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Atlantic Continental Shelf and Slope of the United States

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Color of Marine Sediments

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Atlantic Continental Shelf and Slope of the United States— Color of Marine Sediments

By DANIEL J. STANLEY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 529-D

Sediment colors on the continental margin reflect differences of composition, texture, physiography, and sedimentary processes active now and in the recent geological past

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By Daniel J. Stanley [2]

ABSTRACT

A systematic examination of the regional color distribution of the upper sediment layer on the Atlantic continental margin between Nova Scotia and southern Florida reveals that brown, dark green, and yellow predominate on the shelf north of Cape Hatteras, N.C., whereas olive, gray, and yellow predominate to the south. Color is affected by composition, texture, physiography, and geological events in the recent past. Many of the color patterns on the shelf are more closely related to Pleistocene and Holocene sedimentary events than to modern dispersal processes. Relict color patterns occur in areas such as Georges and Browns Banks, which were exposed during lower stands of sea level. Linear but discontinuous belts of yellow sediment on the outer shelf and along the shelf break south of Cape Hatteras are probably also related to strandline features formed during the Pleistocene low stands of sea level and during the transgressive advance of the Holocene sea.

Color patterns on the continental slope and rise and on the Blake Plateau, unlike those on the shelf, are arranged in linear belts that trend parallel or subparallel to the shelf break. Major trends vary directly with depth, ranging from olive and green at the top of the slope, through light gray and pale yellowish brown, to brown and yellow at the top of the continental rise. These trends are probably related to the oxidation-reduction potential of the environment, which results from a balance between the rate of deposition and the rate of bacterial decomposition of organic matter deposited with the sediment. Isolated areas of color on the slope and rise seem to be due to the slumping of sediment masses downslope and to the exposure of pre-Holocene outcrops. Red Pleistocene till masses, which were once exposed on the Scotian Shelf during the glacial epoch, may have been reworked during the Holocene rise in sea level. This may explain why brown and reddish-brown sediments are found at progressively shallower depths northeastward on the rise and slope off the Gulf of Maine and Nova Scotia.

INTRODUCTION

Color is one of the most obvious properties of a sediment, yet a survey of the literature shows that color remains one of the least exploited petrologic properties in investigations of modern and ancient sediment. Color is sensitive to present conditions on the bottom such as depth of water, Eh, and pH, to the texture and mineral composition, and to constituents such as disseminated organic matter, bacteria, and carbonate. Certain colors, particularly yellow shades, can be related to periods of lower stands of sea level when parts of the shelf were exposed to the air. A better understanding of the color distribution can, therefore, supplement our knowledge of the depositional environment existing now and in the past on the continental shelf and slope. Changes of color that take place during and after sediment deposition and that occur after a sample has been collected are also considered in this study. The colors of sediment on the Atlantic continental margin are also compared with those on shelves and shallow seas in other areas. An understanding of colors on Holocene shelves and slopes should be useful to interpret colors of marine shelf and slopes sediments preserved in the geologic record.

This study of the regional sediment color distribution on the continental shelf and slope between Nova Scotia and Key West, Fla., was conducted under the auspices of the U.S. Geological Survey and the Woods Hole Oceanographic Institution as part of their joint Atlantic Continental Margin Project. About 1,600 samples collected for this project were examined systematically, at sea and in the laboratory, to determine the color-distribution pattern.

This study has additional oceanographic applications, particularly to bottom color photography, which is often used in marine geologic and biologic work. The colors in such photographs are distorted because of the effects of lighting at depth. This distortion can be corrected and true colors interpreted by comparing the colors of the sea floor in the photographs with those on the color plate (pl. 1).

[1] Contribution No. 1920 of the Woods Hole Oceanographic Institution. Based on work done under a program conducted jointly by the U.S. Geological Survey and the Woods Hole Oceanographic Institution and financed by the U.S. Geological Survey.

[2] Division of Sedimentology, U.S. National Museum, Smithsonian Institution, Washington, D.C. 20560.

PREVIOUS STUDIES

Although the color of sediment has been recorded as a part of notations on the bottom ever since charts of the eastern margin of North America were compiled, a search of the literature reveals that few regional investigations include an analysis of the sediment-color distribution. The color of sediment is mentioned only in cursory fashion in reports of the different major expeditions, including the *Challenger*, *Snellius*, John Murray, *Meteor*, and Swedish. More recently, however, some attention has been paid to the color distribution in the Barents Sea (Klenova, 1960, fig. 71), the East Pacific Ocean (Arrhenius, 1952), the Gulf of Thailand (Emery and Niino, 1963) and the China Sea (Niino and Emery, 1961), the Gulf of Paria (van Andel and Postma, 1954), the Western Guiana Shelf (Nota, 1958), the Gulf of St. Lawrence (Nota and Loring, 1964), and the Gulf of California (van Andel, 1964).

More specific studies of color as related to minerals and rocks are available in the literature. A key article on the types of coloring in minerals was published by Kennard and Howell (1941). An interpretation of the red and green color in fine-grained sediments was given by Grim (1951) and of green color by Keller (1953). The significance of color in sediments was also outlined in a general way by Sverdrup, Johnson, and Fleming (1942, p. 967–969), Kyrnine (1948), Twenhofel (1950, p. 634–641), and Weller (1960, p. 129–140).

SAMPLES

About 1,600 grab samples of bottom sediment of the Atlantic continental margin were examined in this study. Sampling methods were described by Emery (1966, p. A10). The distribution of the samples is shown by the black dots on plate 1. Details of the locations and sampling equipment, the Munsell color (Munsell Color Co., 1929–60), and a short lithologic description of each sample were listed by Hathaway (1966). Locations of approximately 200 samples collected on the southwest half of the Scotian Shelf by the Marine Geology Group, Dalhousie University, are shown in Stanley and Cok (1968, fig. 4).

ACKNOWLEDGMENTS

This study was made possible by a postdoctoral fellowship and a visiting scientist stipend granted to me by the Woods Hole Oceanographic Institution during the summers of 1964 and 1965, respectively. Discussions with all the staff members of the U.S. Geological Survey and the Woods Hole Oceanographic Institution participating on the Atlantic Continental Margin Project at Woods Hole proved most valuable, and this study could not have been completed so rapidly without their ready and kind advice. I particularly thank K. O. Emery, who suggested the problem to me, and whose suggestions proved most valuable. Elazar Uchupi, R. H. Meade, and G. W. Moore critically read the manuscript and made suggestions that considerably improved the text.

Sample data collected on the west half of the Scotian Shelf (1961–66) by the Marine Geology Group, Institute of Oceanography, Dalhousie University, have been incorporated in this study.

METHOD OF COLOR DETERMINATION

The Munsell color scale (Munsell Color Co., 1929–60) has been used throughout the study to define the colors in a consistent manner. This is the color scale presently used by many scientific organizations in North America, including the U.S. Geological Survey and the Geological Society of America (Goddard and others, 1948). Most colors can be matched directly with color chips in the "Munsell Book of Color." The basis of this scale is the solid color sphere, which has an achromatic color axis (fig. 1). This vertical axis is black at the base, becomes progressively lighter gray, and eventually becomes white at the top of the axis. Every shade of color occupies a specific point within the sphere, and every color shade can be defined by hue, value, and chroma. Hue refers to the primary colors of the spectrum and the intermediates between them. Ten major hues are distributed in radiating fashion around the vertical axis of the sphere. Value refers to the property of lightness,

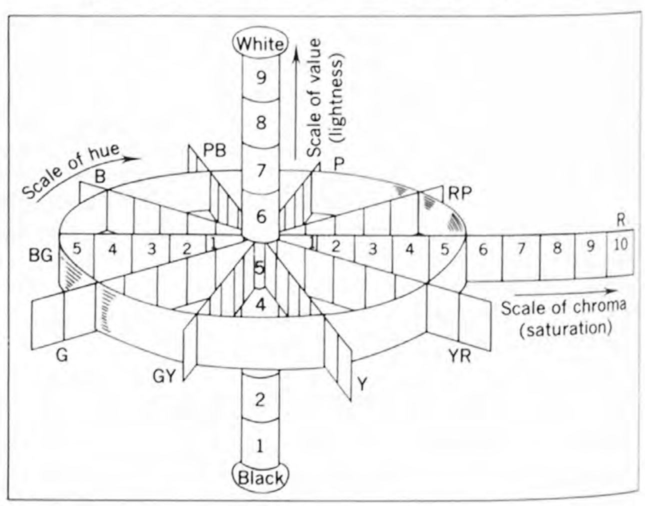

FIGURE 1.—The color sphere showing hue, value, and chroma in their relation to one another. The circular band represents the hues in their proper sequences. The upright center axis is the scale of value. The radii pointing outward from the center indicate chroma; the higher the number, the more intense the chroma. Modified from Munsell Color Co. (1929–60).

and it is measured vertically from the base to the top. Chroma refers to the degree of saturation or color intensity. Colors trend toward the grays near the central axis and are more vivid near the outer circumference of the sphere. Every shade of color is defined by a specific letter and number code according to the Munsell system. An example such as 5*Y* 4/3, can illustrate this: 5*Y* refers to hue, 4 refers to value, and 3 refers to chroma.

All samples were examined wet. When a sample is dry, its color is generally lighter (higher value) and nearer to neutral gray (lower chroma) than when wet. After wetting the sample, the color becomes darker (lower value) and occasionally more vivid and intense (higher chroma). The hue generally remains approximately the same whether a sample is wet or dry. Wetting darkens and intensifies the color largely because (1) the thickness through which light rays must pass has increased, and a greater proportion of rays are absorbed, and (2) the greater thickness reduces the amount of white light that can be diffusely reflected from the absorbing material (Kennard and Howell, 1941).

All samples were examined by one person who has normal color vision to minimize operator variation in recording color. Sets of samples were reexamined to test for consistency and operator error. These tests revealed only minor differences between readings. An effort was made to maintain consistent conditions of lighting in the laboratory and sea. Soft natural lighting, as opposed to bright sunlight, was used; samples were examined near well-lit windows. Color readings were made by spreading approximately 25 grams of a sample on a light waterproof background and then comparing its colors with the colored chips in the Munsell color book. For almost all samples the color recorded is that of the sediment beneath the thin oxidized layer at the water-sediment interface. The thin upper layer, generally several millimeters to several centimeters thick, is almost always lighter than the underlying sediment (fig. 2*A*).

A total of 83 different color shades were observed (table 1). Differences between these shades are subtle. The 83 colors have been divided into nine natural color groupings for plotting on a regional scale (table 1 and plate 1).

TABLE 1.—*Colors of wet sediment on the continental margin off the Eastern United States*

Symbol used in explanation of pl. 1	Color shades in each group (hue, value/chroma)	Color names (Name best describing color group given first)
A	2.5*YR* 5/6 5*YR* 3/4, 4/4	Light brown Moderate brown
B	7.5*YR* 3/2, 4/2 10*YR* 3/2, 4/2 25*Y* 3/2, 4/2	Dusky yellowish bown Dark yellowish brown Grayish brown
C	10*YR* 4/4, 5/4, 6/4, 7/4, 5/6, 6/6, 5/8 2.5*Y* 4/4, 5/4, 6/4, 7/4, 8/4, 4/6, 5/6, 6/6	Yellow ochre Moderate yellowish brown Dark yellowish orange
D	10*YR* 5/1, 6/2, 7/2, 8/2 2.5*Y* 5/2, 6/2, 7/2, 8/2	Pale yellowish brown Very pale orange Yellowish gray
E	5*Y* 4/1, 5/1 10*Y* 4/1, 5/1, 6/1 5*GY* 4/1, 5/1, 6/1	Greenish gray Light olive gray Dark greenish gray
F	5*Y* 4/4, 5/4, 6/4, 7/4, 5/6	Dusky yellow Moderate olive brown Light olive brown
G	5*Y* 4/2, 5/2, 6/2, 7/2 7.5*Y* 4/2, 5/2, 6/2, 7/2 10*Y* 4/2, 5/2, 6/2, 7/2 2.5*GY* 4/2, 5/2, 6/2, 7/2	Pale olive to grayish olive
H	7.5*Y* 4/2, 5/4, 6/4, 7/4 8/4, 5/6 10*Y* 4/4, 5/4, 6/4 2.5*GY* 5/4 5*GY* 4/2, 5/2	Light olive Moderate greenish Dusky yellow green
I	5*Y* 2/2, 3/2, 3/4 7.5*Y* 3/2, 3/4 10*Y* 2/2, 3/2 5*GY* 3/1, 3/2 *N*3	Greenish black Olive black Dark olive green Dark gray

THE PROBLEM OF COLOR CHANGE

Samples used in this investigation had been collected at different times and were in different stages of preservation. For example, all samples collected prior to 1964 by the U.S. Bureau of Commercial Fisheries were dry by the time this study began. Other samples collected during 1964 were still slightly wet, and still others were thoroughly wet.

It was necessary, therefore, to determine how much the color changes from the time a sediment is collected to the time that it has completely dried out and has been stored for at least 1 year. Samples collected in June 1964 (sample stations 1668–1895) on the continental shelf south and north of Cape Hatteras and on the northern part of the Blake Plateau were examined immediately on shipboard, and fresh colors were recorded. These sediments were then reexamined 4 weeks later, while they were still moist and in the process of drying out. This moist state is referred to as a transitional state in this report. These same samples were reexamined a year later, in August 1965, after they had dried completely. The samples were moistened with distilled water during the two reexaminations to obtain wet-color readings. Results from this study are given in table 2.

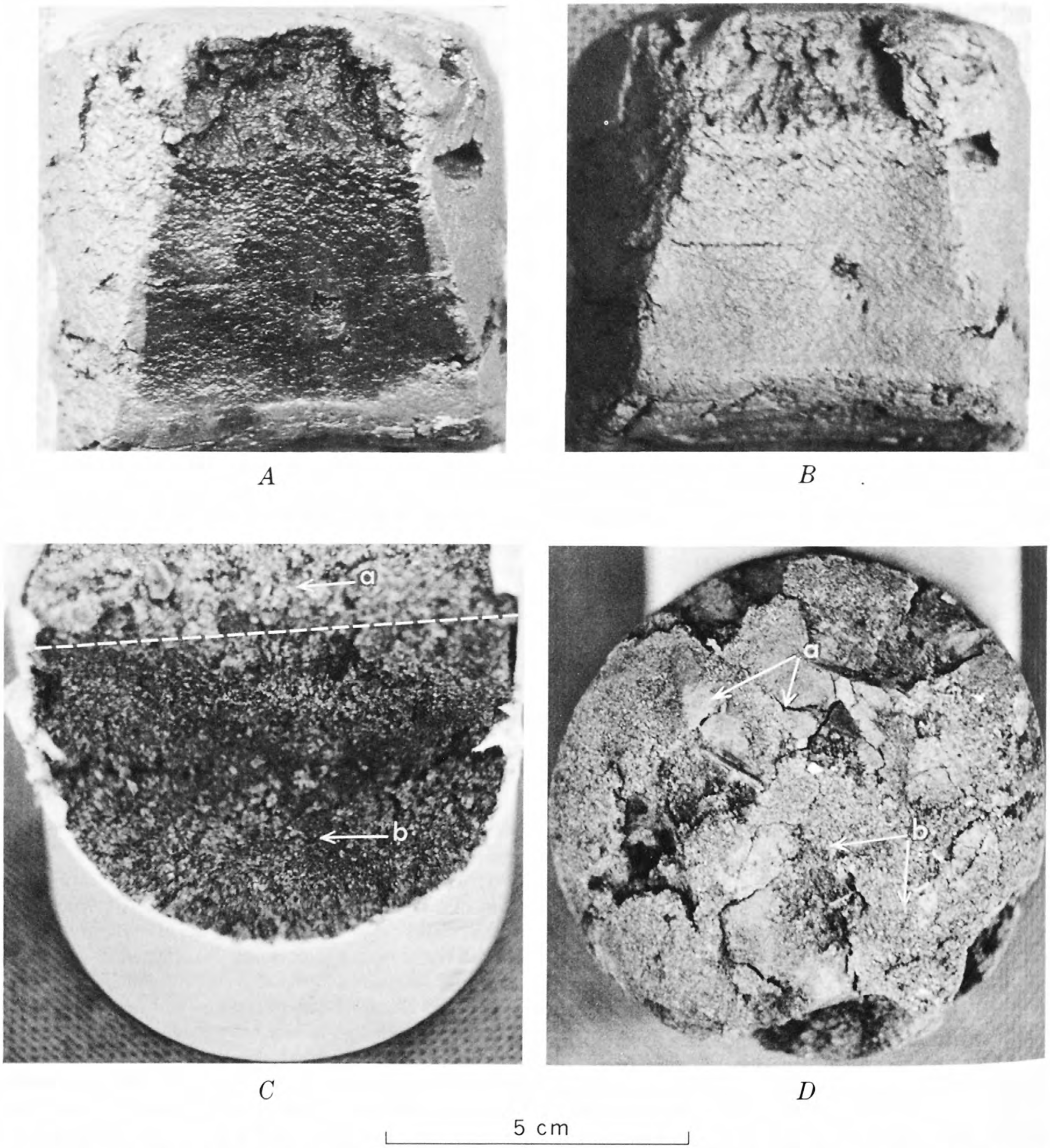

FIGURE 2.—Color changes in sediment after sampling. *A*, Pale-olive *Globigerina* ooze that had just been removed from its container after several weeks of storage; central part is black to dark olive; thin outer veneer is pale olive. *B*, Same sample surface as *A* after nearly 12 hours of exposure at room temperature; the black to dark-olive color has disappeared. *C*, Sample of shell and quartz sand after 10 days of storage. Above dashed line: (*a*) thin, lighter oxidized film at surface; below dashed line: (*b*) darker central part. *D*, Composite sample of the uppermost finer grained oxidized film of silt, *a*, which originally covered the somewhat coarser and darker underlying *Globigerina* sand, *b*.

TABLE 2.—*Changes in color as samples dry out in storage*

[All colors read wet; distilled water added where necessary. X, change observed; +, color change from wet to transitional stage; 0, color change from transitional to dry stage; +0, color change from wet to transitional and from transitional to dry stage]

Sample No.	Sediment type	Degree of change [1]									
		Color			Hue			Value		Chroma	
		Slight	Medium	Gross	More yellow-red	More yellow	More yellow-green	Lighter	Darker	Grayer	More vivid
Color change from wet to transitional stage; returns to original color when dry											
1761	Quartz sand		X					X		X	
1707	do	X						X			
1843	Shell sand	X						X			
1722	Globigerina sand and ooze	X						X			
1737	do		X					X			
1767	do	X									X
Color change from wet to transitional stage only											
1680	Quartz sand (with some shell)			X		X					
1683	do		X			X		X			
1755	do		X			X			X		
1758	do			X			X		X		
1779	do		X				X		X		X
1788	do		X			X		X			
1807	do	X				X					
1872	do	X				X					
1878	do	X						X			
1893	do		X			X					
1689	Shell sand			X		X					
1710	do	X						X			
1776	do	X				X					
1752	Globigerina sand and ooze		X		X				X		
1770	do		X			X			X	X	
1801	do	X				X					
1881	do	X				X					
1731	Pteropod sand and ooze		X			X			X		
1761	do		X			X			X		
1764	do		X						X	X	
Color change from transitional to dry stage											
1822	Quartz and shell sand		X			X					
1866	do		X			X			X		
1716	Shell sand	X				X					
1719	do	X				X					
1750	Globigerina sand and ooze		X			X					
1828	do		X			X			X		
1830	do			X		X			X		X
1855	do		X			X			X		X
1743	Pteropod ooze	X									X
Color change from wet to transitional (+) and from transitional to dry stage (0)											
1668	Quartz sand	+	0						X		
1674	do		+0			X			X		
1698	do	+	0			X					
1701	do	+	0			X			X	X	
1704	do	0	+						X		
1804	do	0	+			X					
1816	do	0	+			X			X		
1819	do	0	+						X		
1858	do	0	+			X			X		X
1861	do	+0				X					X
1863	do	+	0			X					X
1895	do	+0				X			X		
1686	Shell sand	0		+		X					
1692	do	0		+		X					X
1695	do	0	+			X			X		
1740	do	+	0					X		X	
1794	do	0	+			X					
1849	do	+0					X				X
1746	Globigerina sand and ooze		+0						X	X	
1773	do	+	0			X					
1798	do		+0						X		
1810	do		+0			X					
1825	do		+0						X		
1834	do	+0				X			X		
1837	do	0	+			X					X
1840	do		+0			X					
1852	do	0	+				X		X		X
1869	do	0	+			X			X		
1884	do	+0				X			X		

[1] No color change in samples 1677, 1791, 1875, 1887, 1890 of quartz sand; in samples 1713, 1782, 1785, 1813, 1846 of shell sand; and in samples 1725, 1728, 1734 of *globigerina* sand and ooze.

In checking the degree of color change that takes place with time, three categories of relative change, defined as slight, medium, and gross change, have been established. (See the third, fourth, and fifth columns in table 2.) These are defined as follows (all digit changes refer to the Munsell letter-number code):

1. Slight change:
   (a) a 1-digit change in value, or
   (b) a 2-digit change in chroma, or
   (c) a 2.5-digit change in hue.
2. Medium change:
   (a) a 1-digit change in value plus a 2-digit change in chroma, or
   (b) a 2-digit change in value, or
   (c) a 4-digit change in chroma, or
   (d) a 5-digit change in hue, or
   (e) a 2.5-digit change in hue plus a 1-digit change in value or 2-digit change in chroma.
3. Gross change:
   (a) a >2-digit change in value, or
   (b) a >4-digit change in chroma, or
   (c) a >5-digit change in hue, or
   (d) a >2.5-digit change in hue plus a more than 2-digit change in value or more than 2-digit change in chroma.

All the changes observed fell into one of the 12 categories outlined above. More specific observations concerning hue (a sample becomes more yellow red, or more yellow, or more yellow green), value (a sample either becomes lighter or darker), and chroma (a sample becomes either grayer or more vivid) are also listed in table 2.

Most sediments changed color rapidly after they were collected, and the greatest change generally took place almost immediately. The most consistent change in color was that of hue: most samples became more yellow (generally, a hue of 5*Y*) regardless of sediment type. Almost all sediments showed some change in value, and most became somewhat darker with time. Of the few samples that showed a change in chroma, two out of three became more vivid, and the third became grayer.

As would be expected, the most pronounced color changes took place in mud and fine-grained sediment. Mud stored in ice cream cartons showed a remarkably rapid change shortly after recovery: the samples became lighter along the edges of the carton, and the inner part became darker (fig. 2*A*). This was the result of both oxidation and reduction of the pigment within the same sample. A similar change was also observed, but to a lesser degree, in shell and quartz sand (fig. 2*C*). After a 12-hour period, an exposed sample had changed further in color: the edges had become darker and the core had become lighter, so that a uniform shade resulted. (Compare figs. 2*A* and 2*B*.) In 1954, van Andel and Postma observed the same phenomenon in samples collected in the Gulf of Paria and postulated that the color of some fine-grained sediment is formed by a mixture of green and black pigment. The black is rapidly affected by oxidation after sampling and disappears irreversibly, whereas the green is permanent.

As most of the samples were already dry or partially dry by the time they were examined, colors observed were probably slightly more yellow than the original hues. Each of the nine major color groupings includes a broad range of color shades (table 1), however, so that even if fresh colors had been recorded, the contours on the final color map would remain virtually the same. It is recommended, nevertheless, that in any sediment-sampling program of this type, colors should be recorded immediately on shipboard.

REGIONAL COLOR DISTRIBUTION

The continental margin between Nova Scotia and southern Florida can be divided into six geographic areas (fig. 3) for the purpose of a brief regional description and evaluation of the color distribution. These six areas are (fig. 3):

1. Continental shelf east and north of Cape Cod, including the Gulf of Maine, Georges Bank, Bay of Fundy, and western Scotian Shelf.
2. Continental shelf from Cape Cod to Cape Hatteras.
3. Continental shelf between Cape Hatteras and Jacksonville, Fla.
4. Continental shelf between Jacksonville and Key West, Fla.
5. Continental slope and rise from Nova Scotia to Cape Hatteras.
6. Blake Plateau and Straits of Florida.

The principal color patterns in each of these areas are shown on plate 1.

CONTINENTAL SHELF

EAST AND NORTH OF CAPE COD

Three major color belts are present on this segment of the continental shelf (area 1, fig. 3). These include a zone of dusky-yellowish-brown sediment approximately 150 kilometers wide extending north and northeast from Cape Cod and covering the northwestern two-thirds of the Gulf of Maine. South of this color band lies a belt of greenish-black sediment about 50–60 kilometers wide that extends from east of Cape Cod to Northeast Channel. It also covers most of the west half of the Scotian Shelf. The brown and green belts are fairly uniform in width and extent. A third belt, 75–150 kilometers wide, is more patchy in coverage than the

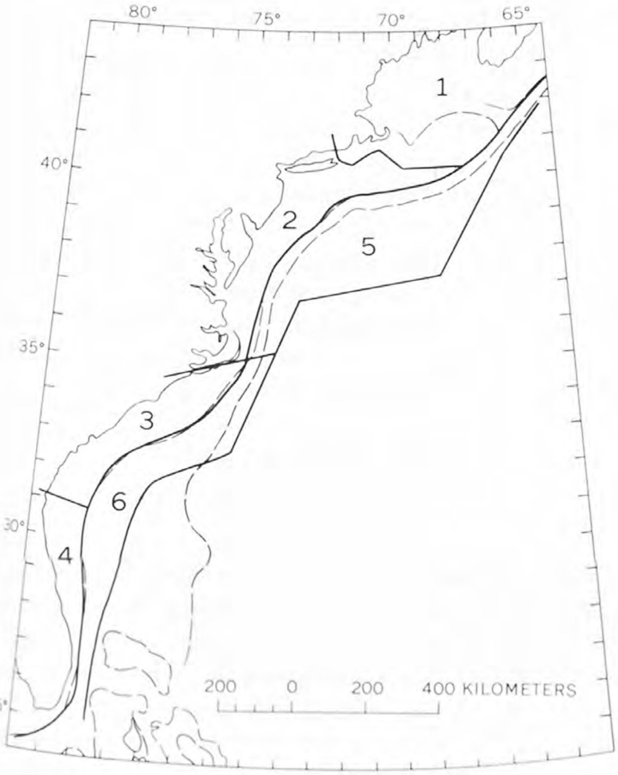

FIGURE 3.—The six geographic areas of the Atlantic continental margin discussed in the text. Dashed lines indicate shelf break and base of slope.

green and brown areas. It is made up of yellow-ochre and dusky-yellow sediment and extends from Cape Cod southeast to the shelf break on Georges Bank and then northeast to Northeast Channel and Browns Bank. Small patches of pale-olive and light-olive sediment lie within the area of yellow-ochre and dark-green sediment, particularly on Georges Bank. The yellow-ochre and dusky-yellow belt conforms closely with the boundaries of Georges Bank and Nantucket Shoals.

Minor color belts include the light-brown sediment east of the St. John River in the Bay of Fundy (Forgeron, 1962) and in the Minas Basin (at the head of the Bay of Fundy, just off the area covered by the maps in figure 3 and on plate 1); and the greenish-black sediment on the inner shelf and in bays of the dissected coastline.

CAPE COD TO CAPE HATTERAS

Colors are distributed fairly irregularly on the shelf from Cape Cod to Cape Hatteras (area 2, fig. 3). Two distinct bands dominate the shelf between New Jersey and Georges Bank. A band of yellow-ochre and dusky-yellow sediment, locally as wide as 125 kilometers, lies on the inner shelf; a triangular zone of greenish-black sediment, having a maximum width of 125 kilometers, covers the outer shelf and upper slope. This is a reversal of the color sequence on the shelf northeast of Cape Cod. Together, these two belts are generally less than 185 kilometers wide. South of New Jersey, three colors abound in irregular or linear patches: yellow ochre, greenish black, and pale olive to grayish olive.

Sediments in Buzzards Bay, Narragansett Bay, Long Island Sound, Delaware Bay, Chesapeake Bay, and Pamlico Sound are arranged in irregular areas of greenish black, greenish gray, and pale olive to grayish olive. Only Albemarle Sound north of Cape Hatteras contains dusky-yellowish-brown and yellow-ochre sediment. Most of the beach samples in this stretch of coast are light colored or yellow.

CAPE HATTERAS TO JACKSONVILLE

Pale-olive to grayish-olive colors dominate the shelf between Cape Hatteras and Jacksonville, Fla. (area 3, fig. 3). Light-colored sediment predominates, and dark-brown and dark-green colors are almost absent. Other colors besides the pale-olive and grayish-olive shades on this part of the shelf are restricted to small isolated patches, many of them limited to individual stations. Many of the near-shore and beach samples are yellow or brown.

JACKSONVILLE TO KEY WEST

As in the area to the north, pale-olive to grayish-olive sediment dominates and dark colors are virtually absent in the southernmost shelf area between Jacksonville and Key West, Fla. (area 4, fig. 3). However, the overall color distribution here tends to be more uniform than in the area to the north, and larger areas of greenish-gray sediment trend normal or subnormal to the coast. Most near-shore and beach sediment is yellow or light colored.

CONTINENTAL SLOPE AND RISE FROM NOVA SCOTIA TO CAPE HATTERAS

Pale-olive to grayish-olive colors in a fairly uniform band about 100 kilometers wide dominate the continental slope and upper continental rise between Cape Hatteras and Northeast Channel (area 5, fig. 3). The upper slope south of Long Island and Cape Cod is covered by greenish-black sediment. Much of the greenish-black sediment lying at water depths greater than 200 meters on the upper slope is in tongue-shape patches and is related to depressions on the slope, including canyons and submarine valleys. A band of pale yellowish brown and another of dusky yellowish brown lie respectively farther down the continental rise and away from shore. Notice that the band of dusky-yellowish-brown sediment is found at progressively shallower depths as one approaches the southern Scotian Shelf (from about 3,000 meters south of Long Island to about 200 meters off Nova Scotia). A tongue of yellow-ochre sediment occurs downslope from the Northeast Channel. An isolated patch of yellowish sediment is found just south of Mytilus Seamount at a depth of 3,975 meters.

BLAKE PLATEAU AND STRAITS OF FLORIDA

Light colors predominate in the area beyond the shelf break south of Cape Hatteras which includes the Blake Plateau, the Florida-Hatteras Slope, and the Straits of Florida (area 6, fig. 3). Pale-olive to grayish-olive sediment covers most of the northwest Blake Plateau south of Cape Hatteras and most of the Florida-Hatteras Slope. Dark-brown and green shades are virtually absent. Particularly noteworthy are the patches of yellow sediment that are alined roughly along the shelf break between Jacksonville and Cape Hatteras. Yellowish sediment lies on the inner edge of the Blake Plateau between Jacksonville and Charleston. Pale-yellowish-brown sediment trends parallel to the coast and to the Florida-Hatteras Slope from Jacksonville to the Straits of Florida. This band of pale yellowish-brown approaches the coast in the vicinity of Miami, where the shallow shelf narrows. An arcuate belt of dusky-yellow sediment parallels the Florida Keys.

RELATIONS OF COLOR TO ENVIRONMENT AND PROPERTIES OF SEDIMENTS

FACTORS INFLUENCING SEDIMENT COLOR

Sediment color is dependent upon many factors, many of which were summarized by Kennard and Howell (1941), Sverdrup, Johnson, and Fleming (1942, p. 967–969), Krynine (1948), Twenhofel (1950, p. 634–641), Grim (1951), Keller (1953), Weller (1960, p. 129–140). The more important factors include:

1. Intrinsic colors of the minerals or rock fragments of which a sample is composed.
2. Secondary effects of rock destruction, climatic conditions, and patterns of sediment transportation on the intrinsic colors of the mineral and rock fragments.
3. Size of sediment particles and the closeness of their packing.
4. Conditions at the site of deposition, including the amount and kind of organic matter present and the degree of oxidation or reduction of pigment at and just below the sediment-water interface.
5. Degree of hydration of iron compounds and the state of iron in clay minerals.
6. Diagenesis during and following deposition of sediments.
7. More superficially, the conditions under which the sample is examined, including index of refraction of the surrounding medium, polarization, diffraction, and scattering.

Although the relative importance of these factors cannot be evaluated completely, we can consider the relations of color to the controlling factors for which we have some data: physiography, texture, and composition. In the sections that follow, it is shown that some of these factors are indeed important and that the dominant factors vary from area to area. Relations will be described sequentially in the six geographic areas outlined on page D6 and illustrated in figure 3. These relations are summarized in table 3.

CONTINENTAL SHELF

EAST AND NORTH OF CAPE COD

Physiography

Although the color distribution seems to be restricted in geographic belts, it does not seem to be related to the marked topographic irregularities in the floor of the Gulf of Maine. Brown sediment indiscriminately covers a region of banks, ridges, and broad basins. The narrower, dark-green zone that lies southeast of the dark-brown band covers swells as well as deep basins. The yellowish sediment extends eastward from Cape Cod across Georges Bank and the outer part of the Northeast Channel to Browns Bank. Unlike the green and brown sands in the inner gulf, the yellow sediments are largely restricted to depths less than 100 meters. On their east margin, at the outer edge of the continental shelf, the yellow sediments are roughly delimited by the 200-meter contour.

Texture

Color is not clearly related to the texture of sediment in this part of the shelf. The complex textural variability does not match the relatively more simple color distribution in the central and northern Gulf of Maine. Sediments at depths greater than 200 meters in this region consist primarily of silty sand, sandy silt, silt, and clayey silt. Sediments in the topographic highs are coarser than those in basins (Uchupi, 1963; Stanley and Cok, 1968; J. S. Schlee, unpub. data). Textural patterns on Georges Bank and Brown Bank are somewhat less complex than those in the Gulf of Maine; the sediments consist primarily of sand, gravel, sandy gravel, and gravelly sand. The color pattern, however, is more complex than the textural pattern and consists of patches of dusky-yellow and olive sediment within a discontinuous yellow band.

Composition

As shown in table 3, the color of the sediments in this area correlates strongly with organic matter, iron stain,

TABLE 3.—*Relations of color to physiography, sediment texture, and sediment composition on the Atlantic continental margin*

[C=correlation; SC=strong correlation; (L)=of only local importance; ND=no data. Dash leaders signify no correlation]

Area	Color	Physiography			Texture	Positive correlations													
						Sand-fraction components								Clay-fraction components			Other components		
		Depth	Distance from shore	Relief		Quartz and feldspar	Rock fragments	Dark minerals	Glauconite	Mica	Shells and $CaCO_3$	Foraminifera	Pteropods	Layered silicates	Quartz	Feldspar-quartz ratio	Iron stain	Organic matter	Pyrite
1. Shelf east and north of Cape Cod.	Light brown	C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	SC	--	--
	Dark brown	--	C	--	--	--	--	C	--	--	--	--	--	SC	--	C	--	SC	C
	Yellow	SC	C	--	C	SC	--	--	--	--	C(L)	--	--	--	SC	--	SC	--	--
	Dark green	--	C	--	--	--	C	--	--	C	--	--	--	SC	--	C	--	SC	C
2. Shelf from Cape Cod to Cape Hatteras.	Yellow	--	C	--	C	--	--	--	--	--	--	--	--	--	SC	--	SC	--	--
	Olive	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Gray	--	C	--	--	--	--	--	--	C	--	--	--	--	--	--	--	--	--
	Dark green	--	C	C	C	--	--	--	SC	--	--	C	--	--	--	SC	--	SC	C
3. Shelf from Cape Hatteras to Jacksonville.	Yellow	--	C(L)	--	SC	ND	ND	ND	--	ND	C	--	--	ND	ND	ND	SC	ND	--
	Olive	--	--	--	C	ND	ND	ND	--	ND	SC	SC	--	ND	ND	ND	--	ND	--
	Green	--	--	--	--	ND	ND	ND	C	ND	SC	SC	--	ND	ND	ND	--	ND	--
4. Shelf from Jacksonville to Key West.	Yellow	--	SC (L)	--	--	ND	ND	ND	--	ND	--	--	--	ND	ND	ND	--	ND	--
	Olive	--	--	--	--	ND	ND	ND	--	ND	SC	SC	--	ND	ND	ND	--	ND	--
	Gray	--	--	--	SC	ND	ND	ND	--	ND	SC	SC	--	ND	ND	ND	--	ND	--
5. Slope from Nova Scotia to Cape Hatteras.	Dark brown	SC	C	--	C	--	--	--	--	--	C	C	C	ND	ND	ND	SC	--	--
	Yellow	--	--	C	C	SC	C	--	--	--	C	--	C(L)	ND	ND	ND	--	--	--
	Olive	SC	C	--	C	--	--	SC	--	C	SC	SC	C	ND	ND	ND	--	SC	--
	Gray	SC	C	--	C	--	--	--	--	--	SC	SC	C	ND	ND	ND	--	--	--
	Dark green	--	--	C	--	--	--	--	SC	--	C	C	C	ND	ND	ND	--	--	--
6. Blake Plateau and Straits of Florida.	Yellow	--	--	C	--	ND	ND	ND	SC	--	--	--	--	ND	ND	ND	SC	--	--
	Olive	C	C	--	C	ND	ND	ND	--	--	SC	SC	SC	ND	ND	ND	--	--	--
	Gray	C	C	--	C	ND	ND	ND	--	--	SC	SC	SC	ND	ND	ND	--	--	--

the mineralogy of the clay fraction, and the proportions of quartz and feldspar in the sand fraction. Organic carbon makes up only 0.2–1.0 percent of the yellow sediments, whereas it makes up 1–4 percent of the dark-brown sediments in the inner Gulf of Maine (Hathaway and others, 1965). The proportions of layered silicates in the clay-size fractions are: Less than 20 percent in the yellow sediment on Cape Cod, Georges Bank, and Brown Bank; 10–40 percent in the dark-green sediment; and 30–100 percent in the dark-brown sediment (J. C. Hathaway, P. F. McFarlin, and A. R. Tagg, unpub. data). The quartz content in the clay-size fraction is greater than 70 percent in the yellow sediment, 50–70 percent in the green sediment, and less than 50 percent in the dark-brown sediment. The yellow color of the sands of Georges Bank is associated with greater proportions of quartz and feldspar.

The color also correlates noticeably, but less strongly, with the rock fragments, dark minerals, and mica in the sand fraction and with the ratio of feldspar to quartz in the clay fraction. The dark-green sediment in the area just north and west of Georges Bank contains more rock fragments than the brown sediments of the central and northern Gulf of Maine. The yellowish sediment of Northeast Channel and Browns Bank also contains a large proportion of rock fragments. The dark-brown sediment contains the largest proportion of dark minerals in the sand fraction, the dark-green sediment contains a smaller proportion, and the yellow sediment contains the smallest proportion. Yellow sediment of Georges Bank contains little or no mica; dark-brown and dark-green sediment, especially that in the coastal and nearshore areas, contains slightly more mica than the yellow sediment. In the clay-size fractions of the yellow sediment on Georges Bank, the ratio of feldspar to quartz is less than 0.2, whereas in the dark-green and brown sediment in the Gulf of Maine the ratio ranges from about 0.2 to 1.0. On the Scotian Shelf, however, the feldspar-quartz ratio in the yellow sediment is greater than that in the yellow sediment on Georges Bank.

CAPE COD TO CAPE HATTERAS

Physiography

Color distribution is apparently not related to topographic irregularities on the shelf south and west of Cape Cod and Georges Bank. The interdigitation of yellow and dark-green sediments in the area southeast of Long Island may be a function of topographic irregularities such as the Hudson Channel. The large linear patches of greenish-black and ochre-yellow sediment that trend northeast-southwest off the Delaware and Virginia coast do not seem to be restricted to topographic irregularities. Dark-green sediment on the outer shelf extends beyond the shelf break onto the upper slope (down to 2,000 meters in some areas). The tongue-shaped distribution is apparently related to canyons and submarine valleys on the slope, such as the Hudson, Baltimore, Washington, and Norfolk Canyons.

Texture

Little direct relation can be observed between color pattern and texture on the shelf between Marthas Vineyard and Cape Hatteras. Color is distributed much more patchily than grain size, which tends to be uniformly sandy and gravelly on a large part of this shelf (Uchupi, 1963; J. S. Schlee, unpub. data). The dark-green sediment on the outer shelf covers a much larger triangular area than the triangular area of silty sand, sandy silt, and silt lying at depths of 59–135 meters south of Marthas Vineyard. Neither texture nor topography can be correlated with interdigitation areas of yellow and dark-green sediment south of New England to New Jersey or with large dark-green bands off Delaware and Virginia.

Composition

North and east of Hudson Canyon, color correlates noticeably with glauconite in the sand fraction, with total quartz and the ratio of feldspar to quartz in the clay fraction, and with the organic content. The sand fractions of dark-green sediment near Sandy Hook and Hudson Canyon contain large proportions of glauconite. The clay-size fractions of the dark-green sediment in the triangular area southeast of Long Island contain less quartz and a smaller proportion of feldspar to quartz than do the clay fractions of the yellow sediment closer to shore. The green sediment in the triangular area and in Long Island Sound contains more organic carbon (more than 0.2 percent) than the yellow sediment (less than 0.2 percent).

The color seems to be related also to the Foraminifera and mica contents in the sand fraction. The dark-green sediment contains slightly more Foraminifera than the yellowish sediment. The greenish-gray color of the silt in the center of Long Island Sound may be related to the abundance of mica in the sand fraction.

Between Hudson Canyon and Cape Hatteras, compositional data were insufficient at the time of writing (1965) to relate composition to the color of the sediments.

CAPE HATTERAS TO JACKSONVILLE

Physiography

Although numerous small isolated patches of light-colored sediments are present south of Cape Hatteras, they do not seem to be related to depth, distance from shore, or topographic irregularities.

Texture

No direct relation has been observed between the color pattern and the areal distribution of mean grain size of the total samples (Gorsline, 1963; Pilkey, 1964). The size distribution of a specific component, the carbonate fraction, however, does seem to be related to color. The patches of yellow colors in the Cape Fear–Cape Romain area of the shelf occur in areas where the carbonate fraction tends to be of the coarse sand and gravel size (Pilkey, 1964, fig. 3).

Composition

In the area south of Cape Hatteras, color is undoubtedly more closely related to the mineral composition than to other characteristics of the shelf sediments. The deposits in this area are principally mixtures of terrigenous matter and shell fragments in various proportions and contain minor amounts of authigenic phosphorite and glauconite. Most of the olive sediment that dominates this section of the shelf contains approximately 25 percent calcium carbonate. The yellow color, as mentioned in the previous paragraph, is more closely related to the carbonate fraction and shell material than to the inorganic terrigenous fraction. Locally isolated zones of dark-green sediment can also be related to locally glauconite-rich sediment. Color does not correlate with phosphorite (which is locally abundant on this part of the shelf), with percent total iron, or with carbon (Pilkey, 1964).

JACKSONVILLE TO KEY WEST

Physiography

Except for yellow beach and near-shore sediment, no direct relation exists between color patterns and depth, distance from shore, or topographic irregularities on the shelf between Jacksonville and Miami.

Texture

Much of the shelf south of Jacksonville is floored with sandsize material (Pilkey, 1964, fig. 3); no relation is apparent between color and textural patterns. The large patch of greenish-gray sediment on the inner half of south of Jacksonville may, however, be related to the presence of medium- and fine-grained sands.

Composition

The dominant olive-colored sand on this part of the shelf contains 25–75 percent calcium carbonate in the sand fraction. Although color is most likely related to shell matter and calcium carbonate, color patterns are difficult to correlate with specific carbonate components such as bryozoans, algae, coral, or Foraminifera. Color cannot be correlated with patterns of percent of total iron, phosphorus, glauconite, or organic carbon.

CONTINENTAL SLOPE AND RISE FROM NOVA SCOTIA TO CAPE HATTERAS

Physiography

Sediment color on the continental slope between Nova Scotia and Cape Hatteras is distributed in bands roughly parallel to the slope. The pale-olive to grayish-olive band dominant on the shelf south of Cape Hatteras and on the inner edge of the Blake Plateau can be traced northeast on the slope as far as Northeast Channel. North of Cape Hatteras, this color band is dominant on the continental slope and extends onto the continental rise to depths as great as 3,500 meters. At depths of 3,000 to 4,000 meters, a band of pale-yellowish-brown sediment lies southeast of olive sediment. A third band, or dark-brown sediment, lies on the rise to the southeast at depths exceeding 4,000 meters southeast of New York. Its upper limit becomes progressively shallower as one approaches the Scotian Shelf. As it rises up the slope toward the northeast, the layer of dark-brown sediment truncates both pale-yellowish-brown and olive sediment in an area just south of Northeast Channel.

Tonguelike extensions of shelf sediment seem to lie beyond the shelf break on much of the slope. One of these tongues is at the mouth of Northeast Channel, where yellow sediment extends to a depth of almost 2,000 meters. The tongues are particularly common near large submarine canyons and valleys between Georges Bank and Cape Hatteras.

Texture

Sediments on the continental slope between Nova Scotia and Cape Hatteras are composed largely of silty sand, sandy silt, silt, clayey, silt, and clay. The grain size of these sediments tends to decrease away from the shelf break. The color distribution is apparently independent of textural variations. Small isolated pods of color may be the result of downslope mass-gravity movement. Color and textural and mineralogical anomalies of the sample collected southwest of Mytilus Seamount may be related to the higher rates of sedimentation in the vicinity. Color is apparently more closely related to depth and distance from shore than to texture.

Composition

The colors are generally related to the abundance of dark minerals, mica, and Foraminifera in the sand fraction and to the organic matter and iron stain in the sediments. The olive sediment of the slope and rise contains more sand-size dark minerals, more mica, and generally more Foraminifera remains than the gray and brown silty clays farther offshore. The olive sediment also contains more organic carbon (0.5–1.0 percent) than the brown clay (less than 0.5 percent).

The transition from olive to brown shades has long been noted in deep-sea sediment and is thought to represent an oxidation of the iron in the sediment, and this oxidation is related to the slow deposition and the scarcity of decomposable organic matter at depth (Sverdrup and others, 1942, p. 969). The sequence of linear olive and brown belts subparallel to the slope and rise in this area would tend to support this conclusion.

Locally, the colors are related to constituents of the sand fraction. The yellow sediment near Mytilus Seamount and in the protrusion seaward of Northeast Channel contains generally larger proportions of rock fragments, quartz, feldspar, and shell fragments than the darker sediments contain. The dark-green sediment near submarine canyons on the slope and the olive sediment contain more glauconite than the brown sediment.

BLAKE PLATEAU AND STRAITS OF FLORIDA

Physiography

Color seems to correlate with depth in this area. Olive sediment extends east of the Florida-Hatteras Slope across the northeastern tip of the crest of Blake Ridge at a depth of 2,000 meters. On the south half of the Florida-Hatteras Slope, olive sediment extends to depths of 600 or 700 meters. East of this olive sediment on the Blake Plateau lies a linear belt of pale-yellowish-brown deposits, which are found at least as deep as 800 meters. Linear belts of yellow sediment parallel the shelf break on Pourtales Terrace and in the large depression east of Miami Terrace in the Straits of Florida.

Texture

No direct relation can be established between the north-south color trends and the areal textural variations.

Composition

Much of the olive sediment on the Florida-Hatteras Slope and Blake Plateau consists of Foraminifera- and pteropod-rich sand and ooze. Color is related, probably in large part, to the organic fractions. The yellow pattern coincides with, and may be related to, a zone of sediment rich in total iron, potassium oxide, and glauconite south of Cape Fear (Gorsline, 1963). No relation can be found between percent organic carbon and color.

COMPARISON WITH SEDIMENT IN OTHER AREAS

The most obvious similarities between the Atlantic margin and other continental margins whose sediment colors have been studied are as follows: (1) The range of colors observed in this study is within the range observed in other shelf and slope areas; (2) most sediments have a thin upper lighter colored surface layer whose colors are generally yellowish brown or light olive (fig. 2*D*); (3) major trends tend to be oriented parallel or subparallel to the coast, and distinct smaller scale trends are oriented normal or subnormal to the coast; (4) dark colors, such as dark green or black, are found in submarine canyons; (5) a transition from green to light neutral and gray to reddish-brown shades takes place with increasing distance and depth beyond the shelf break; (6) pale olive, grayish-olive, pale-yellowish-brown, and yellowish-gray sediment beyond the shelf break are related mainly to the abundance of planktonic Foraminifera and pteropod tests.

The dominant colors on the shelf south of the Virginia coast, on the northeastern tip of the Blake Plateau, and on the continental slope as far north as Northeast Channel include pale-olive and grayish-olive shades, which are probably the most common colors on other continental margins. Other areas showing similar sediment colors include the middle and outer shelf off western Guiana (Nota, 1958), the East China and South China Seas (Niino and Emery, 1961), restricted parts of the Gulf of Paria (van Andel and Postma, 1954), the Gulf of Thailand (Emery and Niino, 1963), and the basin slopes and floors of the continental borderland off southern California (Emery, 1960).

The gray shades that dominate many of the continental shelves and slopes in other areas—such as in the inner and middle shelf off western Guiana (Nota, 1958), most of the Gulf of Paria (van Andel and Postma, 1954), and Gulf of St. Lawrence (Nota and Loring, 1964) the Gulf of California (van Andel, 1964), and the Barents Sea (Klenova, 1960, fig. 71)—are, however, fairly unimportant on the Atlantic continental margin of the United States. Only a few areas of greenish-gray, light-olive-gray, and dark-olive-gray sediment are concentrated on the shelf between Jacksonville and Cape Kennedy and in the Straits of Florida off the Florida Keys.

The large areas of dark-brown sediment in the Gulf of Maine and in the Bay of Fundy have few counterparts in other areas. One such example is the linear belt of yellow-brown sediment in the Gulf of Thailand (Emery and Niino, 1963). The light-brown color found in the Bay of Fundy and Minas Basin has also been recorded off China from the Gulf of Pohai to Taiwan and in a small area near Indochina in the Gulf of Tonkin (Niino and Emery, 1961).

The effects of Pleistocene glaciation and sedimentation during lower stands of sea level have resulted in a complex color assemblage, particularly north of Cape Hatteras, which commonly has not been described in other areas. Differences between the Atlantic coast and other areas are probably due, in part, to the more extensive sampling program off the Atlantic coast that has resulted in more intricate contouring patterns and in a greater diversity of colors than noted elsewhere.

DISCUSSION

SEDIMENT OF THE CONTINENTAL SHELF

Anomalies between color and present conditions on the shelf are due to the fact that much of the sedimentary cover is relict (pre-Holocene) and that modern processes of sedimentation have not completely masked or have only partially altered the older sedimentary cover. The distribution of sediment transported by fluviatile and glacial processes on the shelf is shown on plate 1. North of the Gulf of Maine, former fluviatile and glacial (relict) processes are largely responsible for the sediments on the shelf. Glaciation is probably the largest single cause of differences in coloration between the Gulf of Maine and the rest of the shelf from Georges Bank to Cape Hatteras. Sediment color south of Cape Hatteras, for the most part pale olive to grayish olive, is influenced to a much higher degree by the calcareous fraction, including skeletons of macro- and microorganisms, than by glaciation. This calcareous fraction becomes even more important on the shelf south of Jacksonville, Fla.

The green color that dominates much of the shelf does not necessarily represent the intermediate stages of oxidation or reduction of discrete iron minerals in the sediment, as has often been proposed. The green coloration is more likely due to the abundance of ferric iron in some of the clay minerals that coat grains or that make up the bulk of the samples (Keller, 1953).

Dark-brown sediment in the central Gulf of Maine may have originated as the fine fraction in brown and reddish-brown Pleistocene till sheets on the middle and outer shelf. Reworking of this till during and following the Holocene rise of sea level has resulted in the winnowing and transfer of fine sediment into this central area. The light-brown to reddish-brown sand and mud of the Bay of Fundy and Minas Basin are strongly influenced by the source material which includes red Paleozoic and Triassic rocks and red Pleistocene sediments as well. The unusually high tidal ranges and rapid rates of sediment transport, in suspension as well as along the bottom, allow the red color to be maintained and redistributed throughout this area.

Yellow-ochre and dusky-yellow sediment on the shelf is generally associated with an abundance of iron-stained material, often sand and gravel. This staining is an iron oxide coating on grains; much of it was probably produced subaerially when the shelf was exposed during several lower stands of sea level in the Pleistocene. Yellow and brown coarse material on the shallow Georges and Browns Banks represents, in part, lag deposits of former till sheets and eroded Tertiary and Cretaceous formations on the shelf. The fine material, as mentioned above, has been transported during the Holocene rise of sea level toward the central part of the Gulf of Maine.

Small isolated areas of yellow sediment occur in disconnected linear belts on the middle and outer shelf, or along the shelf break, between Jacksonville, Fla., and Cape Hatteras. These may represent remnants of former strandlines—beaches or terraces—formed during low stands of sea level.

SEDIMENT OF THE CONTINENTAL SLOPE, CONTINENTAL RISE, AND BLAKE PLATEAU

The seaward transition on the continental slope and rise from olive and green through light gray and pale yellowish brown to brown and yellow is probably related to the oxidation-reduction potential of the environment, which results from a balance between the rate of deposition and the rate of bacterial decomposition of organic matter deposited with the sediment. Foraminifera and pteropod tests, which make up much of the skeletal fraction, tend to increase in abundance with distance from shore. Clay-size material also tends to increase with depth, so that foraminiferal and pteropod sand and ooze become progressively more abundant beyond the shelf break. As depth increases, conditions are better for organic matter to be decomposed prior to reaching the bottom and for the sediment to be oxidized on the bottom.

Recent studies based on bottom photographs and bottom-current measurements (Swallow and Worthington, 1957; Knauss, 1965; Heezen and others, 1966; Schneider and others, 1967; Stanley and Kelling, 1968) show that currents are active on the continental rise. This, plus the fact that the sediment is tinted brown or reddish-brown, suggests that opportunity is good for oxidation conditions to prevail on the bottom. Although the fine-clay fraction is probably mainly responsible for the color, skeletal tests may also contribute. Chemical analyses of some foraminiferal tests show that iron oxide is present in amounts as high as 1.68 percent (Sverdrup and others, 1942, p. 991).

At somewhat shallow depths on the rise, where the rate of deposition is more rapid than at lower depths, intermediate stages of oxidation and reduction of the pigment may result in a band of neutral colors. Unstained skeletal tests are generally light pale gray, and foraminiferal sands and oozes in this linear belt are commonly pale yellowish brown. Light-olive colors occur on the upper continental rise and on the slope. These colors may be related to reducing conditions but probably are due to the inherent color of clay containing ferric iron (Keller, 1953).

There may be another explanation for the band of brown and reddish-brown sediment found at progressively shallower depths northeastward on the continental rise and slope off Nova Scotia. Recent studies by Heezen and Drake (1964) and by Conolly, Needham, and Heezen (1967) show that red sediments crop out in the slope seaward of the Laurentian Channel. These authors believe that the red deposits are of Pleistocene age and that their red color was inherited from erosion of red Paleozoic and Triassic rocks during the period of glaciation. Silverberg (1965) suggested that red sediment exposed on the upper continental slope off Nova Scotia has been stained by reworked red Pleistocene till that was once exposed on the Scotian Shelf during lower stands of sea level. This till is thought to have been reworked during the late Pleistocene Epoch by the rising sea during the Holocene transgression, much of the material being transferred from the outer shelf down onto the continental slope and rise (Stanley and Cok, 1968). This hypothesis may help explain why the brown sediments apparently rise up the slope off New England and Nova Scotia, an area which also coincides with the southern limit of glaciation.

Sediment sampled in several canyons was dark green or almost black, probably as a result of the reducing environment in these depressions. The few samples collected on the upper slope in the area off Chesapeake Bay had a strong H_2S odor. In such environments, iron oxide is transformed to sulfide in the presence of organic matter and a low Eh.

Tongue-shaped patterns of anomalous colors extending from the shelf break down the slope and isolated patches of color on the slope and rise probably indicate slumping and mass gravity transfer of sediment. Anomalous color patterns may also indicate exposures of relict sediment.

The yellow sediment at the base of the Florida-Hatteras Slope on the Blake Plateau southeast of Charleston, S.C., as far as the latitude of Jacksonville, contains fairly high percentages of total iron, potassium oxide, and glauconite and low percentages of organic carbon (Gorsline, 1963). The enrichment in iron, potassium oxide, and glauconite in this area may be due to a concentration or ponding effect by the Gulf Stream (the main axis of the current passes over this area) as it changes course from north to northeast. A similar enrichment may be responsible for the yellow deep-water sediment off Key West, Miami, and Cape Kennedy in the Straits of Florida.

CONCLUSIONS

The Atlantic shelf between Nova Scotia and Key West, Fla., can be divided into two major areas on the basis of gross color differences, the break between the areas being approximately at Cape Hatteras. North of Cape Hatteras, sediments are dominantly brown, dark green, and yellow. South of Cape Hatteras, sediments are mostly olive, gray, and yellow.

Major belts of color on the shelf are not oriented parallel to the coastline or the shelf break but generally trend subparallel and even transverse to the coast.

Color does not correlate well with either topography or texture on the shelf. There are a few exceptions to this generalization, the most striking being on Georges Bank, where the color patterns follow the bottom morphology. Color patterns correlate locally with compositional properties of the sediment, but the degree of correlation varies from area to area.

Beach samples, regardless of locality, are generally light colored—gray or yellow. They generally display the color of the major constituent, which in most samples in the area north of Florida is quartz. Sediment in bays, sounds, and estuaries is usually dark green (that in many of the bays of the Gulf of Maine is dark brown) and is probably accumulating in areas of fairly abundant organic material and low oxygen concentration.

Unlike those on the shelf, color patterns beyond the shelf break on the continental slope and rise and on the Blake Plateau tend to be alined in belts that trend parallel or subparallel to the shelf break. These trends display a distinct transition with depth—that is, from olive, green, and more neutral colors (light gray and pale yellowish brown) to brown and yellow.

In almost all the environments sampled, the uppermost several millimeters are lighter than the underlying material, probably because the oxygen supply is greater at the surface and the oxidation-reduction potential is not as low as in the underlying sediments.

This study confirms the conclusions made by others that bacterial activity and oxidation processes affect a color after sampling. Color should, therefore, be recorded on board ship immediately after a sample has been collected, and a standard color chart should be used.

Results of this study, when combined with data from detailed geochemical and mineralogical studies presently being conducted as part of the Atlantic Continental Margin Project, will help in interpreting sedimentary conditions active now and in the past on the continental margin between Nova Scotia and the Florida Keys.

REFERENCES CITED

Andel, Tj. H. van, 1964, Recent marine sediments of Gulf of California, *in* Andel, Tj. H. van, and Shor, G. G., eds., Marine geology of the Gulf of California—A symposium: Am. Assoc. Petroleum Geologists Mem. 3, p. 216–310.

Andel, Tj. H. van, and Postma, Hendrik, 1954, Recent sediments of the Gulf of Paria; reports of the Orinoco shelf expedition, v. 1: Koninkl. Nederlandse Akad. Wetensch. Verh., ser. 1, v. 20, no. 5, 238 p.

Arrhenius, Gustaf [1952?], Sediment cores from the east Pacific: Swedish Deep-Sea Exped. 1947–1948, Repts., v. 5, pt. 1, 227 p.

Conolly, J. R., Needham, H. D., and Heezen, B. C., 1967, Late Pleistocene and Holocene sedimentation in the Laurentian Channel: Jour. Geology v. 75, p. 131–147.

Emery, K. O., 1960, The sea off southern California—A modern habitat of petroleum: New York, John Wiley & Sons, 366 p.

——1965, Joint program of U.S.G.S. and W.H.O.I. for continental shelf and slope, *in* Summary of investigations conducted in 1964: Woods Hole Oceanog. Inst. Reference 65–13, pp. 67–68.

——1966, Atlantic Continental Shelf and Slope of the United States—Geologic background: U.S. Geol. Survey Prof. Paper 529–A, 23 p.

Emery, K. O., and Niino, Hiroshi, 1963, Sediments of the Gulf of Thailand and adjacent continental shelf: Geol. Soc. America Bull., v. 74, p. 541–554.

Forgeron, F. D., 1962, Bay of Fundy bottom sediments: Carleton Univ., M.S. thesis, 117 p.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington Natl. Research Council, 6 p. (repub. by Geol. Soc. America, 1951).

Gorsline, D. S., 1963, Bottom sediments on the Atlantic Shelf and Slope off the southern United States: Jour. Geology, v. 71, p. 422–440.

Grim, R. E., 1951, The depositional environment of red and green shales: Jour. Sed. Petrology, v. 21, p. 226–233.

Hathaway, J. C., ed., 1966, Data file, Continental Margin Program, Atlantic coast of the United States, v. 1, Sample collection data: Woods Hole Oceanog. Inst. Reference, 66–8, 184 p.

Hathaway, J. C., Schlee, J. S., Trumbull, J. V. A., and Hülsemann, Jobst, 1965, Sediments of the Gulf of Maine [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 343–344.

Heezen, B. C., and Drake, C. L., 1964, Grand Banks slump: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 221–225.

Heezen, B. C., Hollister, C. D., Ruddiman, W. F., 1966, Shaping of the continental rise by deep geostrophic contour currents: Science, v. 152, p. 502–508.

Keller, W. D., 1953, Illite and montmorillonite in green sedimentary rocks: Jour. Sed. Petrology, v. 23, p. 3–9.

Kennard, T. G., and Howell, D. H., 1941, Types of coloring in minerals: Am. Mineralogist, v. 26, p. 405–421.

Klenova, M. V., 1960, Geologiya Barentsova Morya: Moscow, Akad. Nauk SSSR, 367 p. (English translation, Geology of the Barents Sea: U.S. Navy Hydrog. Office Translation 130, 1961).

Knauss, J. A., 1965, A technique for measuring deep ocean currents close to the bottom with an unattached current meter, and some preliminary results: Jour. Marine Research, v. 23, p. 237–245.

Krynine, P. D., 1948, The megascopic study and field classification of sedimentary rocks: Jour. Geology, v. 56, no. 2, p. 130–165.

Munsell Color Company, Inc., 1929–1960, Munsell book of color: Baltimore, Md.

Niino, Hiroshi, and Emery, K. O., 1961, Sediments of shallow portion of East China Sea and South China Sea: Geol. Soc. America Bull., v. 72, p. 731–762.

Nota, D. J. G., 1958, Sediments of the western Guiana shelf: Wageningen, Landbouwhogeschool Mededeel., v. 58, no. 2, 98 p.

Nota, D. J. G., and Loring, D. H., 1964, Recent depositional conditions in the St. Lawrence River and Gulf—a reconnaissance survey: Marine Geology, v. 2, p. 198–235.

Pilkey, O. H., 1964, The size distribution and mineralogy of the carbonate fraction of the United States South Atlantic shelf and upper slope sediments: Marine Geology, v. 2, p. 121–136.

Schneider, E. D., Fox, P. J., Hollister, C. D., Needham, H. D., and Heezen, B. C., 1967, Further evidence of contour currents in the Western North Atlantic: Earth and Planetary Sci. Letters, v. 2, p. 351–359.

Silverberg, N., 1965, Reconnaissance of the upper continental slope off Sable Island Bank, Nova Scotia: Dalhousie Univ., M.S. thesis, 79 p.

Stanley, D. J., and Cok, A. E., 1968, Sediment transport by ice on the Nova Scotian Shelf, *in* Ocean sciences and engineering of the Atlantic Shelf: Marine Technology Soc., Fourth Ann. MTS Conf. and Exhibit, 1968, Trans., p. 109–125.

Stanley, D. J., and Kelling, G., 1968, Sedimentation patterns in the Wilmington submarine canyon area, *in* Ocean sciences and engineering of the Atlantic Shelf: Marine Technology Soc., Fourth Ann. MTS Conf. and Exhibit, 1968, Trans., p. 127–142.

Sverdrup, H. U., Johnson, M. W., and Fleming, R. H., 1942, The oceans, their physics, chemistry, and general biology: Englewood Cliffs, N.J., Prentice-Hall, Inc., 1087 p.

Swallow, J. C., and Worthington, L. V., 1957, Measurements of deep currents in the western North Atlantic: Nature, v. 179, p. 1183–1184.

Twenhofel, W. H., 1950, Principles of sedimentation: 2d ed., New York, McGraw-Hill Book Co., 673 p.

Uchupi, Elazar, 1963, Sediments on the continental margin off eastern United States: U.S. Geol. Survey Prof. Paper 475–C, p. C132–C137.

Weller, J. M., 1960, Stratigraphic principles and practice: New York, Harper & Brothers, 725 p.

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