BIOGRAPHICAL SKETCH

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Mr. Mairs was born on March 7, 1943, in Alameda, California. He received the B.A. degree in zoology from the University of California, Santa Barbara, in 1966. He has recently completed requirements for the M.S.E. degree in water resourc engineering at the Catholic University of America, where his interests were remote sensing of estuarine effluents. From 1965 to 1966, he was involved in the development of infrared sensors for the Santa Barbara Research Center. During 1966, he worked as a biological oceanographer conducting field research on the efficacy of anti-fouling paints. He joined the Naval Oceanographic Office in 1967, and his principal areas of work before joining the Spacecraft Oceanography Project were oriented toward the understanding of coastal oceanographic phenomena. His interests are presently directed toward the application of remote sensors to the study of coastal marine processes.

OCEANOGRAPHIC INTERPRETATION OF APOLLO PHOTOGRAPHS

Coastal Oceanographic and Sedimentologic Interpretation of Apollo IX Space Photographs; Carolina's Continental Shelf, U. S. A.

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ABSTRACT

Apollo IX photographs, color band separations, and oceanographic and meteorological data are used in the study of the origin, movement, and dissipation of masses of discolored water on the Carolina's shelf. A model has been developed incorporating jet theory, climatology, currents, surface temperatures, color separations, and other oceanographic data to explain the processes involved in the life cycle of these discolored water masses seen in Apollo photograph AS9-3128.

The "plume-like" patterns of discolored water seen emanating from Ocracoke and Hatteras Inlets are the ebb tide discharges of low density, highly turbid water. Remnant plumes from the previous ebb flow and the boundary between the Gulf Stream and the turbid continental shelf waters are visible further offshore. The photographs show the turbid shelf water being entrained by the Gulf Stream. The intrusion of the Virginia coastal water, which is separated from the Carolina's shelf waters by the Cape Hatteras oceanographic barrier, can be seen to coincide with the $7^{\circ}C$ isotherm.

Water mass variability patterns, shown by color space photographs in conjunction with pertinent historical and environmental data plus a concurrent ground truth collection program, can provide valuable synoptic oceanographic data. Space photography is demonstrated to be a powerful tool for the development of a detailed understanding of the basic patterns of circulation, flushing, and mixing on the continental shelves of the world.

INTRODUCTION

Due to the enormous national investment in space technology over the last few years, the environmental sciences now have a unique global tool: space photography.

Space photographs can produce extremely complete and clear images of the earth's surface, revealing large-scale phenomena and relationships that often cannot be seen from the surface perspective, or at the least are very difficult to grasp from this perspective (Huh, 1969). The intent of this paper is to show that space photographs can be used to detect distinctive water masses, large-scale suspended sediment patterns, and infer coastal and continental shelf processes.

Because ocean water is a complex mixture of solubles, colloids, suspensoids, and biologic matter such as algae, plankton, and seaweed, visible light is absorbed, scattered, and reflected from below the surface in different spectral bands and in varying amounts. These differences create variations in color, brightness, and contrast boundaries on the film. These image variations are the clues by which oceanic masses can be distinguished. If the variable surface water configurations could be detected and plotted regularly, then the resultant charts would provide: (a) a scientific basis for a sampling plan for collection of additional ground truth data, (b) a basis for discriminating between the transient and the more enduring oceanic features, (c) useful data for the surface navigator, and (d) guidance for the fisheries.

The flight of Apollo IX provided several clear, near-vertical color photographs of coastal areas around the world. Of particular interest is the series of photographs taken along the North and South Carolina coasts at various times throughout the mission. Pertinent information concerning some of these photographs can be found in Table 1.

The distribution of turbid waters in one particular photograph, AS9-3128 (Plate 1) illustrates a number of interesting patterns of discolored water that appear to reflect oceanographic conditions on the continental shelf.

Although no ground truth oceanographic data were collected in conjunction with the flight of Apollo IX, meteorological, historical, and oceanographic data are used to interpret the photographs. In addition to these data, photographic color separations of frame 3128 were used in the analysis. Philcò-Ford Corporation (1969) has shown that additional subsurface detail is available from color photography by making color separations in the red, green, and blue regions of the spectrum. A transition in depth penetration is found from red to green to blue. They have found that in the green and blue bands considerable detail is evident in deep waters, whereas the red band yields only near-surface detail.

This paper offers a description and an interpretation of the patterns of discolored water in relation to their origin, movement, and dissipation.

INTERPRETATIONS

"Plume-Like" Patterns of Suspended Sediment

In frame 3128, one of the most prominent features is the plume-like pattern of turbid water (Figure 1) which is pouring out through Ocracoke and Hatteras Inlets, N. C. These plumes of discharged water are sharply delineated from the two other distinctive water masses in contact with the plumes (the dark clear coastal waters and the less turbid water outside the plumes). What are the processes that determine the origin, movement, and dissipation of these plumes?

Climatological data supplied by NOAA show near-normal precipitation for March with moderate rainfall on the 9th, 10th, and 11th in various parts of the state. This would indicate significant runoff was being supplied to Pamlico Sound; however, the waters within the Sound appear to be much more turbid than do the waters of the contributing rivers such as the Pamlico and the Neuse, suggesting a relatively small amount of sediment discharge into the Sound. An examination of the contributing rivers and the Pamlico Sound area in the three color separations (Figures 2A, B, and C) should yield information as to the origin of the suspended sediment. The red separation indicates very little suspended sediment is being carried by the rivers, whereas the Pamlico Sound itself appears to be very turbid. This observation is substantiated by the fact that the amount of fine sediment being carried by the contributing rivers was not large enough to account for the amount that appeared to be flowing out. There must be some other process operating to cause this turbid water. Climatological data for Ocracoke and Hatteras Inlets (Table 2) indicate very consistent northwest winds averaging 6 to 17 mph during the period 9-12 March. These data and the shallowness of Pamlico Sound (less than 15 feet) are strongly suggestive that on 12 March 1969 the turbid waters were being generated in the Sound, dependent on wind-generated shallow water turbulence rather than on heavy rainfall and river discharge.

The tidal origin of the sediment plumes is supported by the fact that the photograph was taken at 1001 EST, which was 4 hours-55 minutes after the predicted ebb current flow began. Slack waters occurred at 0506 and 1154 EST, with the maximum current at 0758 (Table 3). The distribution of the turbid water outside each inlet clearly shows a flow pattern indicative of an ebb-flowing current.

If the plume is of a tidal origin, the horizontal distance it travels as it flows out the inlet could be determined by multiplying the average velocity during the ebb cycle by the duration.

(average velocity) x (duration) = horizontal distance. (1)

Without direct measurements, the simplest method for determining the average current velocity is to assume that the current-velocity curve approximates a sine or cosine curve. On a cosine curve it is known that the ratio of the mean ordinate to the maximum ordinate is $2/\pi$, or 0.637. Therefore, the average current velocity will be the strength of the maximum current multiplied by 0.637.

(0.637) (maximum current) = average current. (2)

Ocracoke Inlet actually has a slightly skewed sine tidal curve (Figure 3); this would not appreciably affect the results, considering the approximations that are made. However, an adjustment must be made to the formula because in this particular instance, the latter low velocity portion of the curve (Figure 3) is not included; from 1001 to 1154 EST. It represents nearly 17 percent of the total area under the curve and covers the currents as they fell from approximately 1.2 knots to 0. Therefore, instead of the area under the curve representing 0.637, a recalculation must be made to take into account the missing portion. Upon measuring the remaining area graphically, one finds that the new ratio of mean ordinate to maximum ordinate is approximately 0.75.

The tidal current table for Ocracoke Inlet (Table 3) shows an average maximum ebb current velocity of 2.1 knots. By applying the approximation Formula 1, the average current velocity should be:

(0.75) (2.1) = 1.6 knots.

Ignoring any interfering effects, a suspended sediment particle that flowed out Ocracoke Inlet at 0506 and was photographed at 1001 should be (from Equation 1):

(2.1 knots) (0.75) (4 hr 55 min) = 7.7 nautical miles outside the inlet.

Measurements from the photograph show the plume extending approximately 6.7 nautical miles out over the shelf.

Here it should be noted that the formula can give only approximate results because the average current is derived through an approximate relationship. More important is the assumption that the suspended particle maintains its velocity throughout its journey, although it undoubtedly does not. Some mixing will obviously take place, and any existing currents will modify its movement. However, a river outflow (in this instance an estuary, but still of hypopycnal nature in the nearshore area) can travel many miles as a plane jet before density differences between river (estuarine) and oceanic water become so small, due to mixing and sinking, that the uniqueness of the outflow is destroyed (Bates, 1953). Typical density, temperature, and salinity profiles from the shelf waters off Ocracoke Inlet (Figure 4) show the hypopycnal nature of the outflow.

Albertson (1950) has found that the velocity of flow along a jet's axis remains practically equal to the speed of issuance up to a point four channel widths away from the orifice. The Ocracoke Inlet plume extends out over the shelf between four and five inlet widths. Once beyond the limit of four channel widths, lateral turbulence predominates. However, it has been found that, in a two-layer system caused by density differences, not only the above phenomena exists but also the density difference tends to buoy up the outflowing fluids. A two-layer system is difficult to destroy because of the marked stability and the inhibition of vertical or downward mixing caused by the density contrast between layers. Because of density differences, (Figure 4) the ebb flow is basically a surface flow out onto the shelf, whereas the flood flow is basically from the underlying waters. The plume that flows out the inlet during ebb flow does not flow back during flood flow. Some reversal of flow undoubtedly takes place near the inlet mouth, but not enough to destroy the symmetry of the outflow. The sediment plume visible in frame 3569 (Plate 2) off Wynyah Bay, S. C., illustrates the stability of the outflow even during a flood flow.

These data indicate that the plumes are formed by an ebb-flowing current of low density, highly turbid water jetting out onto the shelf through a barrier island inlet. They are cyclic in nature, their origin being linked to each ebb flow. With each change of the tidal flow, they lose the characteristics of a jet and become dependent on the existing winds and currents on the shelf.

For the sediment plume off Ocracoke Inlet to maintain its symmetrical shape on 12 March 1969, the winds and currents in the area would either have had to be rather weak or to move in the same direction as the plume. Data provided by NOAA show a steady resultant northwest wind on 12 March 1969 with an average speed of 16 mph. Figure 5 is a vector plot of the resultant winds for a period 1-12 March at the Cape Hatteras Station and Figure 6, Haights data (1942), shows the directions and velocities of the average currents accompanying winds blowing from different points of the compass at Capes Hatteras and Lookout. The vector plot (Figure 5) shows that the winds had been blowing from the NW quadrant for four consecutive days and should, according to the Haight chart (Figure 6), generate a wind-driven current moving in a southeasterly direction. However, the fact that the plume is in the lee of the shoreline would decrease the possibility of a strong current in this area because of such a small fetch. This is in agreement with the position and shape of the plume in the photograph as no particular deformation can be detected.

Haights chart (Figure 6) shows that a northeast wind would yield a southwesterly wind-driven current. The effect of prolonged winds from the northeast, is seen in frame AS9-3276 (Plate 3, March 8) of the North Carolina coastal plain. Here the plumes have been driven down the coast in a southwesterly direction as predicted by Haight (1942).

These two photographs, 3128 and 3276, as well as others, all indicate that these plumes are a tidally induced estuarine discharge and that their pattern of travel, once outside the inlet a sufficient distance to overcome the characteristics of a jet, is controlled by the winds and currents prevailing at the time of their discharge.

Previous Tidal Plumes

In frame AS9-3128, just seaward of the discharge plumes, are sharp sediment boundary lines trailing off from each respective inlet's plume. The lines are aligned to the southeast, and it appears that they are moving in this direction. These sediment lines may represent the remnants of the previous ebb flow discharge plume (Figure 1), because distinct boundaries can still be discerned and the associated waters appear to be more diffuse than the present plume. This should be expected if these features are previous ebb flow plumes as it has been outside the inlet, on the shelf, for a period of from 12 to 17 hours. During this time, differential sinking and turbulent diffusion have undoubtedly taken place causing what seems to be a more dilute turbid water.

An examination of frame 3128 and the three color separations (Figures 2A, B, and C) can make the determination more clear as to whether sinking, mixing, and diffusion have taken place. The red separation (Figure 2A) shows detail only near surface because of the high attenuation coefficient of water in this part of the spectrum. As can be seen in the red separation, the contrast within the present plume is very uniform, suggesting uniformity of composition, and supporting the earlier hypothesis that the plumes flow out of the inlet and maintain their uniqueness for a considerable length of time. The contrast seen along the previous plume line shows a decreasing gradient moving offshore, indicative of sinking. No contrast can be seen further offshore which indicates that the sediments have sunk to a level below that which can be detected in the red band, although they can be seen in the green and blue bands.

Some process or combination of processes must have been operating to cause this sinking. Stefansson and Atkinson (1967) have found that during the winter months, following a period of low air temperature (March 1969 was among the lowest 10 percent of all Marches on record), the temperature-salinity relationships at stations located near the edge of the shelf indicate downwelling of water that has acquired sufficient density by cooling nearshore. The sinking of the turbid water, visible in the three color separations, to a level of density equilibrium below that of the surface, could be explained by the extremely cold temperatures, the steady NW winds, and the relatively large amount of suspended sediment in the water. Typical winter profiles of the density, temperature, and salinity for this area taken between 23-26 February 1966 (Figure 4) show how this sinking process could take place. There is a progression from the shoreline to the Gulf Stream of cold low salinity estuarine water becoming more saline and warmer (more dense), due to mixing, then flowing under the less dense Gulf Stream associated waters. Equal density levels can be seen trending downward along the outer continental shelf.

The slight south-west bending of the plume can be explained by two separate but interacting phenomena: a generally southwest shelf current and Coriolis Force. Drift bottle experiments made in April and August 1962, described by Gray and Cerame-Vivas (1963) showed conclusively a southwest coastal flow from Cape Hatteras. Stefansson and Atkinson (1967) found that their work on surface density distribution suggested a weak southerly coastal current in Raleigh Bay, N. C. This current was found to follow the depth contours very closely throughout the year. In addition to the southerly shelf currents, Coriolis Force will cause the water currents to bend slightly to the right of the wind direction.

The foregoing interpretation and supporting evidence indicates that these boundary lines and associated turbid waters are a tidal discharge plume from the previous ebb flow. Once they lose the characteristics of their jet flow, they are subject to influences of the existing winds and currents on the shelf. They become subjected to wave-induced mixing, sinking, and dilution and thereby lose their symmetry of shape progressively with increasing time offshore.

A suggested model for the origin and dissipation (life cycle) of the suspended sediment plumes for 12 March 1969 is given in Figure 7.

Gulf Stream Boundary

In frame 3128, approximately 20 to 30 miles from Ocracoke Inlet, another boundary line is aligned NE-SW as shown in Figure 1. This line represents the contact line between the sediment-laden shelf waters and the Gulf Stream.

The Gulf Stream System is closer inshore off North Carolina than at any point north of Cape Kennedy. The distance from the coast to the inner edge of the Stream generally is about 22 miles from Cape Lookout, 24 miles from Ocracoke Inlet, and 20 miles from Cape Hatteras (Stefansson and Atkinson, 1967). The axis of the Gulf Stream normally lies over the slope between the 100- and 1,000-fathom depth lines. The boundary line in frame 3128 is measured to be 20 miles off Cape Hatteras and as found on

C&GS Chart 1110, 20 miles off Cape Hatteras coast lies halfway between the 100- and 1,000-fathom lines.

Sea surface temperature data for 18 March (NMFS, 1969), six days after the photo, show the Gulf Stream to be very nearly following the 100-fathom line (Figure 8). These data show the North Wall to be fairly straight, and they do not show any meander in the Gulf Stream as might be interpreted from the photograph. However, upon close examination, the sharp boundary line (representing contact) is only present off Cape Hatteras and Hatteras Inlet. The Gulf Stream is visibly in contact with the shelf waters in this area. Off Ocracoke Inlet and to the south, the change in color and apparent density seems to be much more gradual than off Cape Hatteras and represents a gradual sinking and diffusion within the continental shelf waters, rather than the actual margin of the Gulf Stream.

Due to the oblique angle of the photograph, the measurements reported are not exact, but the results from all the lines of evidence do show a close agreement between historical findings (Stefansson and Atkinson, 1967), sea surface temperature charts (NMFS, 1969), and the measurements of the Gulf Stream boundary made directly from the photograph.

The apparent furrows (Figure 1) in the turbid water, that trend in the direction of Gulf Stream flow, indicate that the contact line is being pulled along by the Gulf Stream, much the same as entrained waters would be pulled along by a jet flow. The contact line is very sharp and indicates that sediment is being carried a considerable distance offshore. This movement offshore is very apparent in Plate 3. In contrast, look at the diffuse, sediment line (Plate 1) off the Hatteras Island coast. Here there is no strong current such as the Gulf Stream, so the sediment sinks differentially as mixing takes place.

Cape Hatteras Oceanographic Barrier

A number of reports mentioned the existence of an oceanographic barrier at Cape Hatteras, separating the northern Virginia coastal waters from the Carolina's shelf waters. The separation of these two water masses is thought to be due to their dissimilarity in temperature and salinity during the winter months. The northern waters are colder, less saline and less dense than the waters on the Carolina shelf. Bumpus (1955) indicated that the shelf waters south of Cape Hatteras did not receive regular intrusions of Virginia coastal waters. Chase (1959) concluded that the extreme changes in temperature and salinity noted at Frying Pan Shoals Lightship was due to the influx of Virginian water which had breached the oceanographic barrier at a time of northeast winds. Bumpus and Pierce (1955) indicated that northeast storms prevalent from November to May often provide sufficient energy to drive northern coastal waters past Cape Hatteras into nearby Raleigh Bay, N. C. Harrison et al (1967) found that the recovery of seabed drifters and drift bottles south of Cape Hatteras depended on northeast winds. Observations taken at the Diamond Shoals Lightship lend further support to the contention of these workers that northeast winds are necessary to accomplish a break in the oceanographic barrier at Cape Hatteras.

It is postulated that this oceanographic barrier (Figure 1) can be seen in photograph 3128 as a sediment boundary line curving around Cape Hatteras. This frame shows an accumulation of turbid water to the east and southeast of Cape Hatteras overlying the Diamond Shoals area. The turbid water seen to the north of the boundary line is interpreted as an intrusion of Virginian coastal water. This low-salinity, low-temperature water mass from the north flows down Cape Hatteras Island coast onto the Diamond Shoals. Here it seems to be diverted from its southerly flow, forming a large pool of turbid water moving to the east. Without northeast winds, this water mass is unable to break the Hatteras oceanographic barrier, and apparently eddies in this area. Sea surface temperature data (Figure 8) for 18 March 1969 show the colder Virginia coastal waters bending around Cape Hatteras onto the Carolina shelf. If the $7^{\circ}C$ isotherm from these data is drawn over the photograph (Figure 9), the area of turbid water and the area of the $7^{\circ}C$ water are in very nearly the same position, indicating a slight intrusion of these waters onto the Carolina shelf. But without the strong northeast winds, these colder waters are unable to penetrate further south onto the shelf and instead must flow in an offshore direction.

CONCLUSIONS

The main objective of this investigation was to develop and evaluate an interpretive procedure for utilizing space photographs to gain a large-scale understanding of the oceanographic and sedimentologic patterns existent on the continental shelves of the world. The results presented in this paper show that space photography can be used as an efficient means for providing the oceanographer with a permanent record of very detailed near-synoptic data on a very large scale.

Space photography coupled with a properly coordinated program utilizing pertinent historical and routine environmental data with a well planned concurrent ground truth collection program can provide information that will lead to an understanding of the basic patterns of circulation, flushing, and mixing on the continental shelves of the world.

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GLOSSARY

1. Color Band Separations - A photographic process by which a Ektachrome color film exposure of wide spectral sensitivity (.4-.7 microns) is split into 3 component spectral bands: blue (.4-.5 microns), green (.5-.6 microns), and red (.6-.7 microns).
2. "Plume-Like" Patterns - Low density, highly turbid water as it flows from an inlet during an ebb current.
3. Remnant Plumes - A plume of low density, highly turbid water formed during the previous ebb current.
4. Oceanographic Barrier - A separation of two water masses due to their dissimilarity in temperature and salinity.

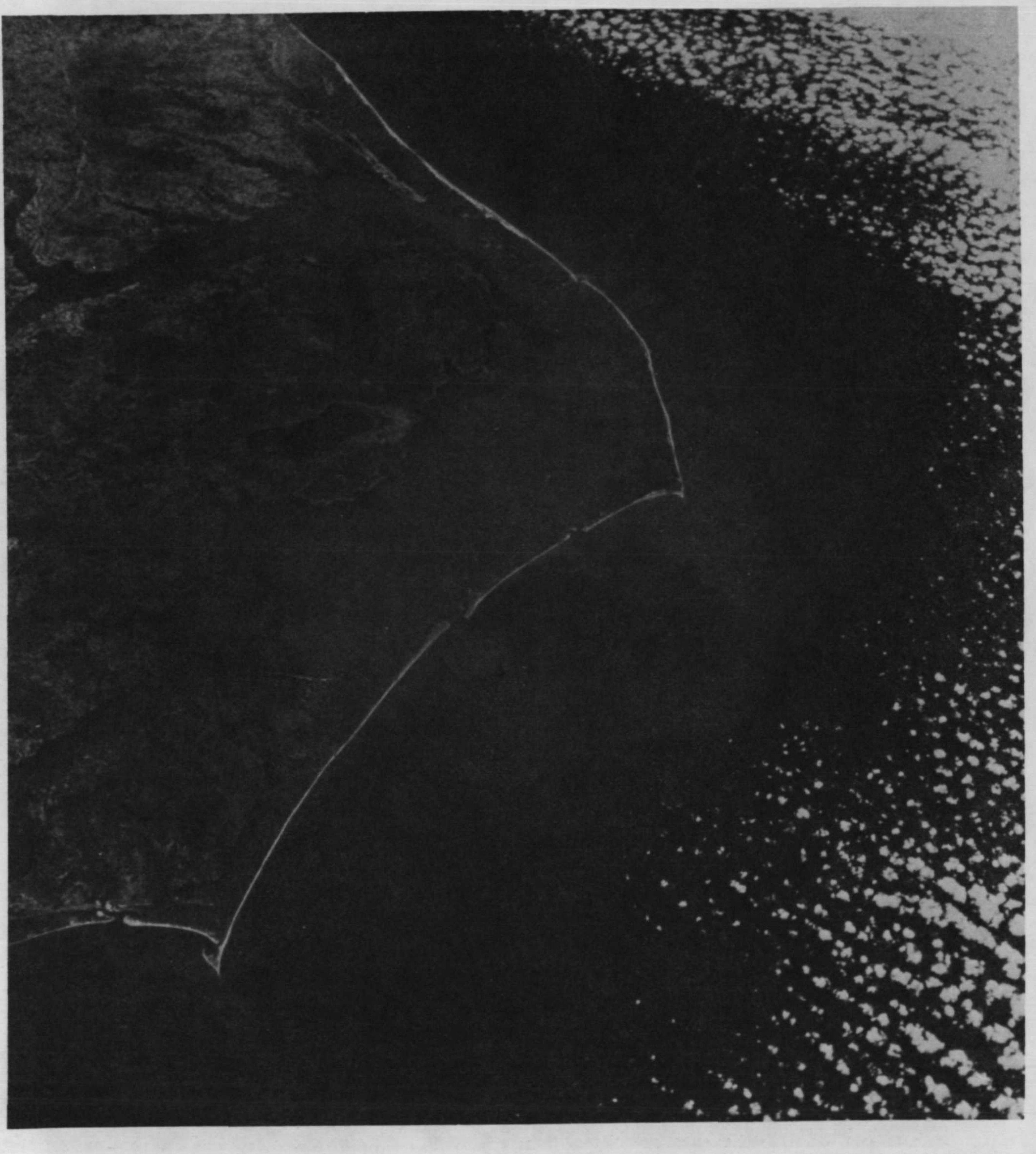

PLATE 1. Apollo IX photograph, AS9-3128, of the North Carolina Coast, taken 12 March 1969, by Astronauts McDivitt, Scott, and Schweickart.

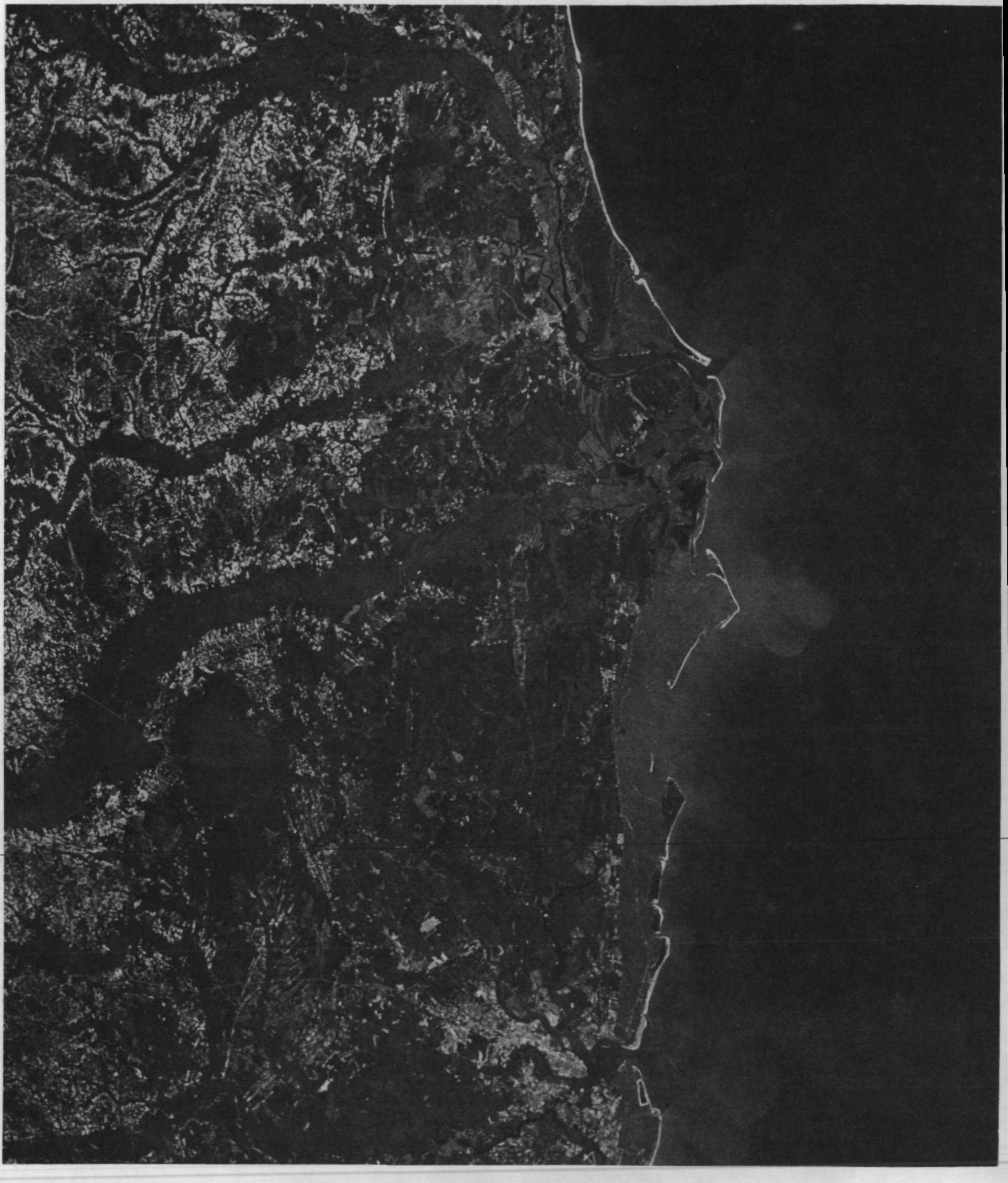

PLATE 2. Enlargement of Apollo IX photograph, AS9-3569, showing Wynyah Bay, S.C., taken 11 March 1969 by Astronauts McDivitt, Scott, and Schweickart.

PLATE 3. Apollo IX photograph, AS9-3276, of the North Carolina Coast taken 8 March 1969 by Astronauts McDivitt, Scott, and Schweickart.

FRAME NO.	DATE	PRINCIPAL POINT				PERCENT OVERLAP	IMAGE EVALUATION	SUN ELEVATION	TIME GMT	ALTITUDE N. MI.	ONC WAC NO.	PERCENT CLOUD COVER	VIEWING MODE	DESCRIPTION
		LATITUDE DEG.	LATITUDE MIN.	LONGITUDE DEG.	LONGITUDE MIN.									
3276	8	35	51N	76	06W	60	Normal	50	1717		G-21	15	Oblique	North Carolina coastal plain, Albermarle Sound, Pamlico Sound.
3568	11	32	48N	80	02W	0	Normal	49	1622	104	G-21	0	Oblique	East coast of United States, St. Helena Sound, Charleston, South Carolina, Santee River
3569	11	33	06N	79	28W	50	Normal	50	1622	104	G-21	0	Oblique	South Carolina, Charleston, Santee River, Garden City
3570	11	35	07N	77	04W	0	Normal	50	1623	103	G-21	30	Oblique	North Carolina, Cape Hatteras, Wilmington, Atlantic Ocean
3127	12	34	35N	76	30W	0	Normal	40	1500	116	G-21	15	Vertical	North Carolina, Cape Lookout, Pamlico Sound
3128	12	35	04N	76	01W	0	Normal	40	1501	116	G-21	30	Oblique	North Carolina, Cape Lookout, Cape Hatteras, Pamlico and Albermarle Sounds

TABLE 1. TIME, POSITION, CAMERA DATA AND SALIENT FEATURES OF SELECTED APOLLO IX PHOTOGRAPHS TAKEN OVER NORTH AND SOUTH CAROLINA COASTS.

CLIMATOLOGICAL DATA, CAPE HATTERAS, N. C.

LATITUDE 35°16'N, LONGITUDE 75°33'W, ELEVATION 7'

DATE	TEMPERATURE (°F)					PRECIPITATION	PRESSURE	WIND				
											FASTEST MILE	
	MAXIMUM	MINIMUM	AVERAGE	DEPARTURE FROM NORM.	AVERAGE DEW POINT	WATER EQUIVALENT (IN.)		RESULTANT DIRECTION	RESULTANT SPEED (M.P.H.)	AVERAGE SPEED (M.P.H.)	SPEED (M.P.H.)	DIRECTION
1	53	37	45	-3	41	1.57	29.79	090	7.5	15.4	27	SE
2	43	37	40	-8	35	.01	29.63	330	20.2	22.7	30	NW
3	49	36	43	-6	30	0	29.86	330	8.1	12.2	17	NW
4	44	35	40	-9	30	0	29.82	020	11.9	12.2	22	NNE
5	44	27	36	-13	25	0	30.06	020	9.6	12.5	23	N
6	60	27	44	-5	36	.75	29.85	120	6.6	9.2	26	S
7	57	39	48	-1	40	1.13	29.47	290	12.3	18.3	40	WNW
8	55	32	44	-6	32	0	29.88	120	1.6	5.8	9	NW
9	59	37	48	-2	44	.34	29.42	340	6.0	13.8	46	WSW
10	48	35	42	-8	27	0	29.66	330	11.9	14.8	23	NW
11	44	33	39	-11	18	0	29.72	310	17.2	17.7	22	WNW
12	42	28	35	-15	14	0	29.89	310	14.9	16.0	24	WNW

DAILY TEMPERATURE AND PRECIPITATION

OCRACOKE INLET, N. C.

		1	2	3	4	5	6	7	8	9	10	11	12
TEMPERATURE	MIN.	41	37	34	37	37	33	38	38	46	35	32	41
	MAX.	51	44	52	49	49	61	57	56	59	55	55	47
PRECIPITATION		1.00	2.45	0	.40	0	.02	1.71	0	.30	.03	.05	0

TABLE 2. CLIMATOLOGICAL DATA FOR THE PERIOD 1 - 12 MARCH 1969 AT CAPE HATTERAS AND OCRACOKE INLET, N. C. (ESSA 1969).

OCRACOKE INLET, N. C., CHANNEL ENTRANCE

F - FLOOD, DIR. 0° TRUE E - EBB, DIR. 145° TRUE

DAY	SLACK WATER WATER	MAXIMUM TIME	CURRENT VELOCITY (KNOTS)
8	0730	0946	2.0 F
	1306	1604	2.5 E
	1936	2210	2.3 F
9	0142	0440	2.6 E
	0824	1034	1.7 F
	1354	1652	2.3 E
	2030	2258	2.1 F
10	0242	0434	2.4 E
	0924	1134	1.5 F
	1448	1752	2.1 E
	2130	2358	2.0 F
11	0354	0640	2.2 E
	1036	1234	1.3 F
	1600	1858	2.0 E
	2242	0110	1.8 F
12	0506	0758	2.1 E
	1154	1346	1.2 F
	1724	2016	2.0 E
	2354		

ABLE 3. TIDAL CURRENT TABLE FOR OCRACOKE INLET, N. C., FOR THE PERIOD 8 - 12 MARCH 1969 (FROM ESSA).

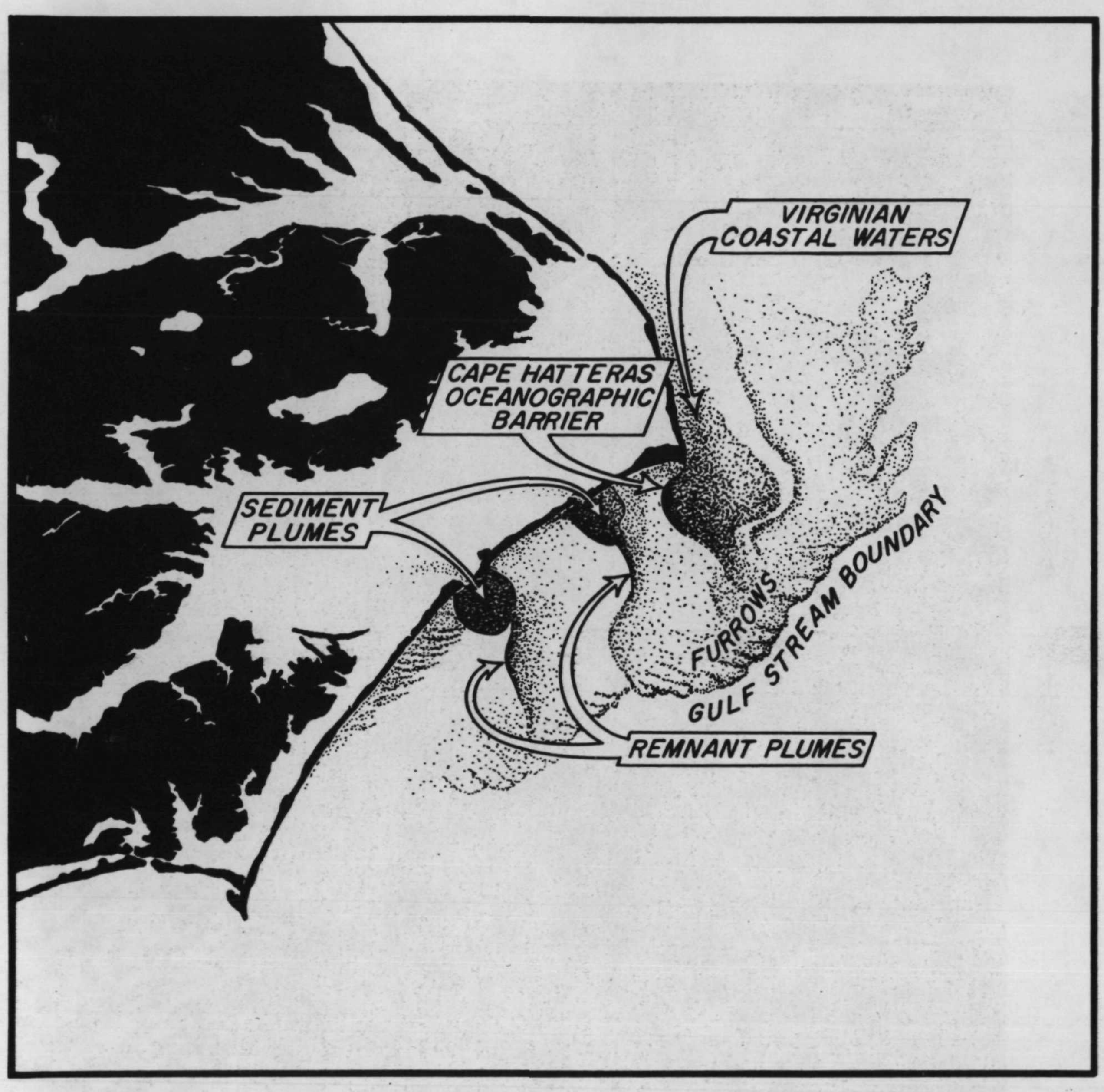

Fig. 1. Oceanographic Analysis of Apollo IX Photograph AS9-3128

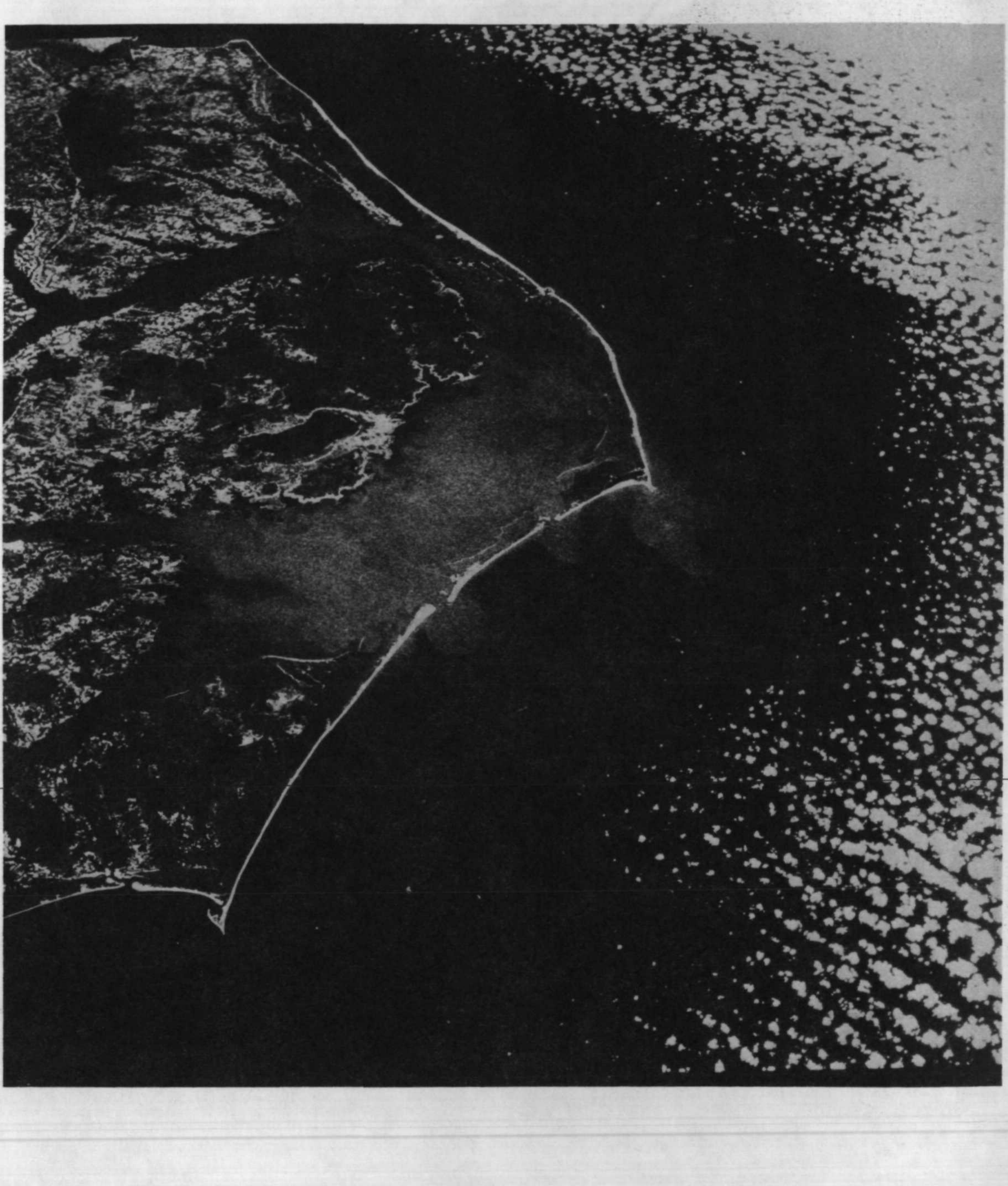

Fig. 2A. Red Band Separation

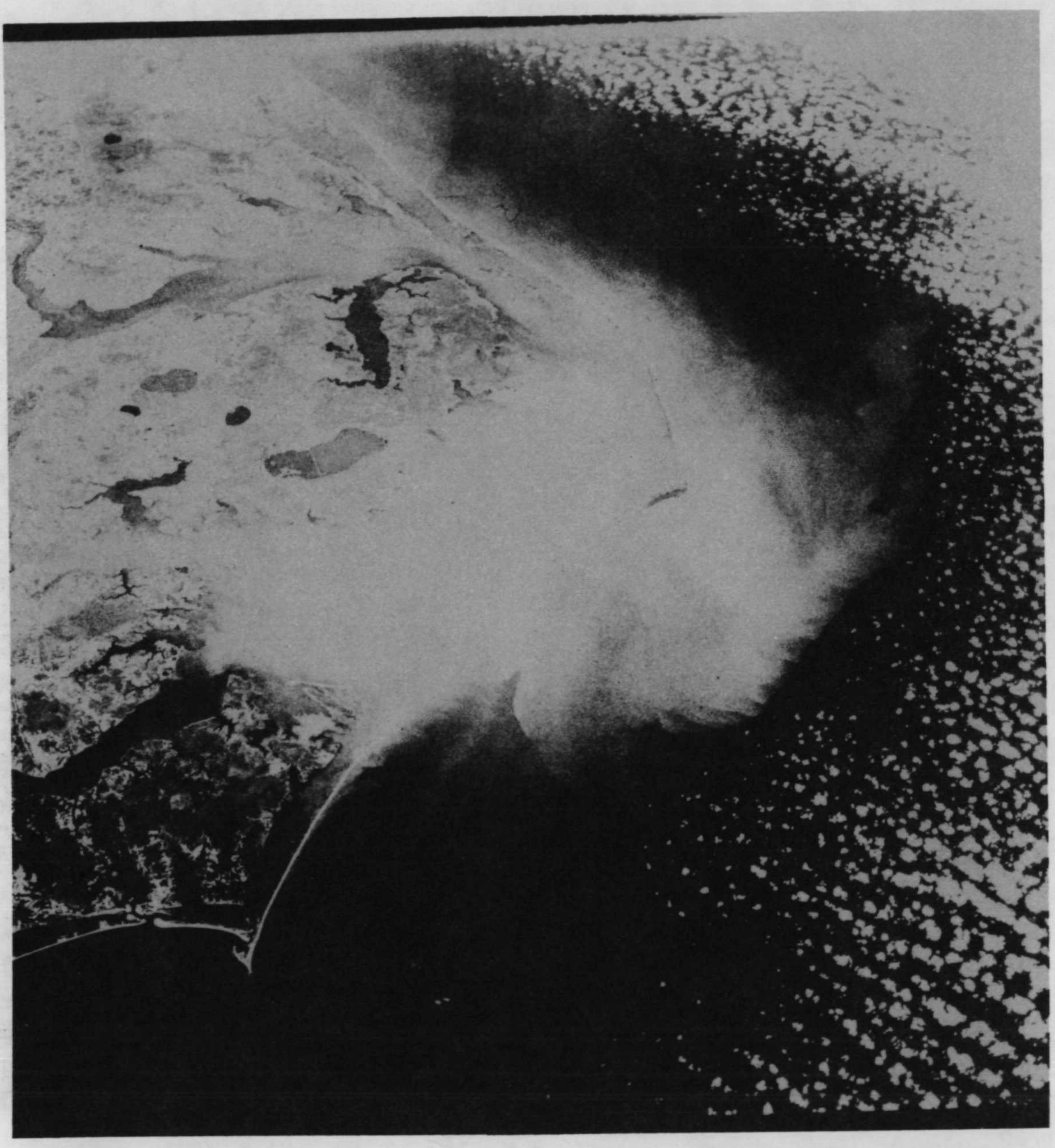

Fig. 2B. Green Band Separation

Fig. 2C. Blue Band Separation

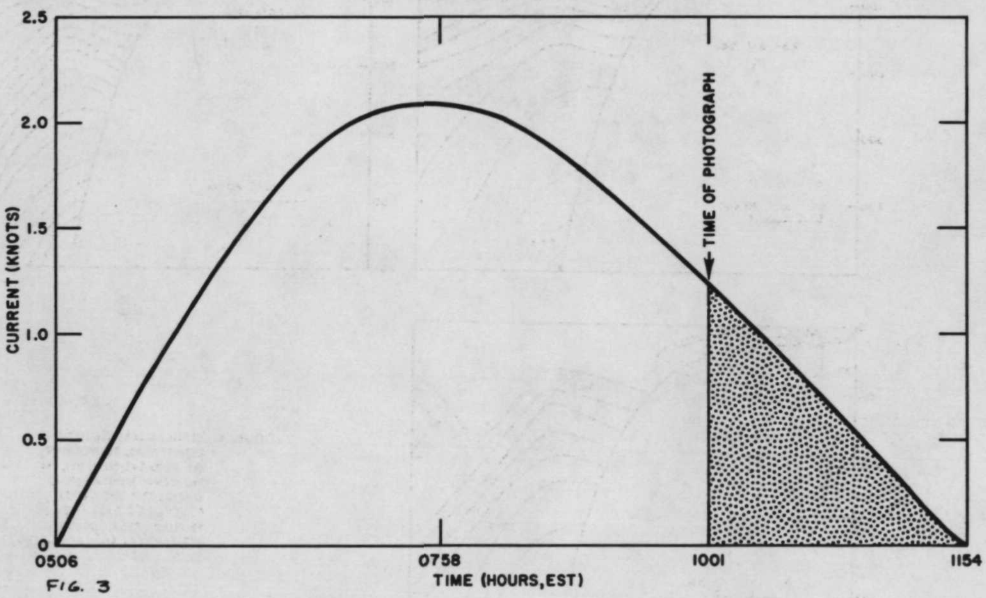

Fig. 3. Theoretical Tidal Current Curve for Ocracoke Inlet, N. C., 12 March 1969

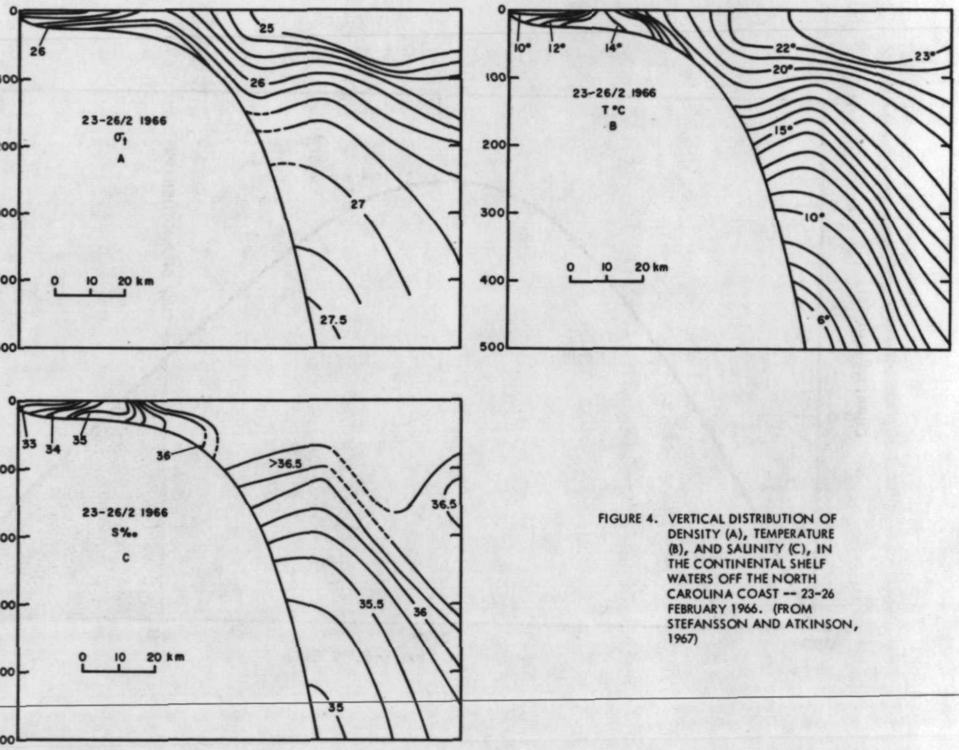

FIGURE 4. VERTICAL DISTRIBUTION OF DENSITY (A), TEMPERATURE (B), AND SALINITY (C), IN THE CONTINENTAL SHELF WATERS OFF THE NORTH CAROLINA COAST -- 23-26 FEBRUARY 1966. (FROM STEFANSSON AND ATKINSON, 1967)

Fig. 4. Vertical Distribution of Density (a), Temperature (b), and Salinity (c) in the Continental Shelf Waters off the North Carolina Coast, 23-26 February 1966 (from Stefansson and Atkinson, 1967)

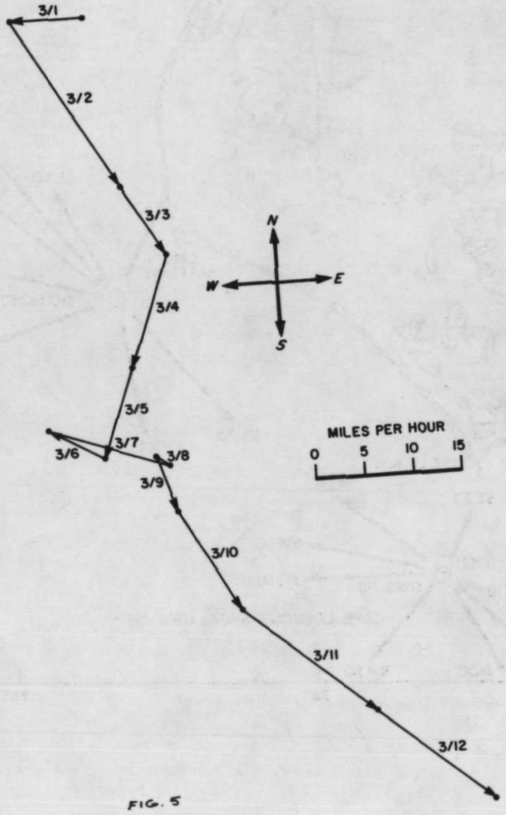

FIG. 5

Fig. 5. Vector Plot of Wind Speed and Resultant Direction for Period 1-12 March 1969 at Cape Hatteras, N. C.

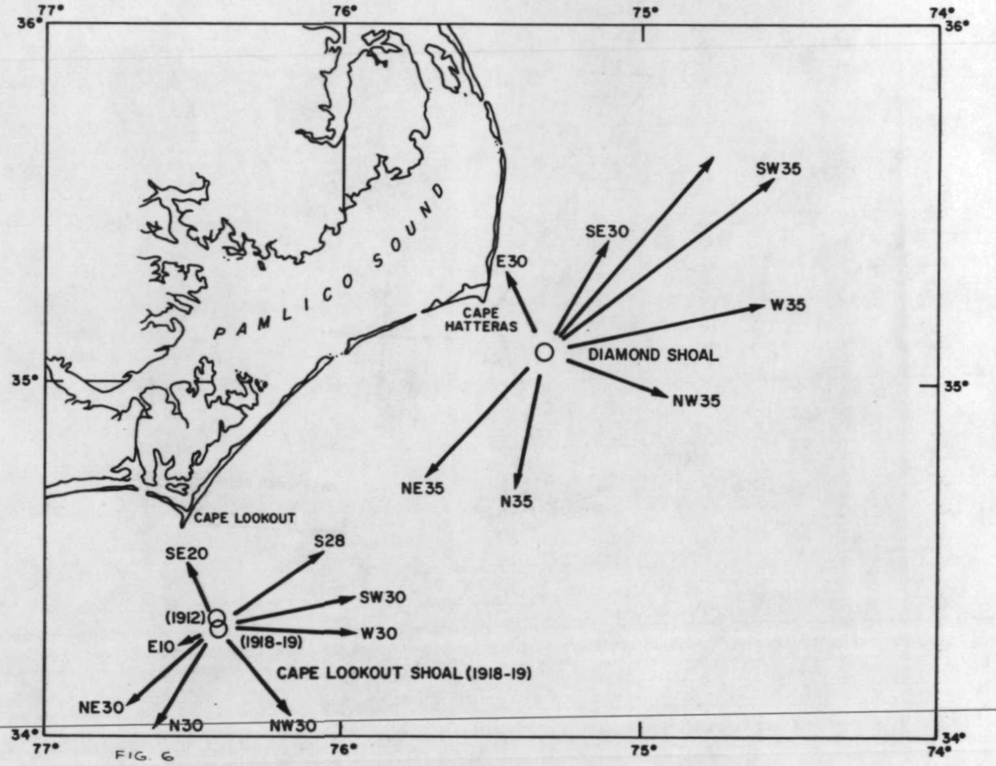

FIG. 6

Fig. 6. The Directions and Velocities of the Average Currents Accompanying Winds Blowing from Various Points of the Compass at Capes Hatteras and Lookout (Haight, 1952)

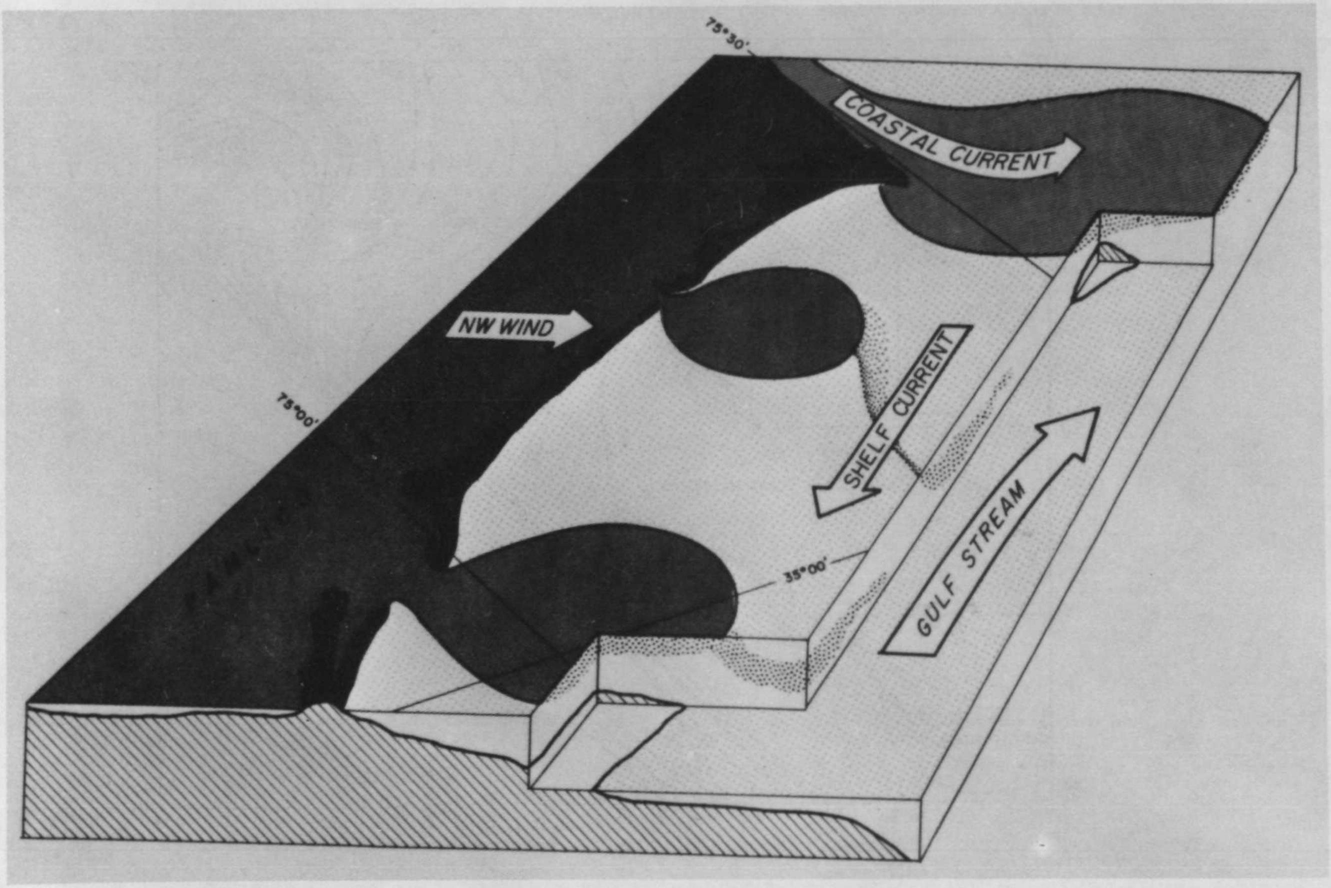

Fig. 7. Theoretical Model for the Formation, Movement, and Dissipation of Discolored Water Masses Seen on the Continental Shelf, 12 March 1969

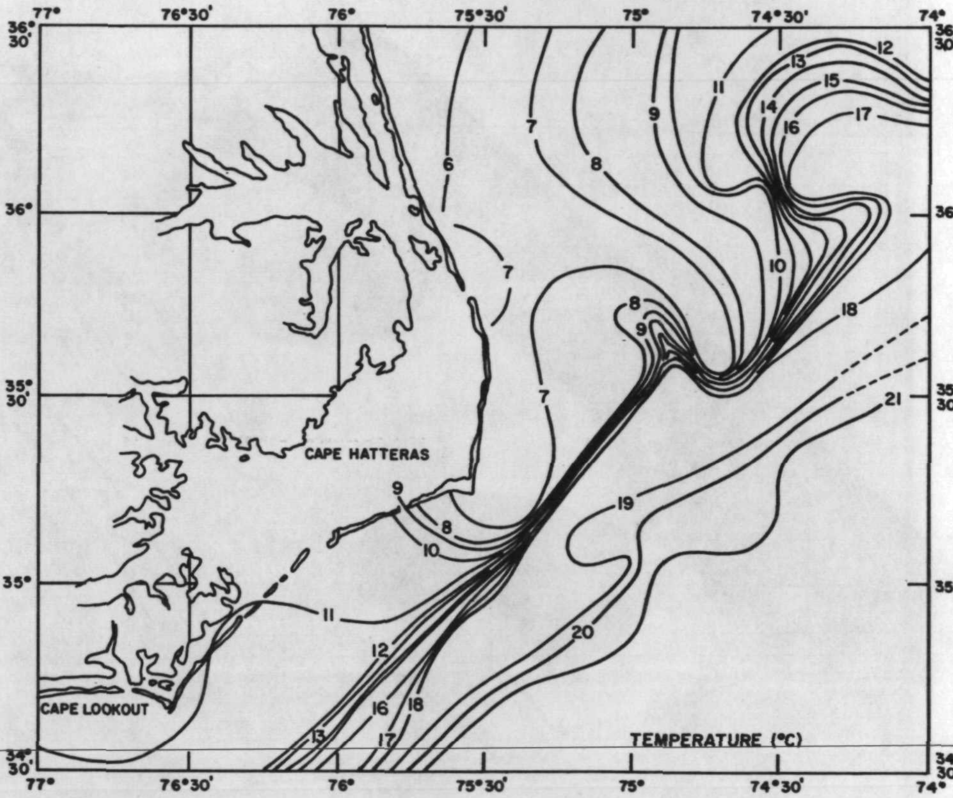

FIG. 8

Fig. 8. Sea Surface Temperature Contours off the North and South Carolina Coasts Taken from an Airborne Radiation Thermometer 17, 18, 24, 27 March 1969 (National Marine Fisheries Service, 1969)

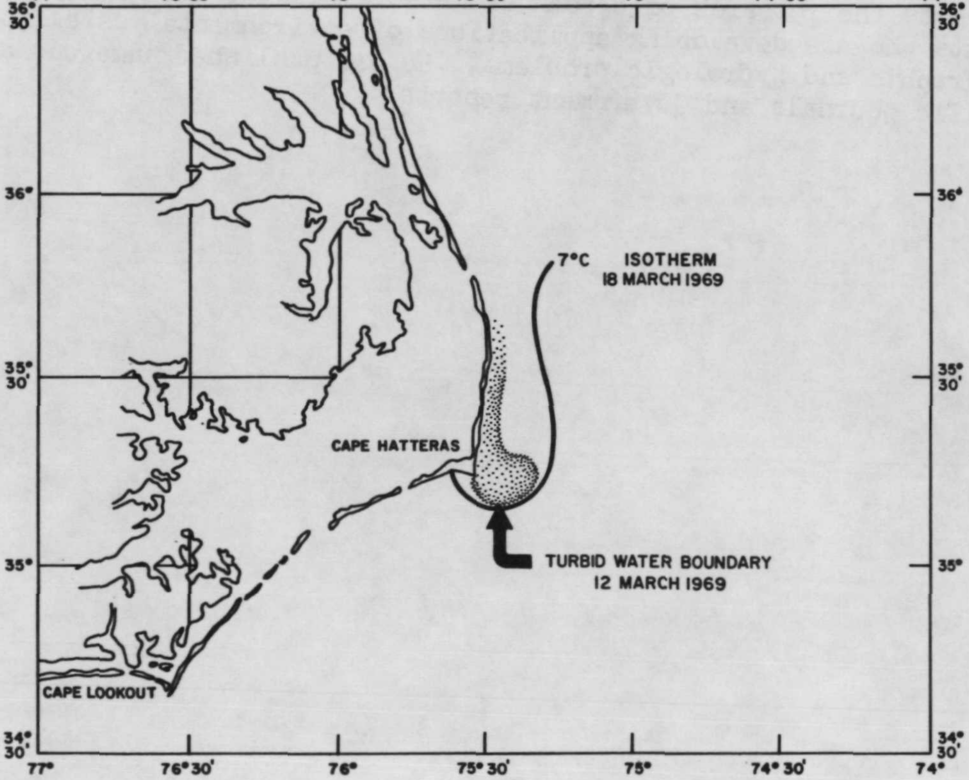

Fig. 9. The 7°C Isotherm from Figure 8 Overlying Apollo Photograph AS9-3128