38. BLACK SHALES OF THE BAY OF BISCAY AND CONDITIONS OF THEIR FORMATION, DEEP SEA DRILLING PROJECT LEG 48, HOLES 400A, 402A

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INTRODUCTION

Lower Cretaceous black shales of the Atlantic Ocean, rich in organic matter of various kinds, are of special interest because of their petroleum potential in the continental shelves and because their origin and environment of deposition are controversial. The composition of the organic matter within them is not only a sensitive indicator of facies environment, it also is a measure of the degree of post-depositional diagenesis that has occurred thus serving as a geological thermometer. The petrography of the black shales, their stratigraphy, and their spatial distribution in the paleogeography of the oceanic shelf zone enable determination of near sea-shore sedimentation processes; comparison with black shales of the continental blocks assists in correlation of geologic phenomena and events on a global scale.

PETROGRAPHIC COMPOSITION OF ORGANIC MATTER IN THE BLACK SHALES

Study of the organic matter in marine black shales by coal petrographic methods is a new approach to the problem of the origin of such sediments. The high resolving power of the method, which has proven so reliable and informative in the investigation of continental coal deposits, provides a precise means of studying the microcomponents of the black shales, the nature of their initial state, origins, mode of accumulation, and subsequent changes.

The study of bifaced polished sections was accomplished using a Leitz "Ortholux" petrographic microscope under a magnification of 150 to 200 times. Detailed examination of the internal structure of fragments and attritus, their shape and dimensions, was carried out under magnifications of 400 to 1000 times, using a dry objective, in oil immersion, without the analyzer, and under crossed nicols.

Because the organic matter (kerogen) in the black shales is the same as that in humic and sapropelic coals, we applied the coal petrographic classification that we had previously devised (Timofeev and Bogolyubova, 1965; Timofeev et al., 1962). According to this classification the microcomponents of kerogen comprise humic, leiptinitic, sapropelic-humic, humic-sapropelic, and sapropelic matter (Table 1). The initial humic material (lignin-cellulose tissues) is allochthonous. It can be subdivided into four classes — fusinites, semi-fusinites, and gelenites A and δ — which are products of the fusinization and gelefication processes. The classes are thus distinguished on the basis of the degree of preservation of the cellular structure within the lignin-cellulose tissues and on the various size of their inclusions. Fusinites, semi-fusinites, and gelenites A originate on the continent and are transported to the site of deposition, hence are here termed *allothigenic*. This group of telenites comprises mostly vitrain-fusains, semivitrain-fusains, and vitrains which, under the microscope in translucent light, are opaque to semi-transparent; in the case of vitrains they are brown in color. Their detrital nature is recognized in the tabular, angular shape of the fragments, the layer of which are often rounded, by the sharp contours of inclusions, by the compact rather than plastic nature of the material, which is often fractured and jointed, and by the absence of pyrite.

A second group consisting mainly of gelenite δ class with telinitic and collinitic structure contains fragments and attritus of gelefied tissues altered to xylain, xylovitrain, and, seldomly, vitrain; the groundmass has a lumpy, granular or flocculent nature. Because their origin and coalification, through diagenic processes, takes place in the basin of deposition, they are termed *syngenic*. In translucent light they are reddish brown in color, with diffuse contours, and irregular, elongate, fusiform or complex shape. They often appear as small to large fragments of split ("dishevelled") tissue now more now less gelefied (*in situ*) and merging gradually into a lumpy or granular groundmass. Pyrite is common both dispersed through the groundmass and as nodules replacing fragments and attritus.

Leiptinitic matter in the black shales is represented by small amounts of yellowish pollen, pollen grains, rare orange resinous bodies, and products of maceration all of which are visible under the microscope in thin section. This material is undoubtedly allochthonous.

Sapropelic matter in the black shales is typically autochthonous. Microcomponents in the sapropel involve the alginite-thallomite and sapro-collinite classes. Microscopic colonial algae, presumably the blue-green variety, are classed as alginite-thallomite. Under high magnification (400× or more) the algal colonies have a rounded or oval shape of thallomes, the size of which varies from 4 to 15 μm or more. In translucent light they are more or less dark brown in color; colonies colored yellow with orange and olive tints occur less frequently. They are either structureless due to gelefication or have a granular inner structure. Sapro-collinite is a structureless groundmass, of beige-olive color in translucent light. It is composed not only of the decomposition products of incrustate and non-incrustate algae, but also animal remains such as sponge spicules, foraminifers, mollusk, and fish debris. Sapro-collinite "saturates" the mineral components of the sediment, forming a finely dispersed organo-mineral complex.

Sapropel-humic and humic-sapropelic matter is composed of sapro-humo-collinite and humo-sapro-collinite microcomponents which forms a mechanical admixture of gelefication products (of varying quantitative ratios) of allochthonous remains of higher plants, autochthonous algae,

TABLE 1
Classification of Microcomponents of Organic Matter (kerogen) of the Black Shales and Their Initial Material

Matter	Initial Material: Type of Accumulation	Initial Material: Composition			Structure (composition of plant matter)	Direction of the Transformation Process	Group (Location of Microcomponent Occurrence)	Class (Type of Matter)	Type	Species: By Degree of Structure Preservation	Species: By Degree of Fragmentation
Humic	Allochthonous	Remains of higher plants	Remains of lignin-cellulose tissues		Telinitic	Fusenisation	On the continent (allothigenic)	Fusinites	Fusinito-telinite	Fusain, xylo-vitrain-fusain, vitrain-fusain	Fragmentary[a] Attrital (coarse[b], fine[c])
Humic	Allochthonous	Remains of higher plants	Remains of lignin-cellulose tissues		Telinitic	Fusenisation	On the continent (allothigenic)	Semi-fusinites	Semifusinite-telinite	Semifusain, semixylovitrain-fusain, semi-vitrain-fusain	Fragmentary. Attrital (coarse, fine)
Humic	Allochthonous	Remains of higher plants	Remains of lignin-cellulose tissues		Telinitic	Gelefication	On the continent (allothigenic)	Gelinites "A"	Gelinite-telinite "A"	Vitrain	Fragmentary. Attrital (coarse, fine)
Humic	Allochthonous	Remains of higher plants	Remains of lignin-cellulose tissues		Telinitic	Gelefication	On the ocean bottom (syngenic)	Gelinites "S"	Gelinite-telinite "S"	Xylain, xylo-vitrain	Fragmentary. Attrital (coarse, fine)
Humic	Allochthonous	Remains of higher plants	Remains of lignin-cellulose tissues		Collinitic	Gelefication	On the ocean bottom (syngenic)	Gelinites "S"	Gelinite-collinite	Lumpy, granular, flocculent, sapropel-humic ground mass	Colloidal
Leiptinitic	Allochthonous	Remains of higher plants	Stable elements	Polinite	–	–	–	–	–	Pollen	–
Leiptinitic	Allochthonous	Remains of higher plants	Stable elements	Resinite	–	–	–	–	–	Resin bodies	–
Sapropelic-humic	Autochthon-allochthonous	Mechanical admixture of decomposition products of higher and lower plants and animal organisms			Collinitic			Sapro-humo-collinite		Lumpy, granular, flocculent, sapropel-humic groundmass	Colloidal
Humic-sapropelic	Autochthon-allochthonous	Mechanical admixture of decomposition products of higher and lower plants and animal organisms			Collinitic			Humo-sapro-collinite		Humo-sapropelic groundmass	Colloidal
Sapropelic	Autochthonous	Decomposition products of higher plants and algae	Not incrustated		Thallomitic	Gelefication	On the ocean bottom (Syngenic)	Alginite-thallomite			Fragmentary
Sapropelic	Autochthonous	Decomposition products of higher plants and algae	Incrustated		Collinitic	Gelefication	On the ocean bottom (Syngenic)	Sapro-collinite		Structureless sapropelic groundmass	Colloidal
Sapropelic	Autochthonous	Decomposition products of animal organisms	Chitinous		Collinitic	(?)	On the ocean bottom (Syngenic)	Sapro-collinite		Structureless sapropelic groundmass	Colloidal
Sapropelic	Autochthonous	Decomposition products of animal organisms	Siliceous		Collinitic	(?)	On the ocean bottom (Syngenic)	Sapro-collinite		Structureless sapropelic groundmass	Colloidal
Sapropelic	Autochthonous	Decomposition products of animal organisms	Carbonate		Collinitic	(?)	On the ocean bottom (Syngenic)	Sapro-collinite		Structureless sapropelic groundmass	Colloidal
Sapropelic	Autochthonous	Decomposition products of animal organisms	Phosphate		Collinitic	(?)	On the ocean bottom (Syngenic)	Sapro-collinite		Structureless sapropelic groundmass	Colloidal

[a]Fragmentary, >100μm
[b]Coarse detrital, 25-100μm
[c]Fine detrital, <25μm

and decomposition products of animal origin. Like saprocollinite they are finely dispersed with clay minerals. The petrographic aspect of humo-sapro-collinite abounds in beige-olive sapropelic structureless brownish flakes (>50%) with admixed clots and fine grains (<1 μm) of humic material. The mixture produces a nonuniform color with a granular, sometimes dotted-granular or flocculent structure. With increase in humic components of this nature (>50%) the groundmass becomes a sapropelic-humic, distinctly brown in color, with a more pronounced lumpy and granular structure. The sapropelic, sapro-humic, and humic-sapropelic microcomponents are syngenic.

The total organic content in various beds of the black shales ranges within wide limits, from 0.42% to 2.6% $C_{org.}$ in Hole 402A and from 0.1% to 3.3% $C_{org.}$ in Hole 400A. These variations are responsible for color in the sediments which ranges from light gray through gray, dark gray, almost black to olive-black. It is principally attributable to the concentration of gelatinized syngenic microcomponents, both allochthonous and autochthonous. In Hole 402A, gradual transitions between darker and lighter colored layers are characteristic, reflecting a wide gamut of organic content. In Hole 400A, transition colors are not present; dark and light layers containing, respectively maximal and minimal organics, are abruptly juxtaposed.

The petrographic composition of the organic matter from the two holes also differs. This is a function of the different paleogeographic locations of the sites relative to the strandline. In Hole 402A, a near-shore, shallow water zone (macrofacies), all classes and types of microcomponents except algo-thallomites are present. Predominant among them are humic and sapropelic-humic matter. In Hole

400A, a near-shore but deeper water zone (macrofacies), the organic matter abounds in sapropelic components; humic matter is present in rather subordinate amounts.

The associated mineralogy and texture of the sediments at the two sites also differ. In sediments from Hole 402A abounding in silty material, and in marls containing dolomitic crystals and shell limestones, a greater part of those strata containing 1.0% $C_{org.}$ is composed of the complex algothigenic group of fusinites, semi-fusinites, and gelinites A in both fragmentary and attritus form. More argillaceous sediments in which the $C_{org.}$ content is from 1% to 2% or greater, are characterized by both allothigenic and syngenic components, the former most frequently being attritus in size. Syngenic constituents are mainly gelenite S and sapro-humo-collinite. It is noteworthy that in dolomitized nannofossil marls, fusinite-telinite and almost black gelifusinite-collinite(?) occurs as cavity fillings between large dolomite rhombs. Gelifusinite-collinite is most likely an oxidation product of syngenic gelinite-collinite material formed under very shallow water of the near-shore zone. Supporting this contention is the presence of accompanying gypsum crystals. No regular association of any one of the organic microcomponents with a particular part of the black shale stratigraphic column is apparent in Hole 402A.

In Hole 400A differences in the organic components occur depending on the mineralogy and genetic features of the sediments; certain components are characteristic of particular intervals in the section. For instance, in the clay sediments of the lowest third of the black shale sequence, the $C_{org.}$ content, varying from 0.2% to 0.7% (rarely 1.8% in Cores 74-CC and 67-1) is characterized by an allothigenic group of humic fusinitic and partly gelinitic A classes. They occur as fine and, less frequently, as coarse attritus and fragments. Sapro-collinite and, less seldom, humo-sapro-collinite types are present as well.

In the middle third (66-4, CC to 63-4) consisting of calcareous clays and nannomarls, the $C_{org.}$ content is nearly 3.0% and is represented by algo-thalomites and humo-sapro-collinite with admixed allothigenic microcomponents of fine, and occasionally coarse, attritus. In sediments of the same mineral composition in this interval, but with a $C_{org.}$ content <1.0%, the allothigenic attritus is a mixture of sapro-collinite with lesser humo-sapro-collinite.

In the upper third of the sequence (63-3 to 62-1), the $C_{org.}$ in the nannomarls is <0.5% and is represented by the finest of fusinitic attritus and no visible amount of sapro-collinite.

The differences in the organic microcomponents in the black shales recovered at Sites 400 and 402 are the result of two major controls: (1) the initial composition and particle size of allochthonous humic material delivered to the near-shore environment and (2) the variable ecologic, physicochemical and hydrodynamic conditions of that environment. At Site 400, located southwest of and further offshore than Site 402, the black shales accumulated in deeper near-shore waters than did those of Site 402. They are characterized by clays, and silts comprising mostly mica plates and quartz, and are enriched in the smallest fusinitic particles. In contrast, at Site 402 located in a shallower near-shore environment, the black shales, comprising more mica and quartz silt fraction than at Site 400, contain coarser fusinitic, semi-fusinitic and allothigenic gelinitic particles; the clays at Site 402 are enriched in syngenic gelinitic microcomponent. The ecologic, physicochemical, and hydrodynamic conditions within the near-shore zone controlled the diversity of autochthonous and syngenic humic material, as well as the direction and rate of its alteration. As a result, sapropelic (algothallomitic and humic-sapropelic) matter predominates in the sediments of Hole 400A whereas those of Hole 402A abound in sapropelic-humic and humic matter of both allothigenic and syngenic origin. The relationship of organic microcomponents to genetic types of sediments and their regular association with particular paleoenvironments are valuable clues in petroleum exploration.

LUMINESCENT-BITUMINOLOGICAL AND CHROMATOGRAPHIC STUDY OF ORGANIC MATTER IN THE BLACK SHALES

For study of the bitumoid constituents of the black shales, after isolation by cold extraction with chloroform and alcohol-benzol, detailed luminescent-bituminological analyses were used, combined with paper chromatography and, selectively, spectral analyses. This complex of optical micromethods, elaborated by Iljina (1970) in the VNIGNI luminescent-spectral laboratory, was described in detail by the present authors in their study of the organic matter of sediments from Site 336, Leg 38 (Bogolyubova and Timofeev, 1976).

Figure 1 shows a comparison of luminescent characteristics of chloroform and alcohol-benzol extracts from the black shales of Hole 402A. Colored characteristics of luminescence are plotted on the X-axis Ic/Io (see also Table 2), and the intensity of luminescence, measured with the help of a fluorescent photometer through a blue light filter, are plotted on the Y-axis. The combination of both parameters of the chloroform and alcohol-benzol extracts enable judging of the degree of bituminosity of the samples, and the syngenetic character of bituminoids. On the graph the points corresponding to chloroform extracts fall into four groups. The first group (Figure 1, I) includes Samples 409, 424, 429, 430, 453, 454, 455, and 460. Their chloroform extracts are characterized by weak intensity of blue luminescence varying from 0.4 to 0.8 units. This indicates their weak bituminosity, varying from 0.0006 to 0.005 per cent, or 3 to 6 points on the scale of luminescent-bituminological determinations. Chromatograms of extracts of the first group are characterized by weak luminescence (bluish or gray) at the origin, and washed out zones at the front, with white bluish or yellowish gray luminescence. These samples (Table 2) consist of dolomitized marls, silty calcareous clays with crystals of dolomite, and shelly limestones. The $C_{org.}$ content is generally <0.5 per cent but reaches 1.3 per cent. The organic matter is attrital and fragmentary allothigenic microcomponents of the fusinitic and semifusinitic classes, in places with a small admixture of syngenic microcomponents.

The second group (Figure 1, II) consists of Samples 389, 391, 392, 394, 395, 417, 444, 449, 450, 452, 456, 457, 459, 461, 462, and 463. They are characterized by a somewhat greater bituminosity (mainly 0.01% or 7 points). This is manifested by intensification of blue luminescence

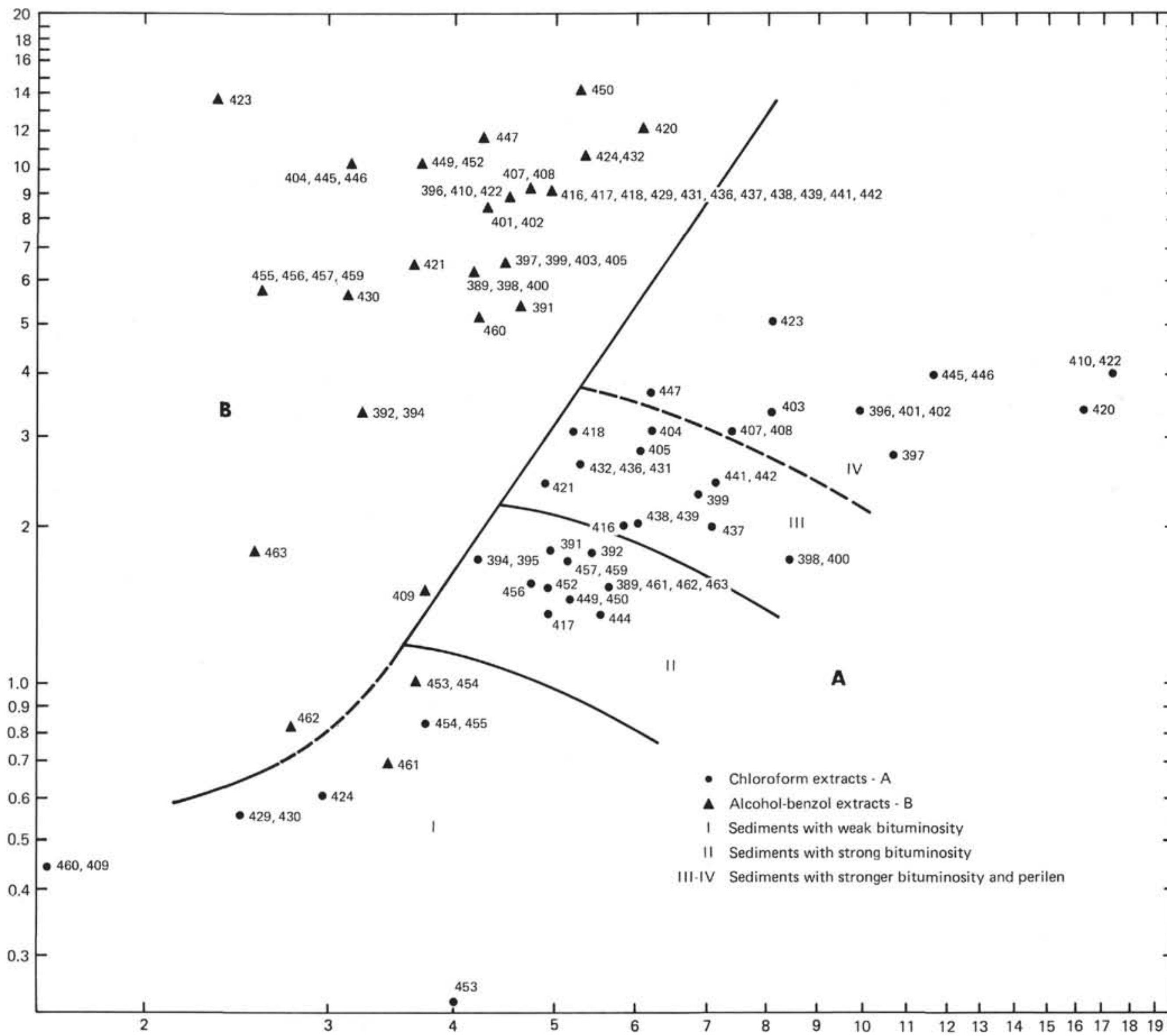

Figure 1. *Luminescent characteristics of chloroformal and alcohol-benzol extracts of sediments, Hole 402A.*

(Ic >1) and shifting of the points upwards; the Ic/Io ratio increases tentatively from 4 to 7 units. The presence of polycyclic aromatic hydrocarbons of the perylene type is thus indicated. Presence of hydrocarbons in the chloroform extracts can be confirmed by spectral analysis data; perylene was found in amounts >0.11 mg/100 g of sample (the perylene content in the organic matter of the first group is less < 0.10 mg/100 g of sample).

Chromatograms of the second group of samples differ somewhat from those of the first. Weak zones with bluish or grayish luminescence, and sometimes a brownish margin below, appeared at the origin. Near the front a more intense bluish light, or white bluish luminescence was recorded. Sometimes lusterless yellow-gray zones were present.

The sediments of these samples are composed of fine-grained calcareous siltstones, clayey marls, and silty calcareous clays. The $C_{org.}$ content in them varies from 1.0 to 1.5% and consists of an association of syngenic microcomponents of the sapro-humo-collinitic type (class) with allothigenic fusinites and semifusinites in equal or somewhat greater quantitative ratios.

The third group (Figure 1, III) contains Samples 398, 399, 400, 404, 405, 416, 418, 421, 431, 432, 436, 437, 438, 439, 441, and 442. Their chloroform extracts are characterized by a higher color ratio (Ic/Io ~7-9) and bright blue luminescence reaching 3 units. According to spectral analysis date, the concentration of perylene in a chloroform bitumoid of these samples is ~0.2 mg/100 g per sample, thus corresponding to a high color ratio. The bituminosity of the samples is a little higher than that of the second group. The content of bituminous components is tentatively estimated as 0.01-0.02% per sample, or 7 to 8 points.

Chromatograms of samples of this group show, in most cases, bluish or grayish zones at the origin, and well-pronounced light blue bluish, passing sometimes into

TABLE 2
Luminescent-Bituminological Characteristic of Organic Matter of the Black Shales, Hole 402

Depth (m)	Sample (Interval in cm)	Sample (GIN of USSR)	$C_{org.}$, in dry weight (%) / Depth of Sampling (m)	Genetic Type of Sediment	Microscopic Characteristic of Organic Matter	Bituminosity (% in Rock): Chloroform Extract	Bituminosity (% in Rock): Alcohol-Benzol Extract	Luminiscent Characteristic of Extracts[a]: Chloroform Extract I_c	Chloroform Extract I_c/I_o	Alcohol-Benzol Extract I_c	Alcohol-Benzol Extract I_c/I_o	Group According to Bituminosity and Character of Chloroform Bitumoid
272.05	15-2, 54-56	389	0.9 / 271.91	Siltstone, fine-grained, calcareous-clayey, gray, with abundant fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, echinoderm remains, foraminifers	Fusinite-, semifusinite-telinite with sapro-humo-collinite	0.01	0.02	1.54	5.7	6.04	4.2	II
273.96	15-3, 96-99	390	–			0.01	0.02	–	–	–	–	
274.85	15-4, 35-38	391	–			0.01	0.01	1.8	5.0	5.3	4.8	
276.60	15-5, 59-62	392	1.1 / 277.29			0.01	0.01	1.8	5.5	3.3	3.3	
280.0	16-1, 51-53	394	1.0 / 280.67			0.01	0.01	1.7	4.25	3.3	3.3	
282.0	16-2, 98-101	395	–			0.01	0.02	1.7	4.25	not defined		
290.10	17-1, 108-111	396	1.6 / 289.81	Siltstone, fine-grained, calcareous-clayey, dark gray, with abundant fragments of carbonate shells, siliceous sponge spicules, zeolites, fish bones, coccoliths, echinoderm remains, and foraminifers	Sapro-humo-collinite with gelinite-, fusinite and semifusinite-telinite	0.005	0.02	3.3	10.0	8.7	3.6	IV
291.65	17-2, 115-119	397	–	Marl, silty, dark gray with abundant fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, echinoderm remains, foraminifers	Sapro-humo-collinite with gelinite-, fusinite- and semifusinite-telenite	0.01	0.04	2.7	10.8	6.4	4.6	
292.20	17-3, CC 20-22	398	–			0.01	0.02	1.7	8.5	6.04	4.2	III
299.72	18-1, 122-124	399	1.3 / 299.56	Clay, silty, calcareous, dark gray, almost black, with abundant fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, echinoderm remains, and foraminifers	Sapro-humo-collinite and gelinite-telinite with fusinite- and semifusinite-telinite	0.02	0.04	2.3	7.0	6.4	4.6	
301.10	18-2, 108-110	400	1.1-1.5 / 300.64			0.01	0.02	1.7	8.5	6.04	4.2	
302.70	18-3, 120-124	401	1.7 / 301.56			0.02	0.04	3.3	10.0	8.2	5.3	IV
303.25	18-4, 25-27	403	–	See Samples 397, 398	See Samples 397, 398	0.02	0.04	3.3	8.3	6.4	4.6	
305.55	18-4, CC 104-107	402	–			0.02	0.02	3.3	10.0	8.2	4.3	
308.60	19-1, 59-63	404	1.4 / 308.63			0.02	0.02	3.0	6.3	10.5	3.2	III
310.15	19-2, 64-67	405	1.0 / 310.59			0.02	0.04	2.7	6.1	6.4	4.6	
315.15	19-4, 115-118	407	–	See Samples 399-401	See Samples 399-401	0.01	0.02	3.0	7.5	9.1	4.8	VI
318.55	20-1, 103-107	408	1.7 / 318.20			0.01	0.02	3.0	7.5	9.1	4.8	
319.50	20-2, 50-52	409	1.0 / 319.85	Marl, silty, gray, dolomitized, with gypsum, minor carbonate shell detritus, coccoliths, siliceous sponge spicules, zeolites, foraminifers	Fusinite-collinite, fusinite-telinite	0.005	0.0006	0.44	1.67	1.5	3.8	I
321.75	20-3, 125-127	410	1.4 / 321.14	Clay, silty, calcareous with crystals of dolomite, dark-gray, with fine shell detritus, siliceous sponge spicules, fish bones, coccoliths, echinoderm remains, and foraminifers	Fusinite-, semifusinite-, gelinite-tellinite with sapro-humo-collinite	0.02	0.02	3.9	17.7	8.7	4.6	IV
333.65	21-5, 62-65	416	–	Marl, silty, gray with crystals of dolomite, abundant fine shell detritus, zeolites, siliceous sponge spicules, fish bones, coccoliths and echinoderm remains	Fusinite-, semifusinite-telinite, with sapro-humo-collinite	0.01	0.02	1.95	5.9	9.0	5.1	II
334.60	21-6, 8-10	417	0.7 / 335.13			0.005	0.02	1.34	5.0	9.0	5.1	
335.30	21-6, 79-81	418	–	See Samples 397, 398	See Samples 397, 398	0.01	0.02	3.0	5.3	9.0	5.0	III
337.10	22-1, 109-112	420	1.4 / 337.66			0.02	0.04	3.3	16.5	11.8	6.2	IV

TABLE 2 – (*Continued*)

339.05	22-2, 103-107	421	–	See Samples 397, 398	See Samples 397, 398	0.01	0.02	2.4	5.0	6.4	3.7	III
340.35	22-3, 83-87	422	1.2 / 340.44			0.02	0.04	3.9	17.7	8.7	4.6	IV
341.60	22-4, 61-64	423	0.9 / 341.57			0.02	0.04	4.9	8.2	13.5	2.4	
342.05	22-4, 104-107	424	–	Marl, silty, dark gray with abundant fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, and echinoderm remains	Fusinite-, semifusinite-telinite with sapro-humo-collinite	0.005	0.02	0.6	3.0	10.5	5.5	I
348.55	23-2, 105-107	429	0.4 / 348.13	Shell limestone with silty-clayey cement, light gray, in places gray, with rare sponges, zeolites, fish bones, and echinoderm remains	Fusinite-, semifusinite-telinite	0.005	0.01	0.55	2.5	9.0	5.1	
349.75	23-3, 73-76	430	–			0.0025	0.005	0.55	2.5	5.6	3.2	
350.80	23-4, 28-31	431	1.6 / 351.07	Marl, silty, dark gray, in places almost black, with abundant coccoliths, fine carbonate shell detritus, siliceous sponges, zeolites, foraminifers	Sapro-humo-collinite with gelinite-, fusinite- and semifusinite-telinite	0.01	0.02	2.6	5.4	9.0	5.1	III
353.15	23-5, 115-118	432	–			0.02	0.04	2.6	5.4	10.5	5.5	
359.50	24-3, 99-102	436	–			0.02	0.02	2.6	5.4	9.0	5.1	
360.95	24-4, 94-97	437	–			0.01	0.02	1.95	7.2	9.0	5.1	
361.75	24-5, 24-27	438	–			0.005	0.02	2.0	6.1	9.0	5.1	
365.90	25-1, 89-93	439	1.0 / 366.38			0.01	0.02	2.0	6.1	9.0	5.1	
368.65	25-3, 63-69	441	–			0.01	0.02	2.4	7.3	9.0	5.1	
370.65	25-4, 113-118	442	–			0.01	0.02	2.4	7.3	9.0	5.1	
375.0	26-1, 48-51	444	1.1 / 375.26	See Sample 431, but with crystals of dolomite	Fusinite-, semifusinite-telenite, sapro-humo-collinite	0.01	0.02	1.34	5.6	not defined		II
413.51	30-1, 101-103	445	1.5 / 413.87	Marl, silty, dark gray, with abundant coccoliths, fine carbonate shell detritus, sporadic zeolites, crystals of dolomite, foraminifers	Sapro-humo-collinite, gelinite-telinite with fusinite-, semifusinite-telinite	0.01	0.02	3.9	11.8	10.5	3.2	IV
414.05	30-2, 4-6	446	–			0.01	0.04	3.9	11.8	10.5	3.2	
416.20	30-3, 69-71	447	2.6 / 416.46			0.01	0.04	3.6	6.3	11.5	4.3	
419.20	30-5, 68-70	449	1.73 / 419.20	Clay, silty, calcareous, almost black, with fine carbonate shell detritus, coccoliths, foraminifers	Sapro-humo-collinite with fusinite-, semifusinite- and gelinite-telinite	0.005	0.04	1.44	5.3	10.3	3.8	II
420.45	30-6, 44-46	450	–			0.01	0.04	1.44	5.3	14.0	5.4	
424.05	31-2, 55-59	452	–	See Samples 445, 446	Sapro-humo-collinite with fusinite-semifusinite-telinite	0.02	0.04	1.5	~5	10.3	3.8	
425.65	31-3, 62-69	453	–	Clay, silty, calcareous, gray, in places light gray with crystals of dolomite, fine carbonate shell detritus, coccoliths, foraminifers	Fusinite-, semifusinite-telinite with sapro-humo-collinite	0.0006	0.0012	0.24	~4	1.0	3.7	I
427.25	31-4, 75-78	454	1.3 / 426.96			0.0025	0.01	0.83	3.8	1.0	3.7	
428.30	31-5, 34-37	455	0.48 / 428.30			0.0025	0.01	0.83	3.8	5.6	~2.7	
430.95	31-6, 144-148	456	–	Clay, silty, calcareous, dark gray, with fine carbonate shell detritus, coccoliths	Sapro-humo-collinite, fusinite-, semifusinite-telinite	0.01	0.04	1.58	4.8	5.6	~2.7	II
431.50	32-1, 13-17	457	1.45 / 431.50			0.01	0.04	1.7	5.2	5.6	~2.7	
435.45	32-3, 91-95	459	1.5 / 434.63			0.01	0.02	1.7	5.2	5.6	~2.7	
436.90	32-4, 88-91	460	0.48 / 436.90	Nannofossil marl, silty, light gray, dolimitized, with fine carbonate shell detritus, foraminifers	Fusinite-telinite, fusinite-collinite	0.0012	0.02	0.44	1.63	5.1	4.3	I
438.35	32-5, 82-86	461	–	Nannofossil marl, silty, light gray, with crystals of dolomite, foraminifers, and fine fragments of carbonate shells	Sapro-humo-collinite, fusinite-, semifusinite-telinite	0.005	0.02	1.54	5.7	0.7	3.5	II
439.55	32-6, 57-60	462	–			0.01	0.0025	1.54	5.7	0.83	~2.8	
440.65	32-7, 15-20	463	–			0.0025	0.005	1.54	~5.7	1.8	~2.6	

[a]Bituminosity in per cent per sample, obtained through visual comparison of luminescent intensity of the extract relative to the extracts containing a certain amount of bitumoid of the same type. Intensity of blue luminescence (I_c). Intensity of orange luminescence (I_o). Colored characteristics of luminescence (color ratio) – I_c/I_o.

lusterless brownish luminescence, near the front. The chromatograms were from samples with the bright blue luminescence and a high color ratio (Ic/Io) due to high perylene content. In some samples the luminescence of the upper chromatogram zones varied from grayish yellow to blue brownish, sometimes with whitish zones in the middle; they resemble those of the second group.

Sediments of group three are mostly marls, less frequently silty, calcareous clays. $C_{org.}$ content varies from 1.0 to 1.5% or more consisting chiefly of syngenic microcomponents of the gelinitic class, with an admixture of allothigenic as secondary and, in some cases, accessory constituents.

The fourth group (Figure 1, IV) is composed of Samples 396, 397, 401, 402, 403, 407, 408, 410, 420, 422, 423, 445, 446, and 447. Their chloroform extracts showed very bright blue luminescence (Ic up to 5 units;, clearly shown on the graph by the shifting of points upwards. Along with this, the color ratio increased roughly from 6 to 12 and even to 17, caused by perylene (> 0.2 mg/100 g) being present in the chloroform extract. The change of the luminescent-bituminological parameters of chloroform extracts of this group, as compared to that previous, is a result of a higher perylene content. The bituminosity of the samples ranges, as a whole, from 0.01 to 0.02% per sample (7-9 units), similar to samples of the third group, as shown by the chromatography. Extracts with color ratios of from 10 to 17 units, with the perylene content over 0.2 mg/100 g of sample, yielded chromatograms with bluish zones at the origin and bright, light blue luminescence of the upper zones at the front, passing below into greenish zones. This is representative of chromatograms of extracts with a higher perylene content. Chloroform extracts with the color characteristic of 7.5 to 10 units showed the upper zones with predominance of bluish and whitish tints of luminescence.

Samples of group four are chiefly marls and silty calcareous clays, the $C_{org.}$ content usually varying from 1.5 to 2.0% and over. $C_{org.}$ of the group (Table 2) is similar in microcomponent composition to that of the third group. Noteworthy is sapro-humo-collinite that frequently shows, in translucent light under a microscope, a bright brown color with orange tints, which may testify to sudden predominance of humic matter in the microcomponent. Organic matter of this type contains somewhat more microcomponents of gelinite-telinite "C" and a lesser amount of allothigenic microcomponents of the fusinitic and semifusinitic class, excluding Sample 410 in which the latter are prevailing.[1]

In comparing the amount and petrographic composition of $C_{org.}$ of the sample groups and their luminescent-bituminological and chromatographic characteristics, a regular increase of $C_{org.}$ occurs from the first to the fourth group (Figure 1, Table 2).

This is accompanied by an increase of syngenic microcomponents of humic allochthonous matter, and a higher concentration of polycyclic aromatic hydrocarbon, i.e. perylene, in the chloroform extracts. A progressive increase of the humic acid contents was observed in the same direction. Thus, perylene can be assumed to be a product of the organic humic constituents in oceanic sediments of the syngenic origin. The comparison of luminescent characteristics of chloroform and alcohol-benzol extracts shows that bituminous components are syngenetic with the organic matter of the sediments concerned, as the points characterizing bituminosity of alcohol-benzol extracts in Figure 1 are located higher on the left side relative to the points of chloroform extracts. The shift of the points towards increasing Ic and Ic/Io emphasizes the fact that brighter blue luminescence of chloroform extracts, and bright gray-light blue zones near the front, sometimes with a greenish tint, are due to the organic components readily going into solution, i.e., perylene. At the same time, the character of alcohol-benzol extracts, when judged by paper chromatograms, demonstrates the absence of chlorophyll or products of its degradation, because neither pink nor reddish luminescence of these extracts or their chromatograms was recognized.

The chromatographic study failed to show any indication of bituminous components of the oil type in the samples with their peculiar transition from bright bluish (near the front) to yellowish and red-orange tints of luminescence. Bright blue zones near the front appearing on paper chromatograms of chloroform extracts, changing below into white bluish, emphasize presence of oily components in the bitumoid part of the black shales from Hole 402A.

The luminescent-bituminological and chromatographic analyses of chloroform extracts from Hole 400A sediments (Table 3) revealed, except for Samples 686, 689, and 692, their extremely weak bituminosity. It corresponds, on the average, to 0.0025% per sample or 7 points in the scale of luminescent-bituminological determinations. As result, the chloroform extracts of these samples display a weak bluish or grayish blue luminescence with relatively intense values ranging from 0.1 to 0.3 units. The data of the luminescent-bituminological chromatographic analyses correspond to one another. The paper chromatograms of chloroform extracts show very weak luminescence of the zones, usually narrow at the origin, and washed out bluish and gray near the front. A higher color ratio of chloroform extracts (Ic/Io ~9-10) in Samples 678 and 680, corresponding to their bluer luminescence, as well as gray-light blue with a greenish tint zones near the front on the paper chromatograms, are related to the presence of perylene in the bitumoid of the organic matter. Contrary to the rest of this group, in sediments of the given samples (Table 3) there is more organic matter ($C_{org.}$ 0.5%-1.5%) with syngenic microcomponents (humo-sapro-collinite) containing humic matter.

The above samples are nannofossil marls, silty calcareous clays, the $C_{org.}$ content of which (except for Samples 678 and 680) ranges within some per cent portions. It is composed of sapro-collinite and allothigenic microcomponents, mainly of the fusinite class.

The organic matter in Samples 686, 689, and 692 is of the algo-thallomite and humo-sapro-collinite types; this fact distinguishes it from the petrographic composition of the

[1]Due to the extremely variable composition of the mineral and organic matter of black shales observed even within a thin section, the data of various research methods may not coincide in some cases, because the analysis was carried out on microweights.

TABLE 3
Luminescent-Bituminological Characteristic of Organic Matter of the Black Shales, Hole 400A

Depth (m)	Sample (Interval in cm)	Sample (GIN USSR)	$C_{org.}$ % in dry weight / Depth of sampling (m)	Genetic Type of Sediments	Microscopic Characteristic of Organic Plant Matter	Bituminosity (% in rock)		Luminescent Characteristic of Extracts			
								Chloroform Extract		Alcohol-benzol Extract	
						Chloroformic Extract	Alcohol-benzol Extract	J_c	J_c/J_o	J_c	J_c/J_o
654.50	62-1, 51-54	675	0.1 / 654.69	Nannofossil ooze, silty, light gray, abundant foraminifers, zeolites, radiolarians and fine carbonate shell detritus	Sapro-collinite and fusinite-telinite	0.005	0.0025	0.4	~ 4	0.7	~2.5
654.95	62-1, 95-97	676	–	Nannofossil marl, silty, light gray, abundant foraminifers, zeolites, radiolarians, and fine carbonate shell detritus		0.0012	0.0025	0.24	gray bluish	0.7	~ 3.5
655.75	62-2, 25-27	677	–			0.0012	0.0025	0.24	gray bluish	0.7	~ 2.5
656.75	62-2, 125-129	678	–	Nannofossil marl, silty, gray, abundant foraminifers, zeolites, radiolarians, and fine carbonate shell detritus	Humo-sapro-collinite and fusinite-telinite	0.0025	0.0025	0.5	~ 10	0.68	~ 2.1
658.15	62-3, 114-117	679	0.17 / 658.15	See Samples 676, 677	See Samples 676, 677	0.0025	0.005	0.24	gray bluish	1.4	4.2
659.50	62-4, 100-104	680	0.5-1.2 / 659.60-658.86	See Sample 678	See Sample 678	0.005	0.005	0.44	~ 8.8	1.54	3.2
661.75	62-6, 22-26	682	0.23 / 661.75	See Sample 679	See Sample 679	0.005	0.0025	0.24	gray bluish	1.54	4.7
664.75	63-1, 117-120	683	–			0.0025	0.0025	0.1	gray bluish	0.75	6.3
665.65	63-2, 62-65	684		See Sample 680	See Samples 680-681	0.0025	0.005	0.34	gray bluish	1.34	~ 5
666.75	63-3, 26-28	685	0.1 / 666.77	See Sample 679	See Sample 679	0.0025	0.0025	0.24	gray bluish	0.68	2.1
668.45	63-4, 40-45	686	2.8 / 667.47	Nannofossil marl, silty, dark gray, abundant foraminifers, zeolites, radiolarians, and carbonate shell detritus	Algo-thallomite, humo-sapro-collinite with fusinite-, semi-fusinite-telinite	0.01	0.02	1.0	~ 4.5	4.5	4.1
673.35	64-1, 32-36	687	–	See Sample 685	See Sample 685	0.0025	0.005	0.3	gray bluish	1.34	~ 5
675.25	64-2, 73-77	688	–			0.0012	0.0025	0.1		0.6	~ 2.5
676.95	64-3, 92-95	689	3.3 / 676.90	Clay, silty, calcareous, dark gray to olive, abundant coccoliths, zeolites and radiolarians	Algo-thallomite, humo-sapro-collinite with fusinite and semifusinite-telinite	0.01	0.08	2.2	~ 10	6.6	2
678.15	64-4, 62-66	690	0.08 / 676.90	Nannofossil marl, silty, light gray, abundant zeolites, and radiolarians	Sapro-collinite, fusinite, and gelinite-telinite	0.0006	0.0025	0.1	gray bluish	0.65	3.6
679.75	64-5, 72-75	691	0.26 / 678.75	Clay, silty, calcareous, gray, abundant coccoliths, zeolites, diatoms, and radiolarians	Sapro-collinite and fusinite-telinite	0.0025	0.005	0.12	gray bluish	0.65	3.6
683.15	65-1, 65-69	692	1.0 / 682.72	Clay, silty, olive-black, abundant zeolites, coccoliths, diatoms, and radiolarians	Algo-thallomite, humo-sapro-collinite with fusinite- and gelinite-telinite	0.02	0.04	3.24	4.9	2.7	2.25
684.30	65-2, 28-31	693	0.89 / 683.30	Clay, silty, calcareous, gray, with coccoliths, zeolites, diatoms, and radiolarians	Sapro-collinite, gelinite- and fusinite-telinite	0.0025	0.0025	0.1	gray bluish	0.68	2.1
693.15	66-1, 112-117	694	0.3 / 692.61	Clay, silty, calcareous, dark gray, abundant zeolites, diatoms, coccoliths, and radiolarians	Sapro-collinite, gelinite-telinite, abundant fusinite-telinite	0.005	0.01	0.3	gray bluish	2.7	4.1
694.05	66-2, 54-57	695	0.11 / 694.05	Clay, silty, calcareous, gray, with zeolites, diatoms, radiolarians, and coccoliths	Fusinite-, semi-fusinite- and gelinite-telinite	0.0025	0.0012	0.1	gray bluish	1.54	3.2
695.60	66-3, 59-63	696	0.3 / 695.62			0.0025	0.0025	0.1	gray bluish	1.54	3.2
701.70	67-1, 18-21	698	1.8 / 701.85	See Sample 694	See Sample 694	0.0025	0.01	0.24	gray bluish	2.7	6.75

organic matter in the above-described samples. Its $C_{org.}$ content also proved to be higher, from 2.8 to 3.3 per cent. Due to this the chloroform extracts of the samples are characterized by higher bituminosity (0.01-0.02% or 7 to 8 points), resulting in more intense blue luminescence of from 1 to 3 units and more, and a graying-brown zone near the front on the paper chromatograms. Variations of the color ratio value (Ic/Io ~4.5-10) are most probably due to a different perylene content in the chloroform bitumoid of these samples.

Alcohol-benzol extracts of the samples showed plant pigments of the chlorophyll derivatives type. They gave pinkish luminescence and a greenish color of the zone near the front on the paper chromatograms. Presence of chlorophyll derivatives in an alcohol-benzol bitumoid matches well with algae being in the initial material of the organic matter of these samples. Alcohol-benzol extracts of all samples displayed higher bituminosity than chloroform extracts (Table 3), indicating a higher content of slightly mobile, less reproduced components barely extracted by "cold" chloroform. Such a ratio is peculiar to bituminous components syngenic with organic matter. In all samples the data of luminescent-chromatographic characteristics of the chloroform extracts, as well as those on Hole 402A, do not show the zones representative of components of the oil type. The same can be said of Samples 386, 389, and 392 which are characterized by a higher $C_{org.}$ content and higher bituminosity. Absence of oil indications in sediments of Hole 400A, with a significant sapropelic character of the organic matter, especially in Samples 386, 389, and 392, is due to its low rank. The sediments of Hole 400A may thus be regarded as having a potential for oil.

Diagenesis and Rank of the Black Shales Organic Matter

The complex of syngenic microcomponents of the black shales organic matter occurring in Holes 402A and 400A shows that, under conditions of near-shore sedimentation, the transformation of the initial plant material, both autochthonous and allochthonous, is associated with the process of microbal gelefication only (Table 1). As a result, the organic matter displays a gamut of syngenic gelefied microcomponents with varying structure, from telinitic to collinitic.

The brownish color of the humic gelefied syngenic material, the absence of homogenization, and the lignitic character of wood tissue fragments testify to low rank decomposition, tentatively corresponding to the stage of brown coal. The low carbon content in the elemental composition of humic acids ranging from 60.0 to 66.0%, and the presence of perylene in its bitumoid portion are evidence of only sight transformation of the organic matter.

The values of refraction index of syngenic gelinite-telinite stratigraphically upwards through the black shales series of Hole 402A (from 1.633 to 1.595) fix the boundary limits of the brown coal stage, and demonstrate that the organic matter rank increases with depth. The average values of the maximum reflectance of syngenic gelinite-telinite (R_{max} in oil = 0.42% - 0.43%) characterize the lower boundary of the limits of the brown coal stage. From this it may be concluded that the black shales organic matter of both holes is in a state of diagenesis.

Genetic Type, Facies, and Composition of the Black Shales

Sediments of the black shale series from Holes 400A and 402A are of Aptian-Albian age. They consist of silty calcareous clays, silty marls, and calcareous-clayey siltstones.

Hole 402A penetrates a black shales series 171 meters thick (Cores 32-7, CC-1.15-1). The sediments consist of hydromicaceous montmorillonitic clay with an admixture of kaolinite; terrigenous minerals (quartz, montmorillonite, feldspar, fragments of claystones); fragments of volcanic glass of median composition; a variety of mollusk shells (their size varying from rather coarse to the finest detritus); foraminifers of different dimensions and degree of preservation; fragments of echinoderms and fish bones; products of burrowers' activity; spicules of siliceous sponges; coccolith relics; and an admixture of organic matter of sapropel-humic and humic composition. Authigenic minerals are zeolites, montmorillonite, pyrite, dolomite, gypsum, and cristobalite.

The black shales of Hole 400A occur in an interval 123.5 m thick (74-1, Cc 1.-62-1); the mineral composition of the clay facies is the same as that of Hole 402A, with humic-sapropelic and sapropelic organic matter, a more monotonous assemblage of faunal remains and lesser amounts of terrigenous material, the fragments of which are smaller in size than in Hole 402A; fragments of volcanic glass, of both the median and acid composition are present. Diatoms and radiolarians are present. Relatively small amounts of pyrite, abundant zeolites, and rare inclusions of authigenic montmorillonite occur. Dolomite and gypsum are absent.

The obvious differences in the sediments of Holes 400A and 402A are manifestations of differences in the depositional environments of the two sites. To interpret what those environments were, and consequently their genetic types and facies, four sets of criteria have been applied: (1) the granulometric spectrum and texture of the sediments, carbonate content, color, and sedimentary structures; (2) the amount of $C_{org.}$ and its nature and composition; (3) quantity, composition, size, and state of preservation of faunal remains; (4) mineralogy of the sediments, particularly authigenic minerals. Tables 4 and 5 summarize the genetic types and corresponding facies of the black shales intervals of both holes, using the above criteria; detailed description and discussion of them follows.

Hole 402A

Lying on organogenic-carbonate-clay sediments of relatively shallow-water origin (Facies 402A.0, Genetic Type 402A.0a; Figure 2), the black shales at Site 402 are a near seashore shallow-water series deposited immediately adjacent to the coast. Varying conditions of sedimentation in this zone throughout the period of their deposition produced six facies and 17 genetic types of sediments (Table 4; Plate 1).

The base of the series (Cores 33-2 to 32-5) comprises facies (Figure 2) represented by one genetic type (402A.1a; Plate 1, Figure 4). These are silty nannofossil marls with dolomitized interbeds. They are gray to olive-gray, with

TABLE 4
Genetic Types and Facies of Black Shales Series, Hole 402A

Genetic Type Name	Index	Index	Facies Name
Nannofossil marl, silty, light gray with crystals of dolomite and dolomitized interbeds; organic matter (<0.5%) fusinite-, semifusinite-telinitic, and fusinite-collinitic type with sapro-humo-collinite; foraminifers and small fragments of carbonate tests	402A.1a	402A.1	Marly sediments with allothigenic humic microcomponents of organic matter; near-shore periodically flooded lagoon zone
Clay, silty, calcareous, dark gray sometimes almost black, with organic matter (1.5-2.0%) of sapro-humo-collinitic and fusinite-semi-fusinite-telinitic types; fine carbonate shell detritus and coccoliths	402A.2a	402A.2	Calcareous clay sediments with predominance of syngenic sapropelic-humic microcomponents of organic matter
Clay, silty, calcareous, gray, locally light gray with crystals of dolomite and organic matter (0.5-1.5%) mostly of the fusinite-, semi-fusinite-tellinitic types; with fine carbonate shell detritus and coccoliths	402A.2b		
Marl, silty, dark gray with organic matter (1.0-1.5-2.6%) mostly of the sapro-humo-collinitic and gelinite- and fusinite; abundant coccoliths and fine carbonate shell detritus, sporadic zeolites	402A.2c		
Clay, silty, calcareous, almost black, with organic matter (1.5-2.0%) of the sapro-humo-collinite type with fusinite-semifusinite, and gelinito-telinite; fine carbonate shell detritus, coccoliths, sporadic zeolite	402A.2d		
Clay, silty, calcareous, gray or dark gray with an admixture of organic matter (insufficient core material)	402A.3a	402A.3	Clayey calcareous sediments of the near-shore zone
Alternation of dolomitized nannofossil marls and marls with and without crystals of dolomite; organic matter (<0.5, 1.0, 2.0%), respectively, of the fusinite-, semifusinite-telinitic, fusinite-collinitic, and sapro-humo-collinitic types; abundant coccoliths, fine carbonate shell detritus, siliceous sponge spicules and zeolites	402A.4a	402A.4	Marly sediments with syngenic sapropelic-humic and allothigenic humic microcomponents of organic matter; the near-shore shallow-water periodically flooded lagoon zone
Silty marl, dark gray, in places almost black; with organic matter (1.0-2.0%) ofsthe sapro-humo-collinitic type with gelinite-fusinite, and semi-fusinite-telinite; abundant coccoliths, fine carbonate shell detritus, siliceous sponge spicules and zeolites	402A.4b		
Shell limestone with silty-clay cement, light gray, in places gray with organic matter (<0.5%) mostly of the fusinite-semifusinite-telinitic types; rare spicules of siliceous sponges and zeolites	402A.5a	402A.5	Calcareous clay sediments with allothigenic microcomponents of humic matter
Marl, silty, dark gray with organic matter (1.0-1.5%) of the sapro-humo-collinitic type with gelinite-, fusinite-, and semi-fusinite-telinite; numerous fragments of carbonate shells and their detritus, siliceous sponge spicules, fish bones, zeolites, coccoliths, and echinoderms remains	402A.6a	402A.6	Carbonate-silty-siliceous clay sediments with humic allothigenic and syngenic sapropelic-humic microcomponents of organic matter; near-shore shallow-water periodically flooded lagoon zone

TABLE 4 – *Continued*

Genetic Type Name		Facies Name
Alternation of dolomitized marls and marls with dolomite crystals and gypsum; gray, silty with organic matter (<1.0%) of the fusinite-collinitic (?) and fusinite-telinitic types; fine carbonate shell types and detritus, coccoliths, siliceous sponge spicules, zeolites, and echinoderm remains.	402A.6b	
Clay, silty, calcareous, dark gray, with crystals of dolomite, organic matter (1.0–1.5%) of fusinite-, semifusinite-, and gelinite-telinitic types, with sapro-humo-collinite; fine shell detritus, siliceous sponge spicules, fish bones, coccoliths, and echinoderm remains	402A.6c	
Marl, silty, gray with crystals of dolomite and gypsum; organic matter (<1.0%) fusinite-, semifusinite-tellinitic types with sapro-humo-collinite and gelinite-telinite; fine carbonate shell detritus, coccoliths, siliceous sponge spicules, fish bones, zeolites, and echinoderm remains	402A.6d	
Marl, silty, gray, dolomitized, with gypsum; organic matter (<1.0%) fusinite-collinitic (?) and fusinite-telinitic types; fine carbonate shell detritus, coccoliths, siliceous sponge spicules, zeolites, and echinoderm remains	402A.6e	
Clay, silty, dark gray, almost black; with organic matter (1.0–1.7%) mostly of the sapro-humo-collinitic and gelinite-telinitic types, with fusinite- and fusinite-telinite; numerous fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, and echinoderm remains	402A.6f	
Siltstone, fine-grained, calcareous-clayey, dark gray; with organic matter (1.0–1.6%) of the sapro-humo-collinitic type, with gelinite-, fusinite-, and semifusinite-telinite; numerous fragments of carbonate shells, siliceous sponge spicules, zeolites, fish bones, coccoliths, and echinoderm remains	402A.6g	
Siltstone, fine-grained, calcareous-clayey, gray with interbeds of silty gray marl with crystals of dolomite; organic matter of the fusinite-, semi-fusinite-telinitic types with sapro-humo-collinite and gelinite-telinite; numerous fragments of carbonate shells and their detritus, siliceous sponge spicules fish bones, zeolites, coccoliths, and echinoderm remains	402A.6h	

indistinctly lens-shaped laminae and contain small burrows. Visible under the microscope are abundant coccoliths with well-defined contours, numerous small and large foraminifers, rare small fragments of mollusk shells, echinoderms, small burrows filled with fine-grained dark gray matter, and unoriented angular quartz grains.

The mineral constituents of the clay fraction are montmorillonite, hydromica, mixed-layer phase hydromica-montmorillonite, kaolinite, and a small admixture of chlorite.

The terrigenous material consists of angular quartz grains, plates of hydrated micas, and sporadic montmorillonite inclusions. Authigenic minerals are dolomite, as separate rhomboid grains and layers, and moderate amounts of pyrite as concretions and framboids. The calcium carbonate content varies from 38 to 66%, the greater part of which is secondary dolomite. Organic matter accounts only for 0.4-0.5%. In dolomitized layers it is represented mostly by fusinite-telinite and fusinite-collinite (Plate 4, Figure 1) in nannofossil marls, not enriched with dolomite; an admixture of saprohumocollinite is also present.

Higher in the section (Cores 32-4 to 30-0) are calcareous-clay sediments with a predominance of syngenic sapropel-humic microcomponents of the near-shore shallow-water zone of sedimentation (Facies 402A.2). The

TABLE 5
Genetic Types and Facies of the Black Shale Series, Hole 400A.

Genetic Type		Facies	
Name	Index	Index	Name
Alternation of silty, slightly calcareous, gray and dark gray clays and silty, gray marls with organic matter in both (0.2–0.3–0.7%) of the fusinite-, semifusinite-, and gelinite-telinitic types with humo-sapro-collinite; none with greater or lesser amounts of coccoliths	400A.1a	400A.1	Calcareous-clayey sediments with mostly allothigenic humic microcomponents of organic matter
Silty, calcareous clay, dark gray with organic matter (>1.0%) of the sapro-collinitic type with gelinite-telinite, and abundant fusinite-telinite; zeolites, diatom skeletons, coccoliths, and radiolarians	400A.2a	400A.2	Calcareous-siliceous-clayey sediments with syngenic sapropelic and allothigenic humic microcomponents of organic matter
Clay, silty, calcareous, gray, with organic matter (<1.0%) of fusinite-, semifusinite-, and gelinite-telinitic types; with zeolites, diatoms, radiolarians, and coccoliths	400A.2b		
Clay, silty, olive-black, with organic matter (about 3.0%) of algo-thallomitic types with fusinite-, gelinite-tellinite; abundant zeolites, coccoliths, diatoms and radiolarians	400A.2c		
Nannofossil marl, silty, light-gray, with organic matter (0.1-0.3%) of sapro-collinitic and fusinite-telinitic types; numerous foraminifers, radiolarians, and fine carbonate shell detritus	400A.3a	400A.3	Marly sediments mostly with syngenic sapropelic microcomponents of organic matter
Nannofossil marl, silty, dark gray, olive, with organic matter (about 3.0%) of algo-thallomitic and humo-sapro-collinitic types, with fusinite-, and fusinite-semifusinite-telinite; abundant foraminifers, zeolites, radiolarians, and carbonate shell detritus	400A.3b		
Nannofossil marl, silty, gray, with organic matter (0.5–1.2%) of humo-sapro-collinitic, sapro-collinitic, and fusinite-telinitic types; abundant foraminifers, zeolites, radiolarians, and fine carbonate shell detritus	400A.3c		

sediments are presented by four genetic types (402A.2a-402A.2d) which differ in carbonate content and petrographic composition of the organic matter, which is responsible for the intensity of color both in hand sample and under the microscope. They are silty, calcareous clays or silty marls, gray, dark gray, and olive-black in color, with parallel (sometimes interrupted) and lens-shaped laminae which may be burrowed and disturbed. Characteristic of these genetic types in this interval is rather good sorting and uniform composition of the minerals. Clay predominates, more or less enriched with relics of coccoliths and small shell detritus, and containing small amounts of foraminifers and siliceous sponge spicules.

The clays consist of montmorillonite, hydromica with an admixture of kaolinite, sometimes with a mixed-layer phase hydromica-montmorillonite, and with traces of chlorite in the upper part of the section. The carbonate content in all of the genetic types of the interval varies from 22.0 to 36.0%, increasing upwards in the section due to both the larger amounts of fragmentary shell detritus and the appearance of dolomite crystals. The total organic matter is comparatively high and varies from $C_{org.}$ 1.5 to 2.6%; it decreases to $C_{org.}$ 1.0 to 0.5% only in Genetic Type 402A.2b with an admixture of dolomite rhombs; it consists chiefly of allothigenic fusinite and semifusinite. The syngenic microcomponents sapro-humo-collinite and gelenite-telenite are predominant in those sediments with a higher content of the organic matter (402A.2a, 402A.2c, 402A.2d). Allothigenic fusinite and semifusinite are considered secondary and accessory.

The terrigenous material in every genetic type within the interval comprises silt-sized quartz, plates of decomposed biotite with paniculate habit, muscovite, fragments of claystones, and aggregates of montmorillonite. Occasional fragments of volcanic glass, of median composition, and zeolite are recognized in the upper part of the interval (402A.2d). The latter fills foraminiferal chambers and spicules of siliceous sponges. Microscopic burrows are lens-shaped or round cavities filled with fine-grained ashy organic-mineral matter and, sometimes, disorderly arranged, very angular quartz grains. Foraminiferal and other carbonate tests are partially recrystallized. A high content of pyrite in terms of framboids finely dispersed in the sapropel-humic groundmass is characteristic of all of the genetic types of the interval. Less frequently it replaces plant remains forming compact nodules, or is associated with foraminifers and sponge spicules, partly or wholly replacing them.

Genetic types are randomly distributed within the interval. However, carbonate content increases upwards in the section, as does the appearance of zeolites and a change in the petrographic composition of the organic matter from significantly fusinite-semifusinite to gelenite-telenite and sapro-humo-collinite.

In Cores 29-0 to 27-0, the black shales are presumably represented by Facies 402A.3. Insufficient core material did not allow a more detailed characteristic determination.

In Cores 26-1, CC to 23-3 the black shales comprise Facies 402A.4, marly sediments with syngenic sapropel-humic and allothigenic humic microcomponents deposited in the near-shore shallow-water, periodically bay-lagoon, zone of sedimentation.

The facies is represented by two genetic types of sediments, 402A.4a and 402A.4b. Sediments of the 402A.4a genetic type form the lower half of the interval, and consist of alternating silty, gray and dark-gray marls, more or less enriched with dolomite. They are characterized by a small admixture of organic matter ($C_{org.}$ <0.5-1.0%) chiefly of the fusinite and semifusinite composition. The sediments of the 402A.4b genetic type form the upper half of the interval and consist of silty, dark-gray, sometimes almost black marls. They contain organic matter ($C_{org.}$ 1.0-2.0%) of the sapro-humo-collinite and gelenite-telenite types with an admixture of fusinite- and semifusinite-tellenite. In both types the laminae are parallel, parallel-wavy, and lens-shaped, frequently disturbed by burrows and mixing. The lamination results from alternation in color and texture of the sediment, the lighter layers being coarser grained. Clay predominates, with numerous coccoliths, indeterminent shell detritus, fragments of large mollusk shells and small numbers of differently preserved foraminifers. The facies as a whole are characterized by higher amounts of siliceous organisms, particularly sponge spicules of various sizes, their skeletons having been recrystallized into cristobalite. Authigenic zeolite and montmorillonite are widely distributed; zeolites replace foraminiferal chambers, form pseudomorphs after siliceous organic remains, and develop in burrows and cavities of plant tissues. Zeolites are more abundant in the 402A.4b genetic type, which form the upper half of the interval. Montmorillonite fills foraminiferal chambers and canals of siliceous sponges. Pyrite, as in sediments of the previous interval, is dispersed in the sapropel-humic groundmass associated with foraminifers and sponges, and replaces gelified plant remains, forming small to large accumulations and compact concretions. Dolomitic rhombs in layers with varying concentrations were observed only in the sediments of the 402A.4a genetic type. They contain large crystals of gypsum. Because of the dolomite in the 402A.4a genetic type, the carbonate content ranges from 39.0 to 63.0%, in contrast to 30.0 to 36.0% in the 402A.4b genetic type which lacks dolomite. The upward disappearance of dolomite is coincident with increase in syngenic humic material.

Terrigenous material in both types contains higher amounts of silt-sized fragments of claystones of oval and irregular shape. Particles of quartz and plates of hydromica are fewer than in sediments of the lower intervals. Fragments of volcanic glass of median composition are common. Burrows filled both with organo-mineral matter of ashy color and angular quartz grains are frequent.

Montmorillonite and hydromica, with an admixture of kaolinite and rarely of chlorite, are invariably predominant mineral constituents of the clay fraction. Clinoptilolite and cristobalite are present.

The most striking feature of the facies as a whole is the presence of significant amounts of volcanic glass, increase in number of siliceous sponge spicules, and intense development of zeolite and montmorillonite.

The succeeding core interval (23-3 to 22-6) of the black shales series is represented by Facies 402A.5, a series of calcareous sediments with allothigenic humic microcomponents. This facies consists of one genetic type, 402A, 5a, composed of shelly limestone with silty-clayey cement. Macroscopically, it is light to olive-gray, with barely discernible parallel and parallel-wavy laminae. It is characterized by poor sorting. Under the microscope it is seen to consist of slightly rounded, large fragments of carbonate mollusk shells, foraminifers, and echinoderm fragment embedded in a sparse matrix of clayey-silty material containing coccoliths and minute grains of organogenic calcite. Unbroken foraminifers are present; they are small, thick-walled, and numerous. Rhombs of dolomite are common and the total calcium carbonate content is high, from 46.0 to 47.0%. Siliceous organisms are not numerous; their skeletons occur as cristobalite. Zeolites and mica plates are rare. Quartz grains occur in moderate amounts. Pyrite is negligible, but is seen to replace foraminiferal tests.

The organic matter, which accounts for $C_{org.}$ 0.4-0.5 per cent only, is mostly allothigenic fusain, semifusain and sometimes vitrain attritus. Unlike the sediments of the underlying interval containing hydromica, the mixed-layer phase hydromica-montmorillonite was observed in the clay fraction along with montmorillonite, kaolinite, and traces of chlorite. Cristobalite is present, resulting from recrystallization of siliceous sponge remains. Because of the presence of zeolites, clinoptilolite is also recorded.

The uppermost interval of the black shales series (22-5 to 15-1) is Facies 402A.6 which consists of carbonate-silty-siliceous clayey sediments with humic allothigenic and syngenic sapropel-humic organics of the near-shore, periodically bay-lagoon, zone of sedimentation. Eight genetic types (402A.6a-402A.6h; Plate 1, Figures 1-3) were formed under conditions of this facies; they differ from each other in granulometric composition, carbonate content, and amounts and composition of the organic matter. These limey-clay siltstones, silty calcareous clays, and silty marls are gray, dark gray, sometimes light gray, with numerous burrows and disturbed sedimentary structures. As a whole they are characterized by poor sorting, as a result of which layers and laminae of different color and granulometric composition occur in each genetic type. Layers may be lenticular, lens-shaped-banded, or irregular in form, producing parallel, parallel-wavy lens-shaped, sometimes cross-laminated (in coarser material) sediment in each of the genetic types. Under the microscope are to be seen abundant large, frequently rounded fragments and unbroken tests of various shapes, remains of echinoderms, large unbroken and broken foraminiferal tests, ostracodes, and other carbonate microorganisms in a silty matrix (Genetic Types 402A.6g; 402A.6h). These interbeds contain accumulations of spicules of large siliceous sponges (their skeletons transformed into cristobalite), fragments of fish bones, high quartz, and hydromicaceous contents, the latter being of large size and paniculate habit; also present are allothigenic fusainized and semi-fusainized particles of fragmentary and coarse-attritus-sized grains. They account for less than 1.0 per cent of C_{org}. Numerous large patches of tabular zeolites, with distinct cleavage fill tests of foraminifers, form pseudomorphs after siliceous organisms and, in some cases, are developed within cellular plant tissues.

The facies with a predominance of clay (402A.6c, 402A.6f) and marly material (402A.6a, 402A.6b, 402A.6d, 402A.6e) are characterized by the same assemblage of faunal remains, differing in fewer and smaller sized fragments. They also contain many quartz grains, plates of decomposed hydromica, zeolites, and coccoliths, these being in lesser amounts in coarser sediments. The organic matter ($C_{org.}$ 1.0-1.7%), except those containing dolomite, is represented mostly by syngenic sapro-humo-collinite and gelenite-telenite types, whereas the allothigenic constituents appear to be secondary and accessory. Allothigenic microcomponents (among which syngenic fusinite-collinite is also observed), containing dolomite rhombs, are pre dominant in the marly (402A.6b, 402A.6d, 402A.6f) and clay (402A.6c) sediments. They account for $C_{org.} > 1.0\%$.

All of the genetic types of this facies are characterized by authigenic montmorillonite, observed in chambers of foraminifers; it fills the cavities of siliceous ostracodes and forms shapeless clusters in the clay matrix of the sediment. The pyrite content and its distribution is identical to that in lower intervals, forming nodules around organic remains and dispersed as sporadic grains in the organogenic cement. Separate genetic types (402A.6b-402A.6e; 402A.6h) are characterized by rhombs of dolomite both dispersed and as more or less compact accumulations enriching some clay beds, accompanied with newly formed large gypsum rosettes. The total carbonate content ranges 20.0 to 36.0% increasing up to 68.9% in interbeds where dolomite rhombs predominate. Abundant volcanic glass fragments saturate the silty fraction of the sedment: large burrows filled with large, disorderly arranged, angular grains of quartz are numerous.

Montmorillonite and hydromica with an admixture of kaolinite as well as cristoballite and clinoptilolite are predominant in the clay fraction. Sometimes a mixed layer hydromica montmorillonite phase appears, and sporadic traces of chlorite are observed.

In summary, all of the genetic types in Hole 402A are characterized by a diverse composition of faunal remains, considerable admixture of volcanic glass, abundant authigenesis of montmorillonite and zeolite, and recurrent dolomitization often with accompanying gypsum. Although the genetic types are distributed randomly through the black shale interval, coarser silts are more evident in the upper part.

Granulometric and geochemical[2] analyses of the black shales from Hole 402A are presented in Figure 2. The following observations bear noting.

1) The granulometric composition is fairly constant throughout the interval; where Facies 402A.1 and 402A.6 occur the silt content is greater than average.

2) Both quartz content and total silicon are higher in the more silty facies. In the upper part of the series the increased silicon appears to be related to higher content of siliceous organic remains and zeolites; peaks in the lower part of the series reflect terrigenous influxes.

3) Iron content in the series is generally constant; no relation between Fe^{++} and Fe^{+++} with $C_{org.}$ is observed.

4) Quantitative distribution of Ti follows that of quartz.

5) Carbonate content varies with skeletal abundance and is inverse to that of $C_{org.}$ content. In the lower part of the series (402A, 1-2) the carbonate is derived in larger part from coccoliths whereas in the upper part coarse shell detritus and large foraminifers (Facies 402A.6) are the principal contributors. Markedly high carbonate values most commonly reflect dolomite enrichment.

6) The granulometric and chemical analyses in general confirm the boundaries of the recognized facies within the black shales of Hole 402A.

Hole 400A

The black shales series of Hole 400A is a macrofacies of the near-shore zone of sedimentation. Seven genetic types of sediments, corresponding to three facies, are distinguished with the macrofacies (Table 5; Plate 2).

The lower third of the series (Figure 2) (Cores 74-1, CC to 68-0) comprise the facies (400A.1) of calcareous-clayey sediments with allothigenic humic microcomponents being the dominant organic matter. This facies is associated with one genetic type of sediment (400A.1a) which is represented by alternating gray, sometimes dark-gray silty, slightly calcareous clays and silty marls, variously enriched in fusinitic and semifusinitic microcomponents of fine-attritus-sized inclusions. Rare gelinito-telinite and humo-sapro-collinite are also observed. Sapro-collinite is "invisibly" present, coloring the clay matter beige-olive.

$C_{org.}$ content varies between 0.2 and 0.3%, with rare deviations up to 0.7% or more due to layers with higher contents of allothigenic matter of humic origin. The type is characterized by burrows and thin parallel lamination, emphasized by fusinitic-attritus and axial orientation of clay particles, visible under the microscope. The carbonate content is low at the base (4.0%) but generally varies from

[2]The data of chemical studies are recalculated for carbonate-free matter.

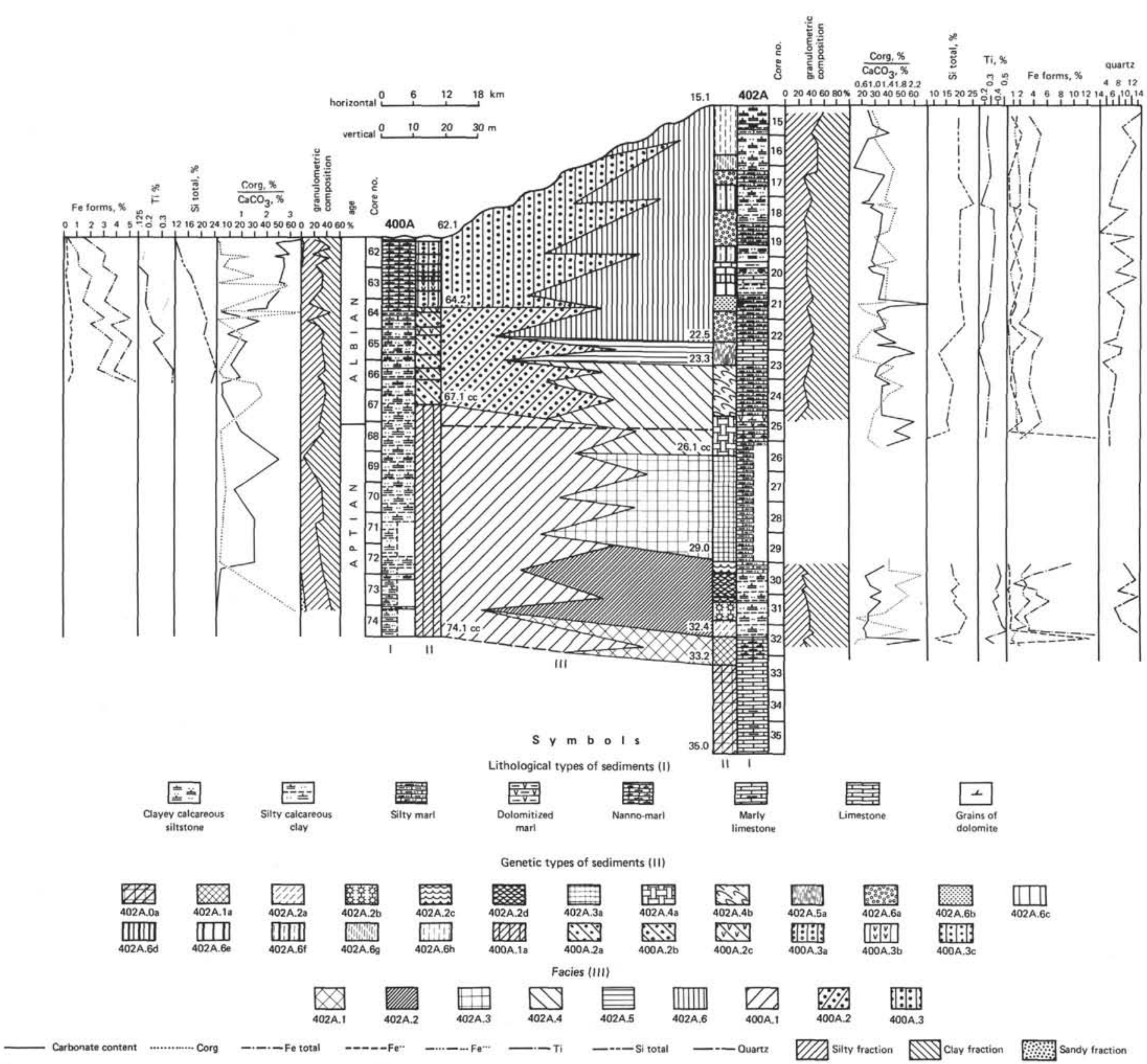

Figure 2. *Schematic facies profile of the black shales series through Holes 400A and 402A, DSDP Leg 48 in the Bay of Biscay. (For explanations to the legends see Tables 4 and 5.)*

18.0 to 30% and more, depending on varying enrichment by coccoliths.

Calcareous clay matter contains rare foraminifers, diatoms, zeolites, authigenic montmorillonite, and small amounts of pyrite. The terrigenous material consists of small quartz grains, feldspars, and mica plates.

The following interval (67-1, CC to 64-3) is characterized by Facies 400A.2 which are calcareous-siliceous clay sediments with syngenic sapropelic and allothigenic humic microcomponents. It is represented by three genetic types (400A.2a, 2b, 2c; Plate 2, Figures 3,4). The silty clays, more or less calcareous, and nannofossil marls are pale gray, dark gray, sometimes olive-black in color, with numerous burrows, and disturbed and slumped structures. Clay matter predominates with varying amounts of coccoliths which results in variations of the carbonate contents. Within the clay, small micaceous plates, feldspars, silt-sized grains of quartz, and fragments of beige claystones containing small dispersed lenses of collomorphic ashy matter occur. The clay particles are axially oriented, thus emphasizing the thin parallel lamination of the sediment. Authigenic minerals consist of abundant colorless monoclinal crystals of zeolites with distinct cleavage, the habit being similar to that of sediments from Hole 402A. In some places they form patches (druses) (Plate 3, Figure 1) in the matrix replacing skeletons of siliceous organisms (Plate 3, Figure 2) and developing in foraminifer chambers. Sporadic fragments of volcanic glass, mostly of median composition, are present. The pyrite content varies and is usually small, occurring as sporadic grains and concretions associated with patches of humic-sapropelic matter and zeolites. Clusters of authigenic montmorillonite are sporadic. Burrows, characteristic of the type, are filled with ashy organo-mineral matter and grains of quartz.

The sediments contain sporadic foraminifers, small amounts of shell detritus and fish bones, abundant siliceous organisms, mostly diatoms and fewer radiolarians, the skeletons having been recrystallized into cristobalite or zeolite. The mineral constituents of the clay fraction are montmorillonite, hydromica, sometimes mixed-layer hydromica-montmorillonite phase, kaolinite, rare chlorite, clinoptilolite, and cristoballite.

The main differences between the three genetic types relate to content and composition of the organic microcomponents. Genetic Type 400A.2b, with a $C_{org.}$ content of 0.2-0.3% is predominant in this facies. It consists mostly of fine-attritus and sharply fragmentary allothigenic microcomponents of the fusinite and gelenite classes, sometimes with syngenic particles of the sapro-collinite type. Those genetic types with high contents of $C_{org.}$ (1.6%, 2.8%, 3.3%) in some cases, such as 400A.2a, contain abundant allothigenic microcomponents of very small fusain and somewhat coarser vitrain attritus, with an admixture of syngenic humo-sapro-collinite. In other cases (400A.2c) microcomponents of the algo-thallomite class type predominate, humo-sapro-collinite and sapro-collinite being secondary, and allothigenic fusinite and gelenite being accessory.

Allothigenic microcomponents (400A.2a) predominate in the base of the section. Higher up, alternation of 400A.2c and 400A.2b types is recorded, the thickness of the layers increasing considerably; a decrease of organic siliceous content upwards in the section is concurrent with an increase of foraminifer content.

The upper interval (64-2 to 62-1) of the black shale series is represented by Facies 400A.3, which are marly sediments with predominant syngenic sapropelic microcomponents. Three genetic types of sediments (400A.3a, 3b, and 3c; Plate 2, Figures 1,2), comprising silty nannofossil marls, correspond to this facies. In appearance they are pale gray to gray, sometimes dark gray, in which the parallel laminae are often distorted by slumping and burrows, mainly in paler interbeds. Microscopically, the nannofossil marls consist of silty clay, enriched with coccoliths, abundant undefinable shell detritus, and numerous large and small foraminifers, their number increasing upwards in the interval. Very small fragments of quartz, feldspars, and plates of mica, occasionally hydrated, are also present. In some cases burrows are filled with pelitic clay containing small lenses of ashy organo-mineral colloidal matter. If the burrows are large, they are filled with angular grains of quartz. Siliceous organisms are relatively rare, radiolarians being most common. Fish bones of various size and shape, yellow in color, are numerous. Pyrite content is low, occurring as separate grains and, at the base, as rare concretions. Zeolites are extremely abundant. They are of short-prismatic shape, penetrate the cement within sediment, form pseudomorphs after siliceous organisms, are frequently observed in clusters resembling druses, and are associated with rare inclusions of vitrain-fusain. Zeolites are very seldom associated with foraminiferal tests, as is the case in sediments of Hole 402A. Authigenic montmorillonite, widely present in the sediments of Hole 402A, is not present in Hole 400A sediments. Fragments of volcanic glass of acid composition are not numerous.

Carbonate content varies from 40.5 to 63.2%, with a tendency to increase in the upper part of the interval because of a larger foraminiferal content. The mineral composition of the clay fraction is similar to that of the underlying unit.

The facies is characterized by contrasting values of the $C_{org.}$ content, varying from 0.1 to 0.2%, 0.5 to 1.2%, and 2.8%, depending on the types of sediment. The composition of the organic matter in nannofossil marls (3.0% in 400A.3b) is similar to that of 400A.2c type of the previous facies. Sapropelic microcomponents, including algothalomite, are predominant, humic ones being accessory. The organic matter in nannofossil marls with the $C_{org.}$ content of 0.1 to 0.2% (400A.3a) is represented by saprocollinite, allothigenic microcomponents of the fusinite class, mainly of fine-attritus-sized inclusions, as well as the finest of organo-mineral lenses of ashy color, which are probably the products of organic activity(?). The organic matter of nannofossil marls of the 400A.3c genetic type (0.5-1.2%) contains, besides microcomponents characteristic of the 400A.3a type, humo-sapro-collinite. The interval is characterized by alternation of 400A.3a and 400A.3c genetic types, whereas the 400A.3b type is sporadic and associated mainly with its lowermost part.

The black shale series in Hole 400A is capped by organogenic-carbonate sediments deposited in a relatively shallow-water zone of sedimentation.

Granulometrical and chemical analyses of the black shale from Hole 400A are presented in Figure 2 which demonstrates that the granulometrical spectrum is consistently silty-clay size. Three distinct intervals where carbonate is abundant can be observed in the section, corresponding to three facies of sedimentation (400A.1, 400A.2, and 400A.3). Variations in carbonate content in the first two facies is a result of varying enrichment with coccoliths. Abnormally high carbonate in the 400A.3 facies is due to greater amounts of foraminiferal tests therein. The curve of the total silicon distribution reflects the relative abundance of siliceous organic remains in the sediments in zeolites, terrigenous particles, and clay constituents; it is a more or less constant value.

The $C_{org.}$ content varies within a wide range and does not show any direct relation to the carbonate content except for singular layers that show inverse relation. The iron and titanium contents decrease regularly upwards, which probably reflects removal of a terrigenous source.

DEPOSITIONAL ENVIRONMENT OF THE BLACK SHALES

Our study of the sediments and their facies in the black shale intervals from Holes 400A and 402A lead us to conclude that they were deposited in the macrofacies of the near-shore sedimentation zone. This can be evidenced by the following diagnostic features: (1) abundant burrows and slump structures; (2) large and small lens-shaped and lens-banded alternation of paler and darker layers produced by varying admixtures of syngenic humic microcomponents, and by varying grain sizes; (3) admixture of syngenic and allothigenic humic material varying in size from fine attritus to coarse fragments; (4) abundant quartz grains, mica plates, foreign fragments of claystones, of fine- to coarse-silty and sandy-sized grains; (5) pyritization of both animal and plant remains; and (6) recurrence in Hole 402A of layers enriched, or entirely composed of authigenic idiomorphic rhombs of dolomite accompanied by gypsum, testifying to shoals or salinized bays and lagoons.

The black shales in Hole 400A appear to be related to a somewhat deeper-water and relatively more distant shallow-water environment compared to the closer in-shore conditions in Hole 402A. The distinguishing criteria are summarized in Table 6.

In Hole 402A the series is characterized by a considerable number of genetic types with interbeds enriched, to a varying degree, in land humic material, and by the presence of dolomitized layers, frequently with associated gypsum. This complexity most likely reflects a shifting strand line during accumulation of the series. In contrast, the succession at Hole 400A is composed of fewer genetic types, more similar to one another in material composition, hence, implying more constant dynamics essentially unaffected by shore-line fluctuations.

A facies profile of the black shales between Holes 402A and 400A is presented schematically in Figure 2. Therein it is apparent that deposition of the series began at Site 402 (Cores 33-2, CC to 32-5) somewhat earlier than at Site 400. These early sediments are gray nannofossil marls of Facies 402A.1 that contain dolomitized interbeds and humic material of the funinite-telenitic and syngenic fusinite-collinitic

TABLE 6
Principal Genetic Criteria for Differentiation of Near-Shore Shallow-and Deep-Water Sedimentation Zones

	Near-shore Sedimentation Zone	
Principal Criteria	Shallow-Water	Deep-Water
Average organic matter content (OM)	Over (1.19%)	Less (0.77%)
Type of accumulation of the initial material	Mostly allochthonous	Mostly authochthonous
Character of OM	Essentially humic	Essentially sapropelic
Predominant composition of syngenic microcomponents of OM	Sapro-humo-collinite, gelinite-telinite "S"	Algo-thallomite, saprocollinite, humo-saprocollinite
Amount of allothigenic microcomponents of OM	Great	Relatively small
Size of inclusions of allothigenic microcomponents of OM	Coarse attrital, fragmentary, less frequently fine attrital	Fine attrital, less frequently coarse attrital and fragmentary
Color of cement under microscope	Brown, brownish, less frequently beige-olive	Beige-olive, less frequently red-brownish
Relative size of terrigenous grains	Coarser (coarse-silty, fine-silty, sometimes with admixture of sandy size	Finer (fine silty with admixture of coarse-silty size grains)
Sorting of mineral material	Poorly sorted; a greater admixture of terrigene material	Better sorted, a lesser admixture of terrigenous material
Intensity of sulfide-formation processes	Strong	Weak
Composition of faunal remains	Diverse	More diverse
Composition of siliceous organisms	Skeletons of large siliceous sponges	Skeletons of diatoms, radiolarians
Character of sediment lamination	Parallel-wavy, parallel-interrupted, lense-shaped, sometimes cross-laminated	Mostly parallel, emphasized by axial orientation of clay particles
Interbeds with dolomite	Periodically recurrent in the section	None
Transitions between layers containing organic matter	Gradual	Abrupt
Structure of the section	Complicated	Simple

types. These ingredients, and the textural and structural peculiarities of the sediments, testify to a near-shore shallow-water deposition zone with areas of salinized bays and lagoons.

In the succeeding interval (32-4 to 30-0), in which Facies 402A.2 was deposited, the shoal environment did not change appreciably except to become somewhat deeper. This resulted in accumulation of interbedded gray and dark gray, to almost black, laminated and lensoid silty marls and silty clays that are calcareous because of coccoliths and shell detritus, and with burrowed and distorted structures. Considerable concentrations of humic organic matter in some layers, transitions between the latter being rather gradual, show that the source of a continuous supply of terrigenous material was near at hand. This is further evidenced by an admixture in the clays of quartz and hydrated micas of fine and coarse silt-sized grains and volcanic glass of median composition. Pyrite is present, testify to considerable amounts of primary decomposition products of animal and plant material. Further evidence of microbial decay and a reducing environment is shown by enrichment of organic matter of the Genetic Types 402A.2a, 402A.2c, 402A.2d in syngenic microcomponents (sapro-humo-collinite and gelinite-telinite "S"). The saline bay and lagoon environments had disappeared, although the lower part of this unit embraces Genetic Type 402A.2b containing authigenic crystals of dolomite and organic matter of the semifusinitic, fusinite-tellinitic types. The sediments characterize a gradual transition from the recurrent lagoon-bay environment to a less restricted near-sea-shore zone. Siliceous sponges were present and zeolite and montmorillonite began forming.

Higher up the section the sediments pass gradually into varieties less enriched in humic and organic matter in general. Due to a low recovery of core material in the succeeding interval (29-0 to 27-0), a detailed study of the sediments was not possible but, judging by samples available, they appear to be similar to those above.

In the latter interval (26-1, CC to 23-3) the sediments are composed of Facies 402A.4. Poor sorting of the mineral grains in this facies, the appearance of coarser-grained beds, the abundance of fragments of foreign claystones, the considarable amounts of rather large siliceous sponge spicules, and the increase of shell detritus with large mollusk test fragments, testify to changes in sedimentation conditions. These changes manifested themselves in greater shoaling of the sedimentation zone, compared to conditions of the two underlying intervals. Sediments of the 402A.4a genetic type, represented by alternating gray and light gray marls enriched to varying degrees with dolomite rhombs and authigenic gypsum, indicate the presence of shoals and/or salinized bays and lagoons. A relatively large admixture of humic matter in some layers, and in lenses and patches, show that the land plant source remained nearby. It supplied reactive humic material, witnessed by pyritized plant remains, and dispersed pyrite in the sapropel-humic-collinite and syngenic microcomponents of 402A.4b type. The fusainic composition of allothigenic ingredients in the 402A.4a genetic type points to an oxidizing environment. The sediments of this type are relatively poor in pyrite but they show abundant evidence of dolomitization and formation of authigenic gypsum rosettes. During accumulation of sediments in this interval the supply of ashy particles increased contributing to authigenesis of monoclinal zeolite crystals and supplying silica to a thriving sponge population.

While the black shales in the above intervals of Site 402 were accumulating, at Site 400 (interval 74-0 to 67-1) the accumulation of calcareous clay sediments of Facies 400A.1 (mostly with allothigenic organic micro-components) took place. These sediments are also of the near-shore shallow-water sedimentation zone. However, the relatively small size of terrigenous grains (including mica plates), the axial orientation of clay particles parallel to the lamination of sediments, the predominance of fusain attritus within humic material, and the absence of dolomite, point to somewhat deeper water relatively more remote from the coast. As a result of the greater distance off shore, the amount of reactive humic material supplied from the adjacent land was less, as manifested in negligible contents of syngenic humic and sapropel humic microcomponents and smaller size of particles of vitrain-fusain detritus. There is also less pyrite.

During the time these sediments accumulated, volcanogenic material was being supplied and, at Site 402, contributed to the appearance of monoclinal zeolites and a flourishing diatom population. These differences in the groups of siliceous organisms at the two sites, in accordance with their ecology, emphasizes greater water depth at Site 400, as compared to Site 402.

At Site 402, interval 23-3 to 22-6 contains coquina (Facies 402A.5), representing a short period of very shallow water close to shore. The Genetic Type 402A.5a contains abundant, slightly rounded shell fragments and unbroken shells of a diverse fauna encased in a sparse matrix of calcareous clay containing particles of quartz, mica plates, fusain coarse attritus, and rare vitrain fragments of wood tissues. These shallow waters were subsequently replaced by somewhat deeper waters (in the period of formation of genetic type sediments of Facies 402A.6, interval 22.5-15.2) but, with time, depth oscillations continued and included periods when salinized bays and lagoons re-occurred. As a result, accumulation of a thick pile of sediments consisting of calcareous silty clays and marls, variously enriched with dolomite rhombs and gypsum rosettes, took place. The optimal water depth during this time favored a wide faunal spectrum; the relative nearness of land favored constant supply of varying amounts of land plant material represented by coarse fusain and semifusain attritus, fragmentary gelinite-telenite and sapro-humo-collinite. Numerous pyrite inclusions, both dispersed and concentrated, point to intense microbial activity and reducing conditions. In local, periodically appearing lagoons and bays where dolomite and gypsum formation took place, the medium was effectively oxidating; in these genetic types (402A.6b-402A.6e) the organic matter is mostly fusinite-collinite and fusinite-tellinite. Abundant ashy material supplied silica for the authigenesis of zeolite and montmorillonites, and the larger sponge population.

While black shale sediments of Genetic Type 402A.6 were being deposited at Site 402, accumulation in two intervals (64-4, CC to 64-3 and 64-2 to 62-1) at Site 400 took place. Both units comprise Facies 400A.2 and 400A.3 and reflect conditions of relatively deeper water sedimentation in the near-shore zone. Facies 400A.2 (interval 64-4, CC to 64-3) is composed mostly of clays (calcareous to various degrees) with burrows, disturbed bedding and thin parallel lamination emphasized by axial orientation of clay particles. Diatoms are abundant as well as sapropelic (Type 400A.2a), including the algo-thallomitic (Type 400A.2c), microcomponents with an admixture of allothigenic humic material (Type 400A.2b); these are reliable criteria of relatively deep-water sedimentation conditions of the facies. Pyrite is not abundant. The small particle size of quartz, mica plates, and allothigenic humic microcomponents indicate relative remoteness of the supply source. Zeolite and numerous ashy particles are present. In the interval, sponge spicule content decreases, and foraminifers appear higher up in the interval suggesting steady deepening as sedimentation proceeded.

During accumulation of sediments of the third facies (400A.3; interval 62-2 to 62-1) represented by nannofossil marls only, the water depth increased, compared to the underlying interval. The sediments became more calcareous because of increase in numbers of coccoliths and small (rarely large) foraminifers. The sediments are impoverished in organic matter (Types 400A.3a, 400.3c) except for a few layers (Type 400A.3b). The latter, however, is not related to an intensified supply of land plant material (allothigenic microcomponents), as it was observed throughout the black shale series of Hole 402A. Rather, it is a result of sporadic local development of microscopic colonial algae (algothallomite). The sapropelic nature of the organic matter with a negligible admixture of allothigenic humic microcomponents is a result of increasing water depth and remoteness from the source of terrigenous material, as is evidenced by a lesser admixture of fine quartz particles and micaceous plates.

The supply of volcanogenic material, that had begun earlier, continued but was of acid, not median, composition. Despite the good supply of ashy material, few siliceous organisms are recorded in the sediments of this interval; the deeper-water conditions did not appear to be favorable for their development or for sulfate-reducing bacteria.

Thus, throughout the history of formation of the black shale series two well-pronounced zones of the near-shore sedimentation are recorded: (1) the near seashore shallow-water zone (Hole 402A) and (2) a deeper, more off-shore zone (Hole 400A). The conditions in the former were not constant in time, but changed, becoming more or less shallow, even to the extent where salinized bays and lagoons appeared; the general temporal tendency however, was one of gradual deepening. At Site 400, black shales accumulated in an environment that, with occasional reverses, became progressively deeper with time. The differences between the two zones caused differences in the parageneses of black shales and their facies, which are reflected in the component composition of the organic matter in them. The "brown-coal" stage of coalification and the essentially humic composition of the organic matter of the near-shore shallow-water zone permits attribution of them to the category of "gas-potential" sediments. The sapropelic composition and the "brown coal" stage of the organic matter in the sediments of the deeper water zone points to them as "oil-potential" sediments.

Study of microfacies is thus valuable for elucidation of the history of oceanic sediment accumulation, and also for prognosis of oil and gas potential.

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PLATE 1

Black shale series from Hole 402A, deposited in the near-shore shallow-water, periodically lagoon, zone of sedimentation.

Figure 1	Siltstone, fine-grained, calcareous-clayey, dark gray, with parallel, parallel-wavy, sometimes lens-shaped lamination; with thin interbeds of silty marl, and more or less evenly distributed organic matter of the fusinite-, semifusinite-telinitic types and sapro-humo-collinite and gelenite-telinite; numerous fragments of carbonate shells and their detritus, siliceous sponge spicules, fish bones, coccoliths, echinoderm remains; rare small burrows are observed. Sample 16-2, 0-25 m.
Figure 2	Carbonaceous marly calcareous chalk, dark-gray, sometimes almost black, with parallel-wavy, sometimes thin lens-shaped lamination. In some places are interbeds with thin cross-laminations (1). The organic matter, present in various amounts (1.0-1.7%), is mostly of the sapro-humo-collinite and gelenite-telenite types with fusinite- and fusinite-telinite. Numerous fragments of carbonate shells, siliceous sponge spicules, fish bones, zeolites, coccoliths, echinoderm remains; small and large burrows are observed. Sample 18-2, 100-125 cm.
Figure 3	Marly clay, gray and dark gray, with parallel-wavy and lens-shaped lamination; slumped bedding and burrows. The organic matter (<1.0%), more or less evenly distributed in the sediment, is of fusinite-collinite and fusinite-tellinite types. Small carbonate shells, their detritus, coccoliths, siliceous sponge spicules, zeolites, echinoderm remains are present. Sample 21-3, 75-100 cm.
Figure 4	Nannofossil-marl, silty, light gray with crystals of dolomite and dolomitized interbeds. The organic matter (<0.5%) is of the fusinite-semifusinite-telinitic and fusinite-collinitic types; foraminifers and small fragments of carbonate tests are present. In mid-sample there are accumulations of pyritic concretions (1); the vitrinized wood between them. (2) is of low degree of carbonification (41%C). Sample 33-2, 120-140 cm.

PLATE 1

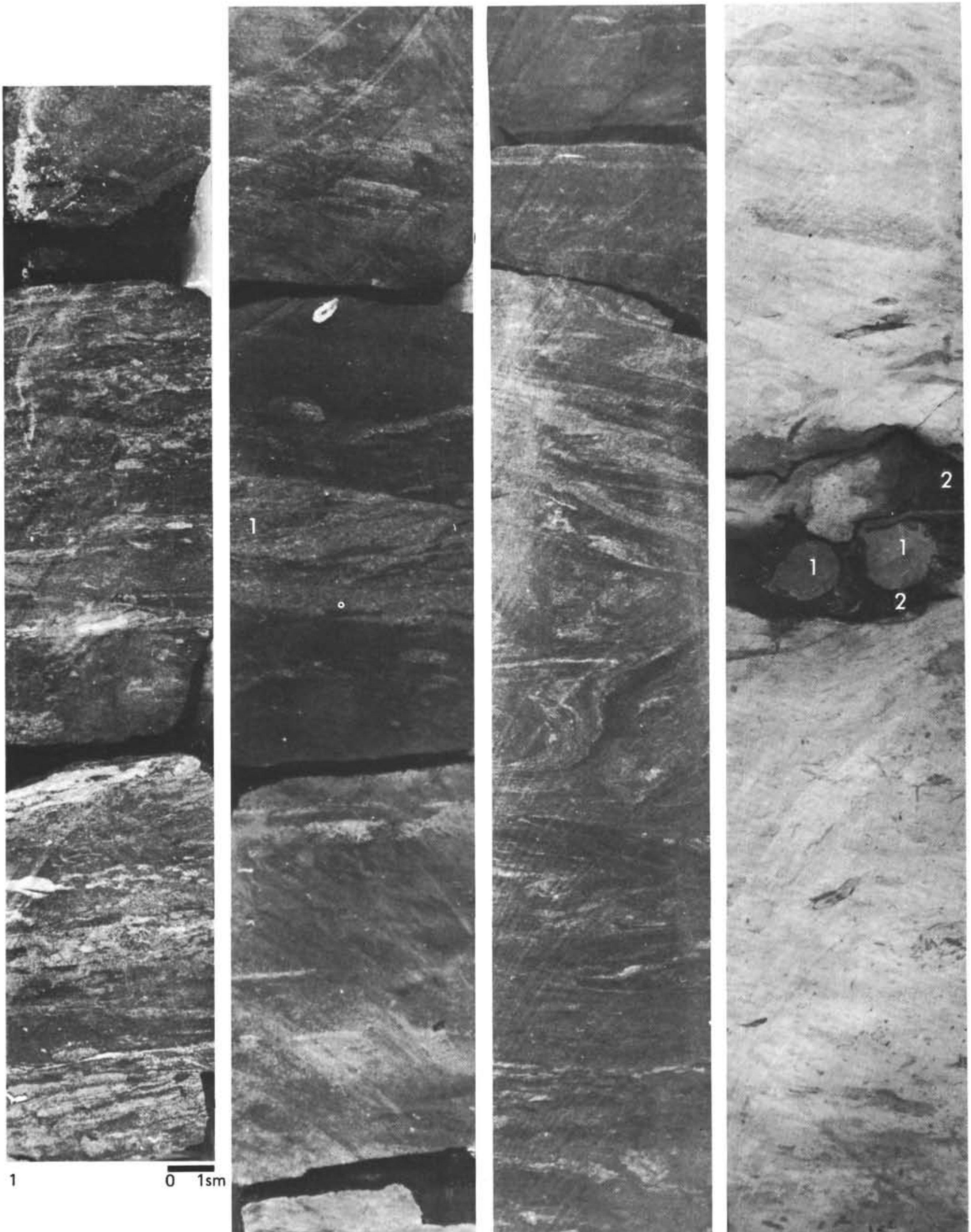

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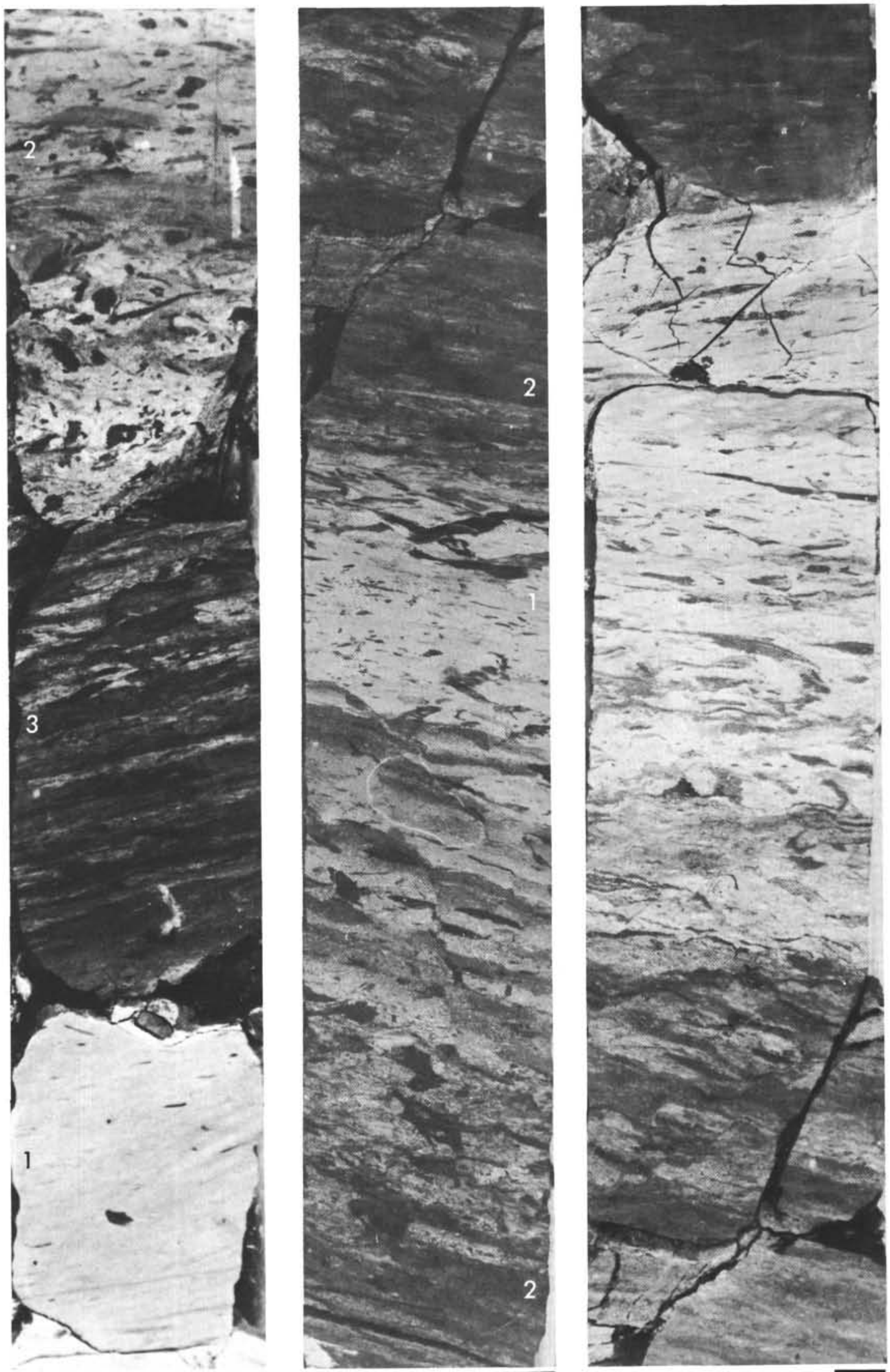
PLATE 2

Black shale series of Hole 400A of the deeper water near-shore zone of sedimentation.

Figure 1	Nannofossil-marl, silty, light gray (1), gray (2), sometimes olive-black with the organic matter (0.5-2.0%) of humo-sappro-collinitic, sapro-collinitic and fusinite-tellinitic types (3). Numerous foraminifers, zeolites, radiolarians, and fine carbonate shell detritus are observed. The interbeds with organic matter have parallel, parallel-wavy, sometimes lens-shaped lamination. Burrows are rare. Sample 62-3, 50-70 cm.
Figure 2	Same as above. Sample 62-5, 23-53 cm.
Figure 3	Nannofossil-marl, silty, gray (1), dark-gray, and almost olive-black (2) with distinct interbeds enriched in organic matter (up to 3.0%) of algothallomitic and humo-sapro-collinitic types, with fusinite-, and fusinite-semifusinite-telinite. There are abundant foraminifers, zeolites, radiolarians, and carbonate shell detritus. Burrows and traces of slumping and roiling are observed. Sample 63-4, 60-90 cm.
Figure 4	The continuation of Sample 63-4, 60-90 cm. The interbeds enriched in organic matter are more distinct. Sample 63-4, 90-115 cm.

PLATE 2



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