978).

[1] Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP*, 75: Washington (U.S. Govt. Printing Office).

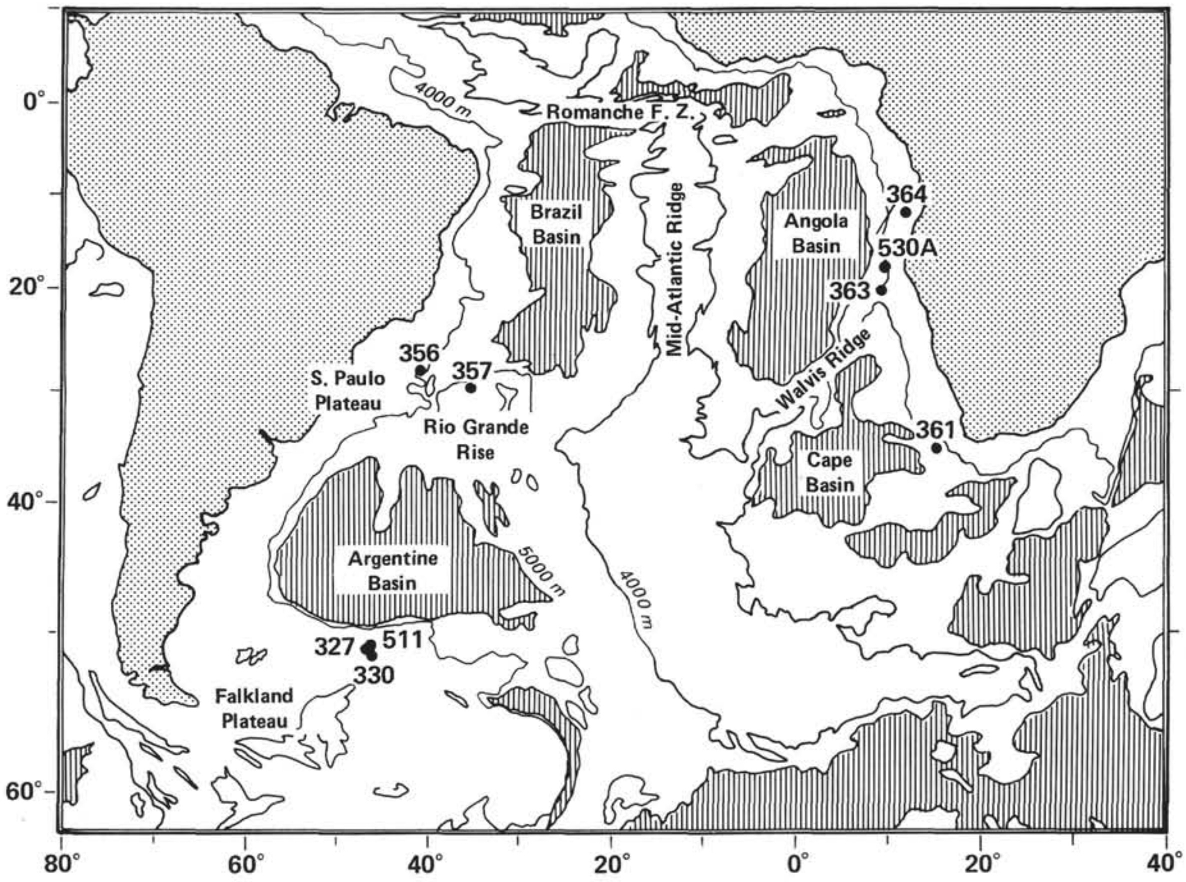

Figure 1. DSDP site locations referred to in this chapter (from Bolli, Ryan et al., 1978).

Table 1. Lithology, total organic carbon, and kerogen distribution of samples from Site 330.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
1-1, 100	Albian	Pinkish gray nanno clay	130	0.07	90			10				
1-2, 100	Albian	Pinkish gray nanno clay	140	0.06	10			90				
2-2, 60	Albian	Green gray nanno clay	185	0.07	10	20			70			
3-1, 100	Aptian	Olive black sapropelic clay	230	0.41	40	20	20	10			10	
4-2, 50	Neocomian	Olive gray sapropelic clay	270	3.50	10		10		80			
5-2, 50	Oxfordian–Kimmeridgian	Olive black sapropelic claystone	300	4.03	10		10		80			
6-1, 80	Oxfordian–Kimmeridgian	Olive black sapropelic claystone	310	3.51	10	5	10		75			
6-6, 80	Oxfordian–Kimmeridgian	Olive black sapropelic claystone	320	3.84	10	5	10		75			
7-1, 80	Oxfordian–Kimmeridgian	Olive black sapropelic claystone	322	4.11	10		10		80			
7-6, 100	Oxfordian–Kimmeridgian	Olvie black sapropelic claystone	330	3.46	20	5	10		65			
8-1, 130	Oxfordian–Kimmeridgian	Olive black sapropelic claystone	340	0.75	20	10	20		50			
8-4, 100	Late Jurassic	Olive black sapropelic claystone	350	3.22	10		10		80			
10-2, 100	Late Jurassic	Olive black sapropelic claystone	410	1.95	20	20	10	10	30		10	
11-1, 60	Late Jurassic	Yellow brown sparry limestone	430	1.89	30	10	20	10	30			
11-6, 40	Late Jurassic	Yellow brown sparry limestone	440	2.01	20	10	10	20	40			
12-1, 130	Late Jurassic	Olive gray limestone	460	1.50	30	10	10	10	30		10	
12 CC	Late Jurassic	Olive gray limestone	465	0.36	50	10	10	20			10	
13-1, 100	Late Jurassic	Olive black sandy limestone	490	1.03	30	10	20	20	10		10	
13-4, 100	Late Jurassic	Olive black sandy limestone	500	0.63	60	10	10	20				
14-1, 100	Late Jurassic	Olive gray limestone	510	0.44	60	10	10	20				
14-4, 10	Late Jurassic	Olive gray limestone	525	1.37	60	10	10	20				
15-2, 63	Mid Jurassic	Olive gray siltstone	550	0.21	50	10	20	20				

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies; IF = indeterminate fines. Blank space = none present.

TOC values within this unit vary considerably from 0.40% to 21.70%. Organic matter types fluctuate considerably, too—from 90% terrestrial to 90% amorphous (probably marine derived). There is a general correlation of high TOC with amorphous-rich samples, and low TOC with terrestrial-rich samples.

The overlying upper Aptian to Maestrichtian unit consists of alternating grayish or greenish black mudstones and reddish mudstones/claystones. There are also relatively thin parallel and cross bedded sands. With the exception of one dark gray to black shale with a TOC of 2.03%, organic carbon contents are less than

Table 2. Lithology, total organic carbon, and kerogen distribution of samples from Site 511.

Core-Section (interval in cm)	Age[a]	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
57-1, 7-9	Aptian-Late Jurassic	Mudstone	499	0.36	20	30	15			30	5	
57-3, 7-9	Aptian-Late Jurassic	Mudstone	502	1.44	30	40	20		5		5	
57-5, 26-28	Aptian-Late Jurassic	Mudstone	505	0.49	20	25	20		10	15	10	
58-1, 35-37	Aptian-Late Jurassic	Mudstone	509	0.42	35	30	20			5	10	
58-4, 85-87	Aptian-Late Jurassic	Mudstone	514	0.20	30		10	10	40		10	
59-1, 43-45	Aptian-Late Jurassic	Mudstone	518	5.02	10		5		85			
59-1, 84-86	Aptian-Late Jurassic	Mudstone	518.5	3.58	5	5	10		80			
59-4, 22-24	Aptian-Late Jurassic	Mudstone	524	2.37	10		10		80			
60-1, 148-150	Aptian-Late Jurassic	Muddy chalk and chalk	529	2.61	10		5		85			
60-3, 148-150	Aptian-Late Jurassic	Muddy chalk and chalk	530.5	3.87	10		5		85			
60-5, 120-122	Aptian-Late Jurassic	Muddy chalk and chalk	534	3.70	10	5	5		80			
61-1, 51-53	Aptian-Late Jurassic	Claystone	537.5	4.98	10	5	5		80			
61-4, 40-42	Aptian-Late Jurassic	Claystone	540.5	5.82	10	5	5		75			5
61-5, 40-42	Aptian-Late Jurassic	Claystone	542	4.78	5		5		90			
62-1, 28-30	Aptian-Late Jurassic	Claystone and nannofossil	547	4.60	5				90			5
62-3, 25-27	Aptian-Late Jurassic	Claystone and nannofossil	550	4.61	10		10		75			5
62-5, 30-32	Aptian-Late Jurassic	Claystone and nannofossil	553	4.50	10		5		80		5	
63-1, 120-122	Aptian-Late Jurassic	Claystone	557	3.82	10		5		80		5	
63-3, 35-37	Aptian-Late Jurassic	Claystone	560	4.62	10		10		75		5	
63-4, 3-5	Aptian-Late Jurassic	Claystone	561.5	4.00	10		10		75		5	
64-1, 14-16	Aptian-Late Jurassic	Claystone	566	4.66	20		10		70			
64-3, 14-16	Aptian-Late Jurassic	Claystone	569	3.67	20		10		65		5	
64-5, 14-16	Aptian-Late Jurassic	Claystone	572.5	3.21	10	5	20		55		10	
65-1, 46-48	Aptian-Late Jurassic	Claystone	575.5	3.68	10	5	15		60		10	
65-3, 57-59	Aptian-Late Jurassic	Claystone	579	5.52	5		10		75		10	
65-5, 10-12	Aptian-Late Jurassic	Claystone	581.5	5.36	5		10		85			
66-1, 20-22	Aptian-Late Jurassic	Nannofossil claystone	585	4.38	5		10		75		10	
66-3, 30-32	Aptian-Late Jurassic	Nannofossil claystone	588.5	4.60	10	5	20		45		20	
66-5, 20-22	Aptian-Late Jurassic	Nannofossil claystone	591	5.02	5		10		80		5	
67-1, 80-82	Aptian-Late Jurassic	Nannofossil claystone	595	4.82	10		15		60		15	
67-3, 32-34	Aptian-Late Jurassic	Nannofossil claystone	598.5	5.10	10	5	20		60		5	
67-5, 32-35	Aptian-Late Jurassic	Nannofossil claystone	602	4.06	10	5	15		60		10	
68-1, 15-17	Aptian-Late Jurassic	Claystone	604	4.07	5		15		75		5	
69-1, 40-42	Aptian-Late Jurassic	Mudstone	613.5	2.64	20	5	10		55		10	
69-3, 40-42	Aptian-Late Jurassic	Mudstone	617.5	2.54	30	5	10		45		10	
69-5, 44-46	Aptian-Late Jurassic	Mudstone	620	4.34	20	5	10		45		20	
70-1, 20-22	Aptian-Late Jurassic	Mudstone	623	5.76	10	5	10		65		10	
70-3, 20-22	Aptian-Late Jurassic	Mudstone	626.5	5.34	15		10		65		10	
70-5, 20-22	Aptian-Late Jurassic	Mudstone	630	3.78	10	5	20		60		5	

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.
[a] Revisions of stratigraphic ages are given in Steinmetz et al., this volume.

Table 3. Lithology, total organic carbon, and kerogen distribution of samples from Site 327.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
10-1, 102	Maestrichtian	Pale blue green foram-nanno chalk	91	0.21	5		10	5	70	10		
11-1, 100	Maestrichtian	Green gray foram nano ooze	100	0.12	25	10		15	40		10	
13-2, 50	Campanian	Green gray nanno ooze	110	0.21	5		5		85	5		
14-2, 100	Santonian	Green gray zeolitic clay	130	0.06	20		10	30	40			
14-6, 60	Cenomanian	Green gray micrite ooze	140	0.16			5		95			
15-1, 100	Albian	Green gray nanno clay	150	0.04	5		30		60	5		
16-1, 100	Albian	Olive gray nanno chalk	180	0.11			20		80			
18-1, 100	Albian	Olive gray nanno chalk	230	0.04	5		20		70	5		
19-1, 100	Albian	Yellow gray nanno ooze	255	0.05			15		80	5		
21-2, 100	Albian	Olive gray nanno claystone	310	0.08				30	70			
22-1, 100	Aptian	Brown-black sapropelic claystone	330	0.50	20	10	30		35		5	
22-3, 130	Aptian	Brown-black sapropelic claystone	340	0.51	10	5	10		65	10		
24-1, 50	Aptian	Brown-black sapropelic claystone	400	2.39	5		5		90			
25-2, 100	Aptian	Olive gray micritic claystone	430	4.16	5		5		90			
26-1, 100	Neocomian	Olive gray claystone	450	3.03	5				95			
27-1, 85	Neocomian	Olive gray claystone	460	1.21	5	10			85			

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

1%. Organic matter types fluctuate between dominantly terrestrial and amorphous, with no relationship between TOC and organic matter type.

Angola Basin (Site 364, Hole 530A)

Two distinct black shale intervals were penetrated in the Angola Basin (see Tables 6, 7; Fig. 5). At Site 364, one of the intervals is upper Aptian through lower Albian, the other is late Albian through Santonian. Hole 530A cored an equivalent upper Albian-Coniacian interval.

The late Aptian through lower Albian interval is a marly dolomitic limestone with finely laminated sapropelic shales. The sapropelic layers contain on average 10% TOC and are dominated by amorphous kerogen. Rock-Eval pyrolysis data indicate that the amorphous matter in this layer was derived from planktonic organisms (type II) (Tissot et al., 1980). Our pyrolysis

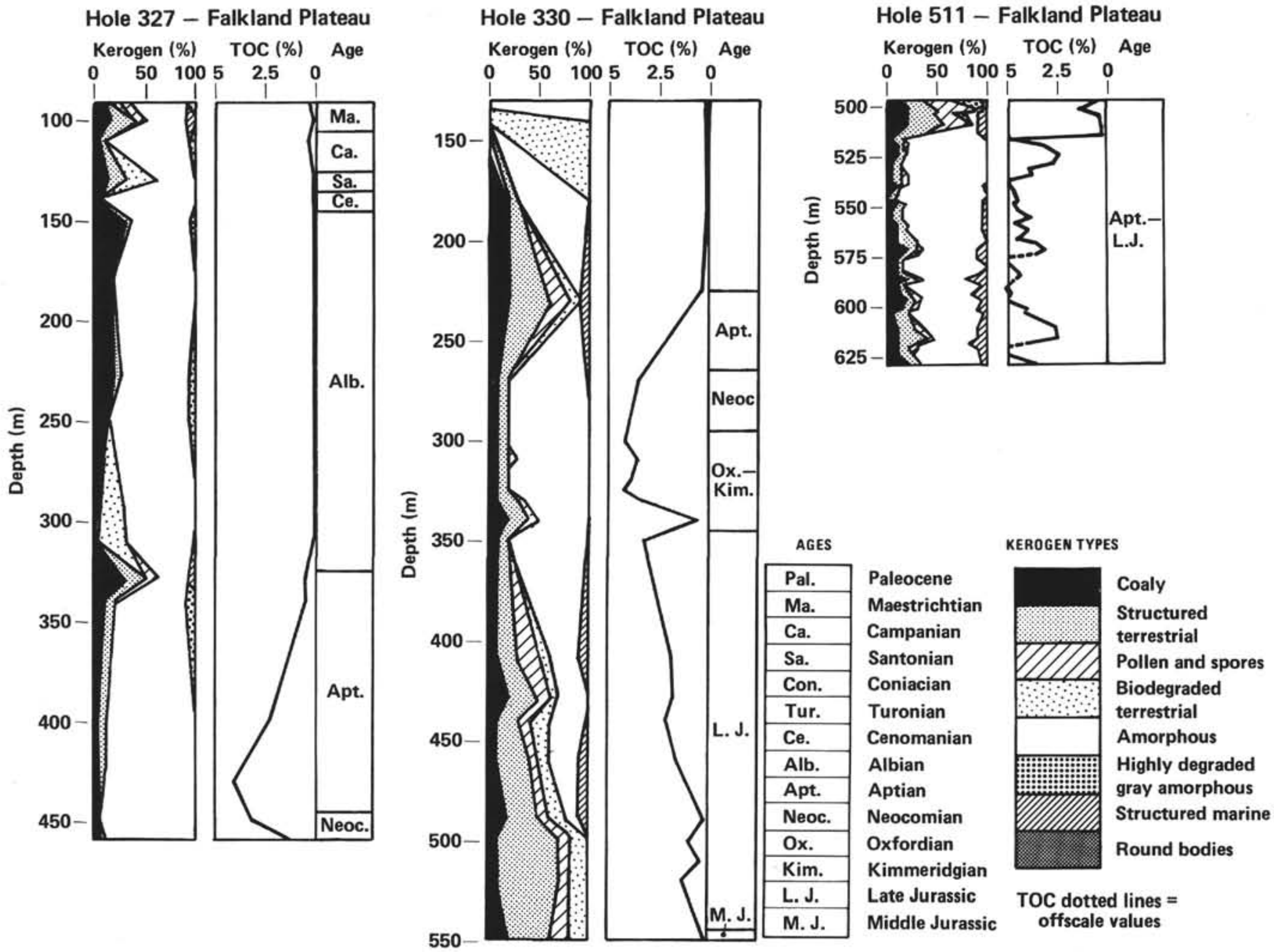

Figure 2. Kerogen, TOC, and ages of sites on the Falkland Plateau.

Table 4. Chromalytics MP-3 pyrolysis data from selected South Atlantic sites.

Core-Section	TOC	Rock-gas index	Rock-hydrogen index	Organic carbon gas—index	Organic hydrogen—index	Free hydrogen index
Site 327						
22-1	0.48	14.9	4.7	31.0	9.8	0.7
26-1	3.58	39.0	321.0	10.9	89.7	2.7
Site 330						
5-2	4.43	35.7	334.9	8.0	75.6	3.6
8-4	3.22	33.7	197.3	10.5	61.3	2.0
Site 511						
59-1	5.02	37.4	498.5	7.5	99.3	10.7
61-1	4.60	34.8	322.6	7.6	70.1	14.3
63-1	3.82	39.6	332.1	10.4	86.9	10.2
64-1	4.66	39.7	345.3	8.5	74.1	10.2
65-1	3.68	38.6	279.3	10.5	75.9	8.4
67-1	4.82	47.2	434.1	9.8	90.1	11.7
Site 361						
23-2	2.00	37.9	22.6	19.0	11.3	1.1
29-1	3.42	26.5	30.1	7.7	8.8	1.2

results confirm that this is hydrogen-rich, oil-prone organic matter (Table 4).

The overlying Albian limestones and shales have considerably less organic carbon, generally less than 0.5%. Although a few samples are terrestrial rich, visual kerogen analysis indicates that much of this material is amorphous. Pyrolysis data indicate that despite its appearance, this material is terrigenous (Tissot et al., 1980).

The second organic-rich interval in the Angola Basin is late Albian through Santonian at Site 364, and late Albian through Coniacian at Site 530. At Site 364, the interval is composed of two subunits: (1) greenish gray to brown nannofossil chalks interbedded with thin sapropels, and (2) greenish gray and dark greenish gray marly chalks and calcareous mudstones interlayered with black sapropelic shale. The second subunit contains barite, pyrite, and marcasite (Bolli, Ryan et al., 1978). TOC values for several of the black shales ranged from 2.89–23.4%, and the kerogen was dominantly amorphous. The greenish gray marls and nannofossil chalks contained negligible amounts of organic matter;

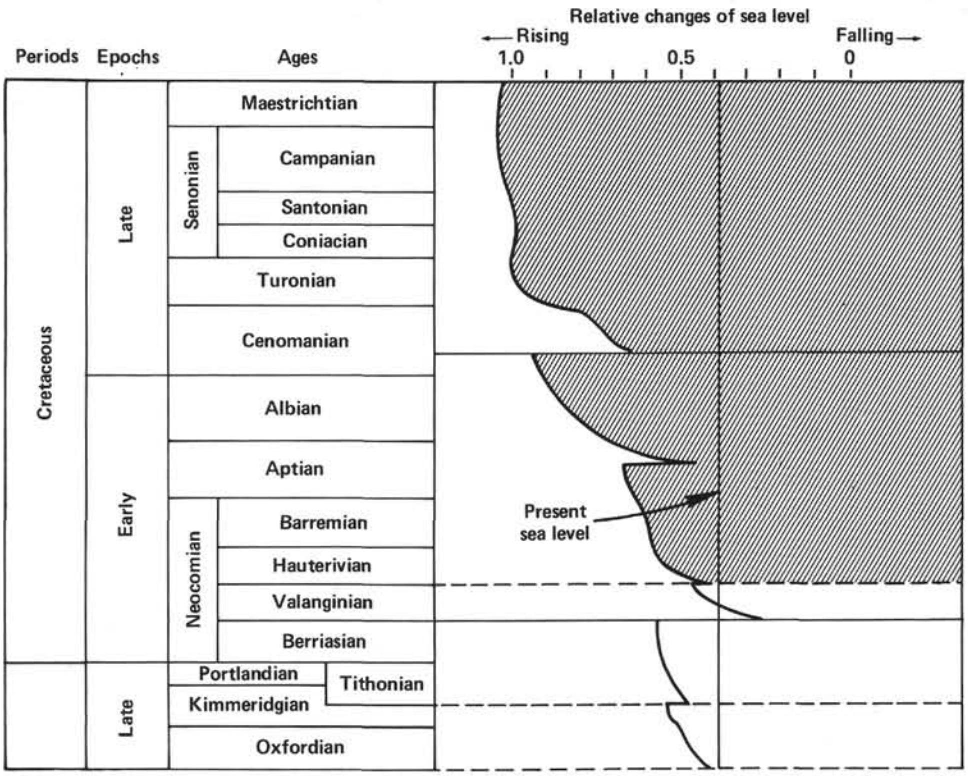

Figure 3. Sea level changes (Vail et al., 1977); Late Jurassic through Cretaceous global cycles of sea level change (Vail, 1977).

however, the one mudstone had a TOC of 1.36% and was enriched in amorphous material.

The organic facies of the green and black sediments was studied in further detail at Hole 530A. Thirty-eight samples from the late Albian to Coniacian were analyzed for TOC and organic matter types. TOC contents differed considerably between the green sediments (av. = 0.42%) and the black shales (av. = 5.06%) (Meyers, this volume). Also, the black shales are dominated by amorphous kerogen, whereas the green sediments are amorphous rich in those sediments with greater than 0.4% TOC and terrestrial rich in those with less than 0.4% TOC.

Walvis Ridge (Site 363)

Aptian through Maestrichtian chalks, marly chalks, calcareous mudstones, and limestones were deposited at Site 363 (see Table 8 and Fig. 6). Though the sediments contain negligible amounts of organic carbon (less than 0.2%) the kerogen type does reflect the sedimentary history of the area. The oldest sediments recovered are Aptain limestones deposited in shallow waters less than 500 m deep (Bolli, Ryan et al., 1978). Fragments of calcareous algae were recovered from the section and structured marine material was preserved in the kerogen fraction.

DSDP Leg 40 staff (Bolli, Ryan et al., 1978) felt that the Campanian through Aptian interval represented a major influx of terrigenous sediments that has been extensively reworked. TOC's are low and the sediments contain poorly preserved structured terrestrial and coaly organic matter.

São Paulo Plateau (Site 356)

Late Albian through Maestrichtian and nannofossil chalks, marly calcareous chalks, and marly dolomitic and calcareous mudstones were deposited at Site 356 on the São Paulo Plateau (Supko, Perch-Nielsen, et al., 1977) (Table 9 and Fig. 7). Two distinct organic matter assemblages occur in the section. An amorphous-rich interval is present from the top of the section through the uppermost Santonian. With the exception of two Albian TOC and amorphous-rich samples, the Santonian through the Albian is dominated by low TOC's and terrestrial material.

Rio Grande Rise (Site 357)

Samples from two sedimentary units were analyzed from the Rio Grande Rise (see Table 10 and Fig. 7). The Campanian through Paleocene unit consists of predominantly pinkish gray chalks and limestones (Supko, Perch-Nielsen et al., 1977). This section contains mainly amorphous kerogen although the amount of organic matter is low. The Campanian–Santonian chalks and silicified limestones are also low in organic carbon but are dominated by terrestrial organic matter.

DISCUSSION

The history of the South Atlantic is the result of many interrelated variables, including the geologic framework, climate, sea level fluctuations, and oxygen contents in the water column.

Table 5. Lithology, total organic carbon, and kerogen distribution of samples from Site 361.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
12-1, 100	Paleocene	Brown pelagic clay	300	0.05		10			90			
13-1, Top	Paleocene	Grayish blue-green sandy mudstone	327	0.10	50	10	20	10	10			
14-1, Top	Maestrichtian-u. Aptian	Grayish blue-green sandy mudstone	365	0.04	30	10	20	10	30			
15-1, Top	Maestrichtian-u. Aptian	Blue gray shale	403	0.13	30	20	30	10				
16-1, Top	Maestrichtian-u. Aptian	Green gray shale	441	0.14	30		30	10	30			
17-2, Top	Maestrichtian-u. Aptian	Dark gray shale	478	0.52	30	20	30	10			10	
18-2, Top	Maestrichtian-u. Aptian	Dark gray shale	526	0.23	50	10	30	10				
19-2, 20	Maestrichtian-u. Aptian	Dark gray shale	575	0.98	40	20	20	10			10	
20-1, 80	Maestrichtian-u. Aptian	Dark gray shale	611	0.48	50	20	20	10				
20-3, 23	Maestrichtian-u. Aptian	Dark gray shale	615	0.78	40	20	30	10				
21-2, 50	Maestrichtian-u. Aptian	Dark gray shale	670	0.50	50	20	20	10				
22-2, 50	Maestrichtian-u. Aptian	Dark gray shale	717	0.15	20	20			60			
23-2, 100	Maestrichtian-u. Aptian	Dark gray to black shale	766	2.03	20	10	20	10	40			
23-4, 50	Maestrichtian-u. Aptian	Dark gray to black shale	768	0.28	40	10	40		10			
24-1, 50	Maestrichtian-u. Aptian	Dark gray shale	811	0.30	40	10	20	10	10		10	
25-1, 50	Maestrichtian-u. Aptian	Med. blue gray shale	860	0.09	30		20	10	40			
25-5, 40	Maestrichtian-u. Aptian	Med. blue gray shale	863	0.08	10		20		70			
26-1, 110	Maestrichtian-u. Aptian	Dusky red shale	908	0.08	30		20		50			
26-5, 120	Albian	Dusky red shale	910	0.15	10		20		70			
27-2, 110	Albian	Dark gray shale	955	0.36	40	20	20		10		10	
28-2, 10	Lower Cretaceous	Grayish black shale	1002	3.42	10		10		70	10		
28-6, 20	Lower Cretaceous	Grayish black shale	1006	1.89	10		10		60			20
29-1, 20	Lower Cretaceous	Black shale	1029	3.42	20	10	20	10	40			
29-6, 20	Lower Cretaceous	Black shale	1036	5.79	30	10	10	10	40			
30-1, 60	Lower Cretaceous	Black shale	1039	21.70	10		10		70			10
30-3, 50	Lower Cretaceous	Green gray sandy mudstone	1048	0.74	40	10	20	20	10			
31-2, 40	Lower Cretaceous	Greenish gray shale	1049	0.90	20	10	20	10	40			
31-4, 110	Lower Cretaceous	Black shale	1056	5.45	20	10	30	10	30			
32-2, 100	Lower Cretaceous	Greenish black mudstone	1058	0.73	30	10	20	10	30			
32-6, 17	Lower Cretaceous	Black shale	1065	4.26	20	10	10		60			
33-3, 40	Aptian	Black shale	1075	7.71	5	5			90			
34-2, 50	Aptian	Black shale	1078	2.74	40	10	20		30			
34-4, 130	Aptian	Black shale	1083	7.95	10	10			80			
37-2, 30	Aptian	Black shale	1106	2.95	40	10	30	10	10			
38-2, 60	Aptian	Black shale	1116	2.08	50	10	30		10			
39-1, 100	Aptian	Dark green gray mudstone	1125	2.08	40		30	10	20			
40-1, 80	Aptian	Black shale	1143	3.78	10		10	10	70			
40-4, 110	Aptian	Black shale	1150	1.92	20		10		70			
41-1, 60	Aptian	Dark green gray sandy mudstone	1165	0.40	50		20	20	10			
41-4, 70	Aptian	Black shale	1170	3.20	20	10	10		60			
42-1, 50	Aptian	Black shale	1182	8.05	10		10		80			
43-1, 50	Aptian	Greenish black sandy mudstone	1202	0.40	40	10	30	10	10			
44-4, 130	Aptian	Black shale	1222	2.34	40	10	20	10	20			
44-3, 100	Aptian	Black shale	1226	2.43	40	10	20	10	20			
45-2, 100	Aptian	Black shale	1241	1.18	50		30	10	10			
46-1, 100	Aptian	Black shale	1258	1.62	40		30	10	20			
47-1, 65	Aptian	Black shale	1267	4.39	20	10	30		40			
48-2, 50	Aptian	Black shale	1285	2.60	20	10	30		40			

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

The geologic setting of the Mid-Jurassic through mid-Cretaceous South Atlantic is one of an ocean divided into two basins by the high standing Rio Grande Rise and Walvis Ridge. It was separated from the North Atlantic Ocean by the still connected South American and African continents, and closed to the south by the Algulhas Fracture Zone Sill (Arthur and Natland, 1979; Sclater et al., 1977) (Fig. 8).

The kerogen record of sediments recovered by DSDP in the South Atlantic begins in Mid-Jurassic coastal plain sediments on the Falkland Plateau. These and the Late Jurassic shelfal sediments are terrestrial-rich and TOC-poor, reflecting their proximity to the land mass. The Late Jurassic sediments were deposited in a restricted basin in water less than 400 m deep. Gradual restriction in circulation continued from the Late Jurassic to the Oxfordian (Barker and Dalziel, 1977). This accounts for the amorphous TOC enrichment in the Late Jurassic sediments. On the Falkland Plateau, a hiatus separates the Late Jurassic from late Neocomian–Aptian sediments (Thompson, 1977). While Aptian sediments were deposited on the Falkland Plateau, concurrent deposition occurred in the 2000 m deep Cape Basin to the north (Natland, 1978). Here, pelagic deposition of amorphous material was periodically interrupted by TOC-poor turbidity currents derived from the Orange River containing organic terrestrial material. The climate in the region of the Aptian Cape Basin was dry and/or cold, resulting in the restricted plant community (McLachlan and Pieterse, 1978). Natland (1978) inferred from their data and his own that the coast was swampy, with ferns and *Classopollis,* a possible mangrove type plant, filling the coastal areas. This served as the source of much of the terrestrial material at Site 361. Swampy conditions may have resulted in part from a rising sea level during the lower Aptian, which flooded the low lying area (Fig. 3).

Concurrent deposition north of the high-standing Walvis Ridge in the Angola Basin was also dominated by amorphous-rich sediments. These sediments are considerably richer in organic matter than those in the southern basins, with TOC values up to 24.3%. This may be the result of high productivity (Melguen, 1978) and rapid sedimentation rates of 42.2 m/m.y. (Bolli, Ryan et al., 1978). Morgan (1978) suggested that this site was some distance from shore in a low energy envi-

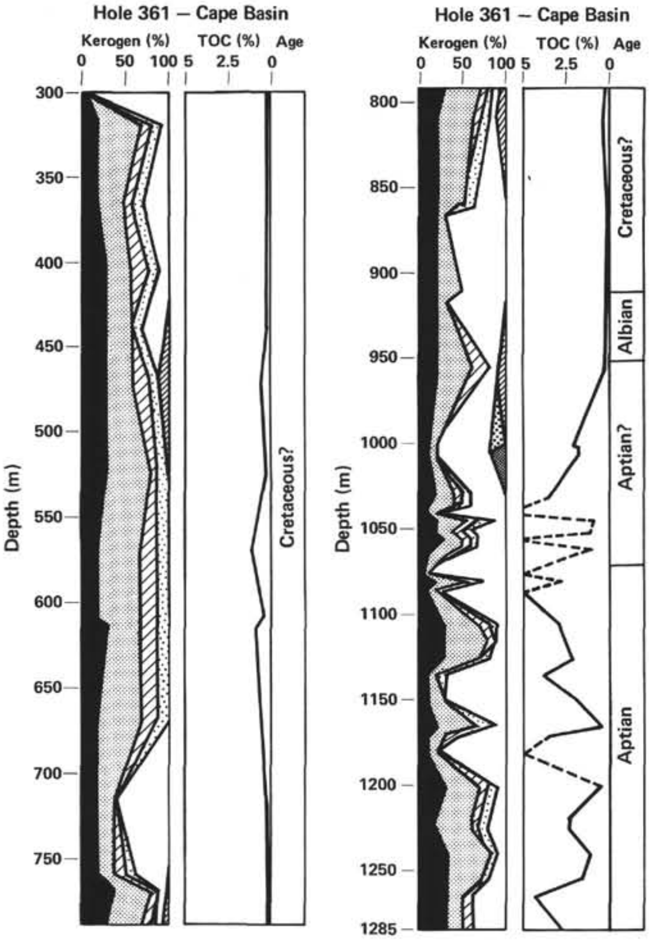

Figure 4. Kerogen, TOC, and age of sediments in the Cape Basin.

ronment and that the climatic conditions were hot and semi-arid. This climate may have precluded development of dense vegetation onshore and may explain why little terrestrial material is observed in the section.

Theories accounting for the preservation of organic matter in these sediments include density stratification in a restricted basin (Arthur and Natland, 1979) (Fig. 9) and the presence of an oxygen minimum zone (Ryan and Cita, 1977). Arthur and Natland's (1979) model of a restricted basin coupled with salinity stratification is certainly plausible in light of the narrow basins depicted in Figure 8 by Sclater et al. (1977), and the large variation in paleowater depths where anoxic sediments occur in the Cape Basin and the Falkland Plateau. A general rise in sea level from the Late Jurassic through early Aptian may have played a role in the development of anoxic conditions (Fig. 3). Transgressions may trigger high organic productivity and in turn depletion of oxygen in the water column (Tissot, 1979).

Whatever the cause of anoxic conditions in the early history of the South Atlantic, it was terminated effectively and uniformly across the southern basins during the late Aptian. The organic facies profiles from the Falkland Plateau and the Cape Basin indicate a rapid change to more oxidizing conditions as witnessed by the dramatic rise in the proportion of terrestrial organic matter and the reduction in TOC. Arthur and Natland (1979) attribute this change to oxidizing conditions resulting from the lowering of the Algulhas Fracture Zone Sill. This allowed the passage of shallow water over the sill and also over the Walvis Ridge and the Rio Grande Rise.

It is also likely that the late Aptian regression (Fig. 3) is important in influencing the kerogen profiles. With lower sea level, there was increased erosion and runoff from the continents, depositing large amounts of terrestrial material. The Aptian–Albian break in the kerogen profile is not as apparent in the Angola Basin, possibly because of a harsh and dry climate which inhibited the formation of dense vegetation. Consequently, there would have been less terrestrial material deposited during the regression.

The second period of organic enrichment is only present in sediments from the northern part of the South Atlantic Basin, the São Paulo Plateau, and the Angola Basin sites. The period is more extensive in the Angola Basin, lasting from the late Albian (Hole 530A) to the Santonian (Site 364). Organic-rich sediments were recovered only from the Turonian of the Sao Paulo Plateau. In fact, the abundance of TOC-poor, terrestrial-rich sediments from the Coniacian to the Santonian at Site 357 on the São Paulo Plateau indicates that the anoxic conditions noted by Bolli, Ryan et al. (1978) did not exist through the Santonian. Much of the organic matter at this site was probably derived from increased runoff associated with the uplift of the Andean Cordillera and the Sierra do Mar mountain range.

The kerogen and lithologies in the Angola Basin vary from amorphous, TOC-rich black shales to bioturbated, terrestrial rich, TOC-poor red shales. Bioturbated green shales are present in the sequence; those with more than 0.4% TOC are amorphous-rich while those with less than 0.4% TOC are terrestrial-rich. The variation in sediment color from red to green to black reflects changes in the oxidation state of iron related to oxygen levels in the water column (Meyers, this volume). Meyers (this volume) suggests that there was a delicate balance between oxidizing and reducing conditions in the Angola Basin at this time. Kerogen and TOC data support this concept. It is likely that organic productivity remained constant over the time interval in which these sediments were deposited and that only the oxygen concentration in the water column varied. These fluctuations would cause destruction or preservation of the more labile organic matter types, ultimately affecting the overall kerogen assemblage.

The organic facies data favor the presence of a midwater oxygen minimum on the northern South Atlantic during the late Albian through Santonian for several reasons. First, sediment color and organic-matter variations at Hole 530A are best explained by a fluctuating oxygen-poor water mass whose lower limit periodically impinges on the sediments. Second, the São Paulo Plateau site is about 1000 m deeper than Angola Basin Site 364 (Arthur and Natland, 1979) and with the exception of the Turonian, the sediments are oxidized. One would expect that the sediments in a stratified or restricted

Table 6. Lithology, total organic carbon, and kerogen distribution of samples from Site 364.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
11-1, 100	Maestrichtian	Yellow calcareous nannofossil chalk	359	0.08	50	10	20		10		10	
13-1, 100	Campanian	Pale brown calcareous nannofossil chalk	397	0.06	10		10		70		10	
14-2, 100	Campanian	Reddish yellow calcareous nannofossil chalk	427	0.05	10		10		80			
15-4, 100	Campanian	Reddish yellow calcareous nannofossil chalk	467	0.02	10		10		80			
16-2, 103	Campanian	Light brown marly nannofossil chalk	503	0.06	10		10		80			
17-1, 100	Coniacian–Santonian	Brown calcareous nannofossil chalk	531	0.05			10		90			
19-3, 120	Coniacian–Santonian	Brown calcareous nannofossil chalk	571	0.07	10		10		70		10	
20-1, 120	Coniacian–Santonian	Green gray calc. nannofossil chalk	578	0.05			10		50	40		
20-4, 120	Coniacian–Snatonian	Green gray calc. nannofossil chalk	580	0.32			30		50		20	
21-1, 50	Coniacian–Santonian	Brown marly chalk	597	0.09	10		10		80			
21-5, 35	Coniacian–Santonian	Grayish brown sapropel	600	23.40	10		10	10	70			
22-2, 100	Coniacian–Santonian	Green gray marly chalk and mudstone	617	0.25	10		20		70			
22-4, 60	Coniacian–Santonian	Green gray marly chalk and mudstone	623	0.17	10		30		40		20	
23-1, 60	Coniacian–Santonian	Greenish gray mudstone	645	1.36	10		10		70		10	
23-4, 120	Coniacian–Santonian	Black shale	652	2.89	10		10		80			
24-1, 65	Coniacian–Santonian	Black sapropelic shale	673	11.29	10		10		80			
25-1, 100	Coniacian–Santonian	Green gray marly nannofossil chalk	701	0.21	20		30		50			
25-6, 100	Coniacian–Santonian	Green gray marly nannofossil chalk	708	0.19	50		20		10	10	10	
26-1, 100	Coniacian–Santonian	Green gray marly nannofossil chalk	711	0.15	10		20		70			
29-1, 100	Albian	Blue gray limestone	769	0.11	40	10	20		10		20	
31-2, 100	Albian	Blue gray limestone	808	0.59	10		10		30		30	20
33-1, 100	Albian	Blue gray limestone	846	0.06	40		30		10	10	10	
34-1, 80	Albian	Blue gray limestone	875	0.63	10		10		50		10	20
36-1, 110	Albian	Blue gray limestone	911	0.19	10		10		60			20
37-1, 100	Albian	Blue gray limestone	931	0.47	20	10	10		20			40
37-4, 35	Albian	Olive gray marly limestone	935	1.24	10		10		60			20
38-1, 100	Albian	Olive gray marly limestone	950	0.32	10		10		20		10	50
38-6, 100	Albian	Olive gray marly limestone	956	1.13	10		10		40			40
39-1, 100	l. Albian–u. Aptian	Black sapropelic shale	967	3.61	10				90			
39-6, 100	l. Albian–u. Aptian	Olive gray marly limestone	975	2.17	10				80			10
40-2, 100	l. Albian–u. Aptian	Black sapropelic shale	988	6.38	10			10	60		10	10
40-5, 100	l. Albian–u. Aptian	Olive gray marly limestone	994	7.89			10		70			20
41,CC	l. Albian–u. Aptian	Black shale		0.57			10	10	50			30
42-1, 80	l. Albian–u. Aptian	Blue gray marly dolomitic limestone	1006	0.03	10		10		60			20
42-6, 32	l. Albian–u. Aptian	Black shale	1032	24.30			10		90			
43-1, 50	l. Albian–u. Aptian	Black shale	1035	14.57			10	10	80			
44-2, 55	l. Albian–u. Aptian	Black shale	1047	1.50			10	10	80			
45-1, 120	l. Albian–u. Aptian	Black shale	1064	16.79			10	10	80			

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

basin with little or no circulation would be reducing throughout the deepest part of the basin. However, Thiede and van Andel (1977) have noted that there are no reduced sediments below 3 km in the northern South Atlantic. Therefore, Turonian organic-rich sediments on the São Paulo Plateau may best be explained by the high sea level, which increased primary productivity and led to an expansion of the oxygen minimum layer (Tissot, 1979).

CONCLUSIONS

The organic facies data presented in this chapter indicate that two distinct periods of organic enrichment occurred in the Mesozoic of the South Atlantic, from the Late Jurassic through late Aptian and the late Albian through Santonian. Organic facies and lithologic descriptions coupled with good geologic control indicate that there were two main causes of anoxia. Salinity stratification was important during the earlier period, and the development of an oxygen minimum was important during the later period.

The organic facies data indicate a causal relationship between rising sea level and organic-rich rocks. Fluctuations in sea level may have played a part in: (1) the development of anoxic conditions in the Early Cretaceous; (2) the large influx of TOC-poor, terrestrial-rich material in the late Aptian–Albian; and (3) the development of the Turonian anoxic sediments at the São Paulo Plateau.

The organic facies history of the South Atlantic is intimately tied to the climate which determined the type of organic material available for deposition. Sea level fluctuations influenced the rate at which organic matter was deposited as well as productivity and oxygen levels in the water column.

ACKNOWLEDGMENTS

I thank R. J. Pokluda, F. M. Weaver, and P. A. Meyers for their help in collecting samples and J. P. Shannon, Jr., C. P. Summerhayes, W. A. Young, D. L. Johnson, and R. Cunningham, Jr. for reviewing this manuscript. TOCs were determined by GeoChem Laboratories and EPRCo; E. B. Brown did the pyrolysis analysis; and I made the kerogen descriptions. I thank Exxon Production Research Company for permission to publish these results.

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Table 7. Lithology, total organic carbon, and kerogen distribution of samples from Hole 530A.

Core-Section (interval in cm)	Age	Lithology	Depth (m)	TOC (%)	TAI	Kerogen distribution S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB	IF
86-5, 31–32	Santonian	Black claystone	937.5	1.28	1.3					80			10	10
86-4, 145–147	Santonian	Green claystone	937.0	0.28										
86-5, 33	Santonian	Black claystone	937.5	2.02				10		80			10	
86-5, 36	Santonian	Dark green claystone	937.6	0.16										
87-1, 37	Coniacian	Black shale	940.5	5.37				90					10	
87-1, 83	Coniacian	Black claystone	941.0	1.31		10	10	20		30				30
87-3, 83–85	Coniacian	Dark red claystone	944.0	0.25										
87-4, 105–106	Coniacian	Black shale	945.6	6.22						80				20
87-4, 118–119	Coniacian	Green claystone	945.7	0.16				40		60				
88-3, 33	Coniacian	Black shale	952.3	9.70						90				
88-3, 90	Coniacian	Black shale	952.9	2.84						90				
89-1, 34	Coniacian	Black shale	958.3	9.60						90				
90-3, 86–87	Coniacian	Black shale	970.9	16.50						90				
90-3, 99–100	Coniacian	Gray marlstone	971.0	0.62		40				60				
91-4, 45	Coniacian	Green claystone	981.0	1.19										
93-1, 40	Coniacian	Green claystone	990.4	0.95	2	40				60				
93-2, 35	Coniacian	Green shale	991.8	0.18		80		10		10				
93-3, 45	Coniacian	Red claystone	993.5	0.11										
94-1, 42–43	Coniacian	Black shale	999.4	12.66		60		40						
94-2, 11–12	Coniacian	Dark green shale	1000.6	0.35										
96-2, 118–119	Cenomanian	Dark red claystone	1019.7	0.11										
96-4, 29–30	Cenomanian	Black shale		1.79										
96-4, 61–62	Cenomanian	Black shale	1022.1	5.82						90				
97-3, 59–60	Cenomanian	Black shale	1029.6	7.29						50				50
97-3, 56–57	Cenomanian				2	10				90				
97-4, 56–57	Cenomanian	Black shale	1013.1	8.04						90				
98-2, 60–61	Cenomanian	Dark green claystone	1037.1	0.28										
98-2, 69–70	Cenomanian	Black shale	1037.2	1.44		10		10		80				
98-3, 92–93	Cenomanian	Black shale	1038.9	8.57						90				
98-3, 110–111	Cenomanian	Dark green claystone	1039.1	0.47	2	10	10			70				
99-5, 70–71	Cenomanian	Black shale	1050.7	1.73	2					90				
100-1, 85–86	Cenomanian	Dark green shale	1053.9	0.28		60		20		20				
100-1, 99–100	Cenomanian	Black shale	1054.0	1.92		10				90				
100-4, 114–115	Cenomanian	Dark green marlstone	1058.6											
100-5, 38–39	Cenomanian	Dark red claystone	1059.4	0.38										
101-1, 16–17	Cenomanian	Green claystone	1062.2	0.70		20	10	20		30		20		
101-2, 8–9	Cenomanian	Black shale	1063.6	0.93		60	10	20		10				
101-4, 36–37	Cenomanian	Dark green claystone	1066.9	1.31				10		90				
101-4, 55–56	Cenomanian	Light green marlstone	1067.1	0.08		10		10		80				
102-1, 149–150	Cenomanian	Dark green claystone	1072.5	1.16				10	10	80				
102-3, 120–121	Cenomanian	Black shale	1075.2	1.73		20		70		10				
102-3, 130–131	Cenomanian	Dark green claystone	1075.3	0.45						90				
103-6, 22–23	Cenomanian	Green claystone	1085.7	0.16		10				90				
104-2, 141–142	Albian	Dark green claystone	1087.9	0.41		20		70		10				
104-3, 0–1	Albian	Black claystone	1088.0	8.21										
104-4, 123–124	Albian	Dark green claystone	1090.7	0.18										
104-4, 91–92	Albian	Green claystone	1090.4	0.47										
104-5, 61–62	Albian	Black claystone	1091.6	0.57										
105-1, 23–24	Albian	Dark green claystone	1094.2	0.23		50		20		30				
105-2, 139–140	Albian	Black shale	1096.9	5.28						80				20
105-4, 35–36	Albian	Light green limestone	1098.9	0.44				10		90				
105-4, 9–10	Albian	Black shale	1098.6	3.60						90				10

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies; IF = indeterminate fines. Blank space = none present.

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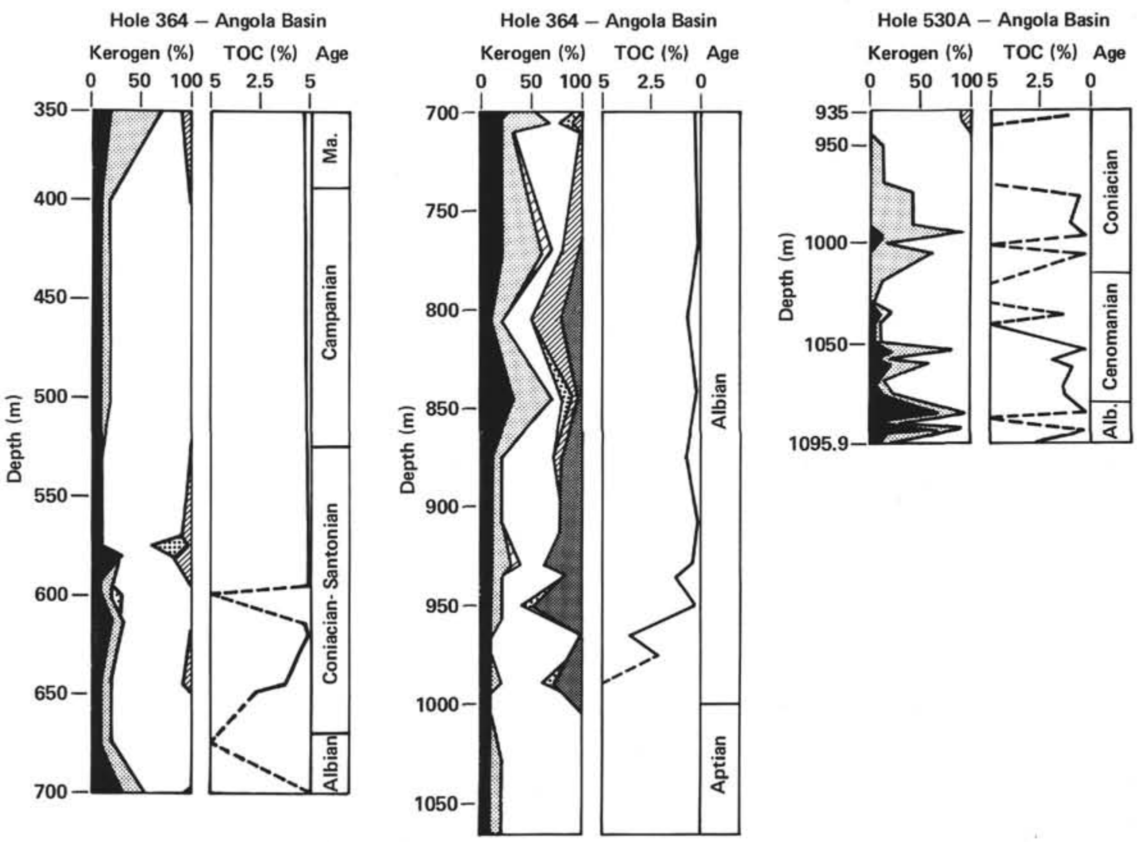

Figure 5. Kerogen, TOC, and age distributions of sediments on the Angola Basin.

Table 8. Lithology, total organic carbon, and kerogen distribution of samples from Site 363.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
18-2, 100	Maestrichtian	Brown gray nannofossil chalk	326	0.16	10		30		60			
23-2, 100	Campanian	Gray nannofossil chalk	390	0.10	30		30		40			
24-1, 1100	Campanian	Gray marly nannofossil chalk	402	0.12	20	10	30	10	30			
25-1, 130	Coniac.-Santonian	Dark olive nannofossil chalk	421	0.05	20	20	30		30			
26-1, 100	Albian	Gray nannofossil chalk	440	0.13	30	10	50		10			
26-4, 100	Albian	Gray nannofossil chalk	448	0.09	40	20	30		10			
27-1, 100	Albian	Gray nannofossil chalk	459	0.10	60		20		10		10	
28-1, 100	Albian	Green gray marly limestone	478	0.09	50	10	20		10		10	
28-6, 61	Albian	Green gray marly limestone	485	0.14	80	10			10			
29-1, 101	Albian	Light gray marly limestone	497	0.11	40		20	20	10		10	
30-1, 100	Albian	Light gray marly limestone	516	0.10	60		20		10		10	
31-1, 100	Albian	Light gray marly limestone	535	0.12	60	10	30					
31-6, 67	Albian	Light gray marly limestone	543	0.12	40	10	30		10		10	
32-1, 100	Albian	Light gray marly limestone	554	0.12	40	10	30		10		10	
33-1, 130	Albian	Light gray marly limestone	573	0.07	40		40	10			10	
36-3, 102	Albian	Gray limestone	630	0.07	40	10	40				10	
37-1, 50	Aptian	Light gray limestone	650	0.05	40	10	30		10		10	
38-1, 60	Aptian	Light gray limestone	670	0.15	40	20	20		10		10	
39-2, 20	Aptian	Yellow gray limestone	690	0.12	30	10	30				30	

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

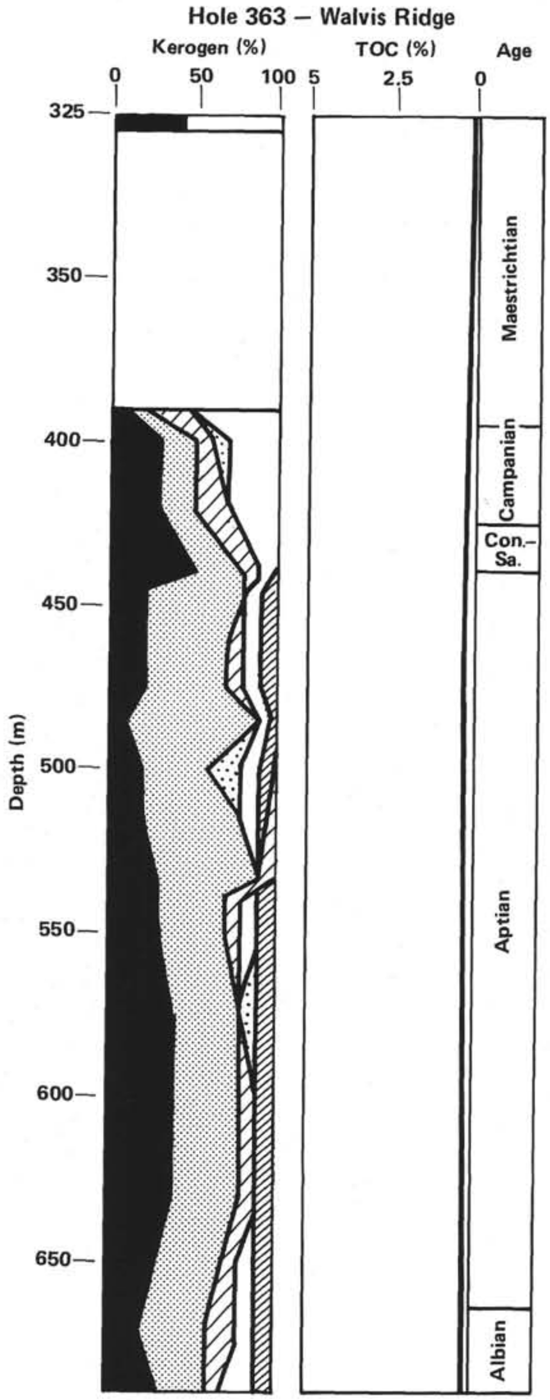

Figure 6. Kerogen, TOC, and age distributions of sediments on the Walvis Ridge.

Table 9. Lithology, total organic carbon, and kerogen distribution of samples from Site 356.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
24-1, 100	Paleocene	Green gray foram nanno clay	361	0.20	20		40		40			
26-4, 100	Paleocene	Pinkish gray foram nanno chalk	385	0.17	10		10		80			
27-5, 100	Paleocene	Pinkish gray foram nanno chalk	391	0.15	10		10		80			
28-4, 104	Paleocene	Pinkish gray foram nanno chalk	401	0.10	10		10		80			
29-5, 100	Maestrichtian	Pale yellow brown foram nanno chalk	412	0.02	10		10	10	70			
30-1, 100	Maestrichtian	Light blue gray foram nanno chalk	418	0.07	10		20		70			
31-1, 100	Maestrichtian	Light gray marly nanno chalk	437	0.04	10		20		70			
32-2, 100	Maestrichtian	Light gray marly calc. chalk	457	0.05	10		20		70			
33-1, 100	Maestrichtian	Light gray marly calc. chalk	486	0.09	10		20		70			
34-1, 100	Campanian	Olive gray marly calc. chalk	515	0.04	20		20		60			
35-1, 100	Santonian	Olive gray dolomite marly calc. chalk	542	0.10	10		10		80			
36-1, 100	Santonian	Med. dk. gray dolomite marly calc. chalk	577	0.11	60		30		10			
37-1, 100	Santonian	Olive gray marly calc. chalk	599	0.15	60		30		10			
38-3, 45	Santonian	Med. gray marly calc. chalk	655	0.14	60		30		10			
39-1, 108	Coniacian	Light gray calc. mudstone	675	0.08	60		30		10			
40-3, 100	Coniacian	Med. gray calc. mudstone	700	0.08	10		20		70			
41-2, 70	Maestrichtian	Green gray dolomitic calc. mudstone	704	2.99	10		10		80			
41-4, 75	Maestrichtian	Light blue gray limestone	710	2.09	10		10	10	70			
42-1, 100	Albian	Green brown calc. mudstone	714	0.19	50		40		10			
43-1, 100	Albian	Med. dk. gray marly limestone	723	0.11	40	10	40				10	
44-1, 100	Albian	Med. dk. gray marly dolomitic limestone	732	0.05	50		40		10			

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

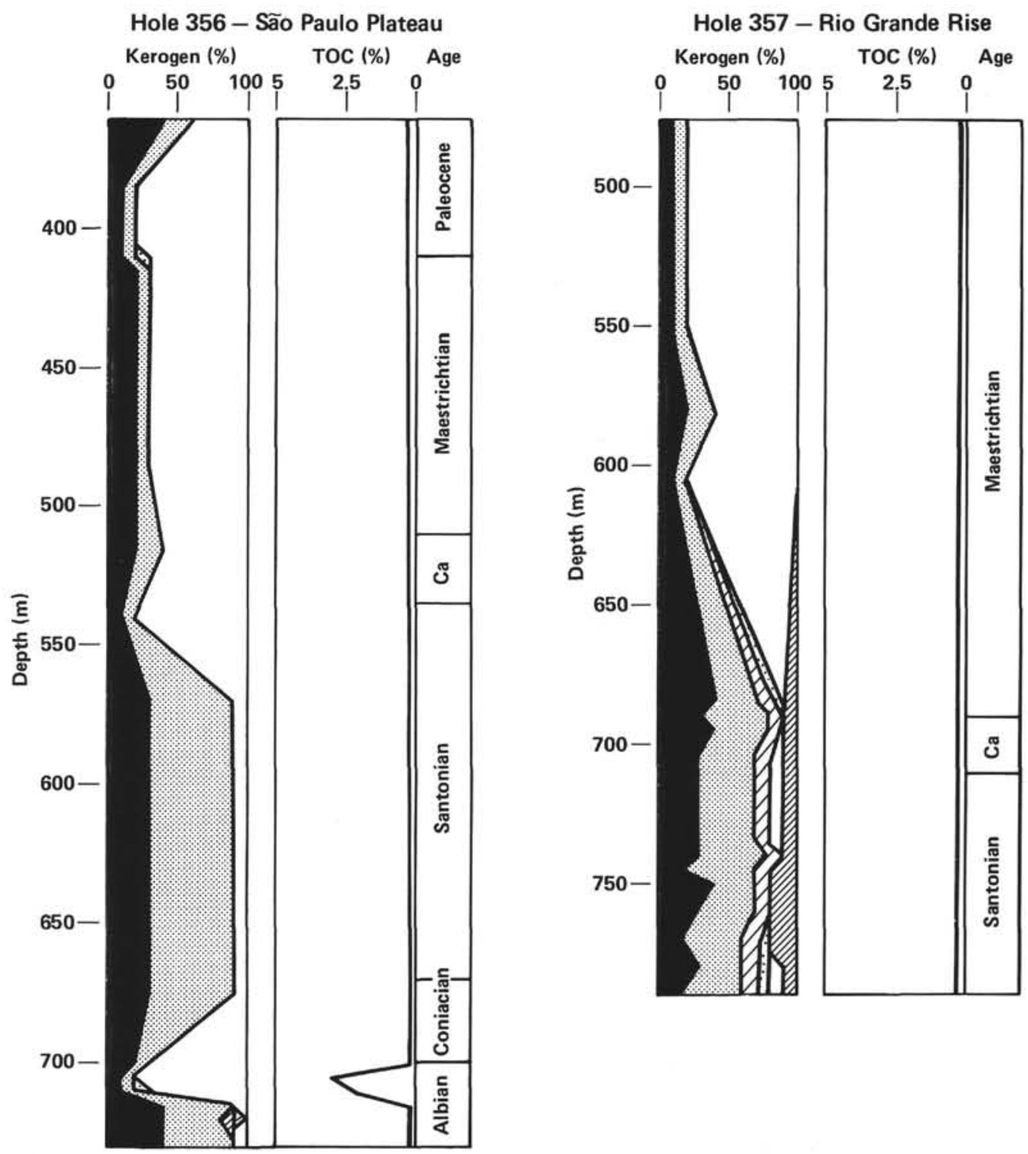

Figure 7. Kerogen, TOC, and age of sediments on the Rio Grande Rise and São Paulo Plateau.

Table 10. Lithology, total organic carbon, and kerogen distribution of samples from Site 357.

Core-Section (level in cm)	Age	Lithology	Depth (m)	TOC (%)	Kerogen distribution							
					S. terr.	P & S	C	Bio. t.	AM	GA	SM	RB
30-1, 100	Paleocene	Light brown limestone	474	0.13	10		10		80			
31-2, 100	Maestrichtian	Pink gray limestone	495	0.09	10		10		80			
32-1, 100	Maestrichtian	Light brown nanno chalk	503	0.06	10		10		80			
33-1, 100	Maestrichtian	Brown nanno chalk	522	0.11	10		10		80			
34-1, 100	Maestrichtian	Blue gray foram nanno chalk	550	0.07	10		10		80			
35-2, 100	Maestrichtian	Brown nanno chalk	580	0.07	20		20		60			
36-1, 100	Maestrichtian	Brown foram nanno chalk	608	0.06	10		10		80			
39-1, 100	Campanian	Olive gray micrite chalk	684	0.10	30	10	40	5	5		10	
40-1, 100	Campanian	Olive gray micrite chalk	693	0.11	50	10	30			10		
40-4, 42	Campanian	Olive gray micrite chalk	697	0.12	40	10	40				10	
41-1, 105	Santonian	Green gray micritic chalk	704	0.07	40	10	30		10		10	
42-1, 100	Santonian	Green gray micritic chalk	714	0.10	40	10	30		10		10	
43-1, 105	Santonian	Green gray foram nanno limestone	723	0.08	40	10	30		10		10	
44-2, 100	Santonian	Greenish gray marly limestone	733	0.09	40	10	30	10			10	
45-2, 100	Santonian	Greenish gray marly limestone	740	0.10	50	10		30			10	
46-2, 100	Santonian	Greenish gray marly limestone	745	0.10	50	10	20				20	
47-1, 100	Santonian	Greenish gray marly chalk	750	0.10	30	10	40				20	
48-1, 100	Santonian	Greenish gray marly limestone	760	0.10	40	10	30				20	
49-2, 100	Santonian	Greenish gray marly limestone	770	0.15	40	10	20	10			20	
50-1, 100	Santonian	Greenish gray siliceous marly limestone	779	0.17	30	10	30	10	10		10	
51-1, 100	Santonian	Greenish gray siliceous marly limestone	788	0.08	40	10	20	10	10		10	

Note: S. terr. = structured terrestrial; P & S = pollen & spores; C = coaly; Bio. t. = biodegraded terrestrial; AM = amorphous; GA = gray amorphous; SM = structured marine; RB = round bodies. Blank space = none present.

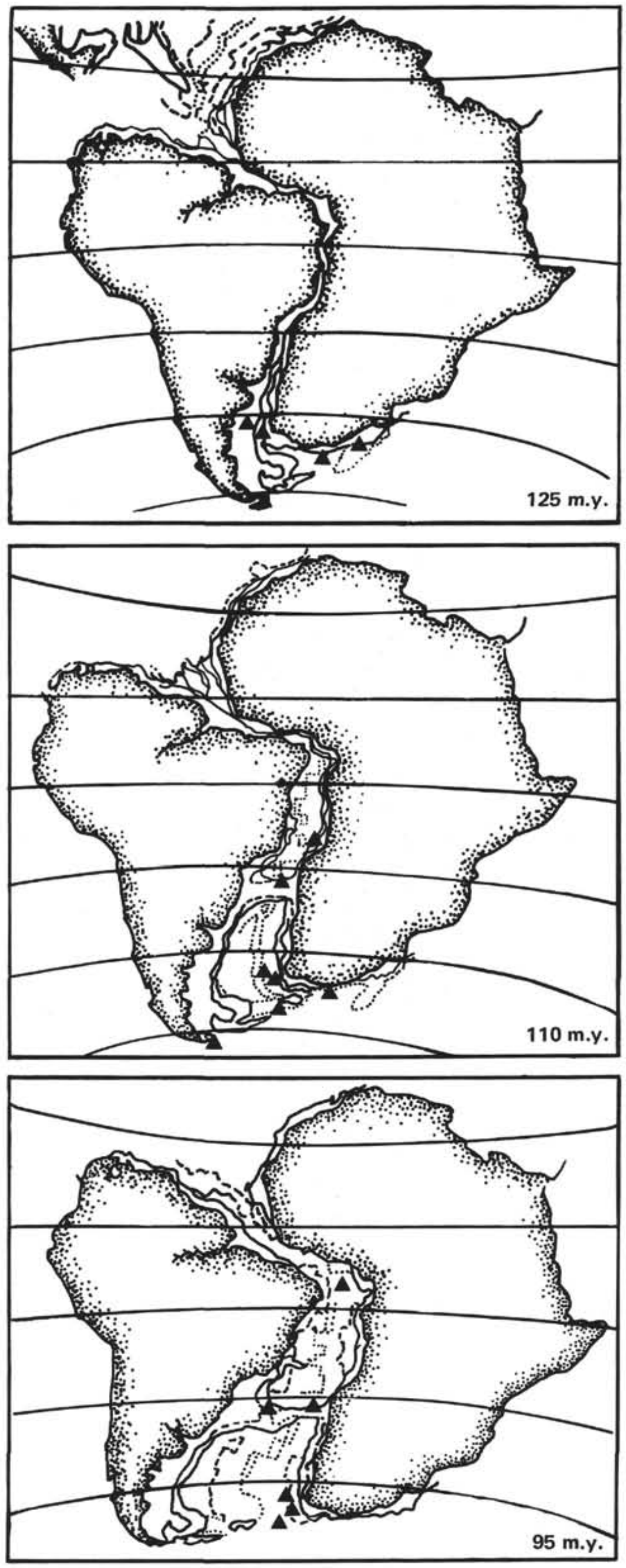

Figure 8. Paleoreconstructions of the Mesozoic South Atlantic (Sclater et al., 1977).

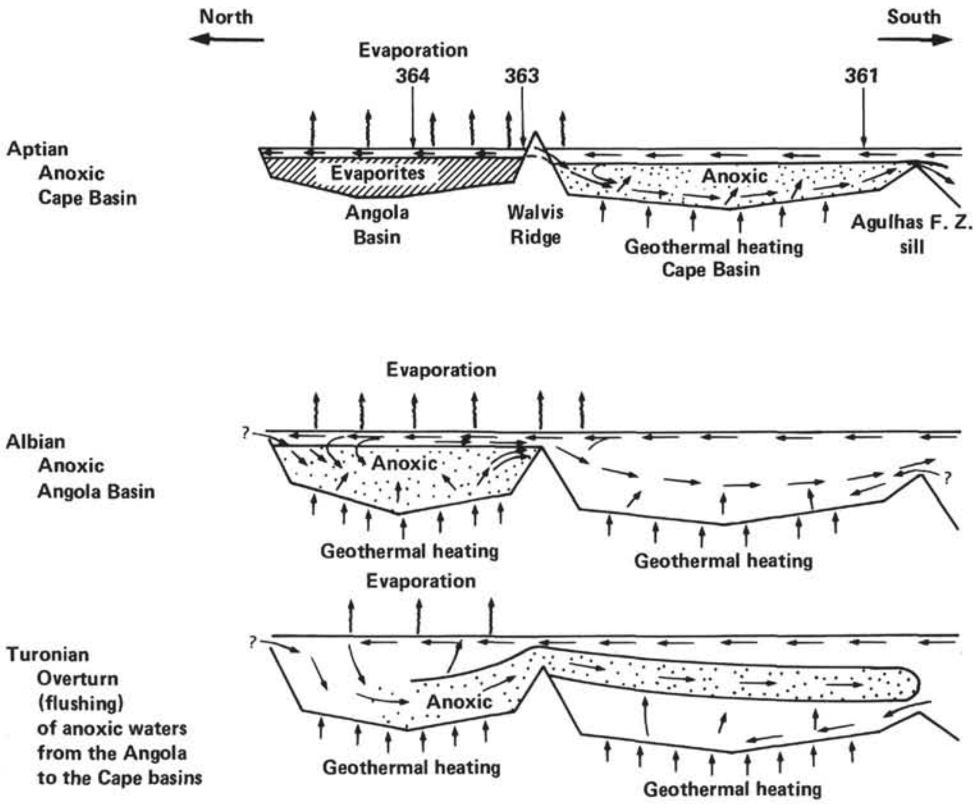

Figure 9. Schematic thermohaline circulation in the South Atlantic during the Cretaceous. Reducing conditions in the South Atlantic can be attributed to salinity stratification and sluggish circulation. This is a schematic diagram by Natland (1978) which summarizes their controls.