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Water Column Thermal Structure Across the Shelf and Slope Southeast of Sandy Hook, New Jersey in 1978

by

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HISTORICAL SUMMARY

Water temperatures in the Middle Atlantic Bight generally range from a minimum of <3°C in the New York Bight in February to >27°C off Cape Hatteras in August (Bumpus et al 1973). The annual range of surface temperature may be >15°C in the slope water to >20°C in the shelf water.

Minimum winter temperatures are reached in late February or early March and may be as low as 1°C. During this coldest season the shelf water column is well mixed (isothermal) from surface to bottom and extends out to the shelf water/slope water front (at approximately 200 m isobath - Wright 1976). Irregular warming usually begins in late February or early March, and a thermocline develops in late April or early May.

A rather intense thermocline develops during the summer, sealing off the bottom waters and isolating a pool or cell of cold winter water that rests on the bottom, surrounded shoreward, seaward, and above by warmer water. As the summer progresses into early fall, this cold cell tends to erode in extent and increase in temperature. This erosion is presumably caused by mixing from above with warmer near surface waters and from a "calving" process, described by Whitcomb (1970), where parcels of this cooler water break off and flow and mix seaward into the slope water.

Water temperatures in the early part of last year (1977) were colder than previous years, decreasing to less than 0°C nearshore, apparently as a result of the much colder than usual winter weather that occurred in the northeast. The effect of the cold winter persisted within the cold cell, where bottom temperatures less than 4°C lasted until early June. Minimum bottom temperatures in the cold cell are usually greater than 7°C in May. So it was apparent that the anomalous winter of 1976-77 had a long-lasting effect, not only in the estuaries where high clam and crab mortalities were realized, but also out on the continental shelf.

Another interesting phenomenon in 1977 was the offshore extension of the cold cell to depths of more than 155 meters. Past Ship of Opportunity (SOOP) data (Cook and Hausknecht 1977, and Cook et al. 1979) indicated cold cell maximum depths of less than 100 meters. Each excursion of the cold cell off the continental shelf (>200 m) was associated with an eddy or Gulf Stream meander. The anomalously large number of eddies around Deepwater Dumpsite 106 during 1977 apparently affected the size and extent of the cold cell on the continental shelf.

TRANSECT ANALYSIS - 1978

During 1978 there were 19 expendable bathythermograph (XBT) transects collected over the continental shelf and slope southeast of New York out to the vicinity of Deepwater Dumpsite 106 (fig. 1). The XBT transects were obtained over a period from 1 January 1978 to 17 December 1978 with the only hiatus occurring in April (table 1).

January: Only one transect was collected in early January (fig. 2) and it showed vertically isothermal water ranging in temperature from 9°C nearshore to 12°C at the shelf break. Warmer than usual (13 to >16°C) water was present seaward of the shelf break over the upper continental shelf. The warmer than usual water was a manifestation of the nearby presence of a warm core (anticyclonic) Gulf Stream eddy. This eddy, although not showing up directly on the January XBT transect, was visible by satellite imagery and was coded as Eddy R by the U.S. Naval Oceanographic Office on their Experimental Ocean Frontal Analysis chart of 4 Jan 1978 and as 77-I by the Atlantic Environmental Group. The eddy was to the southwest of the XBT transect and was in an advanced stage of decay and reabsorption back into the Gulf Stream. It had moved southwestward to off the Delaware Peninsula and apparently had mixed away by mid-February.

February: Three transects were collected in February (figs. 3, 4 and 5). Figure 3 showed vertically isothermal water ranging from less than 1°C nearshore to 7°C at the shelf break. Satellite infra-red imagery showed that another Gulf Stream eddy was present and can be seen in the temperature field between stations 6 and 9. Entrainment of a significant amount of shelf water along the seaward edge of the eddy shows up as a parcel of water of less than 10°C around station 8. This water extended deeper than 40 meters and had a linear distance at the surface of more than 65 km. Entrainment features such as these, if occurring at the appropriate time of year so as to coincide with planktonic blooms or spawning seasons, could provide a mechanism for removing planktonic forms from the shelf waters into warmer slope waters.

Figure 4 (mid-February) still shows vertically isothermal water ranging from 2°C nearshore to 9°C at the shelf break. Eddy Q (77-D) was still influencing the bottom water temperatures on the upper slope, increasing them to almost 12°C from a little more than 10°C a week earlier. The eddy, by that time, had moved further to the southwest and somewhat closer to shore.

A continuous plankton recorder (CPR) transect was obtained concomitantly with the XBT transect. The CPR carried an electronic temperature recorder (ETR) which gave us a continuous temperature profile at 10 meters (the depth at which the CPR was towed). The ETR provided continuous data between XBT observations, allowing us to contour with more detail the shelf water entrainment feature associated with this eddy. For example, it helped define some distortion and mixing of the near surface waters at the shelf water/slope water front which also coincided with the shoreward edge of the eddy. The shelf water (<10°C) that was entrained on the seaward edge of the eddy had deepened to more than 50 meters, but at the same time had narrowed its extent at the surface to less than 18 km.

Figure 5, constructed from data collected toward the end of February, portrays a section slightly to the northeast of Eddy Q (77-D), the eddy is between the reader and the section, showing the after-effects of the eddy passage. The upper slope water had again cooled by more than 1°C and the shelf water/slope water front had extended more than 65 km seaward of the shelf break. It appears that the forcing effect of the eddy, which previously was keeping the shelf water/slope water front more shoreward and within 37 km of the shelf break, had relaxed with the normal migration of the eddy to the southwest and the shelf water was moving in behind the eddy.

On the shelf, the water was still essentially vertically isothermal with just the beginning of thermal stratification and creation of the cold cell showing up between stations 64 and 65. February shelf water data provided the coldest cold cell temperatures for 1978.

March: Both March sections (figs. 6 and 7) were collected in the latter half of the month and show a mixture of vertically isothermal pockets of water and early stratification. Both sections showed a temperature range of 4°C nearshore to 6°C at the shelf break. The shelf water/slope water front was again closely associated with the shelf break.

The earlier section (fig. 6) showed a parcel of 12°C water between 40 and 140 meters depth from station 7 to 9. Four days later (fig. 7), this parcel of water had been replaced by 11°C water. The 12°C water was probably the last remnant of Eddy Q (77-D) passing out of the area to the southwest.

April: No sections were collected in April.

May: The lack of April data precludes assigning an exact time for the cold cell formation, but because of the definite cell structure observed in early May, it would probably be accurate to assume cell formation about mid-April.

The two earlier May sections (figs. 8 and 9) indicated warming of surface temperatures 8 to 9°C inshore and increased stratification. A distinct cold cell structure (defined by water <6°C) had formed. The earliest May transect ('Argus'78-05) indicated a seaward extension of the shelf water/slope water front of more than 74 km, perhaps caused by the general lack of eddy activity in this area beginning in March and lasting through mid-July.

By the end of May and first of June (fig. 10) summer conditions had arrived. Intense stratification over the shelf was obvious with temperature ranges between the cold cell and nearshore surface waters of 4° to 16°C. Lack of data beyond 60 meters (station 7) made impossible the determination of the extent of the cold cell structure and its average temperature.

June: Thermal stratification had increased to where temperatures ranged from >15° at the surface nearshore to <4°C in the cold cell. The thermocline had strengthened and effectively sealed off the cold cell. Figure 11 shows a parcel of 8° to 10°C water at station 12 at about 30 meters depth that apparently calved off the seaward leading edge of the cold cell. The same calved feature was still apparent one week later (fig. 12). At that time the feature had warmed to slightly less than 10°C, moved inshore over the shelf break, and deepened to over 60 meters. Figure 12 also showed an intensifying thermocline and continued offshore movement of the shelf water/slope water front, both of which probably attributed to the warming and deepening of the 10°C parcel of previously calved water. Apparently the deepening of the thermocline also caused a division of the calved parcel of water as reflected by the remnant 10°C water at station 33 and between stations 36 and 37 (fig. 12).

July: The two sections collected near the middle and end of July continued to show increased stratification and associated thermocline deepening. The average cold cell temperature (which is an area-weighted temperature) had increased to over 7°C from 6°C in June and about 5°C in May, (see table 1). The mid-July section (fig. 13) showed an offshore extension of the cold cell between stations 42 and 41. The late July section (fig. 14) showed this extension as a parcel of 11° to 12°C water centered around 40 meters depth at station 7.

The presence of eddy S (78-A) between stations 10 to 15 might have been responsible for the drawing off of the 11°-12°C parcel of cold cell water. The significant offshore extension of the shelf water/slope water front in both sections (figs. 13 and 14) was another indication of how eddies can affect the shelf water mass. In addition the rise in bottom temperatures on the upper continental slope is indicative of eddy processes as they "feel bottom" during their southwestward movement.

August: Unfortunately, a long gap in XBT observations between stations 34 and 35 (fig. 15) prevented any detailed analysis of the cold cell for August. Sea surface temperatures on the shelf had increased to their warmest for the year (>23°C). Eddy S (78-A) had moved closer to the shelf break, and again entrainment of shelf water around the seaward edge of the eddy (stations 27 to 25) was evident in very low sea surface salinity values (not shown).

September: Both sections (figs. 16 and 17) collected in September showed a decrease in sea surface temperature to ≈19°C, down from 23°C the previous month. The cold cell average temperature had warmed to >9°C and its extent across the bottom decreased (see table 1). The presence of eddy S (78-A) was still evident at the end of the transect in figure 16 (stations 145 and 146). Also evident at that time was a parcel of 9°C cold cell water that had apparently calved off and was mixing into slope water.

Figure 17 constructed from data collected three days later showed the cold cell greatly extended to the seaward out over the shelf break. It was apparent that the eddy, which by now had passed out of the area of the transect to the southwest, had left a large amount of shelf water drawn off the shelf into the surrounding slope water.

October: By October (fig. 18) fall overturn had begun, with sea surface temperatures on the shelf ranging from <15° to 18°C. The cold cell had increased in average temperature to >10°C. A lack of XBT observations over the center of the cold cell prevented any detailed analysis. Eddy U (78-D) (see table 1), centered northeast of the transect, had warmed the upper continental slope area to ≈13°C, and had displaced the shelf water/slope water front shoreward more than 55 km from the shelf break. Determination of the shelf water/slope water front position was determined by sea surface salinity data (not shown) to be between stations 43 and 42.

November: The section occupied in early November (fig. 19) showed the after-effect of an eddy passage. Once again the shelf water/slope water front had extended seaward, filling in behind the eddy.

The cold cell had been eroded to nearly its smallest extent and had increased in average temperature to its warmest (≈12°C).

December: The fall overturn was almost complete by mid-December (fig. 20). Temperatures over the shelf ranged from 11° to 13°C. A small parcel of remnant shelf bottom water (14°C) was still present at about 60 meters depth. Eddy U (78-D) had passed out of the area and appeared to be pulling the last remnant of the bottom water (14°C) out into the slope water.

SUMMARY

Water temperatures across the shelf and slope in early 1978 were not as cold as 1977. Cold cell temperatures of <4°C were present in June, as they were in June of 1977. The major difference in cold cell average temperatures between 1977 and 1978 was that in the winter of 1976-1977 the minimum temperatures were colder than those of the winter of 1977-78, but not as persistent. In short, the winter of 1976-1977 was intense but short-lived and the winter of 1977-1978 was not as intense, but longer-lived.

The most noticeable difference between 1977 and 1978 was the lack of eddy activity in March-July of 1978. In 1977, eddies were present at DWD 106 about 67% of the year (Cook 1979), but only about 34% in 1978. Apparently associated with this low level of eddy activity was the major seaward extension of the shelf water/slope water front. At times the front was more than 3 standard deviations seaward of the normal position calculated by Wright (1976).

Another process that should be carefully monitored is the entrainment of shelf water around anticyclonic (warm core) eddies. If the eddies moving from the northeast to the southwest through the southern New England and middle Atlantic Bight regions are acting like huge, powerful mixing machines, their influence on slope water formation must be substantial. The previous sections (figs. 2-20) have shown, as have previous years' sections (Cook 1979) that when eddy activity is high, there is more slope water and conversely, when eddy activity is low, the slope water tends to be overrun with shelf water. These entrainment features, if occurring at the appropriate time of year, could contribute to the removal of shelf planktonic forms into (perhaps lethally) warmer slope waters.

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Table 1 - Water Column Thermal Structure in 1978

Ship	Cruise	Date	Cold Cell Area-weighted Avg. Temp	Depth range cold cell minimum/maximum depth offshore	Position of Shelf/Slope Front/km seaward of 100 m isobath	Eddies present along transect
USCGC Tamaroa	78-01	1/1/78	Isothermal	-	-	Yes (R) 77-I
Mormac Rigel	78-02	2/12/78	Isothermal (2-6°C)	-	Sta 5-6/24 km	Yes (Q) 77-D
USCGC Tamaroa	78-02	2/16-17/78	Isothermal (<2-6°C)	-	Sta 8-9/33 km	Yes (Q) 77-D
R/V Delaware II	78-02	2/27-28/78	Isothermal (<2-6°C)	-	Seaward of Sta 71/>65 km	Yes (Q) 77-D
USCGC Tamaroa	78-03	3/23-24/78	Isothermal (4-6°C)	-	Sta 7-8/52 km	No
M/V Port Jefferson	78-03	3/28-29/78	Isothermal (4-5°C)	-	Sta 14/11 km	No
R/V Argus	78-05	5/9-10/78	5.3°C	37-114 m	Seaward of Sta 67/>76 km	No
USCGC Tamaroa	78-05	5/10-11/78	5.7°C	42-114 m	Seaward of Sta 9/>37 km	No
Mormac Rigel	78-05	5/31-6/1/78	Incomplete data	Incomplete data	Sta 11-12/46 km	No
USCGC Tamaroa	78-06	6/8-9/78	5.7°C	34-92 m	Sta 12-13/70 km	No
R/V Kelez	78-06	6/16/78	6.3°C	41-72 m	Seaward of Sta 33/>61 km	No
Mormac Rigel	78-07	7/15-16/78	6.6°C	35-90 m	Sta 41-40/92 km	No
Mormac Argo	78-07	7/29/78	7.2°C	37-88 m	Sta 7-8/67 km	Yes (S) 78-A
Mormac Argo	78-08	8/31/78	Incomplete data	Incomplete data	≈Sta 34/83 km	Yes (S) 78-A
R/V Delaware II	78-09	9/20-21/78	8.4°C	46-84 m	Seaward of Sta 146/>44 km	Yes (S) 78-A
Mormac Rigel	78-09	9/23/78	9.3°C	45-86 m	Sta. 17-18/130 km	No
Mormac Rigel	78-10	10/31/78	Incomplete (>10°C)	44-92 m	Sta 43-42/56 km*	Yes (U)**78-D
USCGC Tamaroa	78-11	11/7-8/78	11.9°C	42-91 m	Sta 10-11/24 km	Yes (U)**78-D
USCGC Gallatin	78-12	12/17/78	Isothermal w/small patch of water greater than 14°C	62-78	-	No

* SSF 30 km shoreward of shelf break
** Should be (V)

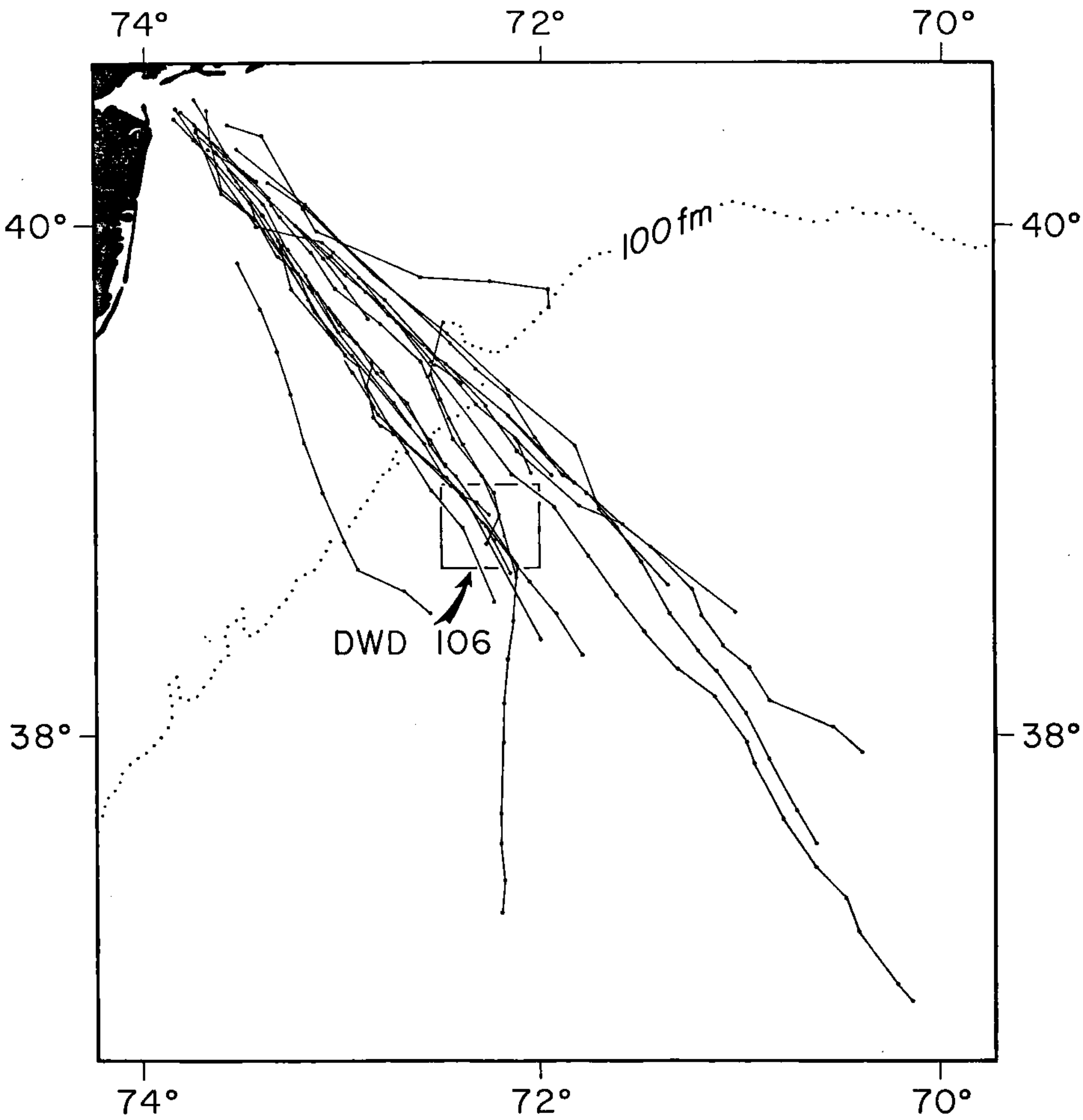

Figure 1 - Locator chart showing transects of the 19 XBT sections collected in 1978.

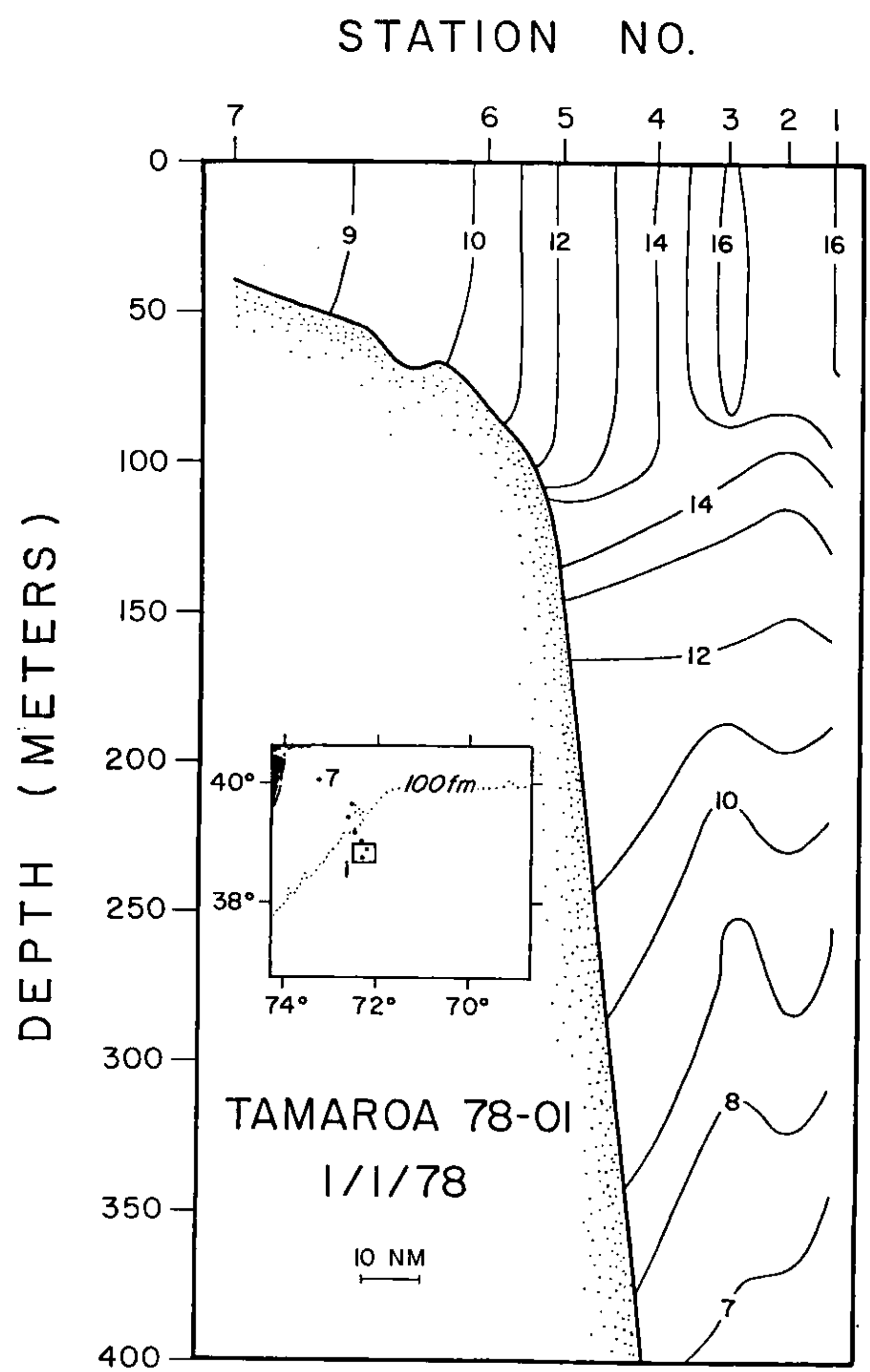

Figure 2. January temperature (°C) transect collected by the USCGC Tamaroa on 1/1/78.

- 10 -

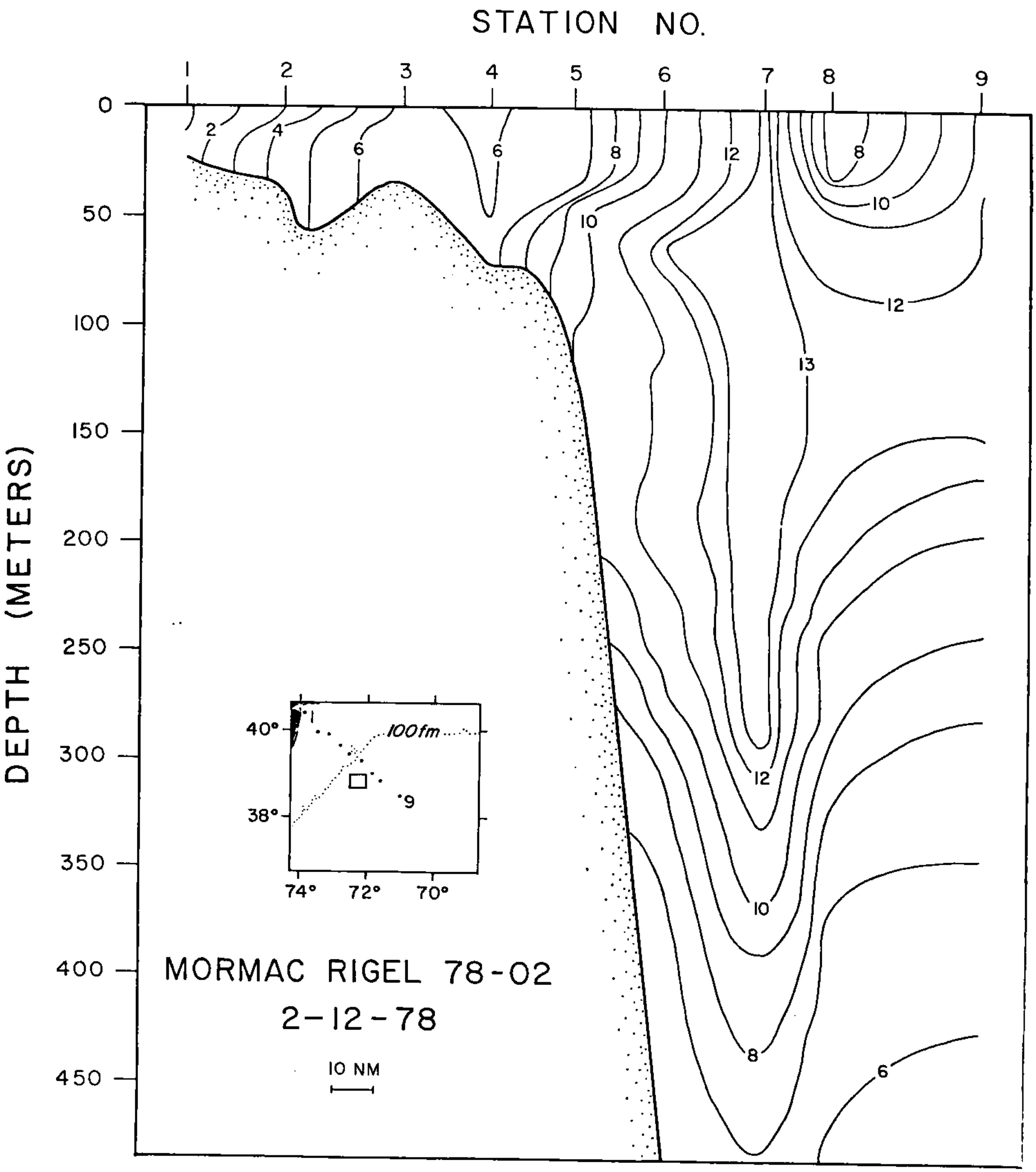

Figure 3 - February temperature (°C) transect collected by the Mormac Rigel on 2/12/78

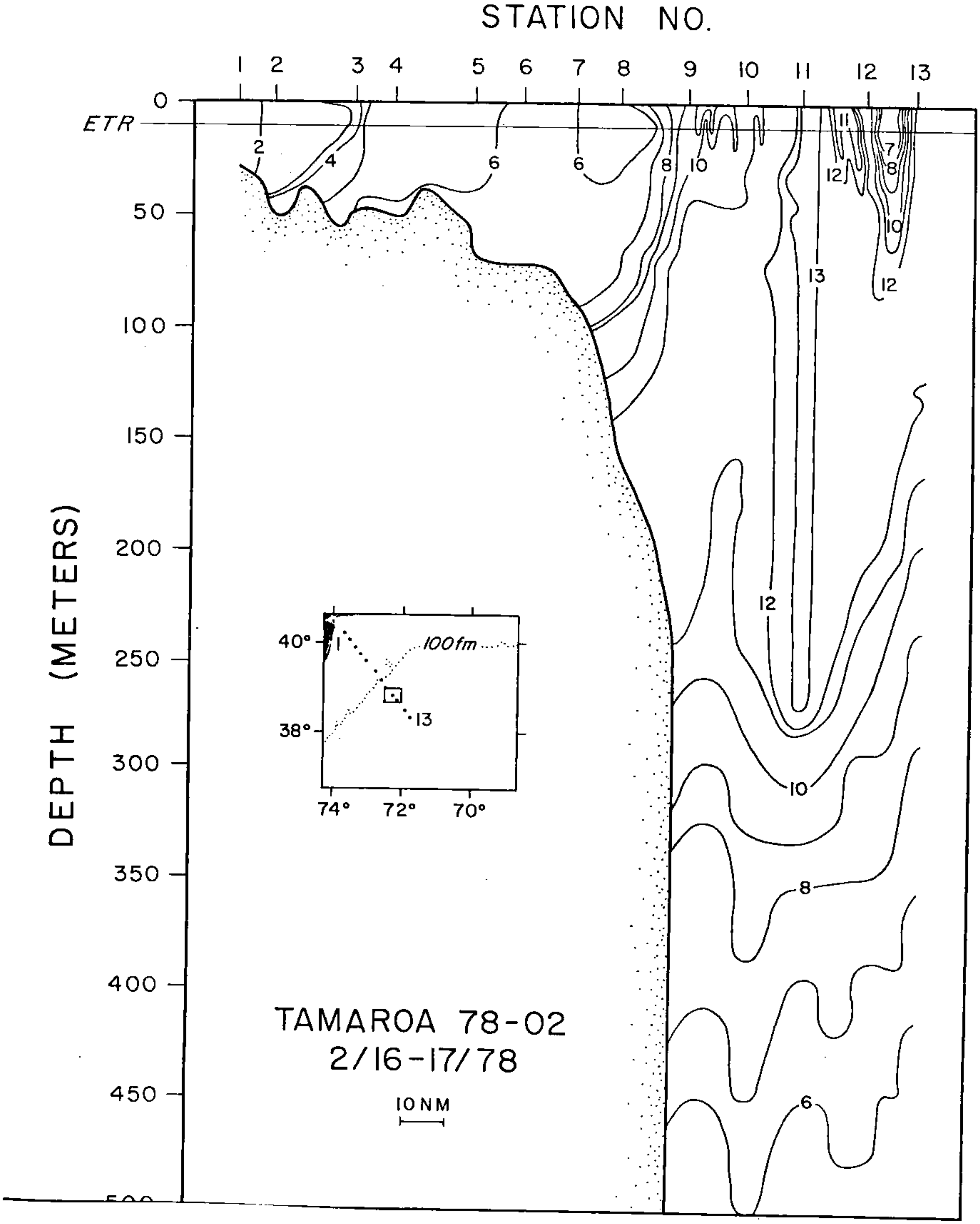

Figure 4 - Second February temperature (°C) transect collected by the USCGC Tamaroa on 2/16-17/78

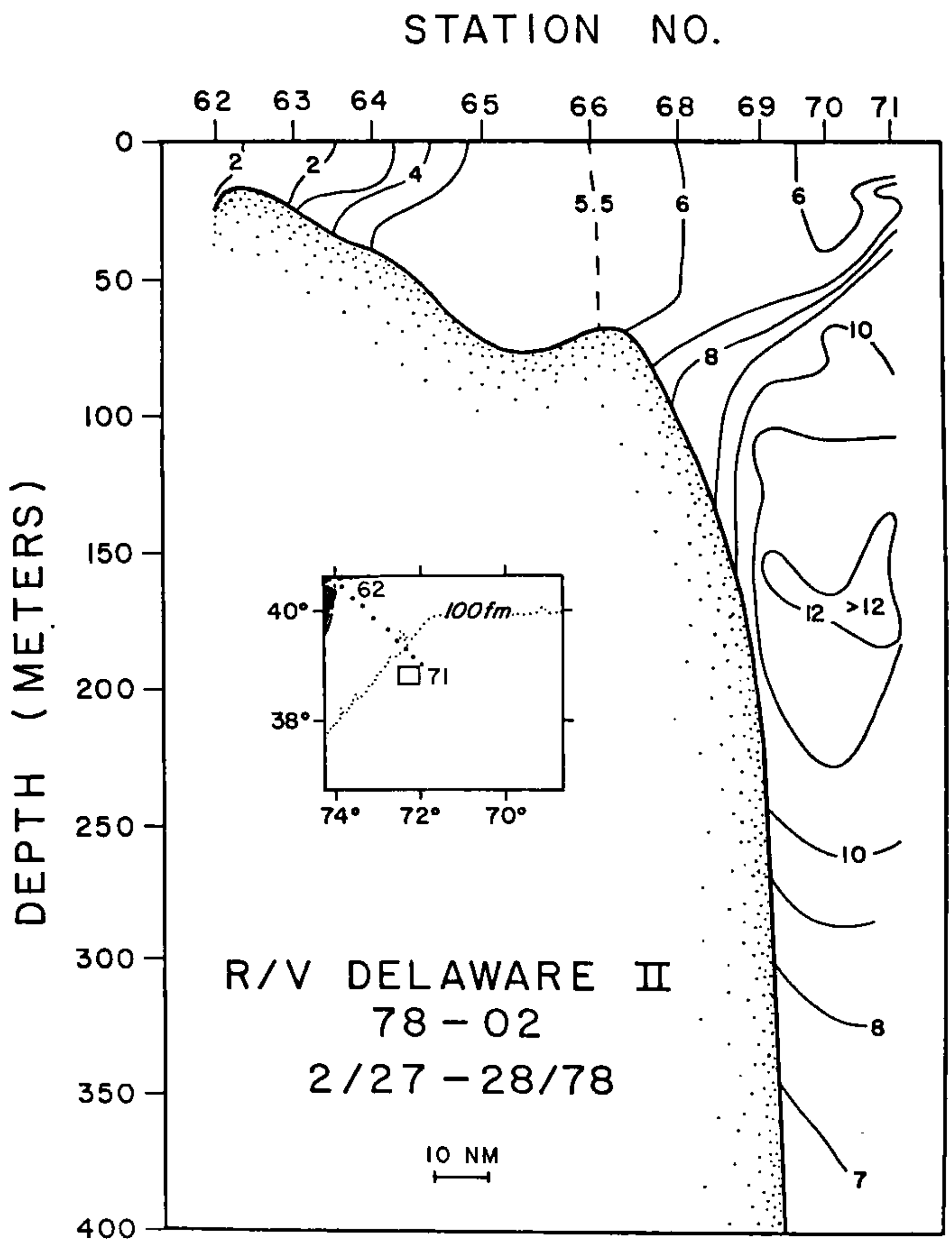

Figure 5 - Third February temperature (°C) transect collected by the Delaware II on 2/27-28/78

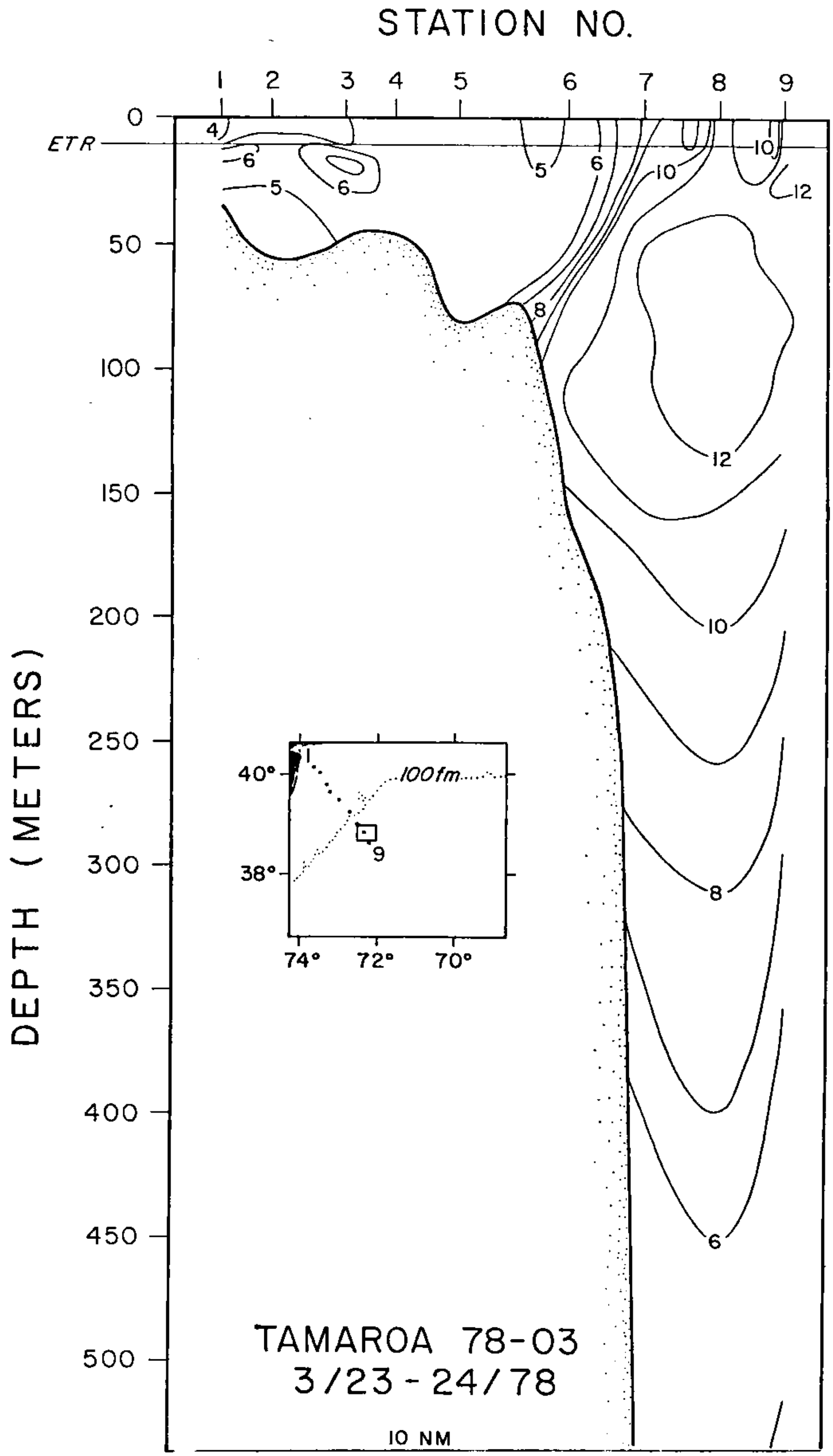

Figure 6 - March temperature (°C) transect collected by the USCGC Tamaroa on 3/23-24/78

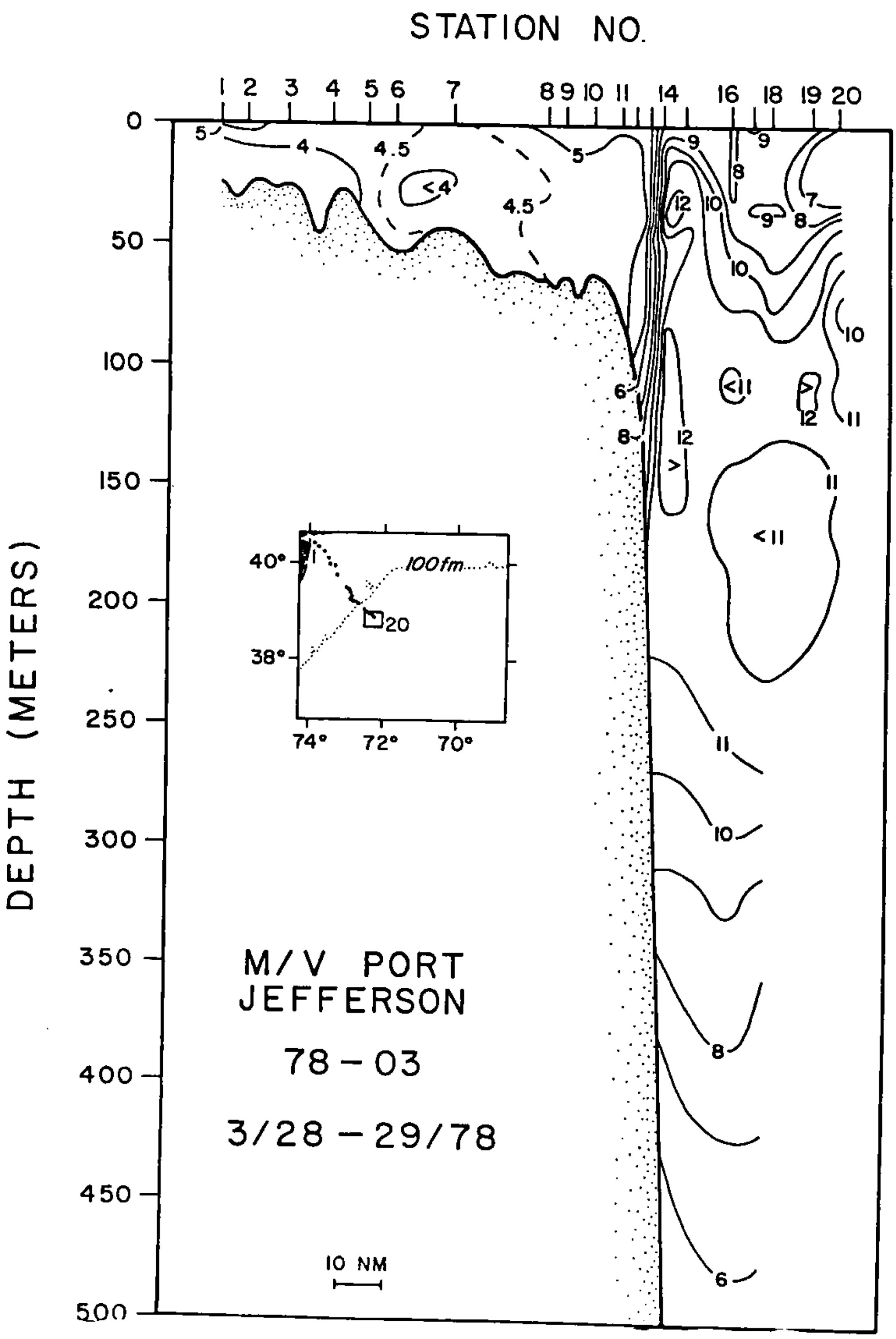

Figure 7 - Second March temperature (°C) transect collected by the Port Jefferson on 3/28-29/78

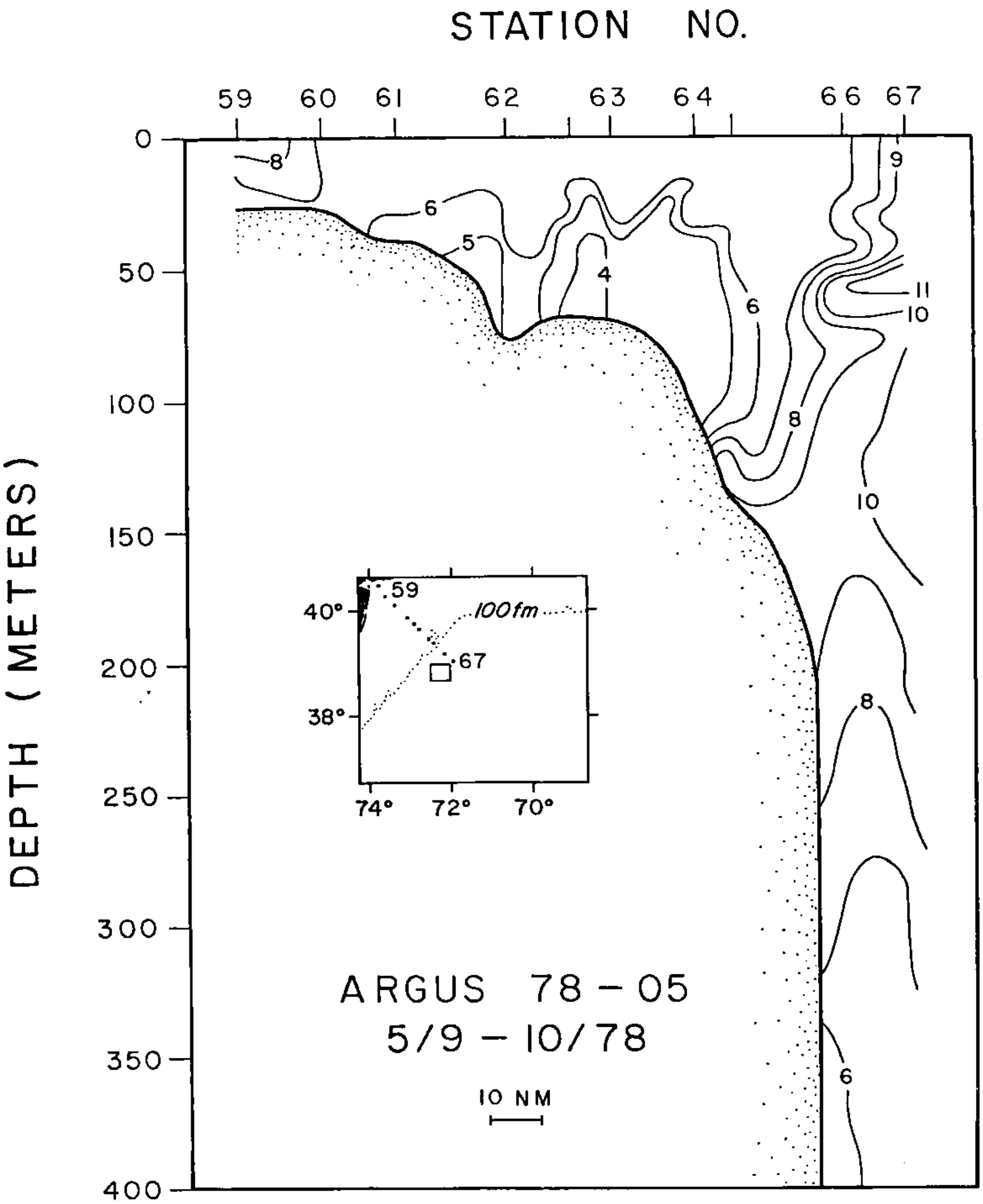

Figure 8 - May temperature (°C) transect collected by the Argus on 5/9-10/78

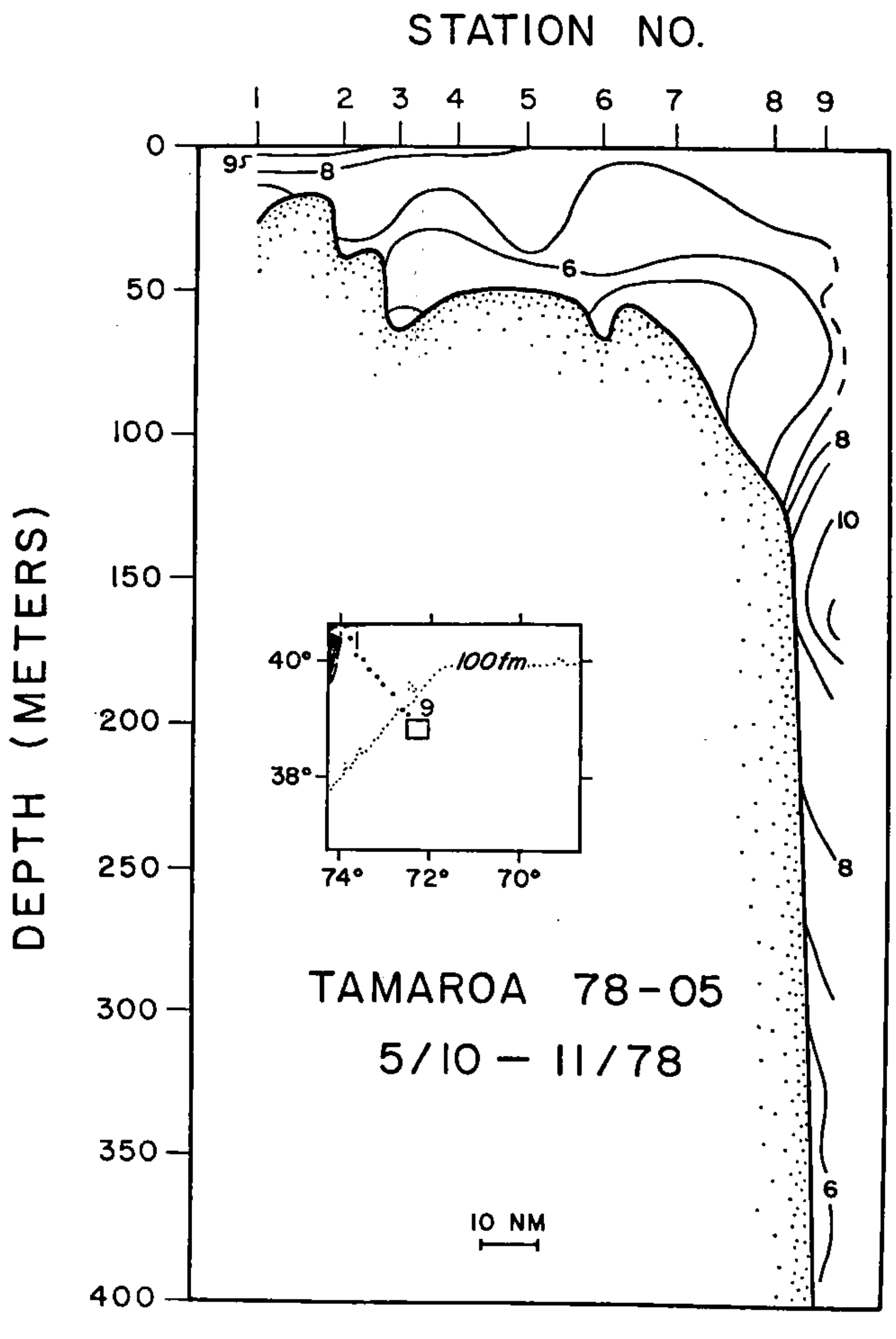

Figure 9 - Second May temperature (°C) transect collected by the _Tamaroa_ on 5/10-11/78

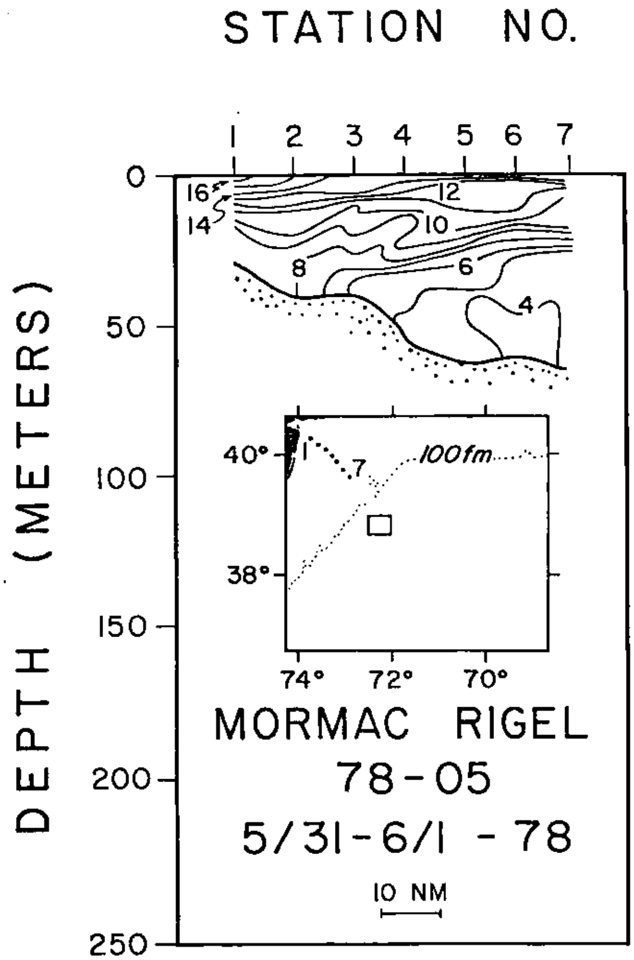

Figure 10 - Third May temperature (°C) transect collected by the <u>Mormac Rigel</u> on 5/31-6/1/78

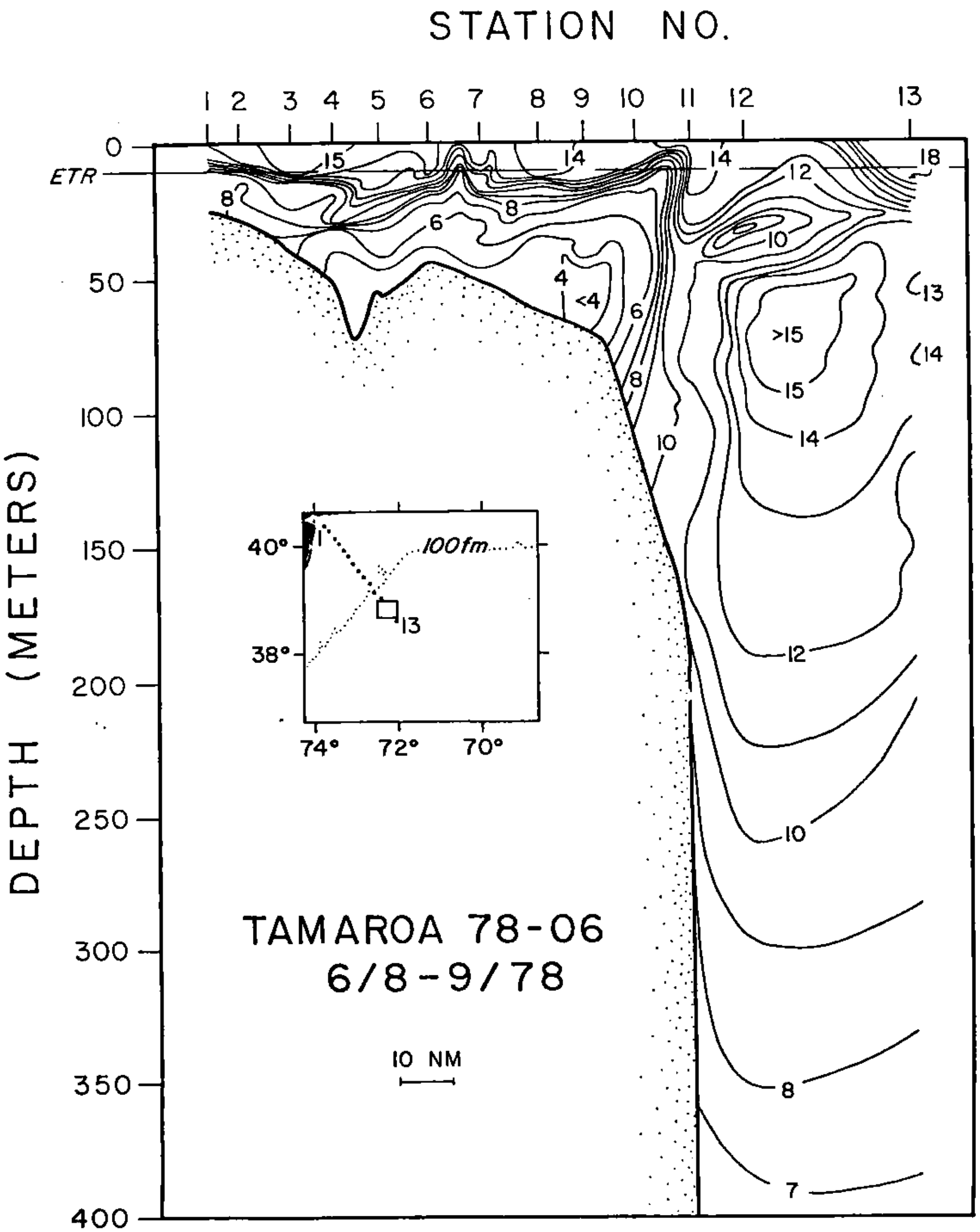

Figure 11 - June temperature (°C) transect collected by the Tamaroa on 6/8-9/78

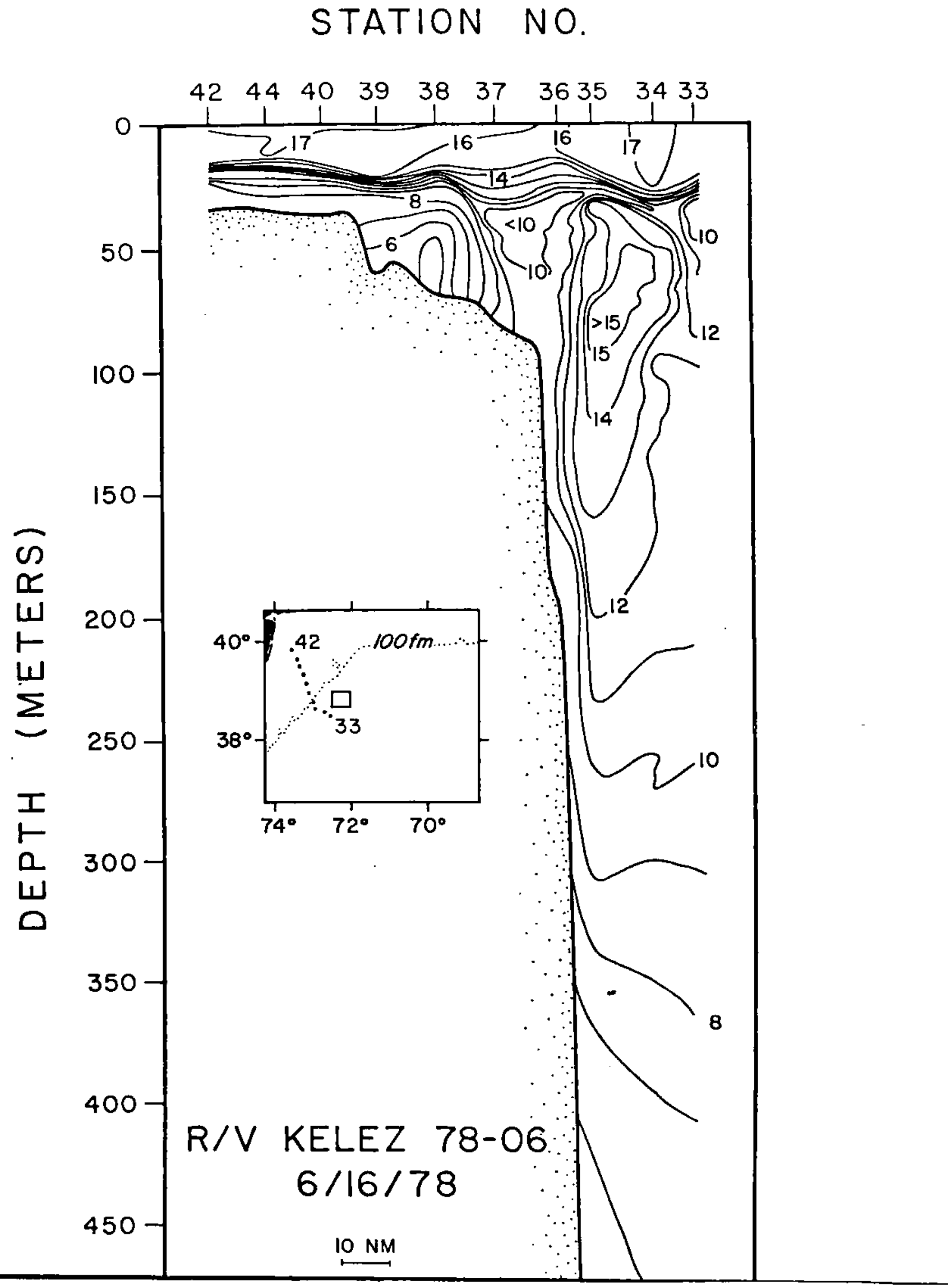

Figure 12 - Second June temperature (°C) transect collected by the Kelez on 6/16/78

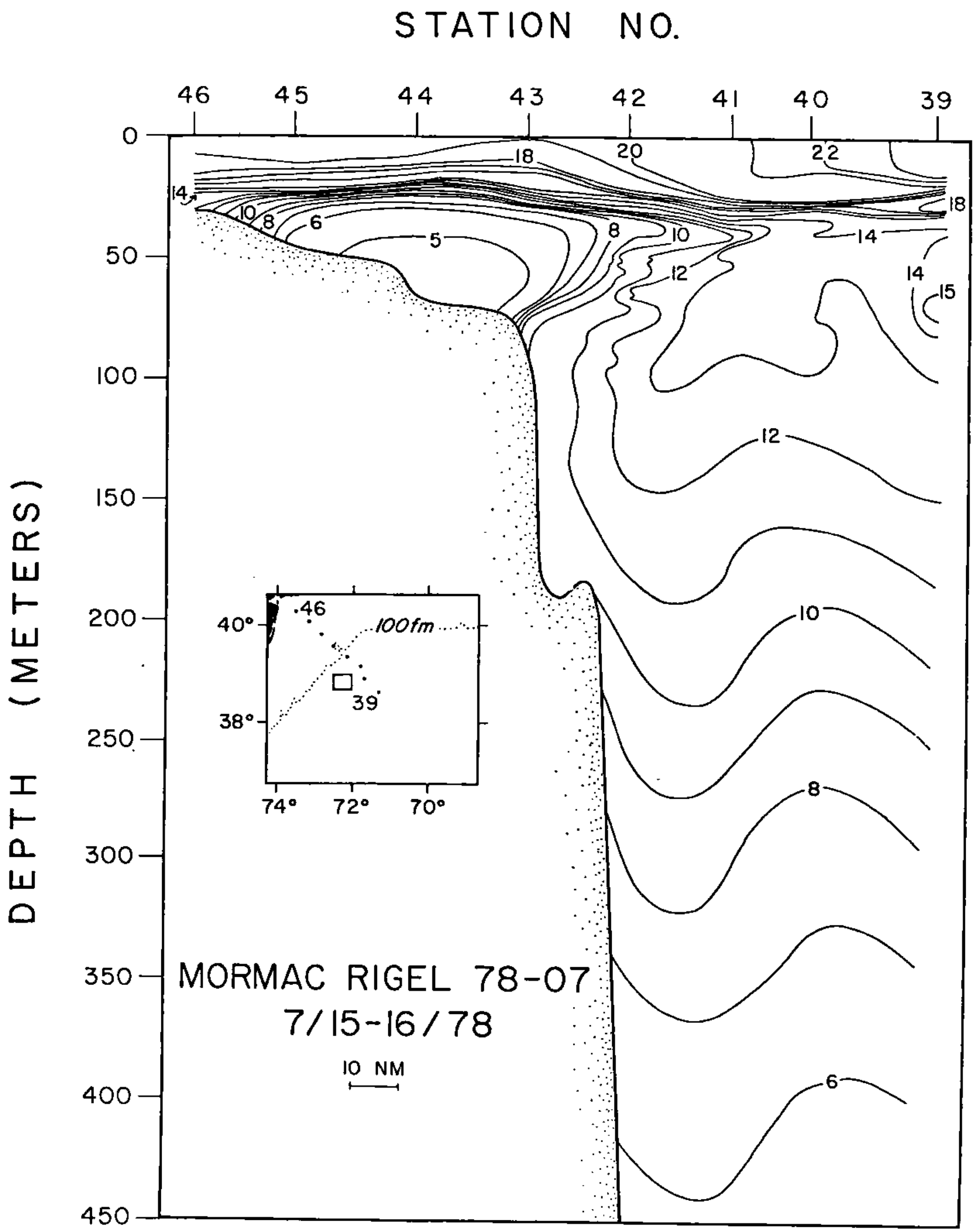

Figure 13 - July temperature (°C) transect collected by the Mormac Rigel on 7/15-16/78

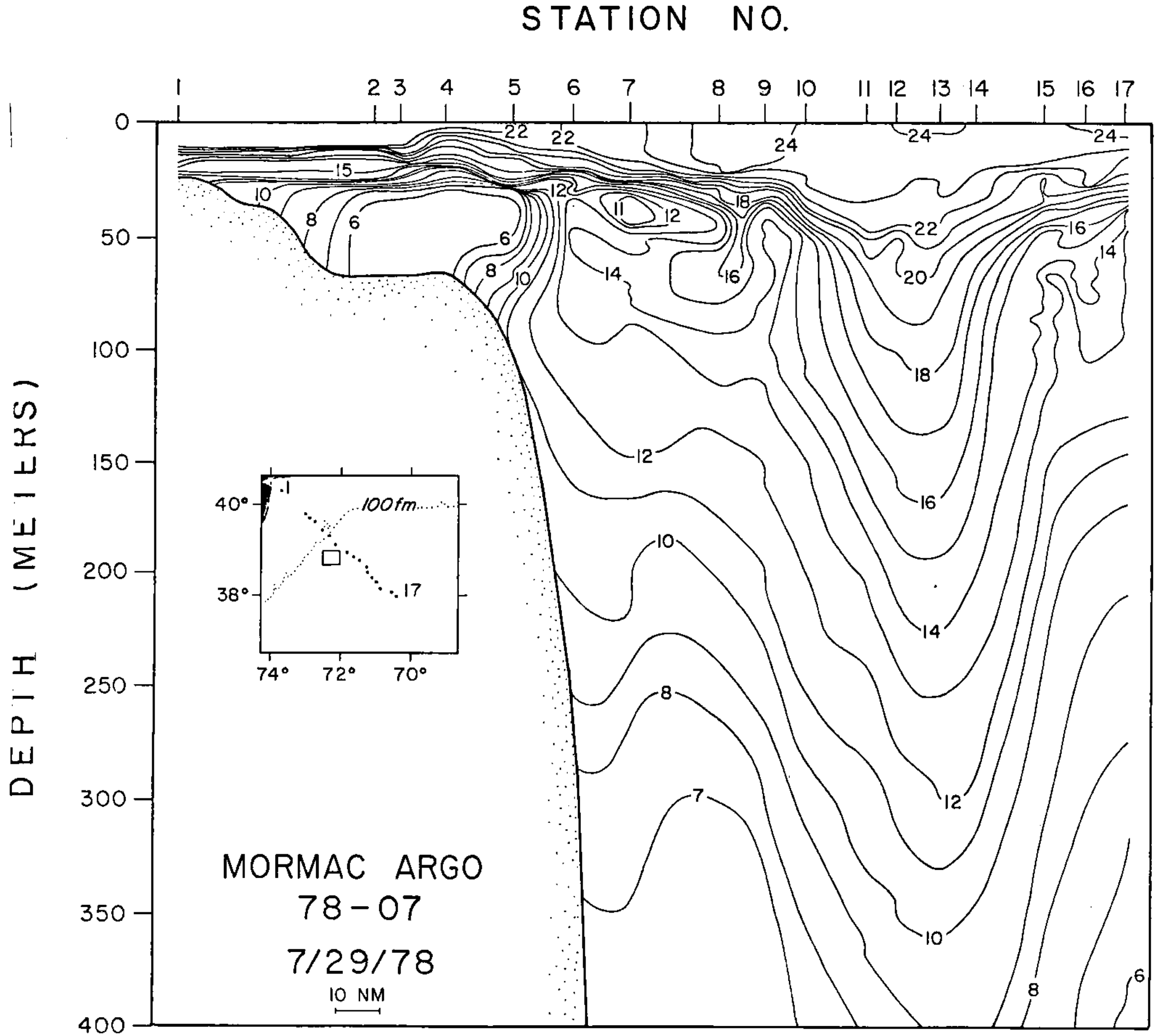

Figure 14 - Second July temperature (°C) transect collected by the Mormac Argo on 7/29/78

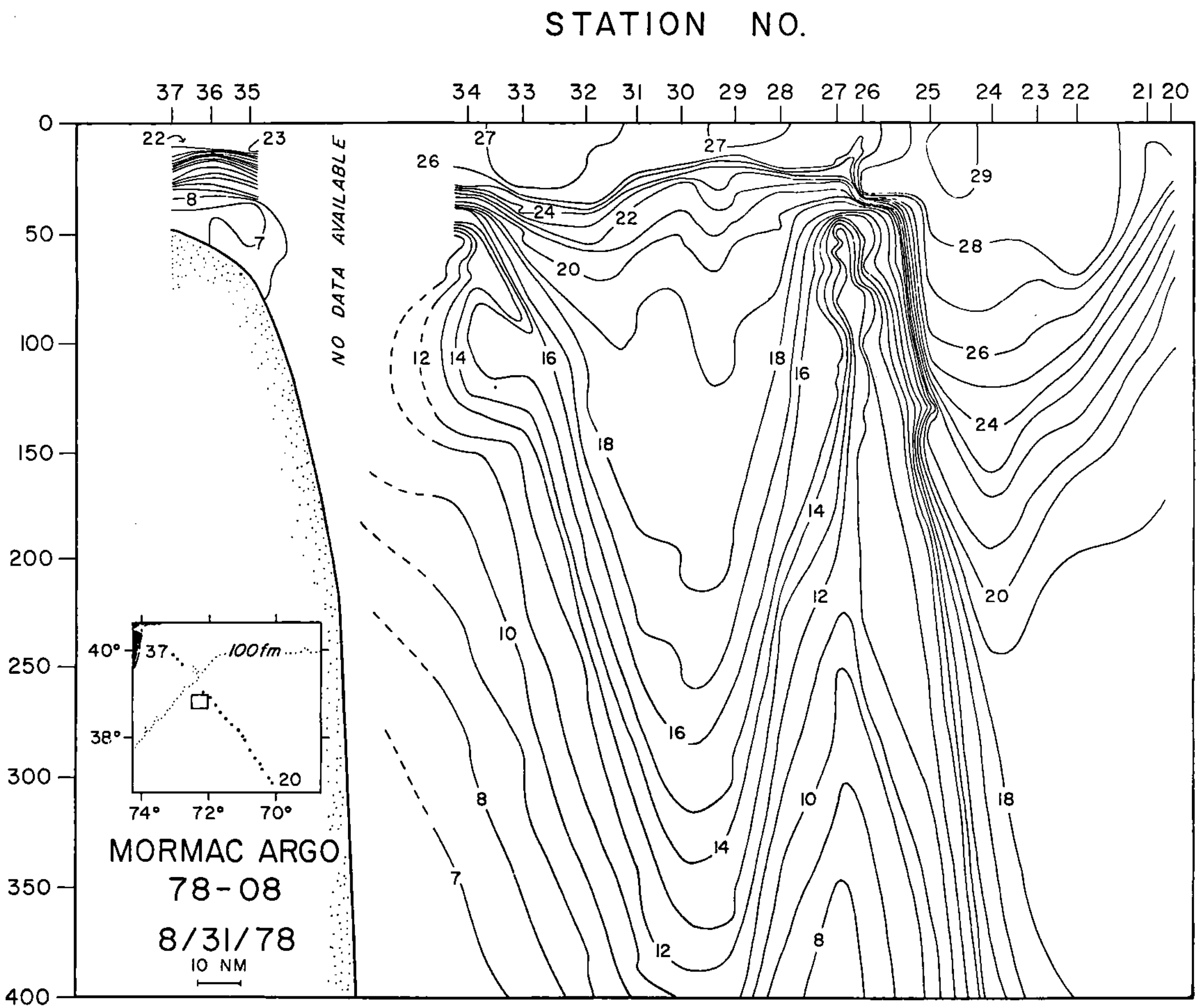

Figure 15 - August temperature (°C) transect collected by the Mormac Argo on 8/31/78

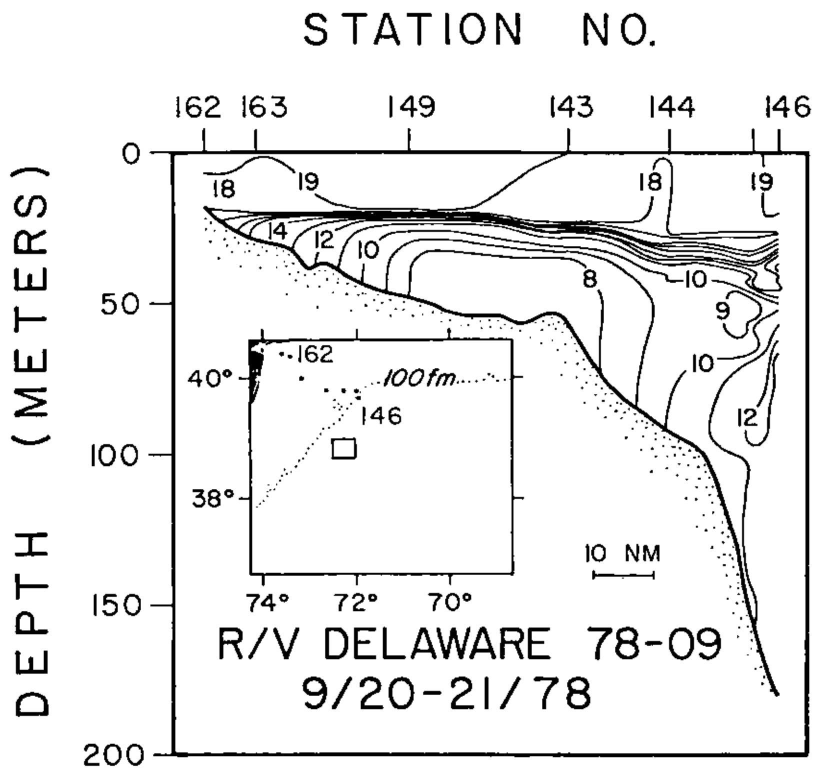

Figure 16 - September temperature (°C) transect collected by the <u>Delaware II</u> on 9/20-21/78

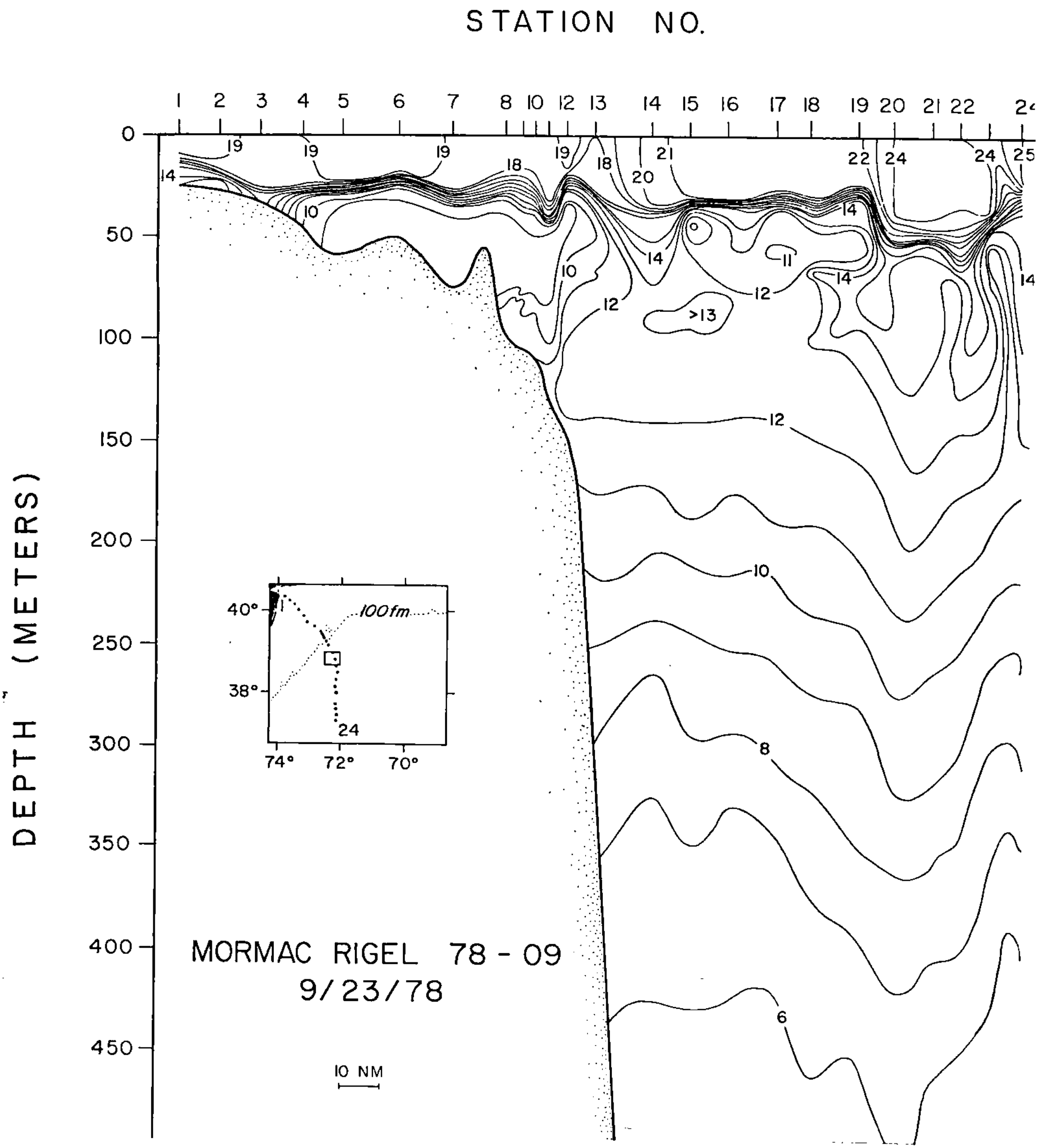

Figure 17 - Second September temperature (°C) transect collected by the Mormac Rigel on 9/23/78

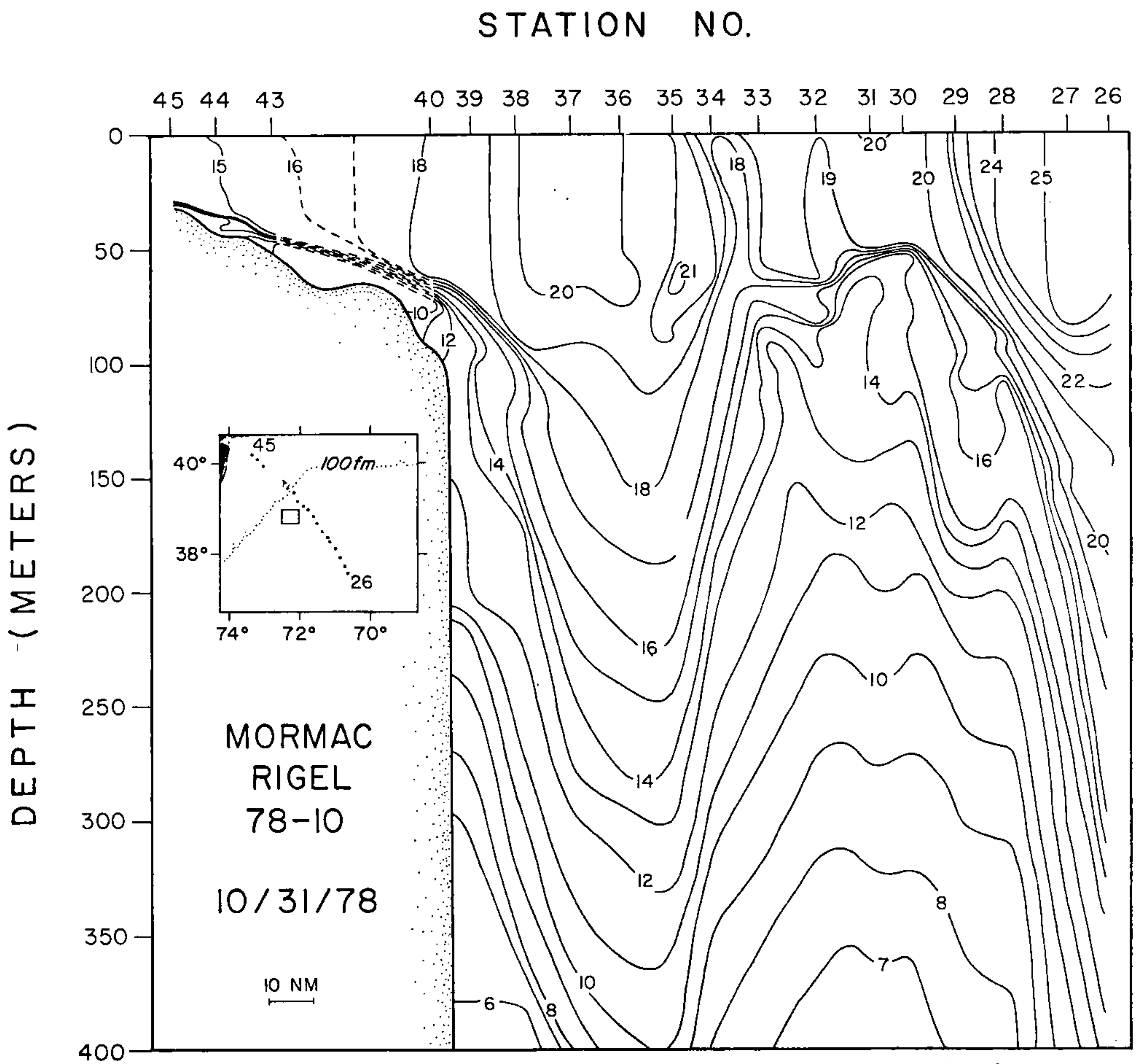

Figure 18 - October temperature (°C) transect collected by the Mormac Rigel on 10/31/78

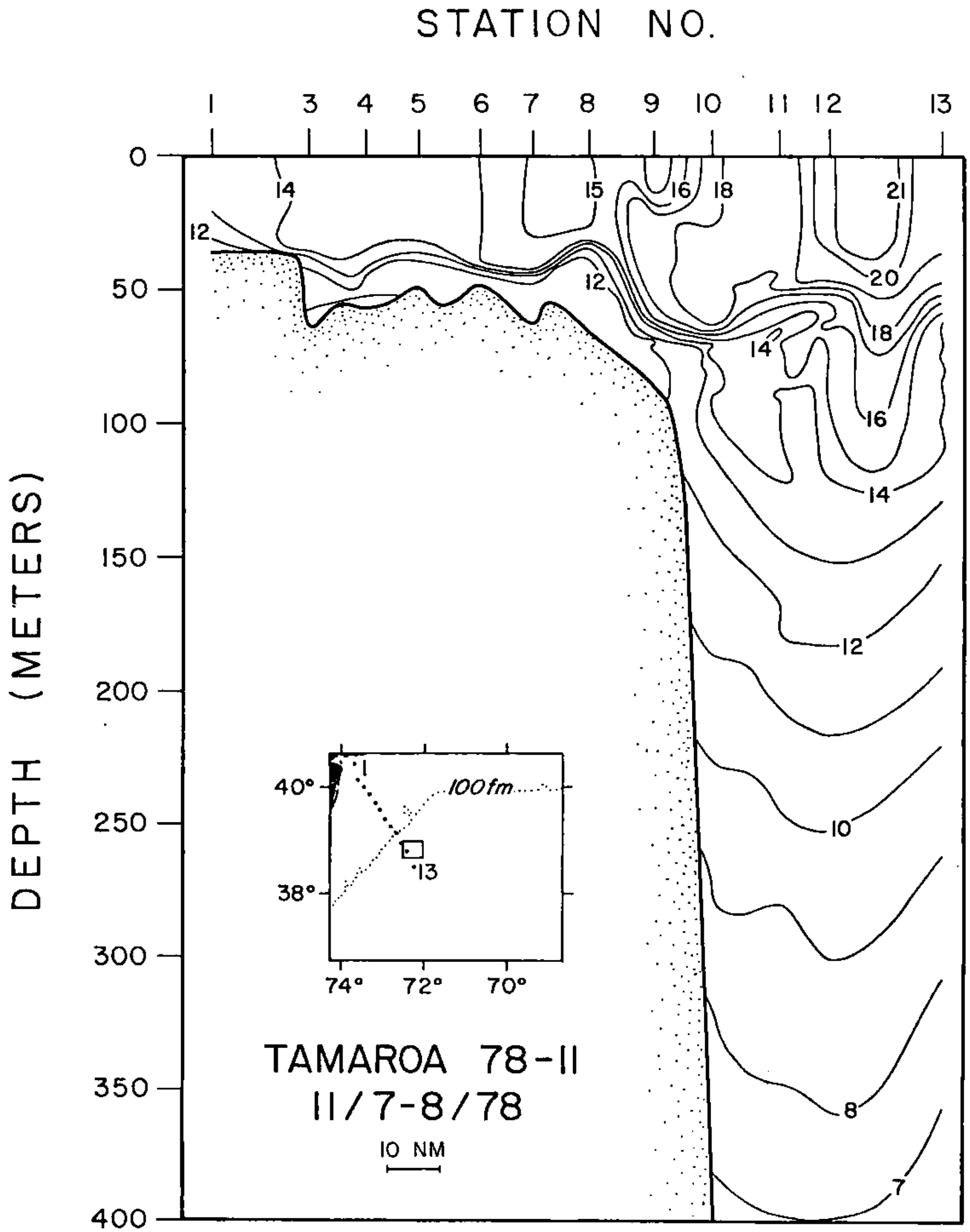

Figure 19 - November temperature (°C) transect collected by the USCGC _Tamaroa_ on 11/7-8/78

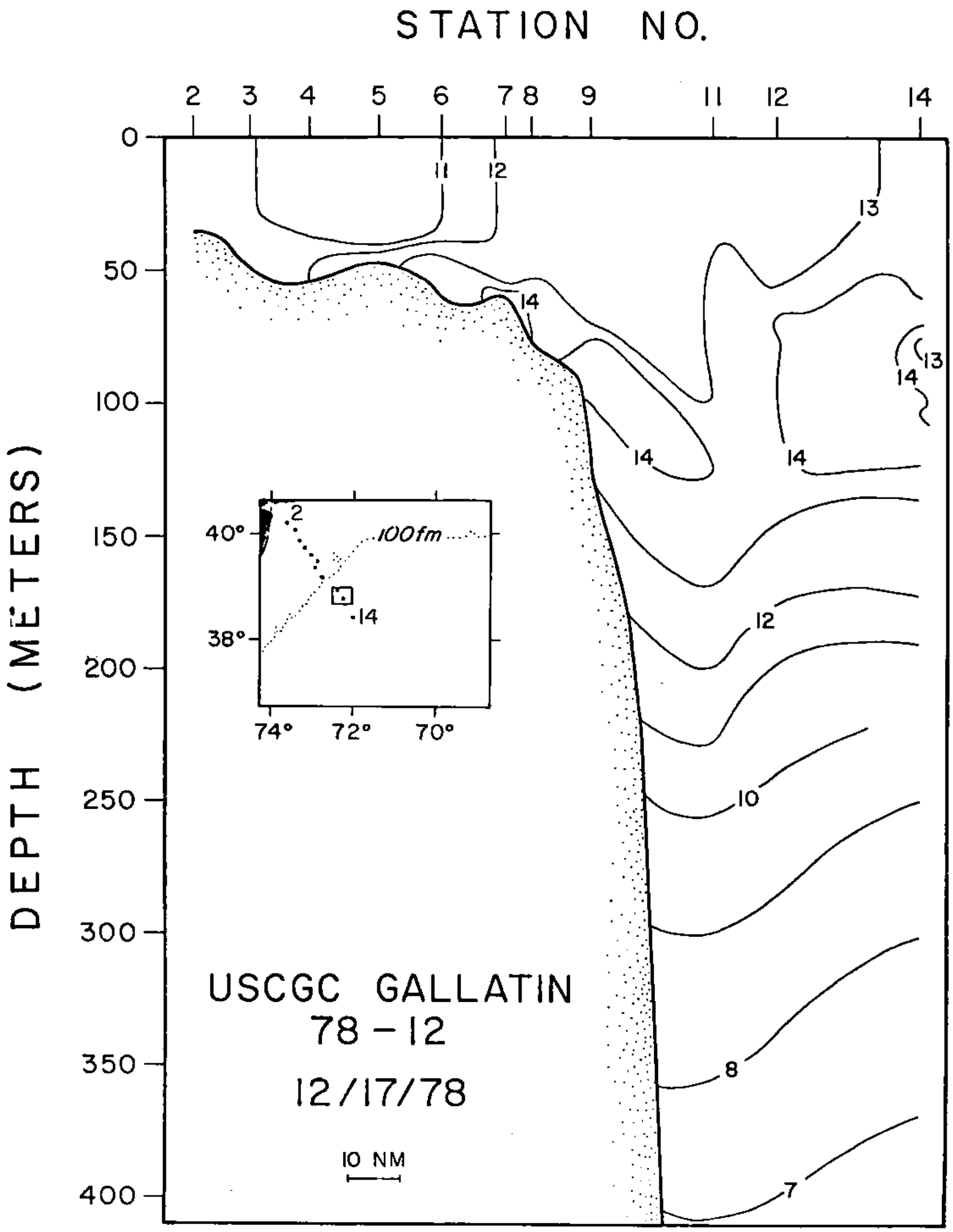

Figure 20 - December temperature (°C) transect collected by the USCGC Gallatin on 12/17/78