Reports

Exceptionally Strong Near-Bottom Flows on the Continental Rise of Nova Scotia

Abstract. *Recent current velocity measurements across the lower continental rise of Nova Scotia show a deep equatorward flow with speeds (maximum, 73 centimeters per second) among the highest recorded for the deep sea. Silicate measurements indicate that this flow usually consists of southern-source (Antarctic) bottom water. These measurements confirm the existence of a second and deeper western boundary flow that was earlier inferred from geological observations.*

The existence of a deep western boundary current flowing equatorward along the western margin of the North Atlantic Basin has been substantiated by physical oceanographic theory (*1*) and observation (*2, 3*). Accordingly, this bottom current generally flows at depths of 3000 to 4000 m and is made up of water formed primarily to the north in the Labrador and Norwegian seas. However, for many years marine geologists have consistently photographed bed forms indicative of strong equatorward flow at greater depths (4500 to 5000 m) on the lower continental rise of Nova Scotia (*4, 5*). As part of the High Energy Benthic Boundary Layer Experiment (HEBBLE) (*6*), we measured current velocities across this region of suspected strong flow.

Current meters were deployed 50 m above the bottom at six stations with ~ 50 km spacing across a HEBBLE study area on the lower continental rise of Nova Scotia (Fig. 1a). At four of these six stations [the two deepest (stations A and B) and two shallowest (stations E and F)], currents were recorded for about 2 weeks. At the two middle stations (stations C and D), currents were recorded for more than 7 months. All but one of these current meters were deployed during a 2-week period in September 1979 (Fig. 1b). Statistics for these current records are given in Table 1.

Despite the short duration of most of these records, some general trends were seen. For the duration of the deployments, the mean current speed was lowest at the shallowest station (station F) and increased monotonically toward the base of the rise (station B), where speeds in excess of 35 cm/sec were sustained for several days with a maximum (6-minute average) of 73 cm/sec (Table 1 and Fig. 1b). Currents along the lower rise (stations B through F) predominantly flowed southwestward along the contours. On the abyssal plain (station A) currents were still strong, although weaker than at station B, with the direction of flow typically northeastward. We recognize that the short-term mean direction may not be representative of the long-term average. For instance, the first 16 days of the record at station D indicate an average velocity to the northeast, whereas the full 230-day record indicates an average flow to the west-southwest (Table 1). However, at greater depths where currents are swifter and more unidirectional in the short term (station B), bottom photographs of well-developed bed forms confirm that the exceptionally strong southwestward flow is neither an ephemeral feature nor an artifact of the short recording period.

Current speeds measured in this area are surely among the highest values recorded in the deep sea. Even by comparison with flows in deep constricted passages (*7*), the maximum speeds of this relatively unconstrained flow are two to three times faster. On the basis of laboratory experiments, this flow is competent to erode and transport sea-floor sediments (*8*), being consistent with local bottom photographs that indicate active shaping of the sea floor (*5*). Indeed, we believe that the high concentrations of suspended particulate matter observed in the region (*9*) are caused by these currents rather than by turbidity flows (*10*).

Despite the high speed and general southwestward direction of these flows (Table 1), there is poor correlation of these current records over the ~ 50 km spacing of these observations (Fig. 1). Cross-spectra for the long-term stations C and D show no significant coherence between current components at periods up to 45 days. Clearly, these energetic flows have rather small-scale structure.

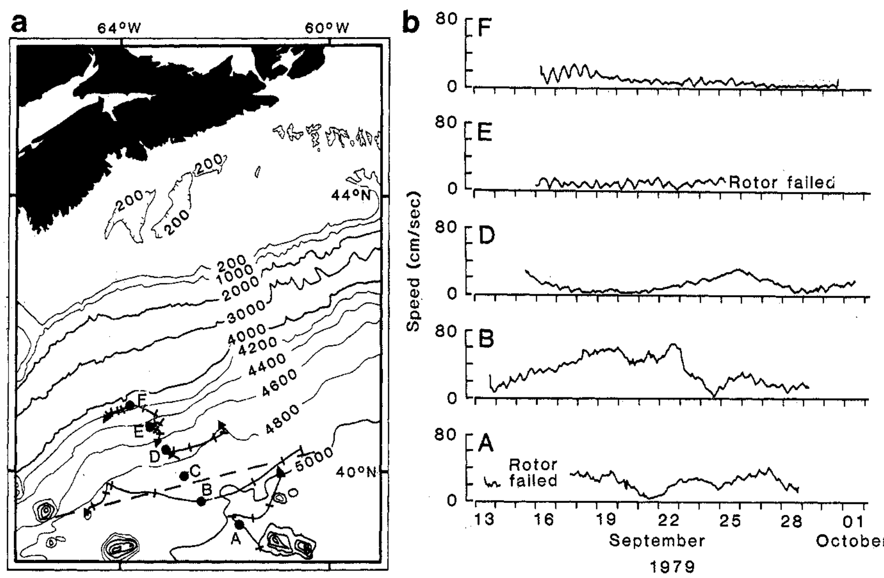

Fig. 1. (a) Study area showing the locations of current meters across the lower continental rise. Progressive vector diagrams are given for records with overlapping time periods. For all records, 20 September 1979 at 0000 hours G.M.T. is the time fixed at the mooring site with tick marks at 2-day intervals. The dashed line marks the mean position of the Gulf Stream axis at the sea surface (*16*). (b) Speed versus time records show the exceptionally strong flow at the base of the rise and the lack of correlation between the moorings.

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Table 1. Current data, 50 m above the bottom.

Station	Latitude (N)	Longitude (W)	Water depth (m)	Duration (days)	Mean speed (cm/sec)	Maximum speed (cm/sec)	Mean velocity Magnitude (cm/sec)	Mean velocity Direction (degrees, true)
F*	40°56.6	63°44.9	4158	14.21	8.0	28.5	6.3	267
E*	40°37.1	63°23.4	4487	8.96	8.6	17.5	3.6	190
D*	40°15.5	63°00.0	4770	16.09	11.7	31.0	6.5	44
D	40°15.5	63°00.0	4770	230.41	12.2	39.2	6.9	254
C	39°47.5	62°47.4	4950	214.55	13.9	40.6	8.2	249
B*	39°33.0	62°27.6	5022	15.25	32.1	73.5	27.9	253
A*	39°09.8	61°37.7	5076	10.83	23.1	42.5	14.5	12

*Records shown in Fig. 1.

We suspect that they are related in some way to the Gulf Stream, whose surface axis is often directly over this region (Fig. 1).

Current meters were confined to the lower portion of the continental rise in this study, but, on the basis of hydrographic data of potential temperature (Θ), salinity (S), and silicate taken during the current-meter deployments (*11*), we infer the existence of a weaker southwestward flow of northern-source water farther upslope at the expected depth of 3000 to 4000 m. The strong northeastward flow recorded below 5000 m may be the northwestern edge of the Deep Gulf Stream System of Worthington (*12*).

In addition to measuring current speed and direction, we tried to determine the source of the water in the observed strong southwestward flow. The Θ-S signature of the bottom water in this area (1.79° to 1.80°C; 34.89 to 34.90 parts per thousand), does not allow an unambiguous interpretation of its source. These values lie at the intersection of Antarctic Bottom Water and Denmark Straits Overflow Water on a Θ-S diagram (*13*). Fortunately, silicate measurements make it possible to distinguish between northern-source, silicate-poor water (10 to 20 μg-atom/liter) and southern-source, silicate-rich water (> 25 μg-atom/liter).

A compilation of historical silicate data for the bottom water of the general region below 4000 m indicates that only southern-source high-silicate water is present (*12*, *14*). Early in the cruise, however, one transect of casts across the lower rise had low silicate values (10 to 20 μg-atom/liter) in the near bottom water, indicative of an advection of northern-source (Denmark Straits) bottom water into the region (Fig. 2a). Reoccupation of the stations along the same transect 2 weeks later showed high silicate values (25 to 40 μg-atom/liter), indicating the presence of Antarctic Bottom Water. The change from northern-source to southern-source water was not obviously related to current direction or speed variations. Another transect was made across the lower rise during the next year. No evidence of northern-source water was seen at that time (Fig. 2b). These later data are in agreement with the observations of Worthington (*12*) for water < 1.80°C of the North American Basin.

Although other investigators have inferred a component of Antarctic Bottom Water in a deep western boundary current of the North Atlantic (*3*, *15*), it is unusual to have such a strong flow this far north comprised predominantly of southern-source bottom water. Further investigation is needed to determine the relationship of this flow to the southwestward flow farther upslope and the northeastward-flowing Gulf Stream system.

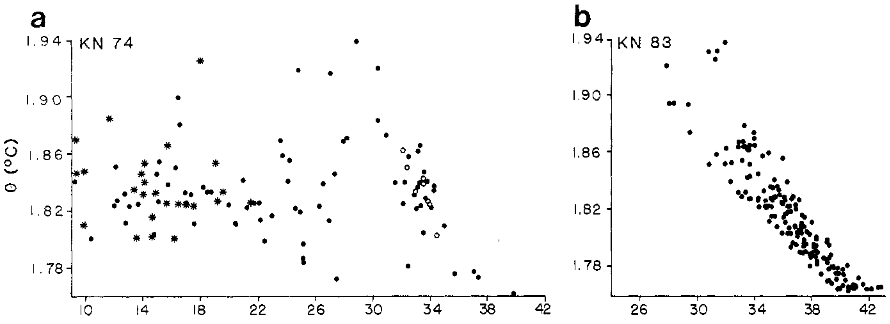

Fig. 2. Plots of potential temperature (Θ) versus silicate for two cruises. (a) *Knorr* cruise 74, September to October 1979: *, early transect across the rise; ○, repeat transect 2 weeks later; and ●, other values in the region; (b) *Knorr* cruise 83, September to October 1980: ●, all values over the 3-week period.

M. J. RICHARDSON

Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York 10964

M. WIMBUSH

L. MAYER

Graduate School of Oceanography, University of Rhode Island, Narragansett 02882

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