NOAA Dumpsite Evaluation Report 76-1

Passage of Anticyclonic Gulf Stream Eddies Through Deepwater Dumpsite 106 During 1974 and 1975

Rockville Md.
April 1976

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

This is the second report in the NOAA Dumpsite Evaluation Report series. The first report was: NOAA Dumpsite Evaluation Report 75-1, May 1974, Baseline Investigation of Deepwater Dumpsite 106, December 1975.

NOAA Dumpsite Evaluation Report 76-1

Passage of Anticyclonic Gulf Stream Eddies Through Deepwater Dumpsite 106 During 1974 and 1975

James J. Bisagni
Atlantic Environmental Group
National Marine Fisheries Service
Narragansett, R.I.

Rockville, Md.
April 1976

U.S. DEPARTMENT OF COMMERCE
Elliot L. Richardson, Secretary
National Oceanic and Atmospheric Administration
Robert M. White, Administrator

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.
Price $1.15

CONTENTS

Tables

Figures

CONTENTS--continued

CONTENTS---continued

PASSAGE OF ANTICYCLONIC GULF STREAM EDDIES THROUGH DEEPWATER DUMPSITE 106 DURING 1974 AND 1975

James J. Bisagni

Atlantic Environmental Group
National Marine Fisheries Service
Narragansett, R.I.

ABSTRACT

The formational theory and characteristics of anticyclonic Gulf Stream eddies in the western North Atlantic Ocean are summarized. Their occurrence, trajectories, and structure, are observed using XBT data and infrared satellite imagery to relate their passage through Deepwater Dumpsite 106 off the New York Bight and over the continental slope and rise. The frequency with which these eddies pass through the dumpsite, their residence times within the dumpsite, and the total time they occupy the dumpsite each year are computed to determine their potential effects on ocean dumping.

INTRODUCTION

Gulf Stream meanders and related eddies have been observed between Cape Hatteras and the Grand Banks for some time. Iselin (1936) reported anticyclonic eddies during cruises between Nova Scotia and Bermuda. An early multiple ship survey of the Gulf Stream, Operation Cabot, defined meanders and both cyclonic and anticyclonic eddies (Fuglister and Worthington 1951). Other published accounts describe an anticyclonic eddy in the region north of the Gulf Stream (Iselin and Fuglister 1948), properties and behavior of cyclonic eddies observed during 1965 and 1966 (Fuglister 1971), formation of an anticyclonic eddy in 1969 (Saunders 1971), and tracking of an anticyclonic eddy for nearly 5 months (Thompson and Gotthardt 1971). More recently, the formation and life cycle of anticylonic eddies during 1972 and 1973 (Gotthardt 1973a; Gotthardt and Potocsky 1974) and seven anticyclonic eddies in the northwestern Atlantic between November 1969 and May 1973 (Gotthardt 1973b) were reported.

New methods of observing surface and subsurface water properties, and the adaptation of these methods to satellite, aircraft, and a variety of surface observation platforms have improved detection and tracking of eddies. Literature concerning eddy formation has increased, but there have been few, if any, recent comprehensive studies of eddy lifetimes, trajectories, and physical characteristics over an extended period. This report is an analysis of anticyclonic eddies observed north of the Gulf Stream during 1974 and 1975, their movements and characteristics, and the observed passage of certain eddies through, and their residence times in, Deepwater Dumpsite 106 (DWD 106)--a dumpsite area 106 nautical miles southeast of Ambrose Light (off New York Harbor) and over the continental slope and rise.

ANTICYCLONIC EDDY FORMATION AND STRUCTURE

Both the method of formation and structure of eddies are closely related to meandering of the Gulf Stream from its mean path. Fuglister and Worthington (1951) reported large-scale sinuous meanders of the Gulf Stream and formation of a cyclonic eddy from the closing off of a large southward meander. This process resulted in an eddy of colder, less-saline slope water being entrained into Sargasso Sea water. Fuglister (1971) postulated a similar mechanism of formation for warm-core, anticyclonic eddies north of the Gulf Stream. Saunders (1971), using synoptic airborne radiometry and airborne expendable bathythermograph (AXBT) observations, showed the formation of an anticyclonic eddy from a large northward meander of the Gulf Stream. This process, which has been documented by Gotthardt (1973a) and other workers, causes entrainment of warmer, anticyclonically circulating Sargasso Sea and Gulf Stream water into colder slope water (fig. 1). Gotthardt and Potocsky (1974) also describe the reverse process of how an anticyclonic eddy was reabsorbed by a large northward meander of the Gulf Stream. Khedouri and Gemmill (1974) used salinity-temperature-depth (STD) soundings to study the thermohaline structure of an anticyclonic eddy. They reported the eddy to be a shallow feature, extending from the surface to about 1,000 m, composed of warmer more saline water than the surrounding slope water (fig. 2a and b). The eddy could be identified by a maximum "bulge" in the dynamic topography of about 26 dynamic cm. Current gradients and volume transport associated with the density field (fig. 2c) show the maximum current to be near the surface and midway between the perimeter and center of the eddy. The eddy was slightly elliptic in shape and approximately 70 km long along its major axis, as defined by the 15° C isotherm at a depth of 200 m.

In summary, anticyclonic eddies form when large northward meanders of the Gulf Stream become separated from the main stream. In the process, warm Sargasso Sea and Gulf Stream water are entrained in colder shelf and slope water. These eddies can be detected by their temperature-salinity characteristics to depths of approximately 1,000 m.

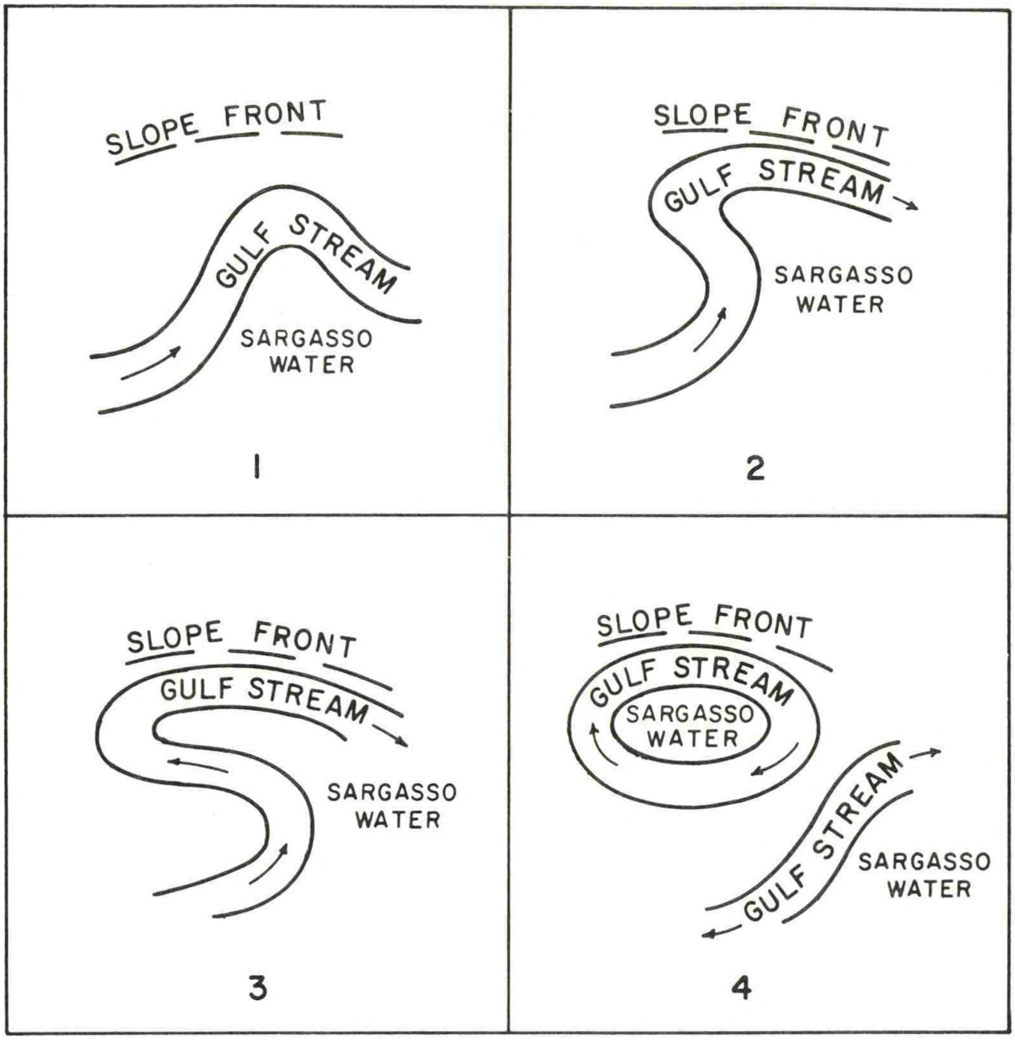


Figure 1.--Schematic of anticyclonic eddy formation (after Gotthardt 1973b).

PASSAGE OF ANTICYCLONIC EDDIES THROUGH DEEPWATER DUMPSITE 106

To determine the potential effects of anticyclonic eddies on ocean dumping at Deepwater Dumpsite 106 (lat. 38°40' to 39°00'N, long. 72°00' to 72°30'W), we must know how often anticyclonic eddies affect the dumpsite and the residence times of anticyclonic eddies within the dumpsite. This information was obtained by plotting trajectories that showed the westward movement of anticyclonic eddies along the northern edge of the Gulf Stream during 1974 and 1975. Several criteria were established for this task.

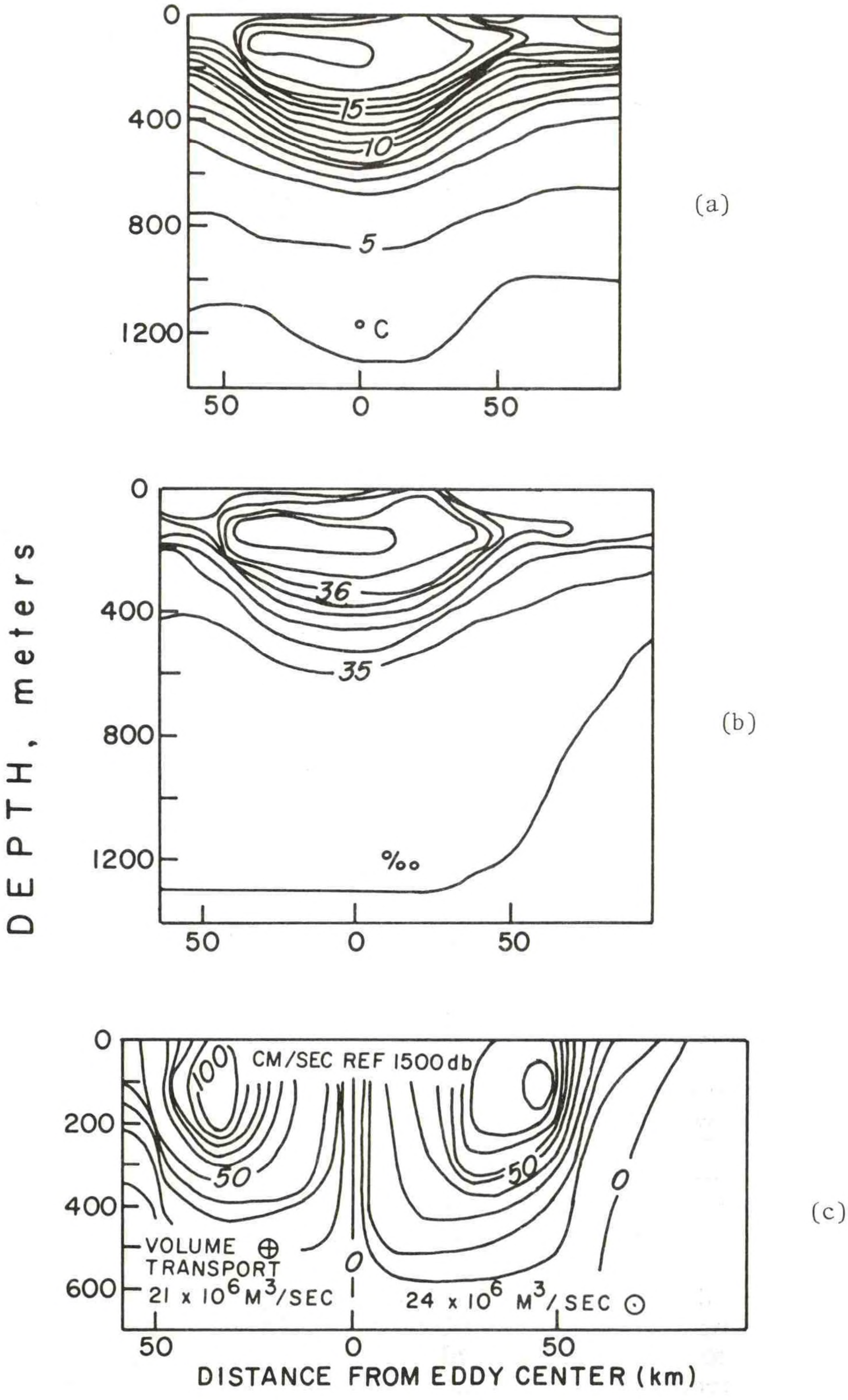


Figure 2.--Sections through anticyclonic eddy showing (a) temperature, (b) salinity, and (c) gradient currents and volume transport (after Khedouri and Gemmill 1974).

1. The mean diameter of an "average" anticyclonic eddy was based on observations obtained by subsurface surveys. Diameters described by VHRR-IR satellite imagery can be erroneous owing to surface spreading of warm or cold water, and hence were not used. Gotthardt (1973b) found that the diameters of anticyclonic eddies decreased as they moved westward. Gotthardt (1973b) also reported highly elliptical eddies when they were newly separated from the Gulf Stream. Later, however, their ellipticity decreases considerably. In this report the "average" eddy is assumed to be circular.

2. A critical sector was defined around Deepwater Dumpsite 106 (fig. 14) such that its area was defined by one mean radius of an "average" anticyclonic eddy. If the center of an anticyclonic eddy was plotted within the critical sector for the dumpsite, the eddy was considered to be either wholly or partially within the geographic confines of the dumpsite, based on the "average" eddy radius.

3. The portion of the anticyclonic eddy trajectory within the critical sector was used to determine the period of time that the dumpsite was either wholly or partially occupied by the eddy.

The above criteria made it possible to compute the amount of time individual eddies affected Deepwater Dumpsite 106, the total amount of time the dumpsite was affected by anticyclonic eddies during 1974 and 1975, and the average residence time of anticyclonic eddies within the dumpsite.

Anticyclonic Eddy Trajectories--1974 and 1975

Trajectories for the centers of 13 anticyclonic eddies observed during 1974 and through October 31, 1975, were plotted. The eddies were numbered consecutively according to their first date of observation (table 1). Trajectories for eddies 1 through 10 are shown individually (figs. 3 through 12), those for eddies 11 through 13 are combined (fig. 13). Both actual and interpolated positions were plotted, based on analysis of 1974 Gulf Stream Monthly Summary and 1975 gulfstream data, Naval Oceanographic Office (NAVOCEANO) experimental ocean frontal analysis charts, and National Environmental Satellite Service (NESS) Gulf Stream analysis charts. These data sources utilize infrared, very high resolution radiometric data collected by the ITOS E/NOAA 3 and NOAA 4 satellites, supplemented by some shipboard XBT data. Additional XBT and AXBT data were made available from a variety of sources, including the 1974-75 NMFS/MARAD Ships of Opportunity Program (SOOP), the 1974 NAVOCEANO New York to Bermuda thermal structure monitoring program, and other available oceanographic sections. These data were used to verify satellite imagery data. However, only NAVOCEANO experimental ocean frontal analysis data were used for plotting trajectories to avoid confusion.

Table 1.--Anticyclonic eddy lifetimes

Anti-cyclonic eddy	Period* observed	Lifetime+ (days)	Days in DWD 106
1	1-7 to 3-11-74	64	2
2	1-28 to 7-8-74	162	55
3	1-28 to 10-20-74	266	22
4	5-15 to 10-7-74	146	0
5	8-21-74 to 3-17-75	209	17
6	1-20 to 10-29-75	283	35
7	3-19 to 5-5-75	48	0
8	4-15-75 to 12-17-75	200	2
9	5-18 to 7-31-75	75	0
10	7-23-74 to 12-17-75	101	0
11	9-11 to 11-19-75	70	0
12	10-6 to 11-11-75	35	0
13	10-22 to 11-12-75	22	0
	TOTAL	1683	133

*As of December 17, 1975.
+As of October 31. 1975.

Anticyclonic eddy movement is basically to the west or southwest, but is often interrupted for extensive periods, at which time the eddies seem to remain stationary (trajectories 1, 2, 3, 4, 5, and 8). Some trajectories are terminated after only a short lifetime, indicating recapture by the Gulf Stream as reported by Gotthardt and Potocsky (1974) (trajectories 7, 9, 11, 12, and 13). Mean translational speeds for five eddies that were observed for extended periods vary between 3.3 and 4.5 nmi/day (table 2). Mean translational speeds sometimes appear to increase west of longitude 71° or 72°W as discussed by Gotthardt (1973b). This type of behavior was exhibited by eddy number 5 (table 2).

Table 2.--Anticyclonic eddy translation rates

Anti-cyclonic eddy	Calculated translational speeds	Mean Speed	Mean speed west of 71°W
	nmi/day	nmi/day	nmi/day
2	3.0, 5.0, 4.0, 2.0	3.5	4.0
3	6.0, 3.0, 1.0, 8.0	4.5	2.0
5	3,0, 2.0, 3.0, 8.0	4.0	10.0
6	7.0, 3.0, 2.0, 1.0	3.3	3.0
8	6.0, 2.0, 3.0, 3.0	3.5	4.0
	Overall mean:	3.8	

An envelope of all 13 plotted eddy trajectories, shown together with the bathymetry in figure 14, covers almost the entire area of DWD 106. The envelope lies approximately between lat. 37° to 41°N and long. 63° to 74°W and is similar to the plotted paths of five anticyclonic eddies reported by Gotthardt (1973b). Width of the envelope decreases from about 100 nmi in the northeast to less than 60 in the southwestern section. The envelope appears to parallel the bathymetry of the continental rise from long. 63° to 66°W at depths of greater than 4,000 meters. However, between long. 66° and 71°W, the envelope is oriented at an oblique angle to the bathymetry, or upslope, and the depth within the envelope decreases rapidly from about 4,000 m to approximately 2,500 m in a westerly direction. At 71°W the envelope is again parallel to the bathymetry at a depth of approximately 2,500 m.

Hydrographic Surveys and Mean Anticyclonic Eddy Diameter

The northern boundary or "north wall" of the Gulf Stream has for some time been defined by the 15°C isotherm at 200 m (Fulgister and Voorhis 1965). This feature was chosen because it approximates the center of the temperature gradient along the northern or western edge of the Gulf Stream. Also, the intersection of the 15°C surface and the 200-m surface usually is directly below the maximum surface current. According to the model for formation of anticyclonic eddies, it is the northern boundary of the Gulf Stream that forms the outermost edge or perimeter of the eddy, its position and extent being established by the 15°C isotherm at 200 m.

Inspection of subsurface temperature data supplied by scientific, military, and commercial vessels from the northwestern Atlantic during 1974 and 1975 has aided greatly in tracking anticyclonic eddies. More important, however, these data describe the subsurface nature of the eddies. For example, six survey crossings of eddy 2 were completed during the late winter and spring seasons of 1974. On February 5 an airborne expendable bathythermograph (AXBT) survey of eddy 2 was conducted by NAVOCEANO and revealed a well-developed eddy centered at approximately 39° 26'N, 67° 55'W (fig. 15). Satellite imagery on February 11 agreed closely with the measured position. The AXBT section shows the eddy to be over 100 km in diameter (15°C at 200 m) with 16°C water extending to 300 m. However, Saunders (1971) reported an accuracy of ±0.5°C for AXBT temperature measurements and an unknown depth accuracy. All AXBT measurements must be used with caution because of these errors.

The USCGC Dallas as part of a shelf dynamics experiment (Flagg and Beardsley 1975) conducted a hydrographic cruise between February 28 and March 4. Temperature, salinity, and sigma-t for section 3 from this cruise (fig. 16) showed the edge of eddy 2 to have high-salinity, 14°C water to a depth of 190 m and the characteristic downwarping of the sigma-t isopleths. The USCGC Evergreen conducted a temperature survey--during Search and Rescue cruise 2 (SAR-2)--beyond the shelf edge in early March. This survey showed eddy 2 much more clearly (fig. 17). The structure was similar to that shown in the February AXBT survey. RV Verrill cruise I, II, and III conducted between March 14 and April 4 (Flagg and Beardsley 1975) showed the presence of eddy 2. A cross-shelf section from Verrill cruise III is depicted in figure 18. The Albatross IV section (fig. 19) also defines the presence of eddy 2 in late March. The New York to Bermuda temperature sections of May 12-20 and 23-25 (fig. 20) show "anticyclonic eddy #1 "just south of Long Island. This is identical with eddy 2 in this paper.

The numerous subsurface sections confirm the rather slow translation rate and meandering nature of eddy 2 as implied by satellite imagery. Apparently eddy 2 also made some contact with the upper continental slope. This is suggested by certain previous sections and by Chamberlin (1975), who presented data showing an anomalous warming trend for March 1974 off southern New England at depths less than 400 m.

Although eddy 3 formed at approximately the same time as eddy 2, it was not surveyed from a ship until the middle part of July when it was reported as "anticyclonic eddy #2" within the New York to Bermuda temperature sections (fig. 20). The position of eddy 3 as determined by the New York-Bermuda XBT sections agrees well with the positions derived from satellite imagery. The USCGC Evergreen surveyed eddy 3 during Search and Rescue cruise 3 (SAR-3) in August 1974. A resulting temperature section is shown in figure 21. Water of 15°C temperature extends to over 350 m in the center, and the diameter (15°C at 200 m) is approximately 70 km. The USCGC Ingham (1974 SOOP) traversed eddy 3 at about 37°N, 74°W on October 20, 1974 (figs. 5

and 22) (Cook and Hausknecht 1974). The eddy appeared to be very weak, as the 15° C isotherm barely reached the 200-m level. This crossing of eddy 3 was about 2 months after its last observed position shown by satellite imagery.

The RV Eastward (cruise 14) traversed a small-scale warm feature near 39°56'N, 71°20'W on September 19, 1974 (fig. 23). This feature, however, does not appear to be an anticyclonic eddy because of its small size and the lack of any indication of an eddy in satellite data for the area.

Eddy 6 was surveyed twice while in the vicinity of DWD 106. On June 29, 1975, eddy 6 was crossed twice (fig. 24) as reported by Cheney (1975) and Cheney and Richardson (1975). The maximum depth of the 15° C isotherm was 520 m, making this eddy one of the most pronounced ever observed. The diameter of the eddy was approximately 120 km (15° C isotherm at 200 m). The eddy was surveyed again in late July by Albatross IV (fig. 25) after it had traveled approximately 30 nmi west-southwest since the late June survey (Goulet 1975). Its center then was located just to the east of DWD 106. The maximum depth of the 15° C isotherm was again measured to be approximately 500 m. Both the June and the July eddy position determinations agreed well with those derived through analysis of satellite imagery.

Eddy 8 was traversed by the USCGC Evergreen (ship of opportunity) on April 28, 1975 near 41°15'N, 66°00'W just east of Georges Bank. The 15° C isotherm extended to approximately 200 m (fig. 26) (Cook 1975). The position agrees well with the eddy's position as shown on May 2 in the April 1975 gulfstream. The distribution of colder water above the warmer water of eddy 8 (fig. 26) may be explained by recognizing that the subsurface shape of an anticyclonic eddy shows a maximum width of warmer water at some mid-depth (see eddy 2, figs. 15 and 17). The USCGC Evergreen temperature section was taken along the northern edge of eddy 8 as shown by satellite imagery and represents a vertical slice through the bulge of warmer water extending horizontally beyond the upper and lower limits of the eddy. Between September 20 and October 23, 1975, eddy 8 was traversed three times by the 1975 SOOP Argo and Rigal between New York and Bermuda. The Argo crossed eddy 8 on October 22 to 23 as shown in figure 27, which depicts the eddy's structure most clearly (Cook 1975). The 15° C isotherm extends to 300 m, and the diameter is approximately 110 km (15° C at 200 m). The center of eddy 8, as reported by satellite imagery on October 22 (fig. 10), was located approximately 30 nmi due east of the Argo crossing as shown in figure 27, and approximately 60 to 70 nmi east of the center of DWD 106.

Based on all recent subsurface temperature data and data from the literature, a conservative estimate for the mean diameter of anticyclonic eddies would be on the order of 100 km, or roughly 60 nmi. This would yield a mean radius of 50 km, or about 30 nmi for the actual subsurface eddy as defined by the position of the 15° C isotherm at 200 meters depth. It is interesting to note that a mean diameter of 100 km was also determined from a consideration of five anticyclonic eddies by Pickett (1972).

Gotthardt (1973b) proposed a regression equation relating longitude to anticyclonic eddy areas (as defined by the 15° C isotherm at 200 m). The equation, determined from five anticyclonic eddies, is:

$$\text{Area } (km^2) = K - 329 \text{ longitude } (°)$$

$$\text{where} \quad k = 26197 \ km^2/(°)$$

Substituting a longitude of 72° (that of DWD 106) yields a radius of approximately 30 km, or 17 nmi. This generally agrees within an order of magnitude with the 50-km or 30-nmi radius determined in this study.

ANALYSIS OF 1974 AND 1975 ANTICYCLONIC EDDY DATA

Using the mean anticyclonic eddy radius of 30 nmi, an area within the generalized anticyclonic eddy trajectory envelope may be delineated (dark shaded portion of fig. 14) about DWD 106. This area was used to calculate the amount of time each of the 13 anticyclonic eddies spent within DWD 106. Since the "average" anticyclonic eddy possesses a mean radius of 30 nmi, the center of an eddy plotted within the critical sector would indicate that DWD 106 was wholly or partially occupied by that eddy. Using these spatial criteria, the period each of the 13 eddies spent within DWD 106 was determined (fig. 28 and table 1). Lifetimes of anticyclonic eddies vary almost by an order of magnitude from 22 days to 283 days and generally agree with Saunders (1971) calculated lifetime of 6 months to 1 year based on heat loss and dissipation of kinetic energy considerations. The amount of time spent by an anticyclonic eddy within DWD 106 varied between 55 days and 0 days for eddies which either dissipated or were entrained into the Gulf Stream before reaching the DWD 106 sector.

The following calculations and results are summarized in table 3. Of the total 1,683 eddy days (1 eddy day is equivalent to 1 anticyclonic eddy existing for one day) shown in table 3, 7.9 percent (133 days) were within DWD 106 as defined above. Viewed another way, during 1974 an anticyclonic eddy (as defined by the 15° C isotherm at 200 m) was located within DWD 106 about 21.6 percent of the time. From January 1 through October 31, 1975, an anticyclonic eddy was located within DWD 106 approximately 17.8 percent of the time. The mean residence time for an anticyclonic eddy at DWD 106, based on the six anticyclonic eddies located within DWD 106 during 1974 and part of 1975, was found to be on the order of 22 days.

Table 3.--Summary of calculations

Total eddy days considered for 1974 and partial 1975:	1,683
Total eddy days spent in DWD 106 for 1974 and partial 1975:	133
Percentage of total eddy days spent in DWD 106 for 1974 and partial 1975:	7.9%
Percent of time in 1974 for which an anticyclonic eddy was wholly or partially within DWFD 106:	21.6%
Percent of time in partial 1975 for which an anticyclonic eddy was wholly or partially within DWD 106:	17.8%
Mean residence time for an anticyclonic eddy at DWD 106:	22 days

CONCLUSIONS

This analysis should be interpreted as preliminary because only 22 months of data were used. However, the calculations suggest that:

1. Three anticyclonic eddies may be expected to affect the dumpsite each year;

2. The average residence time for an eddy within the dumpsite is approximately 22 days; and

3. The dumpsite can be wholly or partially occupied by anticyclonic eddies about 20 percent of the time or about 70 days each year.

Although 1 or 2 years of data analysis represent only a beginning at characterizing the water mass types and circulation at Deepwater Dumpsite 106, it is clear that anticyclonic eddies have been a significant aspect of the physical environment at DWD 106 for the past 2 years.

REFERENCES

Chamberlin, J. L. 1975. Bottom temperatures on the continental shelf and slope south of New England during 1974. Manuscript for 1974 Status of the Environment Report, National Marine Fisheries Service, NOAA, Department of Commerce.

Cheney, R. E. 1975. A comparison of various Gulf Stream ring structures, gulfstream 1(7):6-7.

Cheney, R. E., and P. L. Richardson. 1975. Distribution of Gulf Stream rings in the northwestern Sargasso Sea, MODE Hot Line News No. 79, Woods Hole Oceanographic Institution, Woods Hole, Mass. 02543.

Cook, S. K., and K. A. Hausknecht. 1975. Environmental conditions in the Gulf of Mexico and Western North Atlantic as observed from NMFS/MARAD Ships of Opportunity for 1974. Manuscript for 1974 Status of the Environment Report, National Marine Fisheries Service, NOAA, Department of Commerce.

Cook, S. K. 1975. Unpublished data. NMFS/MARAD Ships of Opportunity for 1975. Atlantic Environmental Group, National Marine Fisheries Service, Narragansett, R.I. 02882.

Flagg, C. N., and R. C. Beardsley. 1975. Report on the 1974 M.I.T. New England Shelf Dynamics Experiment, Part I, Hydrography, Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Mass., and Woods Hole Oceanographic Institution, Woods Hole, Mass. (National Science Foundation Grants GA-41075 and DES 74-03001).

Fuglister, F. C. 1971. Cyclonic rings formed by the Gulf Stream 1965-66, in Studies in Physical Oceanography--A tribute to George Wüst on his 80th birthday, Volume I, A. L. Gordon (ed.), pp. 137-168, Gordon and Breach.

Fuglister, F. C., and L. V. Worthington. 1951. Some results of a multiple ship survey of the Gulf Stream, Tellus 3(1):1-14.

Fuglister, F. C., and A. D. Voorhis. 1965. A new method of tracking the Gulf Stream, Limnol. Oceanogr. Suppl. 10:R115-R124.

Gotthardt, G. A. 1973a. Observed formation of a Gulf Stream anticyclonic eddy. J. Phys. Oceanogr. 3(2):237-238.

Gotthardt, G. A. 1973b. Gulf Stream eddies in the western north Atlantic NAVOCEANO Tech. Note 6150-16-73, 42 pp.

Gotthardt, G. A., and G. J. Potocsky. 1974. Life cycle of a Gulf Stream anticyclonic eddy observed from several oceanographic platforms, J. Phys. Oceanogr. 4(1):131-134.

Goulet, J. R., Jr. 1975. Physical Oceanography of Deep Water Dumpsite 106 Update: July, 1975. Atlantic Environmental Group, NMFS, Narragansett, R. I. 02882.

Iselin, C.O'D. 1936. A study of the circulation of the western North Atlantic, Pap. Phys. Oceanog. Met. 4(4):1-101.

Iselin, C. O'D., and F. C. Fuglister. 1948. Some recent developments in the study of the Gulf Stream, J. Mar. Res. 7(3):317-329.

Khedouri, E., and W. Gemmill. 1974. Physical properties and energy distribution of Gulf Stream eddies, NAVOCEANO Tech. Note 6150-22-74. 25 pp.

National Weather Service. 1975. Gulfstream 1(1 through 9), National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

National Environmental Satellite Service. 1974-1975. Experimental Gulf Stream Analysis Charts (N-69), National Oceanic and Atmospheric Administration, Washington, D. C. 20233.

Pickett, R.L. 1972. Self-induced eddy drift, The Gulf Stream Monthly Summary 7(6):3.

Saunders, P.M. 1971. Anticyclonic eddies formed from shoreward meanders of the Gulf Stream, Deep-Sea Res. 18:1207-1219.

Thompson, B. J., and G. A. Gotthardt. 1971. Lifecycle of a north Atlantic eddy. Trans. Amer. Geophys. Union 52(4):241.

Uchupi, E. 1965. Map showing relation of land and submarine topography Nova Scotia to Florida, U.S. Geological Survey Map I-451, Reston, Va.

U.S. Naval Oceanographic Office. 1974. The Gulf Stream Monthly Summary, 9(1 through 12), Washington, D. C.

U.S. Naval Oceanographic Office. 1974-75. Experimental Ocean Frontal Analysis Charts, Washington, D.C.

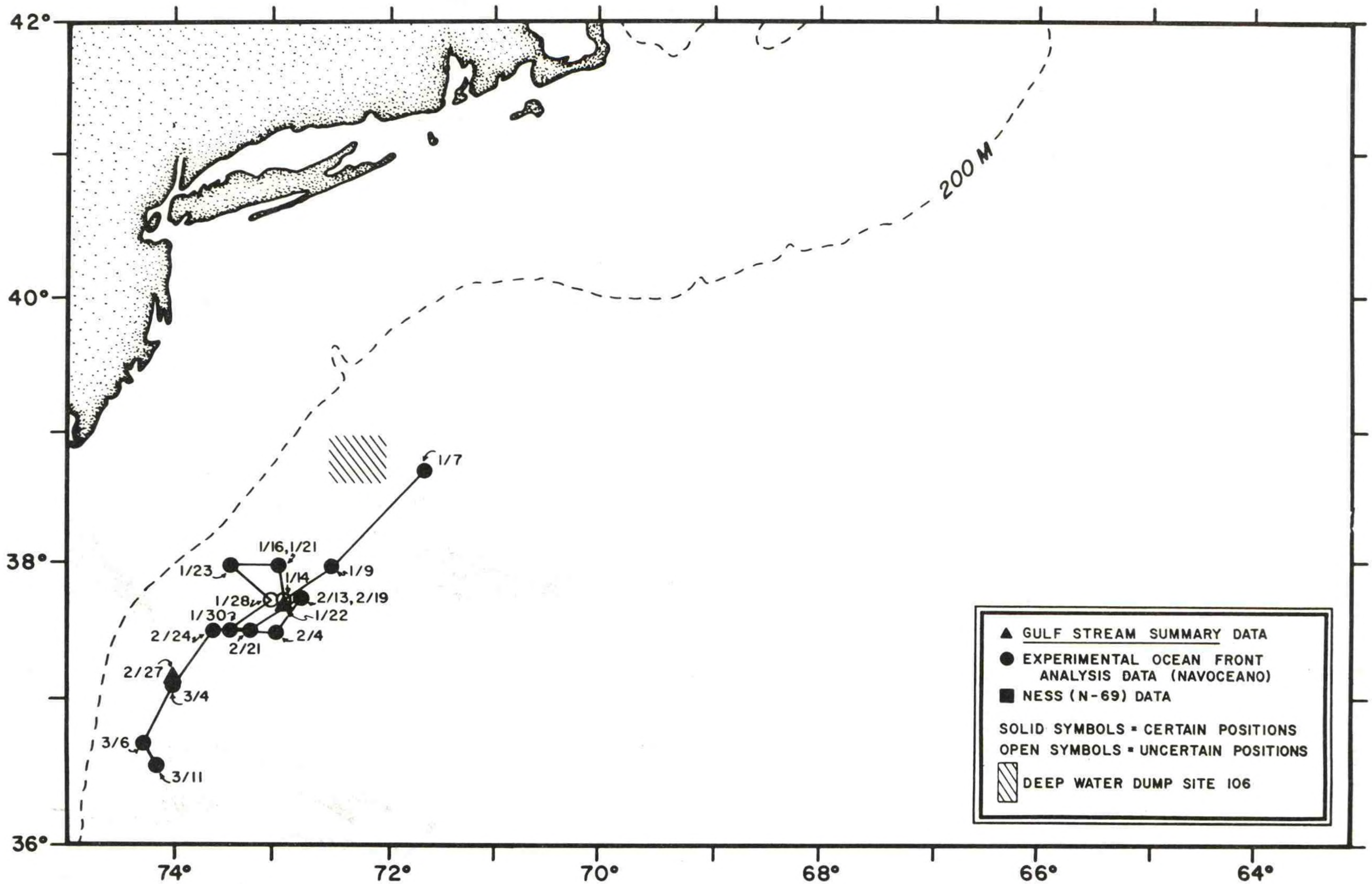


Figure 3.--Trajectory for anticyclonic eddy 1, Jan. 7-Mar. 11, 1974.

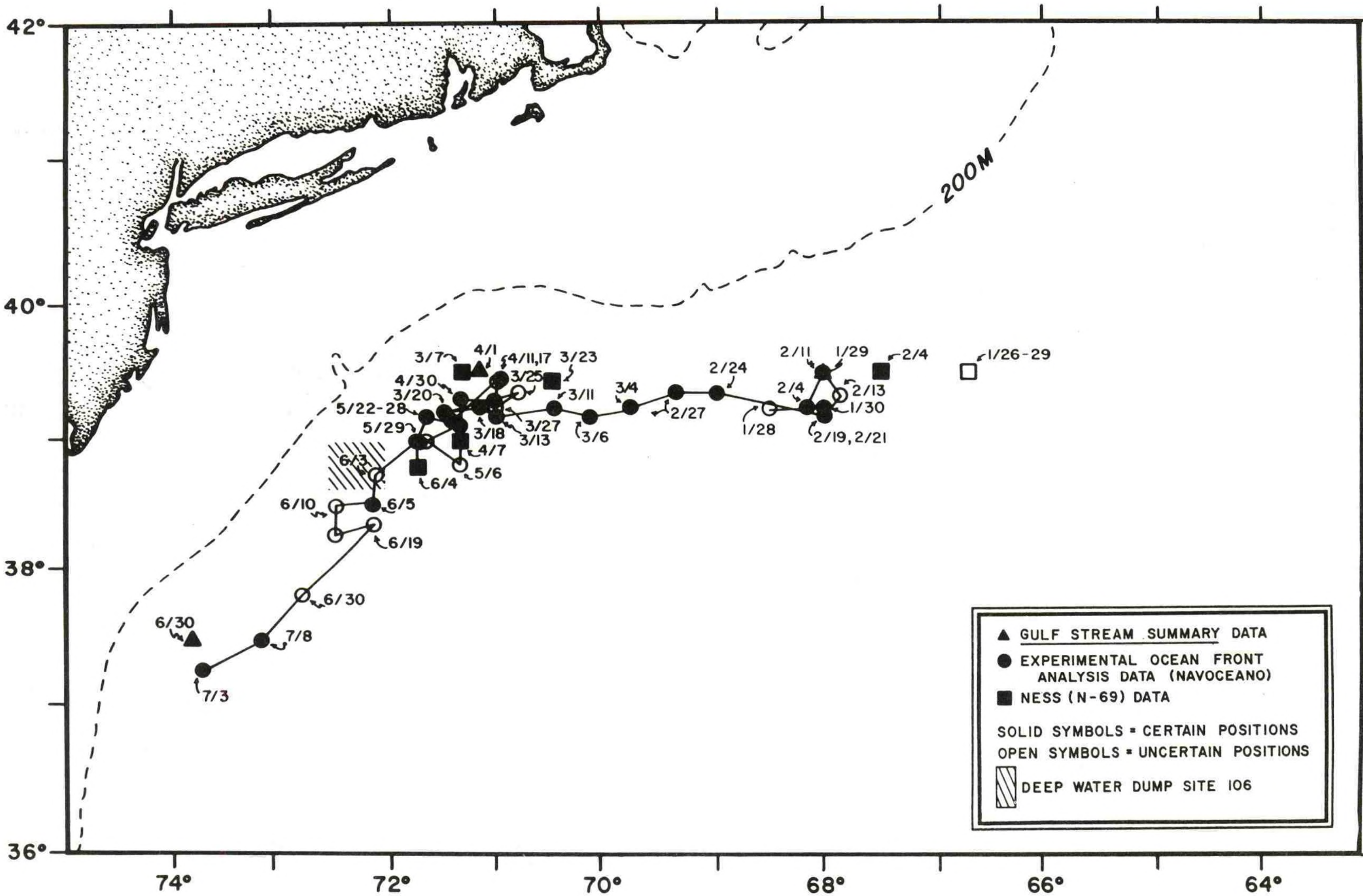


Figure 4.--Trajectory for anticyclonic eddy 2, Jan. 28-July 8, 1974.

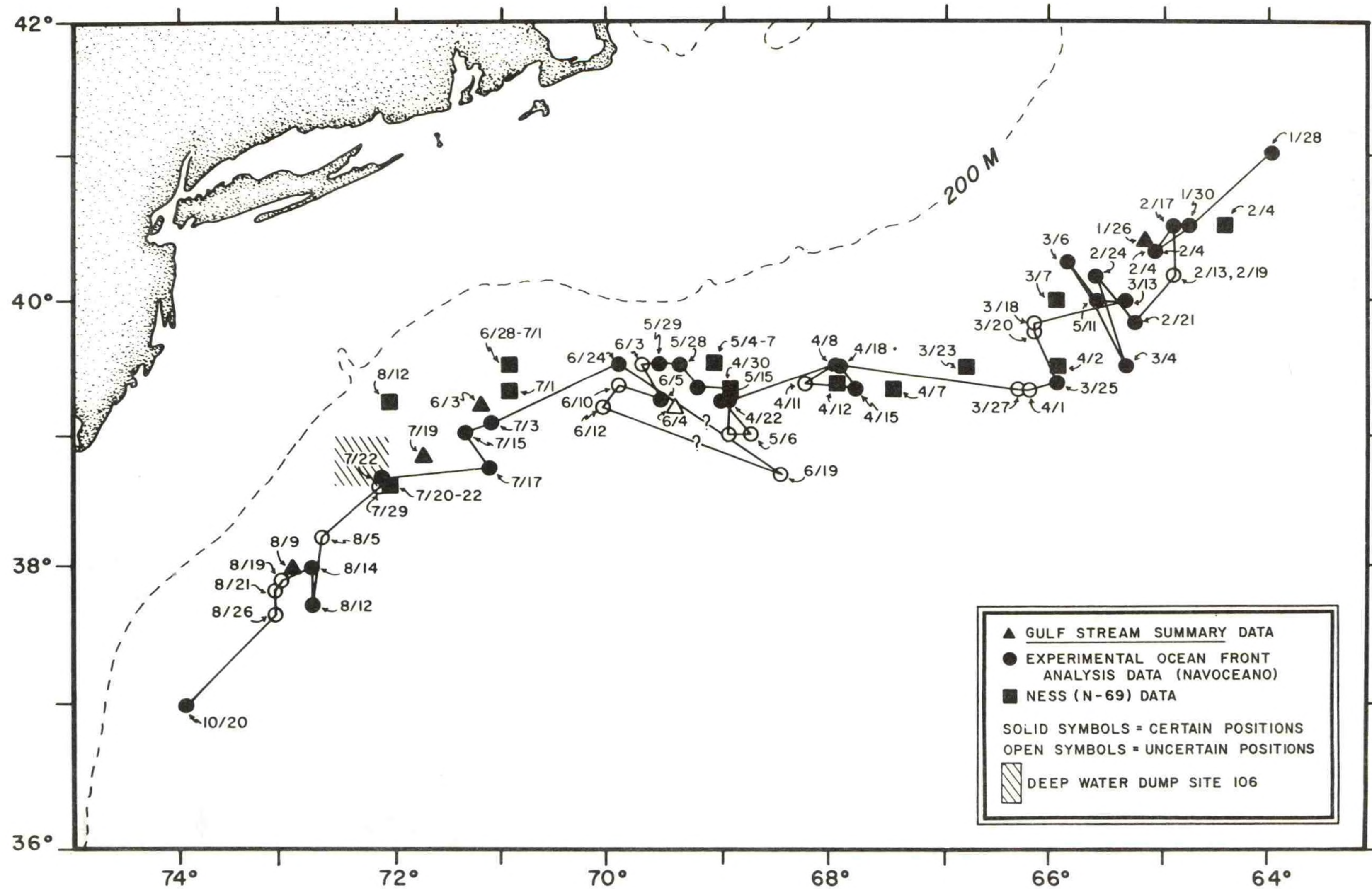


Figure 5.--Trajectory for anticyclonic eddy 3, Jan. 28-Oct. 20, 1974.

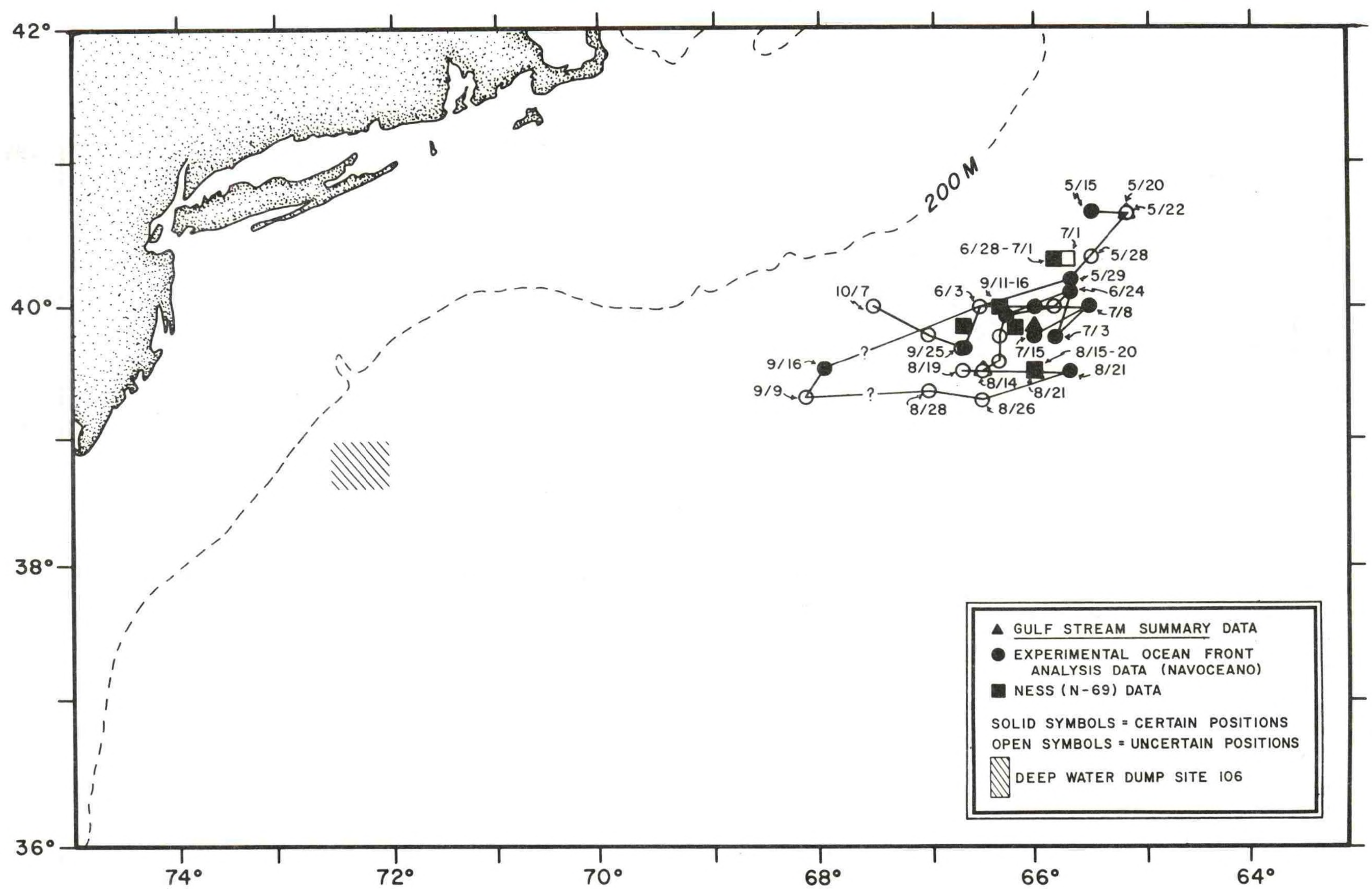


Figure 6.--Trajectory for anticyclonic eddy 4, May 15 --Oct. 7, 1974.

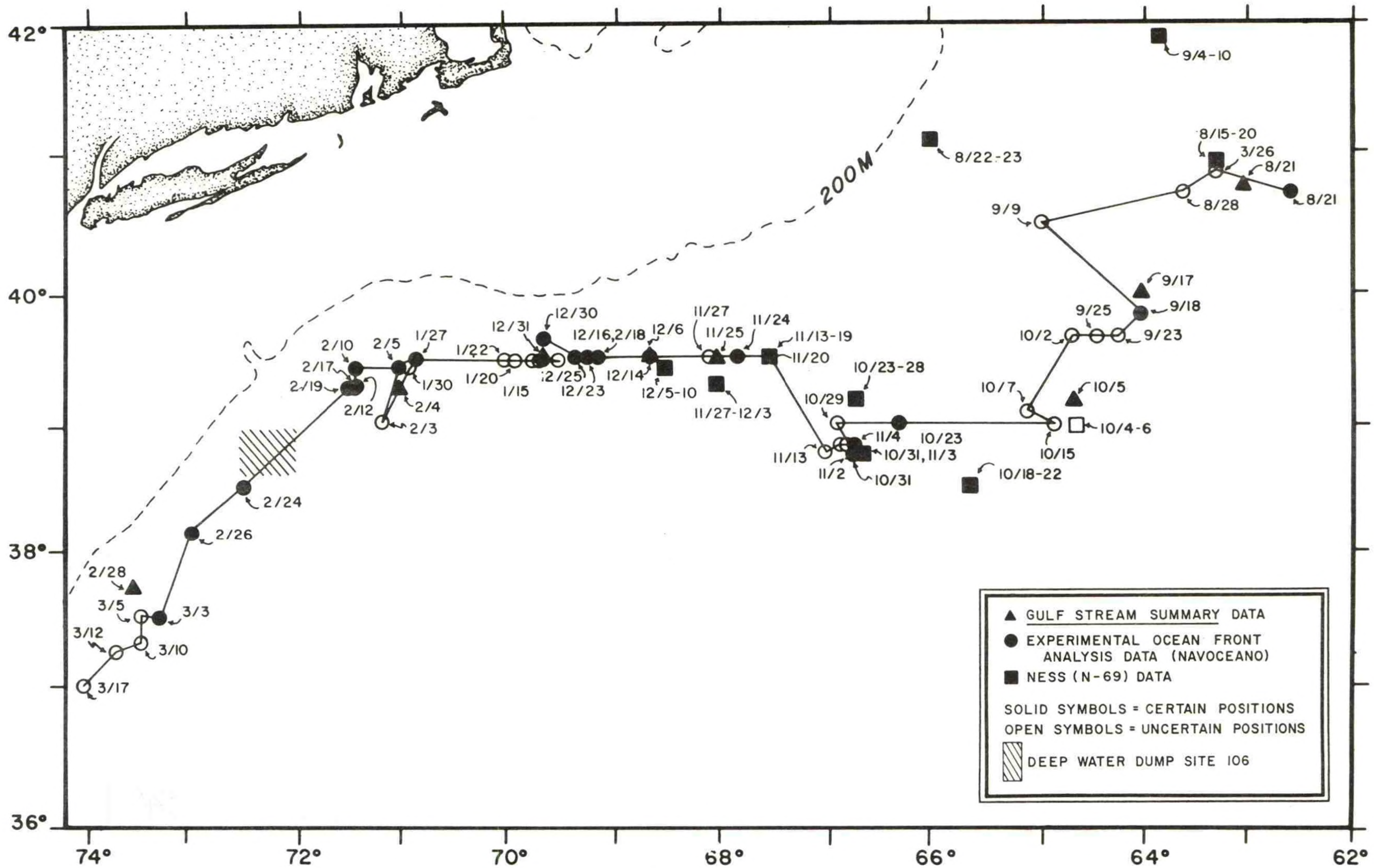


Figure 7.--Trajectory for anticyclonic eddy 5, Aug. 21, 1974-Mar. 17, 1975.

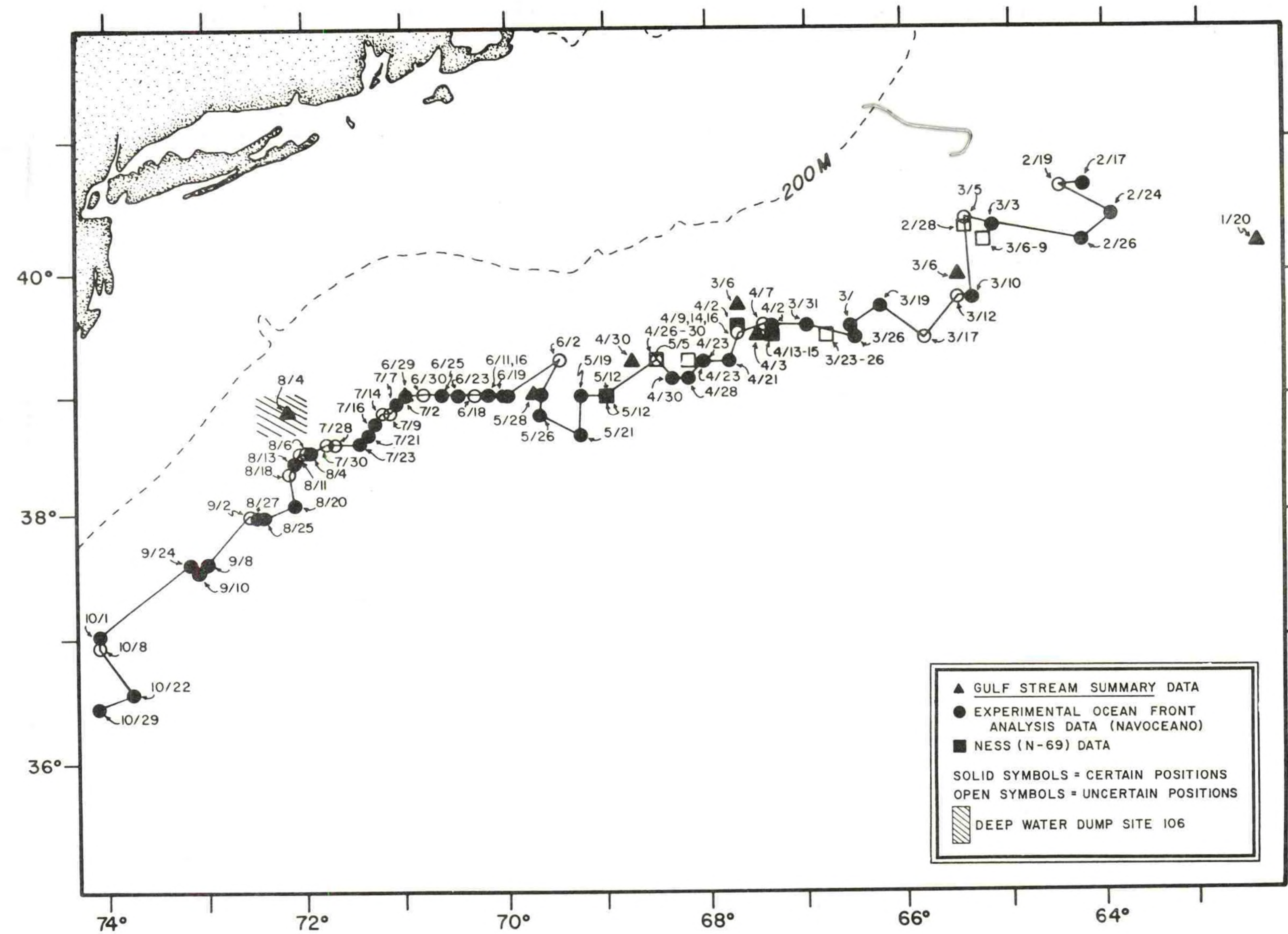


Figure 8.--Trajectory for anticyclonic eddy 6, Jan. 20-Oct. 10, 1975.

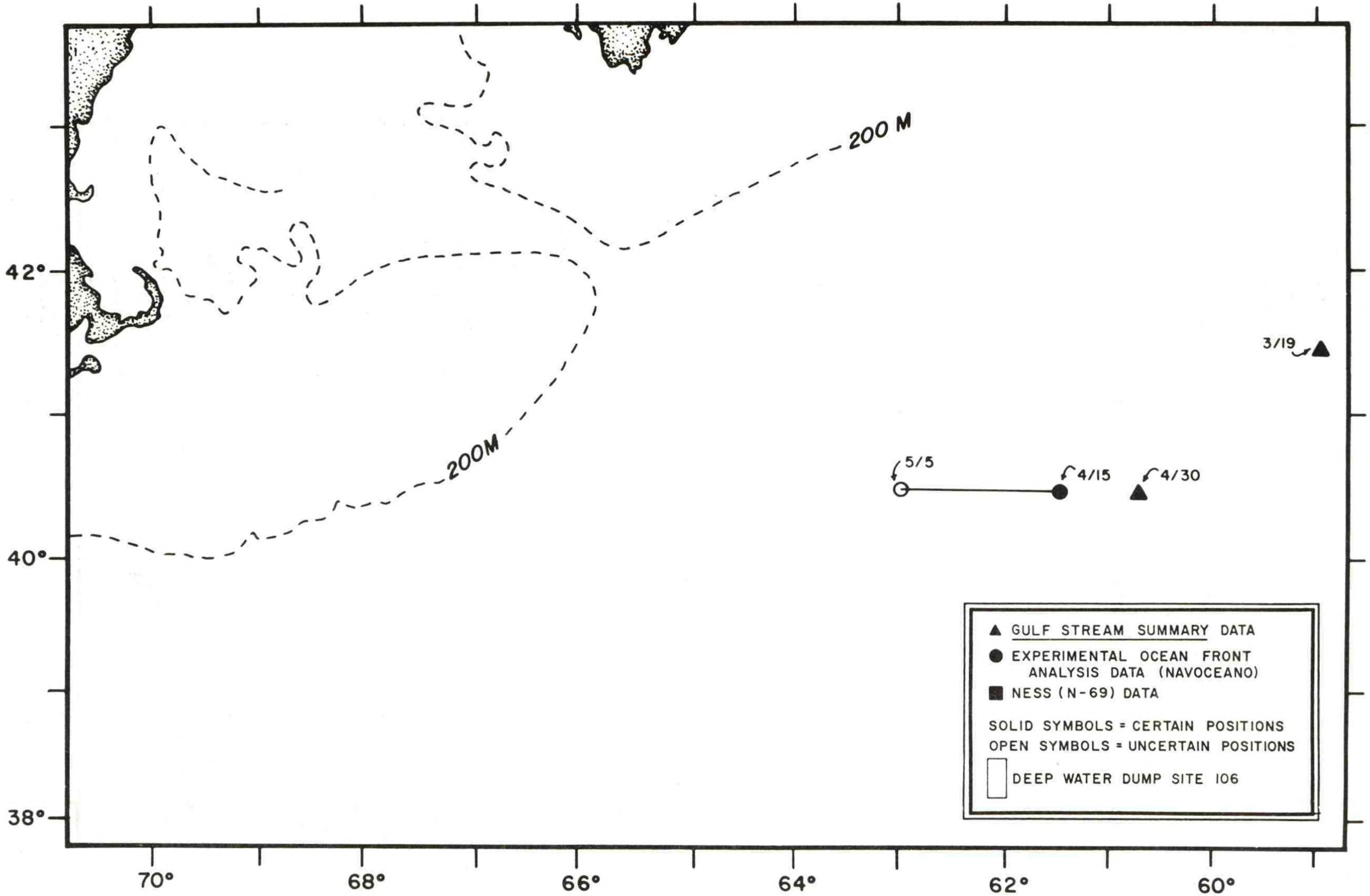


Figure 9.--Trajectory for anticyclonic eddy 7, Mar. 19-May 5, 1975.

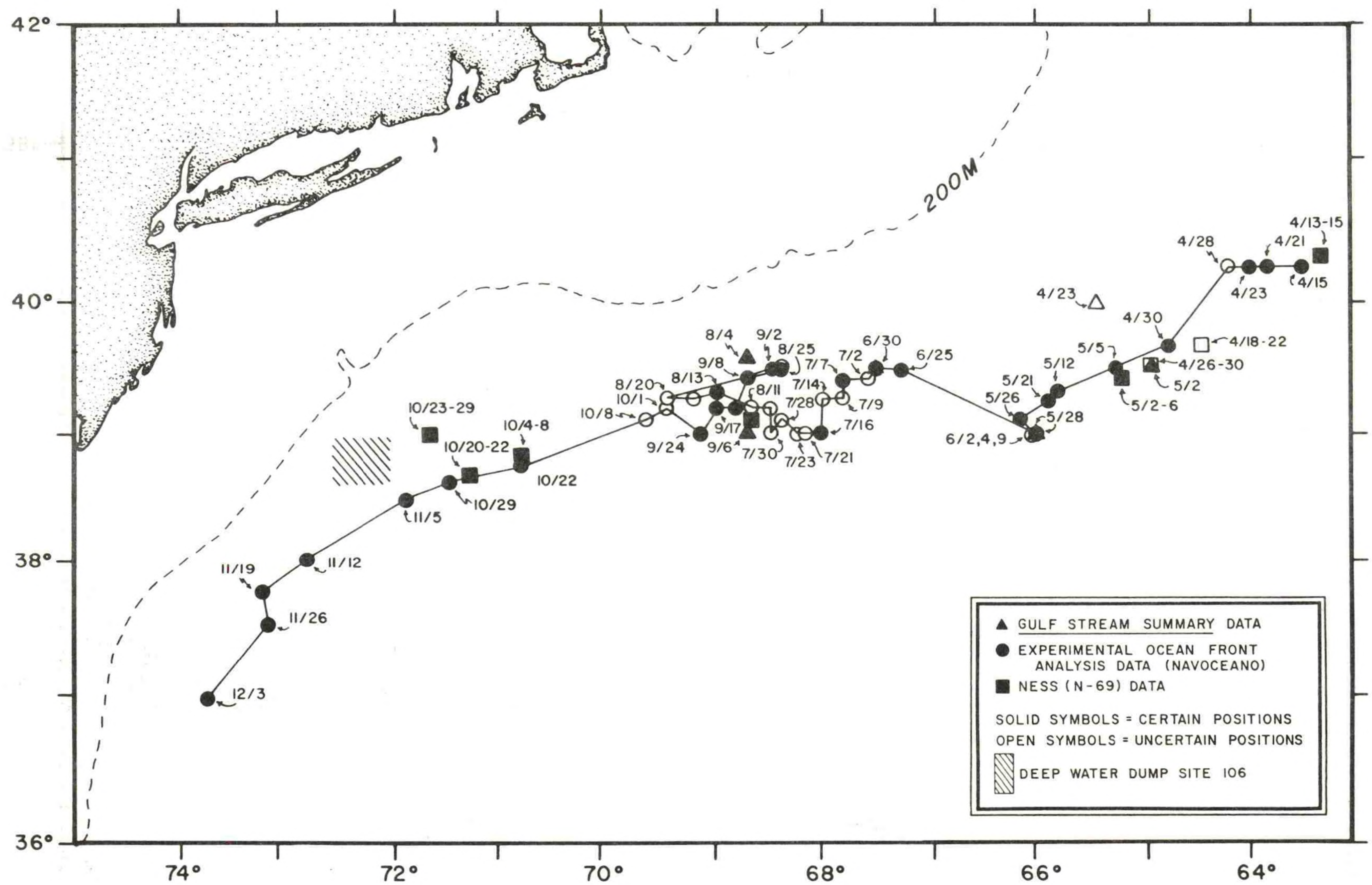


Figure 10.--Trajectory for anticyclonic eddy 8, Apr. 4-Dec. 17, 1975.

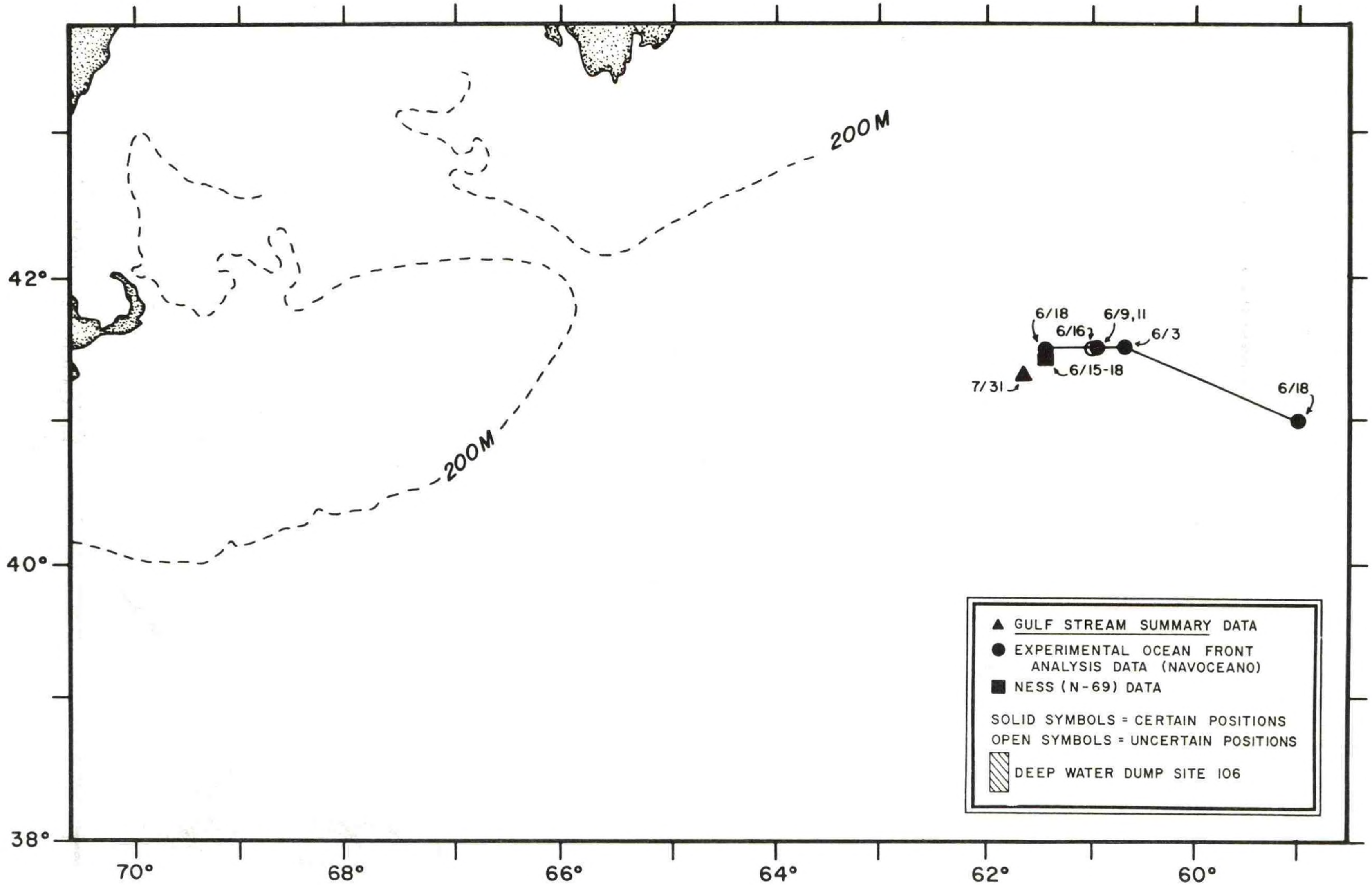


Figure 11.--Trajectory for anticyclonic eddy 9, May 18-July 31, 1975.

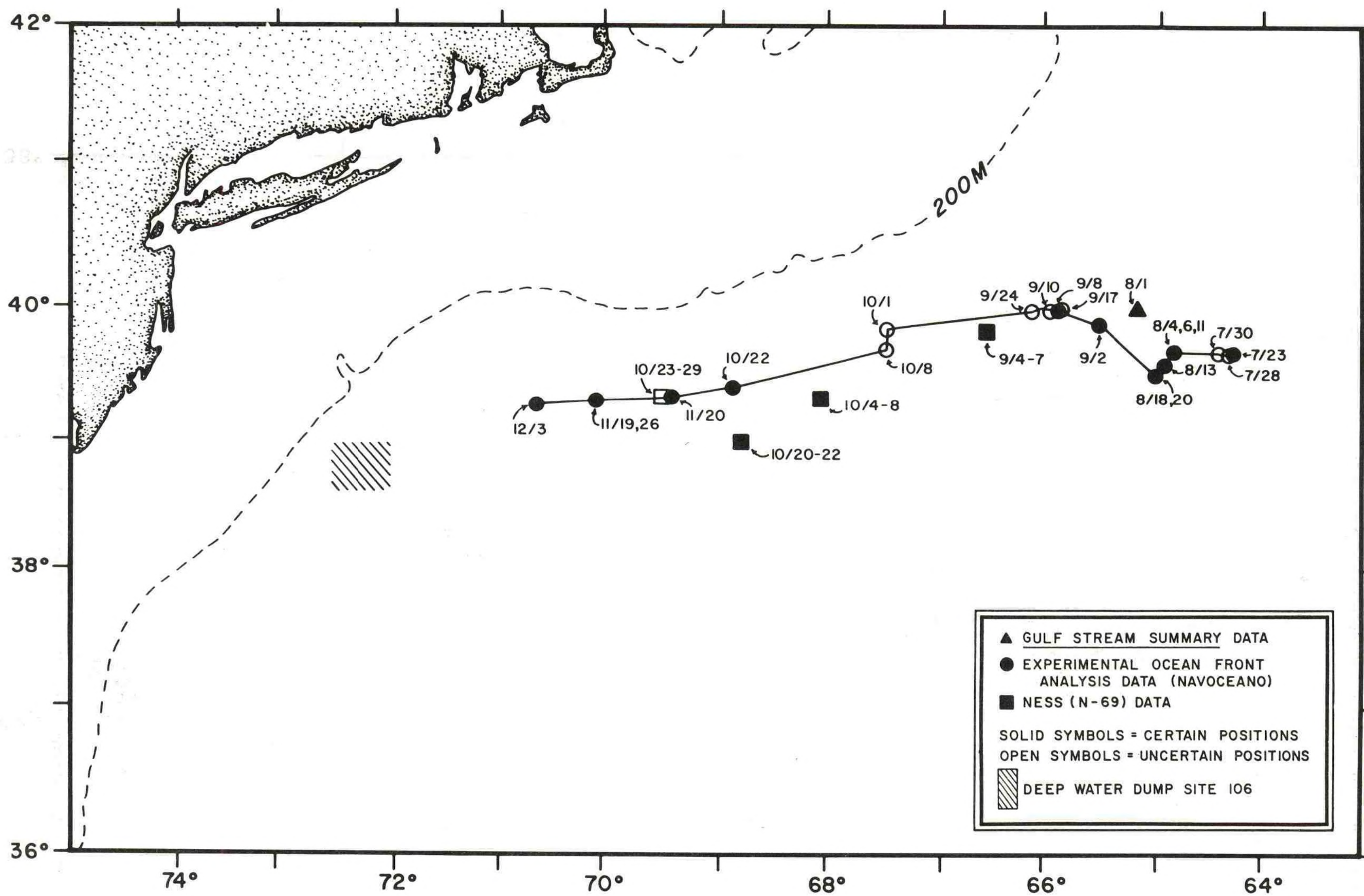


Figure 12.--Trajectory for anticyclonic eddy 10, July 23, 1974-Dec. 17, 1975

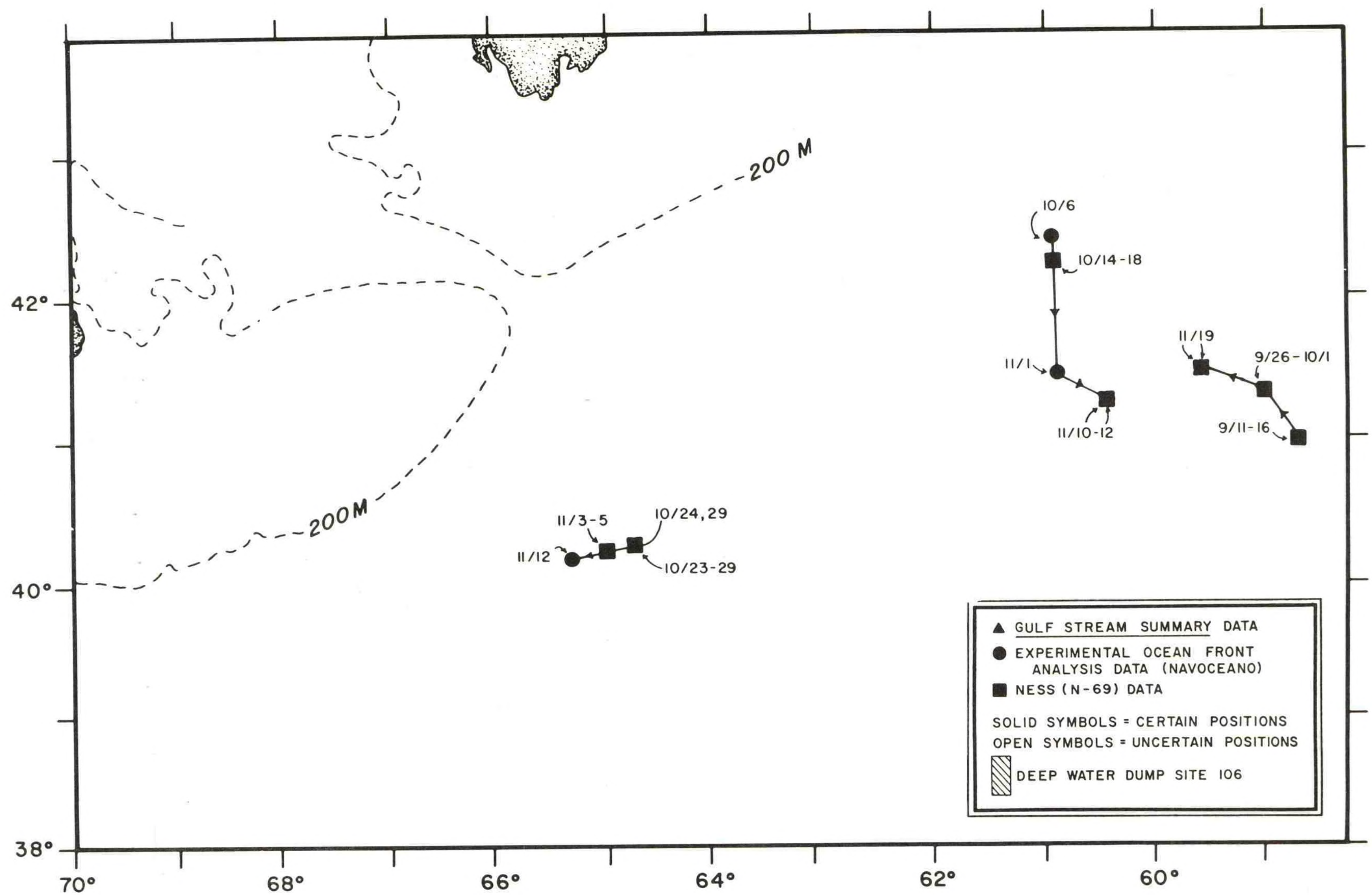


Figure 13.--Trajectories for anticyclonic eddies 11 (Sept, 11-Nov. 19, 1975), 12 (Oct. 6-Nov. 11, 1975), and 13 (Oct. 22-Nov. 12, 1975).

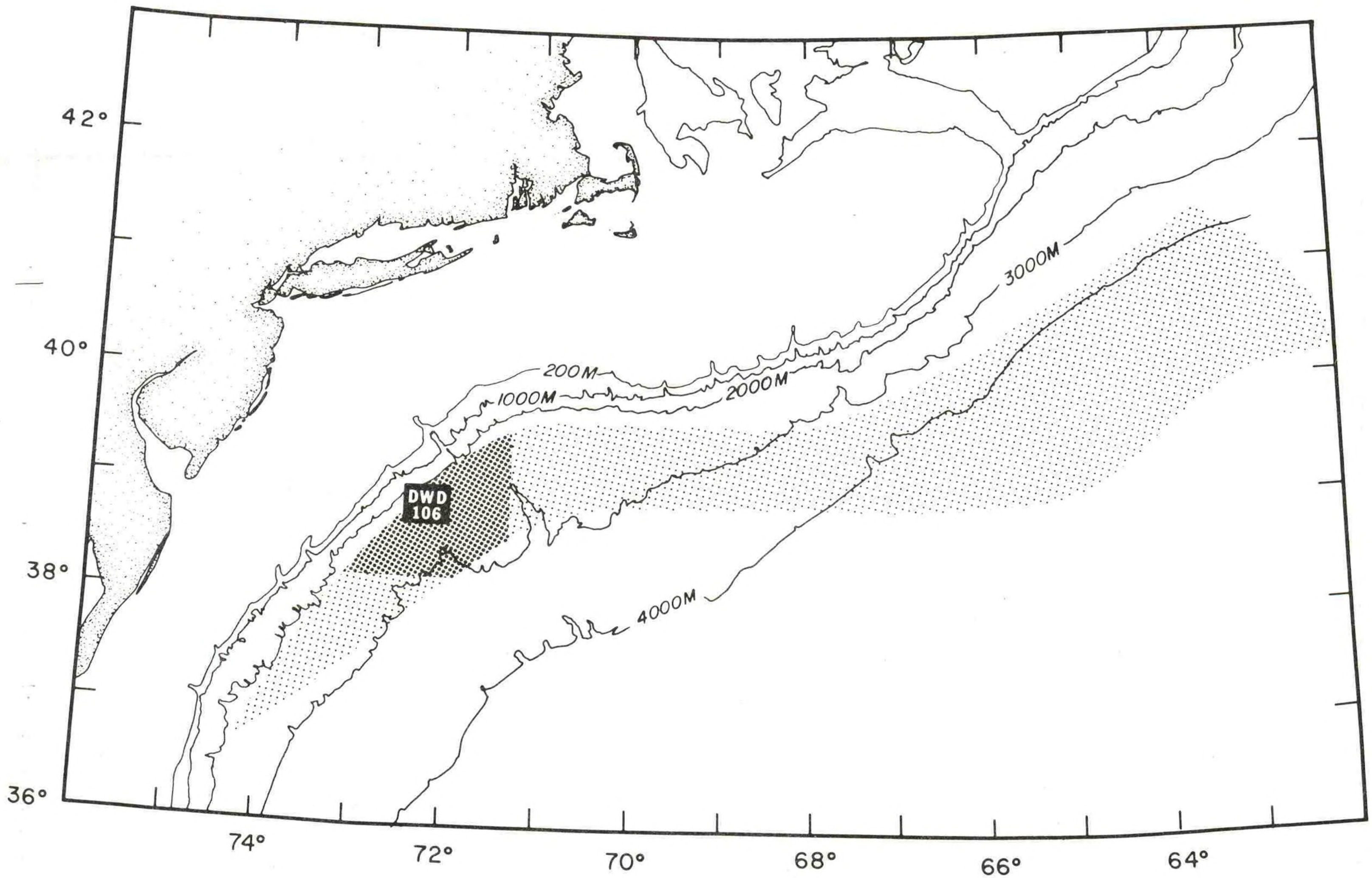
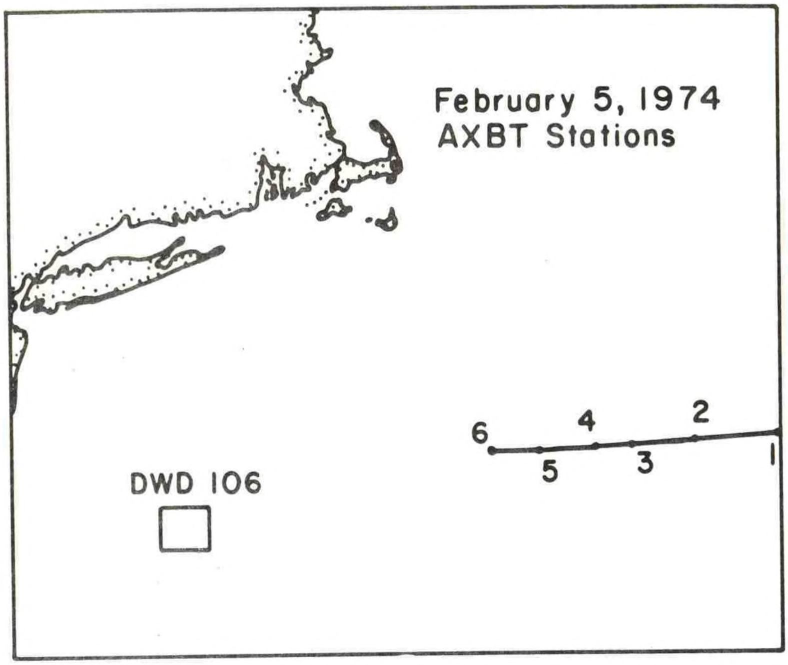


Figure 14.--Envelope for anticyclonic eddy trajectories (light shaded area) and critical sector about DWD 106 (dark shaded area). (Bathymetry after Uchupi 1975.)



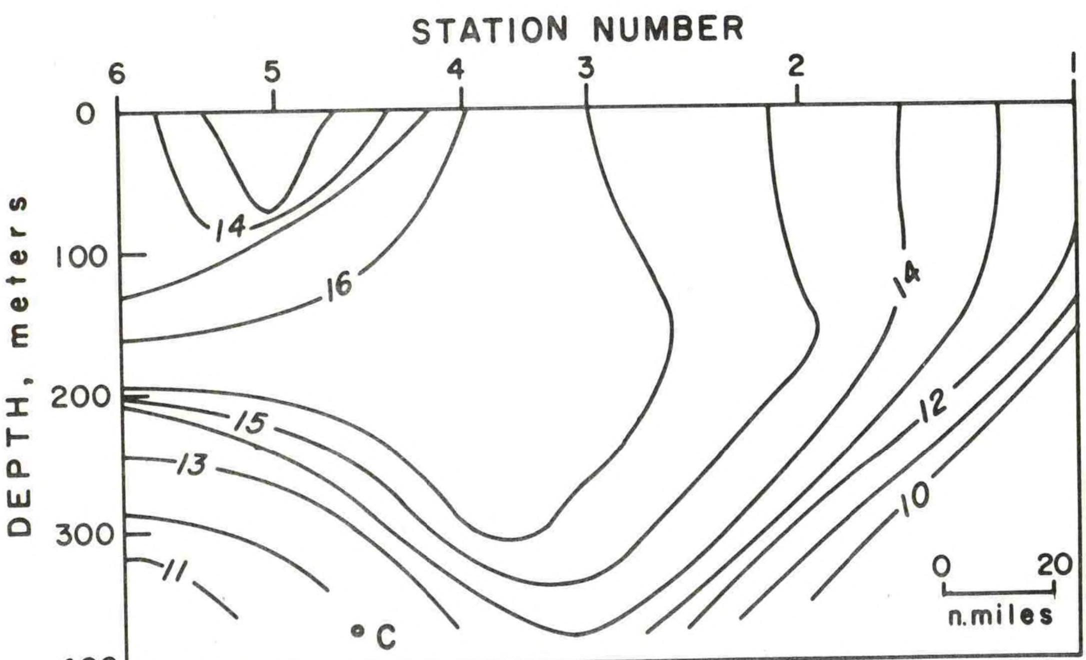


Figure 15.--Anticyclonic eddy 2--Feb. 5, 1974 AXBT Section (courtesy of A. Fisher. U.S. Naval Oceanographic Office).

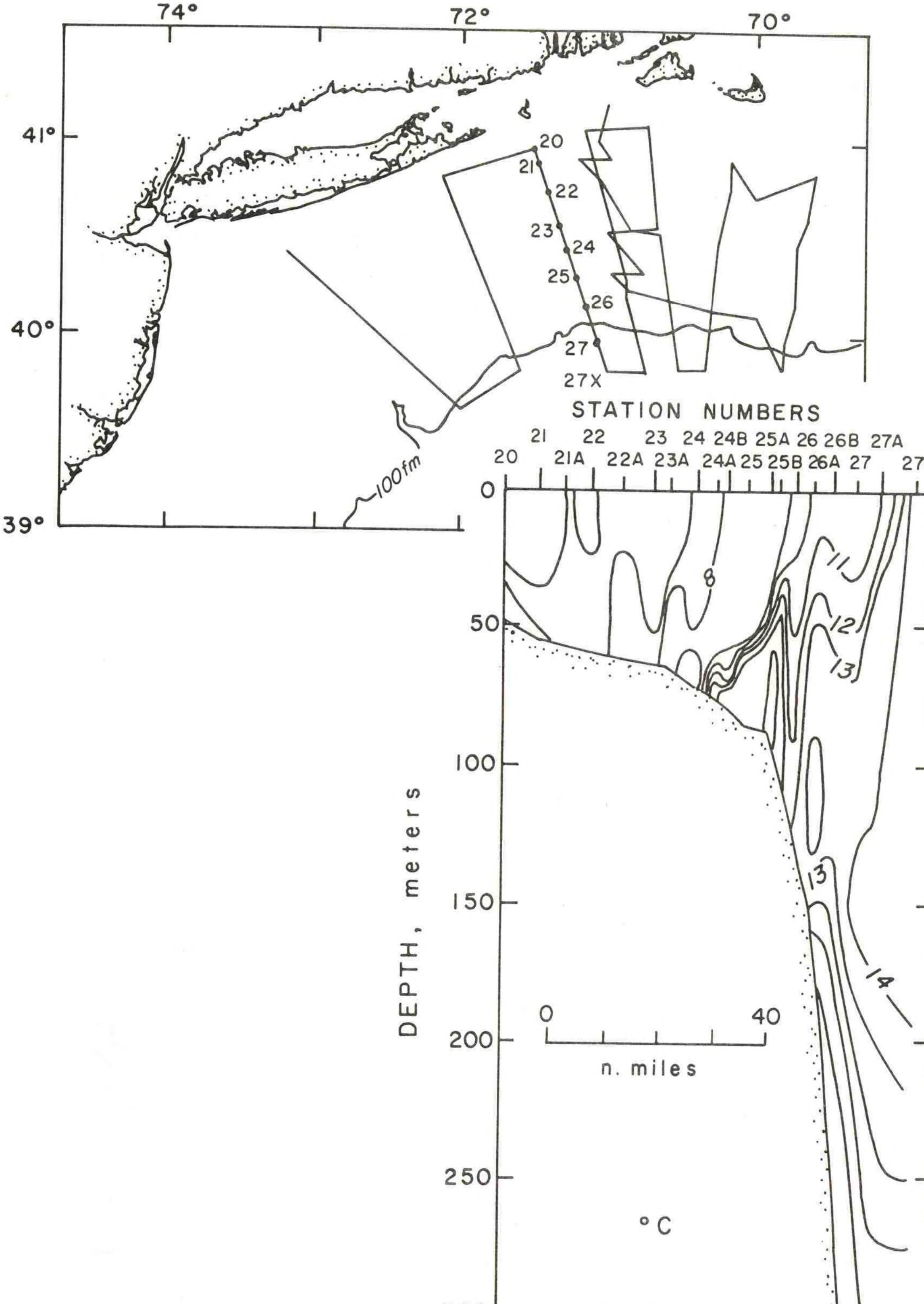


Figure 16.--Dallas cruise Feb. 28-Mar. 4, 1974, temperature section no. 3 (after Flagg and Beardsley 1975).

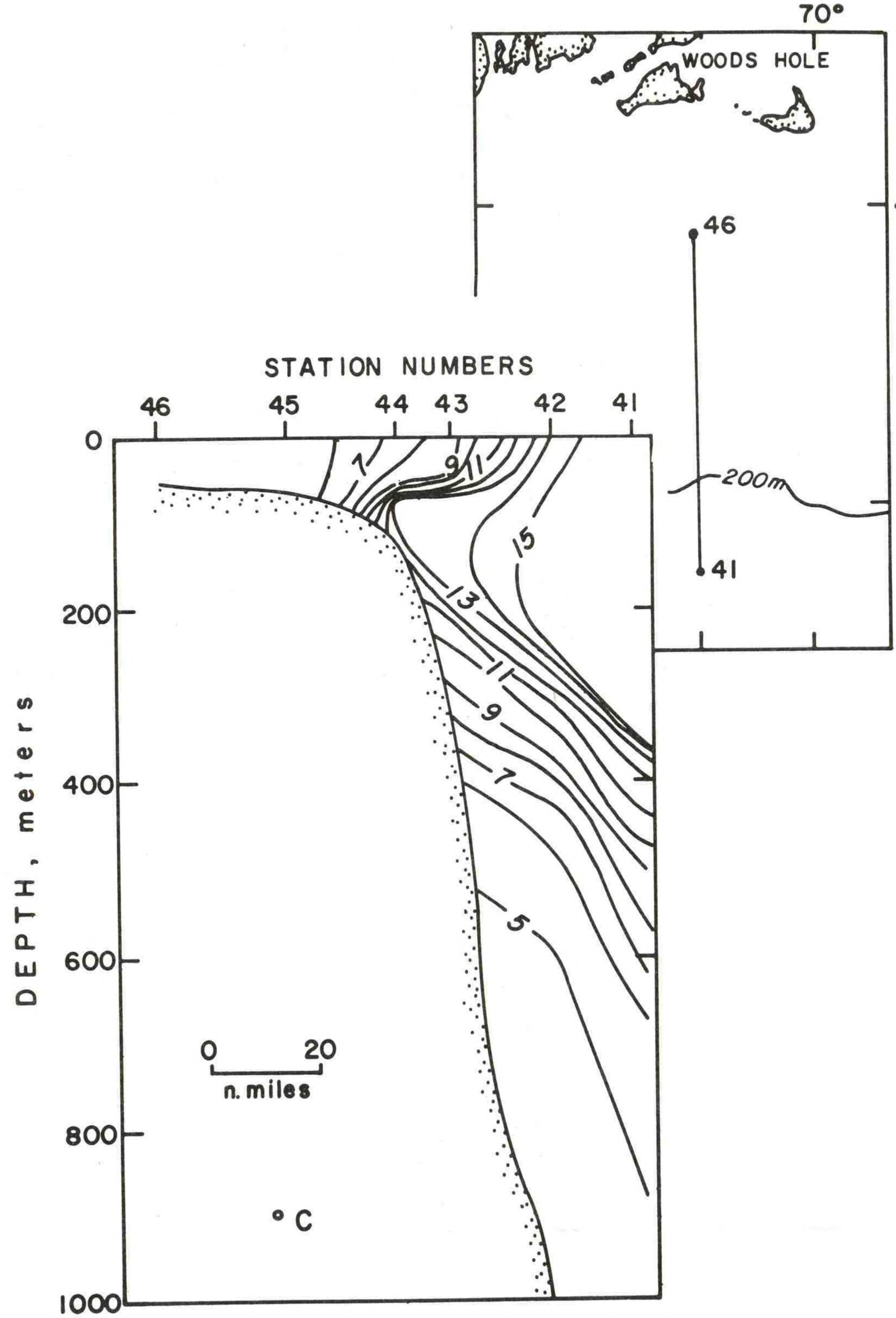


Figure 17.--USCGC Evergreen SAR 2 cruise track, Mar. 5, 1974, and temperature section.

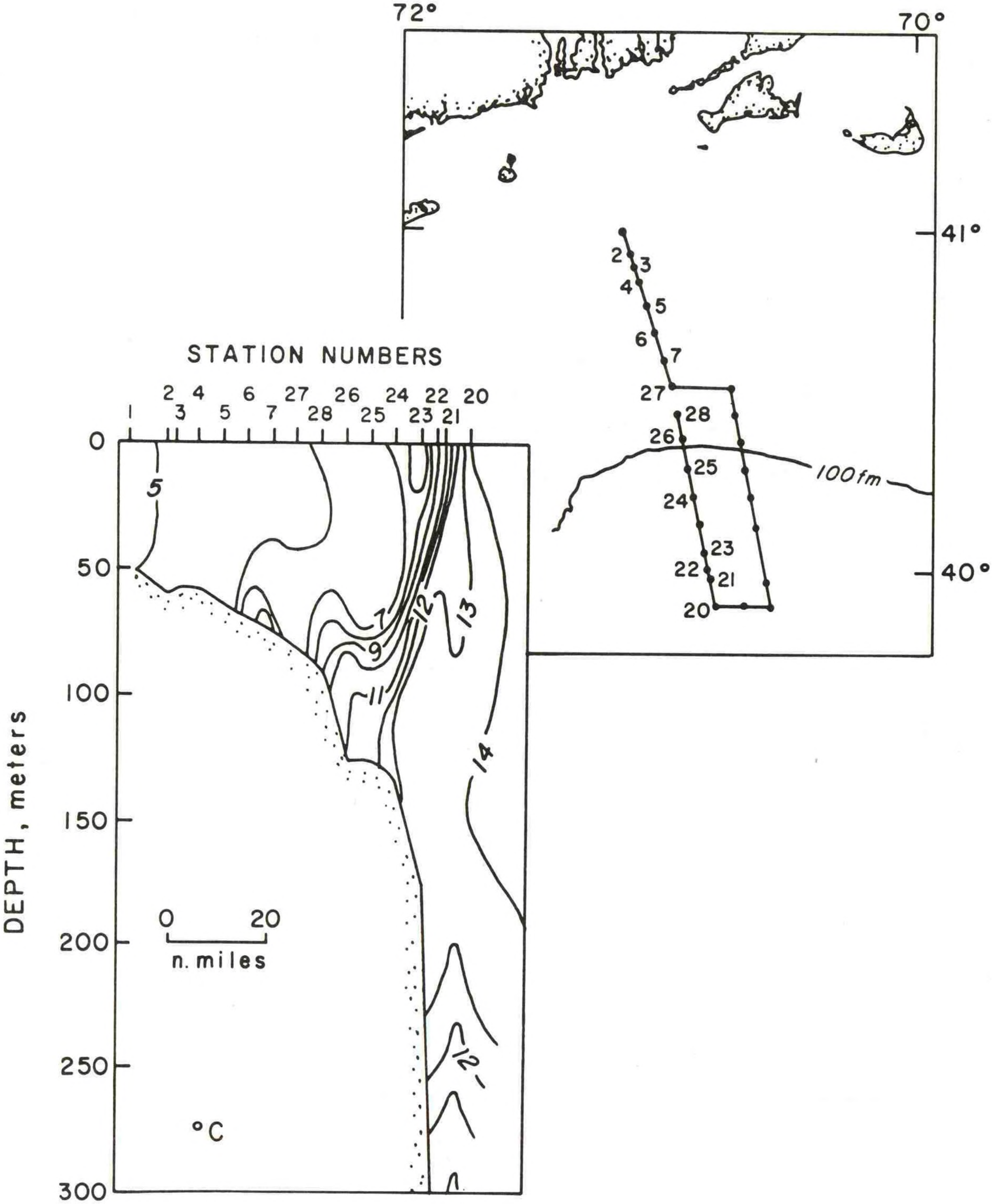


Figure 18.--RV Verrill cruise III, Apr. 2-4, 1974, and temperature section (after Flagg and Beardsley 1975).

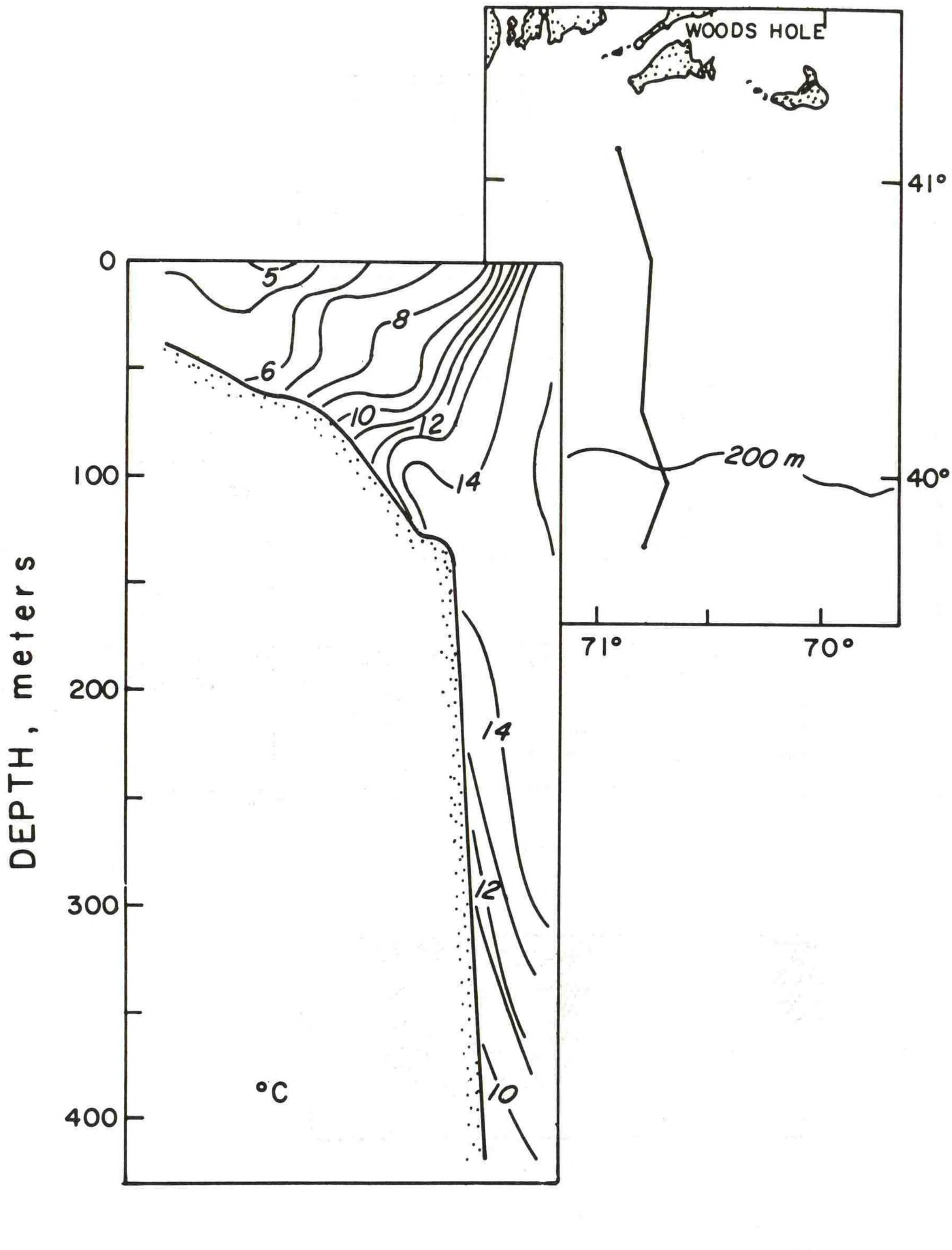


Figure 19.--Albatross IV cruise 74-4, Mar. 1974, and temperature section (courtesy of Northeast Fisheries Center, NMFS).

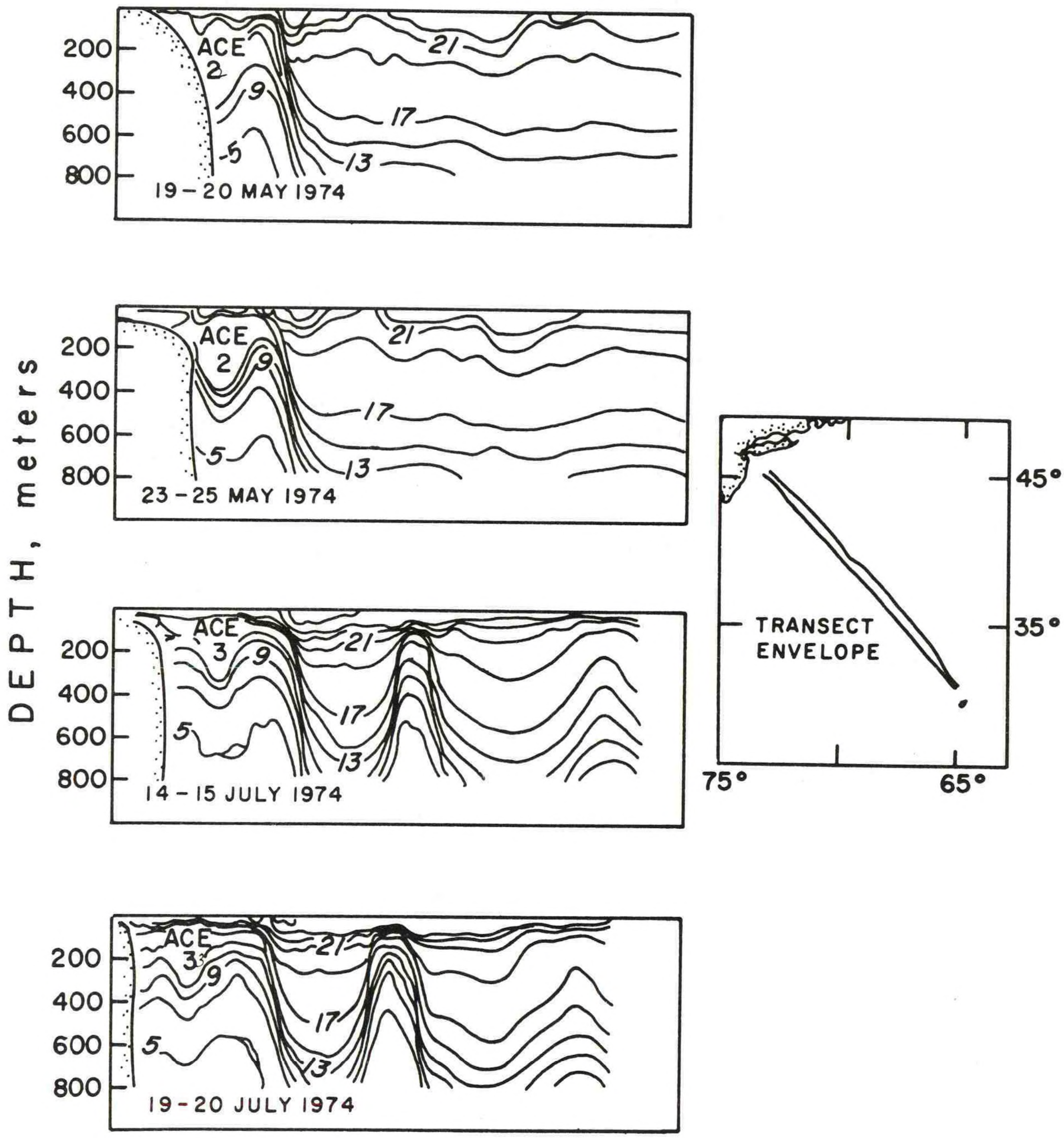


Figure 20.--New York to Bermuda transect and selected temperature sections (adapted from The Gulf Stream Monthly Summary, December 1974).

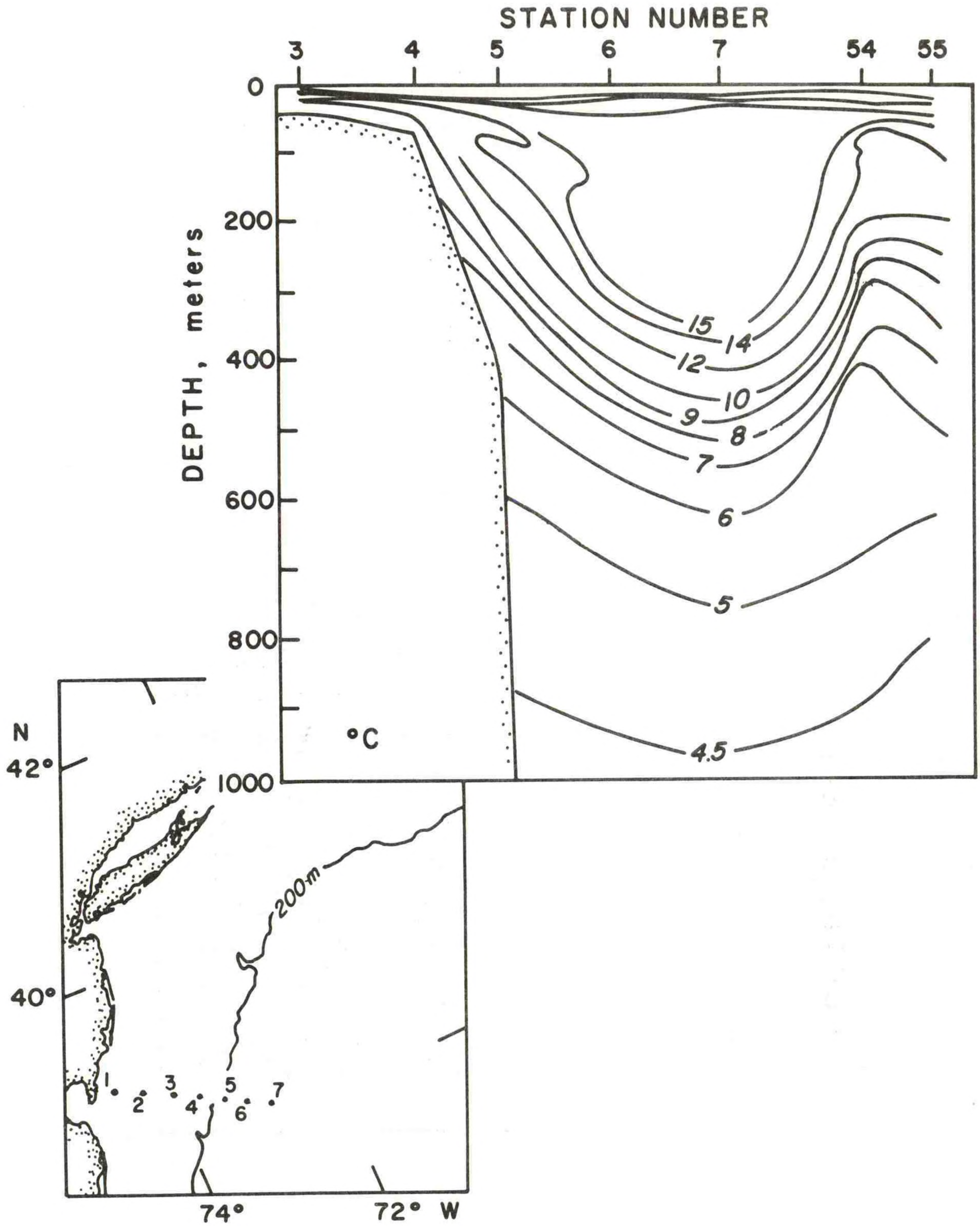


Figure 21.--USCGC Evergreen SAR-3 cruise, Aug. 6-24, 1974, and temperature section.

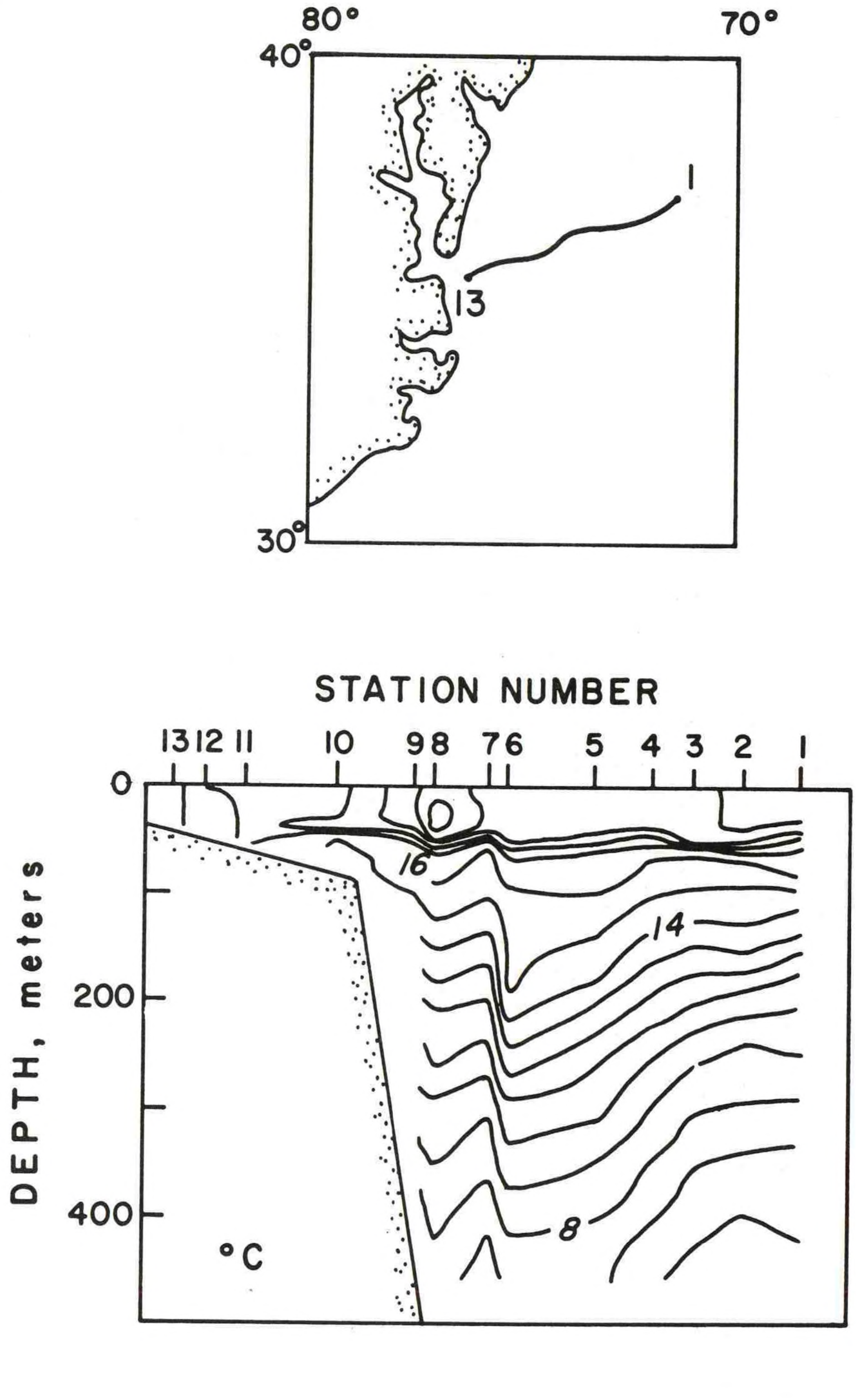


Figure 22.--USCGC Ingham (SOOP 1974) temperature section Oct. 20, 1974 (after Cook and Hausknecht 1975).

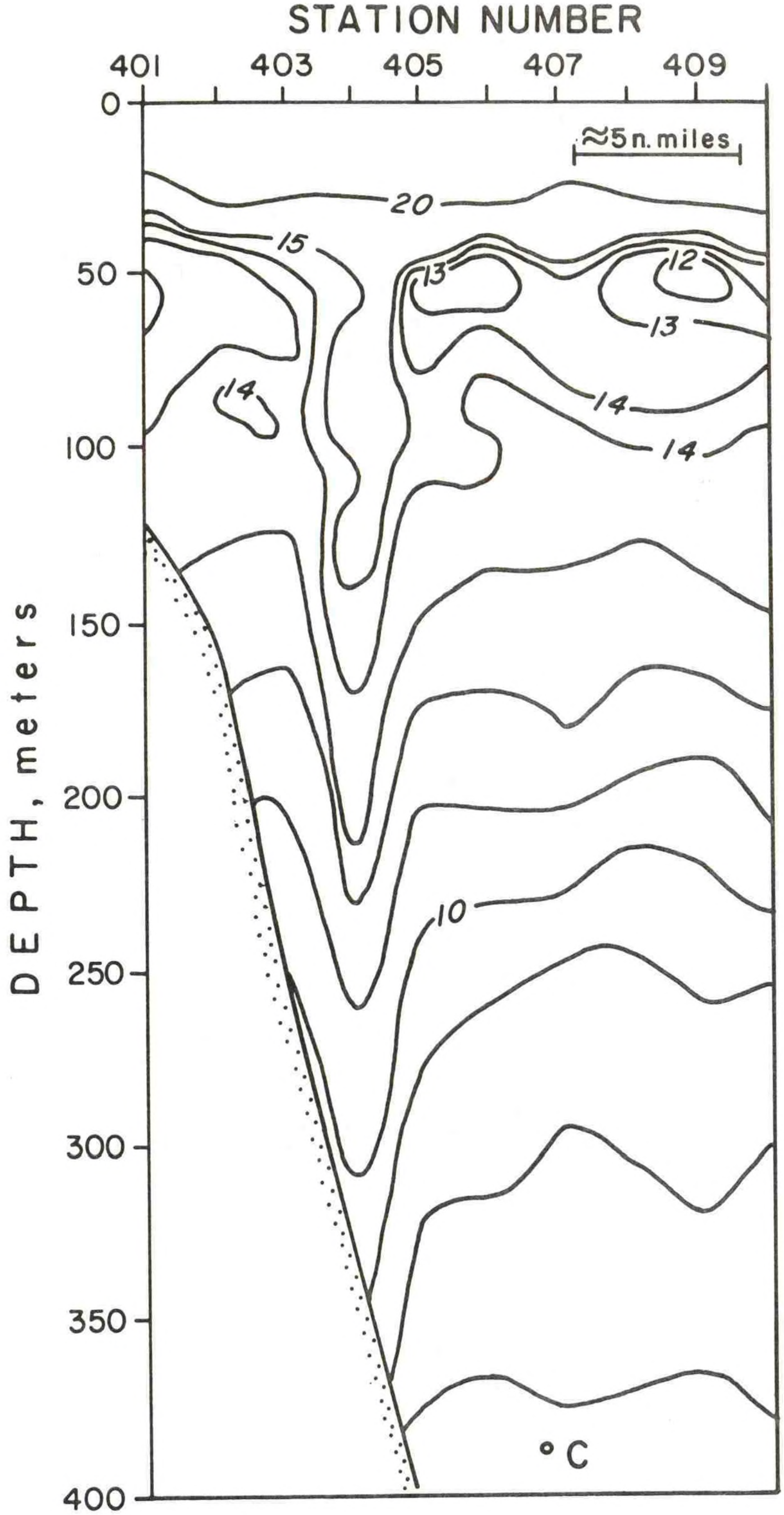


Figure 23.--Temperature section from Eastward cruise 14, Sept. 19, 1974 (courtesty of W. R. Wright)

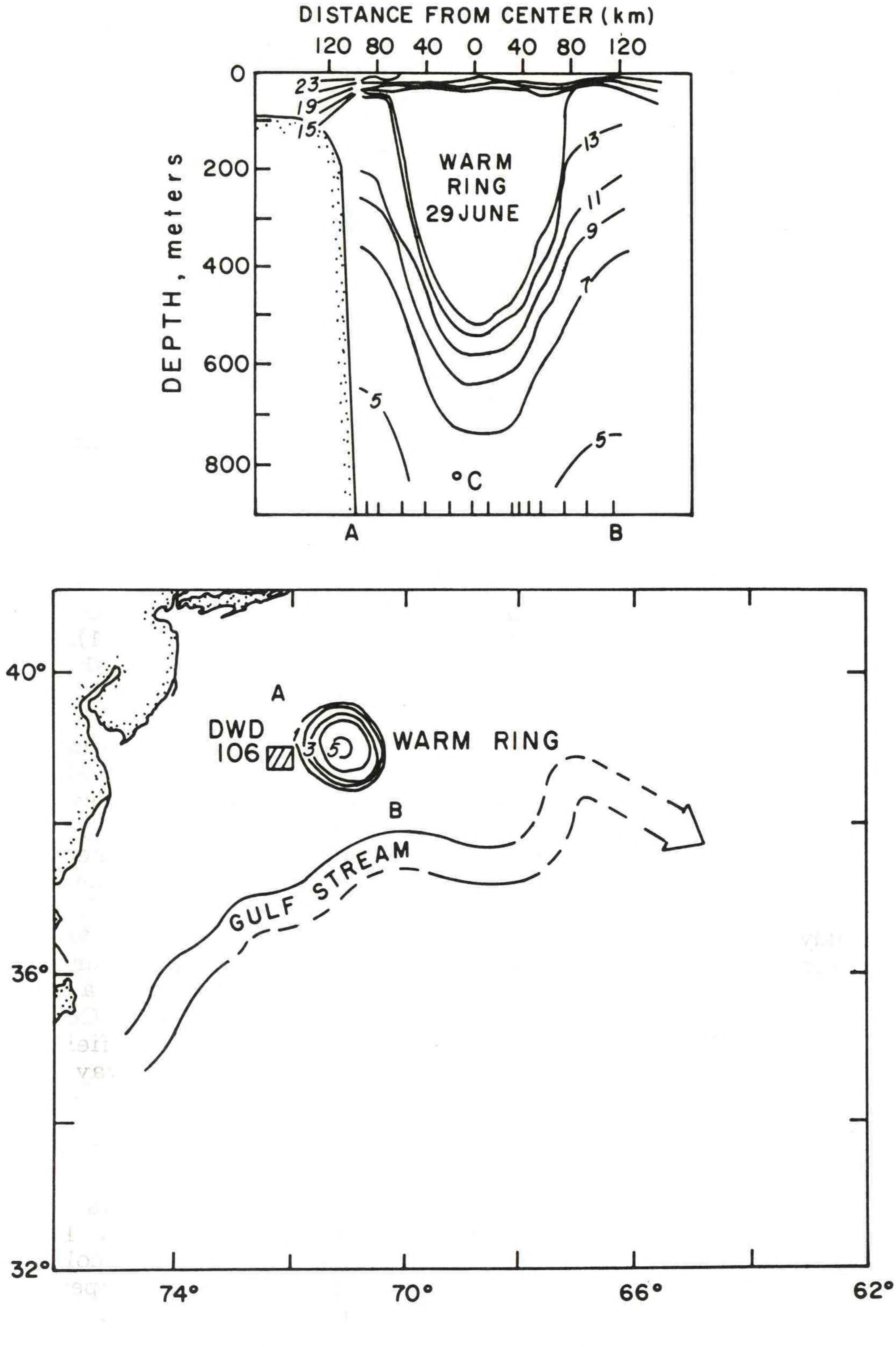


Figure 24.--Position of anticyclonic eddy 6 and temperature section, June 29, 1975 (after Cheney 1975).

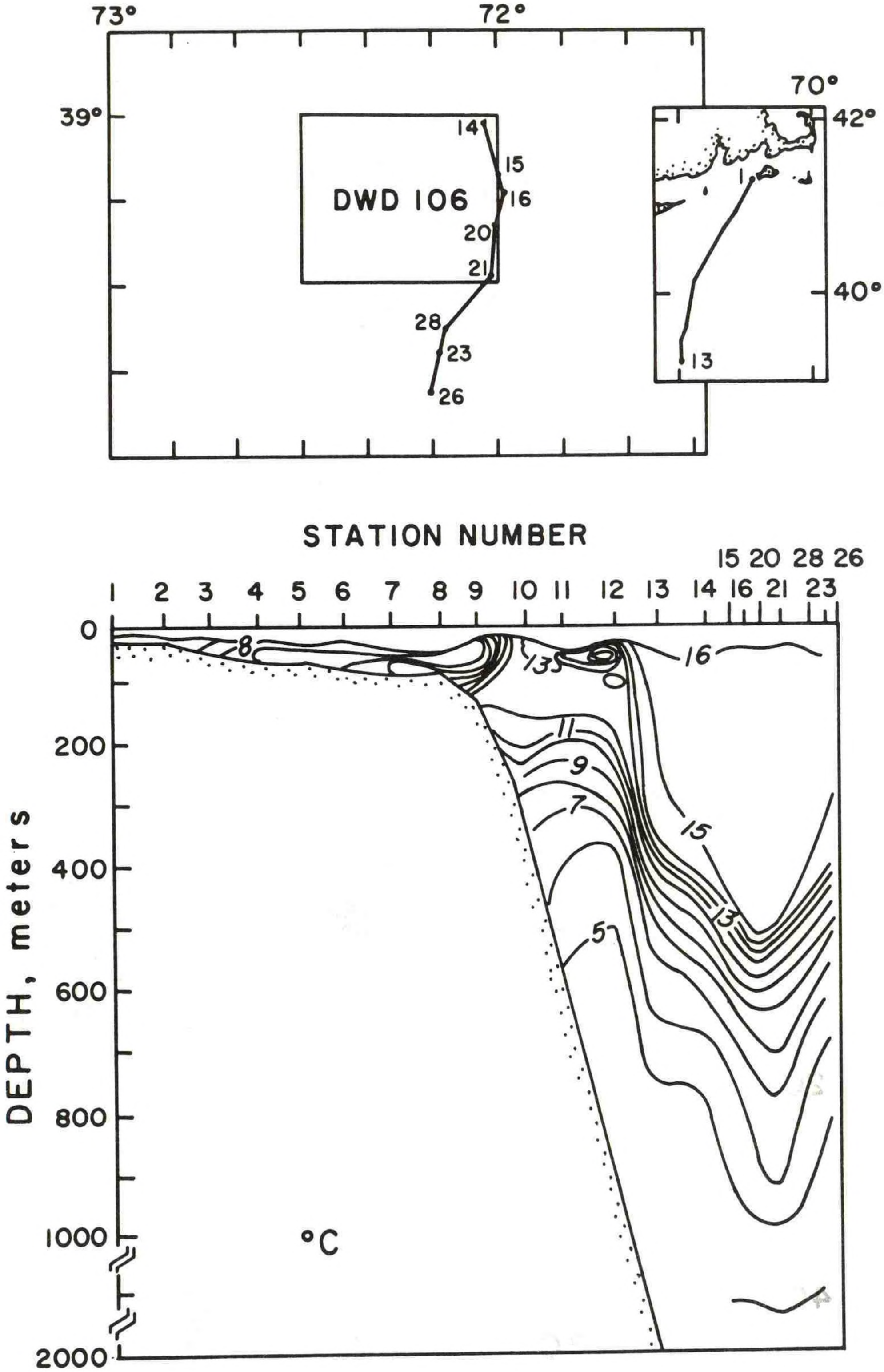


Figure 25.--Albatross IV cruise and temperature section, July 1975 (after Goulet 1975).

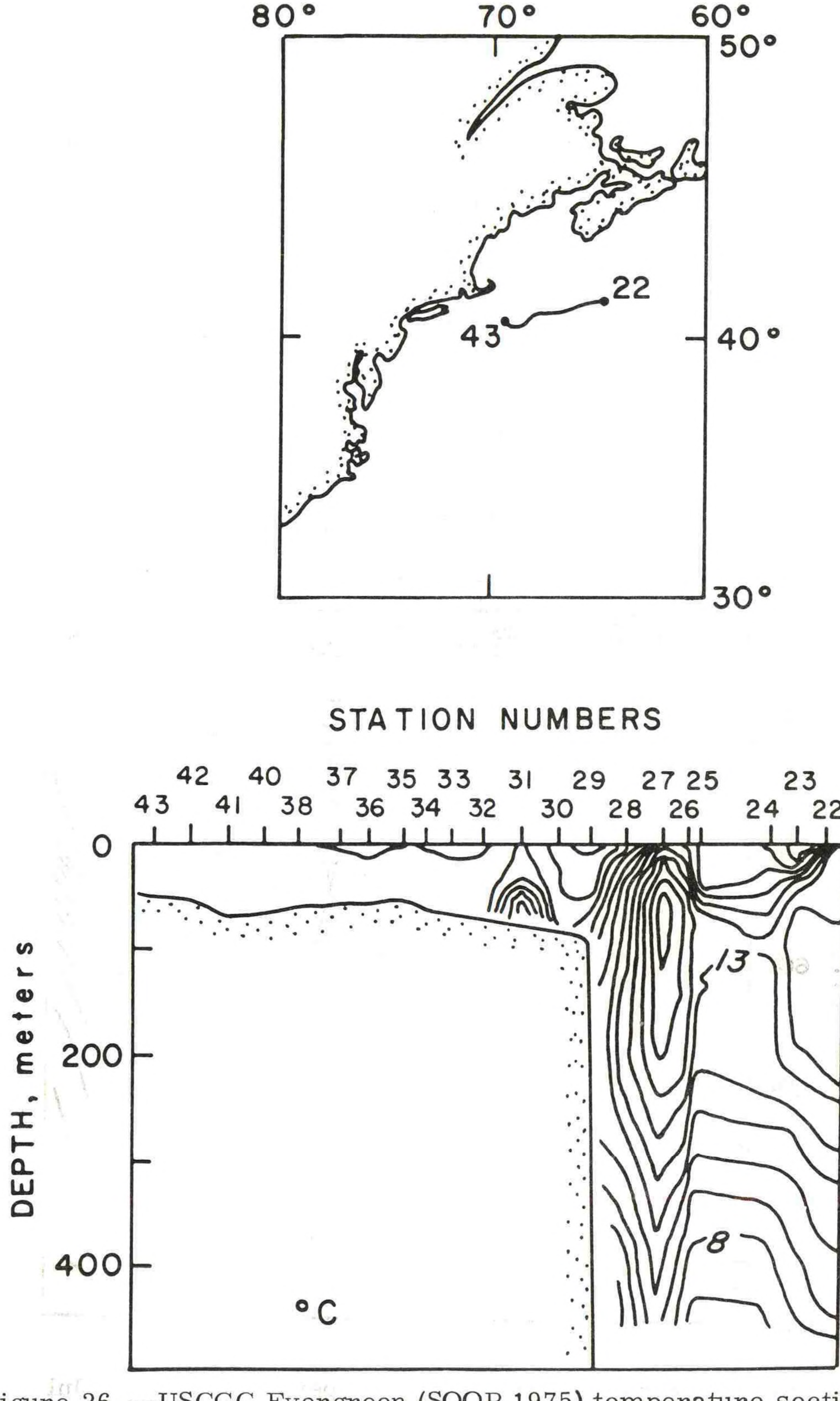


Figure 26.--USCGC Evergreen (SOOP 1975) temperature section Apr. 28, 1975 (after Cook 1975).

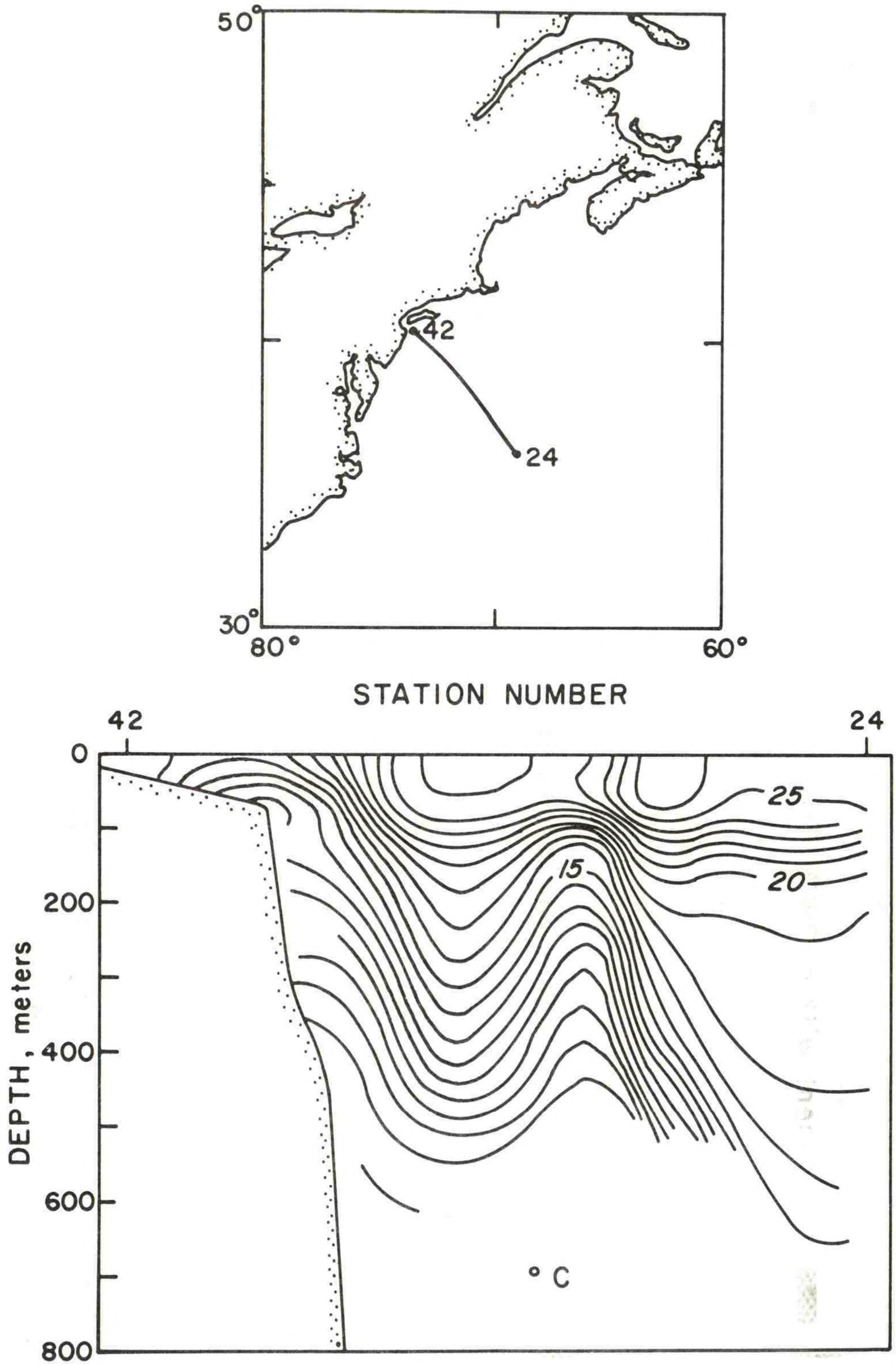


Figure 27.--MORMAC Argo (SOOP 1975) temperature section Oct. 22-23, 1975 (after Cook 1975).

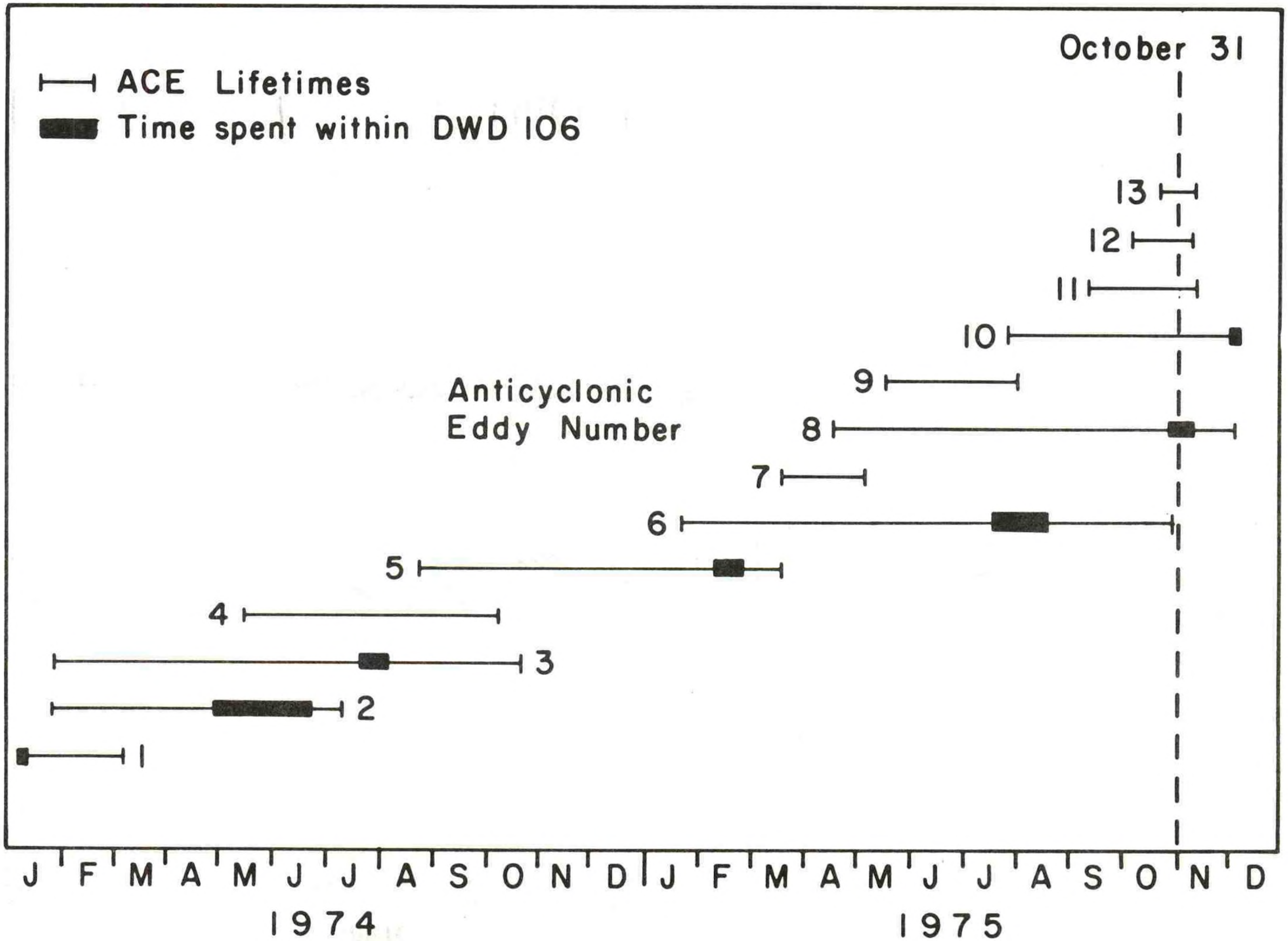


Figure 28.--Lifetimes for anticyclonic eddies 1-13.

☆U.S. GOVERNMENT PRINTING OFFICE: 1976 210-801/260 1-3

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

NOAA--S/T 76-2160