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# BOTTOM CURRENTS, NEPHELOID LAYERS AND SEDIMENTARY FEATURES UNDER THE GULF STREAM NEAR CAPE HATTERAS

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ABSTRACT

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The velocities of near-bottom currents were measured at six locations on a 180-km transect of the Gulf Stream adjacent to Cape Hatteras. The average velocities indicate a southwesterly flow – the Western Boundary Undercurrent. Maximum recorded velocities at each of the six locations ranged from 15 to 47 cm/sec. Depth distributions of suspended particulate matter over the transect indicated that near-bottom nepheloid layers were present and that relatively large amounts of suspended matter were being carried to the southwest. Bottom photographs taken over the same transect, however, showed no evidence that the sediment surface was being affected by the active bottom currents. These results indicate that swift bottom currents do not always leave a record of their work on deep ocean sediment.

## INTRODUCTION

Near-bottom increases in light-scattering have been reported for many areas of the world's oceans and have been used as evidence of nepheloid layers near the sediment–water interface (Jerlov, 1953; Eittreim et al., 1969; Hunkins et al., 1969; Ewing and Connary, 1970; Jones et al., 1970). In the western basin of the North Atlantic Ocean, well-developed near-bottom nepheloid layers may be related to the rapid movement of bottom waters (Betzer and Pilson, 1971). In the Caribbean Sea, slight increases in light-scattering which characterize the bottom waters may be expected from the relatively sluggish movement of deep Caribbean water (Gordon, 1969).

Direct evidence of bottom-water interaction with sediments has been inferred from bottom photographs. Heezen et al., (1966a) pointed to scour marks, current lineations, and other surface sedimentary features as resulting from the Western Boundary Undercurrent flowing over the Blake–Bahama Outer Ridge. Heezen et al., (1966b) used sediment lineations, current streamers, current deflected sponges, and murky water as evidence for sediment transport over the Bermuda Rise by Antarctic Bottom water. Such photographic records of sedimentary structures have been widely used as indications of bottom current activity (Heezen and Hollister, 1964a; Schneider et al., 1967, Rowe and Menzies, 1968).

Relatively high-velocity bottom currents associated with the Western Boundary Undercurrent have been previously reported near Cape Hatteras (Barrett, 1965; Richardson and Knauss, 1971; Swallow and Worthington, 1971). We expected, therefore, that the dynamic conditions of this area might be reflected in the amounts of materials suspended near the bottom, as well as in sedimentary bed forms. Accordingly, we undertook a study of bottom current velocity, depth distributions of suspended particulate matter, and surface sedimentary features on a 180-km transect adjacent to Cape Hatteras (Fig.1).

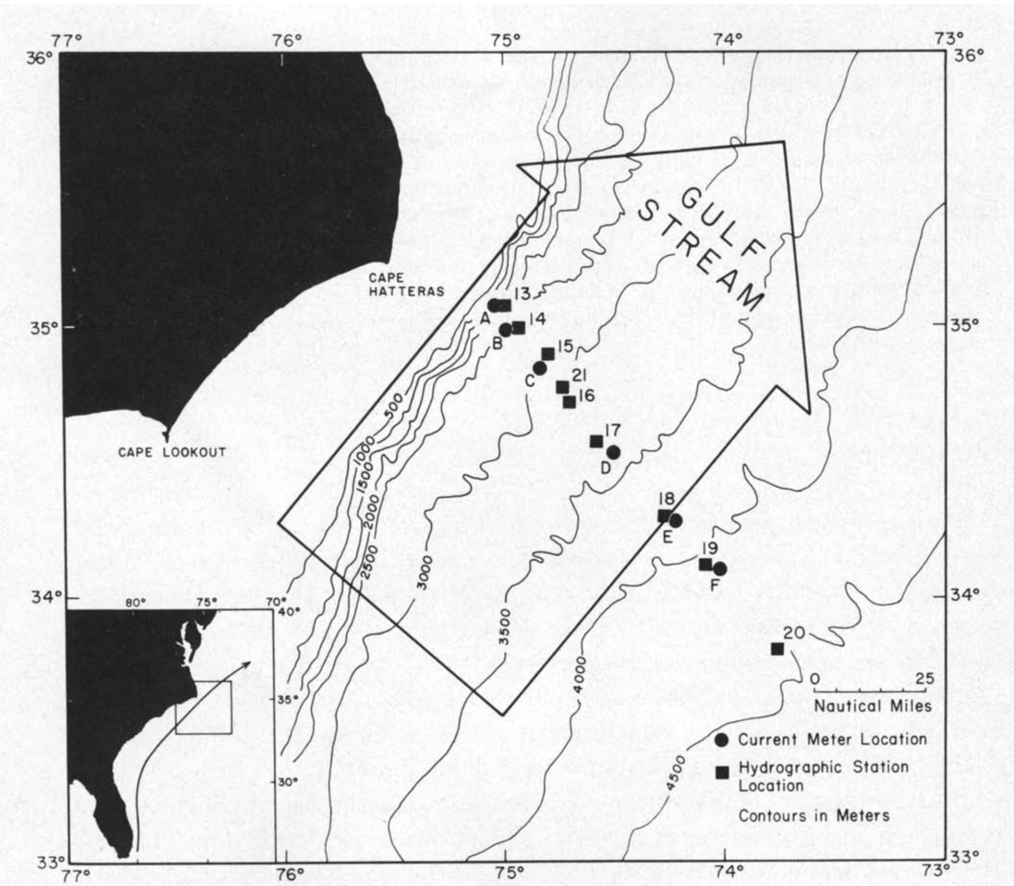


**Fig.1. Location of current meters, hydrographic stations and the mean position and direction of the Gulf Stream based on measurements in May 1971. Bathymetry from Newton and Pilkey (1969).**

## METHODS

Currents were measured by deep-moored Geodyne current meters (Richardson et al., 1963). The mooring apparatus and procedure has been described by Knauss (1965). The meters were moored 100 m above the ocean floor along a line running southeast from Cape Hatteras across the Gulf Stream. Six records were obtained in depths from 1300 to 4000 m over an eleven-week period extending from 8 May to 26 July 1971 (Table I).

TABLE I

Current meter records in the Gulf Stream southeast from Cape Hatteras

| Current meter | Current meter depth (m) | Record length (days) | Highest recorded velocity | | Average velocity | |
|---|---|---|---|---|---|---|
| | | | speed (cm/sec) | direction (°T) | speed (cm/sec) | direction (°T) |
| *A* | 1265 | 17.9 | 15 | 257 | 0.3 | 026 |
| *B* | 2575 | 53.6 | 47 | 230 | 10.9 | 228 |
| *C* | 2810 | 5.4 | 44 | 267 | 12.6 | 266 |
| *D* | 3220 | 17.6 | 23 | 255 | 6.8 | 228 |
| *E* | 3720 | 28.3 | 26 | 250 | 0.8 | 169 |
| *F* | 4145 | 22.0 | 16 | 254 | 9.1 | 253 |

Water samples were collected in 5- and 30-l Niskin bottles at eight stations along the 180-km transect of the Gulf Stream (Fig.1). Normally six 30-1 and ten 5-l samples were collected at deep stations (500 m to the bottom). On the deep hydrocasts, a pinger was used to locate the near-bottom samples, which were taken 100 and 300 m above the bottom. The order of the 30-l bottles on each hydrocast was assigned using a random-number table. In all, 49 samples were collected for determination of suspended particulate matter by weighing.

The processing of the water samples from the Niskin bottles was always started as soon as the bottles were aboard ship and was always complete within four hours of collection. After samples had been removed from the 30-l Niskins for salinity determinations, the remainder of the water was gravity-filtered through 47 mm diameter Nuclepore® filters (0.45 $\mu$ pore size). Filtration took place in a closed system: the water was fed to an all-plastic, Inline filter head (Millipore Filter Corp.) through a silicone rubber tube. Normally about 26 1 was passed through the Nuclepore® membranes. After filtration had been completed, 100 ml of double deionized water was gravity-fed through the filters to remove any residual salt. After this rinse the filters were placed in plastic Falcon® tubes until processing could be carried out in a shore-based laboratory. All filters were handled with Teflon® tweezers.

In the shore-based laboratory, the falcon tubes were transfered to a vacuum desiccator containing silica gel, and the filters were dried for two days and then reweighed on an

Ainsworth balance. The weight of suspended particles on each Nuclepore® filter was calculated by subtracting the tare weight (each had been weighed before the cruise on the same balance) from its desiccated weight, and then dividing by the volume of water which had been filtered. The precision of our weighing procedure, as determined by replicate sample weighing, was equivalent to ± 1 μg/l.

Seven gravity cores and five camera stations were taken along the transect. The sediment was examined for clay mineralogy, carbonate content, and size parameters.

## RESULTS AND DISCUSSION

Three current meters (*A, D, F*) recorded near-bottom current speed and direction at the same time the suspended-matter observations were made (Fig.1). Of the three remaining current meters, *C* provided a near-bottom record for a period that ended 9 days before we began the suspended-matter work; *B* and *E* gave records beginning eight and seven days, respectively, after we had completed our suspended-sediment sampling near their locations. Maximum velocities recorded over a 1-min period ranged from 15 to 47 cm/sec to the southwest (Table I). At current meter *B* (2575 m), which provided a 54-day record, the magnitude of the average velocity was 11 cm/sec. Four of the five deepest meters recorded average flows ranging from 7 to 13 cm/sec toward the southwest, and it is concluded that this flow is the Western Boundary Undercurrent. The highest instantaneous velocities (44 and 47 cm/sec) and the highest average velocities (10.9 and 12.6 cm/sec) were found at the base of the continental slope (meters *B* and *C*) in depths of 2600–2800 m. In an investigation of the Western Boundary Undercurrent in the area of the New England Seamounts, Zimmerman (1971) recorded similar velocities 2 m off the bottom. These near-bottom current velocities are high enough to both erode and transport the unconsolidated lutite-silt bottom sediment (Heezen and Hollister, 1964b; Southard et al., 1971) of the continental rise.

The distribution of suspended particulate matter with depth (Fig.2) shows that a near-bottom nepheloid layer was present over much of the transect. Near the continental slope (stations *13* and *14*) two large plumes of suspended matter are present. The first has a peak of 55 μg/l, averages greater than 50 μg/l, and is present at about 800–1000 m. The second has a peak of 65 μg/l and an average suspended-particle load exceeding 40 μg/l. It extends from about 1400 to 2500 m. The average suspended particle loads for the shallow and deep plumes of suspended matter are 7–8 times the average particle load for clear offshore waters (stations *17–20*). Unfortunately no current meter records were obtained in the plumes of suspended matter. The highest recorded near-bottom speeds were located just offshore of this area at 2575 m (meter *B*). Record *A* was obtained near the low suspended-particle load at 1240 m and had the lowest average velocity of all the records.

Geostrophic velocities were calculated from the hydrographic data (Richardson, 1973). These calculations indicate that the high concentration of suspended matter at 800–1000 m is being carried to the northwest by the Gulf Stream. The deeper maximum between 1400 and 2500 m is associated with an area of large current shear, and this shear is an

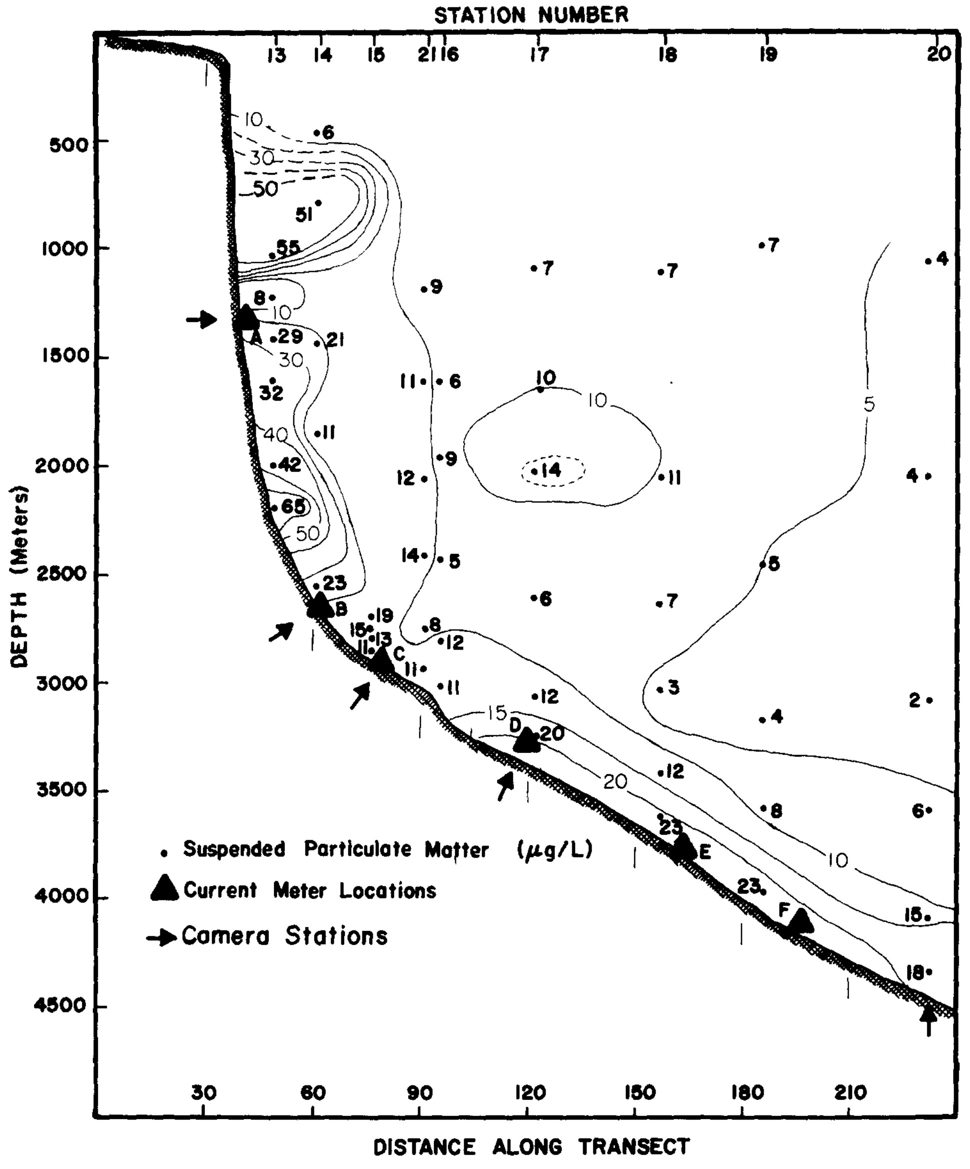


Fig.2. Suspended particulate matter concentrations, current meter and bottom photograph locations on Gulf Stream Transect near Cape Hatteras.

indication of relatively strong currents. Our conclusion is that this deeper maximum is associated with the southwest flow of the Western Boundary Undercurrent. Evidence for this is added by Richardson and Knauss (1971), who reported that the maximum southwest velocities in the Western Boundary Undercurrent are between 1500 and 2500 m at this location. Large fluctuations in the position and direction of the Gulf Stream and in the velocities of the deep currents suggest, however, that caution be used when interpreting the currents as stationary features.

Between about 2700 and 3150 m depth, near-bottom suspended-particle loads are considerably less than on the upper continental slope and in depths exceeding 3150 m. We have, unfortunately, no simultaneous current meter observations from this depth range to compare to our suspended-load and current meter data from other portions of the transect.

Simultaneous observations of bottom currents and suspended particulate matter were made at about 3220 and 4050 m depth (current meter positions *D* and *F*, hydrographic stations *17* and *19*). The average velocity of the Western Boundary Undercurrent at these locations was 7 and 9 cm/sec toward the southwest for *D* and *F*, respectively. A relatively large nepheloid layer was present 100 m above the bottom at both locations. These layers could both have been as thick as 700 m (Fig.2) and the concentrations of suspended particles 100 m above the bottom were 3–5 times greater, respectively, than those 800 –900 m above the bottom.

Eittreim and Ewing (1972) carried out suspended-particle measurements in near-bottom nepheloid layers of the western North Atlantic Ocean. They reported a range in suspended-particle loads for near-bottom nepheloid layers in the western Atlantic of from 10 to 100 μg/l. The most intense light-scattering regions they found had suspended-particle loads of 100 μg/l – 4 times our near-bottom average of 25 μg/l. The clearest ocean water we found on our transect (stations *18–20*) gave average values of 3 μg/l – 1/8th the average particle load in our near-bottom nepheloid layers. Our suspended-particle loads from the Gulf Stream transect are consistent with additional measurements at three stations which were 160, 260 and 370 km northeast of the transect in 3000–3100 m depths. The middle portions of the water column at each station had particle loads which averaged < 10 μg/l. Two of three stations had near-bottom nepheloid layers approximately 300 m thick, with suspended-particle loads between 25 and 30 μg/l. The station 160 km northeast of the transect had no near-bottom nepheloid layer.

The suspended-particle loads in the near-bottom layers off Cape Hatteras are geologically important despite the fact that they have lesser amounts of particulate matter than the most intense measured by Eittreim and Ewing (1972). If we take an average suspended-particle load in the bottom 300 m of the water column as 20 μg/l, and assume an average current speed of 10 cm/sec over the 150-km transect, we calculate a suspended-sediment transport for the Western Boundary Undercurrent of $2.8 \cdot 10^{12}$ g/year. This is equivalent to about 2% of the sedimentation rate for the entire western basin of the North Atlantic Ocean (Ewing et al., 1973). In other words, the bottom water in this area transports geologically significant amounts of suspended particulate material.

Short cores taken along the transect reveal a generally homogeneous gray-green silty clay with no conspicuous sedimentary structures except an occasional worm burrow. The sediment contains 20–40% carbonate material (by acid leaching). X-ray diffraction analysis showed that the < 4 μ size fraction consists of the following clay phases: 20–40% montmorillonite; 40–60% illite; with 20–30% kaolinite and chlorite; and minor amphibole.

The most immediate source for this assemblage of clay minerals is the estuaries of the southeastern United States which exhibit a similar assemblage (Neiheisel and Weaver, 1967; Hathaway, in press; Pevear, in press). Although sediments are generally trapped by the inshore estuarine circulation (Meade, 1969), suspended sediment can be injected into the deep-water circulation during extreme weather conditions (Rodolfo et al., 1971). Alternatively, the high suspended-particle loads found in the Gulf Stream at 800–1000 m could be the result of erosion of slope sediment with subsequent transport to the north. The plume on the lower slope (1500–2500 m) and the broad nepheloid layer on the rise (3200–4200 m) are associated with the southward transport of the Western Boundary Undercurrent.

The current meter and suspended particulate matter data indicate that bottom currents were active in transporting sediments over most of the transect at the time the sampling program was carried out. It was expected that evidence of the Western Boundary Undercurrent would be present in the photographs from the continental slope and rise. Bedforms indicative of current erosion are, however, absent at the sediment–water interface (Fig.3). The majority of photographs reveal a soft, muddy bottom with only tracks, trails and burrows in evidence. We could find no evidence in any of the photographs that bottom currents were actively working the ocean bottom; no ripple marks, lineations, scour marks or sediment streamers can be seen in any of the photographs. One would conclude from the visual evidence that the bottom currents in this area are sluggish indeed.

Fig.3. Crater rings and trails in soft sediment with no current evidence (TR-098; 34°50′N, 74°50′W; 2900 m). Photographs at other stations reveal similar bed-forms.

It seems, then, that swift bottom currents do not always leave their signature in the deep ocean. The absence of sedimentary features from bottom photographs cannot, therefore, be taken as unequivocal evidence that near-bottom currents are too slow to move sediment and should be complemented by in situ current measurements before any firm conclusions are drawn about near-bottom dynamics.

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