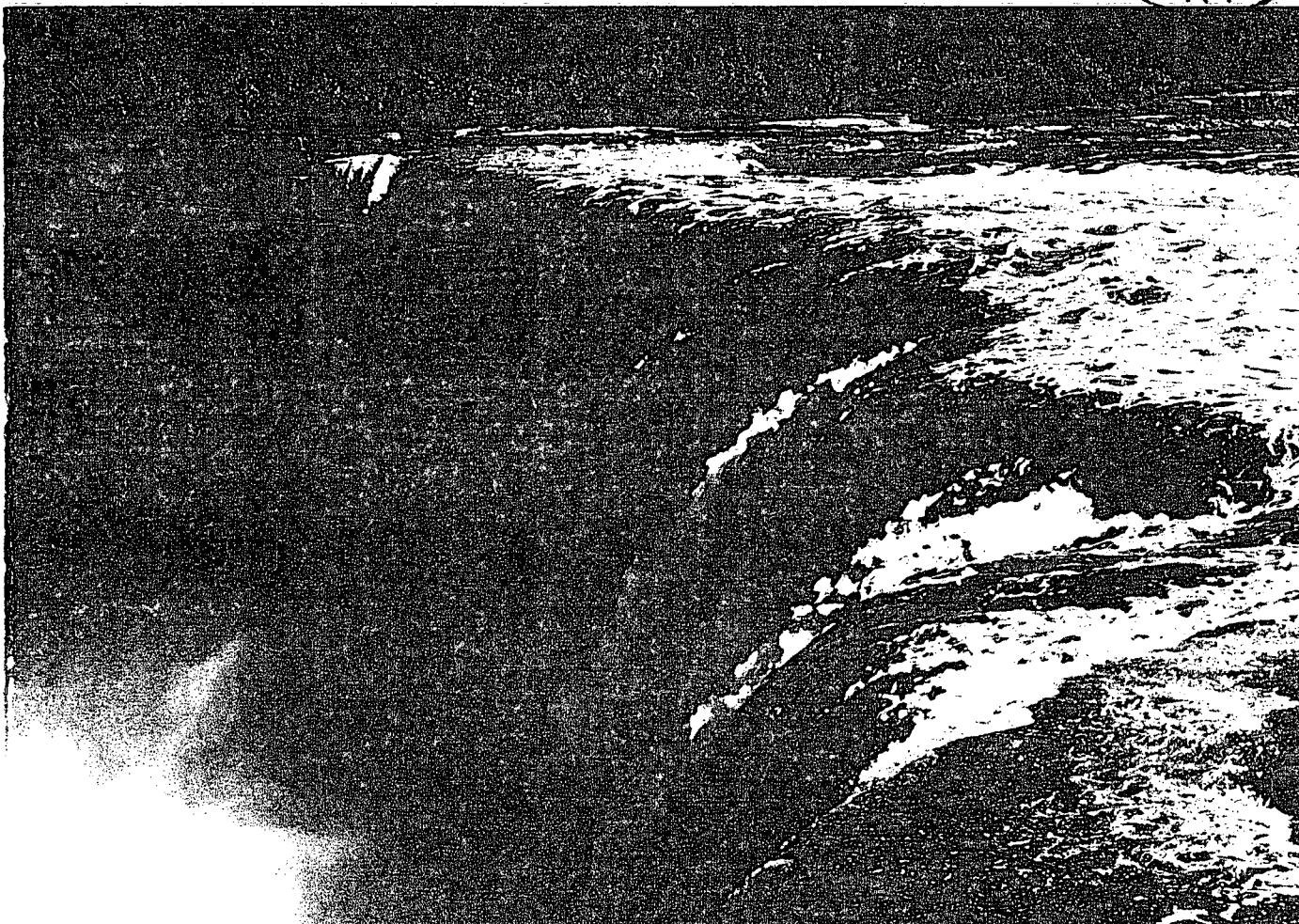


IFYGL TEMPERATURE TRANSECTS, LAKE ONTARIO, 1972

Department of Environment  
Government of Canada

IFYGL Temperature Transects,  
Lake Ontario, 1972

F.M. Boyce and C.H. Mortimer



TECHNICAL BULLETIN NO. 100  
*(Résumé en français)*

Produced jointly by Canadian Centre for Inland Waters, Burlington, Ontario, Canada, and  
Center for Great Lakes Studies, The University  
of Wisconsin at Milwaukee, Milwaukee, Wisconsin,  
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## **Abstract**

During the International Field Year on the Great Lakes (IFYGL) a sequence of experiments was carried out on Lake Ontario wherein it was attempted to measure the temperature structure across three vertical cross sections of the lake simultaneously and continuously for periods of at least four days. Experiments were carried out in July, August, and October of 1972 using up to three research vessels equipped with standard and towed temperature profiling devices. The data have been presented as sequences of cross sections of the lake showing the depths of selected isotherms as functions of horizontal distance and time. The data contain striking examples of both large- and small-scale internal waves, standing and progressive. A very limited discussion of the data in terms of the dynamics of basin-wide internal standing waves is given, since it is intended that this publication be viewed primarily as a data report. Time series plots of isotherm depths from moored temperature profiles are included where they overlap the ship surveys. Data from the coastal chain surveys have been used to extend the measurements shorewards and to verify the ship-based measurements. The instrumentation used to obtain the profiles is described in some detail. A considerable effort has been expended to make the report as complete as possible to facilitate the interpretation of the data for future researchers.

## **Résumé**

Pendant l'Année internationale d'étude des Grands lacs (AIEGL), le lac Ontario a été l'objet d'une série d'expériences par lesquelles on a essayé de mesurer la répartition de la température dans trois sections transversales verticales du lac, de façon simultanée et continue pendant des périodes d'au moins quatre jours. Les expériences ont eu lieu durant les mois de juillet, août et octobre 1972; elles ont été effectuées à l'aide de trois navires de recherche munis d'instruments standard et remorqués pour établir le profil de la température. Les données sont présentées sous forme de séries de coupes du lac montrant la profondeur d'isothermes sélectionnées en fonction de la distance horizontale et du temps. On trouve dans ces données des exemples frappants d'ondes internes, stationnaires et progressives, à grande et à petite échelle. On traite de façon très succincte des données en termes de dynamique des ondes stationnaires internes à la largeur du bassin, cette publication étant d'abord conçue comme un rapport de données. Lorsque les courbes en série chronologique des profondeurs des isothermes tirées des profils de la température aux postes d'amarrage recouvriraient les données des navires, on les a incluses dans le rapport. Des données tirées des réseaux côtiers ont été utilisées pour prolonger les mesures vers la rive et pour vérifier les mesures prises à bord des navires. Les instruments utilisés pour obtenir les profils sont décrits en détail. On s'est efforcé de produire un rapport aussi complet que possible afin de faciliter l'interprétation des données aux futurs chercheurs.

## Introduction and Acknowledgments

One of the objectives of the Water Movements Panel in planning the IFYGL program was to improve understanding of whole-basin dynamics during the season of stratification, paying particular attention to the lake's responses to external forcing by wind stress. The forced and free responses occur over various time scales and take various forms, including for example: quasi-steady, geostrophic currents with quasi-persistent horizontal pressure gradients balanced by the Coriolis force; short-term upwelling-downwelling events confined to within 15 km of shore; and internal waves of various frequencies and wavelengths. Over sufficiently short time intervals and at depths removed from the immediate lake surface, i.e. below the upper 5 m or so, temperature is a relatively conservative property of a given water mass and can be used as a "tracer" in studying time histories of the above-mentioned dynamic responses. Therefore, three cross sections of Lake Ontario were selected (Fig. 1.1) for repeated scans of the temperature-depth distribution, measured with towed, depth-undulating instruments or with thermistor chains or bathythermographs deployed or towed from research vessels (one Canadian, two U.S.). The vessels shuttled continuously to-and-fro across the sections for intervals of five or more days: Olcott to Oshawa (10-14 July, 9-12 August, 2-6 October); Braddock Point to Presquile; and Oswego to Prince Edward Point (both 24-28 July, 7-11 August, 2-6 October). No attempt was made to synchronize individual crossings on the three transects.

On the Olcott-Oshawa section (C.S.S. *Limnos*, research vessel of the Canada Centre for Inland Waters), F.M. Boyce used two complementary systems: an undulating towed body (the "Batfish") carrying an electronic bathythermograph (EBT) probe; and a towed thermistor chain. On the Braddock Point - Presquile section, the NOAA vessel O.S.S. *Researcher* towed an undulating temperature-pressure sensor developed at the Center for Great Lakes Studies (CGLS) (Mortimer, 1972) and described in Appendix A. On the Oswego to Prince Edward Point section, temperature distribution was measured from S.S. *Advance II*, Cape Fear Technical Institute vessel, using mechanical bathythermographs. The various pieces of equipment and the methods employed are described in the next section.

The plan to use research vessels in continuous shuttle operation, producing repeated scans (transects) of temperature distribution in three cross-lake sections, was prompted by earlier detailed findings on thermocline dynamics, also derived from repeated temperature transects of Lake Michigan (Mortimer, 1968). That study was designed (1) to explore the offshore extent of the upwelling and downwelling motions disclosed by temperature fluctuations at municipal water intakes and (2) to test Mortimer's (1963) prediction that the free oscillatory responses would be represented, in simplest model terms, by internal Kelvin wave dominance near shore and by internal Poincaré wave dominance further offshore.

The results from Lake Michigan, based on 80 crossings by a railroad ferry over the 127-km-wide Milwaukee-Muskegon section during a six-week interval starting mid-July 1963, disclosed a thermocline in a continuous state of oscillation, often with large amplitudes (10 m range) after wind disturbances and often combined with a strong downward tilt of the thermocline on either the western or eastern shore, depending on the previous wind direction; the thermocline was almost always associated with upwelling on the opposite shore. The upwelling-downwelling motions were confined to nearshore strips of approximate width 15-20 km; and the nearshore thermocline tilts commonly persisted for several days after the initiating wind disturbance had passed. This was evidence of similar persistence of shore-parallel geostrophic currents, until disturbed by the next storm. The "nearshore zone" characterized by dominance of shore-parallel currents with occasional thermocline "fronts" moving with speeds characteristic of internal Kelvin waves (Mortimer 1963) could be clearly differentiated from the "offshore" regions (>20 km from shore), in which the dominant pattern of thermocline oscillation took the form of a cross-lake standing wave with periods in the range of 16 to 17 hr, i.e. a few percent less than the local inertial period (17.5 hr). A mid-basin nodal region, i.e. a region of little change in thermocline elevation, could often be recognized about 65 km from Milwaukee. Phase relationships between thermocline elevation and the current direction at a mid-lake anchor station indicated the dominance of a uninodal

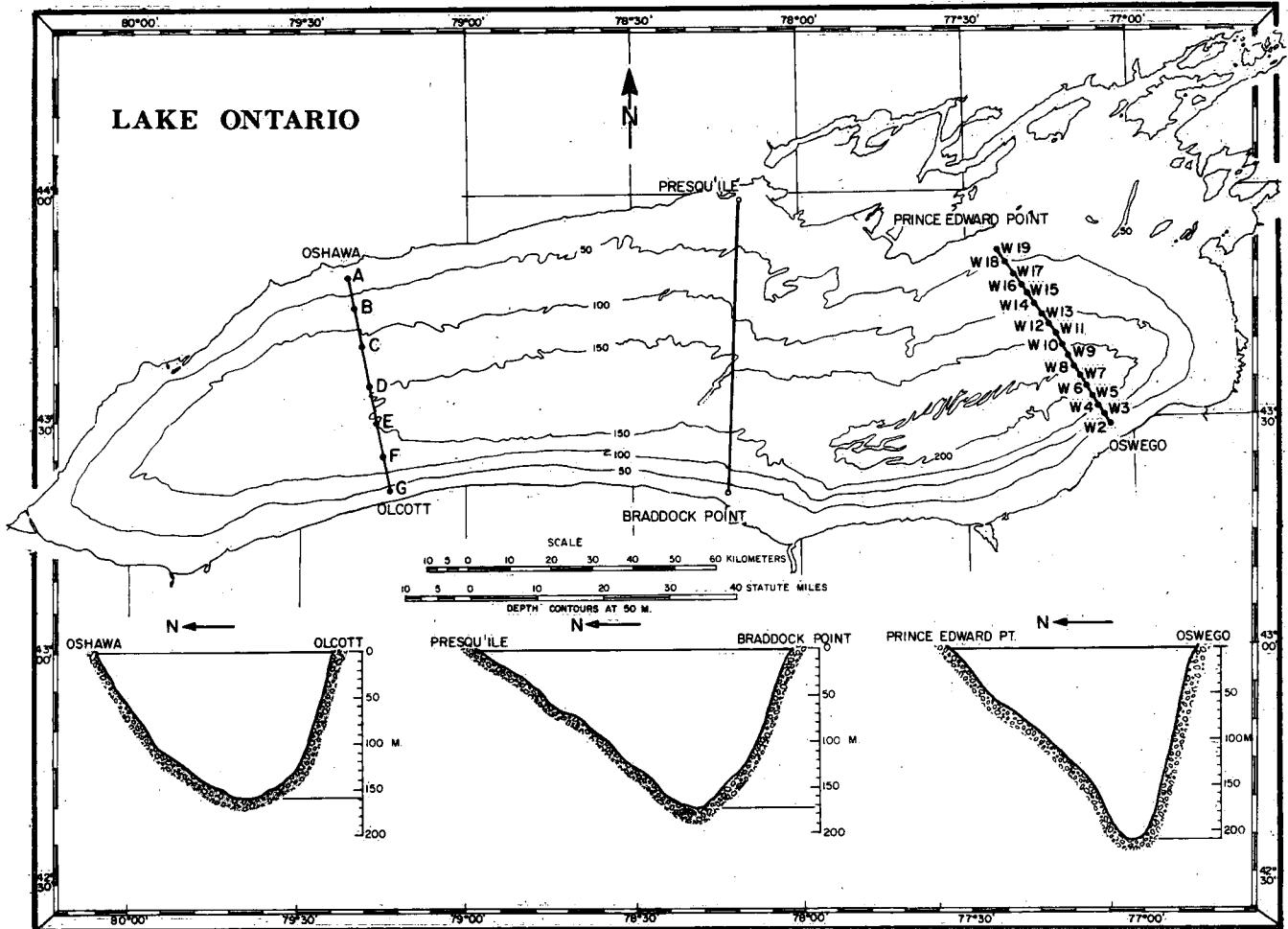


Figure 1.1. Lake Ontario showing the three transects along which the depth distribution of temperature was measured on repeated crossings: Olcott to Oshawa (C.S.S. *Limnos*); Braddock Point to Presqu'ile (O.S.S. *Researcher*); and Oswego to Prince Edward Point (S.S. *Advance II*). More detailed charts of those sections are reproduced respectively, as Figures 4.1, 6.4, and 7.1.

(transverse) internal standing wave on one occasion (4-7 August 1963) and of a mixture of uni-, tri-, and quinti-nodal components on another occasion (19-22 August 1963), in each case consistent with the theoretical model of an internal Poincaré wave exhibiting a standing wave pattern across the Lake. Also conforming to the predictions derived from the Poincaré wave model, the current pattern at the mid-lake anchor station generally exhibited the following features: clockwise rotation of direction, in phase with the internal wave; a fairly uniform distribution of velocity throughout both layers, one above and one below the thermocline; lower velocities in the lower layer, consequent on the greater thickness of that layer. The total transport was the same in each layer, but the directions were always opposed, with a reversal in current direction at the thermocline.

Mortimer (1968) concluded: "The observations and theoretical considerations combine to suggest that motion in the Lake is likely to be a complex mixture of uninodal, trinodal, and perhaps higher nodalities of internal standing Poincaré waves, probably combined by internal progressive waves (particularly during periods of wind stress) and further complicated inshore by the presence of slow moving quasi-geostrophic boundary waves of the Kelvin type. These will impose a dominant shore-parallel component on the inshore currents, while the offshore currents, in summer, will be predominantly rotating, with intermediate patterns in the transition zone between the inshore and offshore regions." In that study, it was only possible to examine the temperature distribution in detail by repeated traverses of one cross section. But a few longitudinal sections, occupied by another research

vessel and chosen where possible to intersect the ferry runs, disclosed a three-dimensional thermocline topography consistent with the presence of longitudinal internal Poincaré waves of very long wavelength.

In the hope that further light would be thrown on the longitudinal features of these whole-basin motions, the present IFYGL (Lake Ontario) study was designed to include three cross sections and to use the information on temperature and flow provided by recording instruments at strategically placed fixed stations.

Work on the Olcott-Oshawa section was carried out by a team from the Canada Centre for Inland Waters, led by F.M. Boyce, using research vessel *Limnos* to tow the "Bedford Batfish" and Thermistor Array described in the next section. The success of the project was due to the work of many individuals. J.G. Dessureault of the Bedford Institute of Oceanography was the chief designer and motive force behind the Batfish system. W.J. Moody and J.A. Bull, CCIW, assisted by CCIW engineering staff were responsible for the assembly and testing of the measurement system used aboard *Limnos*. The programs

of data analysis and plotting were developed and run by J.A. Bull. Willing and cheerful assistance of the officers and crew of C.S.S. *Limnos*, of CCIW Technical Operations Section, and of CCIW Scientific Support Staff in general is gratefully acknowledged.

The Rochester (Braddock Point) to Presqu'ile and the Oswego to Prince Edward Point sections were occupied by the vessels *Researcher* (NOAA) and *Advance II*, respectively, with a scientific team from the Center for Great Lakes Studies, The University of Wisconsin—Milwaukee, led by C.H. Mortimer and D.L. Cutchin, including D.N. Baumgartner (responsible for instrument design and maintenance) and F.W.N. Bates. Subsequent data reduction was also a team effort, the most difficult part of which (analysis of the magnetic tapes) was tackled by Cutchin and Baumgartner. Our special thanks are due to the officers and crew of the above-mentioned vessels and also to R.A. Scott, who designed and constructed the mechanical portions of the towed "Undulator" and winch, described in the next section and Appendix A, and to R.J. Ristic, who prepared the numerous sectional diagrams presented later.

# Description of Equipment and Procedures

## 2.1. THE OLcott TO Oshawa TRANSECT — C.S.S. *LIMNOS*

### Batfish System

The Batfish vehicle (developed at Bedford Institute of Oceanography, Dartmouth, Nova Scotia) is a towed streamlined body whose depth can be controlled from the towing vessel (Fig. 2.1). The vehicle can be towed at a constant depth or made to undulate between two depths. During the transect experiments the Batfish carried a standard Guildline EBT package. The temperature and depth signals were recorded both digitally on magnetic tape and in analog form aboard ship. For the major portion of the experiments, the vehicle was made to undulate between 0 and 50 m depth with a horizontal "wavelength" of about 1 km. The temperature and depth signals were sampled and recorded once each second. The Batfish system provided the main body of data for these experiments.

### Streamlined Bathythermograph (SBT) System

The purpose of this apparatus (Fig. 2.2) was to obtain a record of the temperature fluctuations at a fixed depth while the vessel was underway. The data so obtained were intended to complement the Batfish data, since they provide information on temperature structure at horizontal scales much less than the 1-km wavelength of the Batfish trajectory. The system comprised a standard Guildline EBT mounted within a ballasted streamlined body (Fathom Oceanology) that was towed outboard by a faired cable. A winch equipped with slip rings permitted the depth to be adjusted while the vessel was underway. The normal procedure was to maintain the body within the thermocline region. The temperature and depth signals from the Guildline EBT were recorded on a strip-chart recorder and on magnetic tape. The SBT system was used during the July 10-14 cruise only.

### Towed Thermistor Array

This system provided information on the small-scale horizontal variations of thermal structure at several

depths. A faired multiconductor cable was towed from the stern of C.S.S. *Limnos*. A depressor fin (Braincon 4-ft V-fin) containing a pressure sensor was fastened to the outboard end, and thermistors were mounted at 4-m intervals along the cable (Fig. 2.3). Signals from the thermistors and the pressure sensor were recorded on magnetic tape; and two of the thermistor signals were recorded on a strip-chart recorder. The thermistors were lagged to yield a thermal time constant of approximately 5 s and the signals were sampled and recorded at 1-s intervals. At a towing speed of 6 knots (3 m/s), the approximate horizontal resolution of the system was 15 m. The depth of the depressor fin was maintained at about 30 m. This equipment was used during the August and October cruises.

### Procedure

Seven stations were defined on the Oshawa-Olcott transect. They are labelled A, B, C, D, E, F, G, in order from north to south (Fig. 1.1) and their positions are given in Table 2.1.

**Table 2.1. C.S.S. *Limnos* Station Positions for Temperature Transect Cruises (see Fig. 1.1)**

Station	Latitude N.	Longitude W.
Off Olcott:		
G	43°21'54"	78°43'58"
F	43°26'00"	78°45'00"
E	43°30'26"	78°45'13"
D	43°34'59"	78°47'34"
C	43°39'21"	78°48'48"
B	43°43'38"	78°49'53"
Off Oshawa:		
A	43°48'59"	78°51'16"

The turning points on the line were located inshore of station A and station G but were not precisely defined and indeed were varied depending on depths of towed array cable streamed. For practical purposes, then, stations A and G mark the ends of the transect lines.

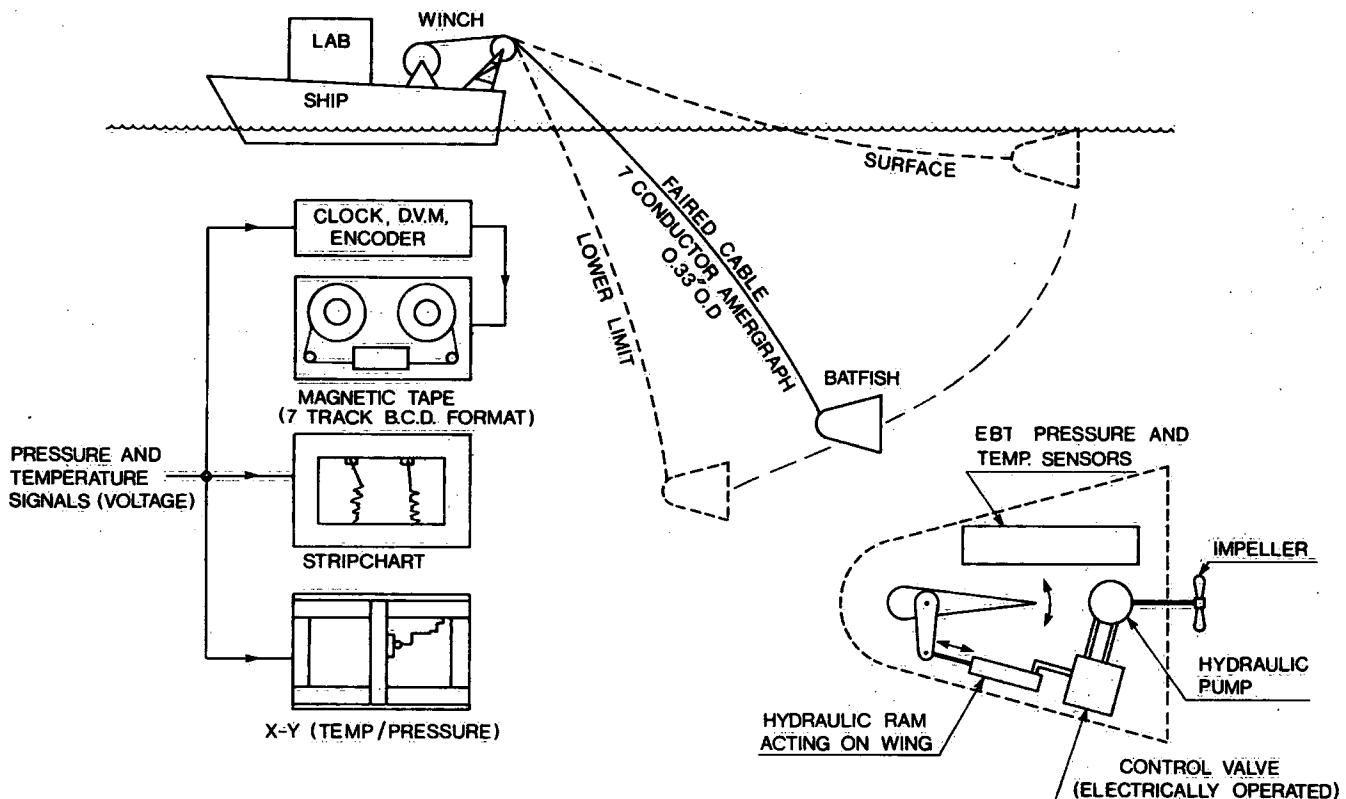


Figure 2.1. The Batfish System (Bedford Institute of Oceanography).

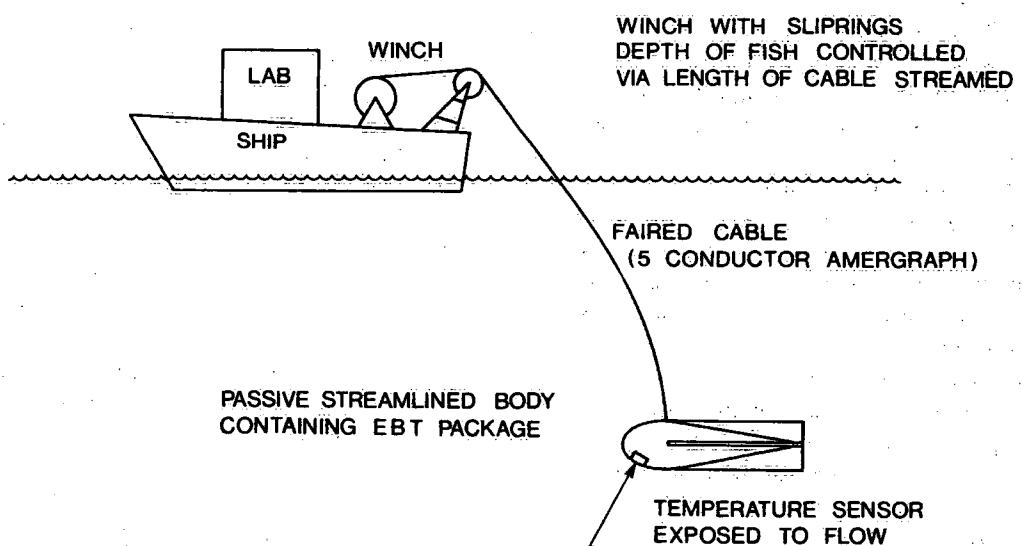


Figure 2.2. The Streamlined Bathymeter (SBT) System.

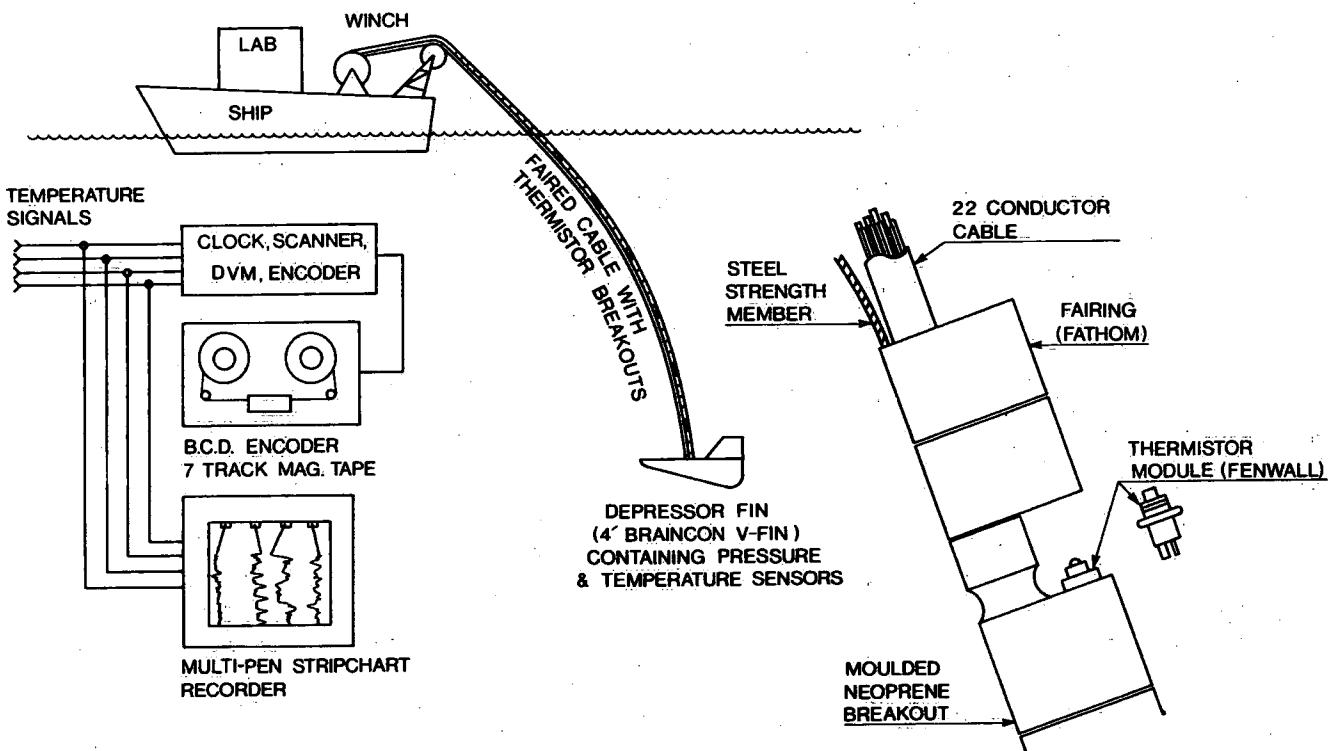


Figure 2.3. Towed Thermistor Array.

Measurements began at a point offshore in water of sufficient depth to allow the towing cables to be payed out with the vessel stopped. The ship then proceeded along the transect line at constant speed (between 6 and 8 knots depending on conditions) turning in wide semicircles inshore of stations A and G. At each of the stations, the officer on watch made an accurate fix of the ship's position with the Decca navigation system, and recorded both time and position in the bridge log. This information was subsequently used to convert the clock time recorded by the ADDS (Analog and Digital Data System) data logger into a geographical position along the transect line. As each of the stations were passed, the strip chart recorders were marked and an analog trace of the vertical temperature profile was made with the X-Y recorder hooked up to the Batfish system. This collection of traces served as material for preliminary cruise reports and as a backup in the event of a failure of the automatic data logging system. A weakness inherent in this system is the fact that correct operation of the logger cannot be established until the magnetic tapes have been read on the CCIW computer.

As the ship approached the turning points, the maximum dive depth of the Batfish was progressively

reduced to keep the vehicle a safe distance from the bottom. This was a delicate procedure, since the exact depth under the Batfish at the end of its dive could not be foreseen. An overcautious handling meant that valuable data would be lost, while excessively bold maneuvers risked fatal collision with the bottom. The Batfish did strike the bottom on at least two occasions, as evidenced by minor damage to the fibreglass housing and the lodging of small rocks in the sensor tunnel. These were lucky escapes. Once inshore of stations A or G the Batfish was brought to the surface and, as the ship turned, the automatic data collection was interrupted while end-of-file marks and header information were written on the magnetic tape. As soon as the ship was abreast of station A or G, automatic data collection was resumed.

This procedure was carried out during the greater part of the cruise periods. Interruptions are noted in the log extracts which precede the transect diagrams in Chapter 3.

A description of the data processing sequence, starting with the field data recorded on magnetic tape, and ending with the plots of isotherm depths versus time-distance, is given in Appendix B.

## 2.2. THE ROCHESTER (BRADDOCK PT.) TO PRESQU'ILE TRANSECT — O.S.S. *RESEARCHER*

### The Towed Temperature-Depth Recording System—Description of the CGLS Undulator

The Undulator System used on the Rochester-Presqu'ile transect was a modified and improved version of the system described by Mortimer (1972). A detailed description of the system and its operation, as modified for IFYGL, is found in Appendix A. Designed for the scanning of Great Lakes temperature fields from moving vessels, the system consists of the following components (Fig. 2.4): an electric winch with single-conductor armored cable; a towed sensor package (later referred to as the "fish") and an on-deck electromechanical control and recording console. As it moves through the water, the fish samples the temperature and hydrostatic pressure around it, relaying this information via the towing cable to the on-deck equipment for recording and real-time monitoring. Together the submerged and on-deck packages make up a semiportable system that can be operated from any vessel, providing there is enough deck space for the winch and adequate electrical power.

The sensor package offers a different approach to previous systems incorporating vessel-towed, undulating-depth sensors, for example the "Baffish" described in section 2.1. It has no moving parts, or moveable control surfaces, or servomotors. It is in essence a continuously operating electronic bathythermograph with depth control derived entirely from the winch on the towing vessel. It appears to be capable of operating at higher towing speeds than was possible with previous designs.

For the IFYGL surveys, two sensors (transducers) were mounted in the fish, one to measure depth (pressure) and the other temperature. Each depth and temperature measurement made up one data sequence, repeated approximately four times a second. The recording and control console on deck provided for real-time monitoring and permanent storage of the data coming from the sensors, and also permitted the path of the towed fish to be followed and controlled by manual operation of the winch. Normal operation required a two-man crew, one to operate the winch and the other to monitor sensor depth and supervise the data acquisition process, described in more detail in Appendix A.

### Operational Procedures with the Undulator on Board O.S.S. *Researcher*

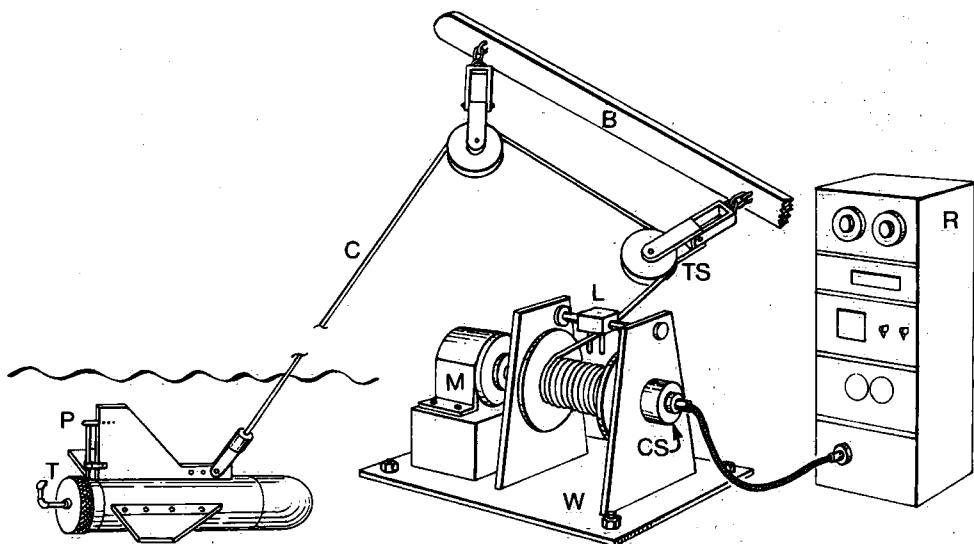
After the vessel's boom had been extended and the fish connected to the towing cable (C) through the slip-

ring swivel (S, Fig. 2.6), the cable was threaded through a measuring sheave (MS, Fig. 2.7), then through the two towing sheaves (TS), and the fish was lowered into the water. The towing sheaves were provided with cable guides (Fig. 2.5) to keep the cable on the sheave at all speeds and tensions, an essential precaution. The outer towing sheave also carried an "end-of-cable" alarm device (E, Fig. 2.5), tripped by a projection on the cable, as a warning to the winchman to stop before the fish came out of the water.

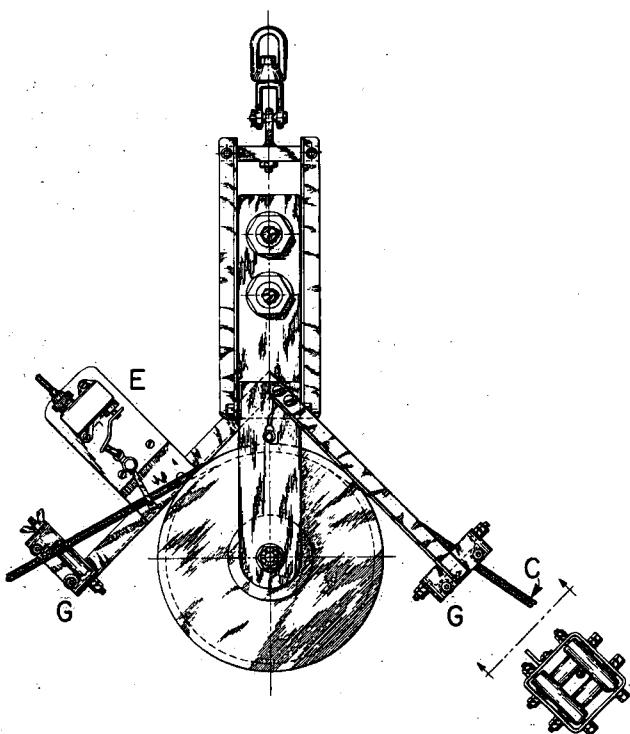
It was routine drill to alert the vessel navigator (the bridge officer) whenever the fish was being put into or taken out of the water. With the vessel in motion and about 25 m of cable payed out, the fish towed just under the water surface. If its towing attitude appeared normal and if the recording system was indicating correct data — i.e. 4 m depth and a surface water temperature close to that shown by the ship's thermograph, also at about 4 m depth — the recorders (tape and X-Y) were switched on, the dive was started, and the GMT time was recorded in the cruise log book.

The normal procedure for each dive was as follows. The control of each dive was in the hands of the operator sitting at the control panel, assisted by the operator at the winch (Figs. 2.8 and 2.7, respectively). In the "ready to dive" position, the fish was travelling just below the surface and the winch brake was on. On command (time recorded and recorders switched on) the winch brake was released, allowing the fish to dive with the cable paying out as fast as it would go. When the depth indicator showed that the desired dive depth had been reached, the control operator signalled to the winchman to apply the brake and end the dive. Immediately thereafter the winch was powered to pull in the cable until the fish was again near the surface, so that another dive could be started. The time of each dive was recorded, and the cycle was repeated continuously during a cruise as long as sea state and bottom conditions allowed. At the end of each transect, the time was again recorded, as were all times of interruptions in the continuous data record. Details of the cruise log are not reproduced here, because all the relevant information on position and time is included on the transect diagrams in Chapter 5.

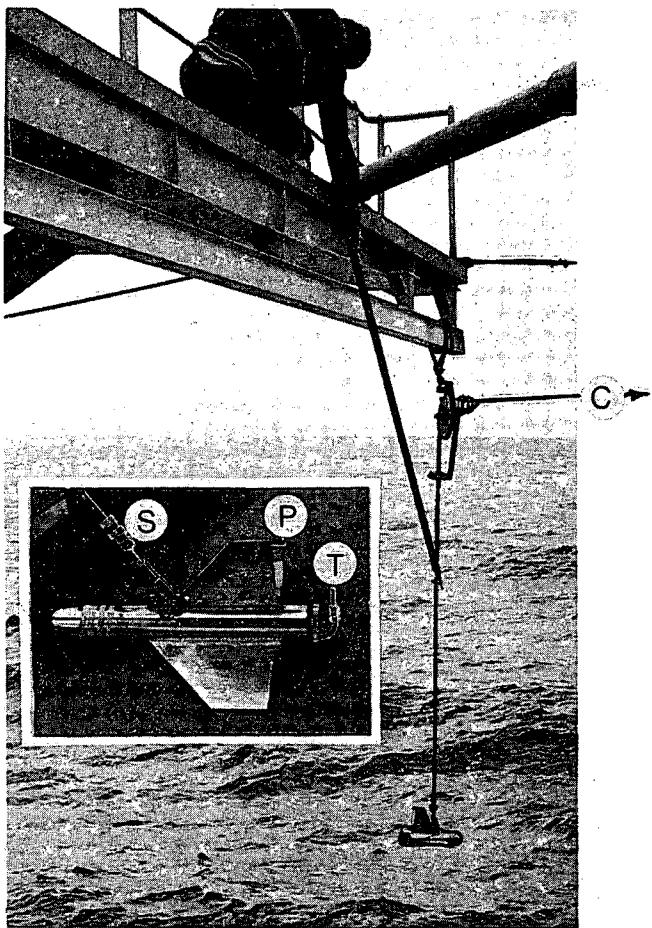
The output from the fish, translated into analog voltages corresponding to pressure (depth) and temperature, took the form illustrated in Figure 2.9. This displays, with a time scale, three extracts from consecutive dive-ascent sequences, serially numbered. The pressure trace (scaled in depth) can be recognized by the sharp downward-facing "spikes" produced by the rapid transition between descent and ascent coinciding with the instant of application of the winch brake. Each



**Figure 2.4.** CGLS Undulator System for recording depth distribution of temperature below a moving vessel. The towed unit (the underwater "fish") is shown on the left with a thermistor (temperature sensor) mounting at T and a pressure recording point at P. The fish is connected through (i) a commutating swivel; (ii) an armored towing cable (C, with a single conductor); and (iii) special towing sheaves (TS) mounted on a towing boom (B), to a winch (W) on the vessel's deck. The winch, driven by motor and clutch M, is fitted with a level-wind device L. The inboard end of the cable is connected through a commutating swivel CS, to the recording and control console R. Further details are given in Figures 2.5, 2.6, and Appendix A.



**Figure 2.5.** The special Undulator Towing Sheave is suspended from a swivel at the outboard end of the towing boom and is provided with cable guides G G. These ensure that cable C stays on the sheave, in spite of variations in the tension and angle of the tow. A small block, attached to the cable near its outboard termination at the fish, trips the "end-of-cable" warning device E, to sound an alarm when the fish reaches a preselected upper towing level.



**Figure 2.6.** The Undulator towed body (fish) being lowered on the towing cable (C) from the towing sheave on the boom of O.S.S. *Researcher*. Inset: details of the fish: S, Slip-ring swivel; P, pressure port; T, thermistor. Details of the towing sheave are illustrated in Figure 2.5. Details of the fish are illustrated in Appendix B.

numbered dive started with a steep descent from a 4-m plateau to typically 60–70 m, followed by an initially rapid rise to typically 30–40 m and then a slower steady rise back to the plateau level, at which the fish was towed between dives. The temperature traces show broader troughs corresponding to the time spent by the fish at subthermocline depths. Normally during the ascent the temperature rose at first slowly and then rapidly as the fish passed through the thermocline. A striking exception is shown by dives 419 and 420 at the top of Figure 2.9. At that time, a storm had caused downwelling with a sharp thermal front 9 km from Braddock Point coinciding with dive 419 (see transect No. 017, Julian day 223). The ascent after dive 419 was unique among our records in that the temperature fell steadily as the fish was rising.

As explained in Appendix A, the particular thermistor used in the Undulator (Yellow Springs Instruments,

No. 44206) possessed a thermal time constant of 1 s in stirred oil. What we did not realize, until tests were carried out on board O.S.S. *Researcher*, was that the method of mounting the thermistor bead in epoxy resin increased the time constant nearly fivefold. This large value (greatly reduced in a later version, Baumgartner, 1976) forced us to ignore the data obtained during the rapid descent portion of the dive and to use only the data obtained during the relatively slow ascent. Even so, appreciable errors were introduced into the estimates of thermocline depth at normal rates of ascent, if the thermocline gradient was steep. The nature and magnitude of these errors are discussed in Chapter 6, which follows the presentation of the Rochester-Presqu'ile temperature transects in Chapter 5.

During some dives, for example those shown in the lower sections of Figure 2.9, the winch was stopped during the ascent to tow the fish for 1 to 4 min at constant depth in the thermocline region, to gain information on short internal waves and to permit a better definition of mean thermocline depth. All the data were recorded in digital form on tape. As a backup and to provide real-time visualization, X-Y plots of temperature against depth were made during the descent and ascent portions of each dive.

The control operator was also responsible for collecting and registering, in the cruise log and on the tape, information on ship's position, time signals, buoy references, and other data. Buoy references were inserted in the log book and on the tape at times (received by phone from the navigation bridge) when the ship passed the various fixed-instrument moorings placed along the section, at the positions shown in the Chapter 5 transects. The moorings, at these known positions, provided spatial check points; and temperature data from instruments at these moorings have been inserted for comparison at the appropriate point on each transect. It was also a prime duty of the control operator to monitor the bottom depth, particularly when approaching the coastal shelves, to prevent the fish from striking the bottom. This happened on one occasion, necessitating a 24-hr repair, while mechanical bathythermographs were continued.

The ship's speed was normally maintained at 10 knots. The period between dives varied from 4 min to 10–15 min depending upon the dive depth and whether a tow at constant, near-thermocline depth was included.

#### Performance Reliability and Subsequent Improvements in the Undulator System Design

Apart from two brief interruptions, following a cable break and the above-mentioned 24-hr interruption for

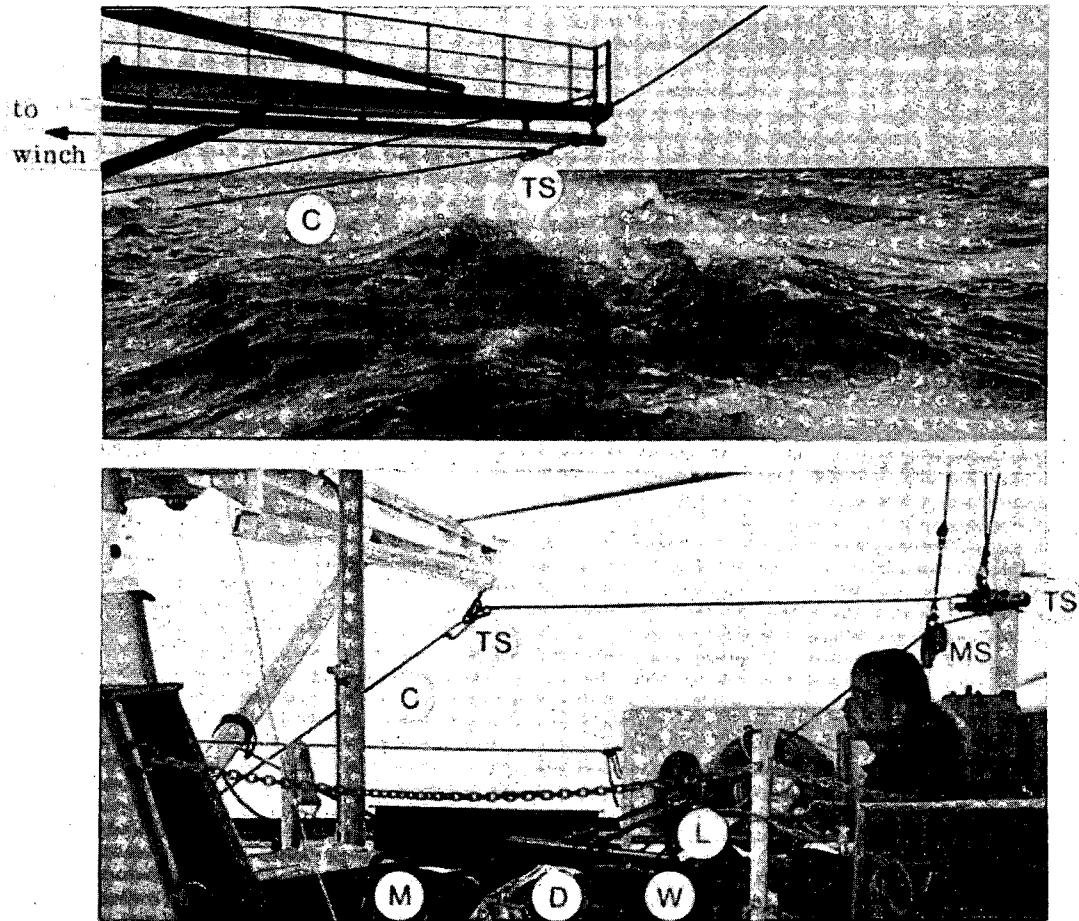


Figure 2.7. Winch and towing arrangements for the undulator on O.S.S. *Researcher*. TS, towing sheaves; MS, measuring sheave; W, winch drum; L, level-wind guides, M, winch motor; D, depth limit indicator; C, towing cable thickened in photo.

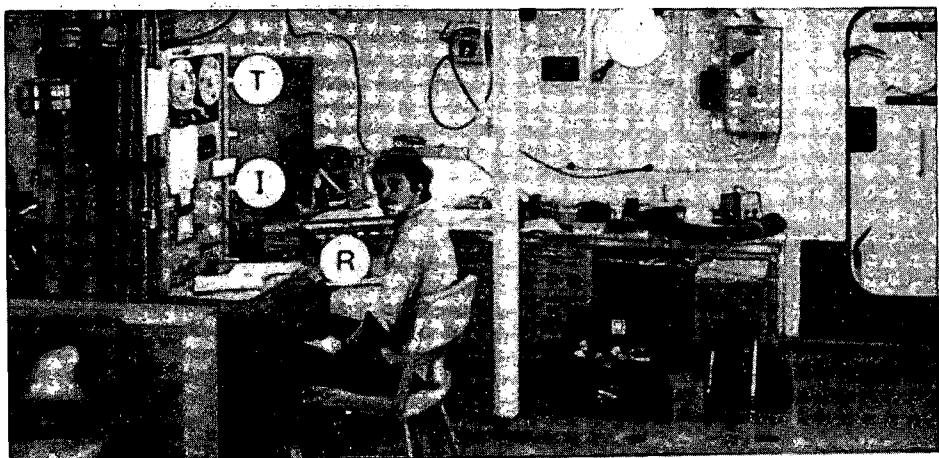
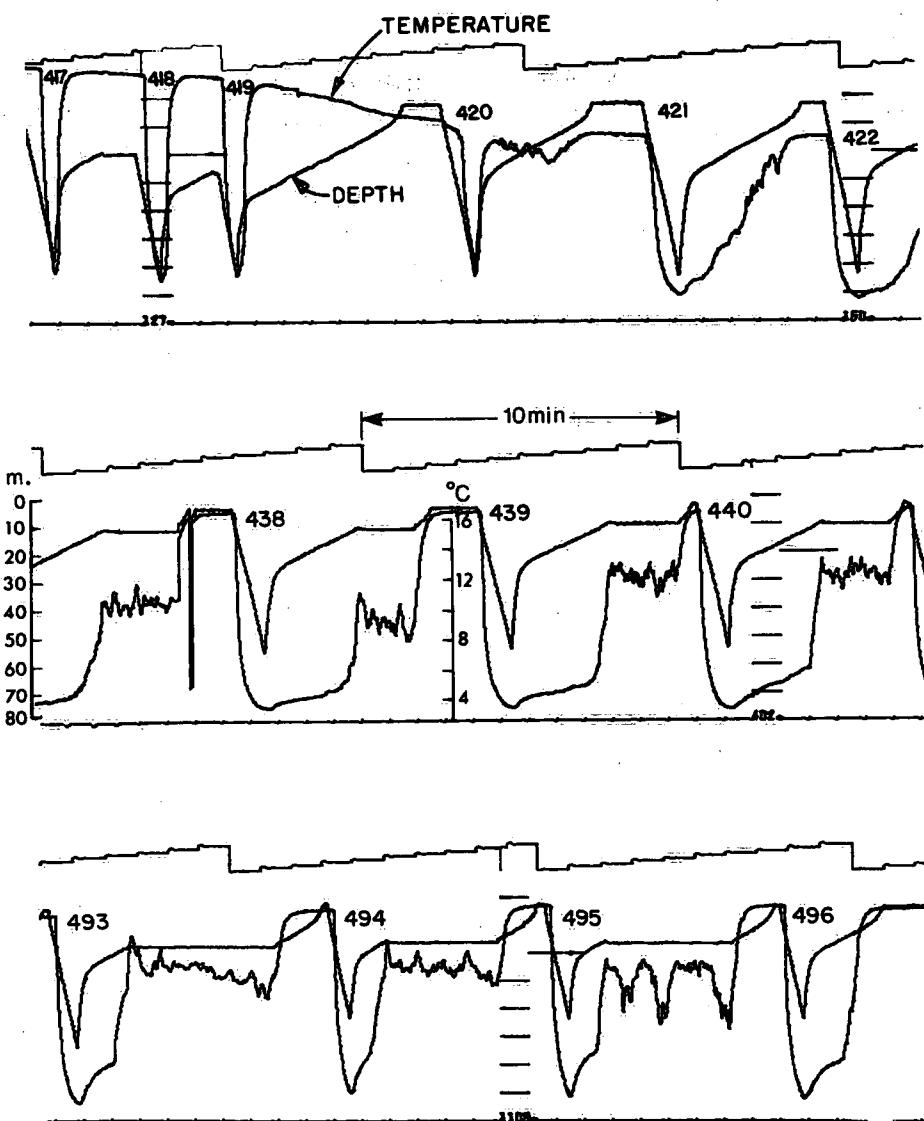


Figure 2.8. Undulator recording and control console. T, tape deck; I, indicator and keyboard panel; R, X-Y recorder.



**Figure 2.9.** Extract of data tape plots obtained with the Undulator on the Braddock Point to Presquile Transect during the 7-11 August 1972 cruise. As explained in the text, the trace with downward-pointing, sharp peaks below each dive number indicates depth (pressure). The upper trace indicates time in 1- and 10-min steps; and the remaining trace is that of temperature.

repairs after the fish hit the bottom, the system performed well for 89% of the possible time, completing 3740 km of towing distance with 1500 dives, during July, August, and October cruises combined. During the brief interruptions in undulator operation, the transects were continued using a mechanical bathythermograph. There was also a tape-deck malfunction, first discovered in later processing. But very fortunately this occurred on the last day of the last cruise, and only 12 hr of data were lost. A record-playback system, omitted to reduce overall cost and complexity, would have disclosed this malfunction.

In spite of the experimental nature and low-cost design, the Undulator System performed well, as the transect diagrams in Chapter 5 attest. The principal fault was that the time constant of the thermistor was too long. The experience gained has enabled design of an improved version (Baumgartner, 1976) that provides station data playback capabilities, while retaining the desired low-cost and portability features. In that instrument, frequency modulation of the IRIG subcarrier bands transmits continuous analog data from the submerged sensor to the on-deck electronics, enabling X-Y plotters

or strip chart recorders to be driven. The regenerated carrier frequencies are recorded, along with a reference frequency, using a low-cost magnetic tape cassette recorder. The reference frequency channel can carry other keyed-in information and is used to correct for tape speed variations during data playback. Compared with the Undulator System used in 1972 (Fig. 2.8) the console size has been reduced by a factor of 30, total power consumption and the thermistor time constant has

been reduced by 10, and the noise immunity has been increased.

### **2.3. THE OSWEGO TO PRINCE EDWARD POINT TRANSECT — S.S. *ADVANCE II***

The procedure, using mechanical bathythermographs, does not warrant detailed description (see Chapter 7).

## Temperature Distributions in the Olcott to Oshawa Transect

The depth distribution of temperature across the Olcott to Oshawa section was scanned by the 'Bedford Batfish' towed by C.S.S. *Limnos*, as described in section 2.1, following the cruise pattern outlined in the log entries listed later. Each crossing, alternately north to south and south to north, usually occupied between 3½ and 4 hr. We present the results in the form of isotherm depth diagrams, with a thousandfold exaggeration of the vertical scale and with isotherms plotted for the 5° and 6°C isotherms and for every 2° above that. Surface temperatures are entered at the top of the diagram and the GMT time scale is placed at the bottom. The temperature and pressure (depth) data obtained by the Batfish on successive descents and ascents were used as input to a computerized interpolation and plotting program, of which the following diagrams were the output. Interpolation was linear between data points; and no attempt was made to smooth the occasionally 'spiky' appearance of the plots, in contrast to the hand smoothing applied to the plots in Chapters 5 and 7.

Three transect cruises were completed. The first cruise (10-14 July) did not coincide with the cruises of 24-28 July on the other two transects (Rochester to Presqu'ile and Oswego to Prince Edward Point); but the second and third cruises (9-12 August, 2-6 October)

coincided. The total numbers of transects completed during the July, August, and October cruises were 23, 21, and 24, respectively, corresponding to a total track length of about 3300 km. The results for each crossing, identified by date and transect number, are presented in three groups in time sequence, with each cruise prefaced by the relevant entries from the ship's log. We have therefore concluded that it is unnecessary to allocate

Table 3.1. Julian Date Table for IFYGL Transect Cruises 1972

July 10	192	August 7	220
11	193	8	221
12	194	9	222
13	195	10	223
14	196	11	224
		12	225
July 24	206		
25	207	October 2	276
26	208	3	277
27	209	4	278
28	210	5	279
		6	280

additional figure numbers to the transect diagrams. All times are shown in GMT, and Table 3.1 will assist the conversion from transect cruise dates to Julian day numbers used throughout the IFYGL project.

**Extract from the Log Narrative, C.S.S. *Limnos* Cruise, 72-00-064  
10-14 July (Julian Days 192-196) 1972**

Instruments deployed: Batfish, SBT  
Transects completed: 23  
Major interruptions: None. Times are GMT.

**10 July**

1450	Depart CCIW
	Start Transect 1 at Station G (Fig. 1.1, Table 2.1).
2018	Towing at 8 knots, 60 m of cable payed out and Batfish diving to 51 m below surface every 5 min. SBT towed near depth of 10°C isotherm.

**11 July**

	Station	Start of Trans. No.
0004	A	2
0353	G	3
0746	A	4
1135	G	5
1152	Stopped to free SBT from an Olcott yacht club buoy snagged en route.	
1212	Underway	
1546	A	6
1941	G	7
2008	Stopped to inspect towed gear. Batfish slightly damaged by contact with bottom. Lower portion of fairing somewhat disarranged.	
2045	Underway - 75 m of cable payed out, maximum depth for Batfish of 62 m.	

**12 July**

	Station	Start of Trans. No.
0004	A	8
0406	G	9
0750	A	10
1136	G	11
1523	A	12
1553	New tape on ADDS	
1934	G	13
2245	A	14

**13 July**

	Station	Start of Trans. No.
0305	G	15
0653	A	16
1037	G	17
1422	A	18
1819	G	19
1840	Stop to examine towed instruments and replace fairing.	
2235	A	20
	New tape on ADDS	

**14 July**

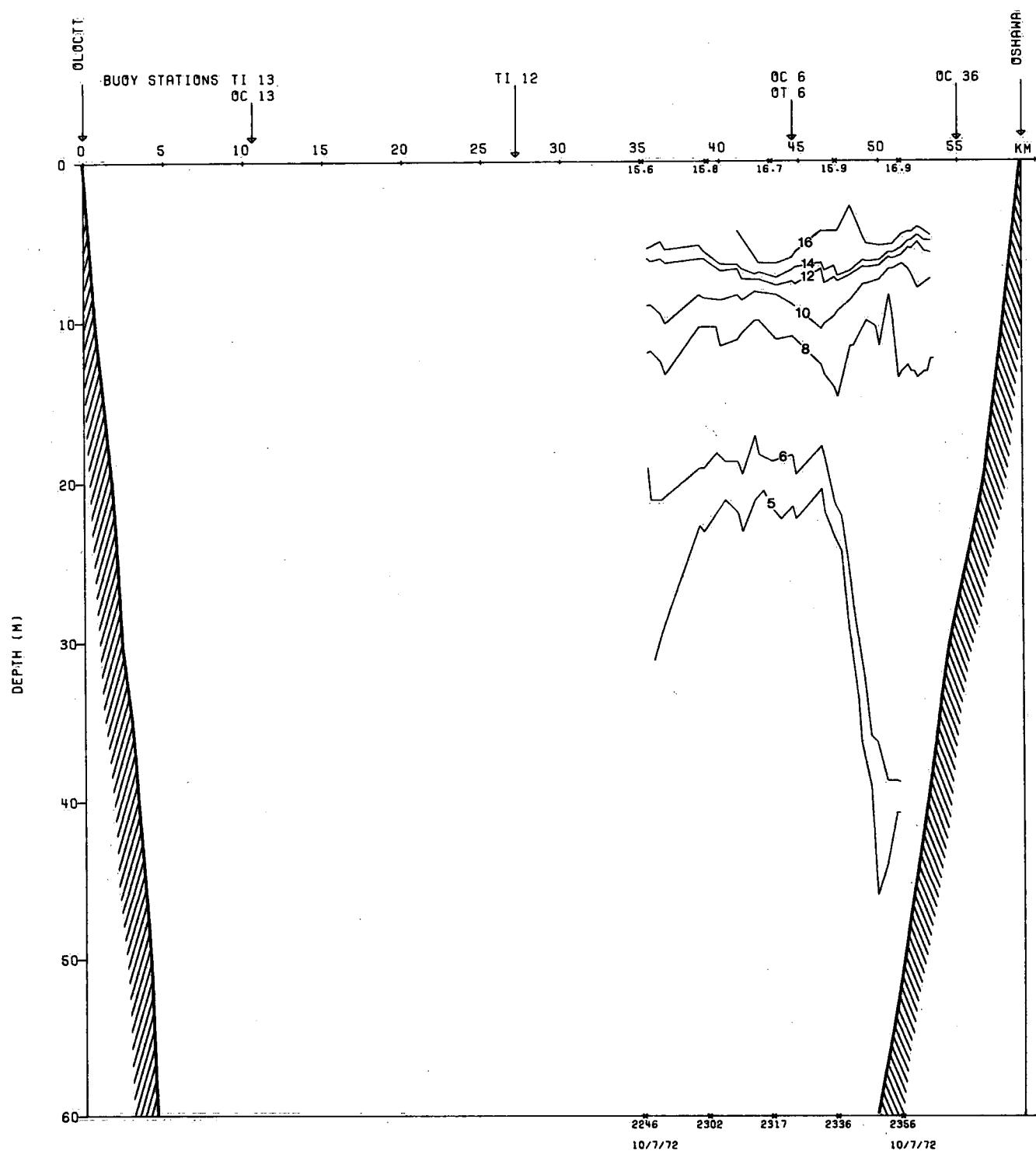
0216	G	21
0608	A	22
0954	G	23
1337	A - Recover instruments and set course for CCIW (alongside 1930).	

Transects 1 to 23 follow.

IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 1

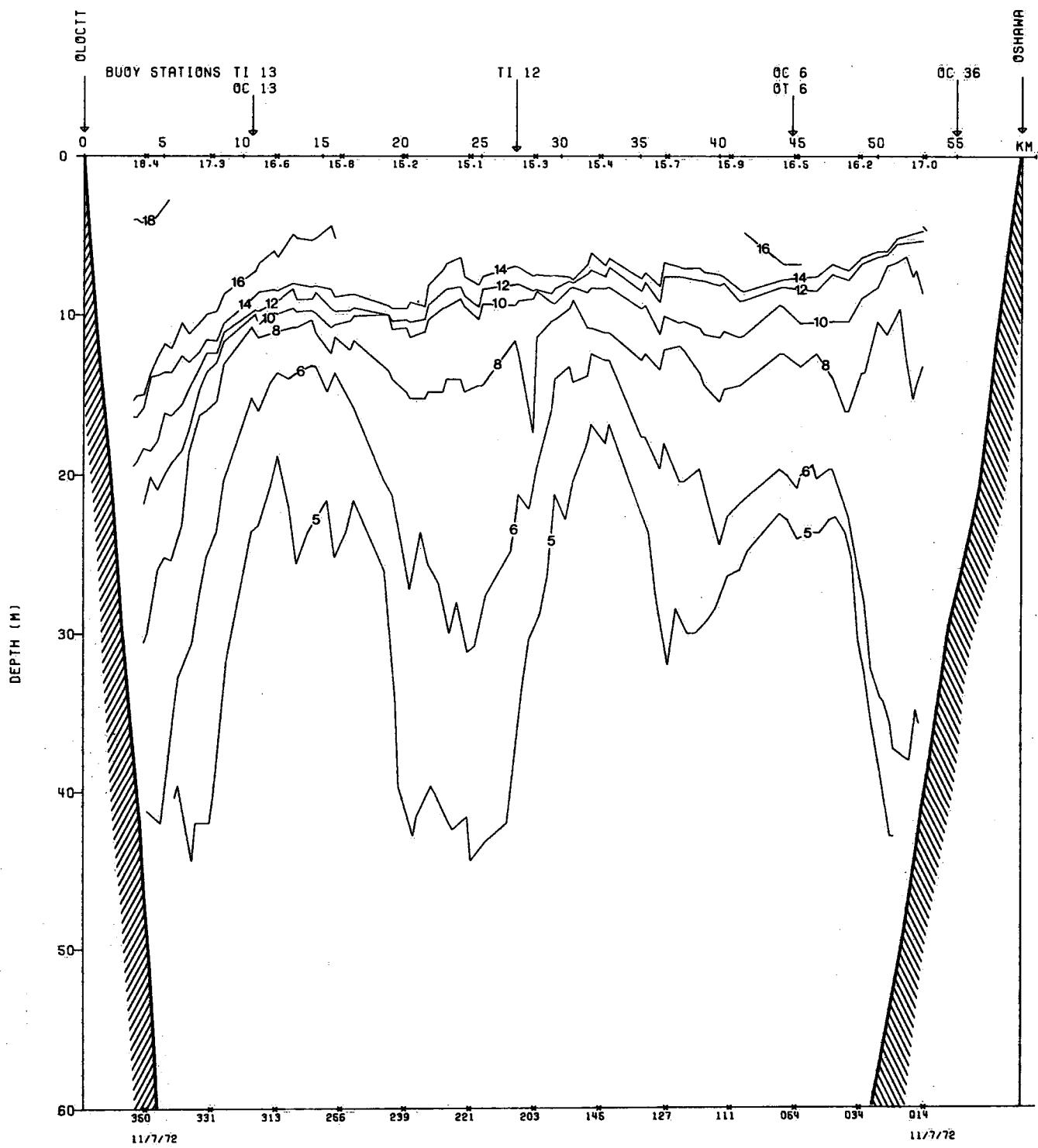
DAY (JULIAN) 192



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - BLCOTT CSS LIMNOS

**TRANSECT 2**

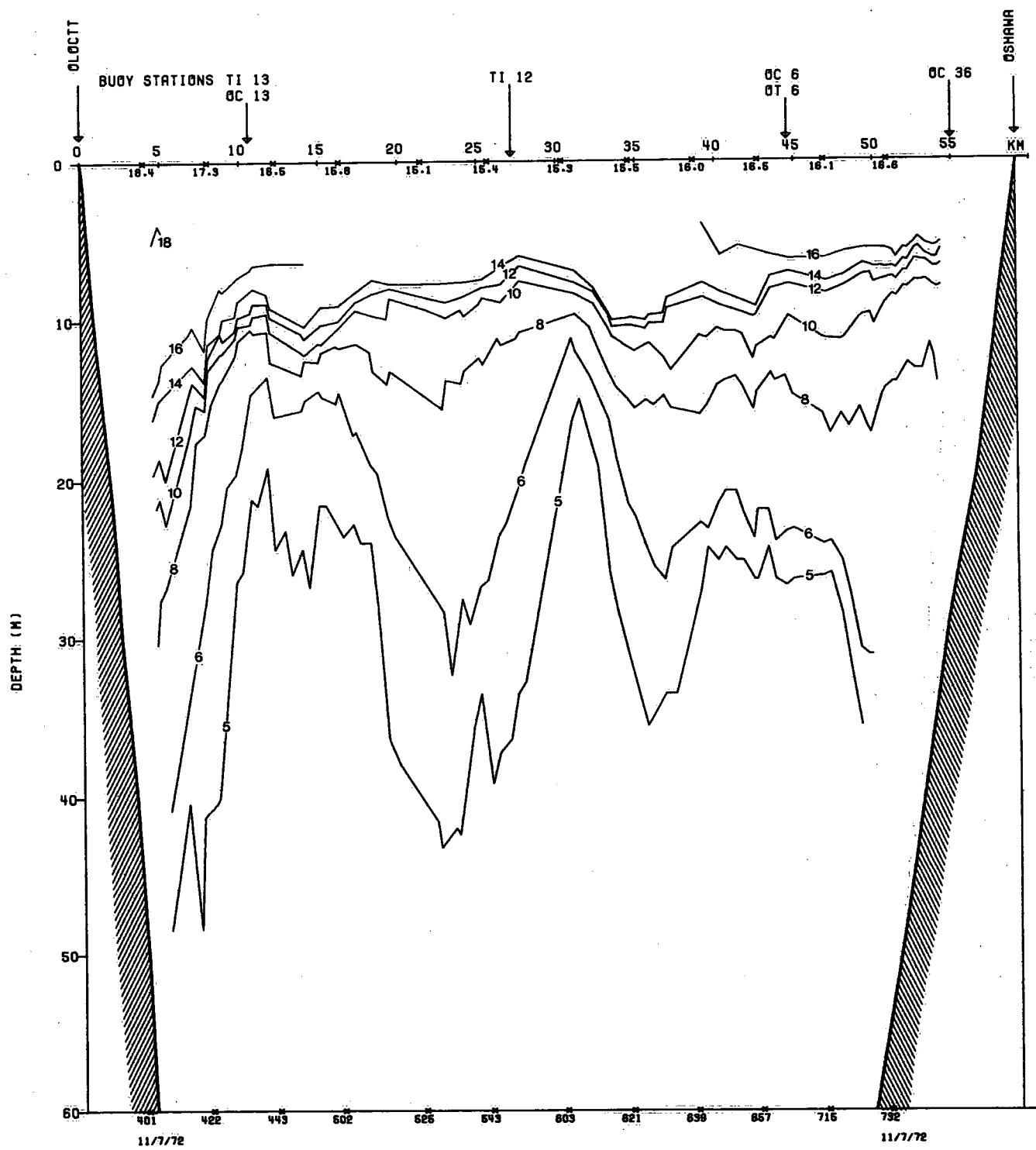
DAY (JULIAN) 193



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT BLCOTT - OSHAWA CSS LIMNOS

**TRANSECT 3**

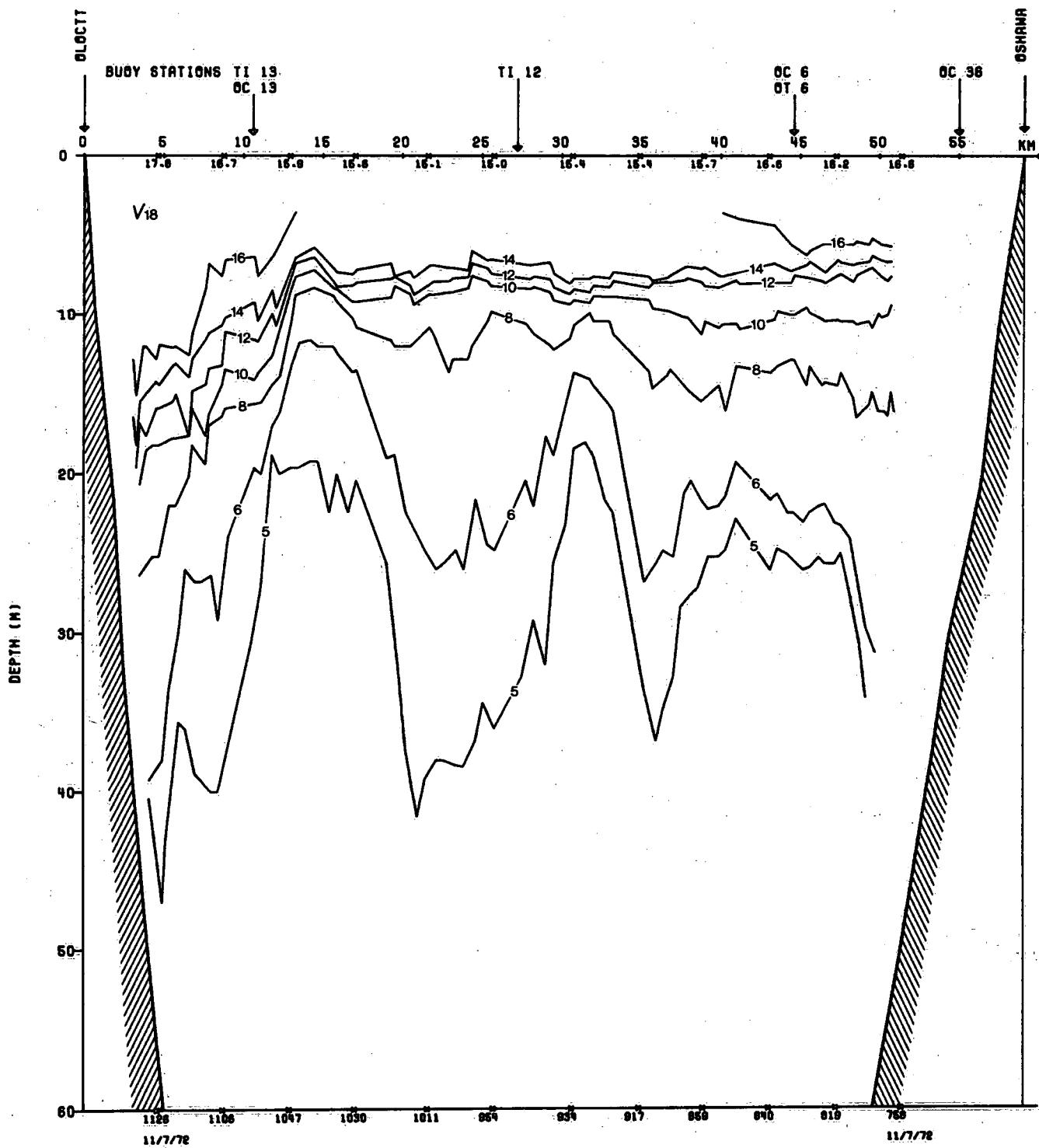
DAY (JULIAN) 193



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

**TRANSECT 4**

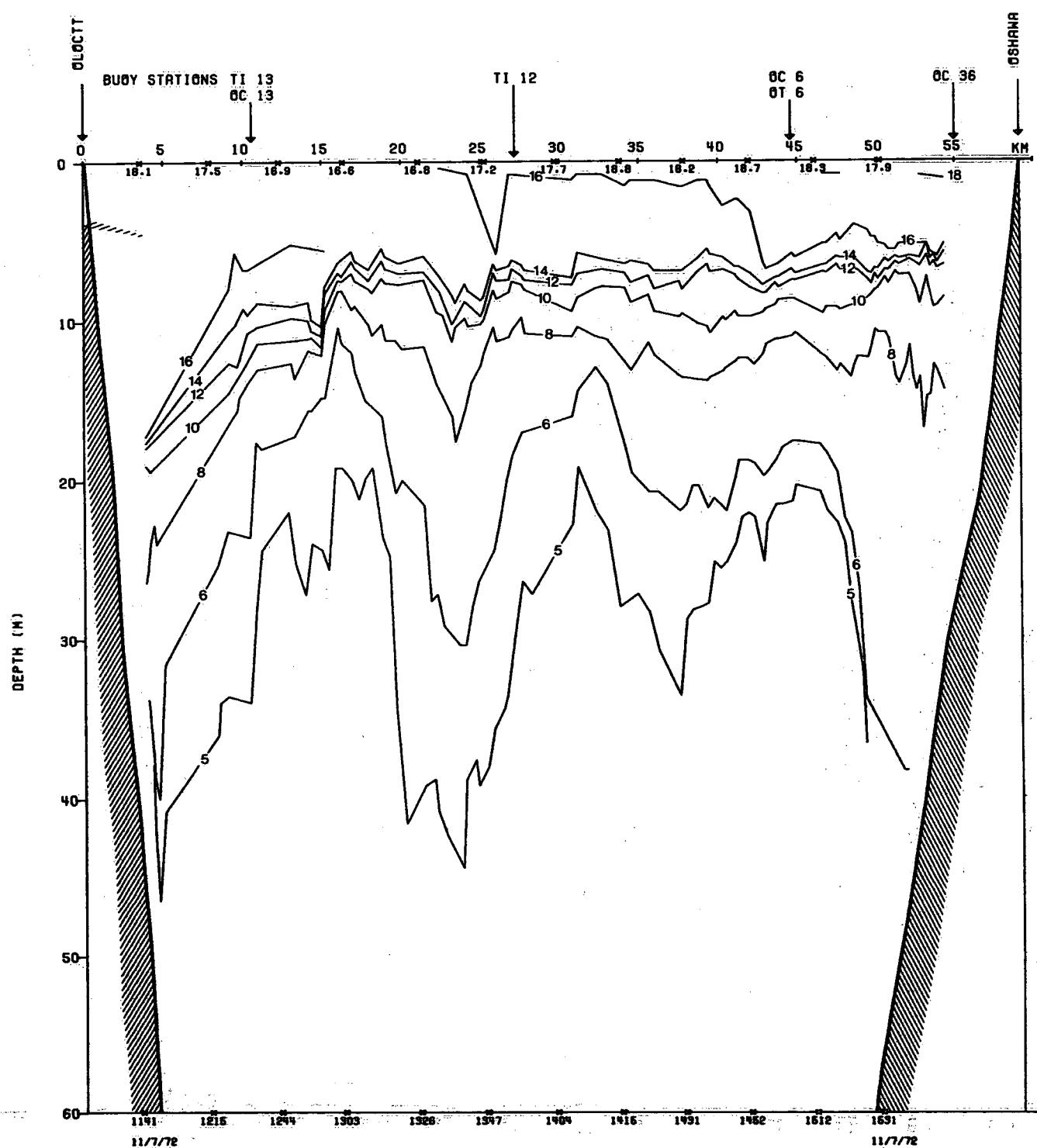
DAY (JULIAN) 193



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 5

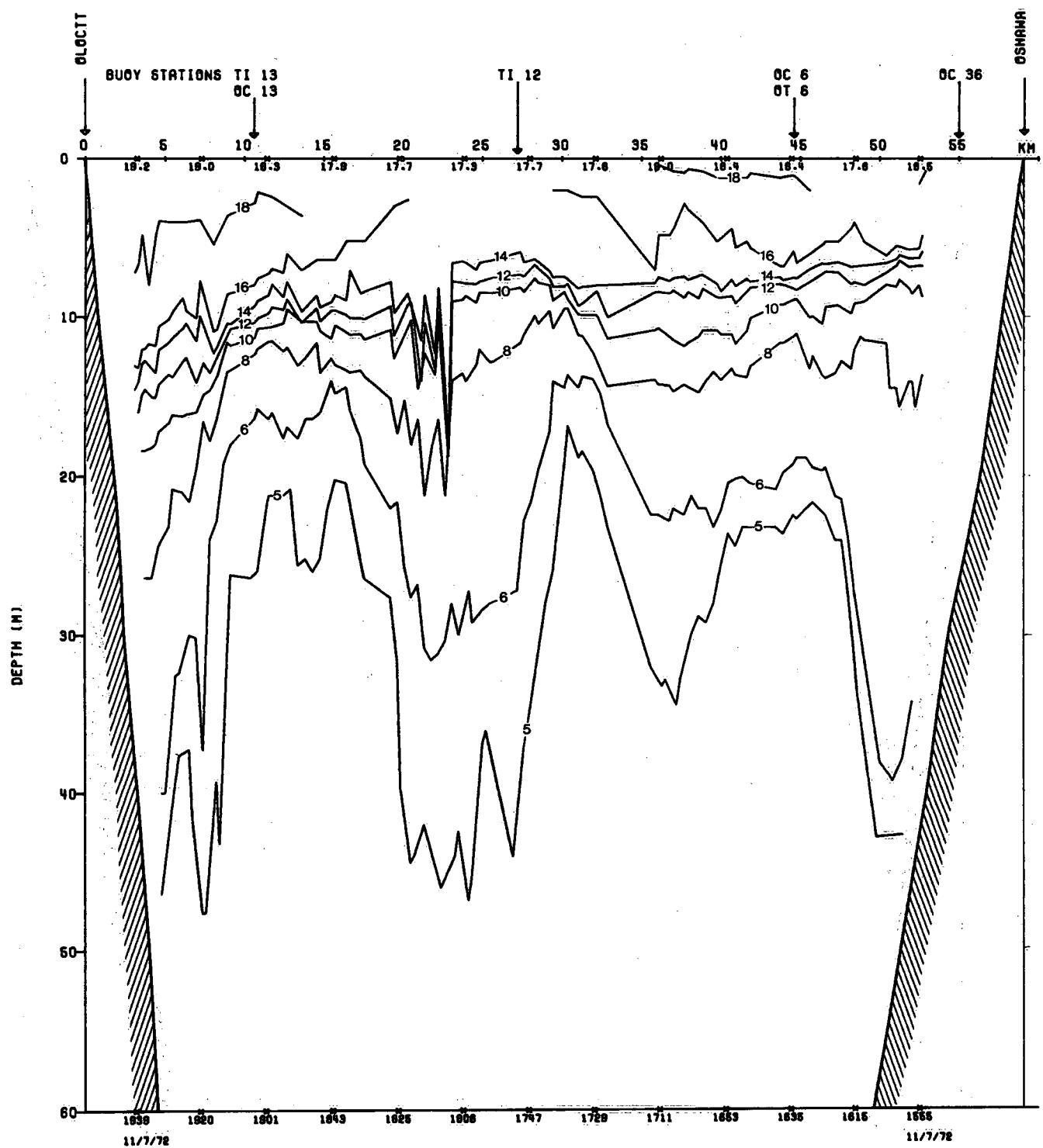
DAY (JULIAN) 193



IIFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 6

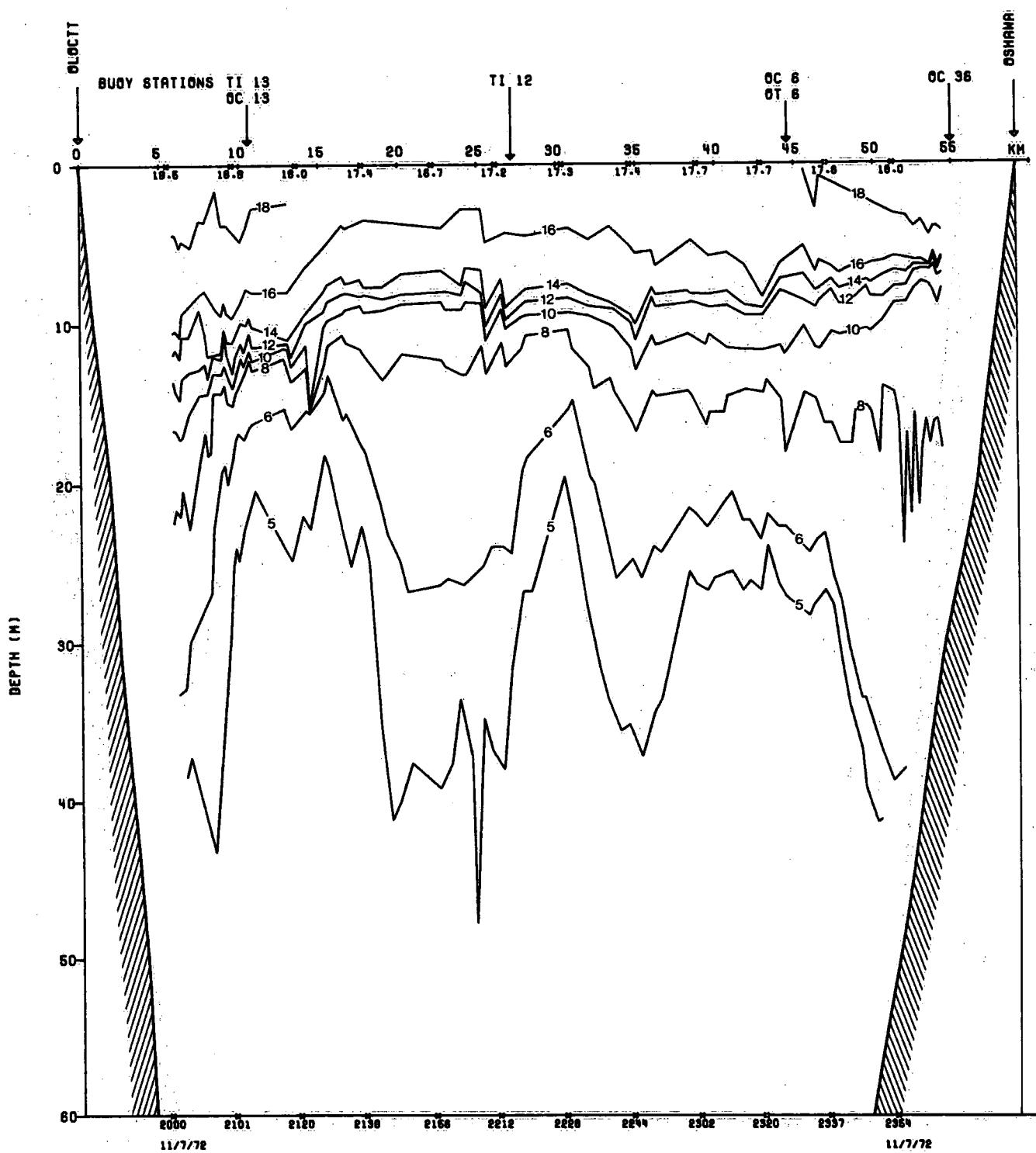
DAY (JULIAN) 193



IIFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS LIMNOS

**TRANSECT 7**

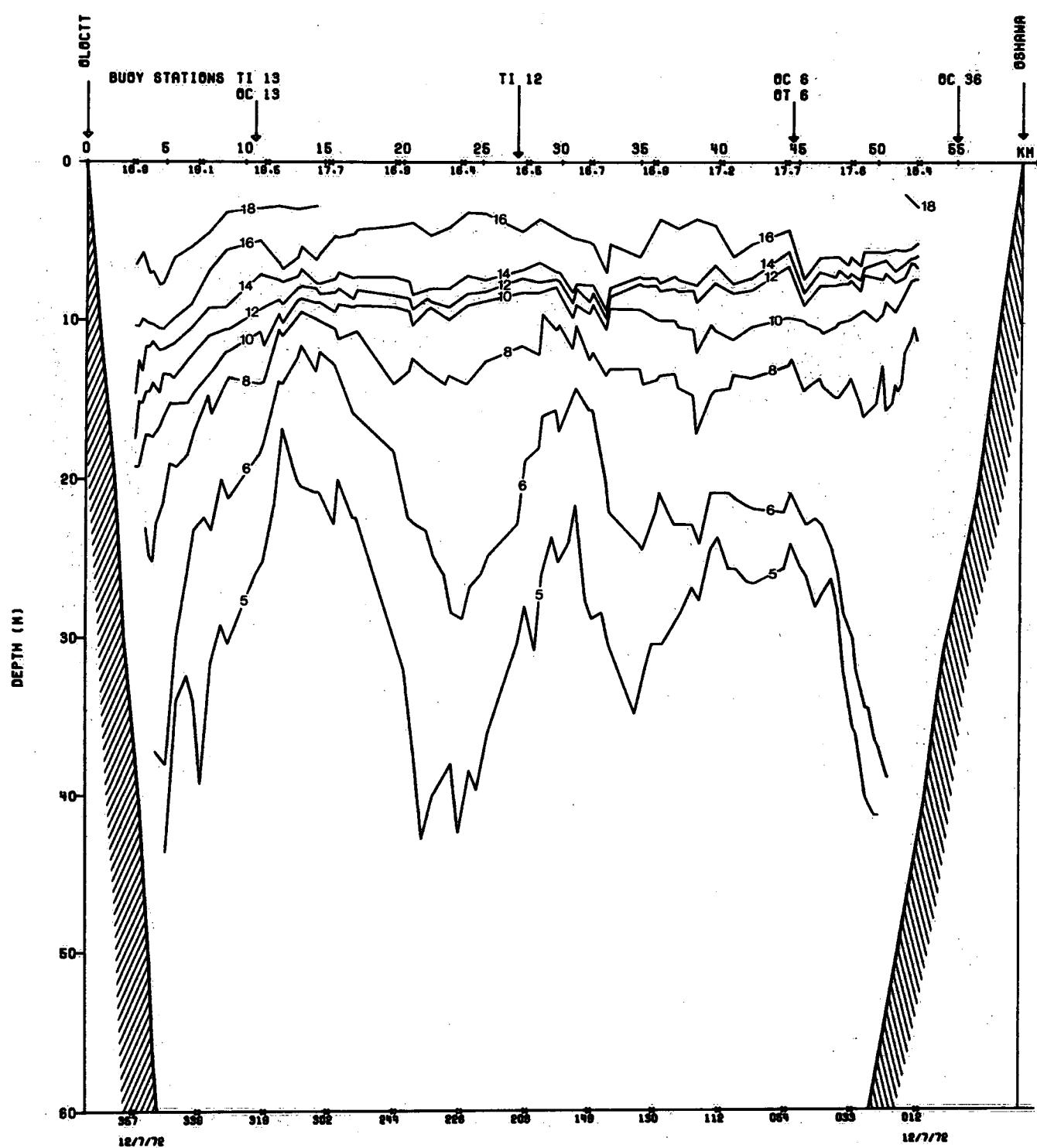
DAY (JULIAN) 193



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOs

**TRANSECT 8**

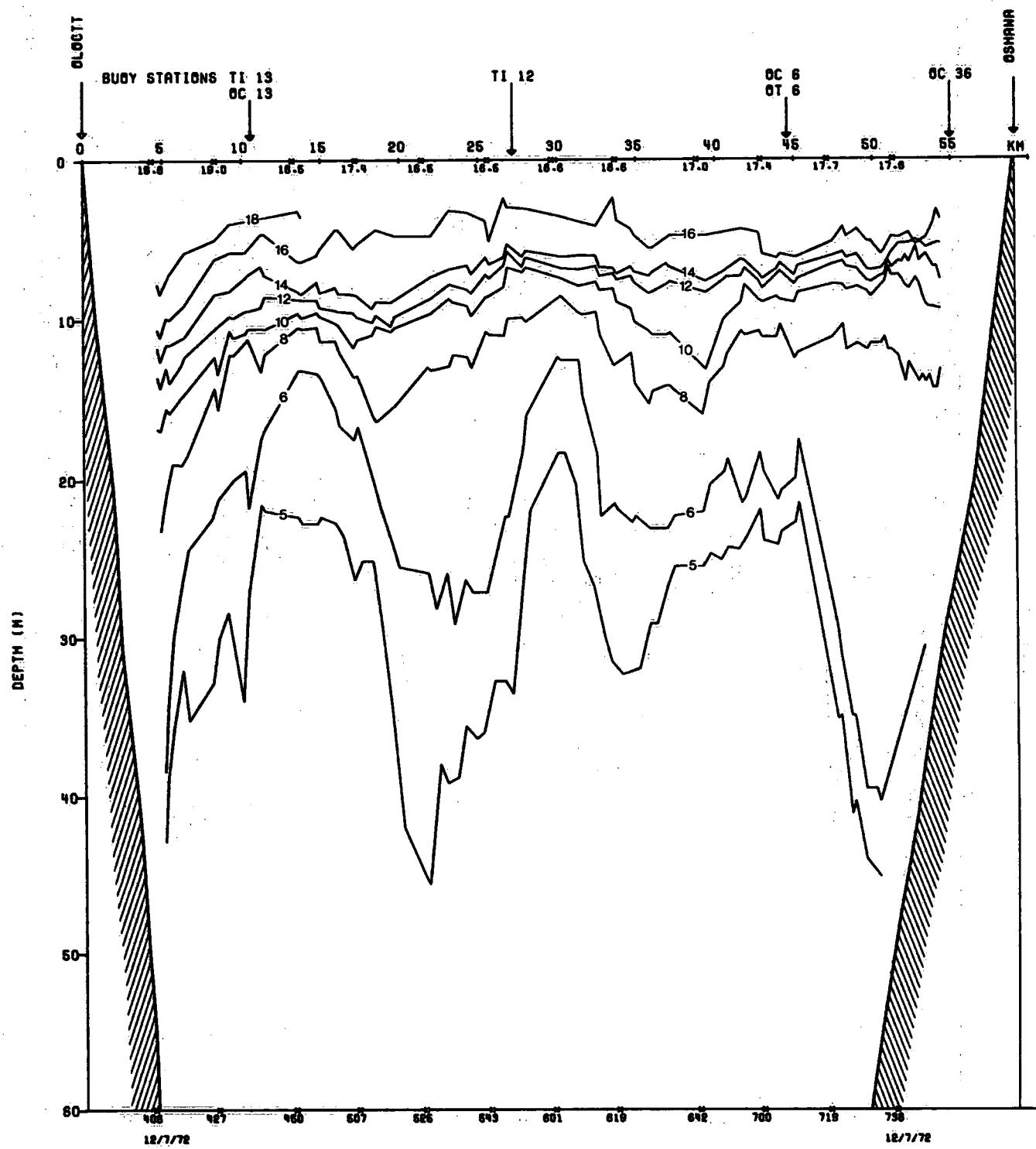
DAY (JULIAN) 194



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 9

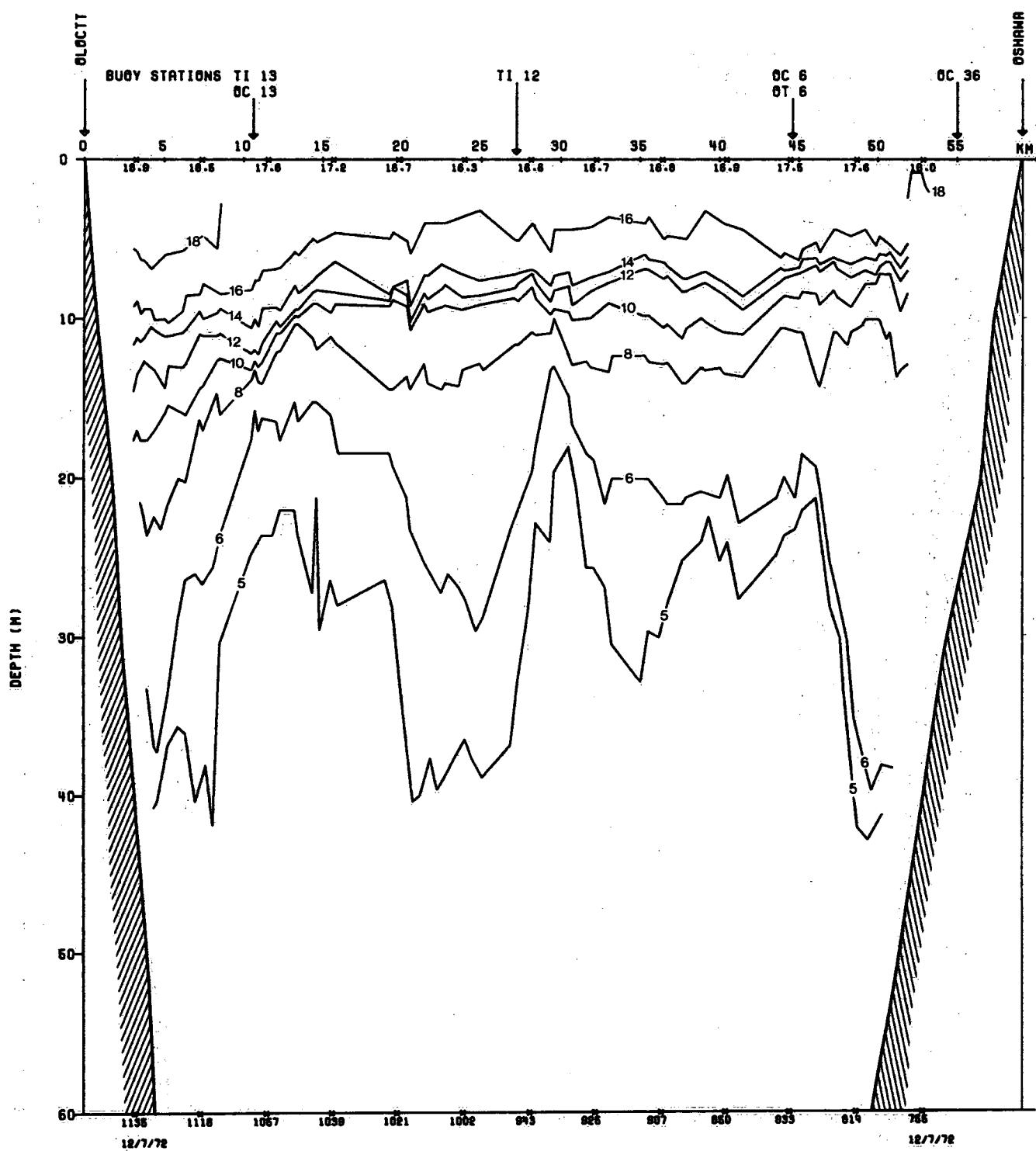
DAY (JULIAN) 194



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 10

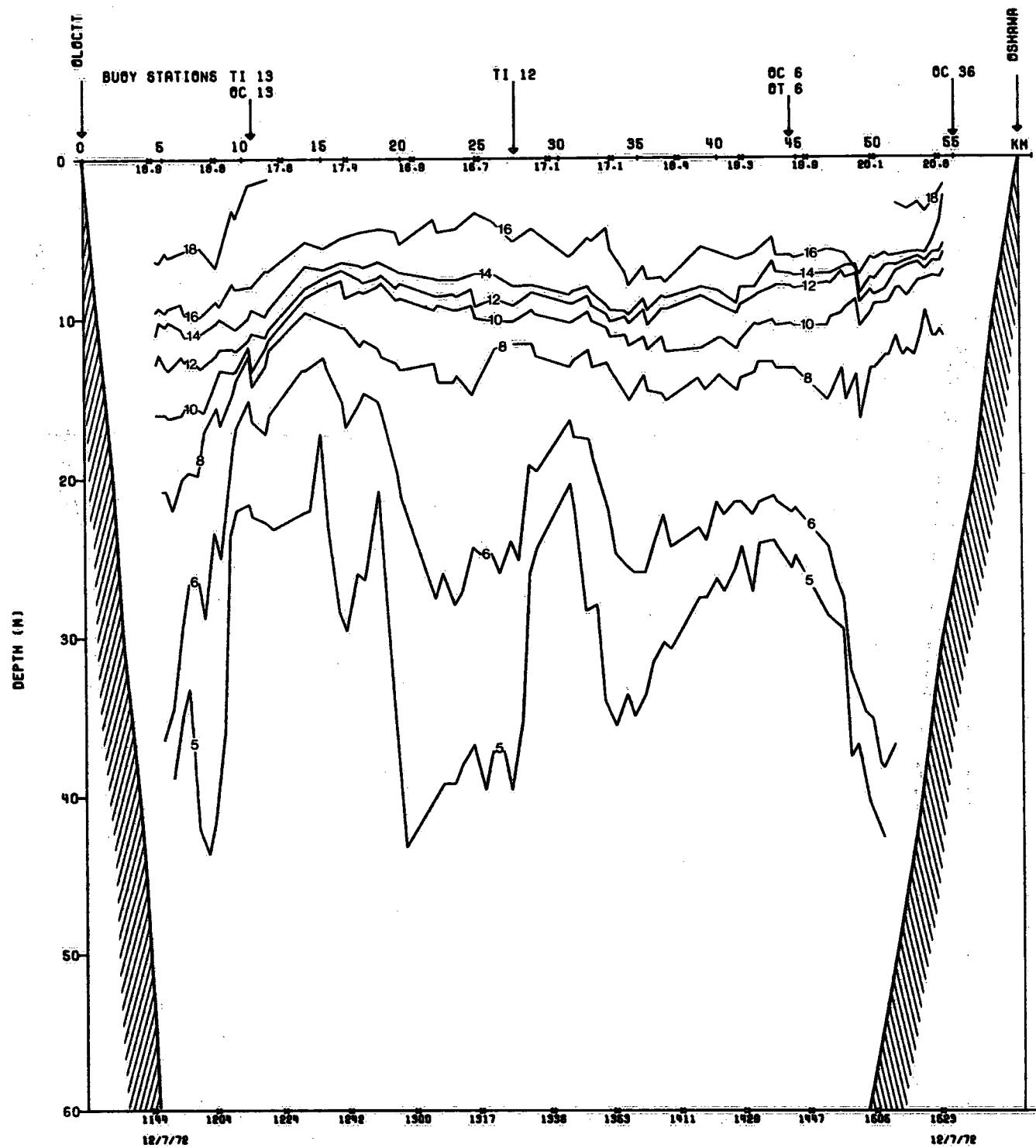
DAY (JULIAN) 194



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLCOTT - OSHAWA CSS LIMNO

TRANSECT 11

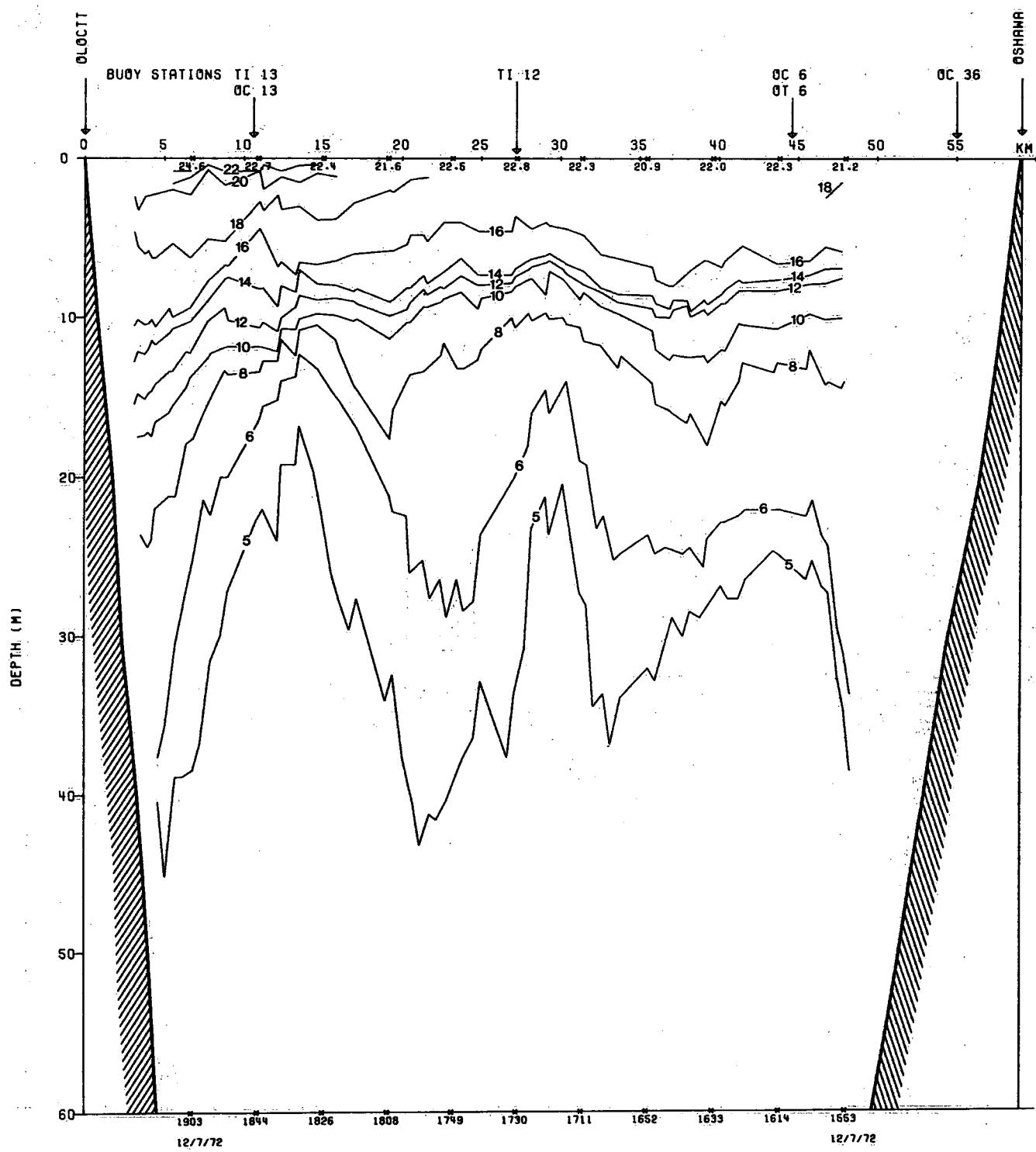
DAY (JULIAN) 194



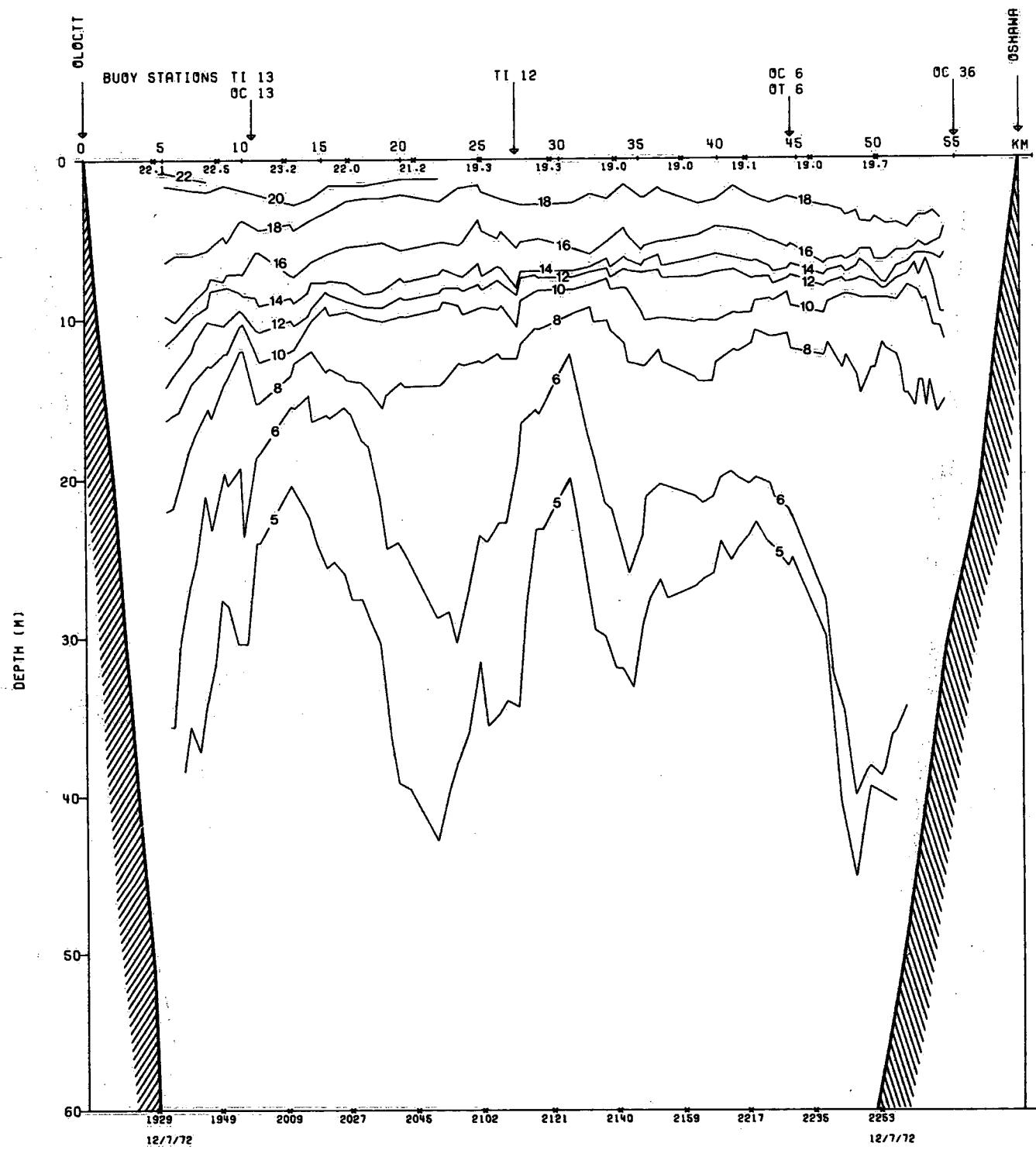
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 12

DAY (JULIAN) 194



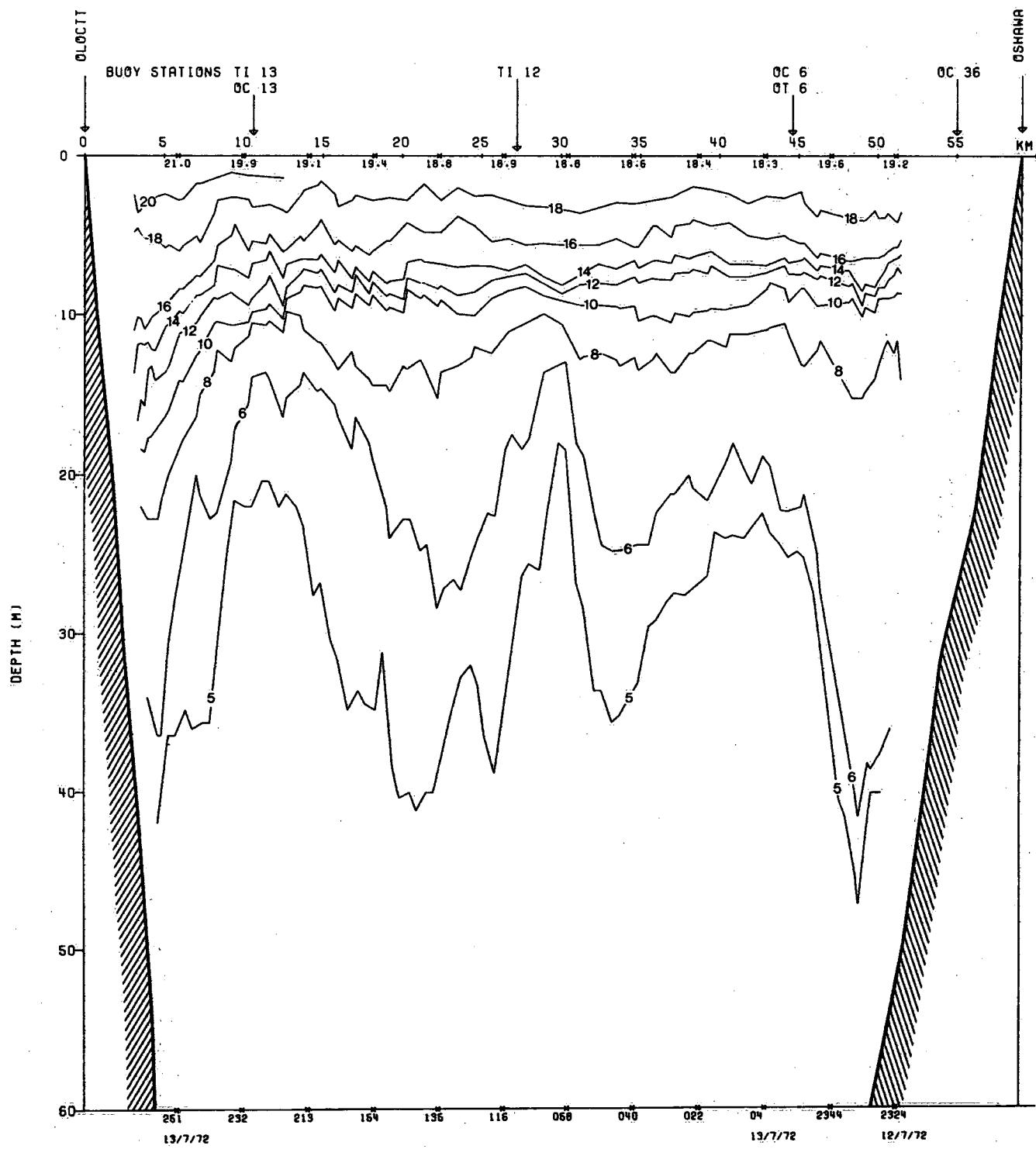
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos  
 TRANSECT 13 DAY (JULIAN) 194



## IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 14

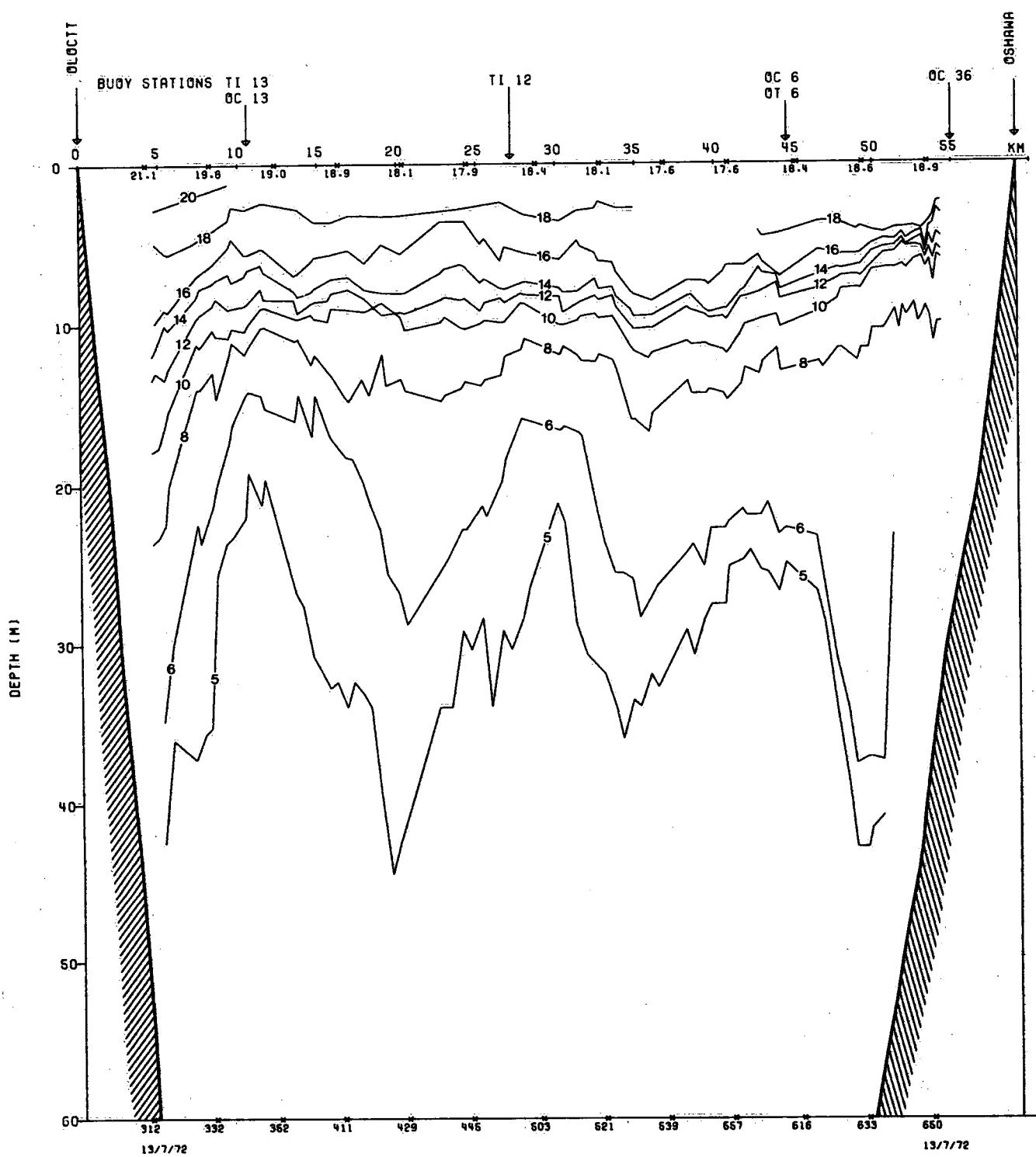
DAY (JULIAN) 194



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 15

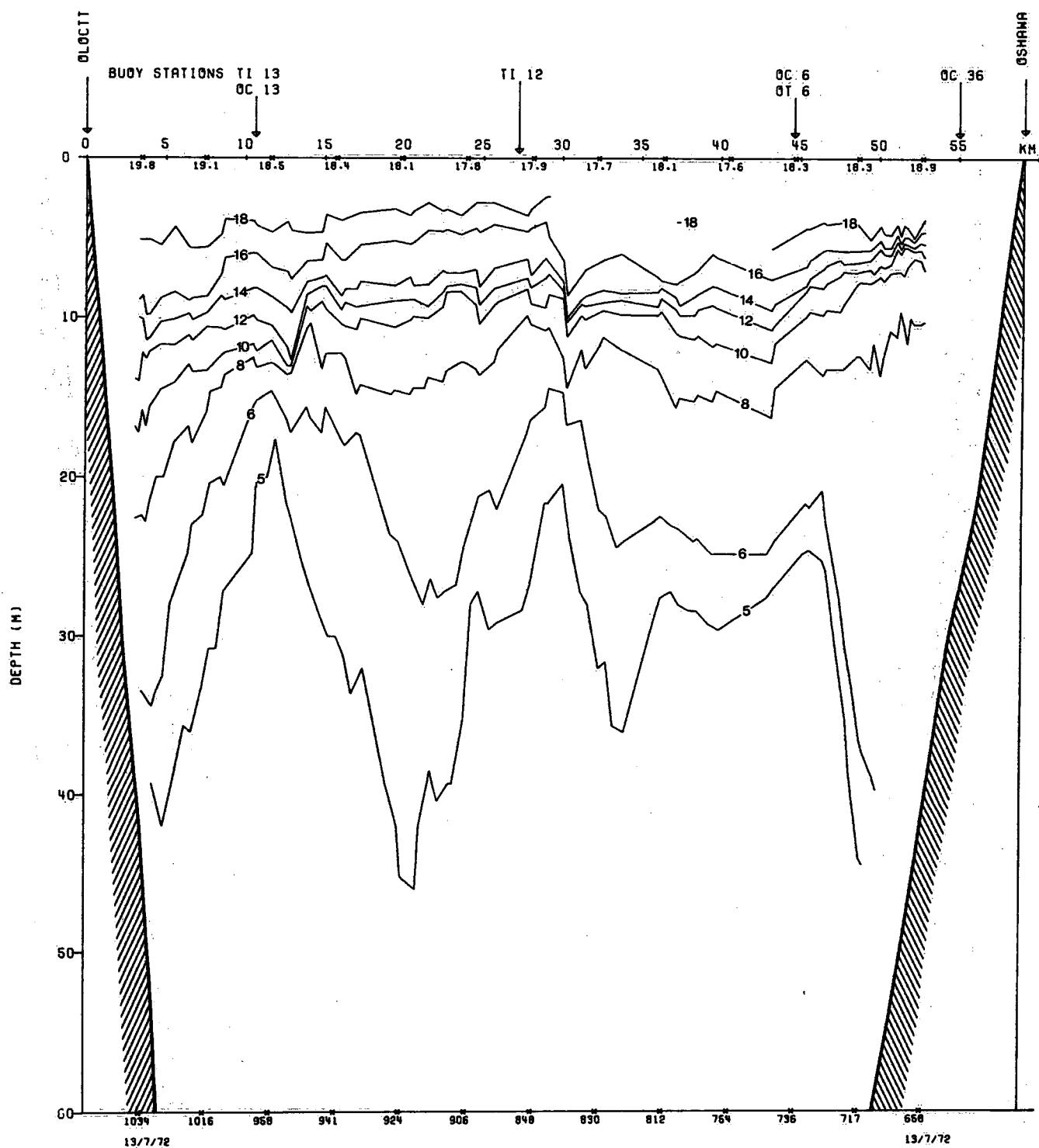
DAY (JULIAN) 195



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 16

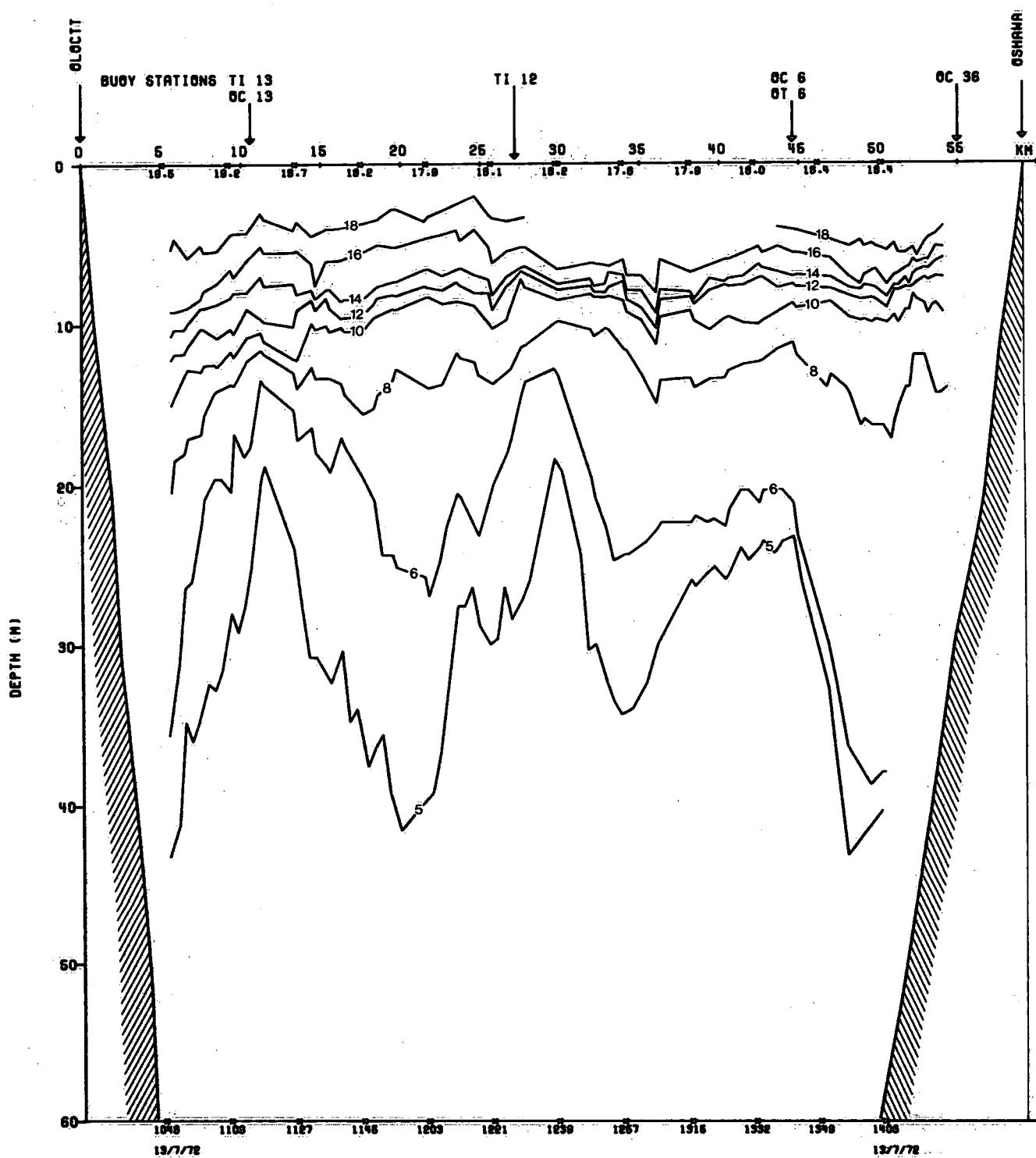
DAY (JULIAN) 195



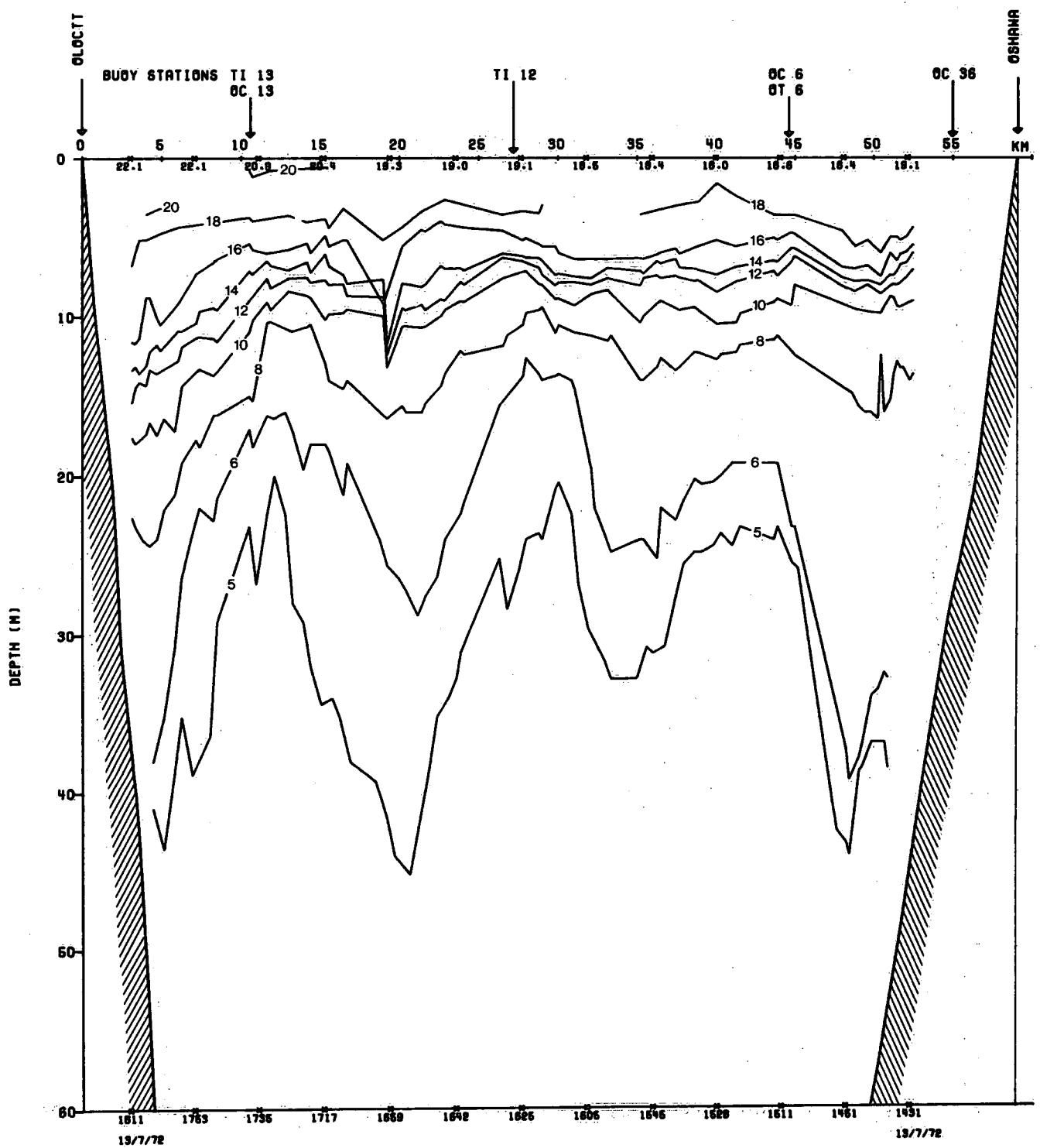
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 17

DAY (JULIAN) 195



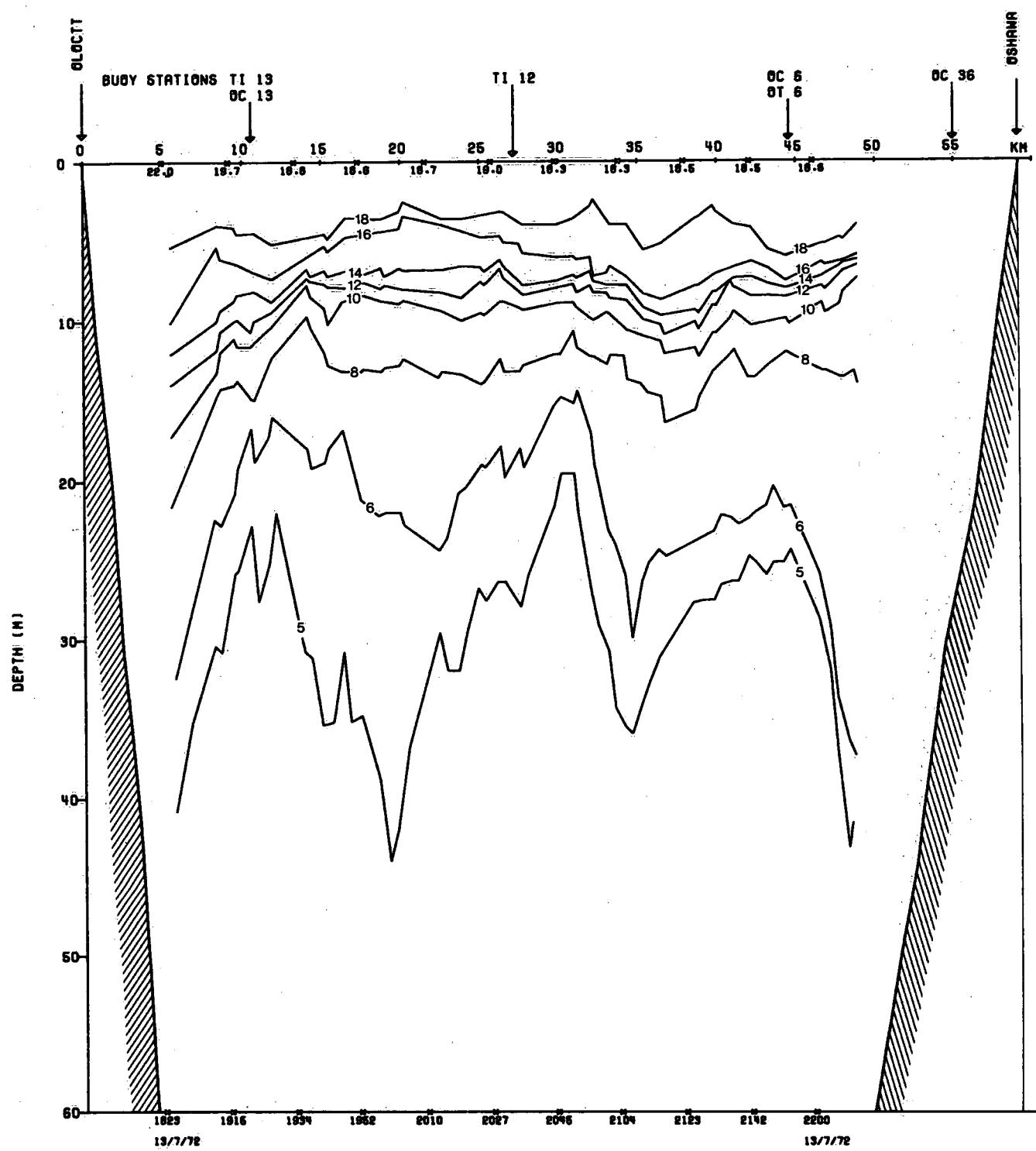
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS  
 TRANSECT 18 DAY (JULIAN) 195



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT GLCOTT - OSHAWA CSS LIMNOS

TRANSECT 19

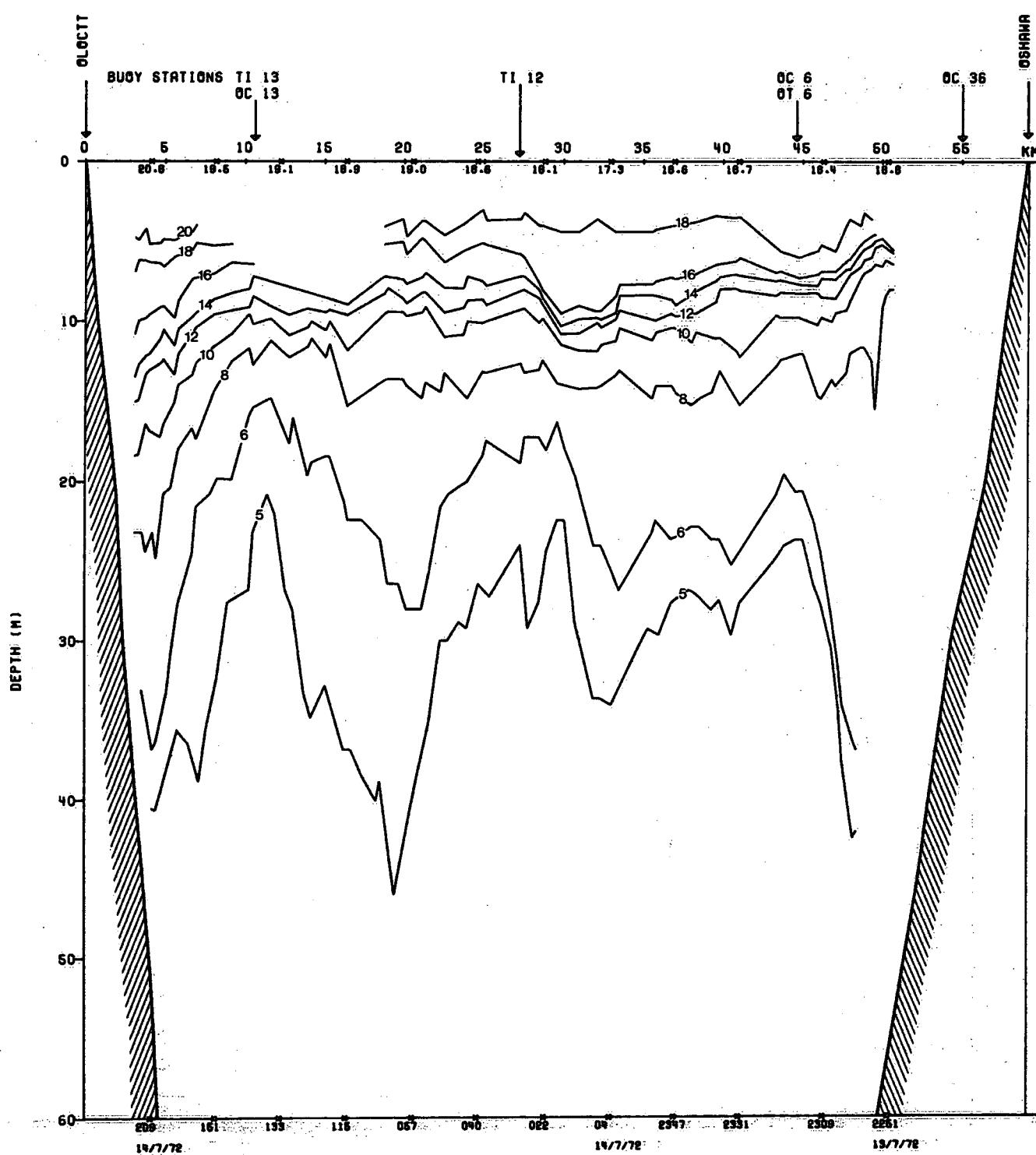
DAY (JULIAN) 195



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOs

**TRANSECT 20**

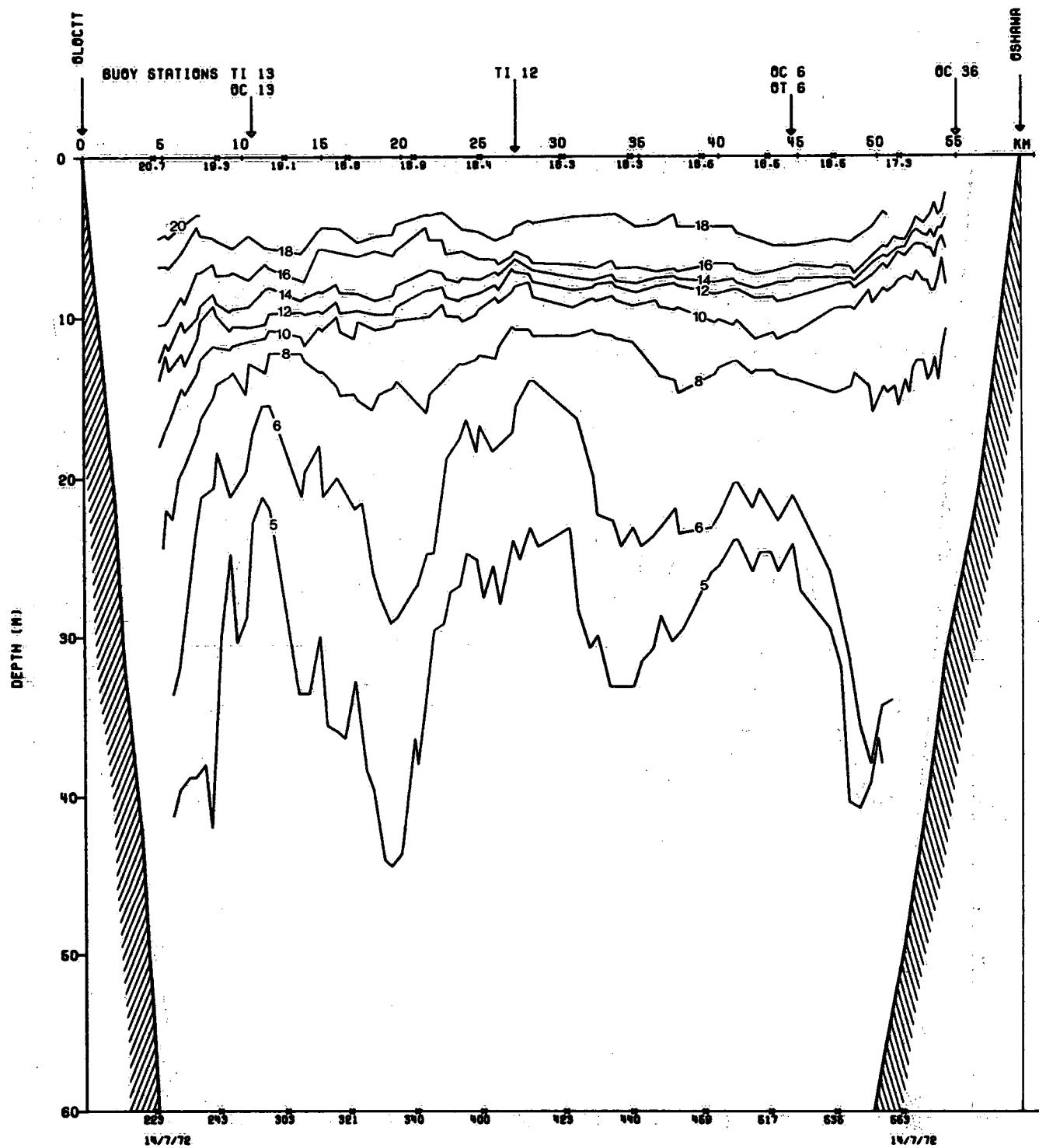
DAY (JULIAN) 195



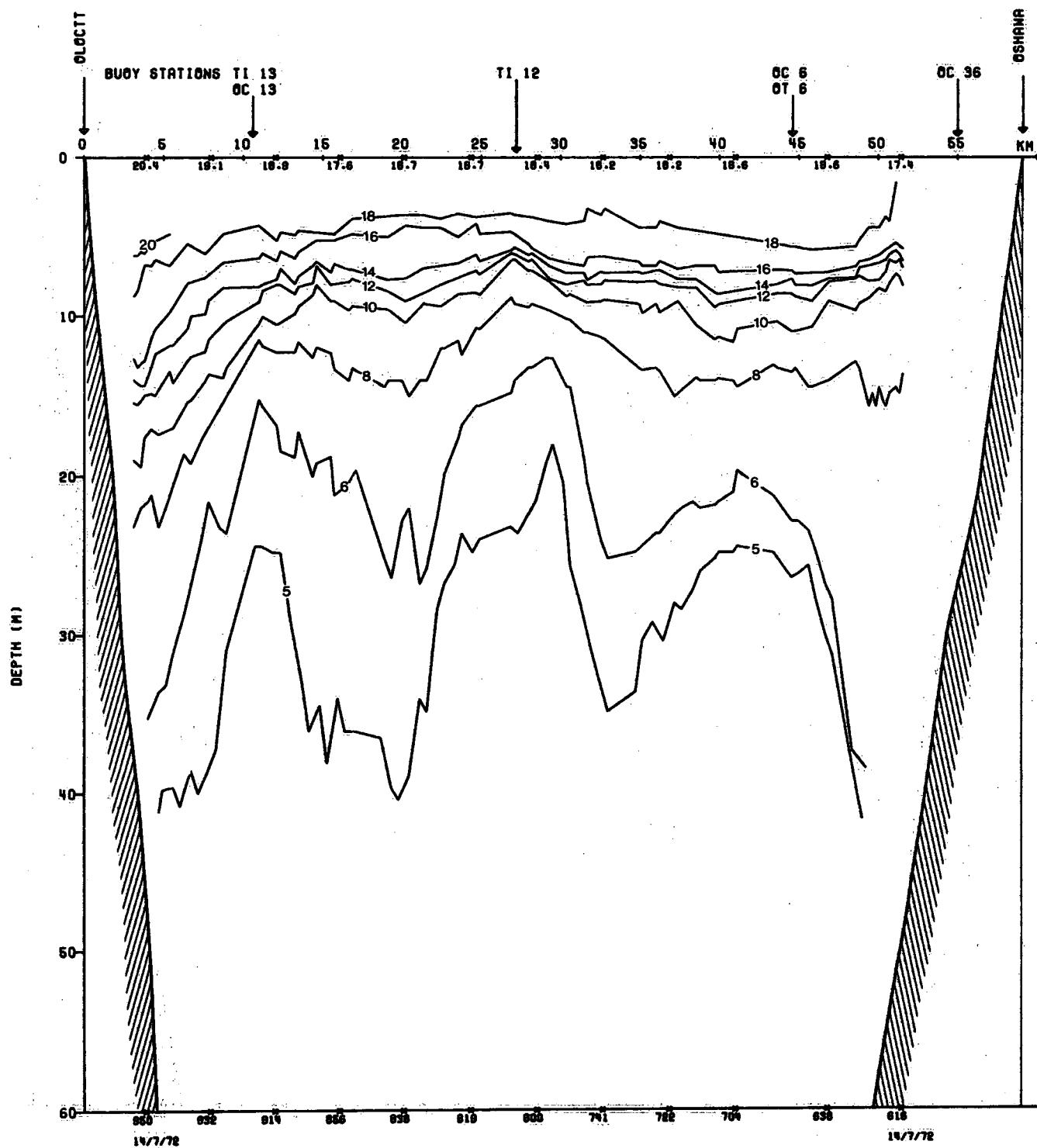
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 21

DAY (JULIAN) 196



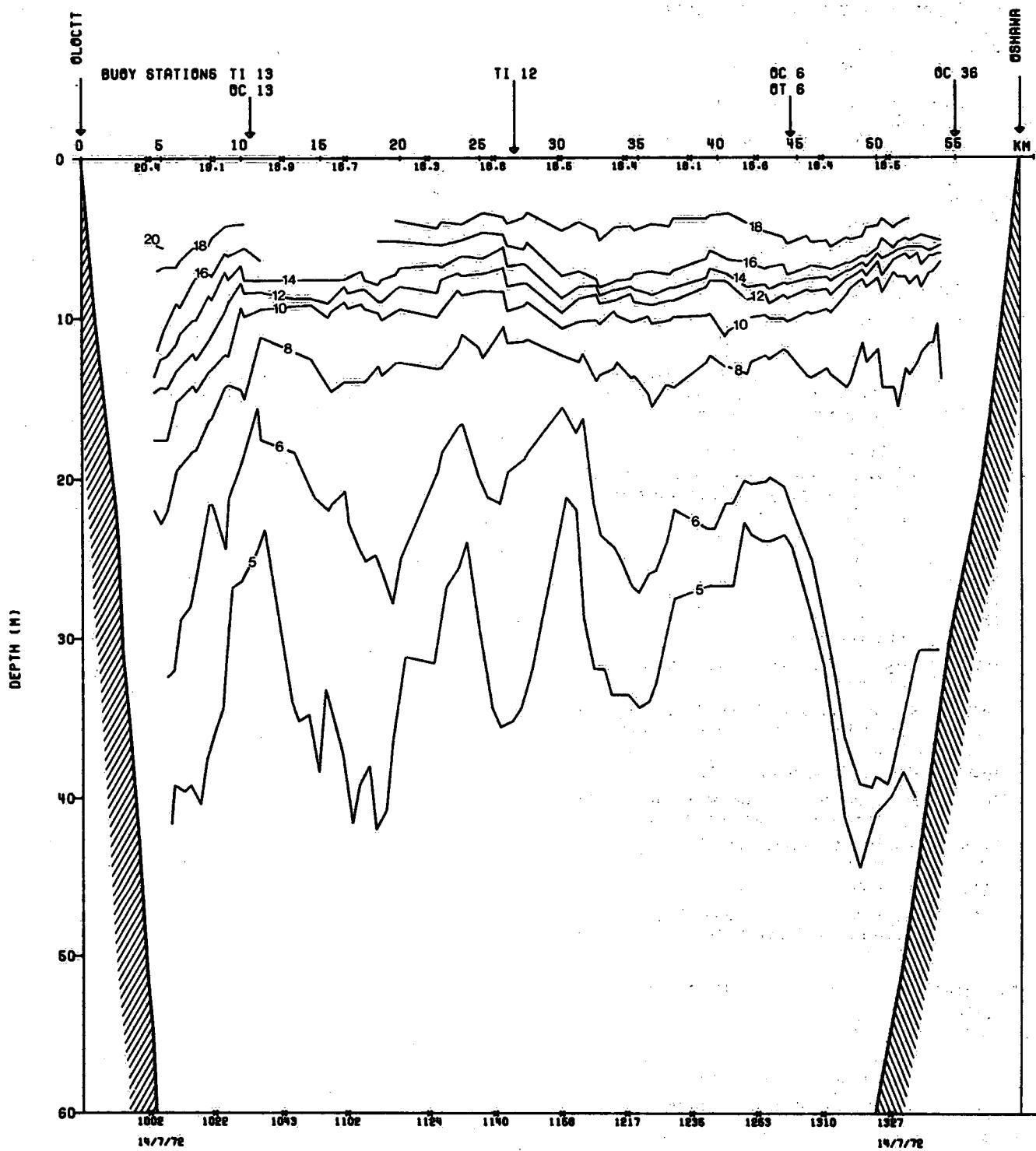
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS  
TRANSECT 22 DAY (JULIAN) 196



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott = Oshawa CSS Limnos

**TRANSECT 23**

DAY (JULIAN) 196



**Extract from Log Narrative, C.S.S. *Limnos* Cruise 72-00-016,  
8-12 August (Julian Days 221-225) 1972**

(amended to conform with the numbering of the following  
transect diagrams)

Instruments deployed: Batfish and Towed Thermistor Array  
Transects completed: 21  
Major interruptions: 2045 to 2350, 9 August, put into Oshawa to  
transfer personnel.

**8 August**

- 1000 Depart CCIW  
1610 Assembling towed array cable off Olcott.  
1850 Towing tests with thermistor array at 6, 8, and  
10 knots.  
2015 Array recovered and electrical continuity of cable  
conductors checked. Pressure case rewired to  
compensate for three of the lower leads that  
appear to be faulty. Final towing configuration  
sets break out 8, 1 m below surface. Batfish  
deployed with 65 m of cable payed out.

**9 August**

- |      | Station  | Start of Trans. No. |
|------|--|---------------------|
| 0135 | Towing at 8 knots, scanning underway, V-Fin at<br>25 m and Batfish diving to 47 m at 5-min<br>intervals. |                     |
| 0231 | C  | 1                   |
| 0349 | A  | 2                   |
| 0740 | G  | 3                   |
| 1122 | A  | 4                   |
| 1531 | G  | 5                   |
- End of tape WE60.  
1617 Resume scanning, tape WB70 at station F  
(re-start 5).  
1927 Stop at sta. B to haul in towed array. Oil seal on  
hydraulic array winch failed, forcing recovery  
by hand.  
1945 Underway to A, towing Batfish.  
2045 Sta. A, stop to recover the Batfish, and note that  
it has hit bottom again; damage slight.  
2105 Underway to Oshawa, cable check-out and  
maintenance.  
2230 Depart Oshawa for sta. A.  
2350 Sta. A, deploy the towed array, V-Fin to 26 m.  
Underway at 8 knots and scanning, transect  
No. 6.

**10 August**

- |      | Station   | Start of Trans. No. |
|------|---|---------------------|
| 0409 | G   | 7                   |
| 0813 | A   | 8                   |
| 1154 | G   | 9                   |
| 1301 | Power failure on ship. Run 10 off here.<br>Run 10 restarted, scanning resumed.                        |                     |
| 1608 | A   | 10                  |
| 2021 | G   | 11                  |
| 2148 | Sta. E, stop to inspect Batfish; fairing replaced and<br>straightened where necessary. Underway 2217. |                     |

**11 August**

0035	A	12
0416	G	13
0812	A	14
1153	G	15
1523	A	16
1827	E	

Stop to examine towed instruments and replace  
fairing. New tape (WE13) on ADDS.

2000	G	17
2340	A	18

**12 August**

0311	G	19
Note the short time for this run; ship steaming better than 8 knots.		
0651	A	20
1027	G	21
1407	A	

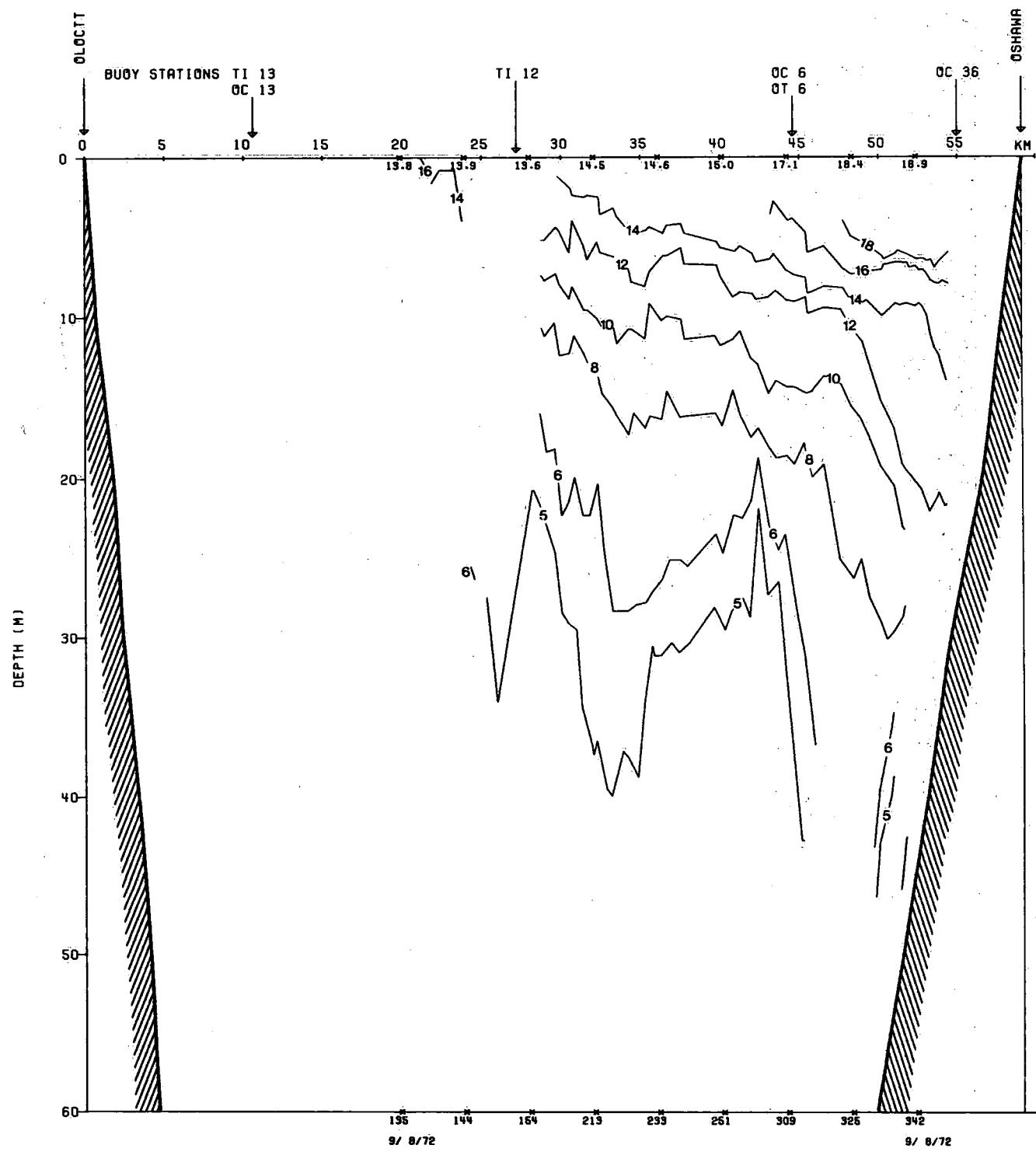
End of tape, 5 EOF's. Steaming to deep water to  
haul aboard towed equipment.

1447 Batfish and Thermistor Array recovered. Underway  
to Burlington. Alongside 2015.  
Transects 1-21, 9-12 August, follow.

IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT GLCOTT = OSHAWA CSS LIMNOLOGY

**TRANSECT 1**

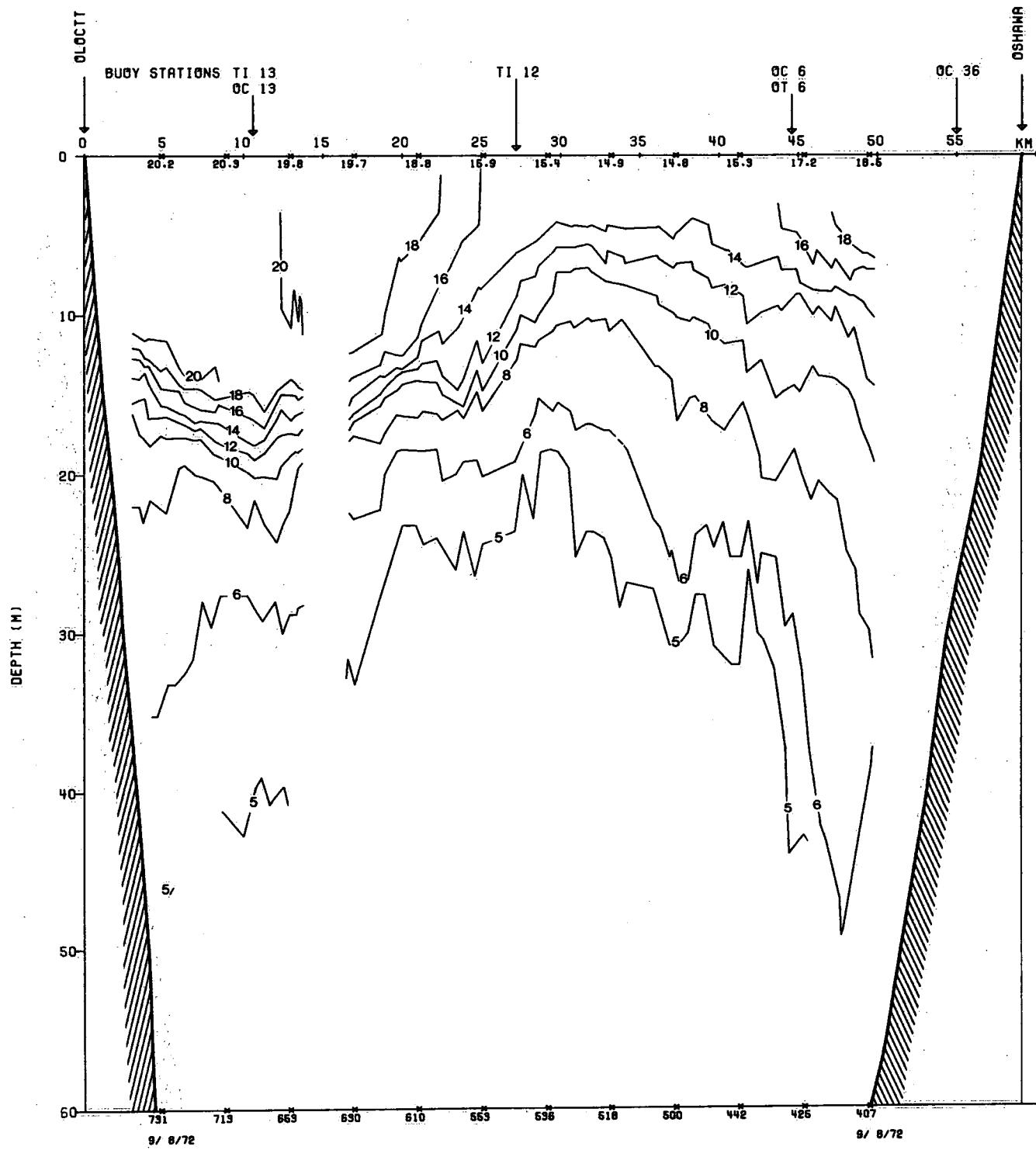
DAY (JULIAN) 222



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

**TRANSECT 2**

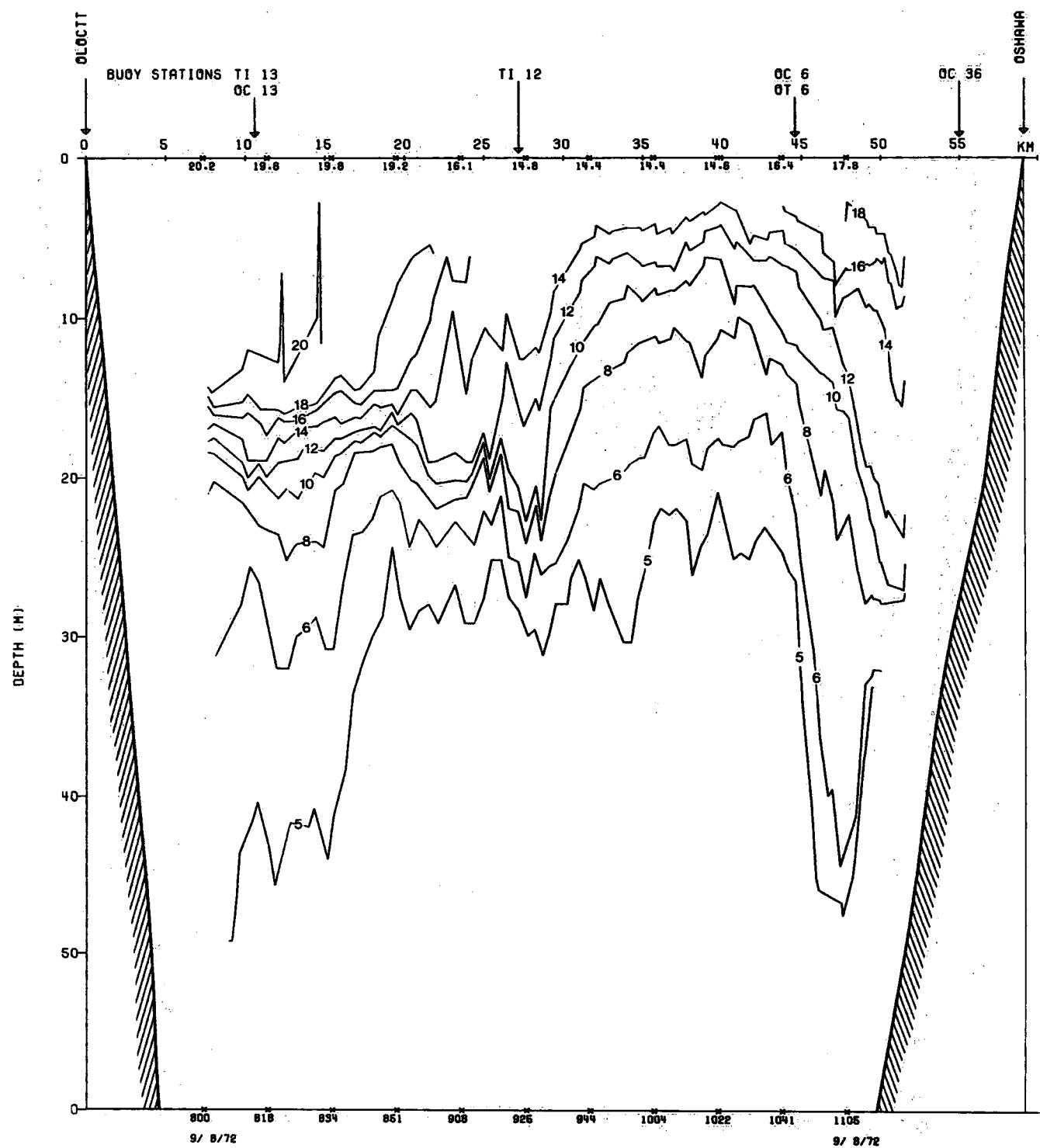
DAY (JULIAN) 222



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 3

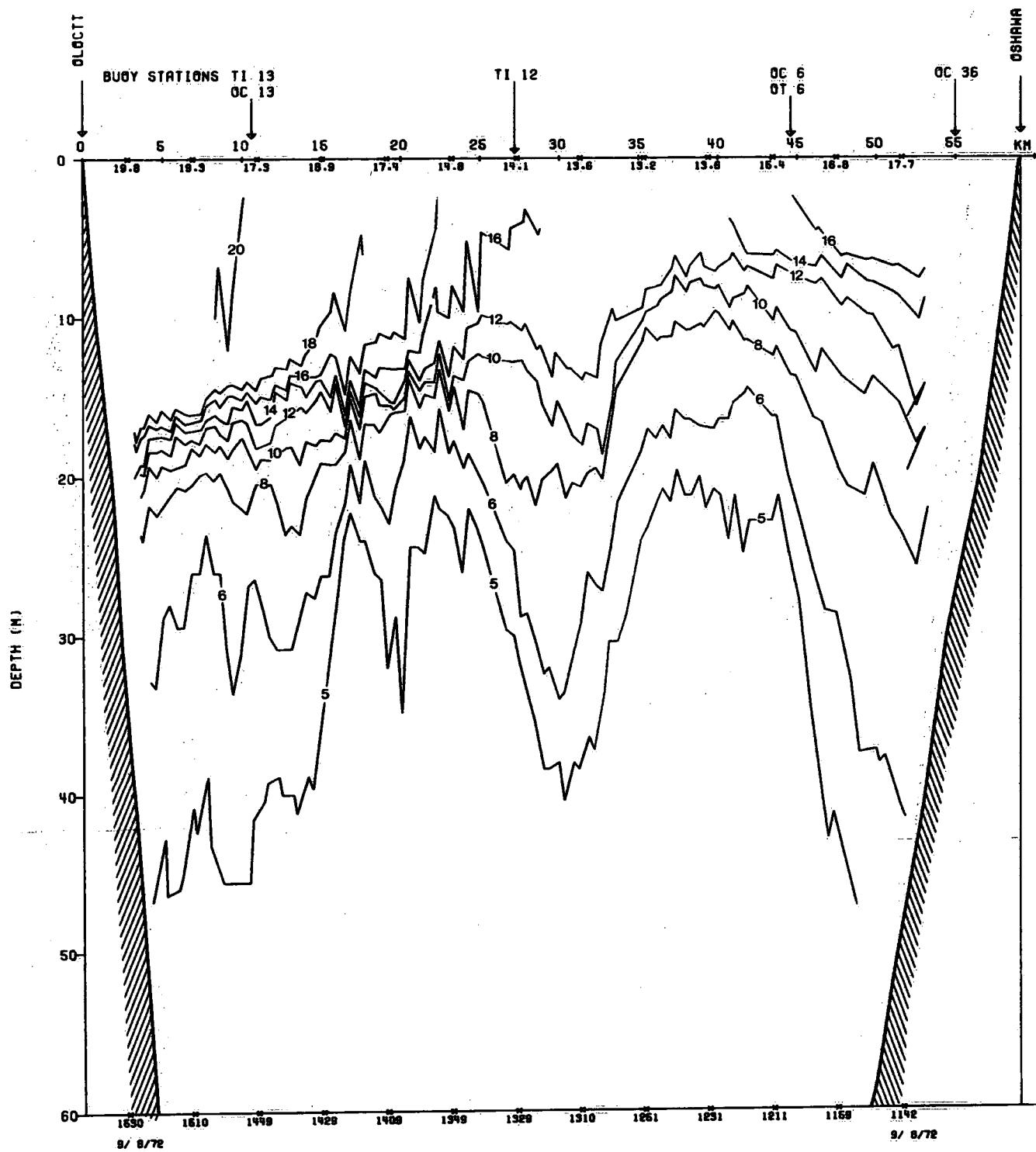
DAY (JULIAN) 222



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 4

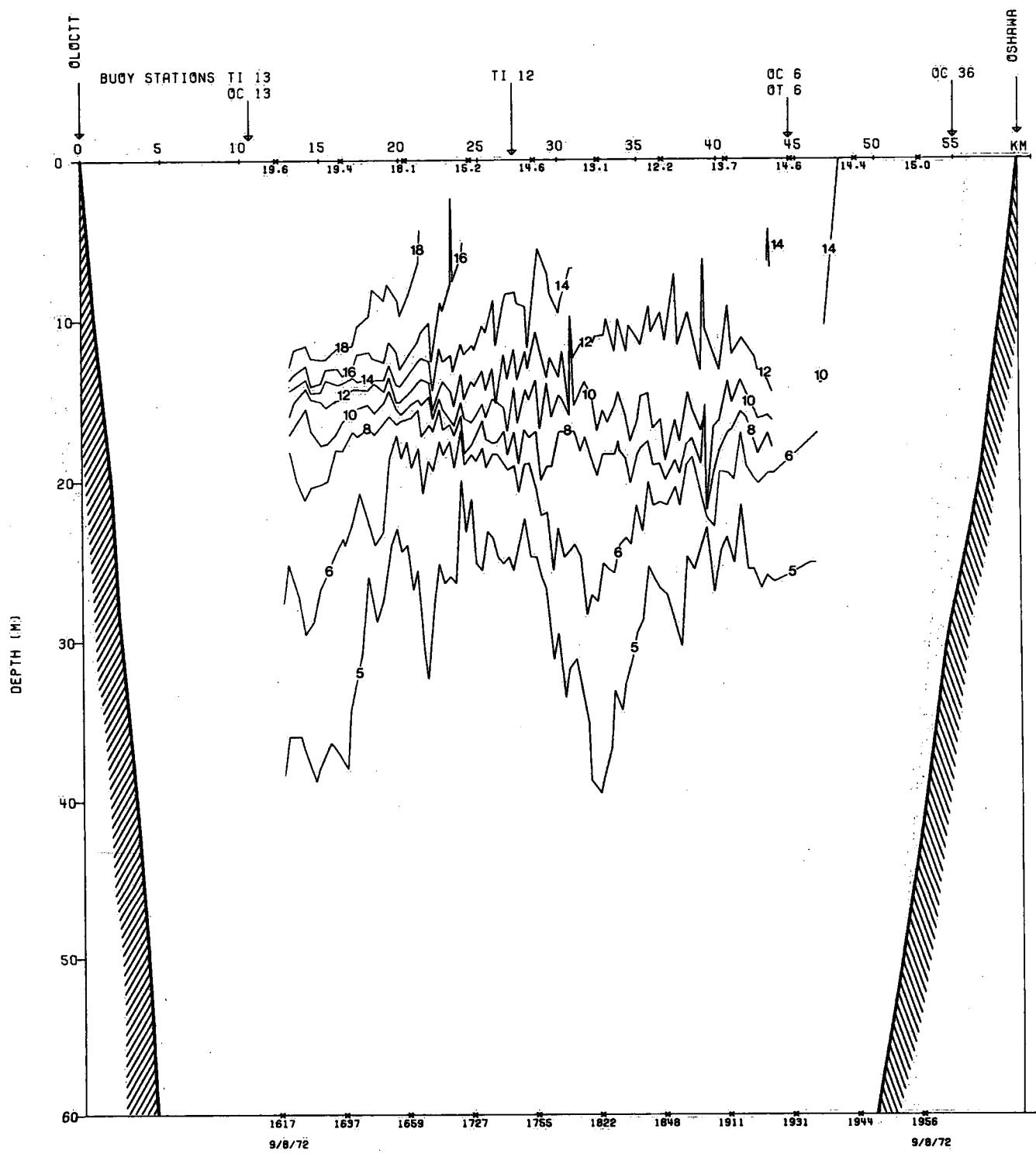
DAY (JULIAN) 222



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 5

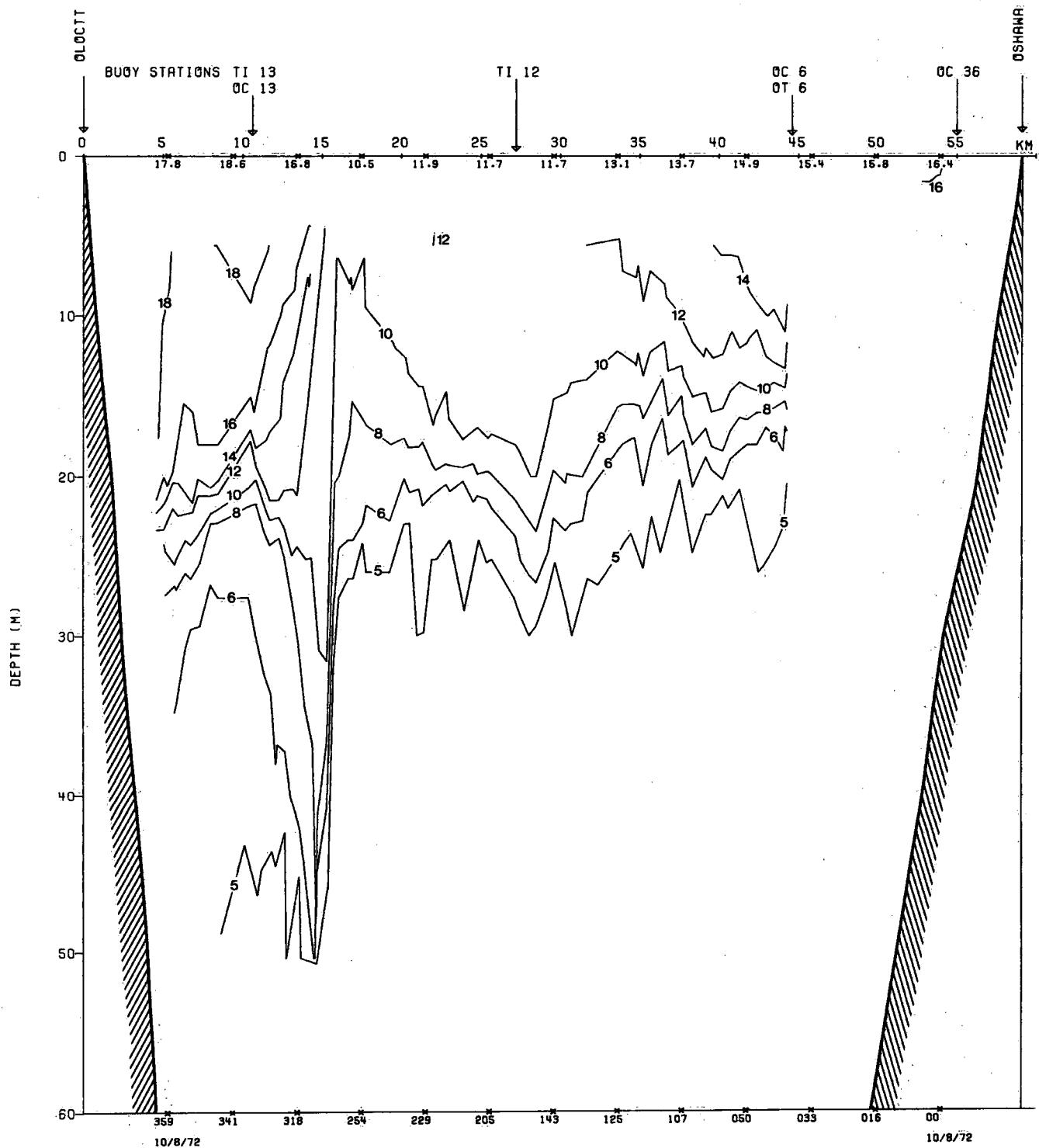
DAY (JULIAN) 222



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 6

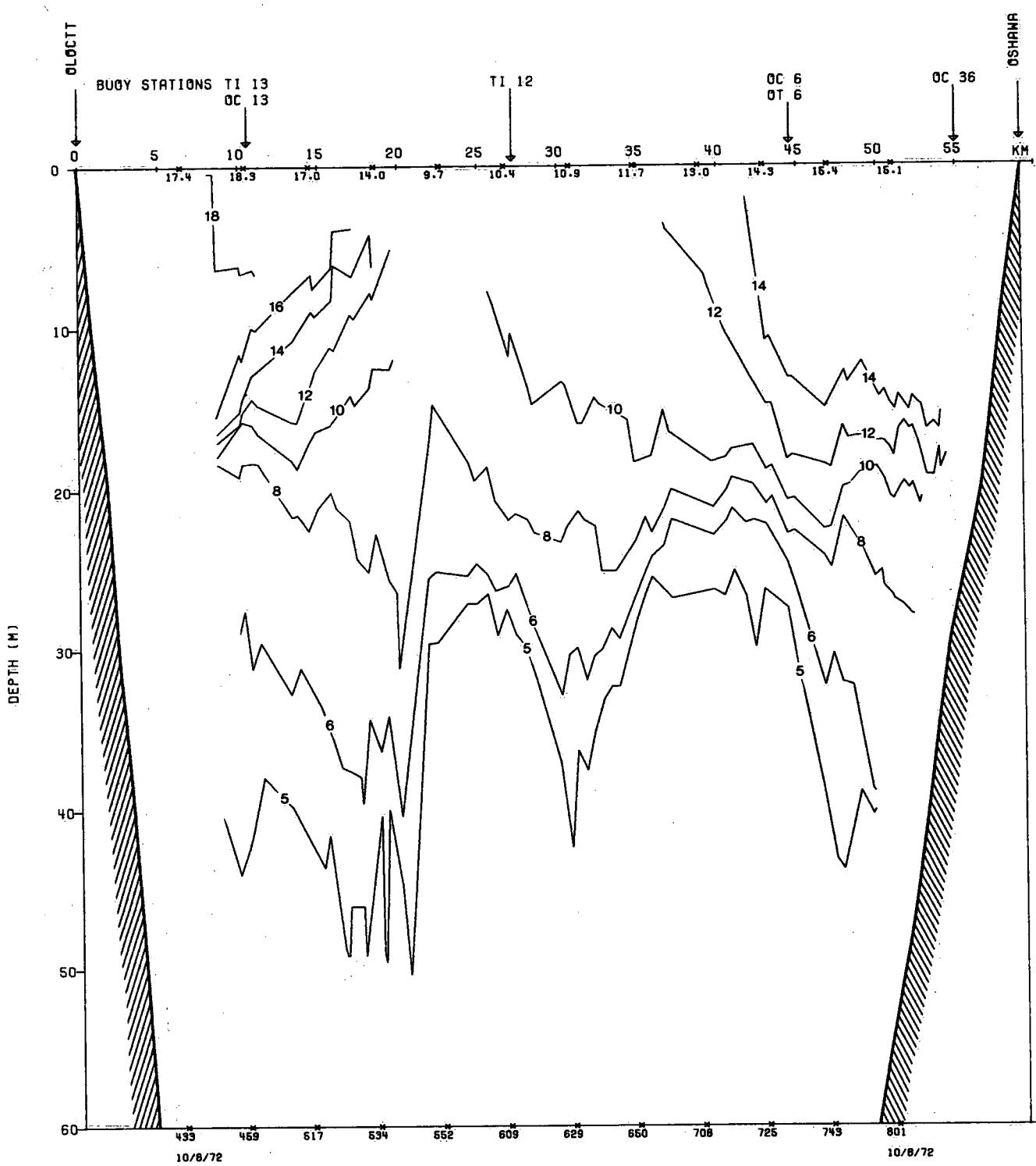
DAY (JULIAN) 223



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 7

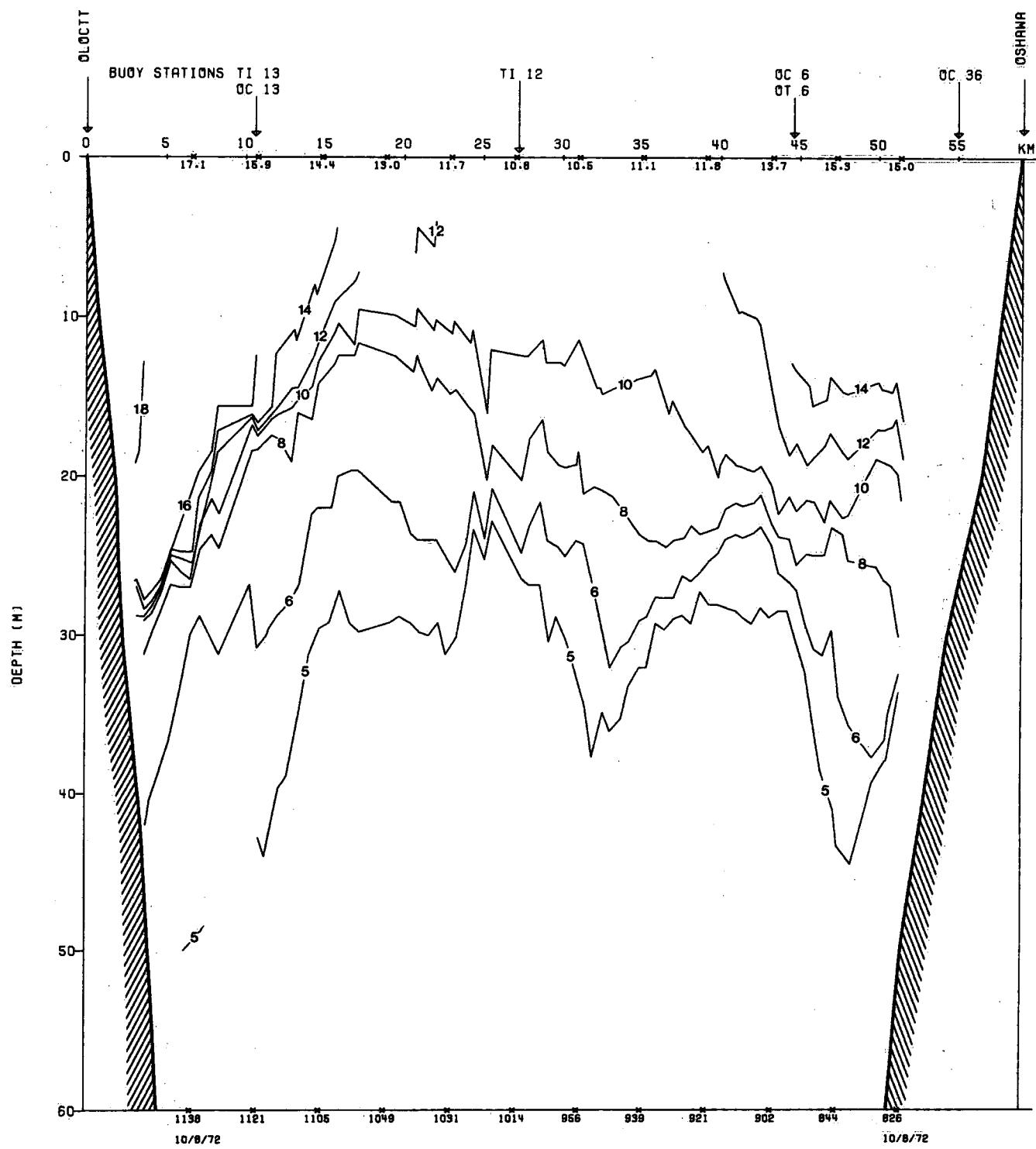
DAY (JULIAN) 223



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 8

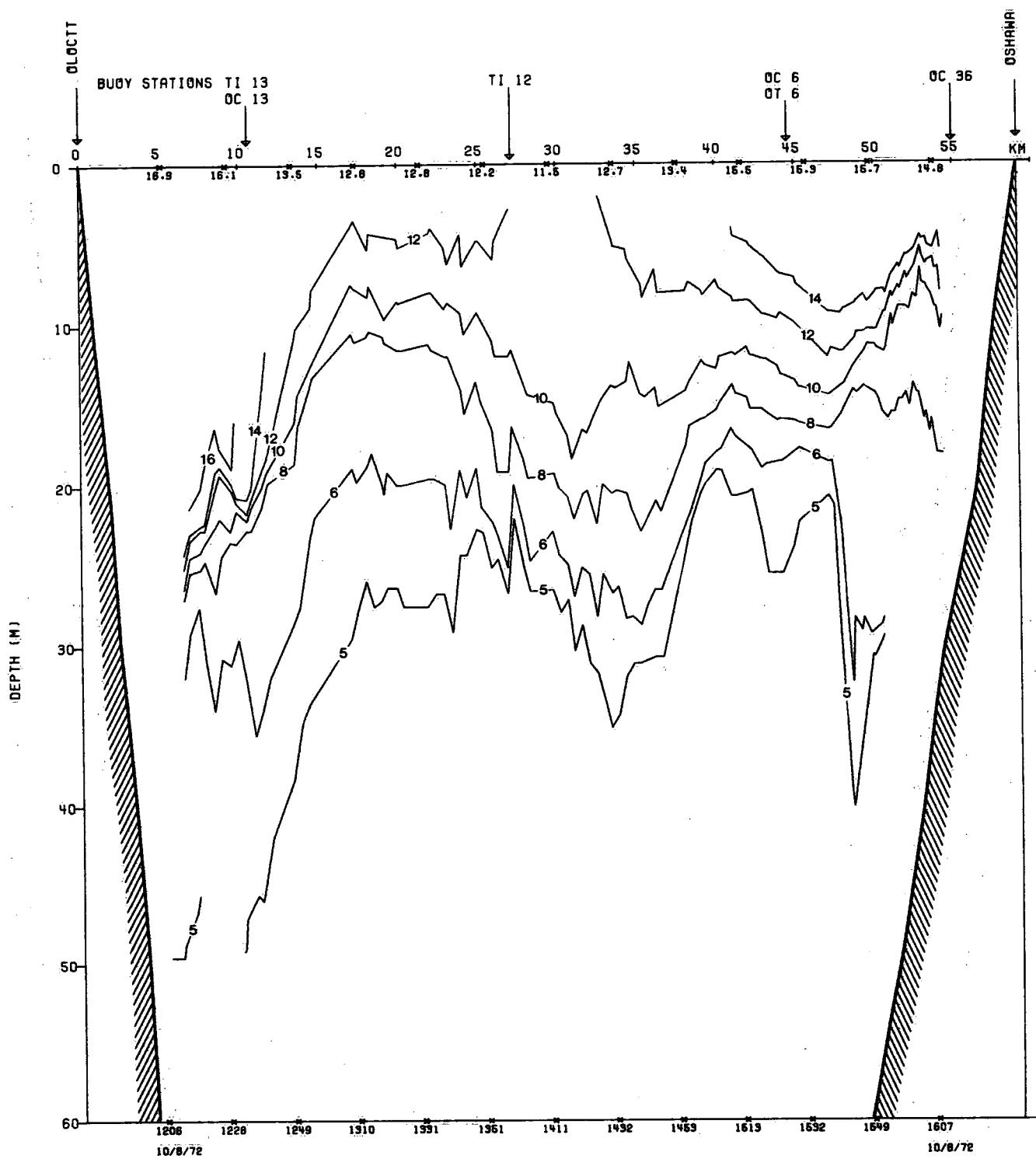
DAY (JULIAN) 223



IIFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLCOTT - OSHAWA CSS LIMNOS

TRANSECT 9

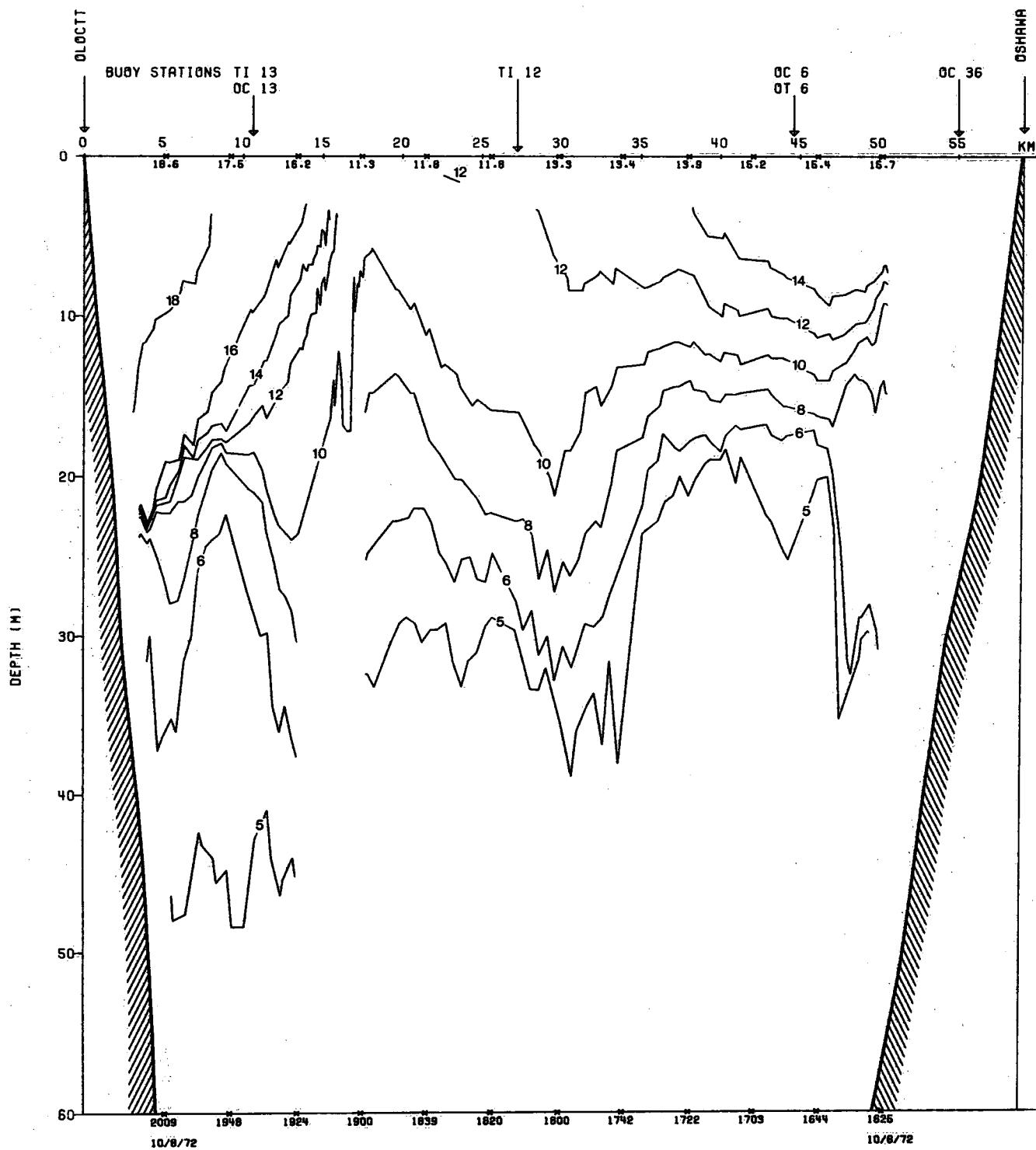
DAY (JULIAN) 223



IIFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 10

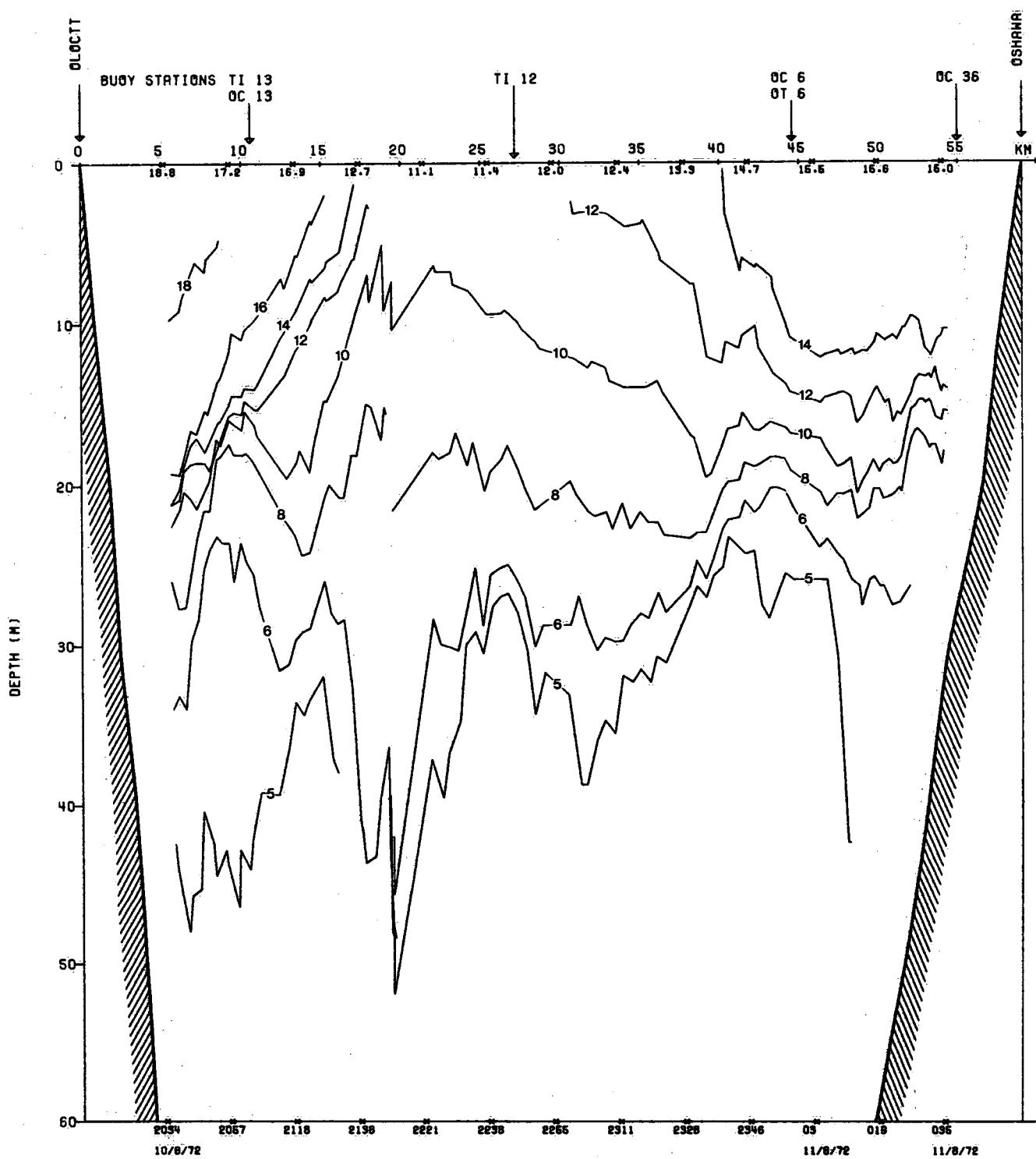
DAY (JULIAN) 223



## IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 11

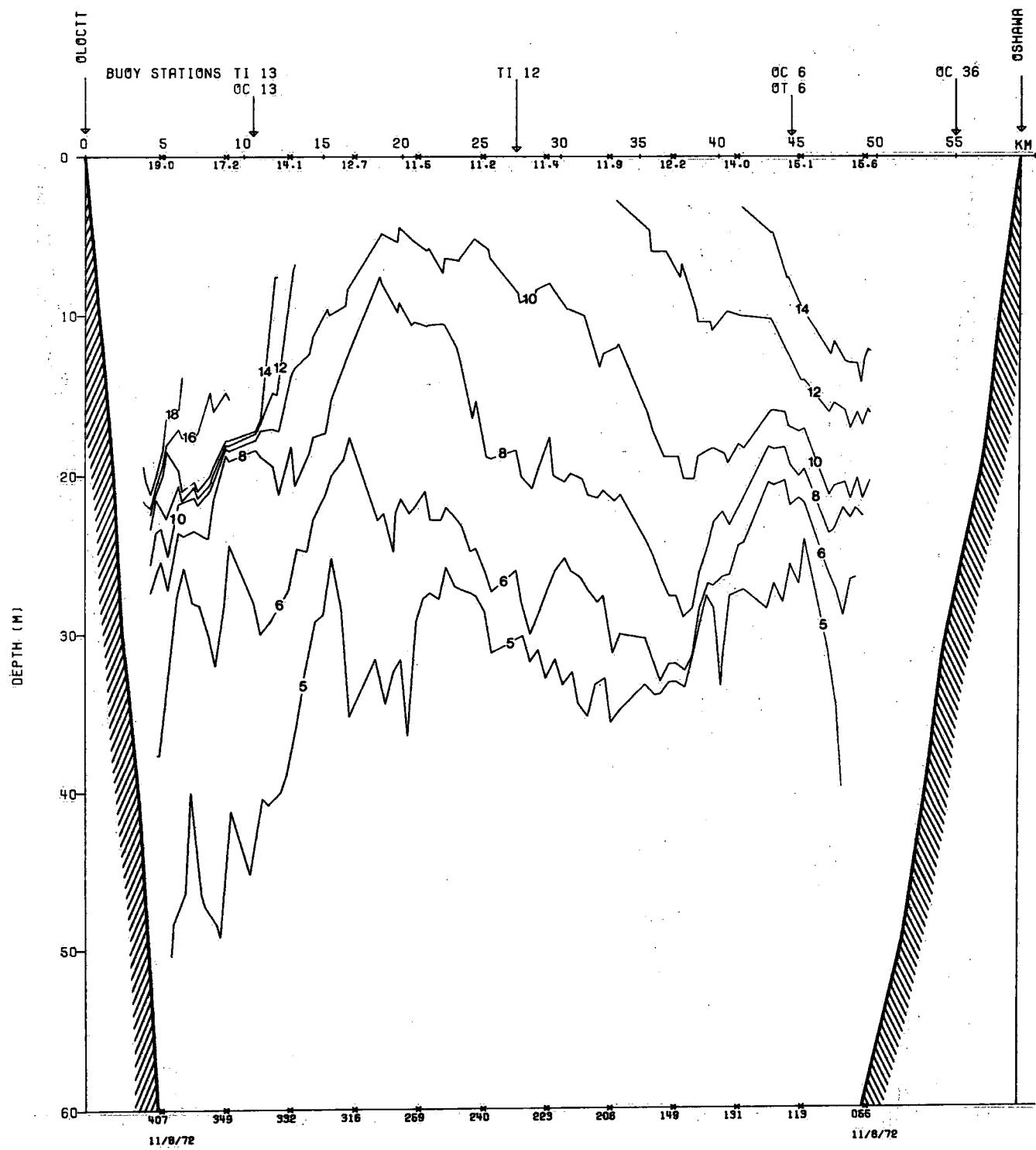
DAY (JULIAN) 223 - 224



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 12

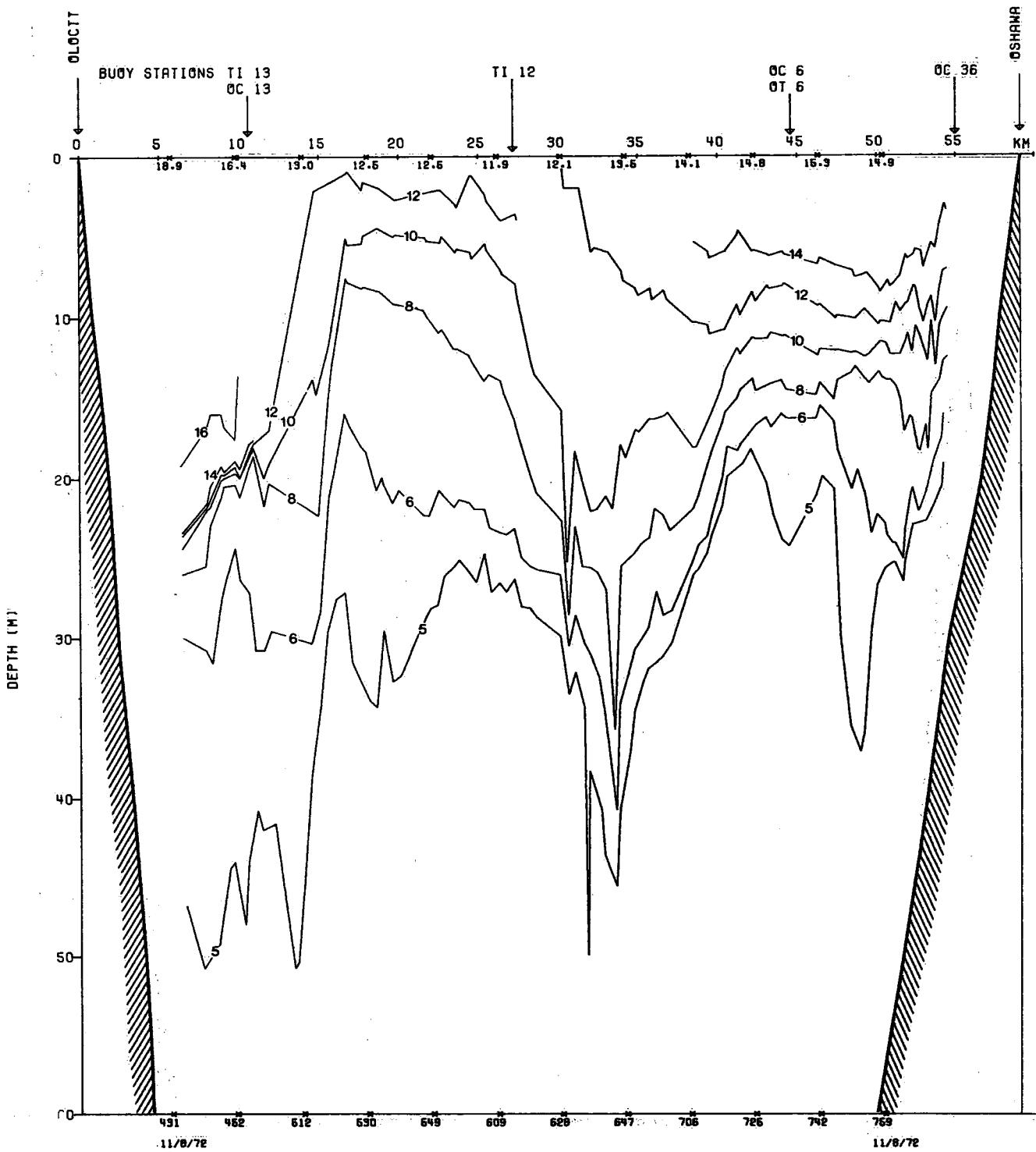
DAY (JULIAN) 224



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnols

TRANSECT 13

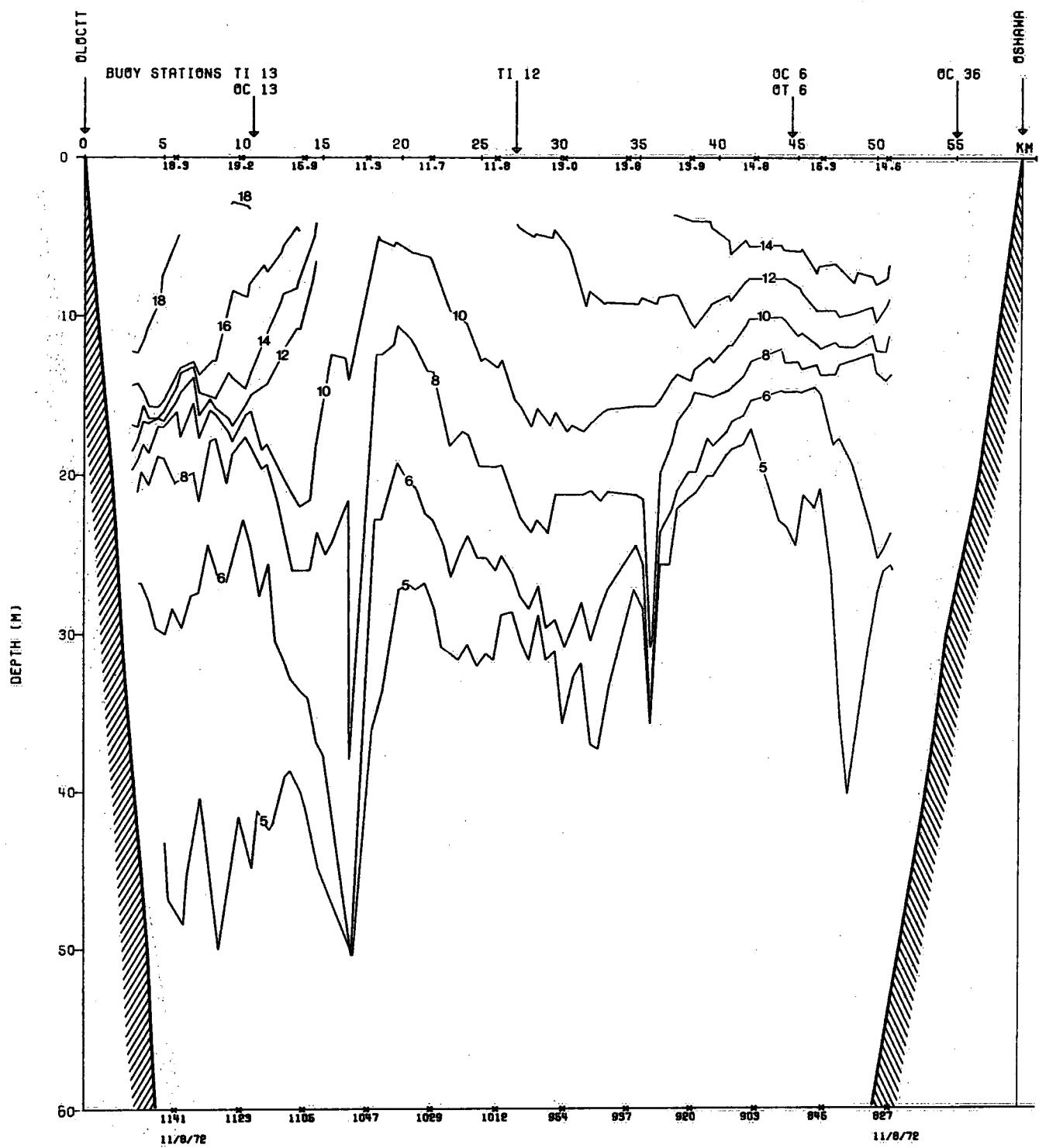
DAY (JULIAN) 224



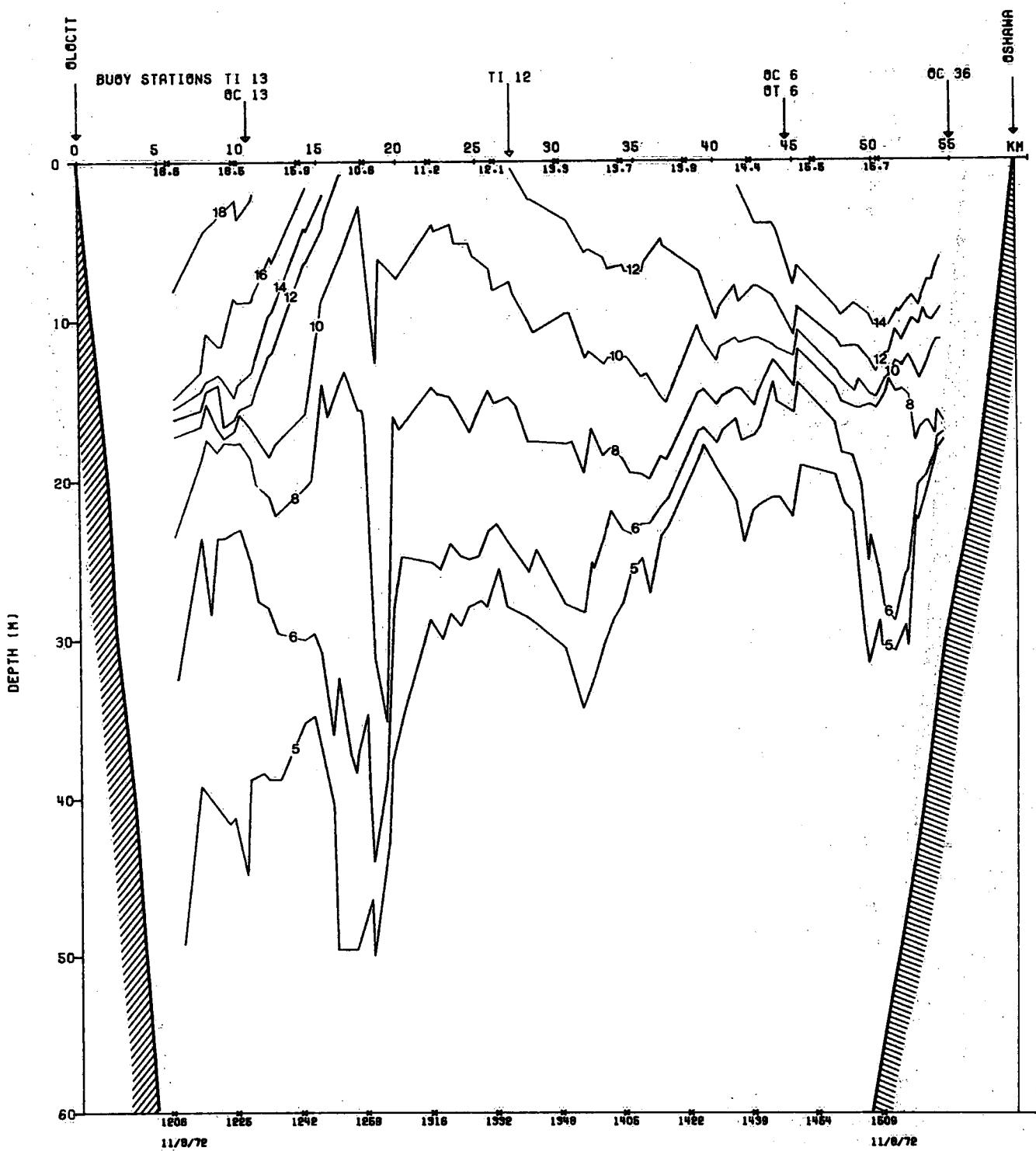
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - GLCOTT CSS LIMNOS

TRANSECT 14

DAY (JULIAN) 224



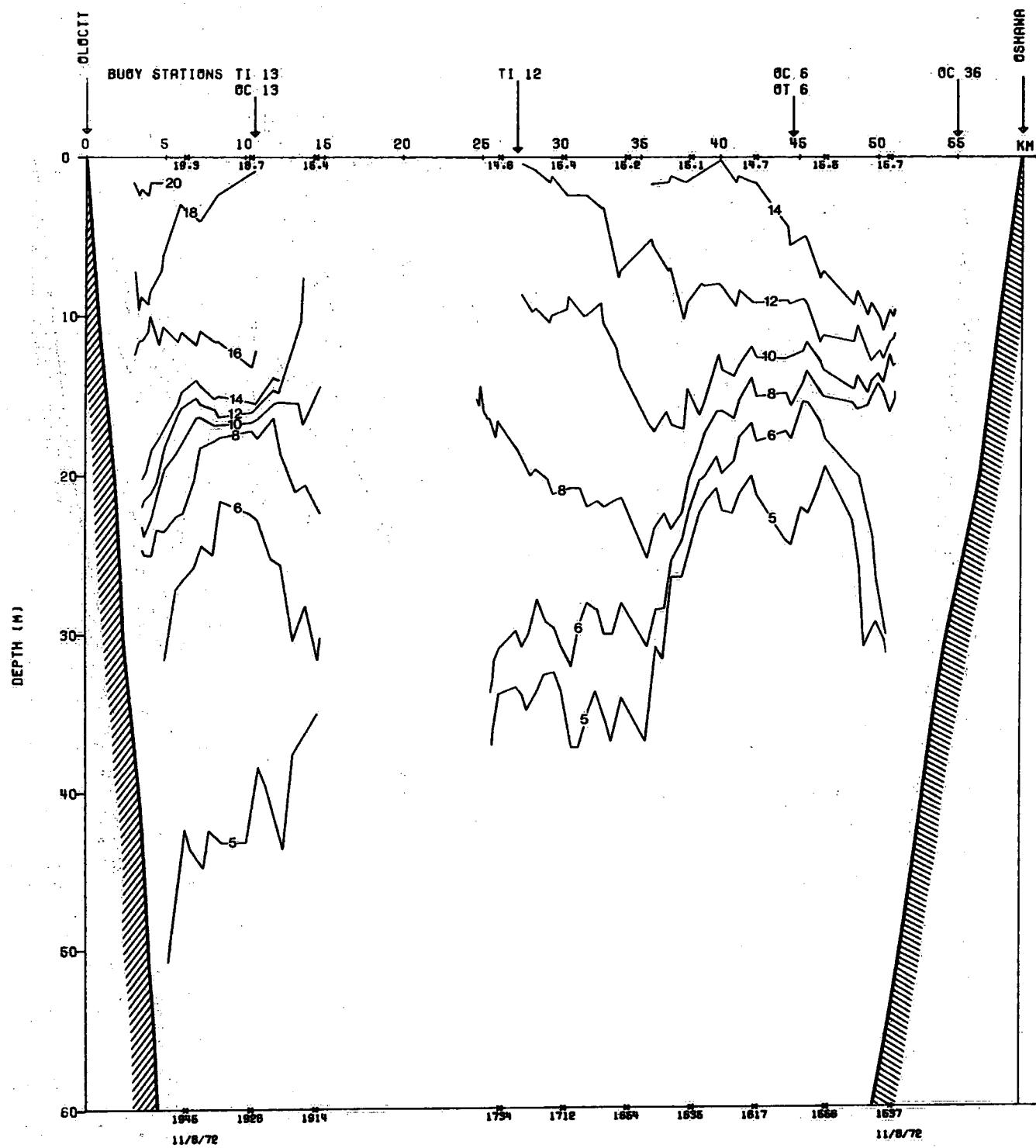
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT BLCOTT - OSHAWA - CSS LIMNOS  
TRANSECT 15 DAY (JULIAN) 224



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott. CSS LIMNOS

TRANSECT 16

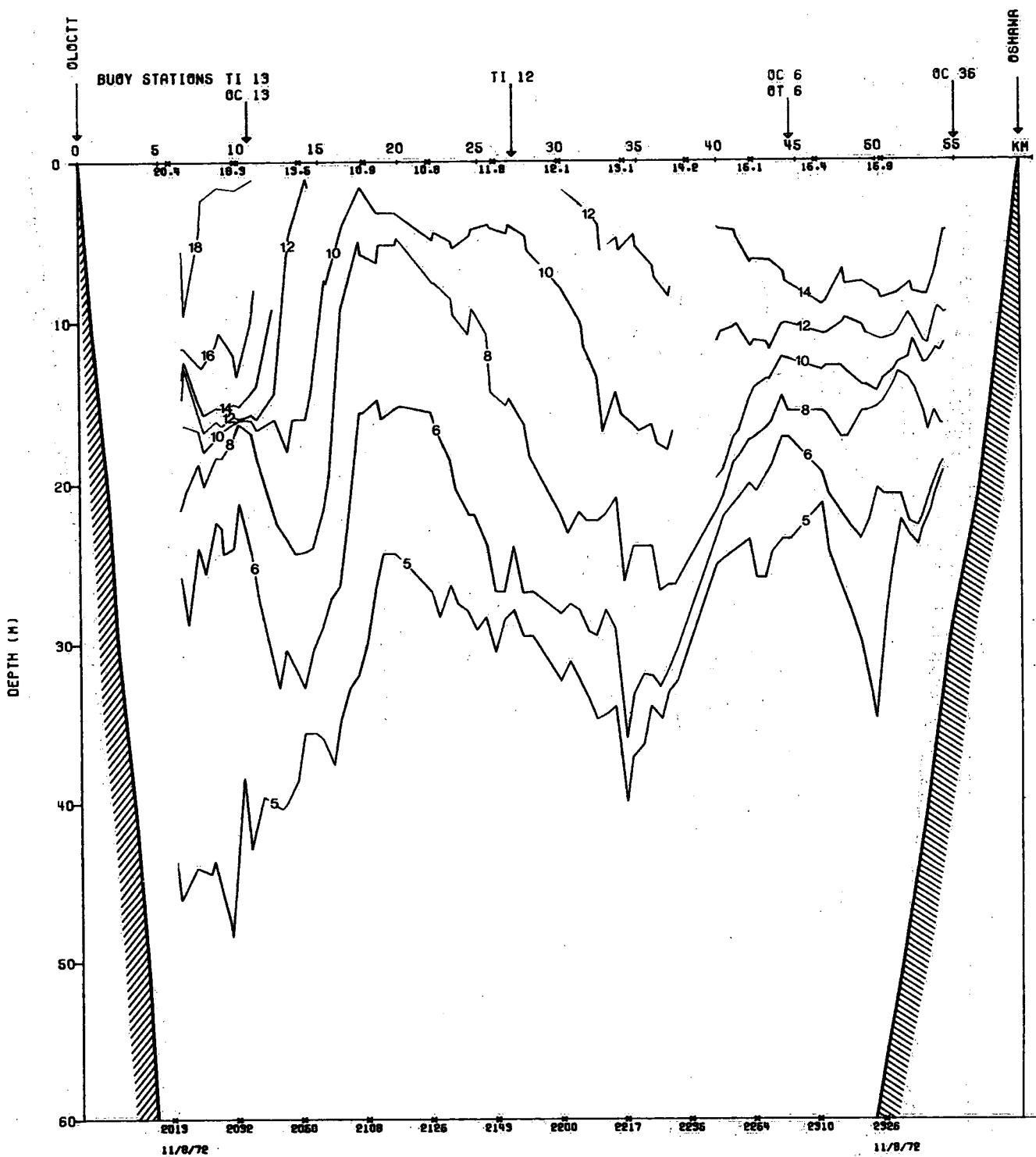
DAY (JULIAN) 224



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

**TRANSECT 17**

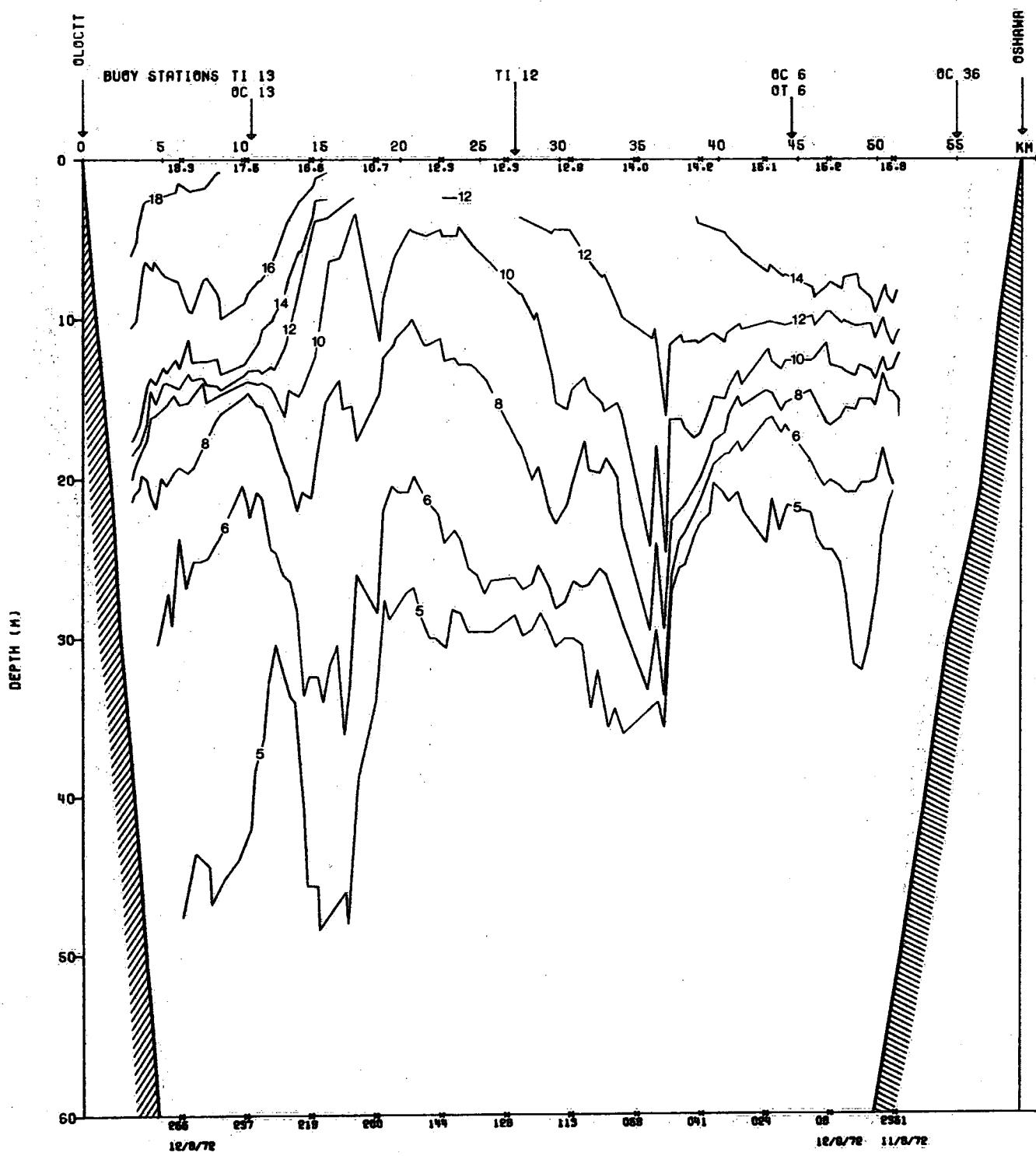
DAY (JULIAN) 224



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 18

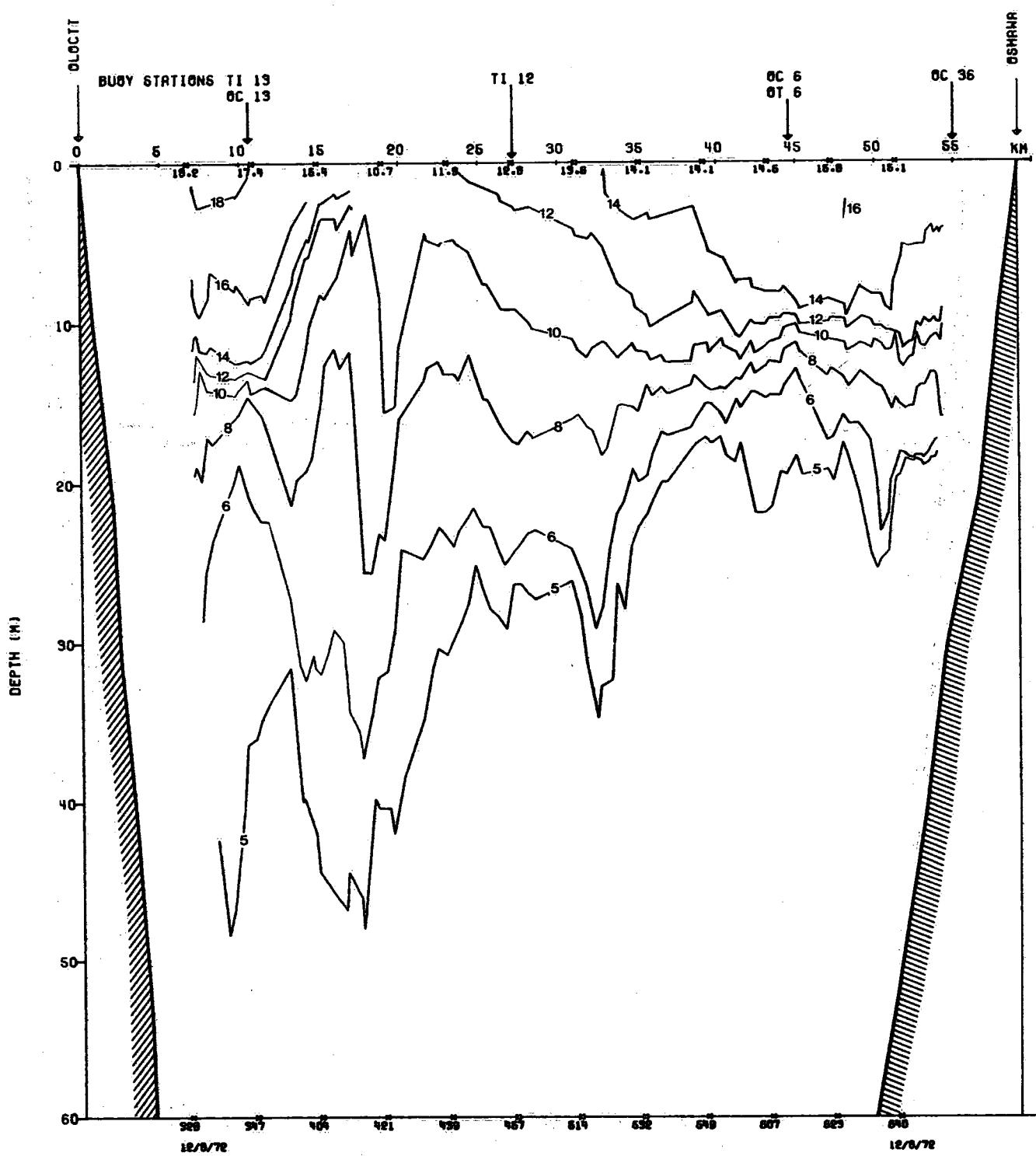
DAY (JULIAN) 224 - 225



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS LIMNOS

TRANSECT 19

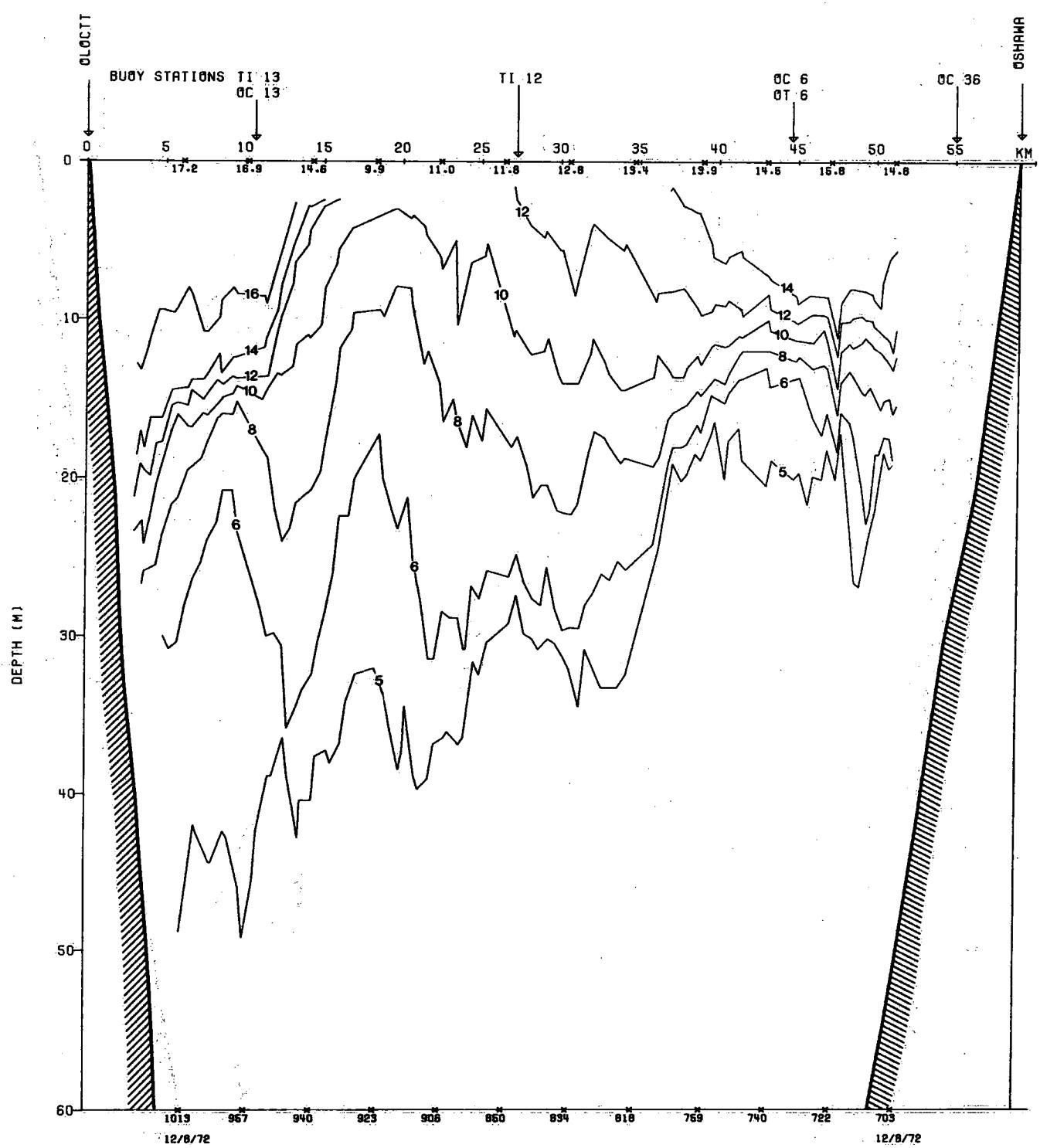
DAY (JULIAN) 225



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLCOTT CSS LIMNOS

TRANSECT 20

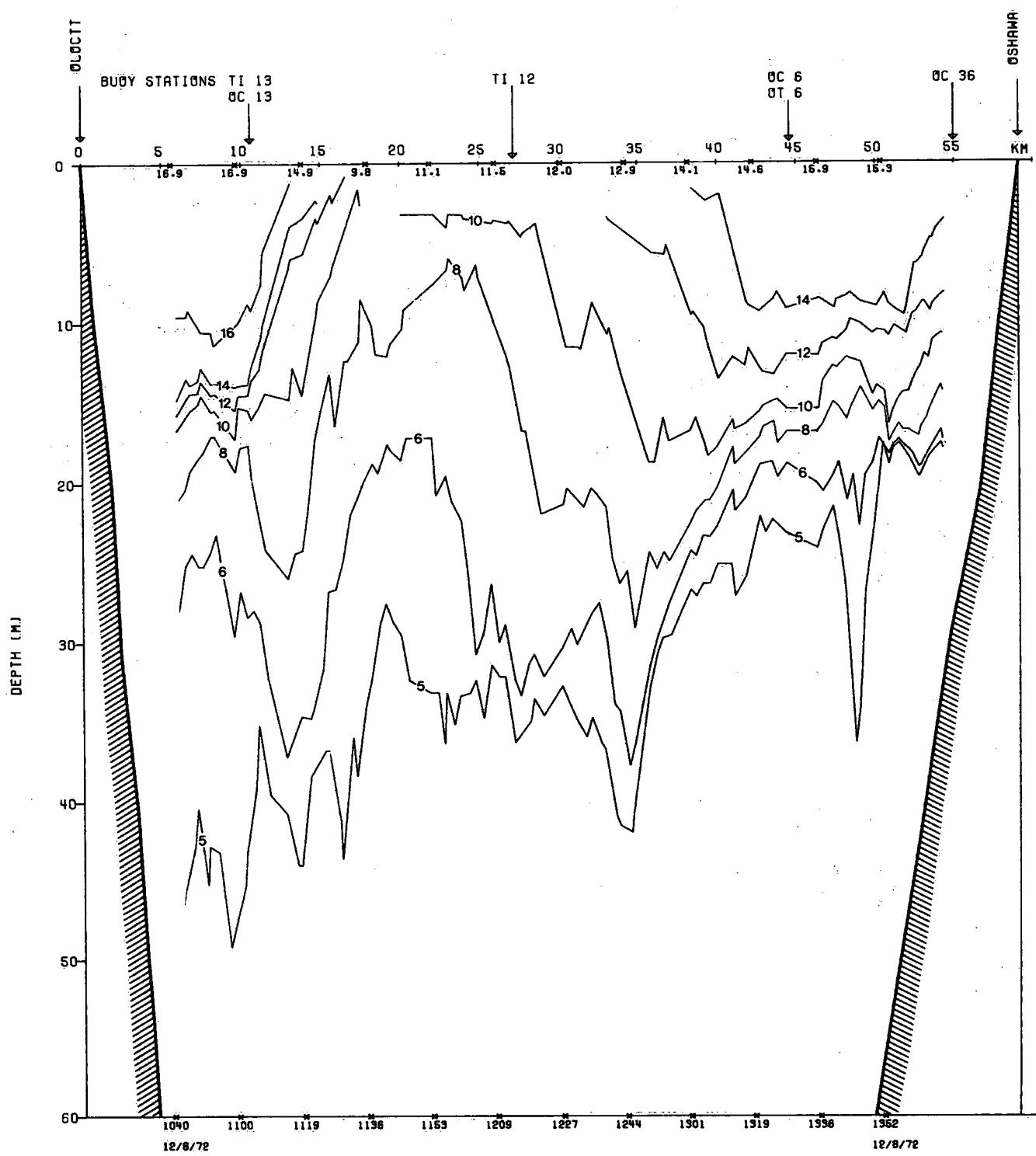
DAY (JULIAN) 225



## IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 21

DAY (JULIAN) 225



**Extract from the Log Narrative, C.S.S. *Limnos* Cruise 72-00-022,  
2-6 October (Julian Days 276-280) 1972**

(amended to conform with numbering of following  
transect diagrams)

Instruments deployed: Batfish and Towed Thermistor Array

Transects completed: 24

Major interruptions: Data interrupted 2204-2334, 3 October;  
northern part of run 7 missing.

**2 October**

- 0130 Depart CCIW
- Set out Satellite Buoy
- 1900 Set out equipment in deep water near station G
- 2000 Underway and towing; system checkout
- 2047 On line at sta. F and moving North. Batfish streamed with 65 m of cable; towed array with breakout #11 just below surface. Tape WE62
- 2052 Commence scanning; transect No. 1
- 2115 Stop to inspect a poorly performing Batfish. Sections of fairing found to be in state of total disarray. Speculate that we have run afoul of a submerged log. Underway 2303.

**3 October**

	Station	Start of Trans. No.
0056	A	2
0523		
	Depth signal from towed array malfunctioning; suspect trouble with lower splice.	
0604	G	3
0803	A	4
1132	G	5
1209		
	Stop to repair Batfish fairing. Underway 1241.	
40	A	
1618		
	Stop for launch "Sturdy". Underway immediately.	
1647	A	6
1915	G	7
2204	B	
	Stopped to inspect Batfish, and found hydraulic oil leak. Batfish hauled aboard.	
2232		
	Underway to A with towed array only. Batfish 1 readied for service. Disregard Batfish channel to end of run. Stop to deploy Batfish 1. Underway 2334.	
2350	C	8

**4 October**

- 0258 G 9
- 0631 A 10
- 1005 G 11
- (New tape WE 63)
- 1340 A 12
- 1732 G 13
- 2043 Thermistor in breakout is malfunctioning
- 2103 A 14
- 2212 C 14
- Stop to inspect Batfish and find once again the expansion teat has failed. Batfish 2 pressed into service. Resume steaming 2257.

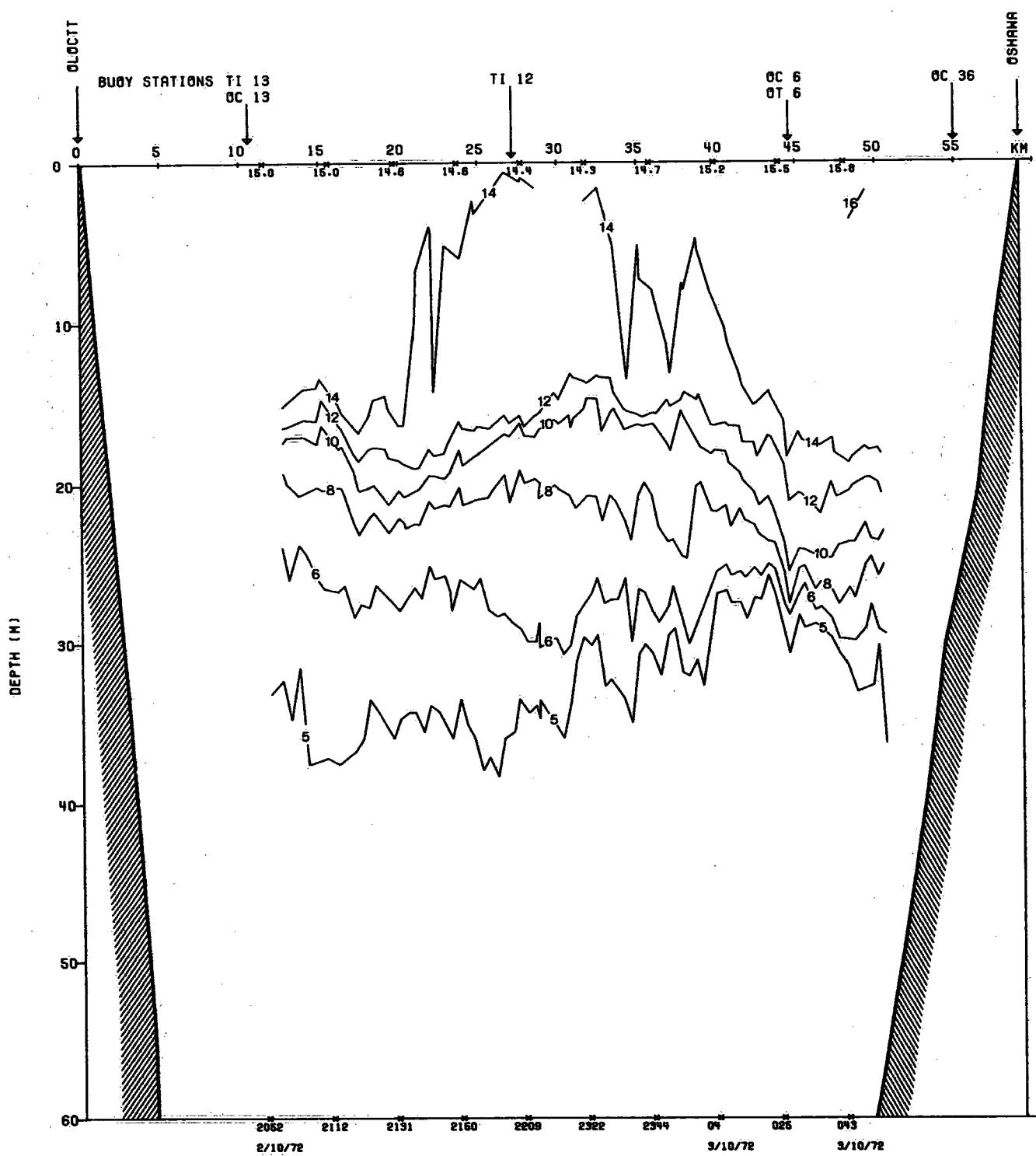
**5 October**

0117	G	15
0452	A	16
0846	G	17
1227	A	18
1522	G	19
1926	A	20
2154	E	
	Stop to repair fairing. Underway 2228.	
2332	G	21
	New tape (WE 64) on ADDS starts run 21.	
	6 October	
0256	A	22
0641	G	23
1014	A	24
	New tape (WE 65) on ADDS starts run 24.	
1337	G	
	End of scanning; head for deeper water.	
1342		
	Stop to recover towed equipment.	
1404		
	Underway to Burlington. Alongside 1900.	
	Transects 1-24, 2-6 October, follow.	

IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS LIMNOS

TRANSECT 1

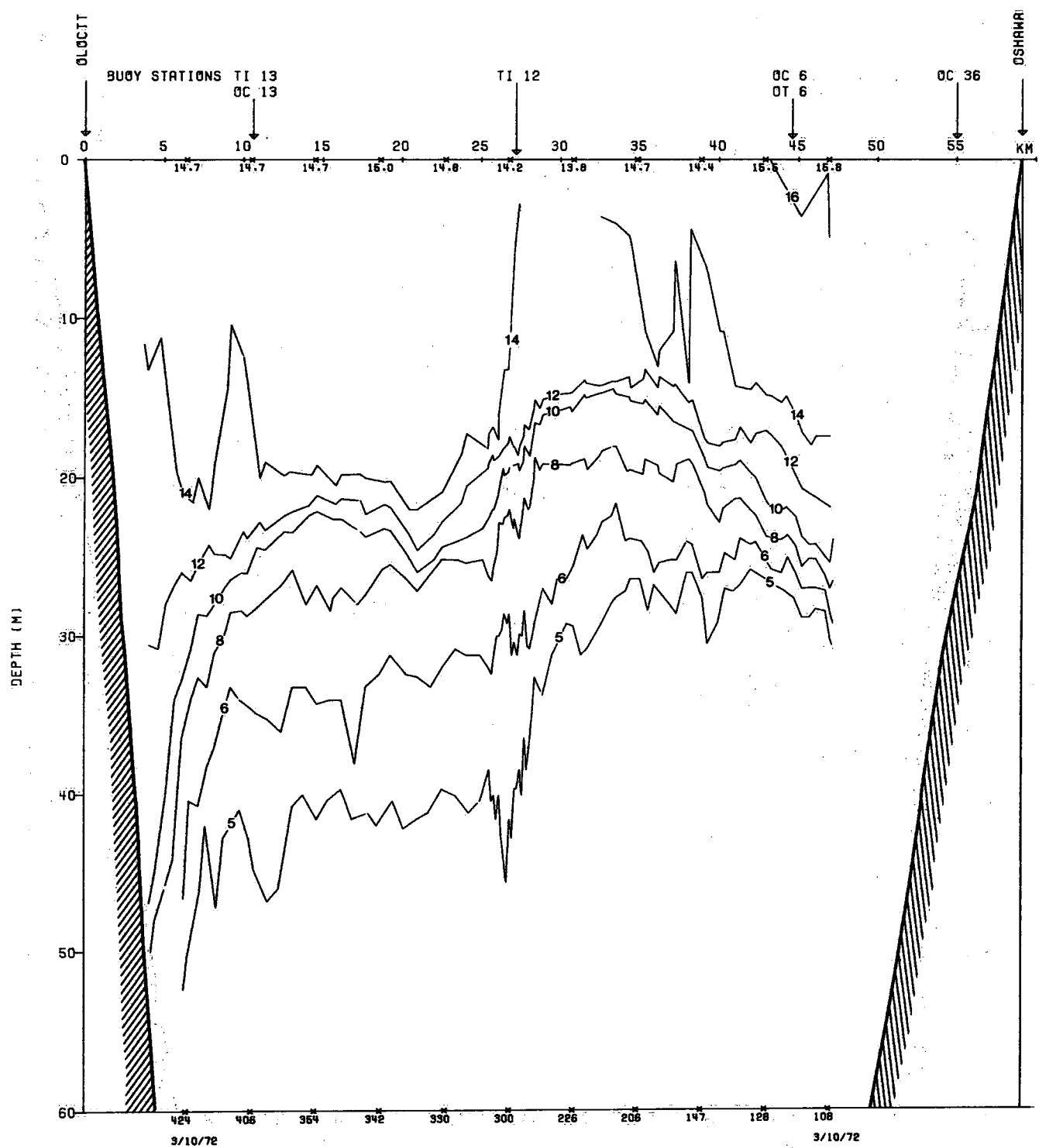
DAY (JULIAN) 276 TO 277



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNO

TRANSECT 2

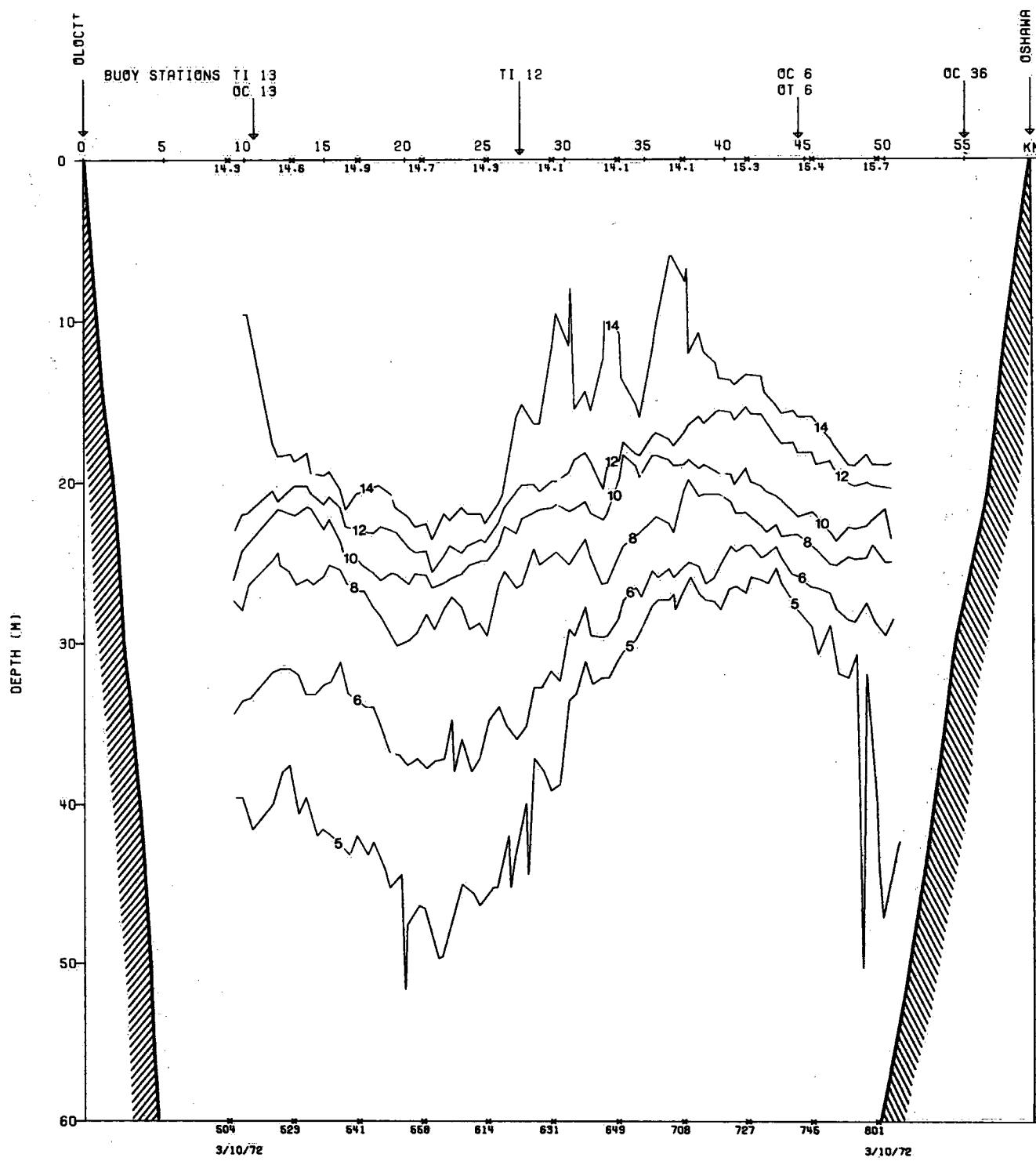
DAY (JULIAN) 277



## IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 3

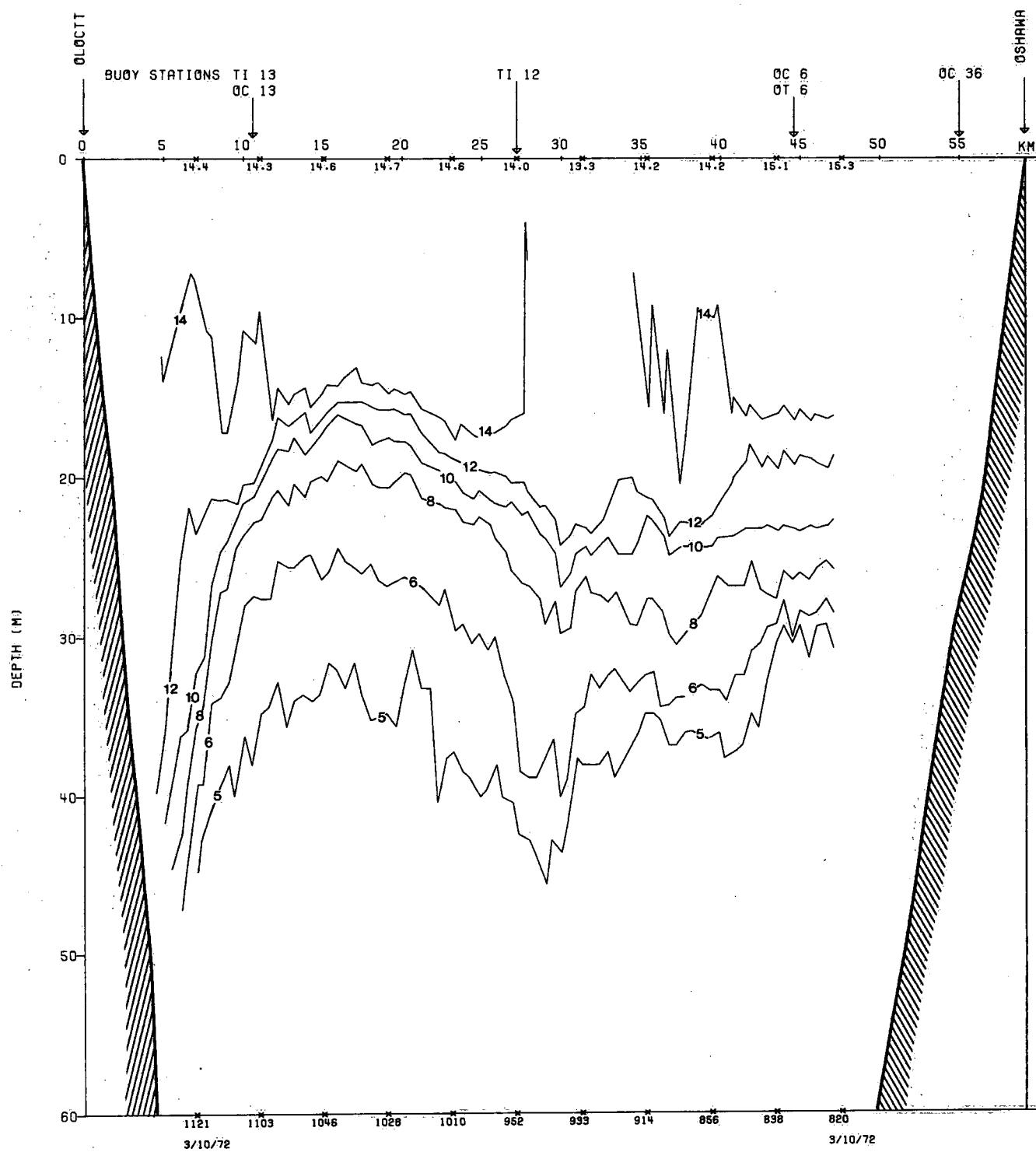
DAY (JULIAN) 277



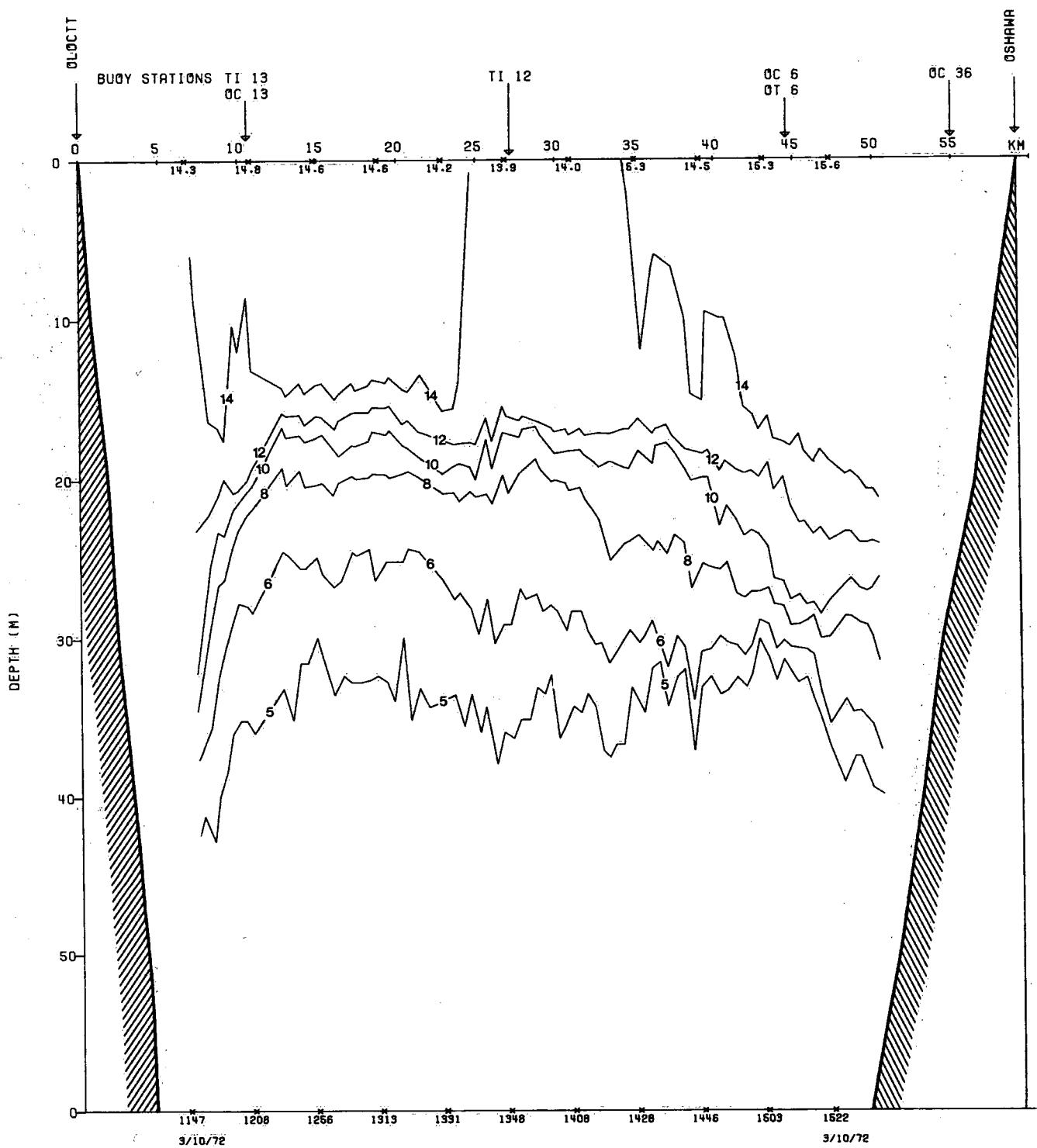
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS Limnos

**TRANSECT 4**

DAY (JULIAN) 277



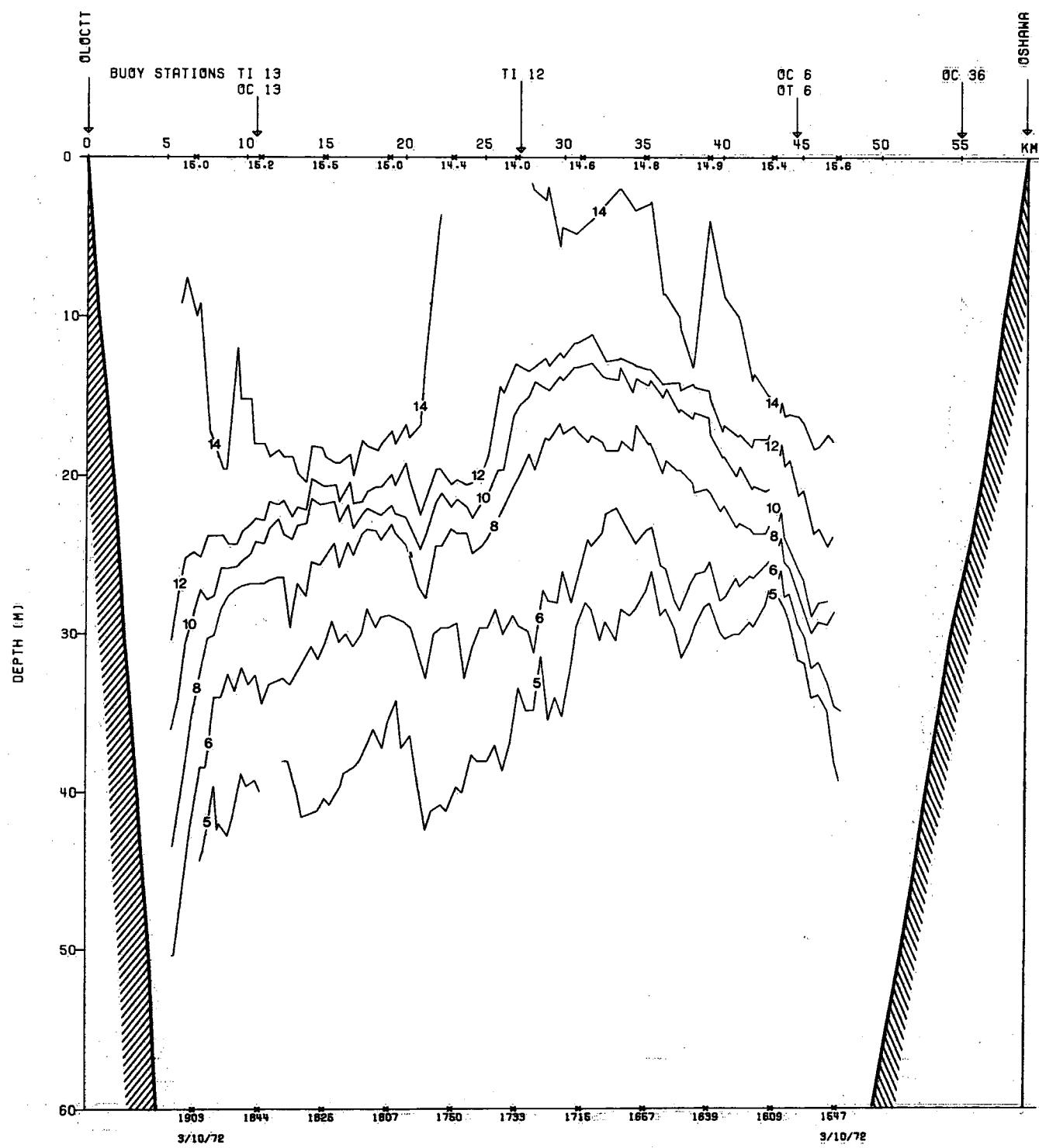
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS LIMNOS  
 TRANSECT 5 DAY (JULIAN) 277



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 6

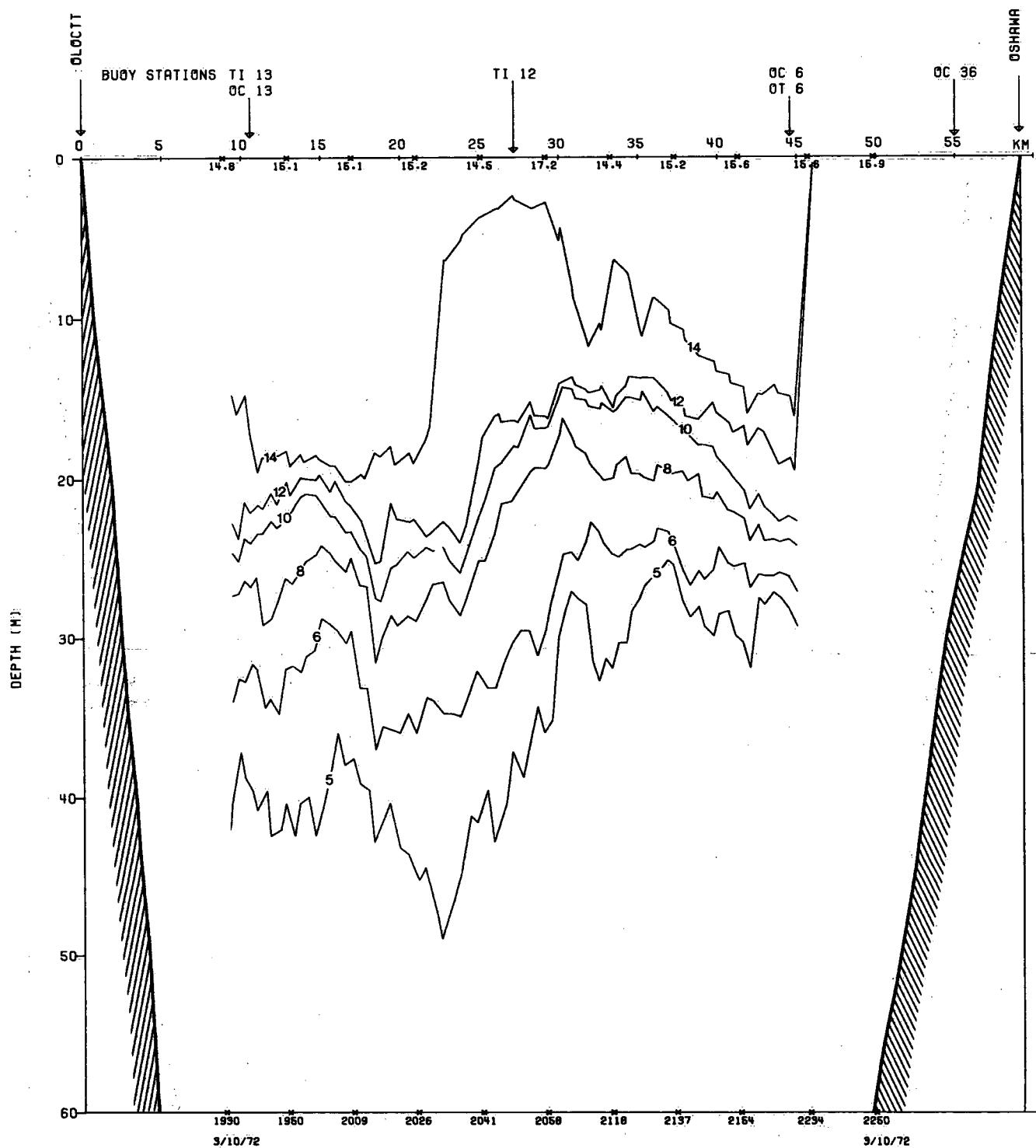
DAY (JULIAN) 277



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 7

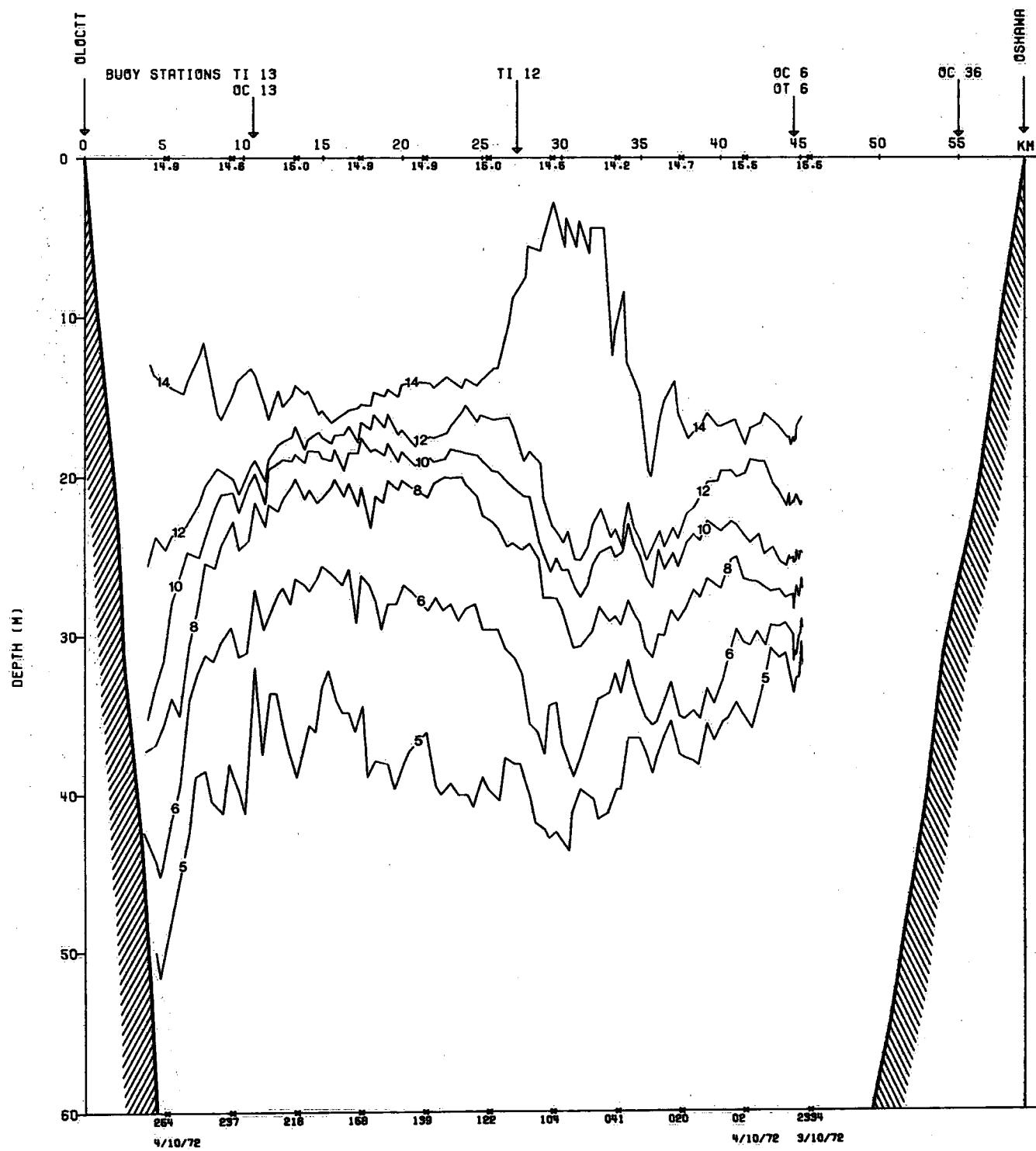
DAY (JULIAN) 277



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - GLOCESTER CSS LIMNOS

**TRANSECT 8**

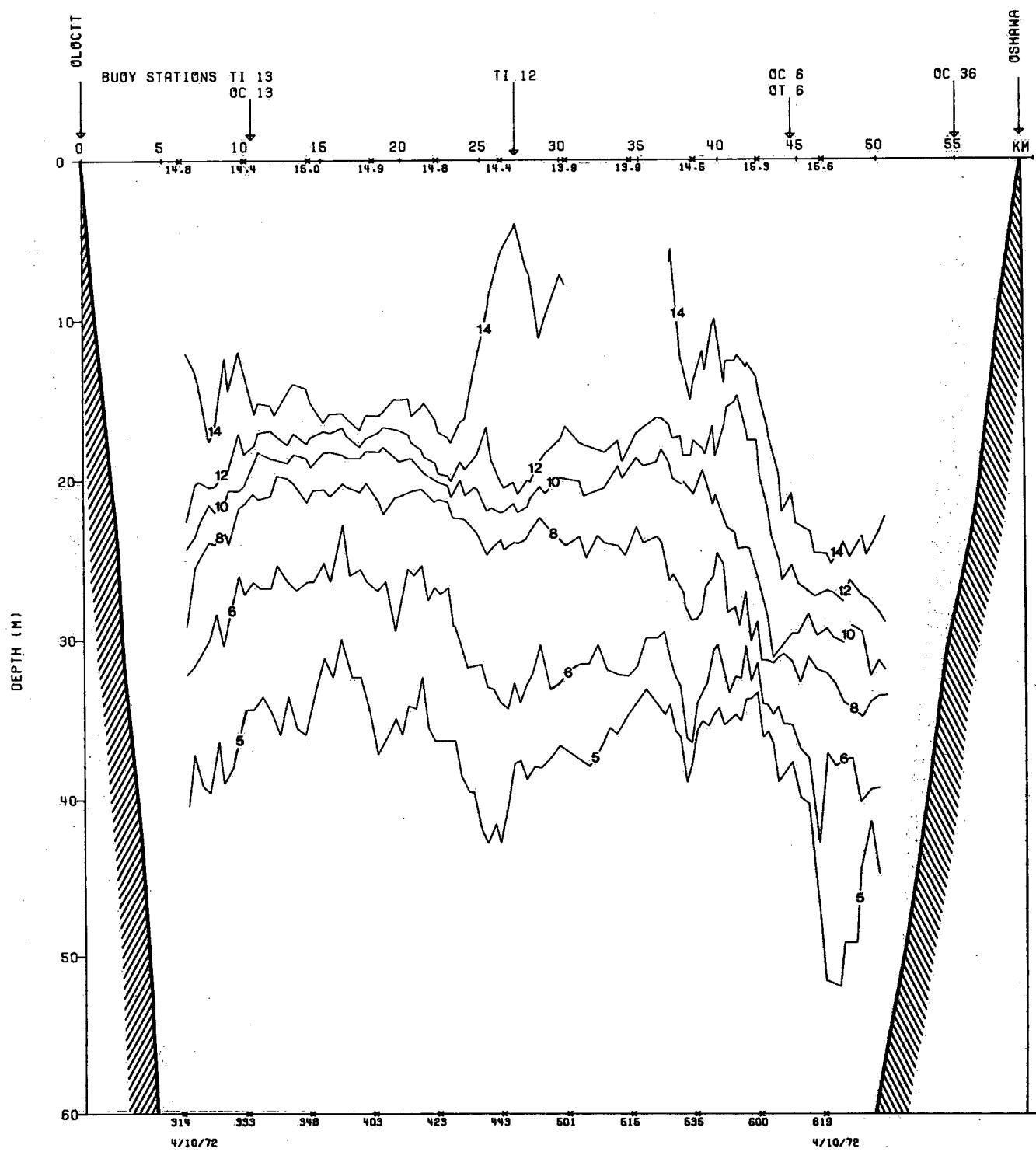
DAY (JULIAN) 277 TO 278



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 9

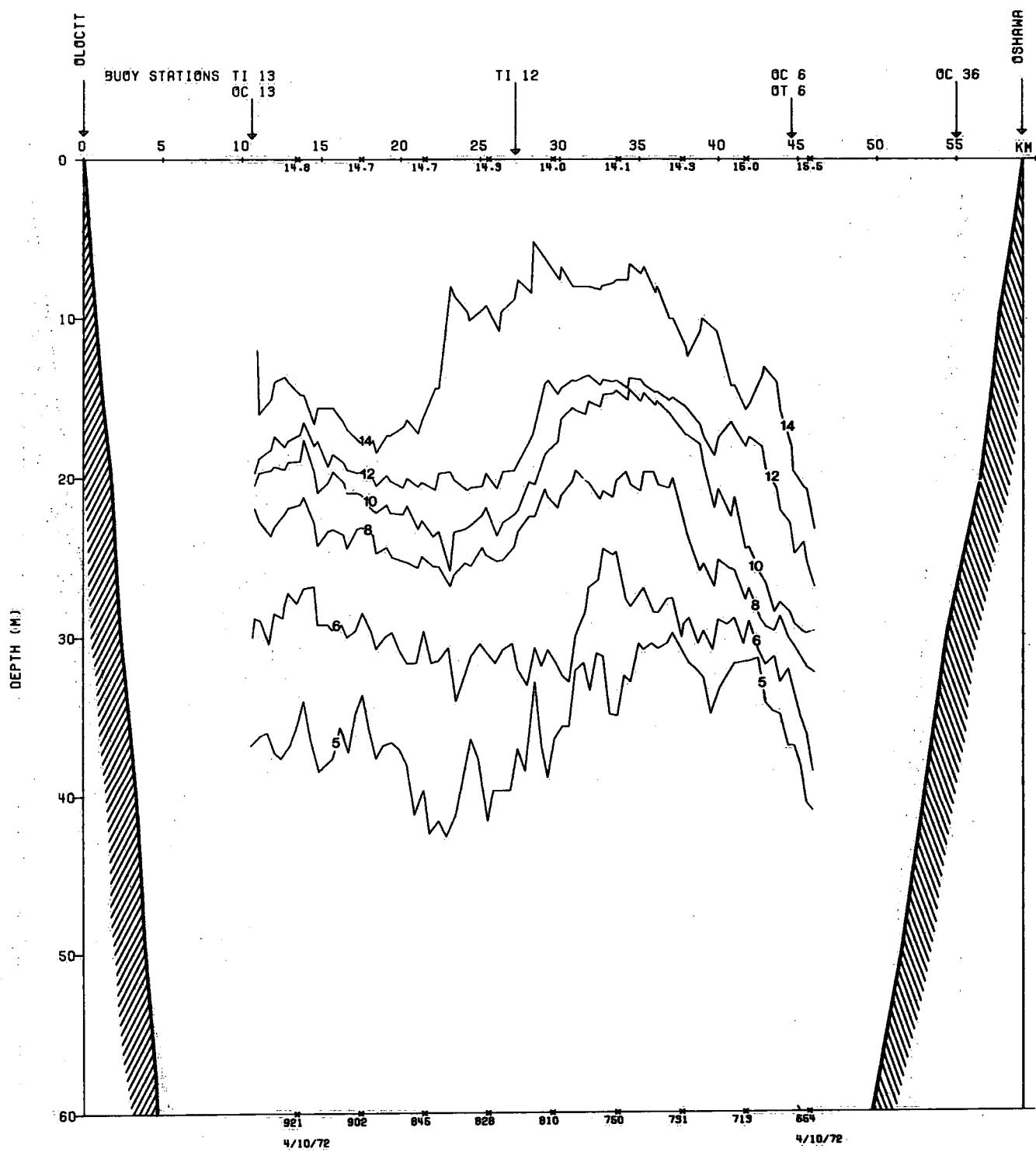
DAY (JULIAN) 278



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 10

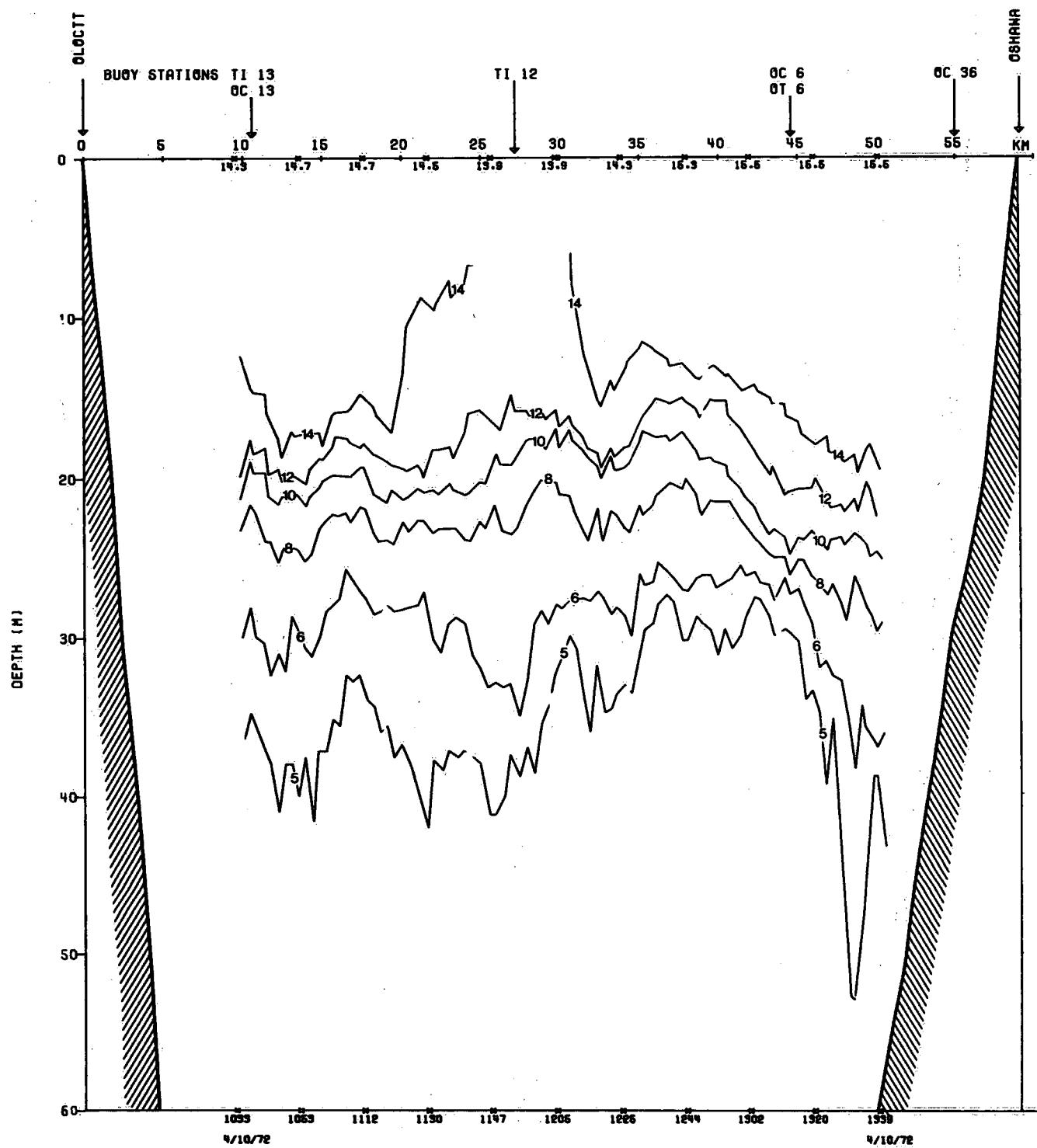
DAY (JULIAN) 278



TFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 11

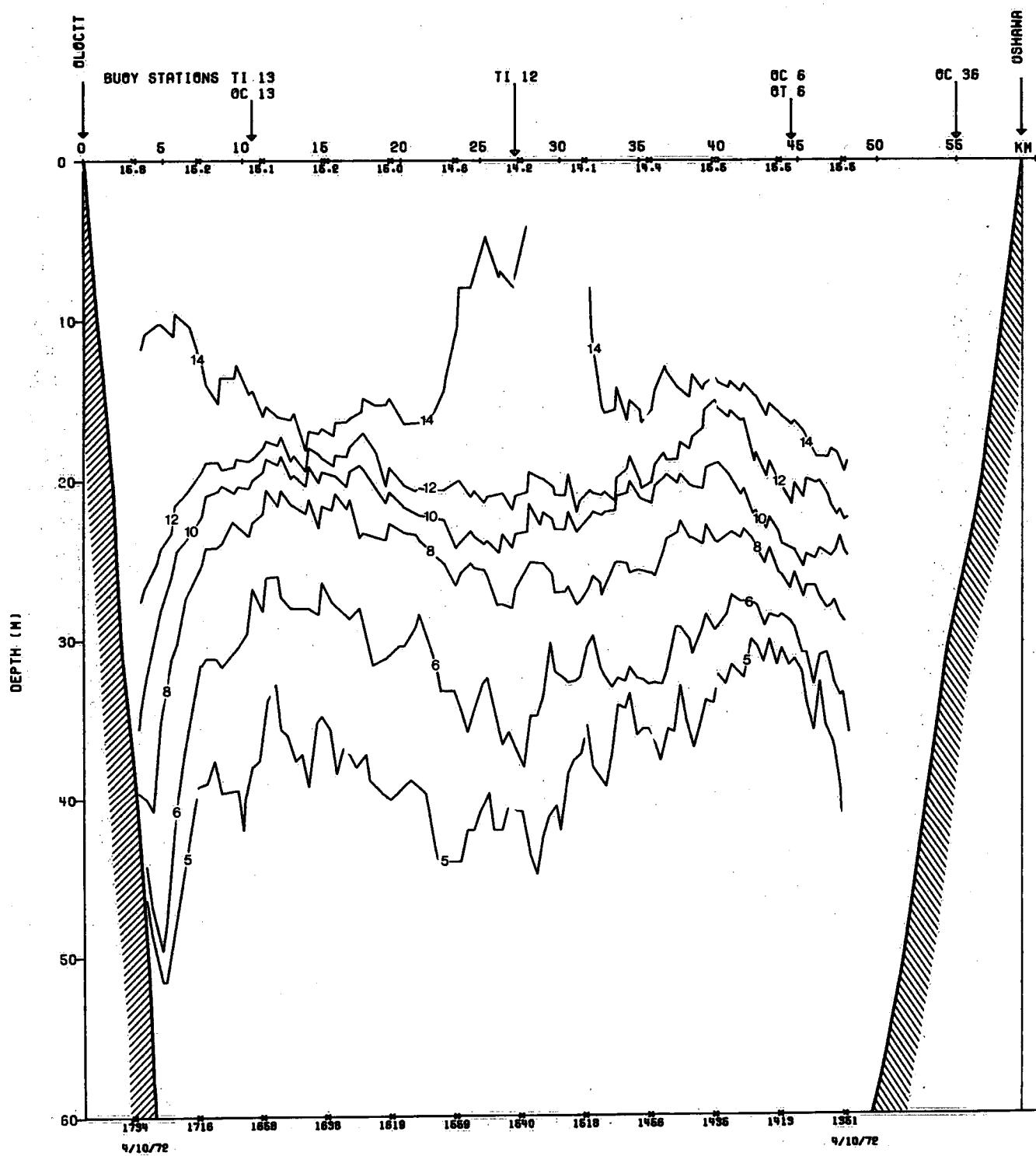
DAY (JULIAN) 278



TFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott - CSS LIMNOS

TRANSECT 12

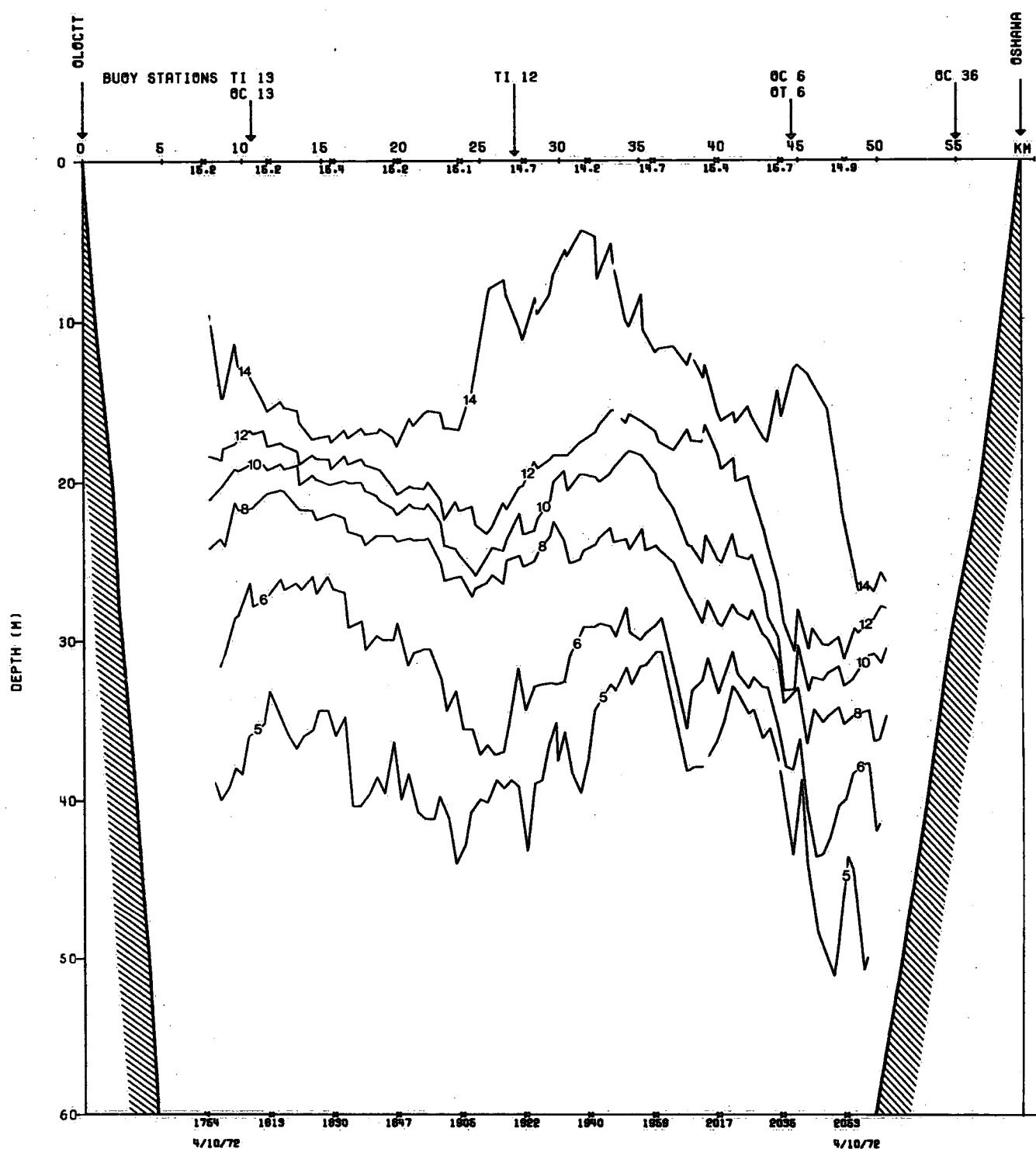
DAY (JULIAN) 278



## IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 13

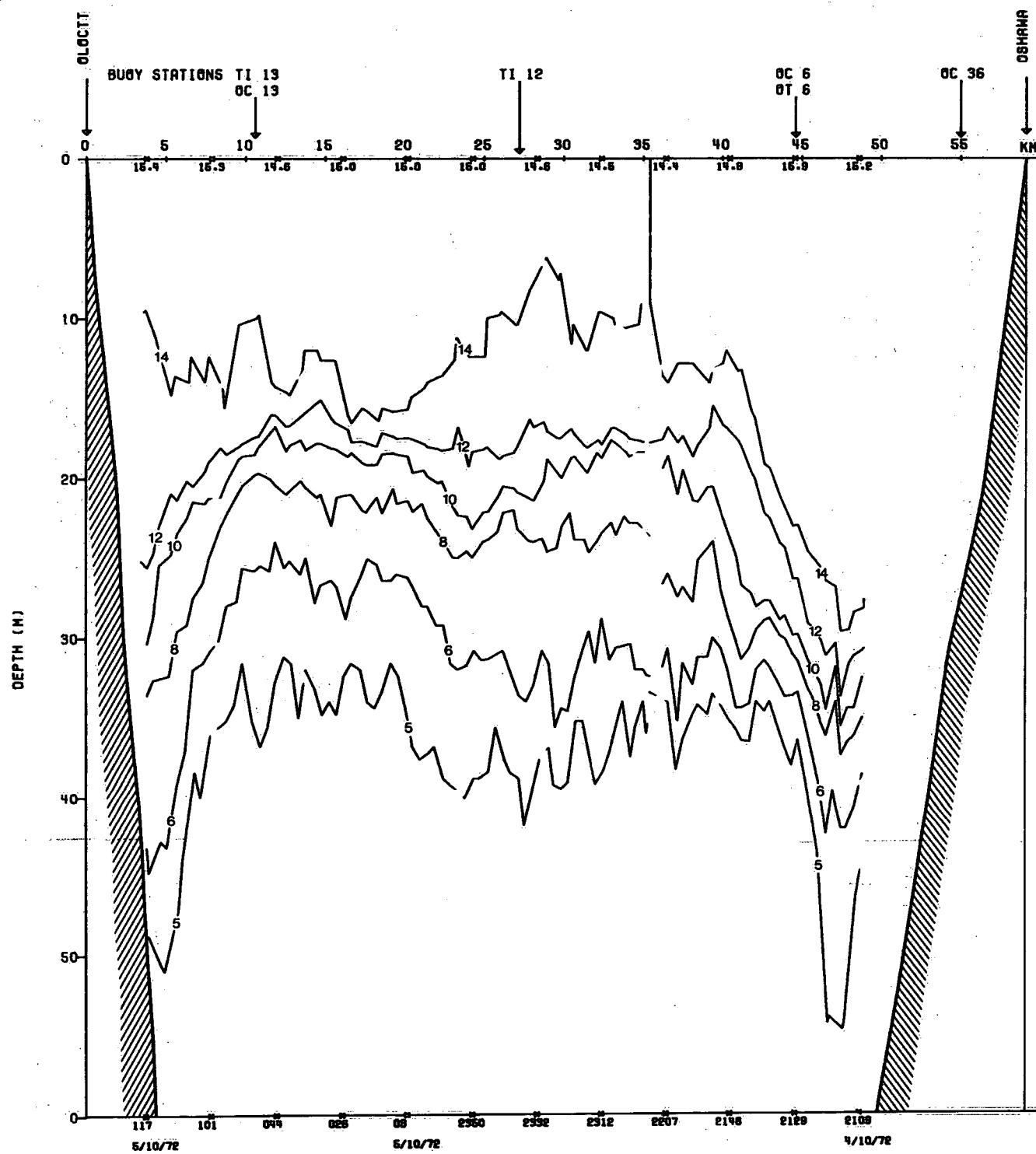
DAY (JULIAN) 278



TFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA = OLcott CSS LIMNOS

TRANSECT 14

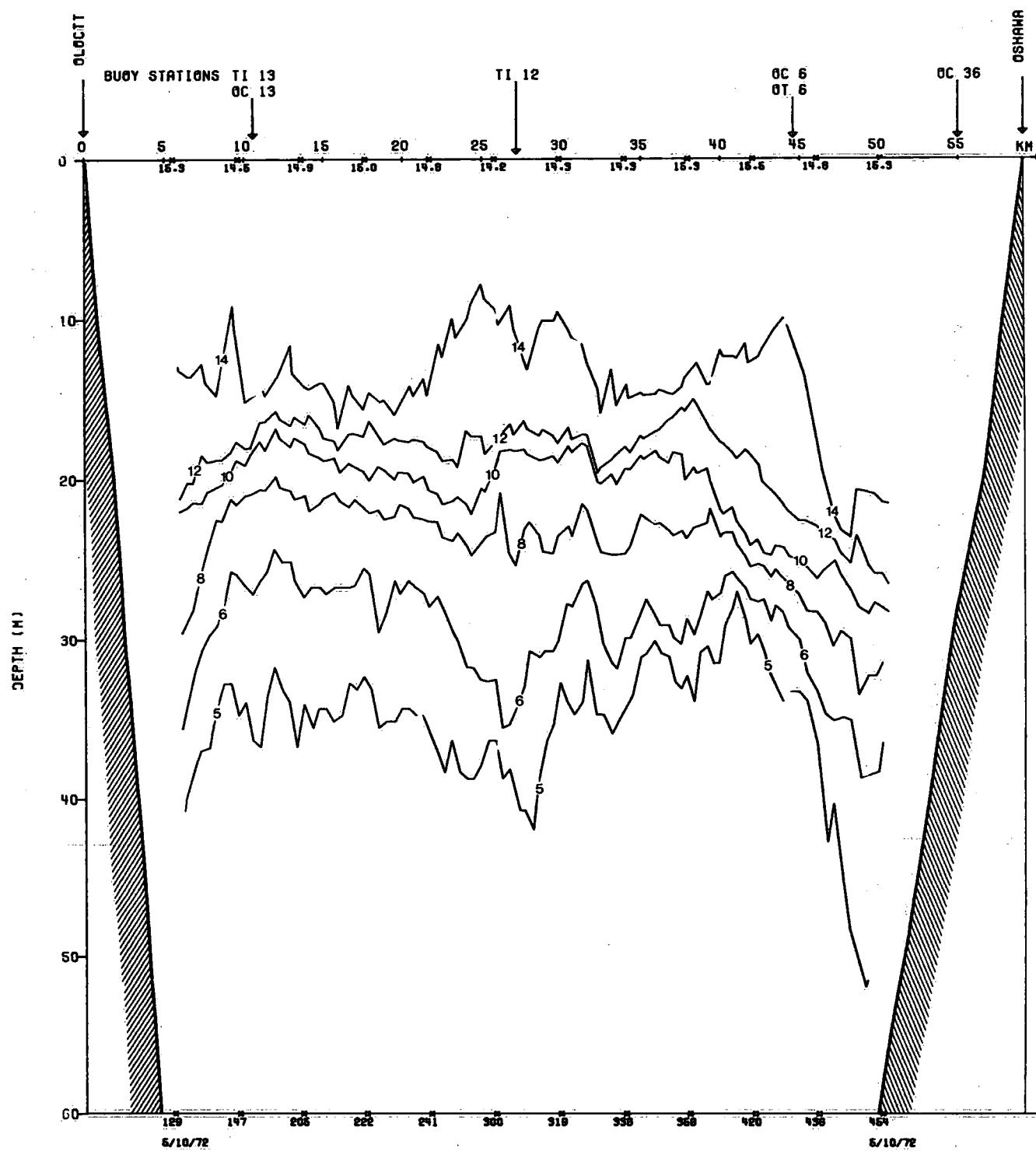
DAY (JULIAN) 278 TO 279



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT 0LCOTT - OSHAWA CSS LIMNOS

**TRANSECT 15**

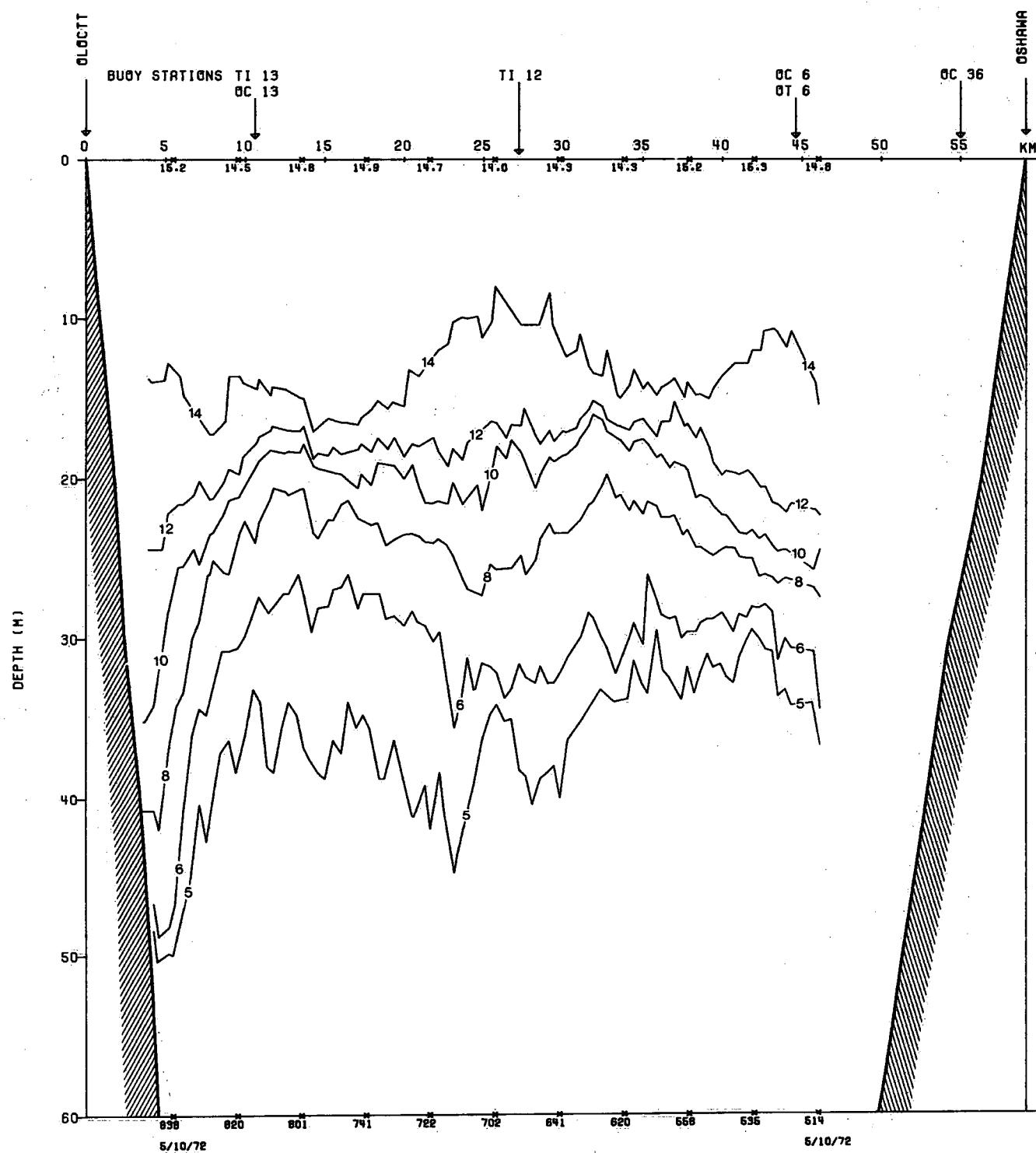
DAY (JULIAN) 279



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

**TRANSECT 16**

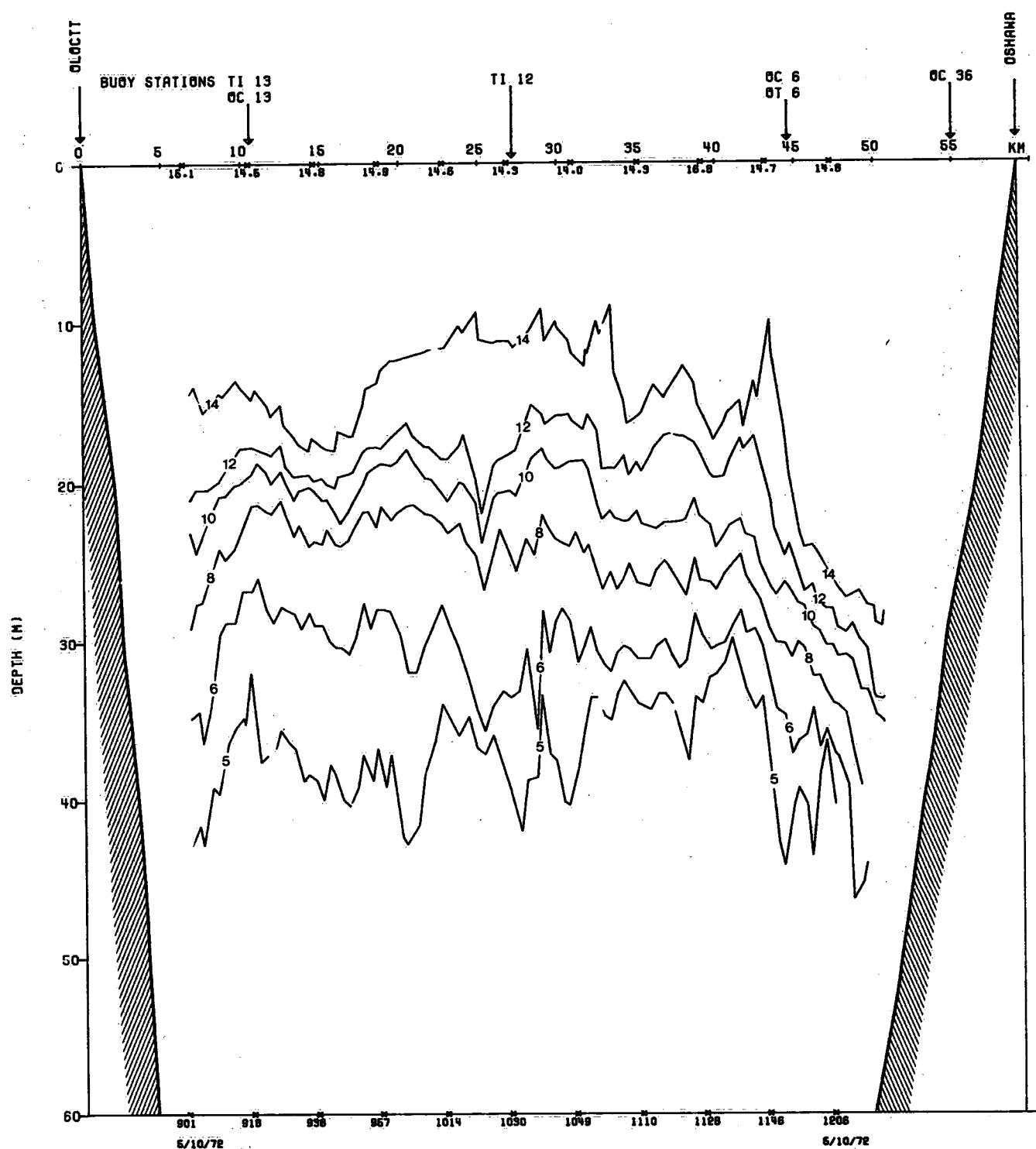
DAY (JULIAN) 279



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa, CSS Limnos

TRANSECT 17

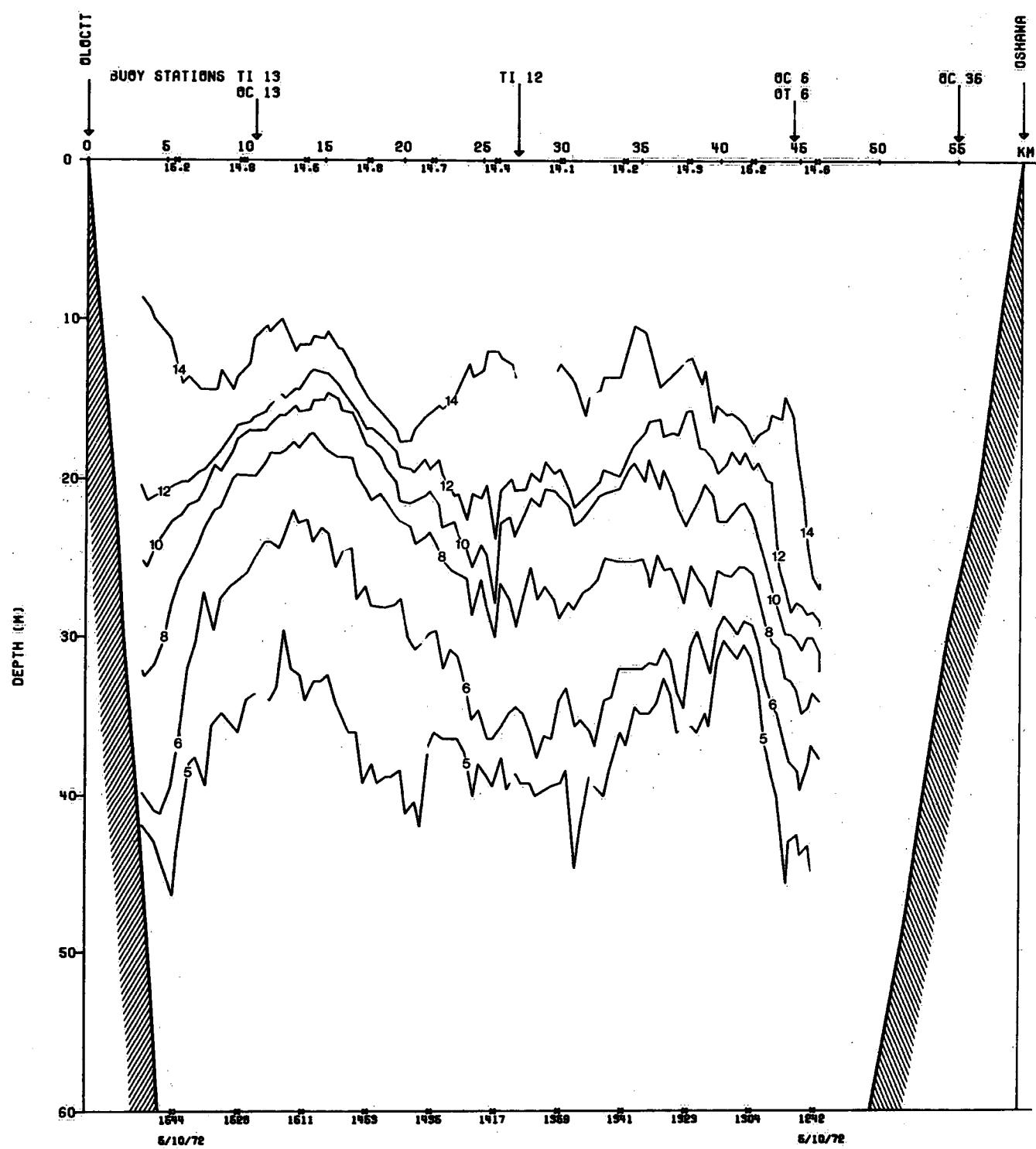
DAY (JULIAN) 279



TFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 18

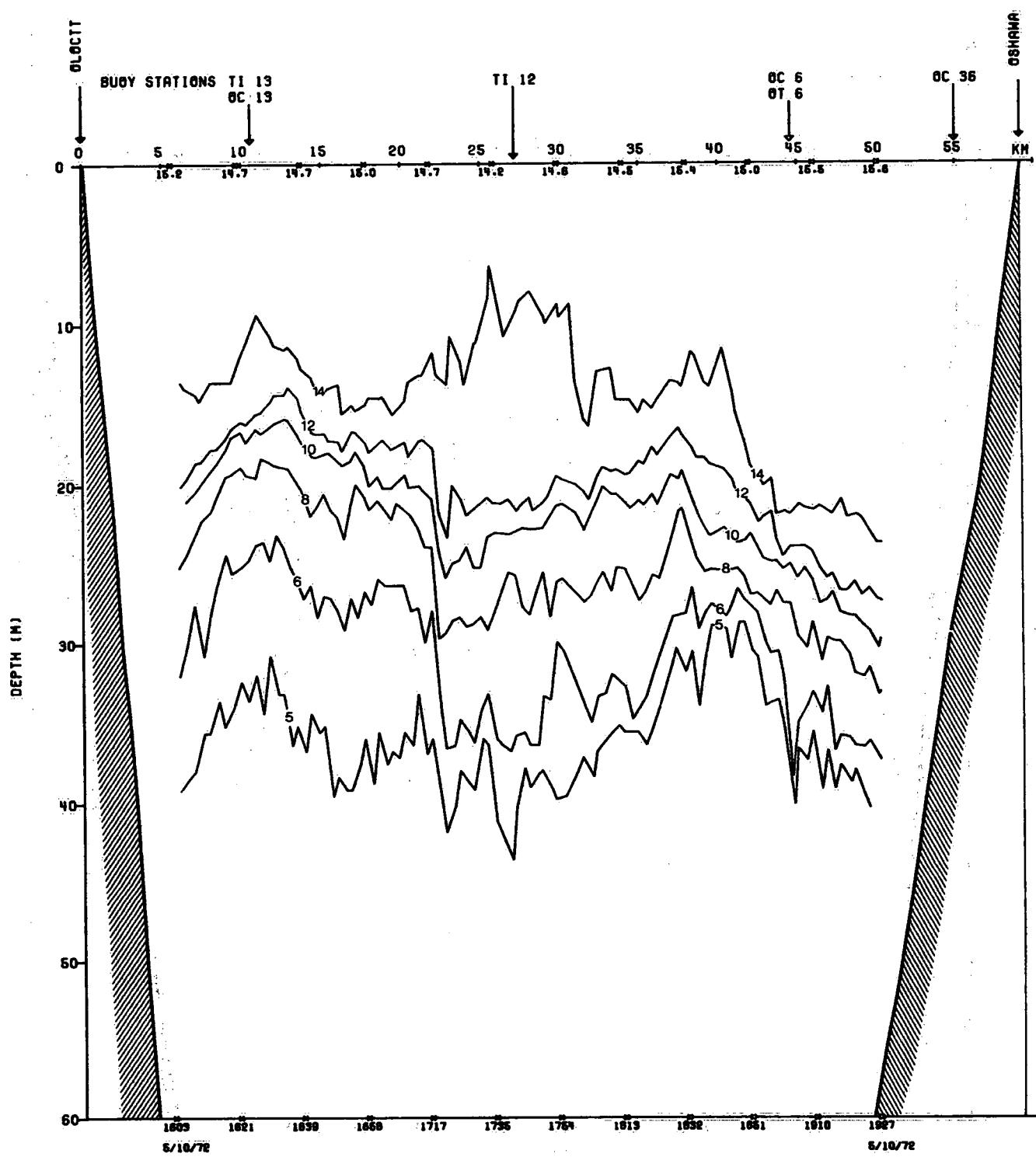
DAY (JULIAN) 279



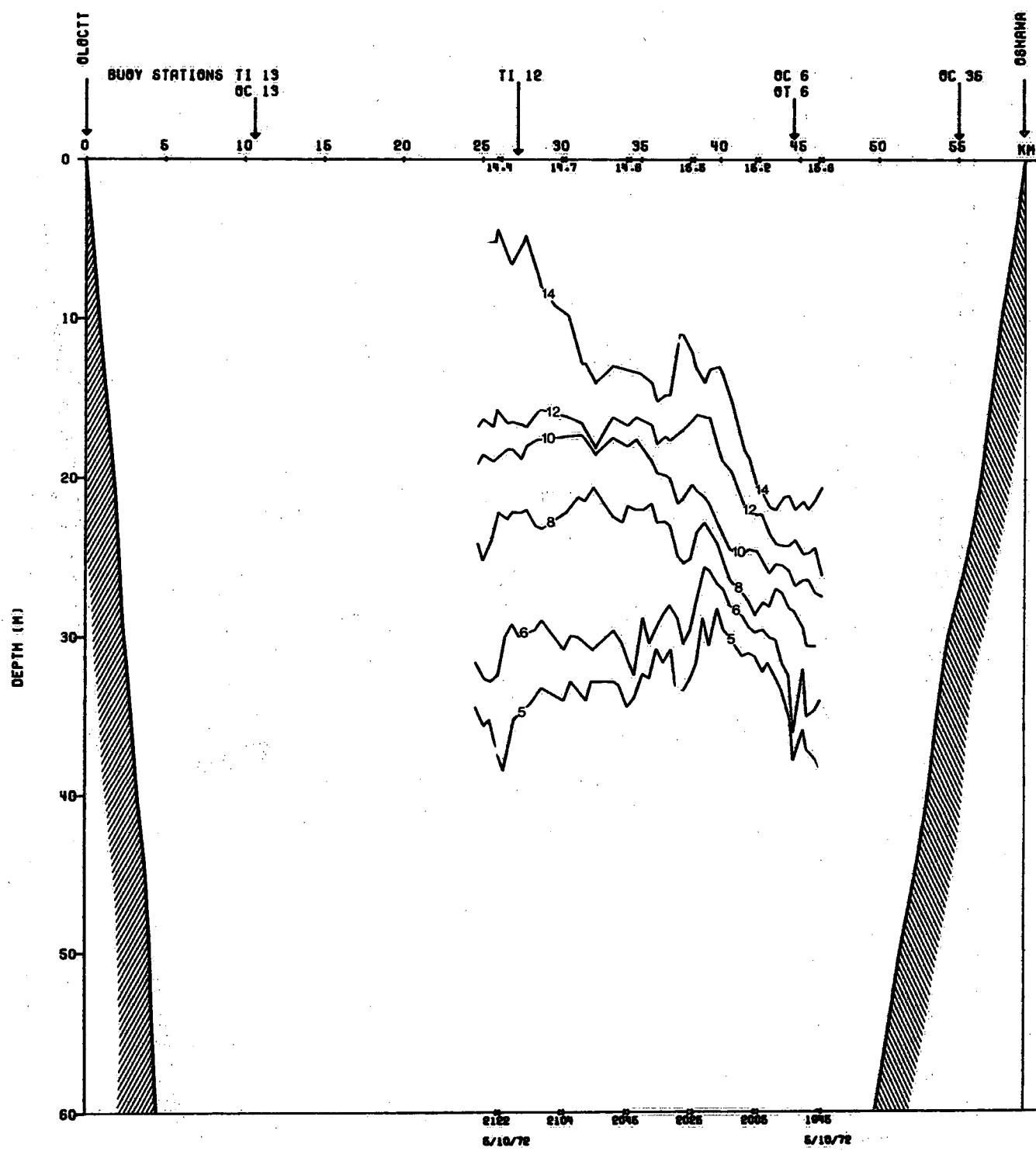
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TRANSECT 19

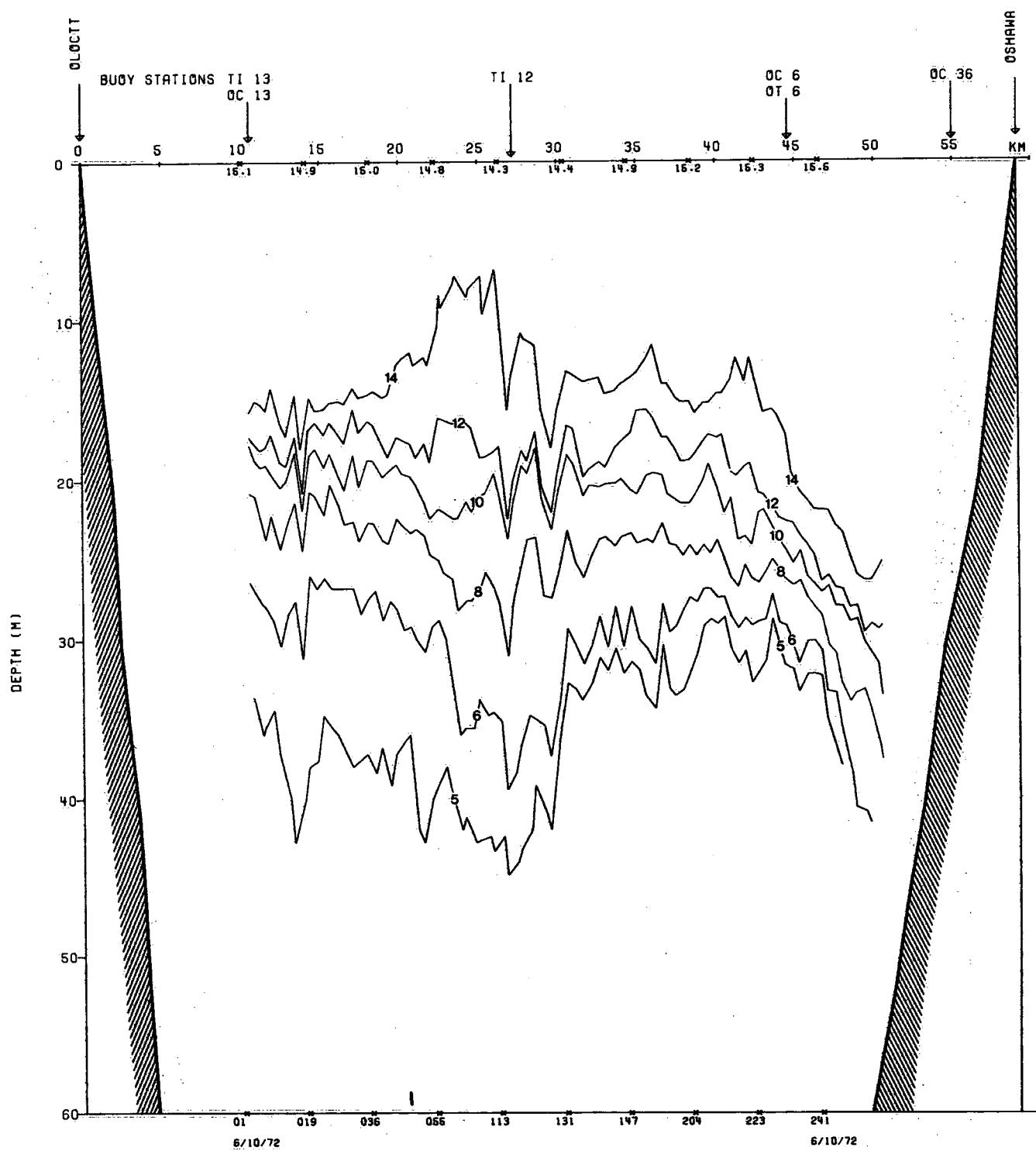
DAY (JULIAN) 279



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS  
 TRANSECT 20 DAY (JULIAN) 279



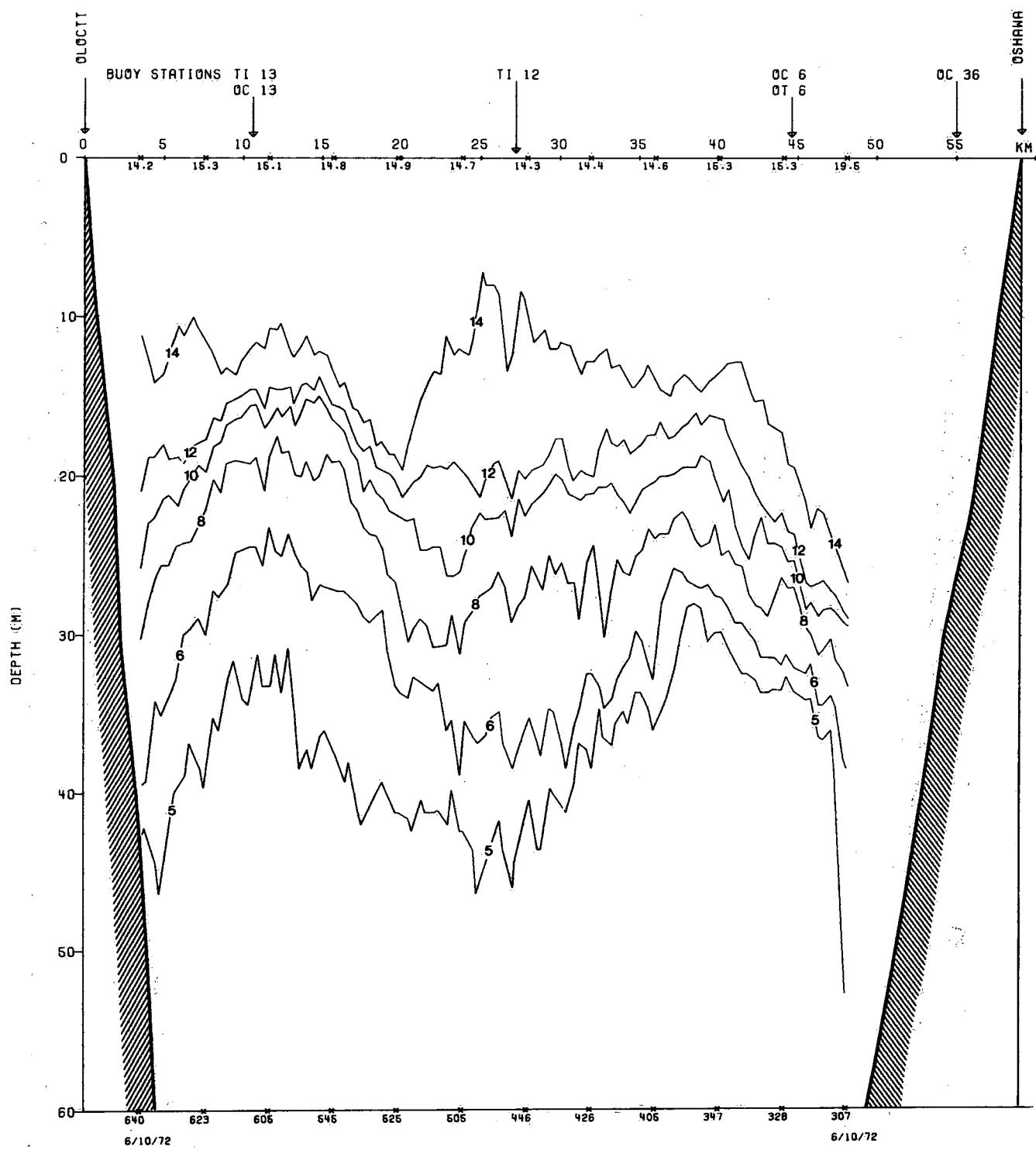
IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos  
 TRANSECT 21 DAY (JULIAN) 279 TO 280



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 22

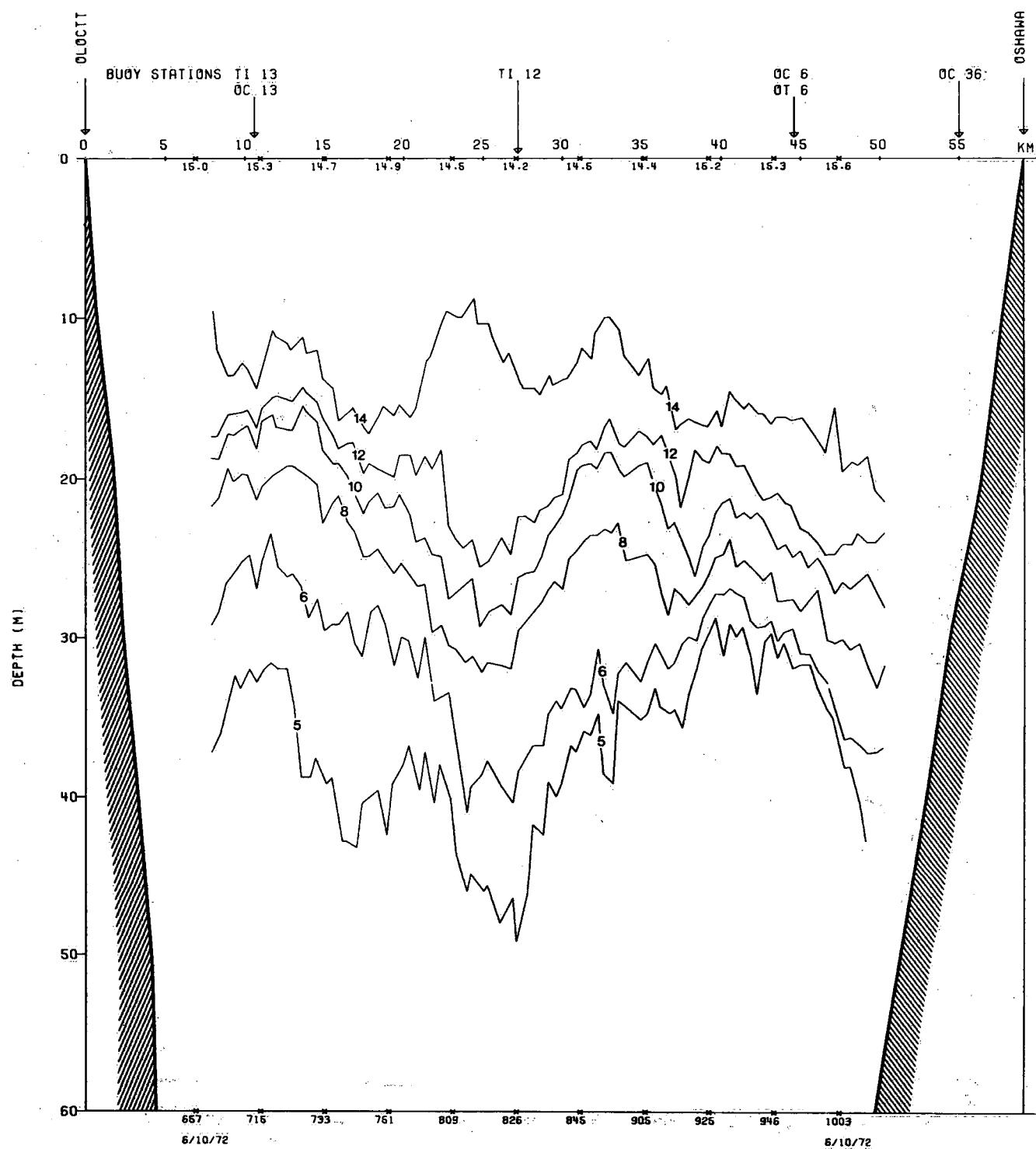
DAY (JULIAN) 280



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OLcott - Oshawa CSS Limnos

TRANSECT 23

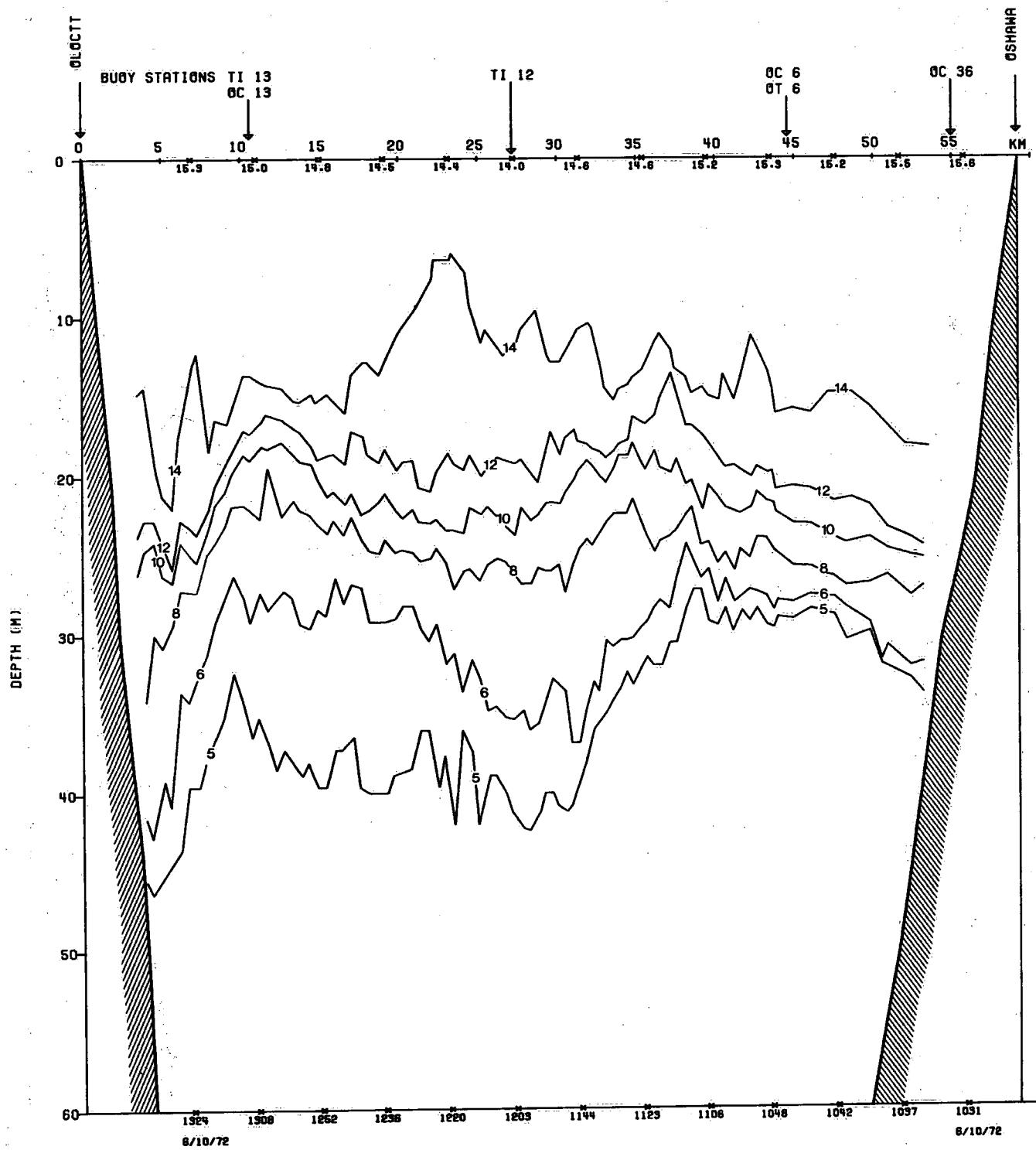
DAY (JULIAN) 280



IFYGL (LAKE ONTARIO) TEMPERATURE TRANSECT OSHAWA - OLcott CSS LIMNOS

TRANSECT 24

DAY (JULIAN) 280



# Intercomparisons of the Olcott-Oshawa Temperature Transects and Contemporary Measurements at "Coastal Chains" and Fixed Recording Stations

## 4.1. INTERPOLATED ISOTHERM DEPTHS AT STATIONS U13 AND C6-T

As planned at the outset of IFYGL, fixed recording instruments (current meters, thermographs, and thermistor chains) were moored or placed on towers along or near the temperature transect lines. The letters C and U are here used to distinguish Canadian and United States instruments, respectively. The numbers are IFYGL station numbers, not to be confused with earlier TI (Texas Instrument) numbers used for the U.S. moored stations.<sup>1</sup> For the Olcott to Oshawa transect Figure 4.1 shows two U.S. moored stations, U12 and U13, and a Canadian moored thermistor chain at C6-T. (Suffixes T and C indicate thermistor chains and current meters, respectively, at Canadian stations.)<sup>1</sup> Unfortunately, data were unavailable from U12 for any of the periods covered by the C.S.S. *Limnos* transect cruises. Water temperatures were available at 6-min intervals from the following depths at U13 during the *Limnos* cruise 2-6 October: 0, 5, 10, 15, 20, 25, 30, 35, 40, 50 and 60 m. Using an interpolation and plotting program devised by Mr. D.J. Schwab, hourly mean temperatures were computed and corresponding isotherm depths were interpolated (Fig. 4.2) for those isotherms available from station U13 during July, and are plotted here (Fig. 4.3) for the 10-14 July cruise, but for the interval 24-28 July (Fig. 4.4) coinciding with cruises on the other two transects. No information was available from U13 during the August cruise.

Also available for the 10-14 July and the 2-6 October cruises, but not for the August cruise, are interpolated isotherm depths derived from hourly averages of temperature readings every 10 min at station C6-T, a vertical chain of individual thermistors secured at the following depths in metres: 0.2, 1.0, 2.5, 5.4, 9.4, 13.4, 17.4, 21.4, 25.4, 29.3, 34.3, 39.3, 46.2, 52.4, 59.4, 59.9, 63.1, 69.9, and 73.1. The interpolated isotherm depths are plotted for 10-14 July and for 2-6 October in

Figures 4.5 and 4.6, respectively. Although interpretation is not the primary objective of this report, a comparison of Figures 4.2 and 4.6 is of interest in showing a 16- to 17-hr thermocline oscillation (internal Poincaré wave) out of phase between stations U13 and C6-T, respectively, near the south and north ends of the transect. This comparison is made in Figure 4.7.

The times at which C.S.S. *Limnos* passed stations U13 and C6-T during July and October cruises are shown by vertical lines in Figures 4.2, 4.5 and 4.6. The station positions are also marked on the transects in Chapter 3.<sup>2</sup> It is therefore possible to compare the isotherm depths interpolated from the Batfish data in the transects of Chapter 3 with the hourly mean interpolations in Figures 4.2, 4.5, and 4.6. The value of such comparisons is limited by the fact that "instantaneous" Batfish results are being compared with fixed-station results derived from hourly means.

## 4.2. TRANSECT - COASTAL CHAIN COMPARISONS

A more direct comparison is possible where the transect measurements overlap in space and time with those made from small boats occupying the buoied flag stations of the Coastal Chains at either end of the transect (Fig. 4.1). The techniques and the results of the Coastal Chain measurements are described for the Oshawa Chain by Csanady and Pade (1973) and for the Olcott Chain by Scott et al. (1973). Direct Transect - Coastal Chain coincidences, which we have defined to be within 1 km on the cross-lake scale and within 10 min in time, occurred once with the Olcott Chain (Figs. 4.8, 4.9) and five times with the Oshawa Chain (Figs. 4.10 to 4.19).

Where Transect - Coastal Chain coincidences (intercepts) occurred, isotherm depths in the corresponding portions of the Transect and Chain are compared (on differing time and depth scales) in one diagram, and the

<sup>1</sup>Note that slightly different lettering was used to label the fixed station positions on the transects presented in Chapter 3. TI is equivalent to U; OC6 is equivalent to C6-C; and OT6 is equivalent to C6-T.

<sup>2</sup>See footnote 1.

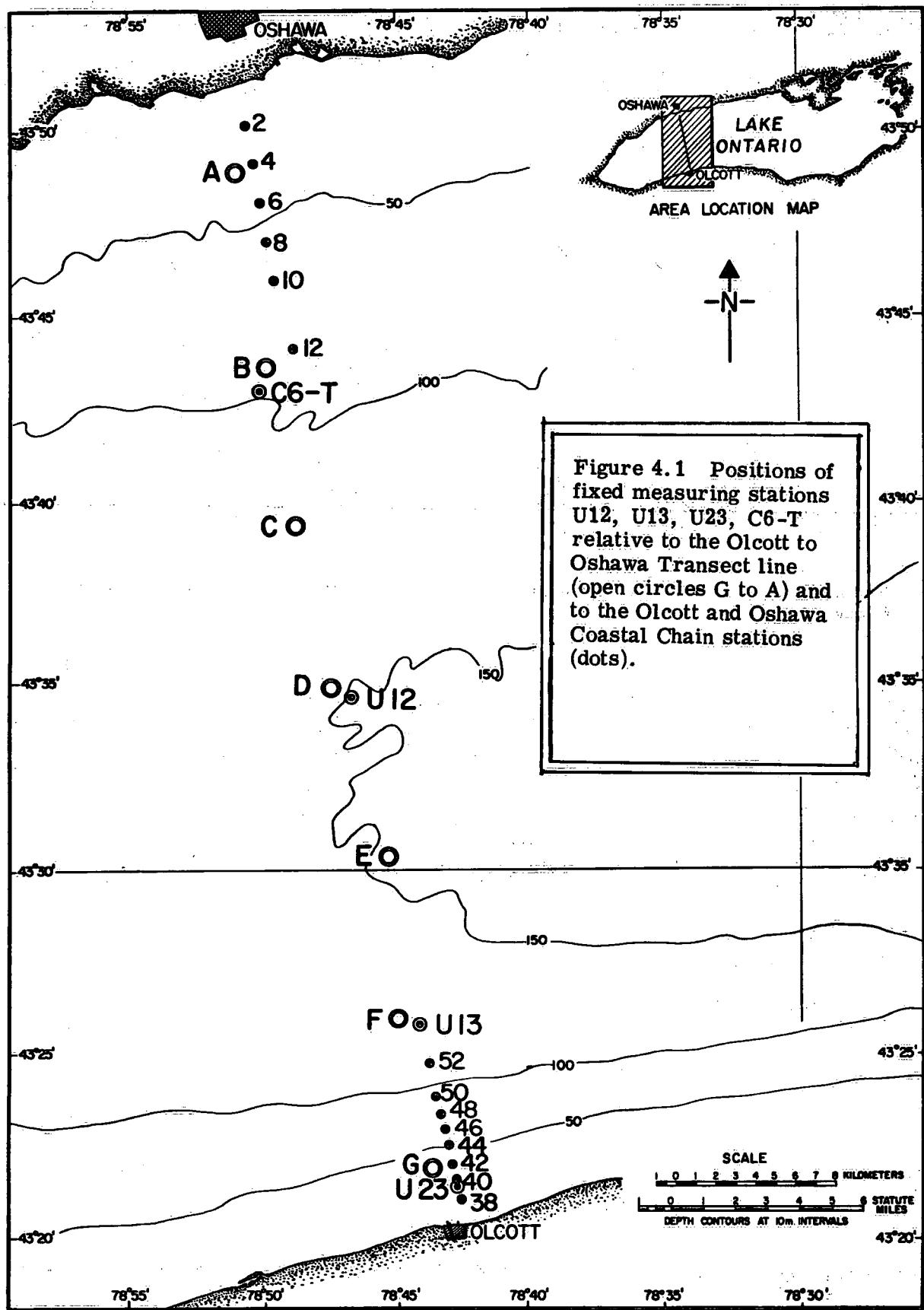
profiles derived from Transect and Chain appear on the same page. There were no intercepts during the July cruise. During the August cruise there was one intercept with the Olcott Chain (Figs. 4.8, 4.9) and three with the Oshawa Chain (figure pairs 4.10 and 4.11; 4.12 and 4.13; 4.14 and 4.15). In those cases (in this chapter and Chapters 6 and 8) for which the intercept fell near one of the Coastal Chain stations, the data from that station, as tabulated in Csanady and Pade (1973) and Scott *et al.* (1973), were used and shown as crosses in the profile comparisons. Where the intercept fell between two Chain stations, data from both stations were plotted, as paired circles, in the profile comparisons.

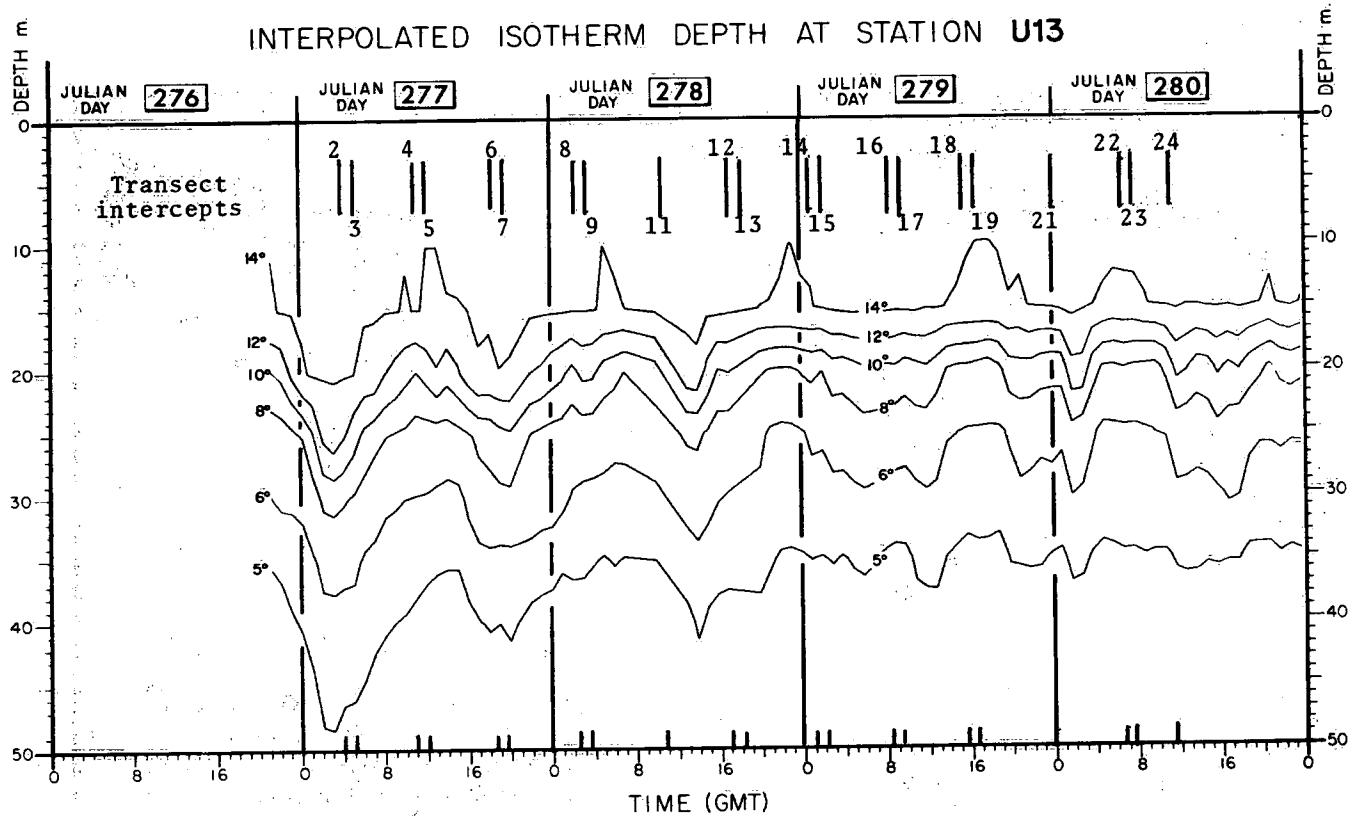
The largest difference between Transect and Chain profiles occurred at the 11 August Olcott intercept. The Transect profile ran about 3 m higher than the Chain profile in the lower part of the thermocline. Agreement at the Oshawa intercepts was much closer, generally within 1 m. The Olcott discrepancy may have arisen because of overestimation of Chain isotherm depth in a region of strong downwelling, from which strong, geostrophic

east-going currents can be inferred, a situation also noted for the Oswego Chain in Chapter 8. Under those circumstances, the cable supporting the Whitney thermometer probe may have departed sufficiently from the vertical to give rise to an overestimation of depth, particularly in the lower part of the profile. Scott *et al.* (1973) noted that the "main problem with the Whitney instrument (with which depth is estimated by length of cable payed out) is in determining sensor depth. This was difficult on rough days because it was difficult to keep the line vertical. In the thermocline region a depth error of a few metres causes a temperature difference of about a degree."

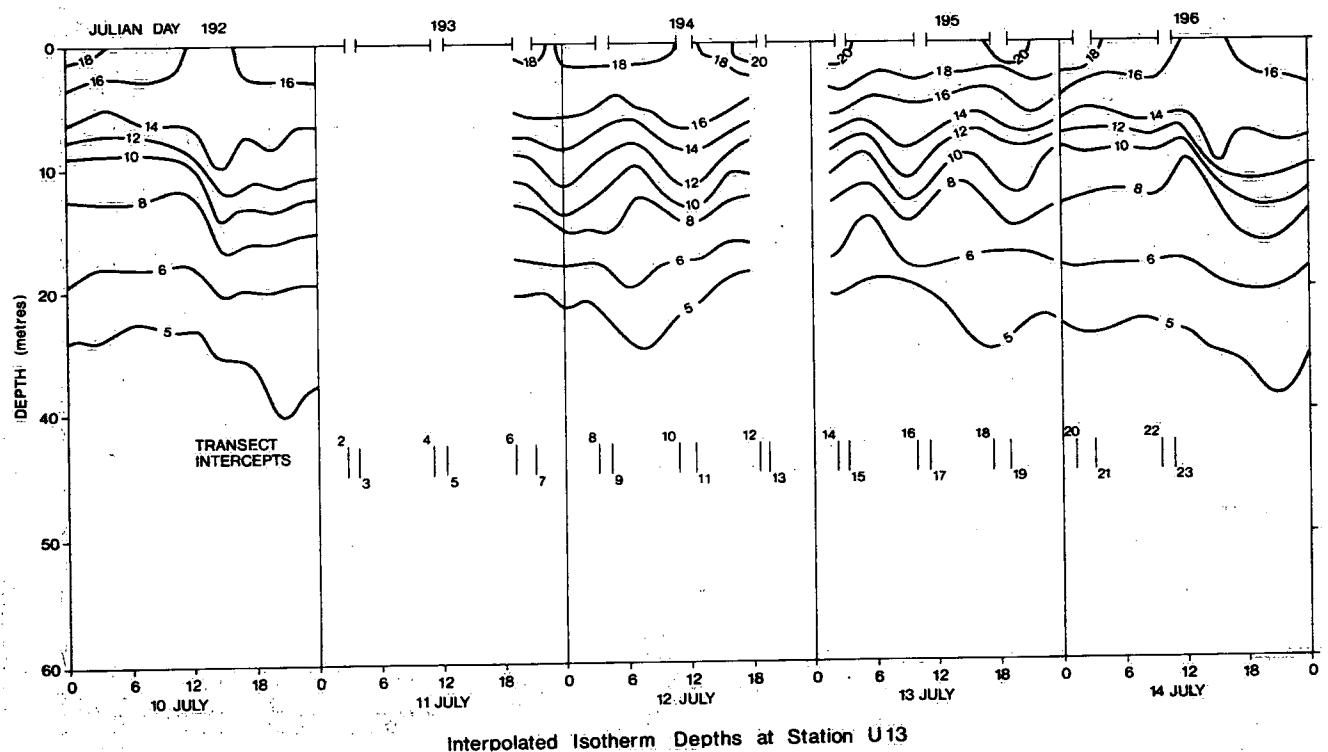
#### 4.3. ADDITIONAL INFORMATION FROM COASTAL CHAINS

The Chain surveys for August and October (Figs. 4.20 to 4.41) provide useful information on isotherm distribution near shore, supplementing and extending the transect diagrams, even when direct coincidences may have been missed by as much as 2 hr.





**Figure 4.2.** Isotherm depths at station U13, Lake Ontario, 2-6 October 1972, interpolated from hourly averaged temperatures at depths listed in section 4.1.



**Figure 4.3.** Isotherm depths at station U13, Lake Ontario, 10-14 July 1972, interpolated from hourly averaged temperatures at depths listed in section 4.1.

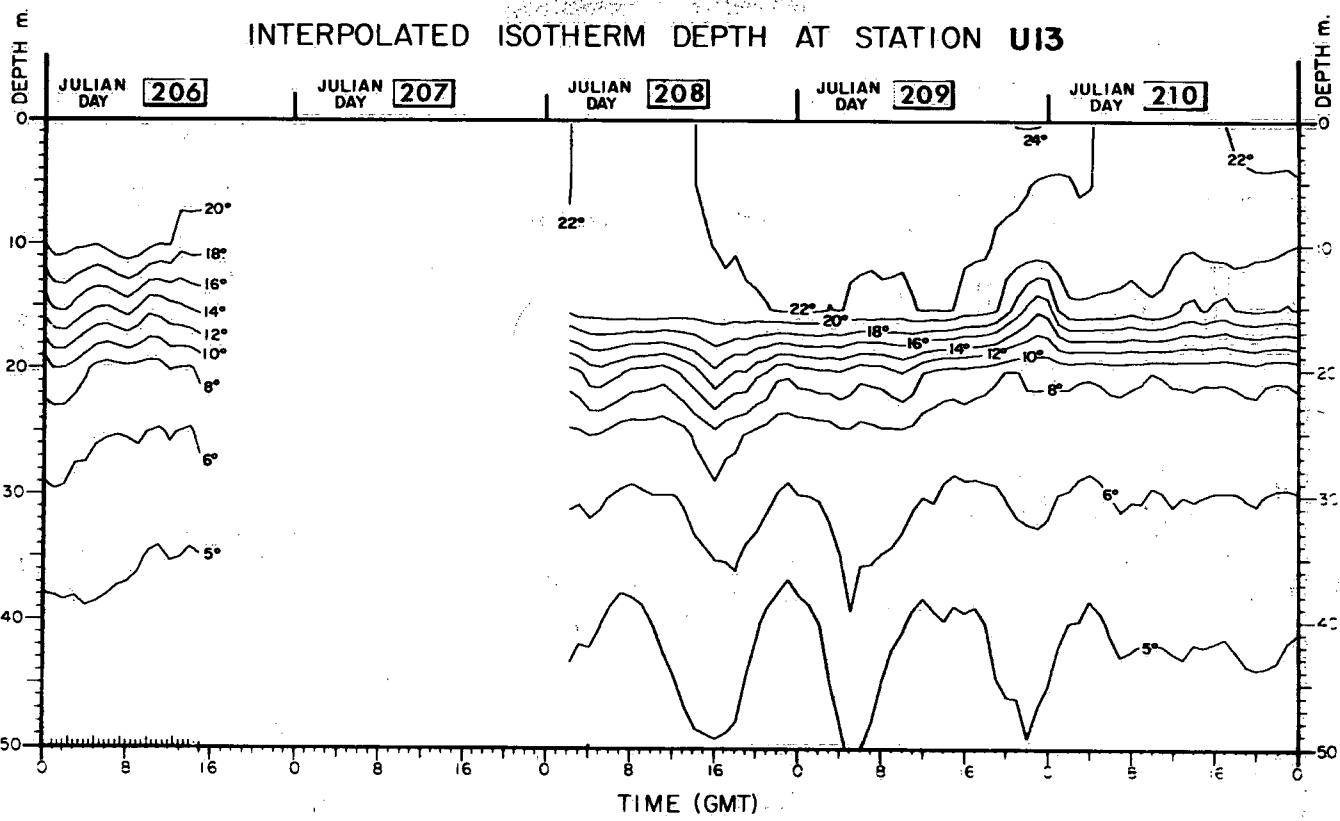


Figure 4.4. Isotherm depths at station U13, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in section 4.1.

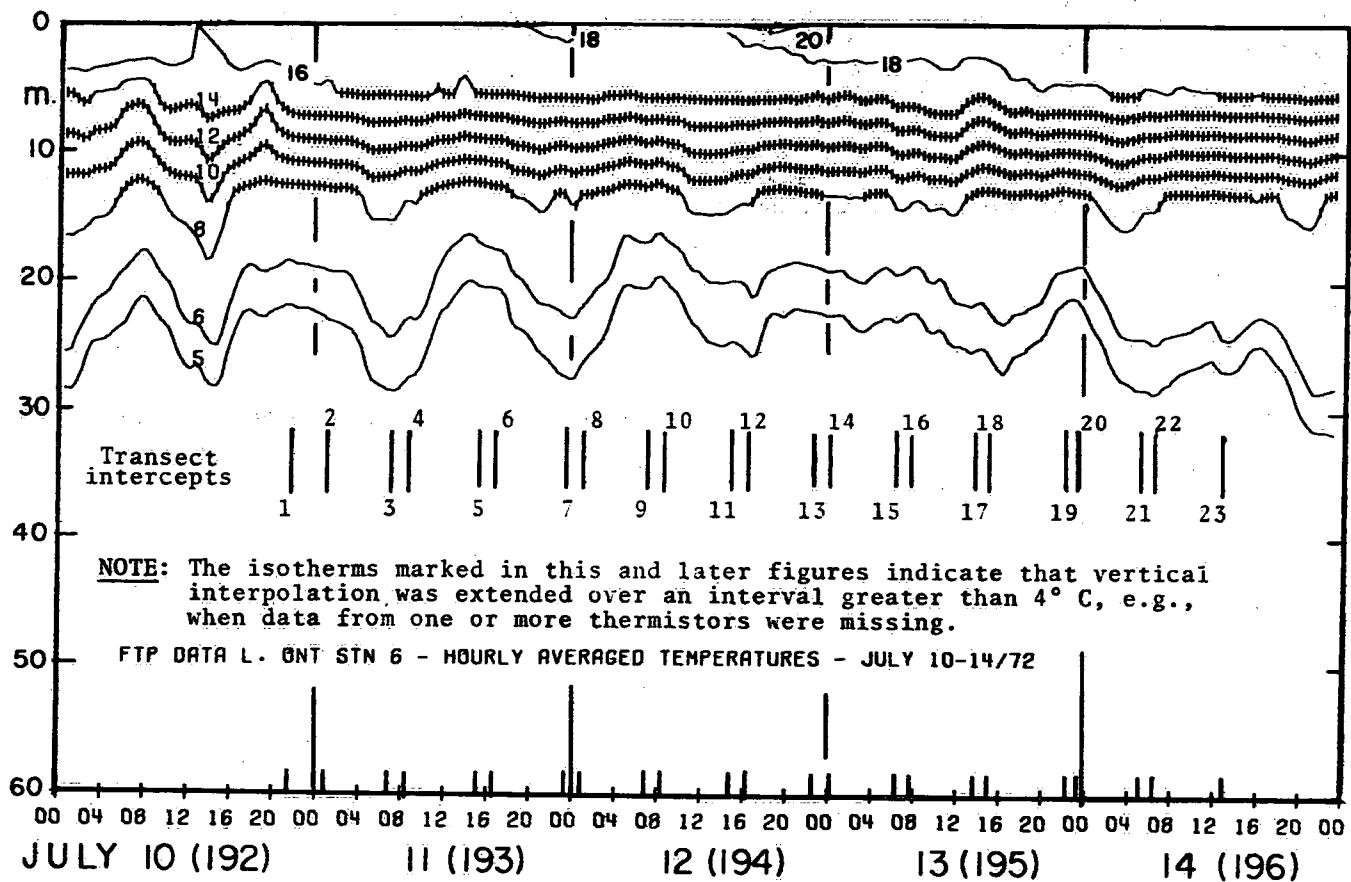


Figure 4.5. Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C6-T, Lake Ontario, 10-14 July 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained above.

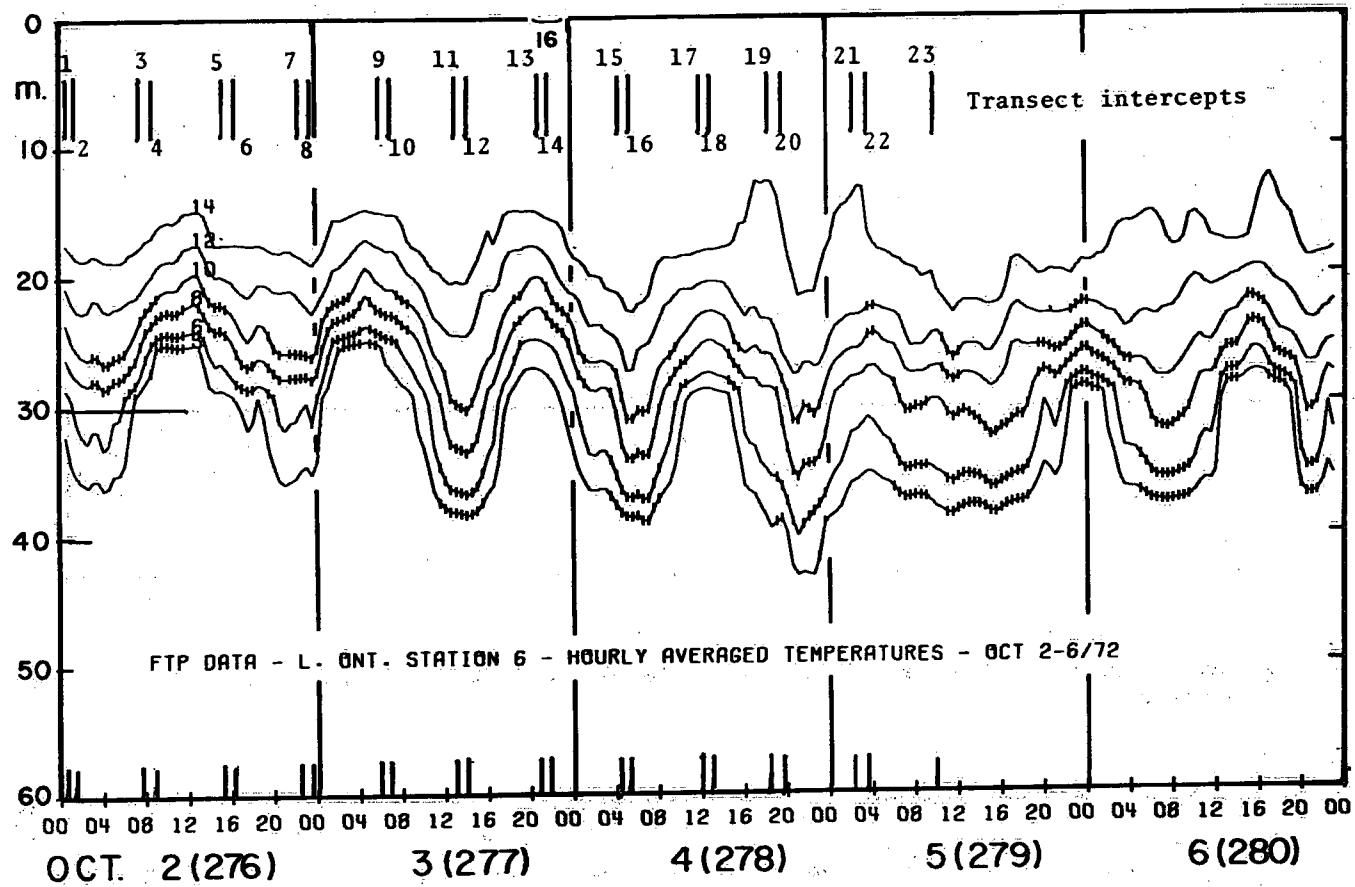


Figure 4.6. Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C6-T, Lake Ontario, 2-6 October 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.4.

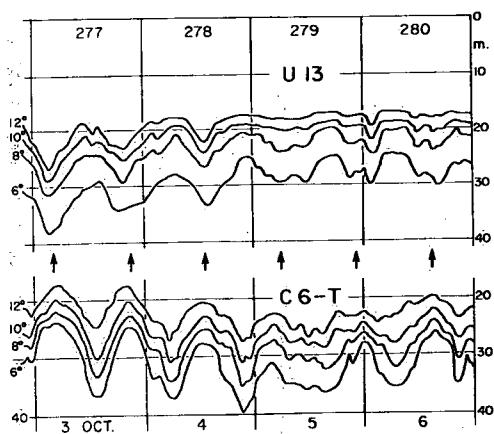
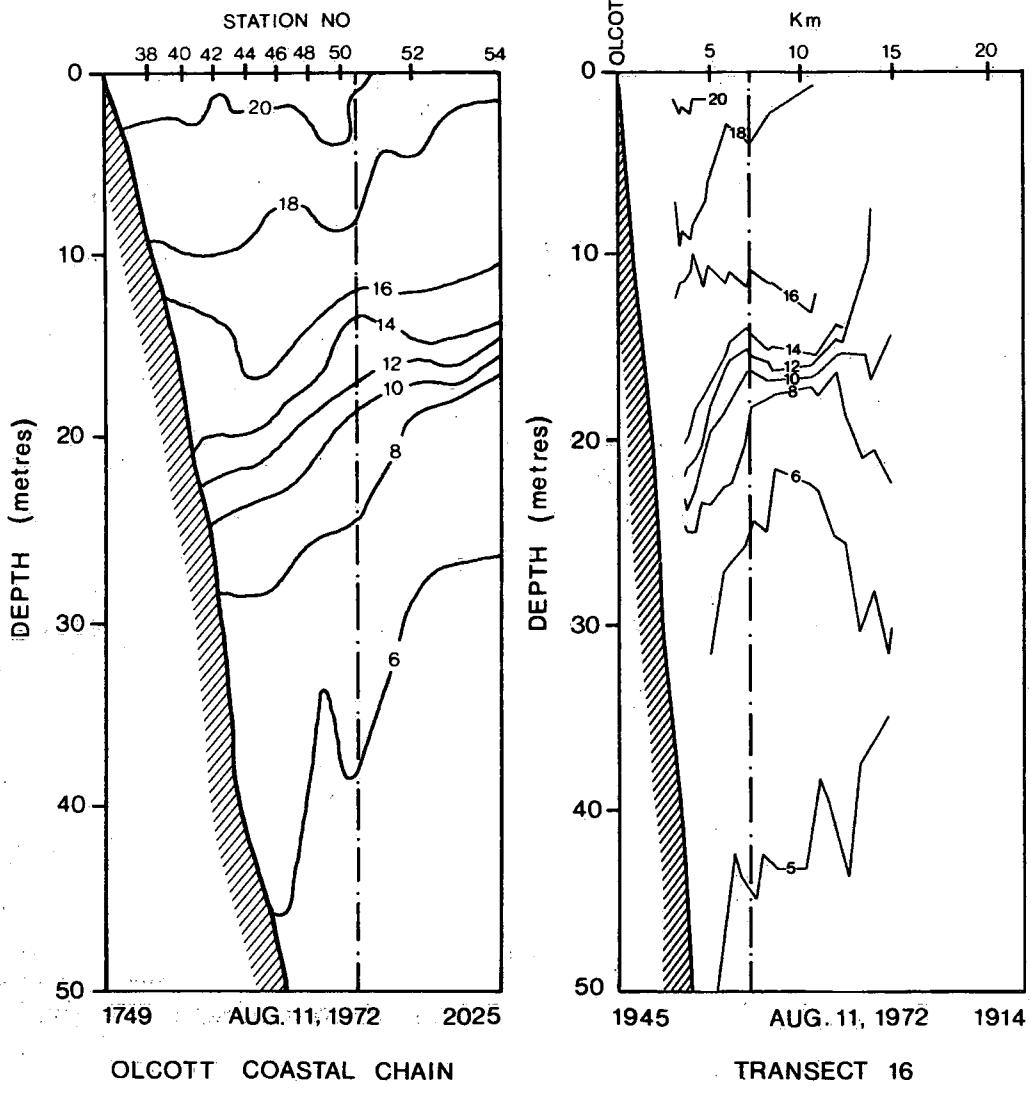
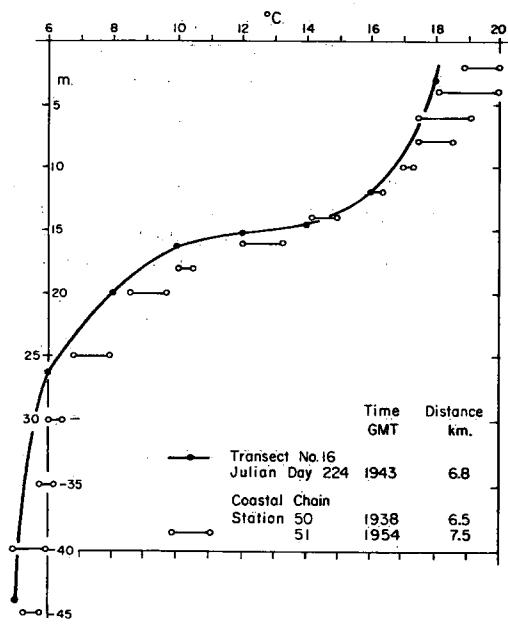


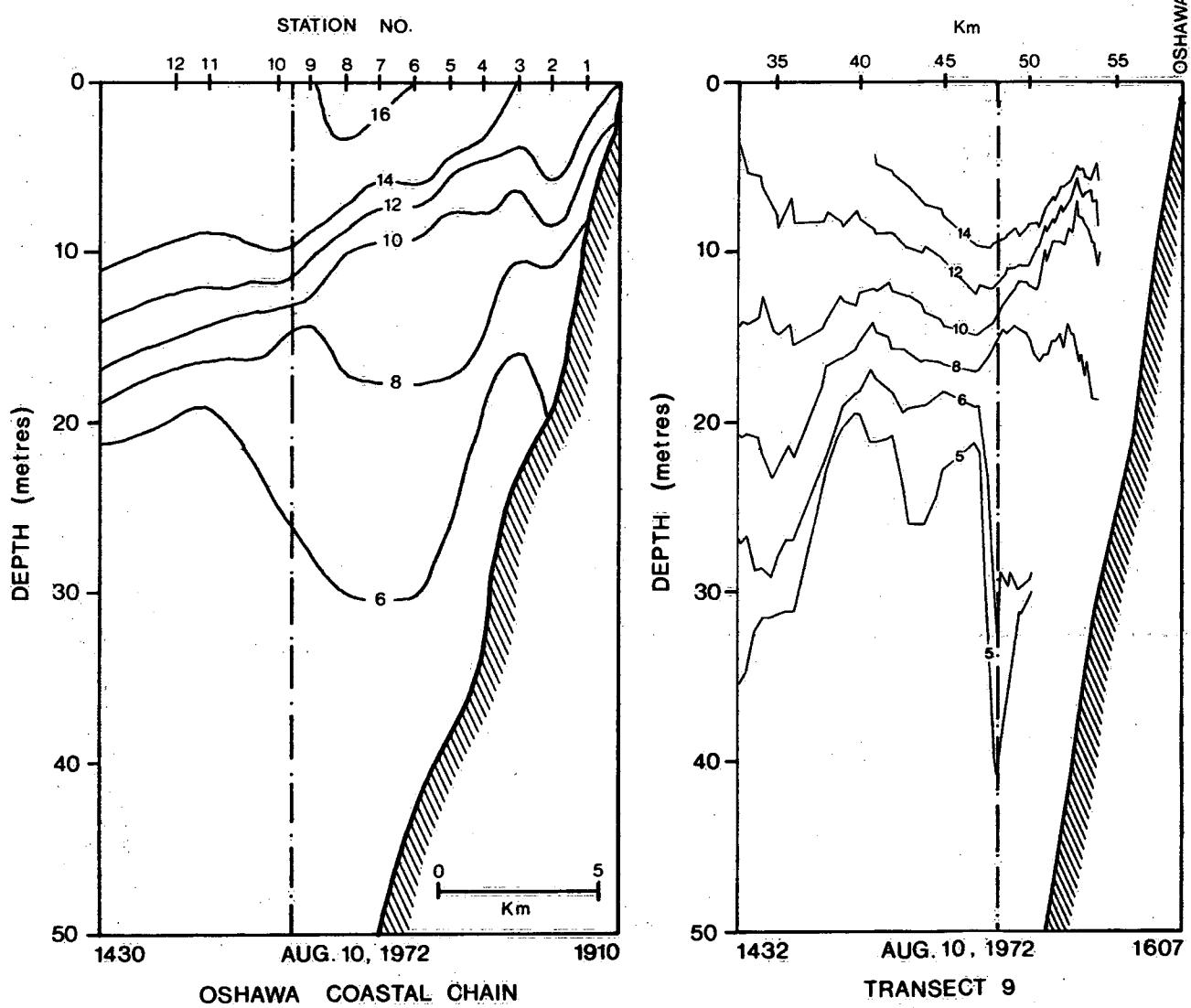
Figure 4.7. Comparison of isotherm depths at stations U13 and C6-T, Lake Ontario, 3-6 October 1972. The vertical arrows are placed at 16.5-hr intervals.



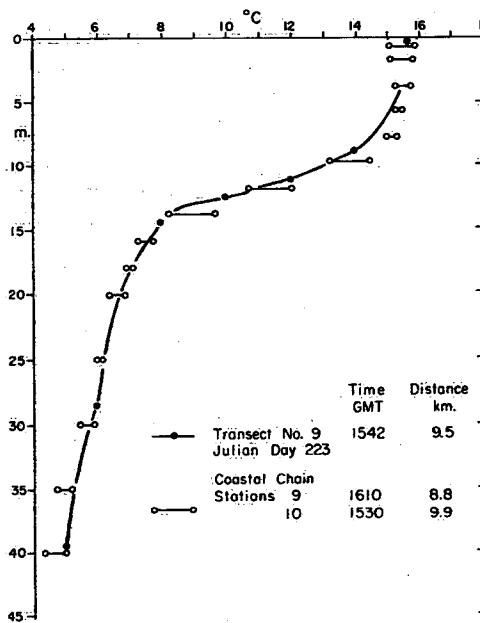
↑ Figure 4.8. Isotherm depths in the Olcott Coastal Chain section, 11 August (Julian day 224), and in the contemporary Transect 16. The coincidence point is shown, in each section, by a vertical broken line.



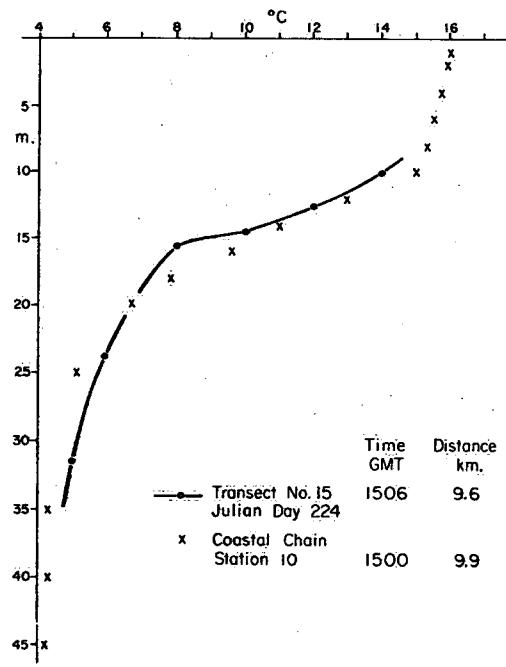
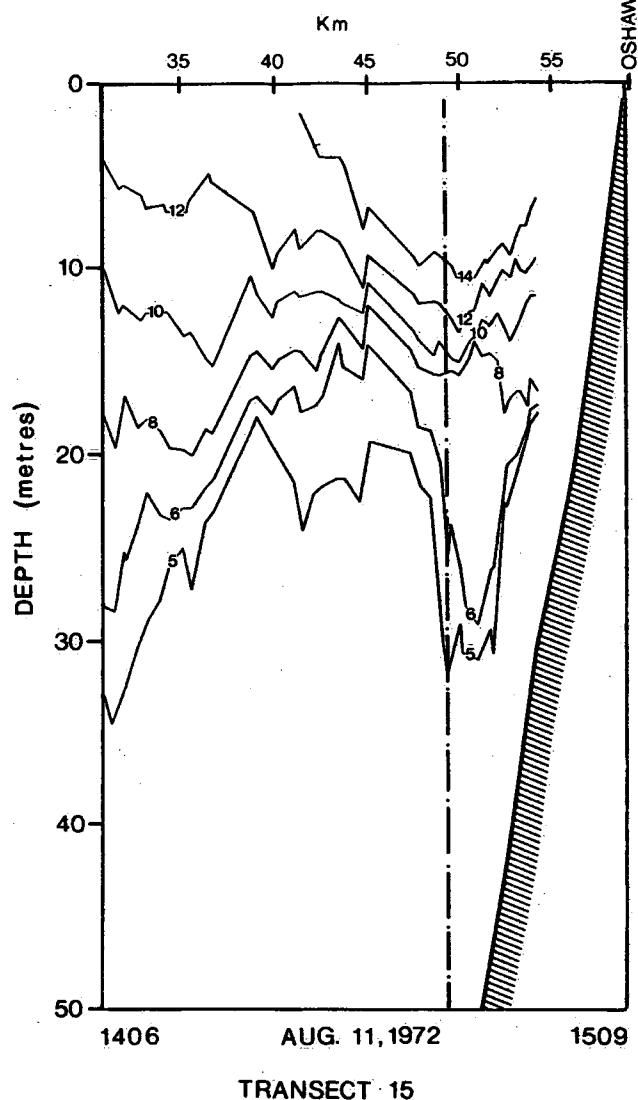
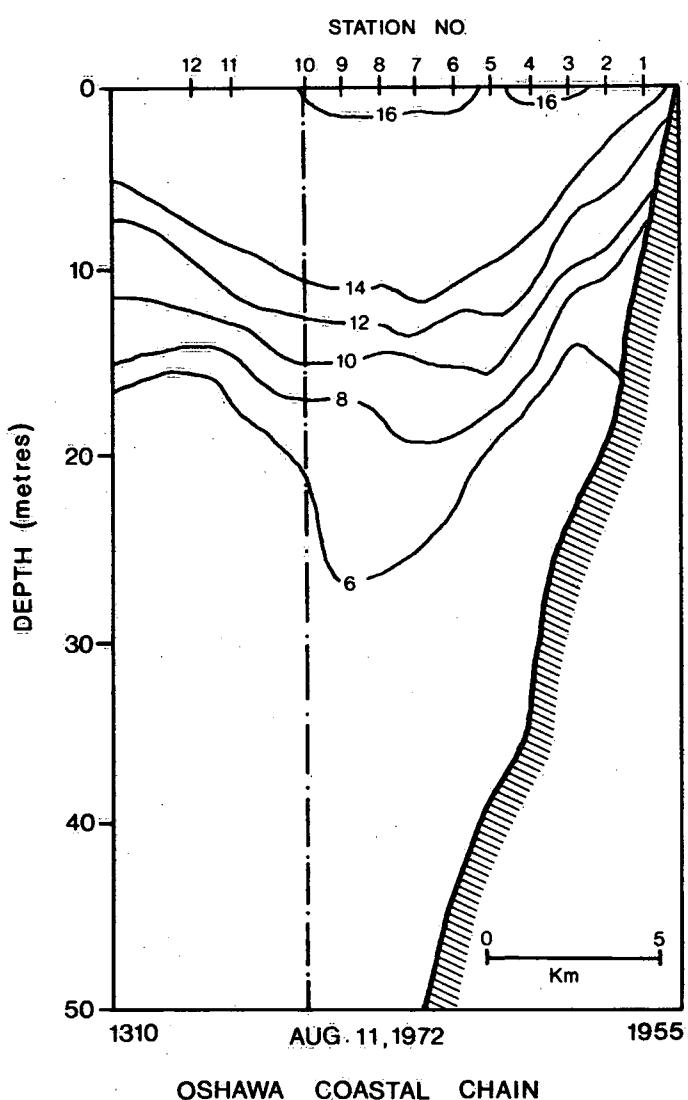
← Figure 4.9. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 16, 11 August, and from the two stations in Olcott Coastal Chain, at the indicated times and distances from shore (see Fig. 4.8).



↑Figure 4.10. Isotherm depths in the Oshawa Coastal Chain section, 10 August (Julian day 223), and in the contemporary Transect 9. The coincidence point is shown, in each section, by a vertical broken line.

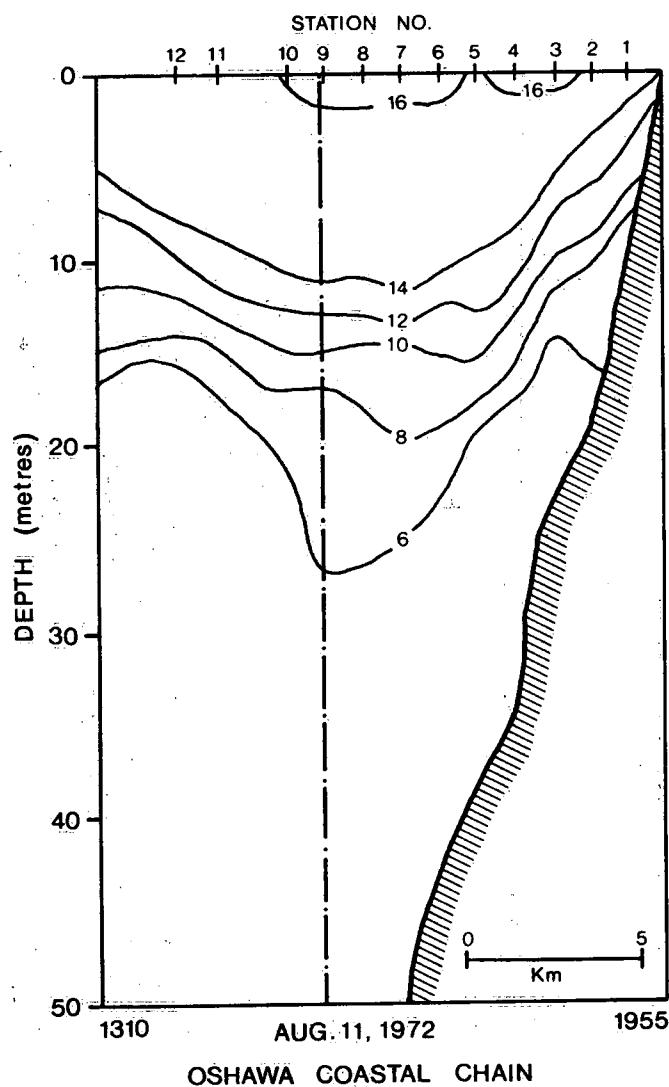


↑Figure 4.11. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 9, 10 August, and from two stations in the Oshawa Coastal Chain, at the indicated times and distances from shore (see Fig. 4.10).

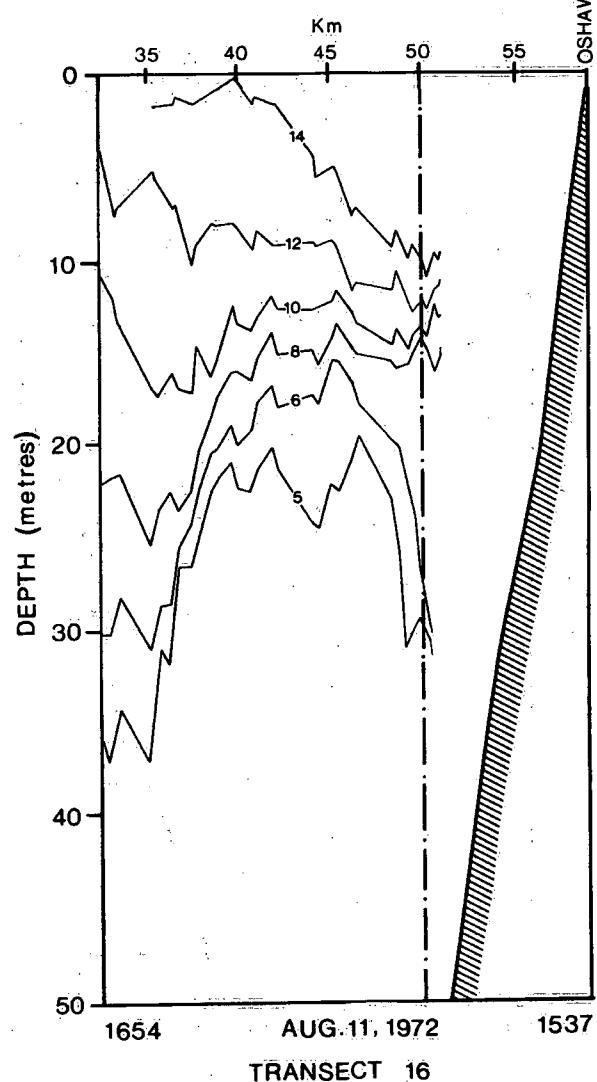


↑ Figure 4.12. Isotherm depths in the Oshawa Coastal Chain section, 11 August (Julian day 224), and in the contemporary Transect 15. The coincidence point is shown, in each section, by a vertical broken line.

↔ Figure 4.13. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 15, 11 August, and from the Oshawa Coastal Chain, at the indicated times and distances from shore (see Fig. 4.12).

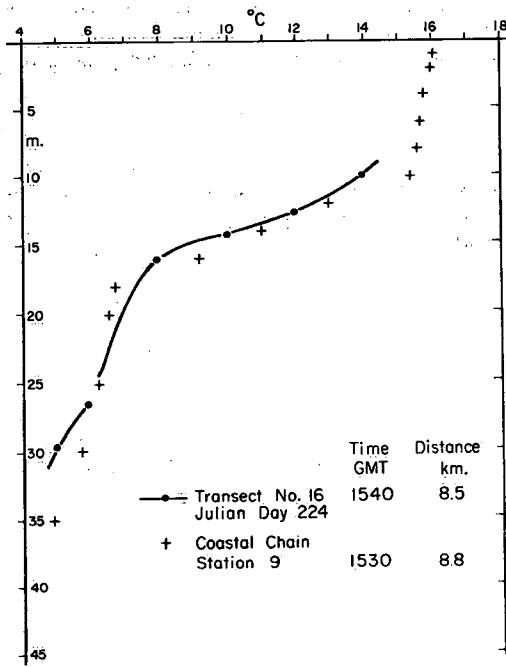


OSHAWA COASTAL CHAIN

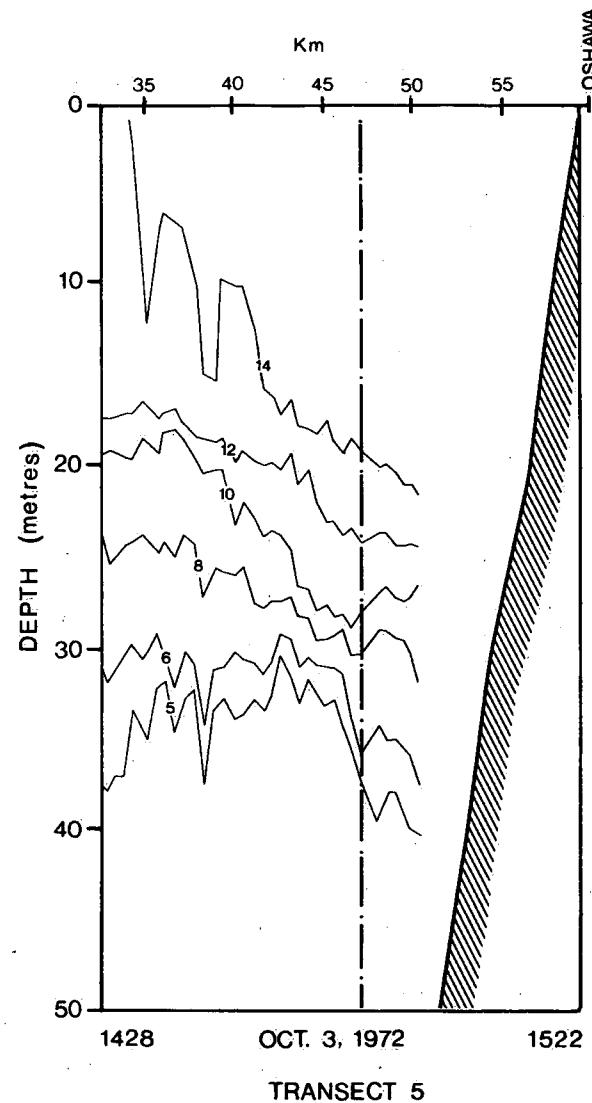
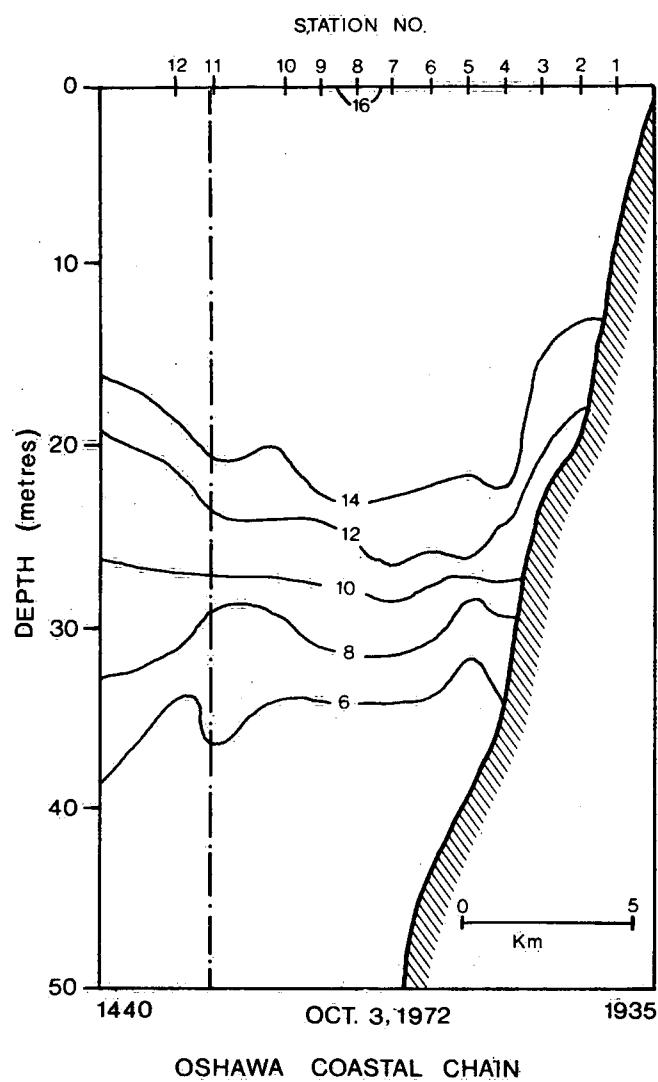


TRANSECT 16

↑ Figure 4.14. Isotherm depths in the Oshawa Coastal Chain section, 11 August (Julian day 224), and in the contemporary Transect 16. The coincidence point is shown, in each section, by a vertical broken line.

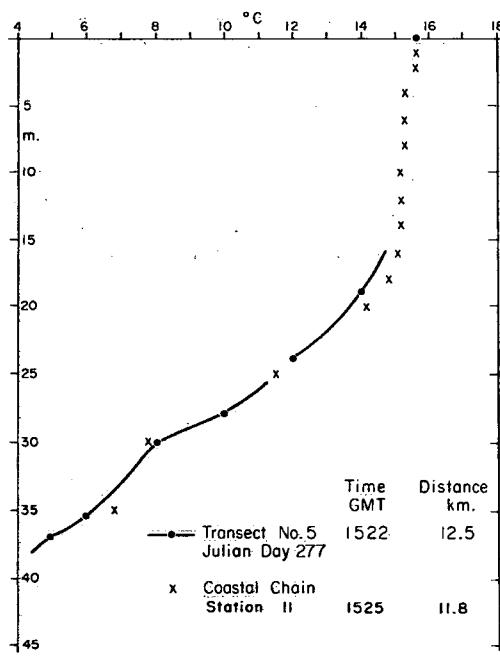


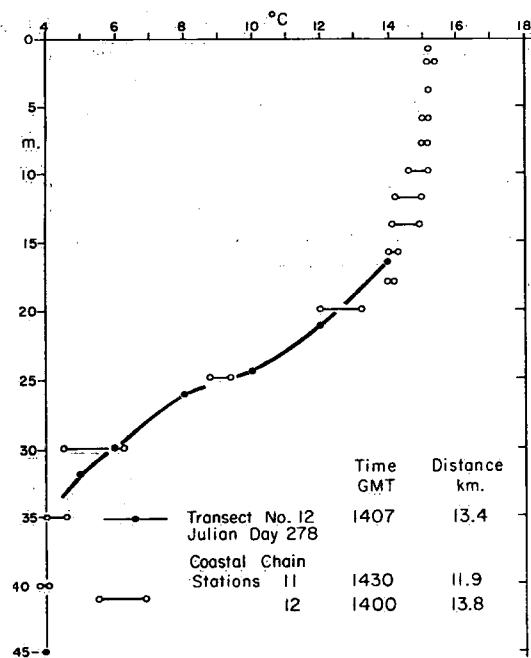
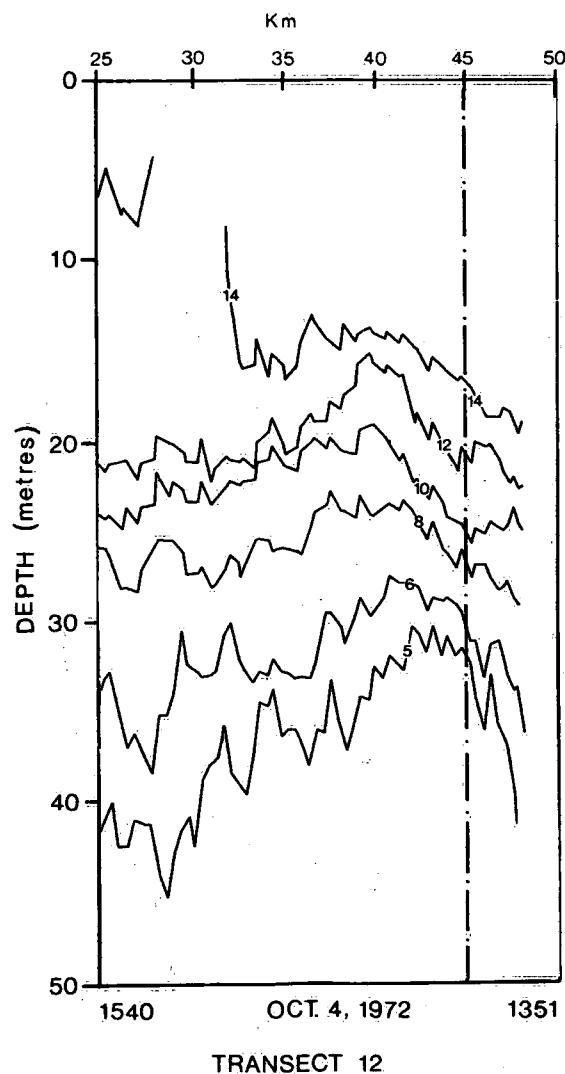
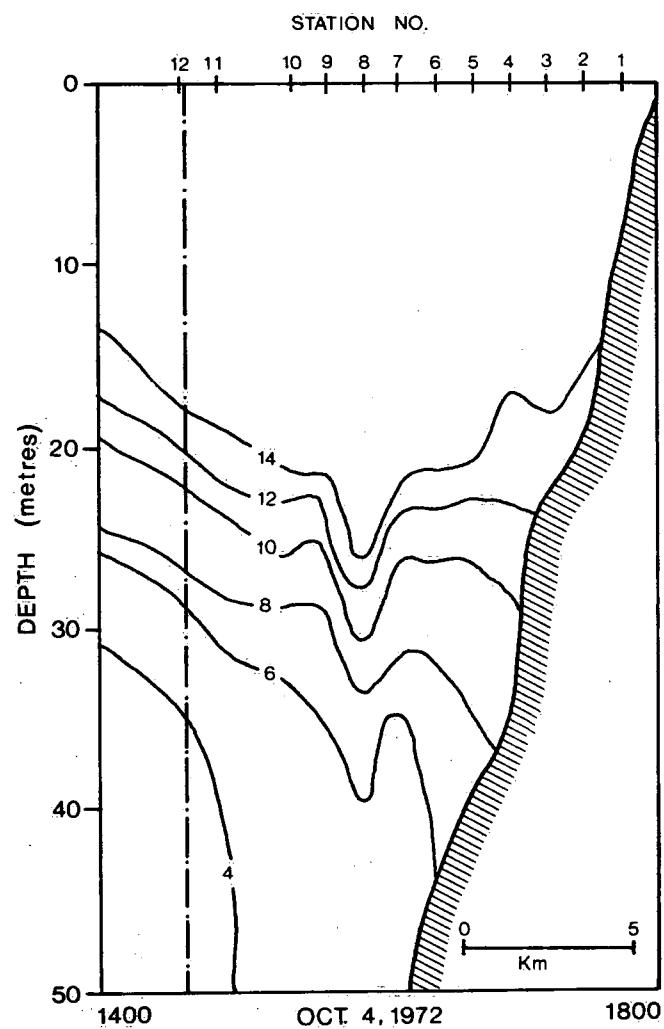
← Figure 4.15. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 16, 11 August, and from the Oshawa Coastal Chain, at the indicated times and distances from shore (see Fig. 4.14).



↑ Figure 4.16. Isotherm depths in the Oshawa Coastal Chain section, 3 October (Julian day 277), and in the contemporary Transect 5. The coincidence point is shown, in each section, by a vertical broken line.

← Figure 4.17. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 5, 3 October, and from the Oshawa Coastal Chain, at the indicated times and distances from shore (see Fig. 4.16).





↑ Figure 4.18. Isotherm depths in the Oshawa Coastal Chain section, 4 October (Julian day 278), and in the contemporary Transect 12. The coincidence point is shown, in each section, by a vertical broken line.

← Figure 4.19. Comparison of "coincident" temperature profiles, derived from C.S.S. *Limnos* Transect 12, 4 October, and from two stations in the Oshawa Coastal Chain, at the indicated times and distances from shore (see Fig. 4.18).

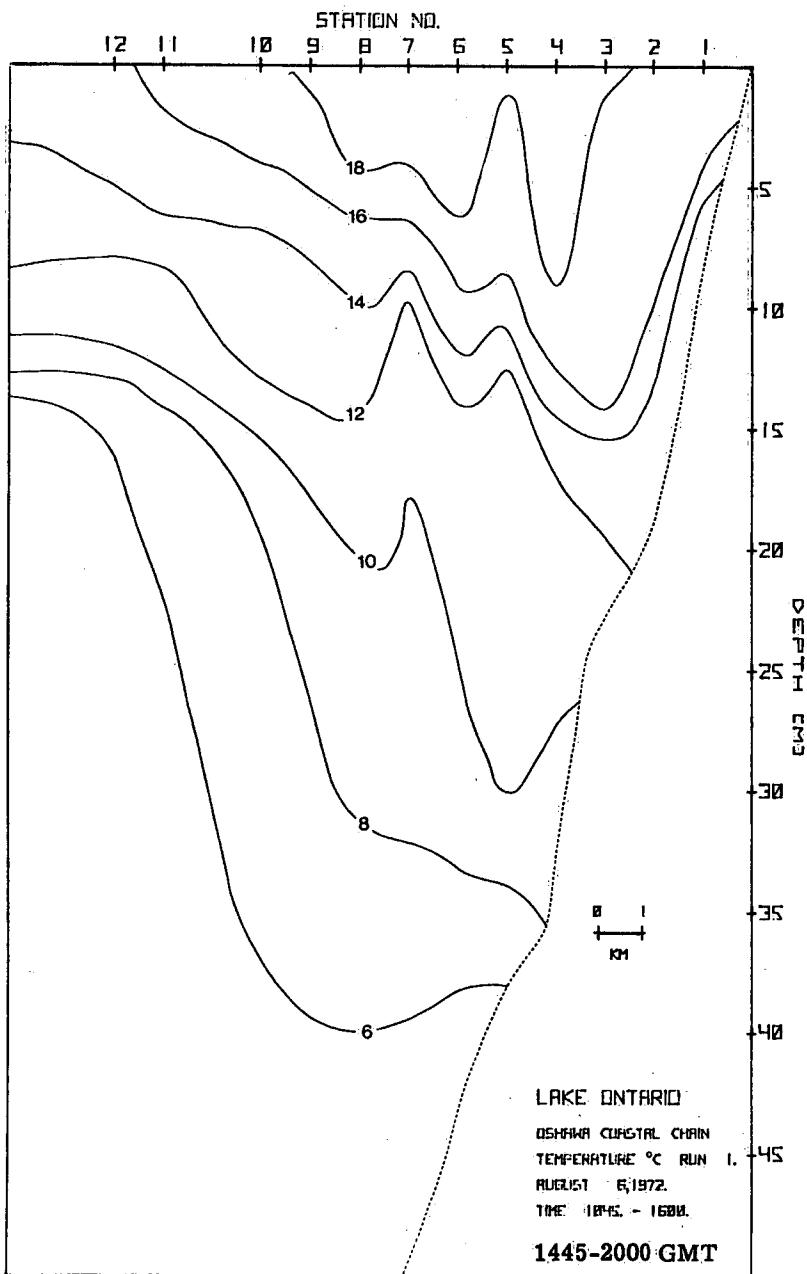


Figure 4.20. Isotherm depths in the Oshawa Coastal Chain section, 6 August (Julian day 219).

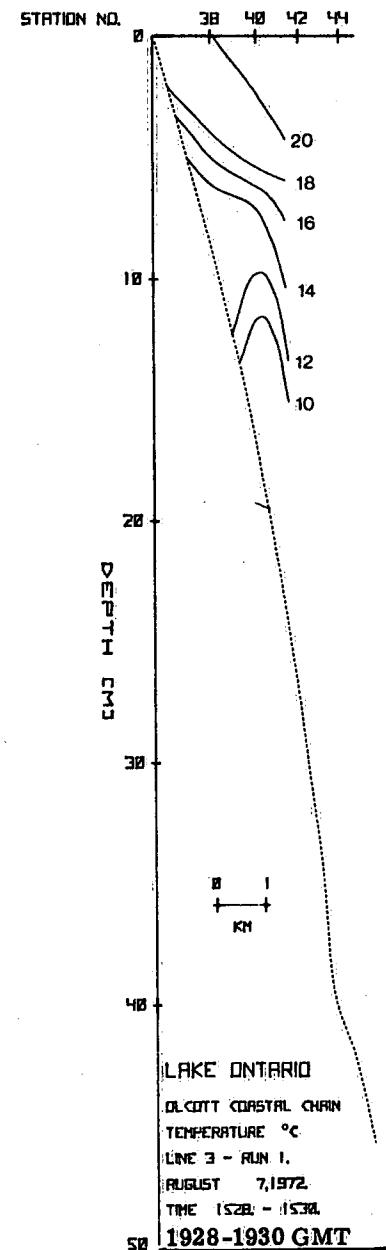
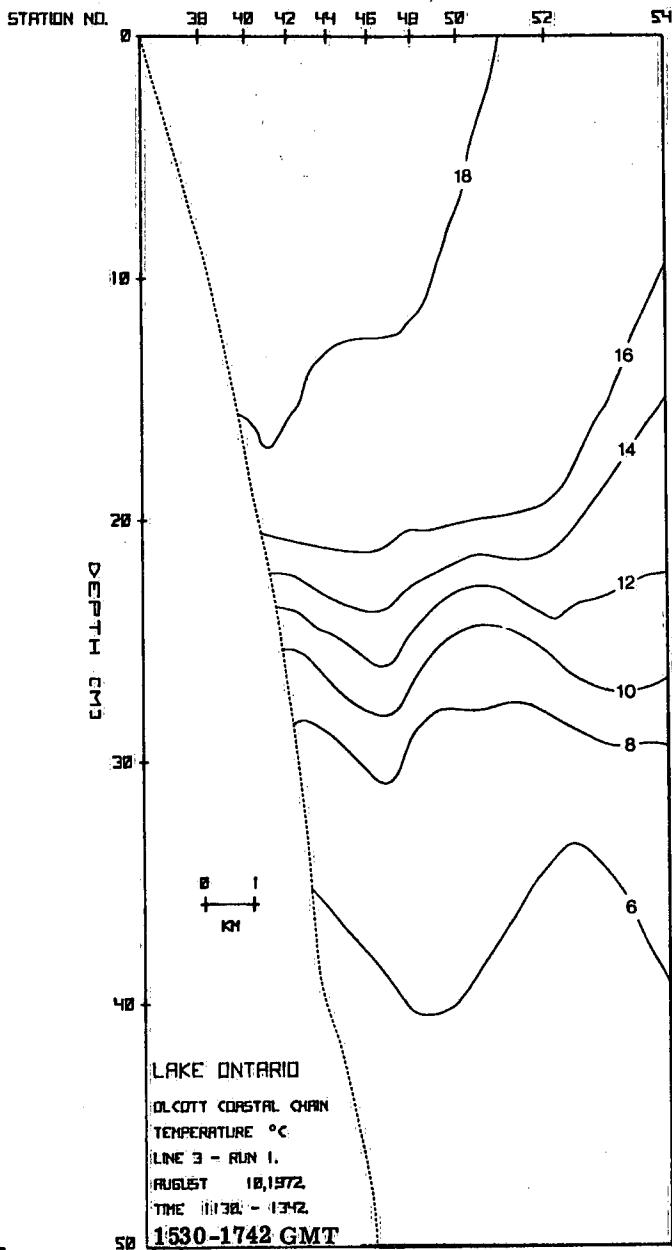


Figure 4.21. Isotherm depths in the Olcott Coastal Chain section, 7 and 10 August (Julian days 220, 223). Compare Fig. 4.20.



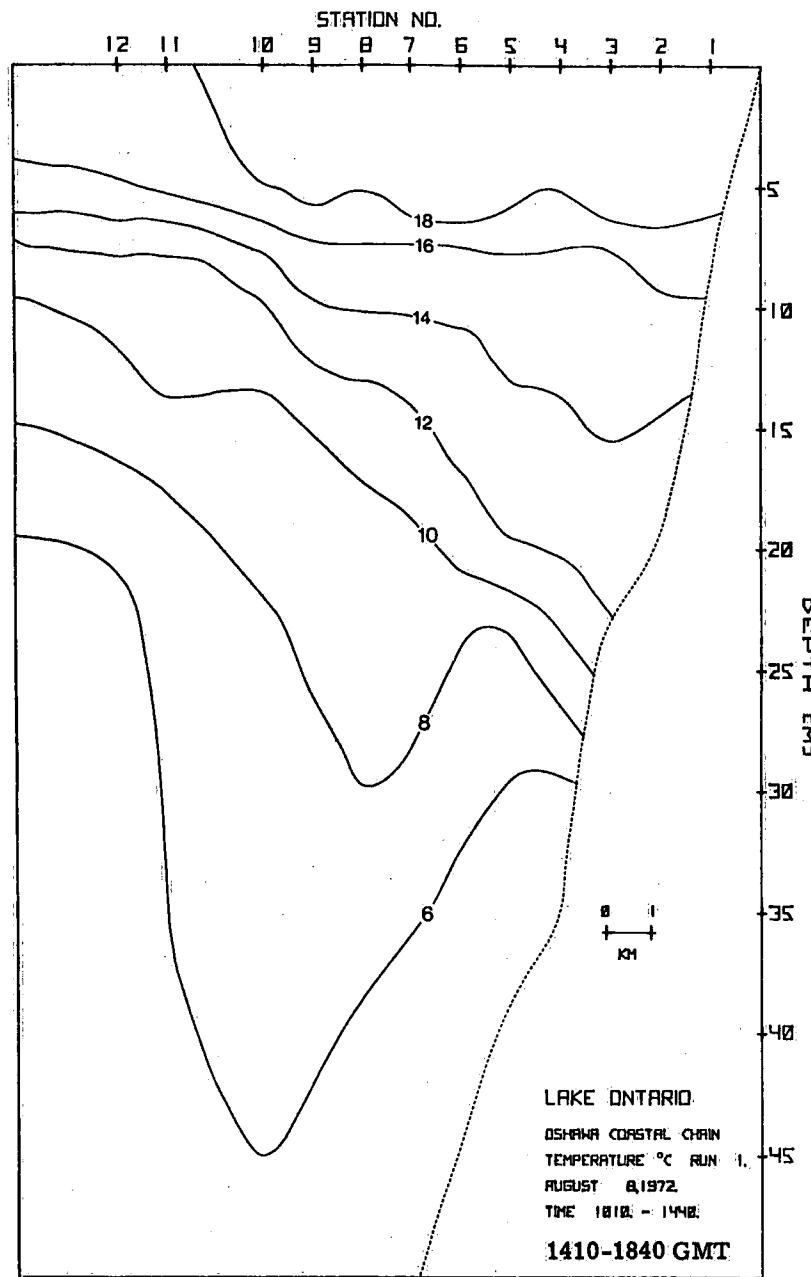


Figure 4.22. Isotherm depths in the Oshawa Coastal Chain section, 8 August (Julian day 221).

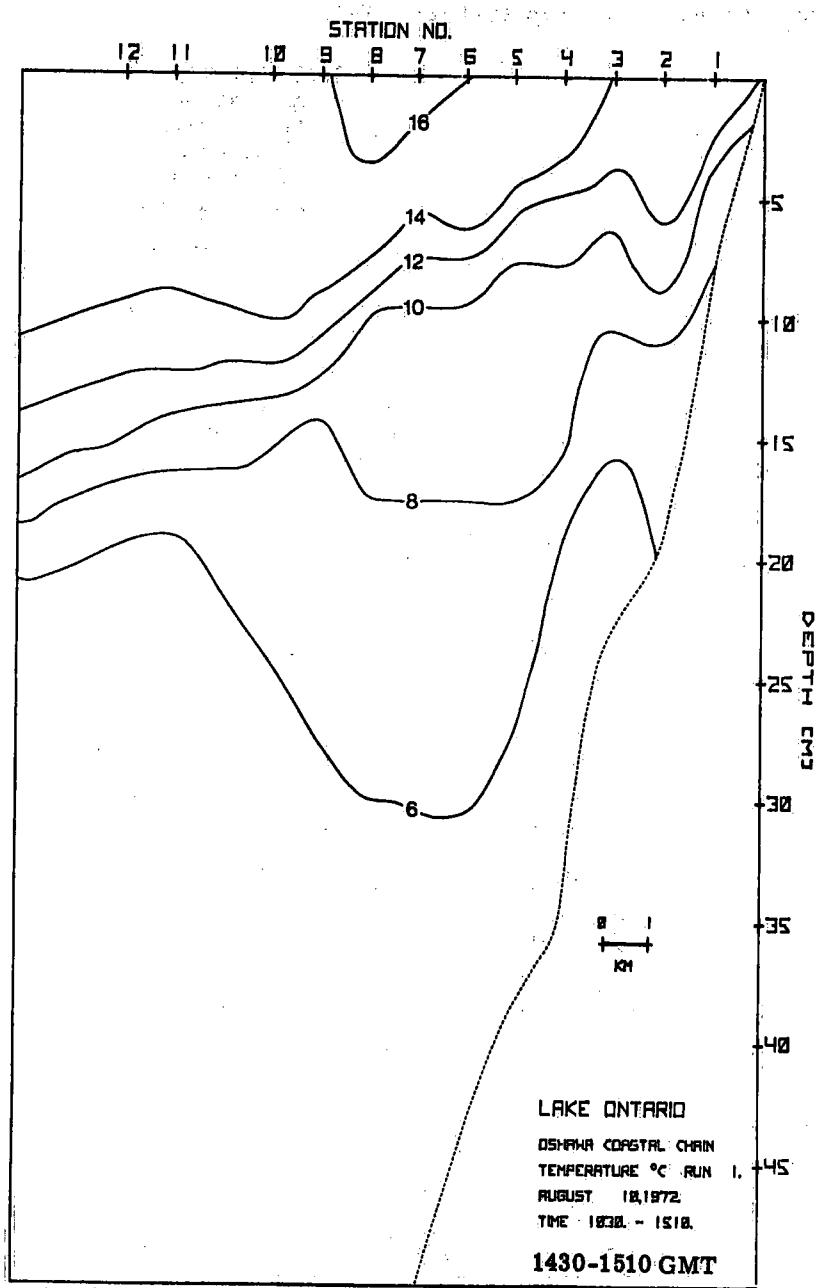


Figure 4.23. Isotherm depths in the Oshawa Coastal Chain section, 10 August (Julian day 223).

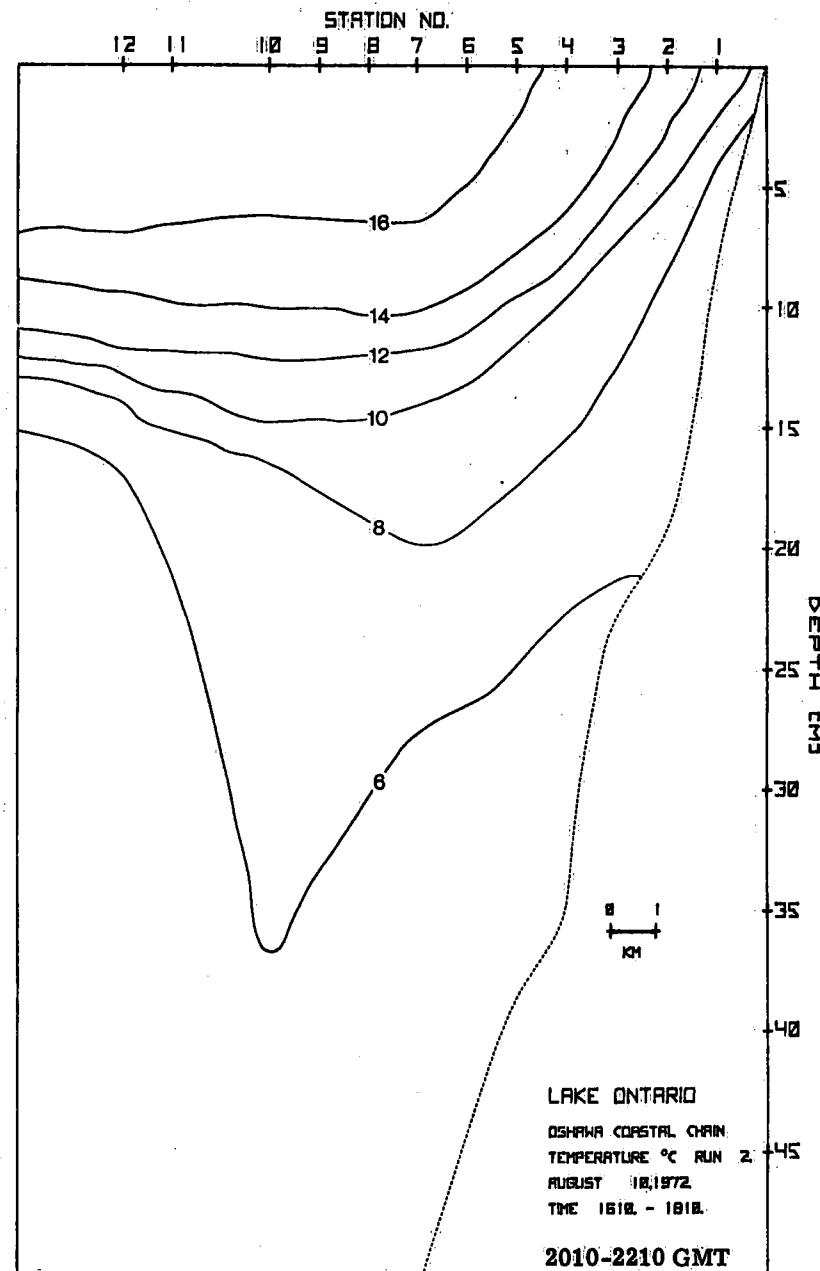
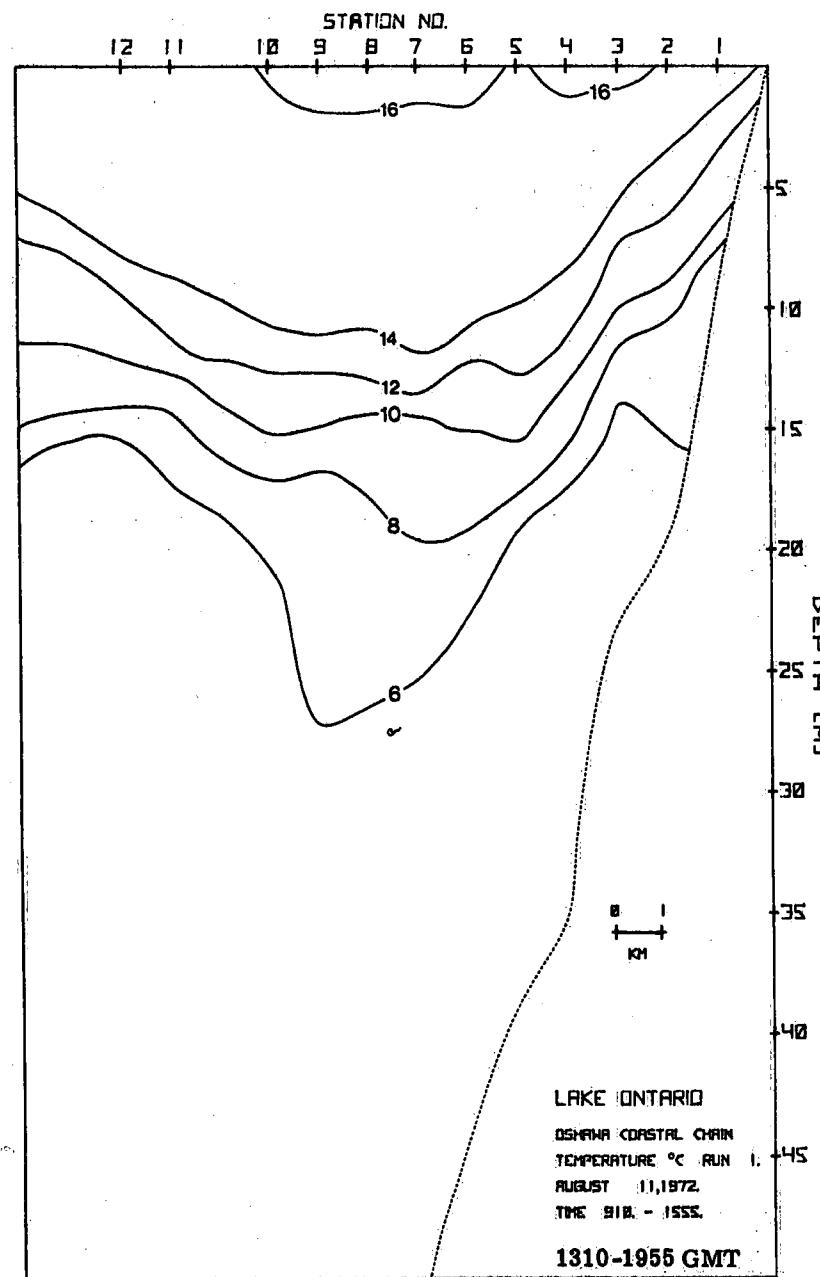
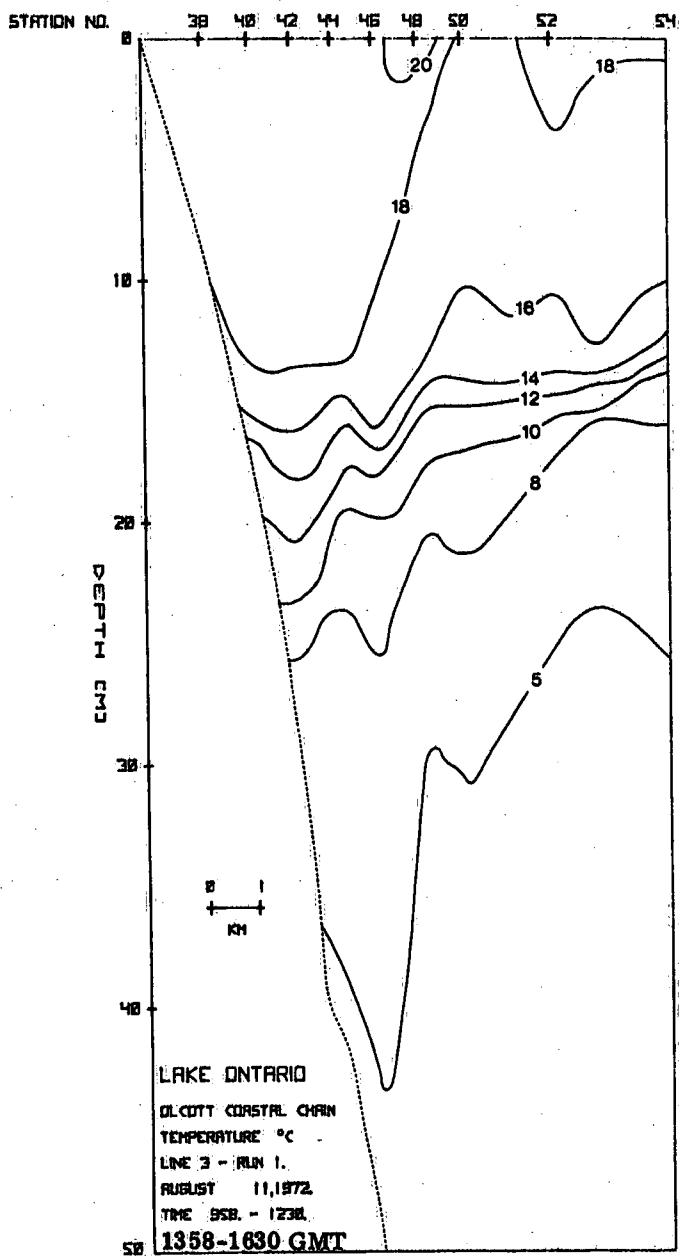
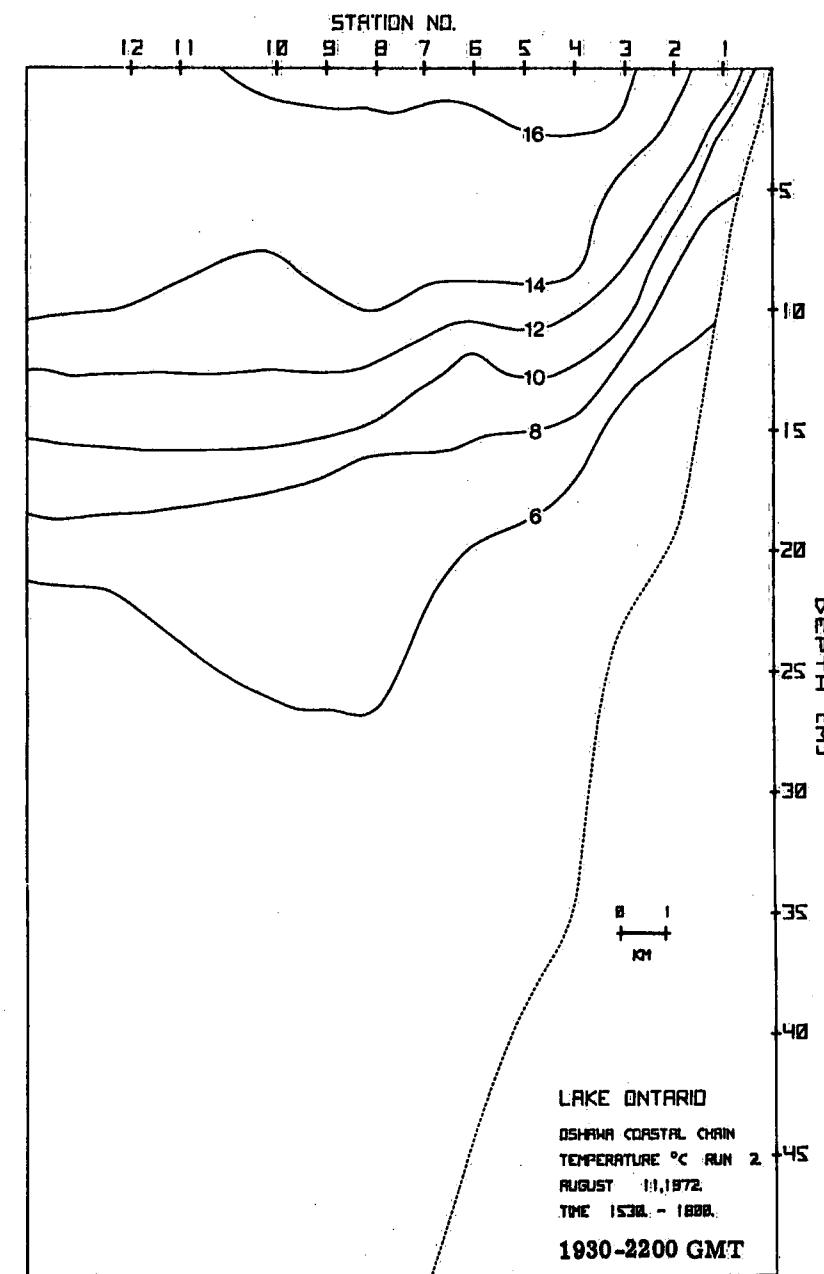
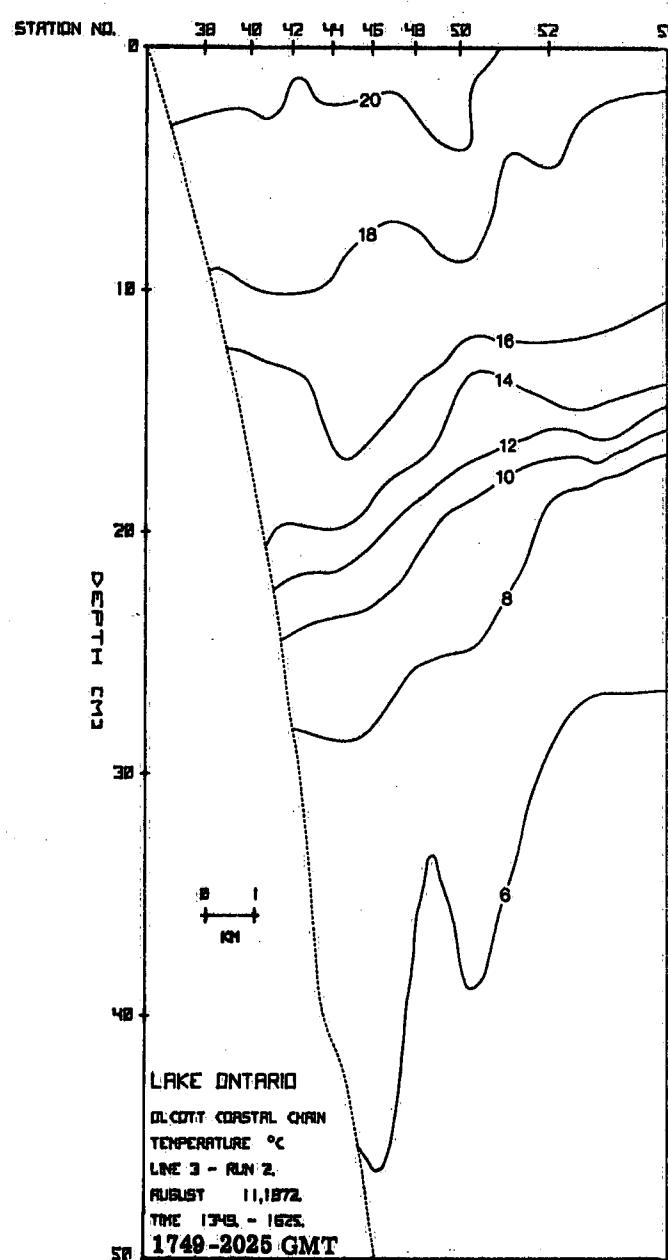


Figure 4.24. Isotherm depths in the Oshawa Coastal Chain section, 10 August (Julian day 223).



Figures 4.25 (left) and 4.26 (right). Isotherm depths in the Olcott and Oshawa section, 11 August (Julian day 224).



Figures 4.27 (left) and 4.28 (right). Isotherm depths in the Olicott and Oshawa sections, 11 August (Julian day 224).

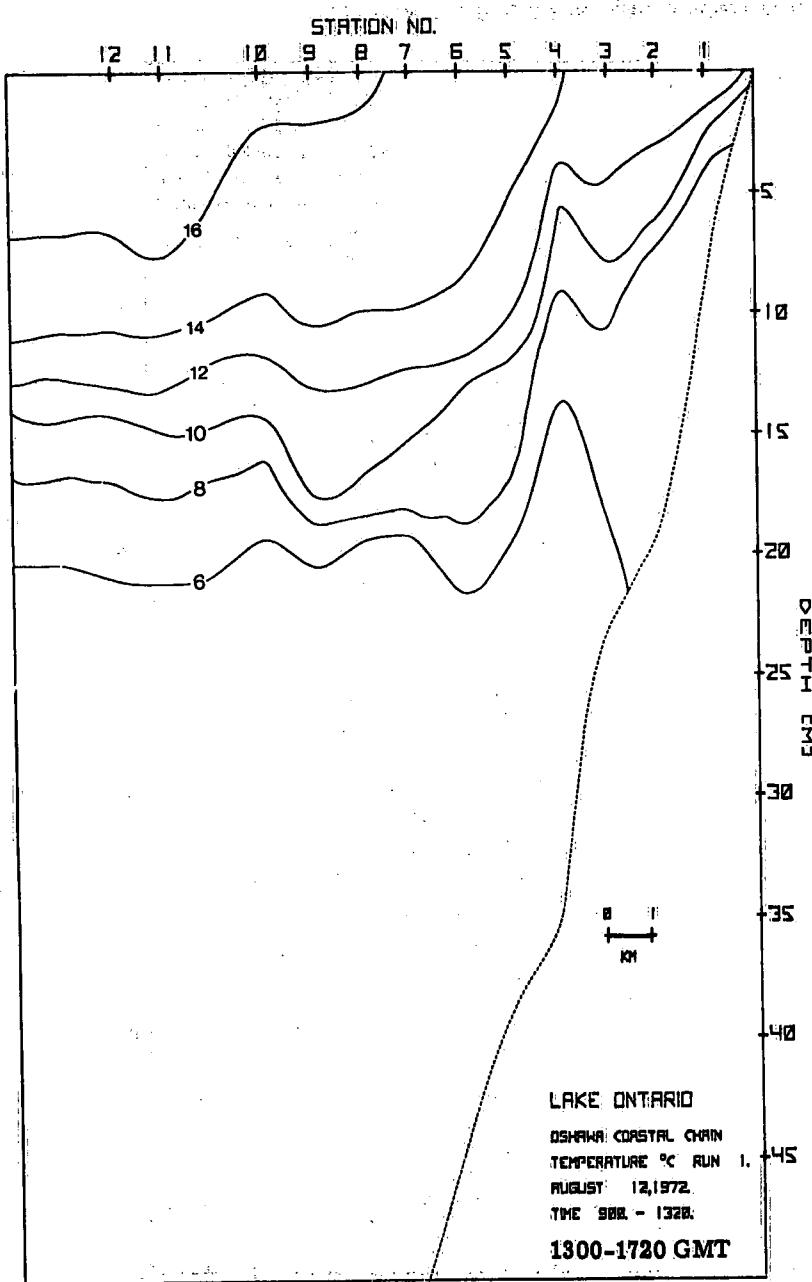


Figure 4.29. Isotherm depths in the Oshawa Coastal Chain section, 12 August (Julian day 225).

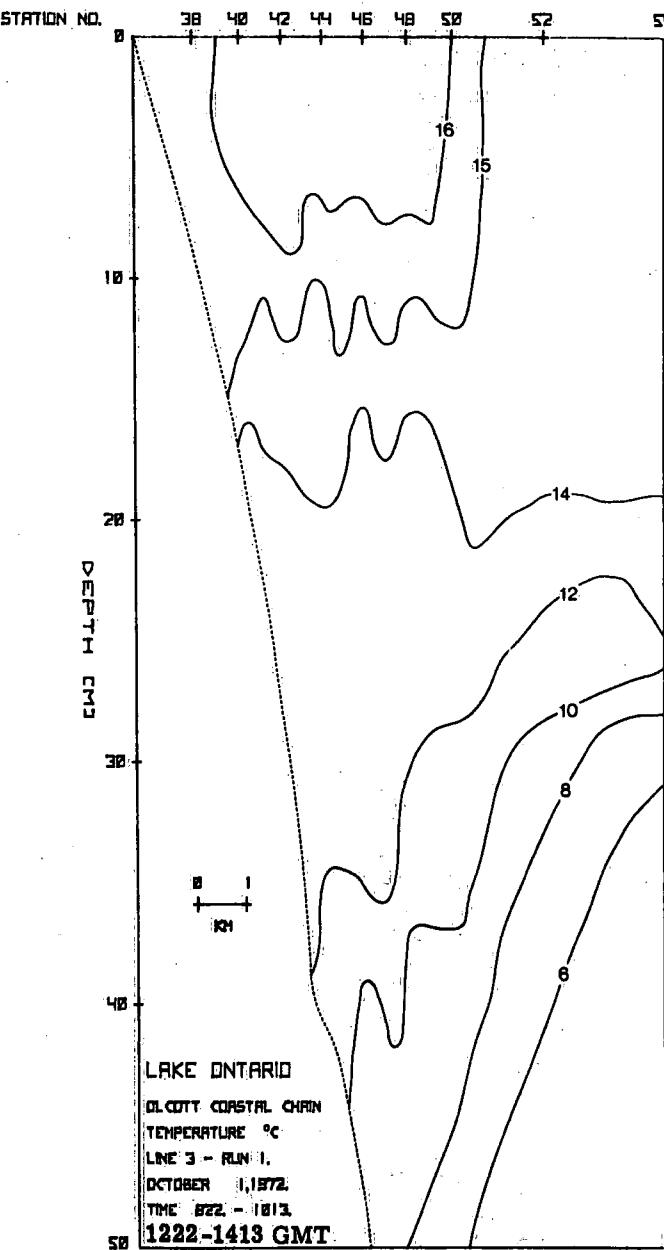
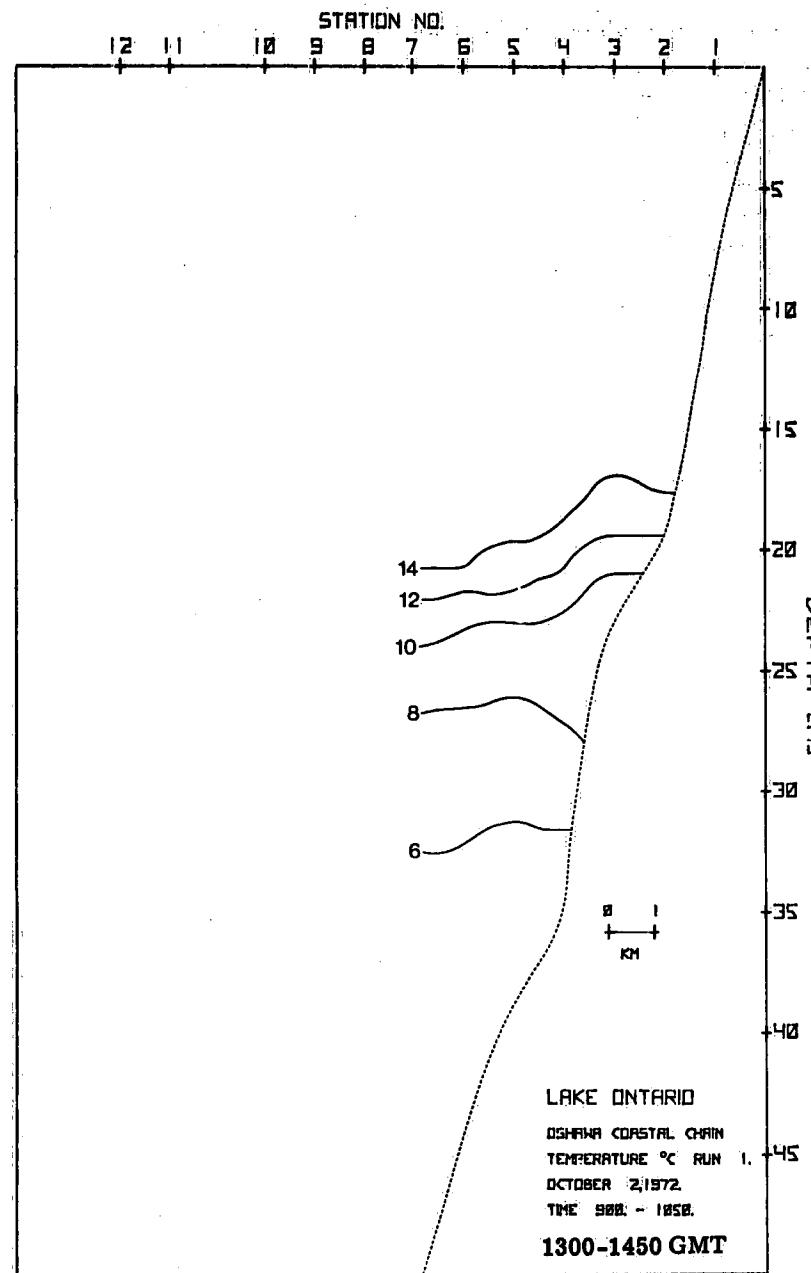


Figure 4.30. Isotherm depths in the Olcott Coastal Chain section, 1 October (Julian day 275).



**Figure 4.31.** Isotherm depths in the Oshawa Coastal Chain section, 2 October (Julian day 276).

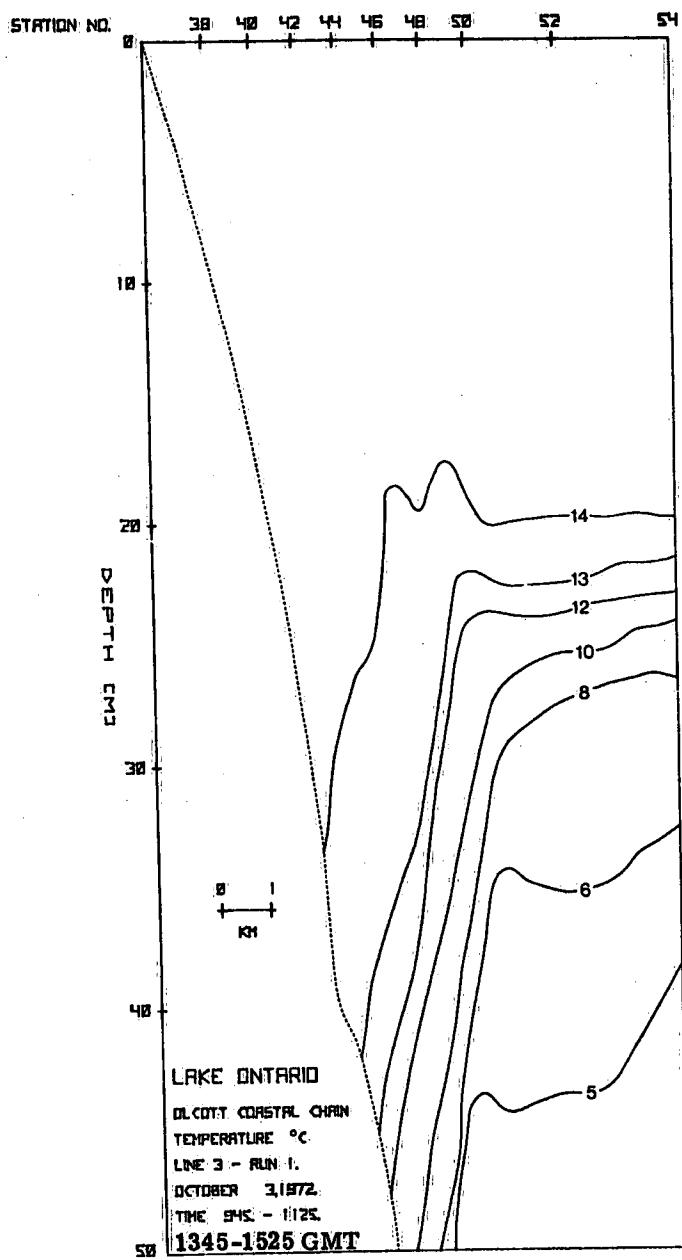


Figure 4.32. Isotherm depths in the Olcott and Oshawa sections, 3 October (Julian day 277).

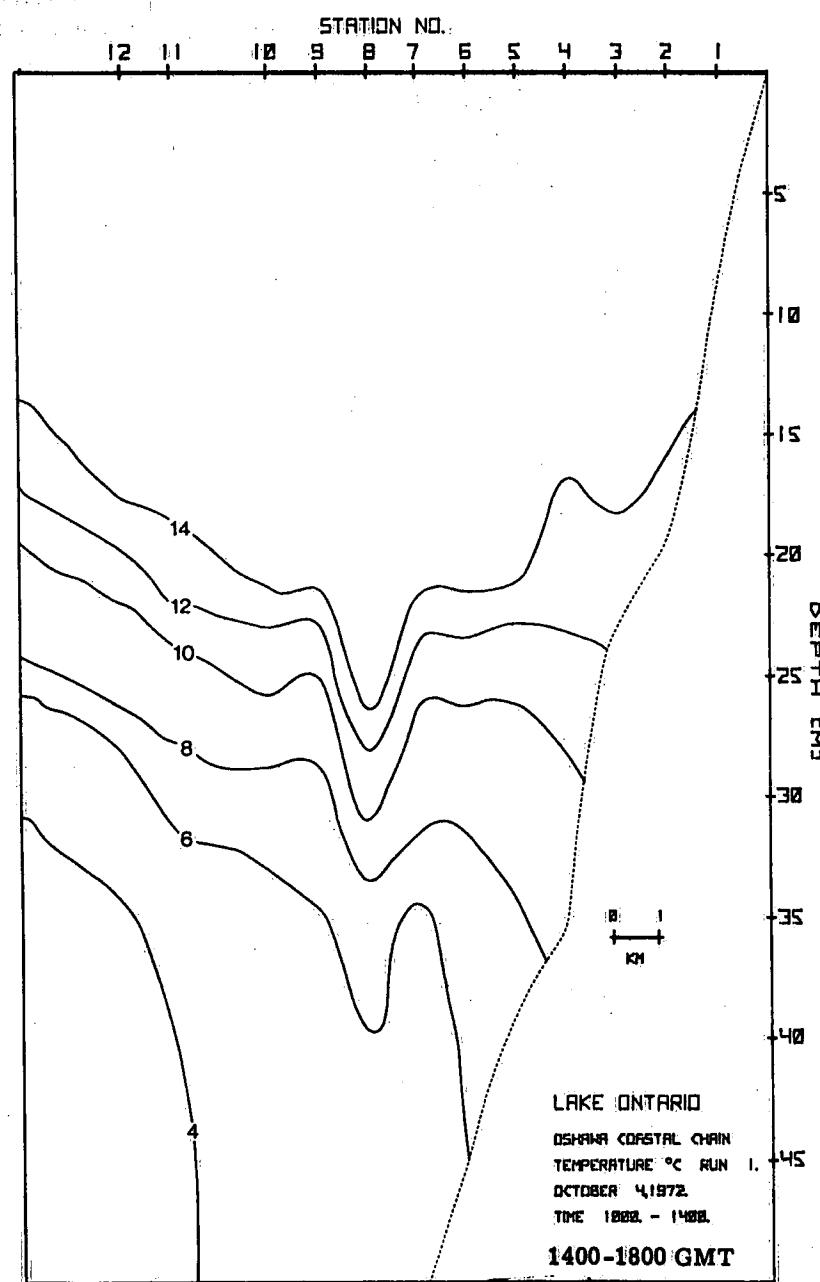


Figure 4.33. Isotherm depths in the Oshawa Coastal Chain section, 4 October (Julian day 278).

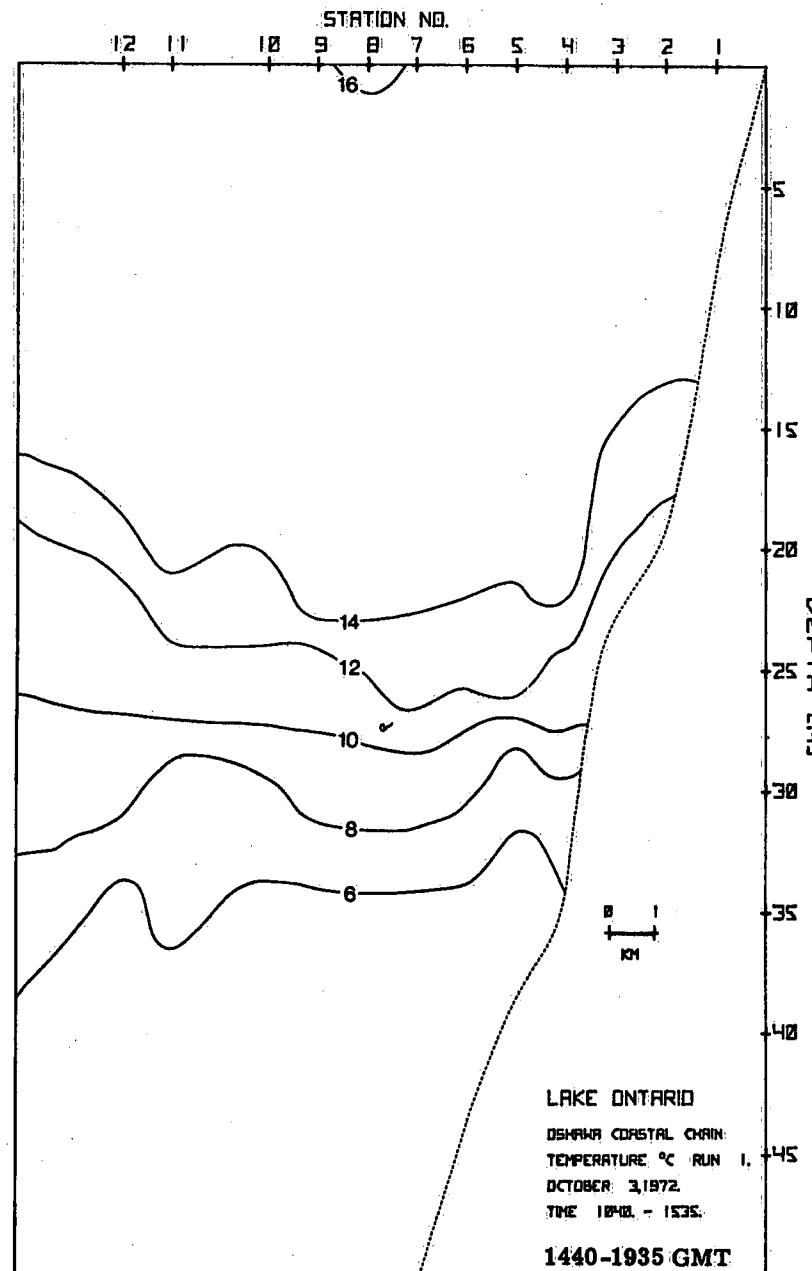
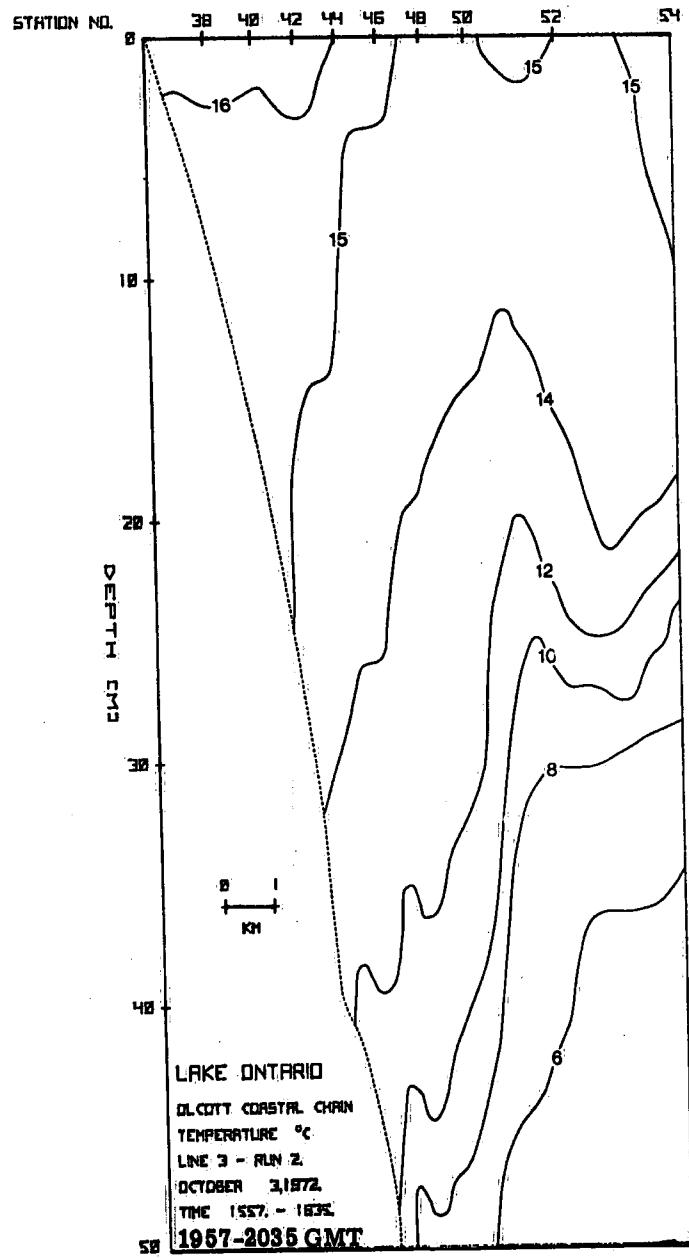
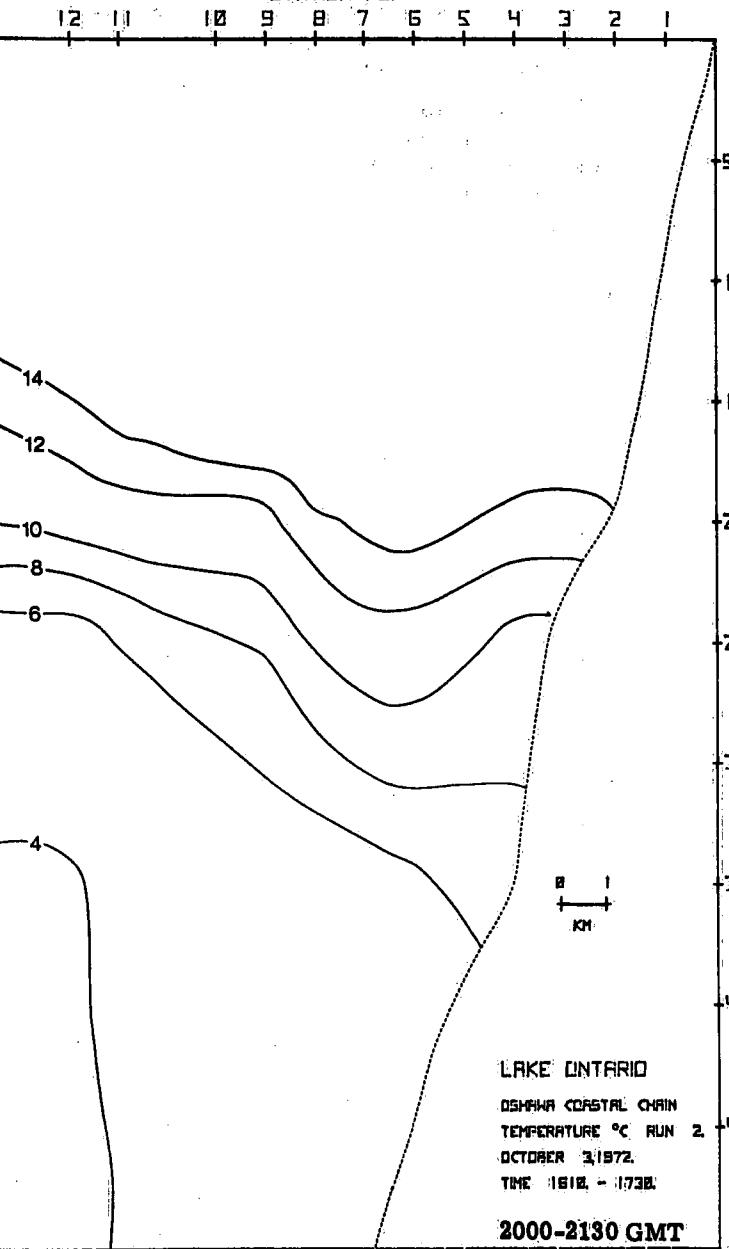


Figure 4.34. Isotherm depths in the Olcott and Oshawa sections, 3 October (Julian day 277).

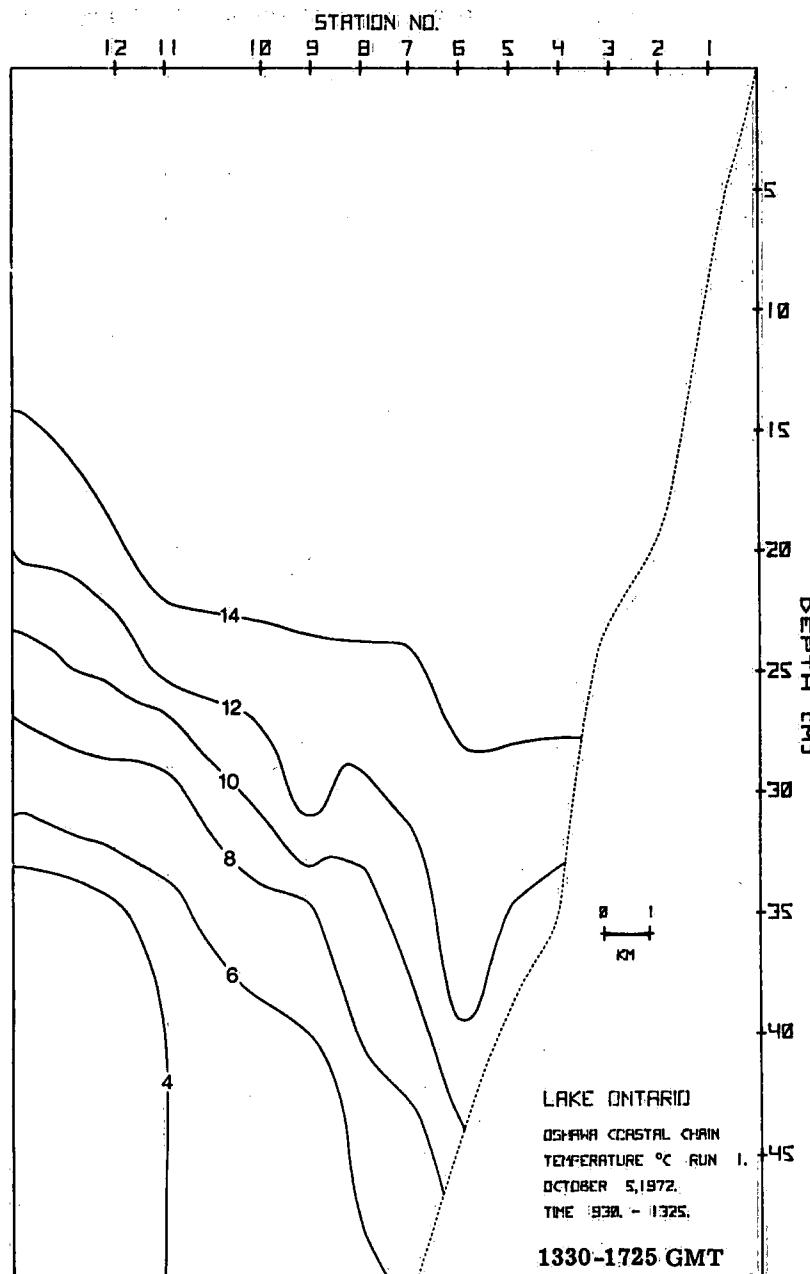
106



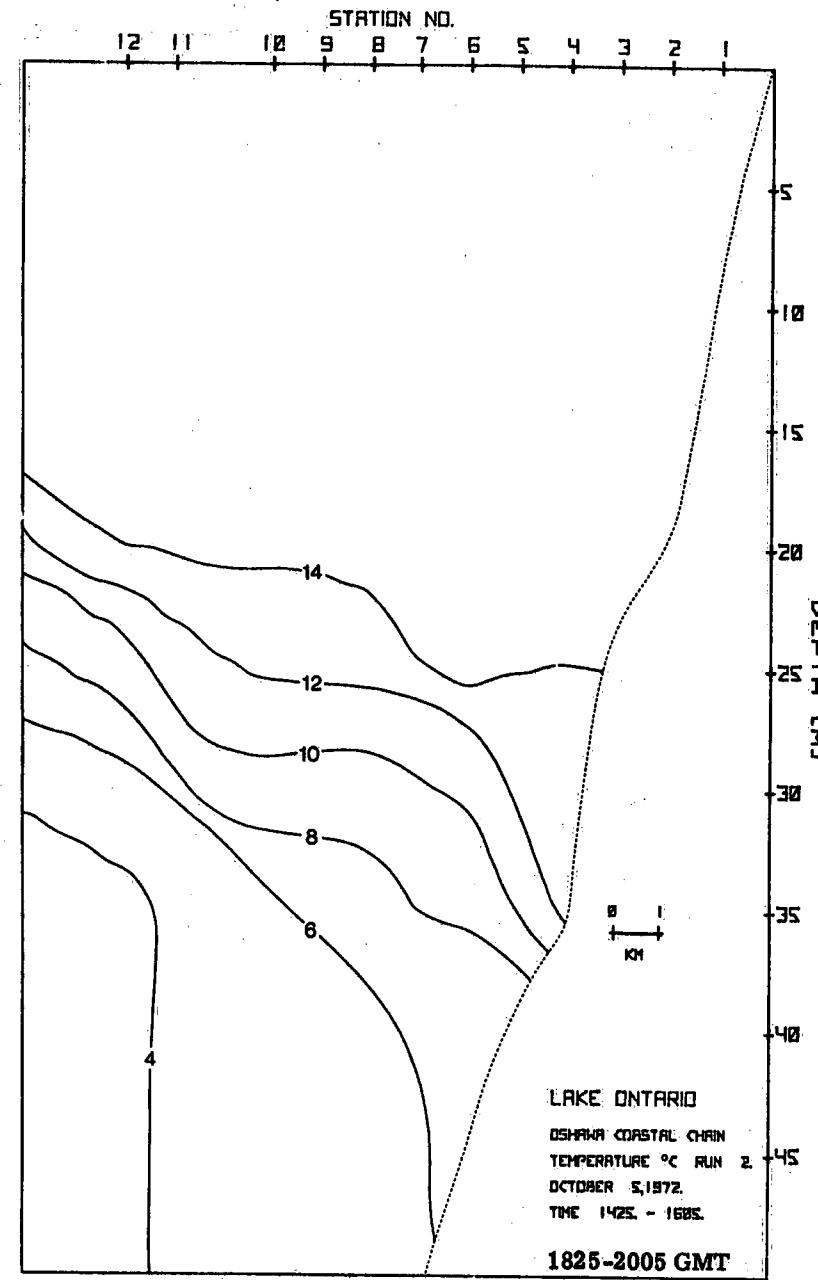
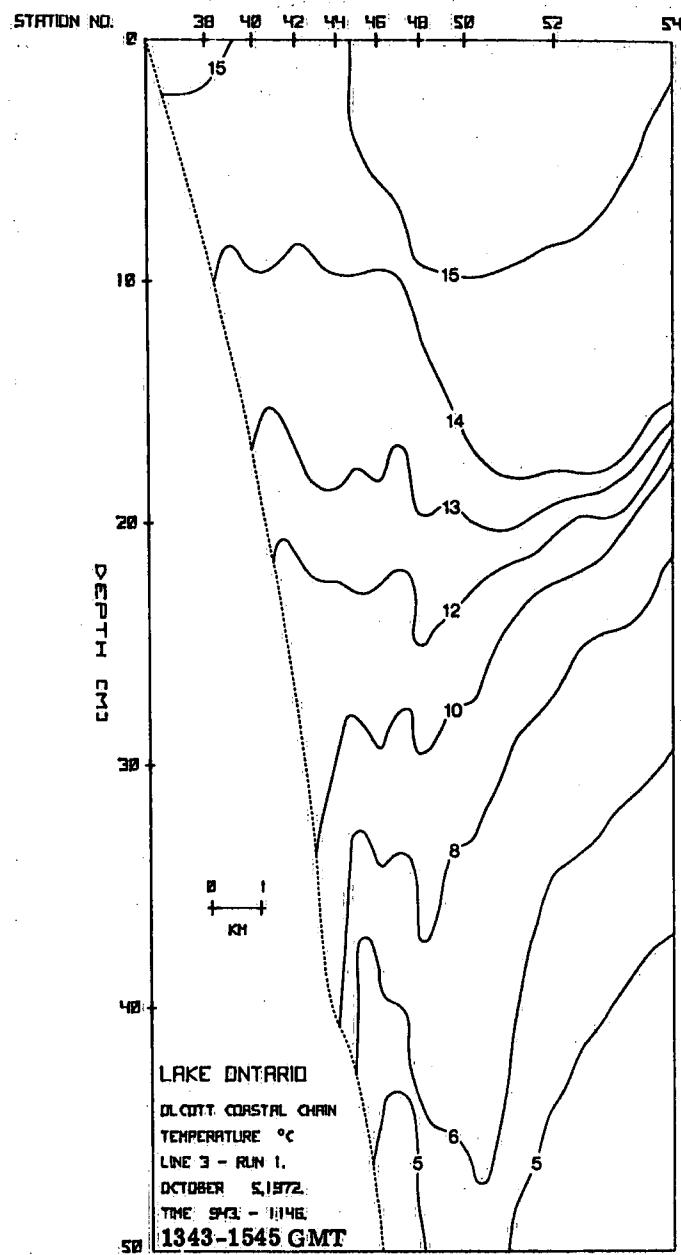
STATION NO.



Figures 4.35 (left) and 4.36 (right). Isotherm depths in the Olcott and Oshawa sections, 3 October (Julian day 277).



**Figure 4.37.** Isotherm depths in the Olcott and Oshawa sections, 5 October (Julian day 279).



Figures 4.38 (left) and 4.39 (right). Isotherm depths in the Olcott and Oshawa sections, 5 October (Julian day 279).

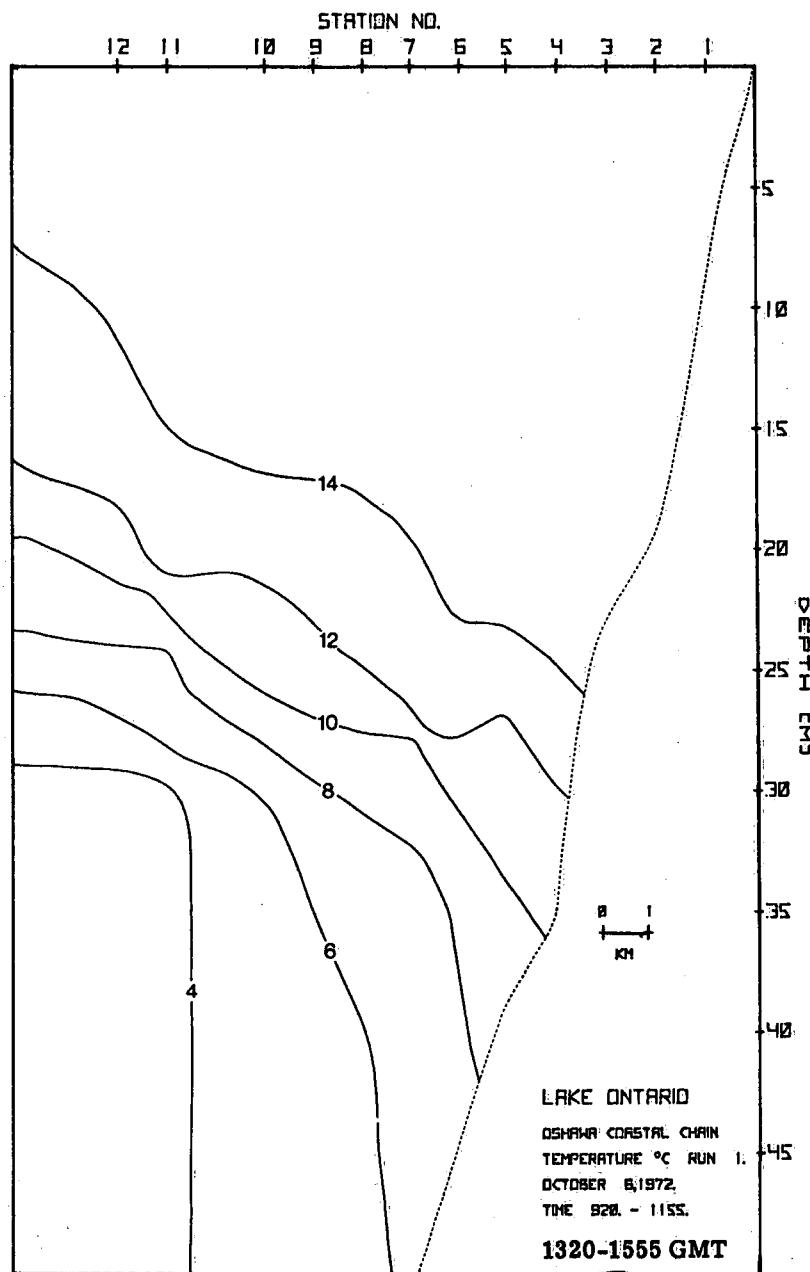


Figure 4.40. Isotherm depths in the Oshawa Coastal Chain section, 6 October (Julian day 280).

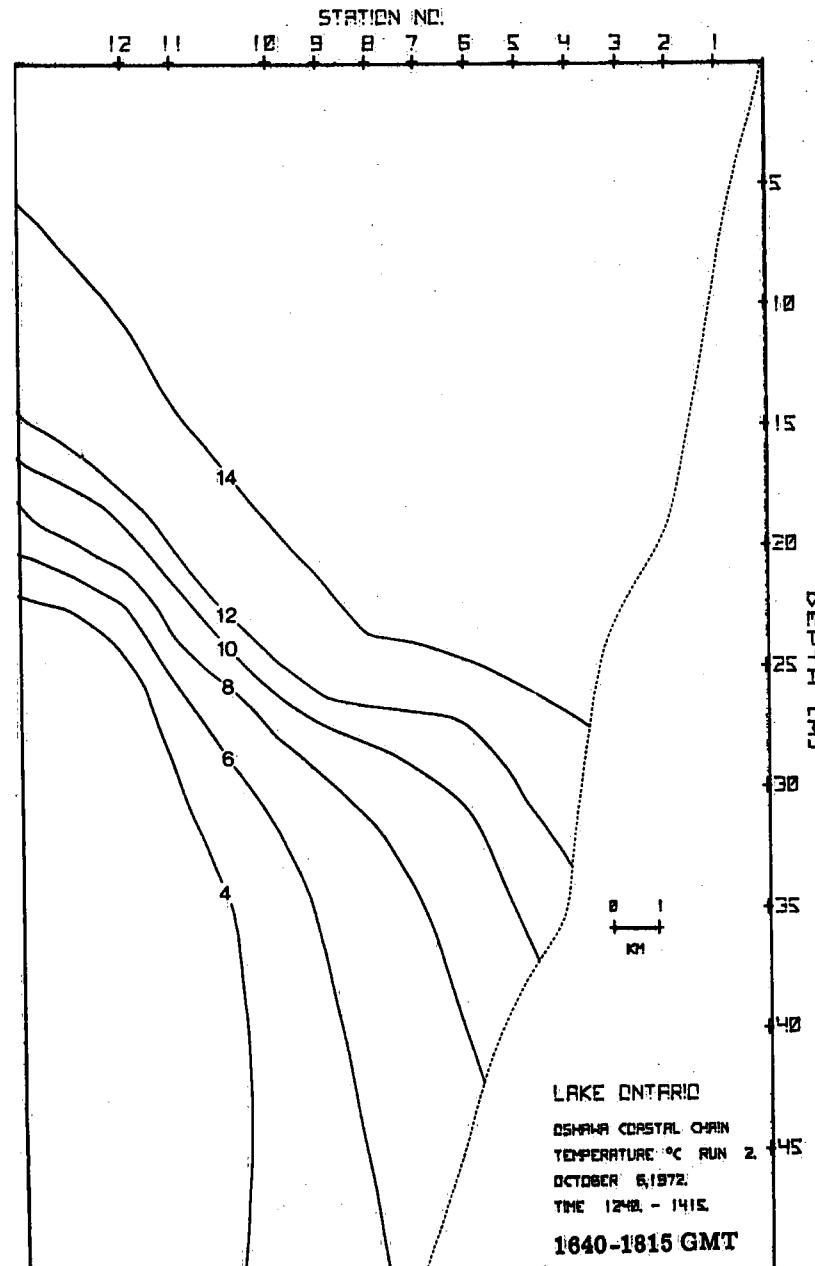


Figure 4.41. Isotherm depths in the Oshawa Coastal Chain section, 6 October (Julian day 280).

## Temperature Distribution in the Rochester (Braddock Point) to Presqu'ile Transect

As described in section 2.2, the CGLS undulator was used to obtain repeated scans of the depth distribution of temperature across the Braddock Pt. (Rochester) to Presqu'ile transect on a continuous to-and-fro shuttle during three cruises: 24 to 28 July (24 transects); 7 to 11 August (26 transects); 2 to 6 October (22 transects). The results for each transect are presented in the following 71 diagrams, with a vertical exaggeration of 1000:1. As each diagram is identified by transect number and Julian day, no additional figure numbering is necessary. At the head of each diagram are shown: (i) the

vessel track for that particular transect, with the starting position of each undulator dive, numbered sequentially; (ii) the positions of fixed measuring stations, i.e. instrumented moorings or towers, located on or near the transect route; (iii) the lines (dotted) occupied by the Rochester and Presqu'ile coastal chains (Scott *et al.*, 1973; Csanady and Pade, 1973); and (iv) the GMT time scale for the particular transect. Official IFYGL numbering is shown for the fixed stations, but we have found it convenient to adopt the prefix C for Canadian instruments (for which the suffixes -T, -C, and -M signify moored

Table 5.1. Depths (m) of Temperature Sensors\* at Fixed Stations in or near the Braddock Pt. to Presqu'ile Transect

U.S. stations, 6-min intervals			Canadian stations, 10-min intervals			
towers	mooring		moorings:	T thermistor chain;	C current meter	
U27	U26	U16	C10-T	C10-C	C9-T	C9-C
		surface	0.2		0.2	
1			1		1	
2	2					
3	3		3		3	
4	4					
5		5	6		6	
7						
9						
11		10	10	10	10	
13			14		14	
15				15		15
17			18		18	
19		20				
			22		22	
			26		26	
			30	30	30	30
			35		35	
			40		40	
			50	50	46	50
			46		49	
			55		55	
					61	
			64		64	
			74			
			86			
		100	100			

\* Data from those sensors are entered, as triangles in the transect diagrams, according to availability and as shown in the time tables, 5.2, 5.3, and 5.4.

NOTE: Temperature also measured at surface at C9-M and C10-M, and at 10 m at C55-C and C59-C.

thermistor chains, current meters, and meteorological buoys, respectively), and U for the United States mooring U16 and instrumented towers U26, U27.

Because of the unduly large thermal time constant of the temperature sensor on the CGLS undulator (see section 2.2 and more detailed discussion in Chapter 6), only the information on the slow ascent portion of each dive was used. The depths of the 4°, 5°, 6° and all even-numbered isotherms above 6°C were determined for each dive and entered as a dot at the corresponding depth and horizontal distance on the diagram. Smoothed isotherms were then drawn in by hand.

The Undulator did not normally provide temperature information at levels above 4 m (the depth at which the fish was towed between dives) or at the inshore ends of the transect, where the water was too shallow to operate safely. Therefore, to provide a more complete temperature picture for each transect and to facilitate comparison between the Undulator results and those from fixed instruments, *all* available fixed-station temperature data (Table 5.1) were extracted from the IFYGL data files for

the times closest to those at which the vessel passed nearest the stations concerned, i.e. "coincidence" to the nearest 6 min for mooring U16 and for towers U26 and U27 and to the nearest 10 min for the Canadian stations, as set out in Tables 5.2 (July cruise), 5.3 (August), and 5.4 (October). These coincident temperature readings are entered, for all available depths, as triangles in each transect diagram, as are also surface temperatures, when available from the ship's thermograph. The isotherm depth contours, however, are based on the Undulator data alone and do not take the fixed station data into account. Comparisons between the two sets of data and the inferences to be drawn are treated in Chapter 6.

It should be noted that near the end of the 2-6 October cruise there was a breakdown in the temperature-recording section of the fish, later repaired. Transect 19 was therefore run using a mechanical bathythermograph. During the remaining transects, 20 to 22, the fish was working, but the data could not be extracted from the tape because of an undetected breakdown in the recording head of one tape channel. For those transects, the temperature-depth information was read, less accurately, from the X-Y recorder graphs.

**Table 5.2. Times (GMT) of Temperature Readings at Fixed Stations and Depths (Fig. 5.1) Entered on the Braddock Pt. to Presquile Transect diagrams: 24-28 July (Julian Days 206-210, see Diagrams)**

Transect No.	U27, U26	U16	C10-T, C10-C	C10-M	C9-T, C9-C	C9-M	C55-C
1	1648†	1742	1900	1850	2000	2000	2030
2	0012	2336	2220	2220	2120	2100	2050
3	0012	0042	0200	0200	0300	0310	0330
4	0712		0530		0430	0420	0400
4/1*	1148	1254	1500		1640	1650	1730
4/2*	2354	2330	2130		1840	1830	1800
4/3*	0136	0224	0440		0610	0620	0620
5	0936	0906	0750		0700	0650	0630
6	0942	1018	1140		1240	1250	1320
7	1654	1624	1500		1400	1400	1330
8	1700	1748	1910		2010	2020	2040
9	0024	2354	2240		2140	2140	2140
10	0030	0106	0240		0340	0350	0420
11	0806	0936	0610		0520	0510	0440
12	0818	0854	1010		1100	1110	1130
13	1506	1442	1320		1220	1220	1150
14	1518	1548	1710‡		1810	1820	1840
15	2224	2154	2030		1940	1930	1900
16	2236	2306	0030		0130	0140	0150
17	0500	0430	0310		0220	0210	0200
18	0506	0536	0710		0800	0800	0820
19	1218	1148	1040		0940	0930	0910
20	1224	1254	1400		1450	1500	1500
21	1618	1618	1610		1520	1510	1510

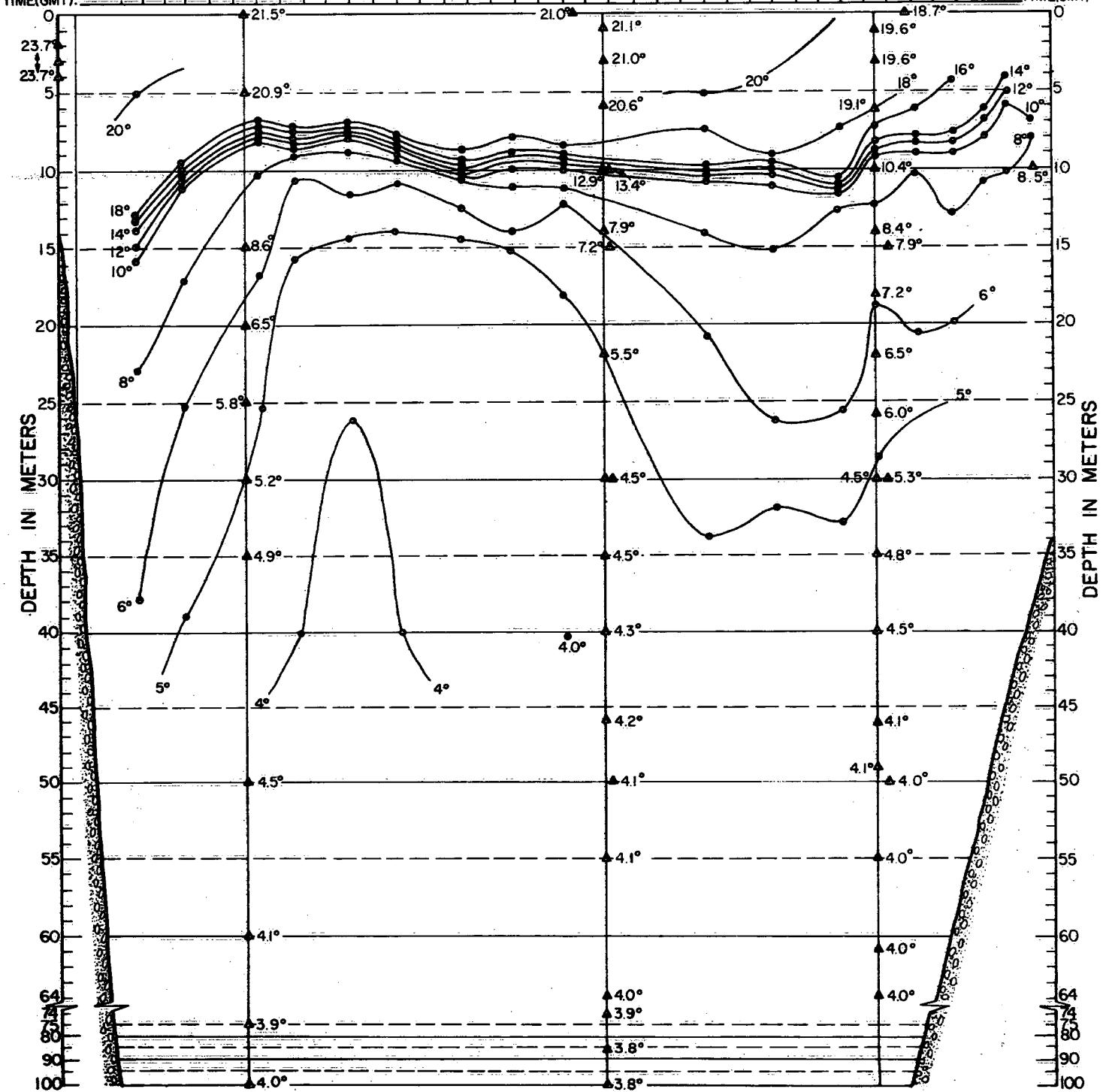
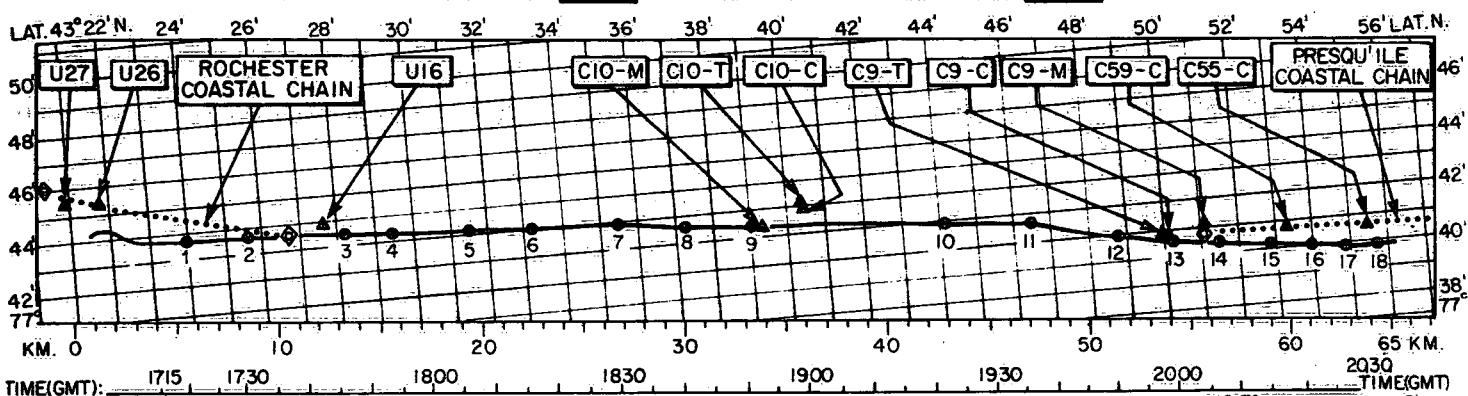
\* Bathythermograph casts.

† No data from U26 for Transects 1 to 4/1.

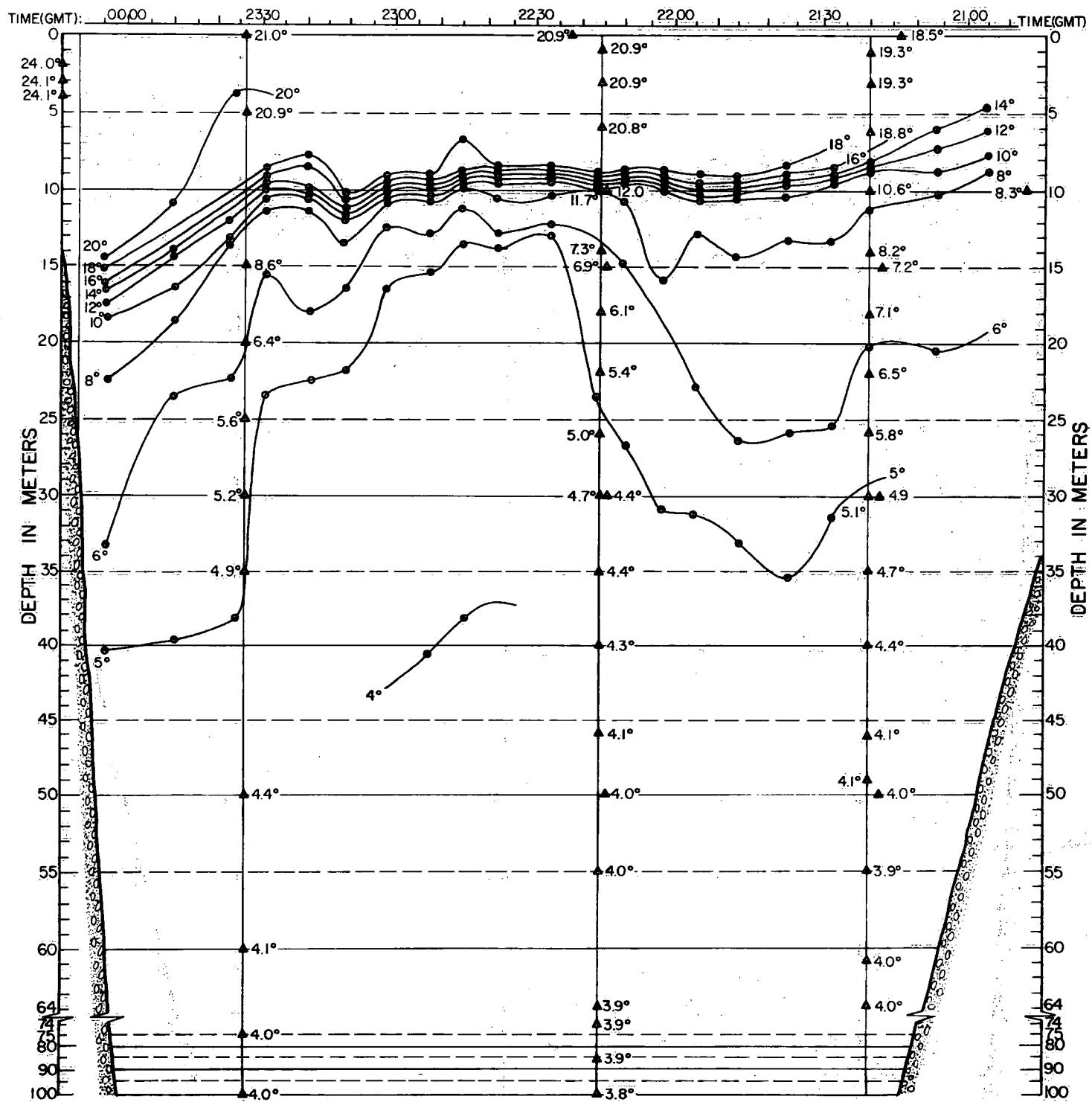
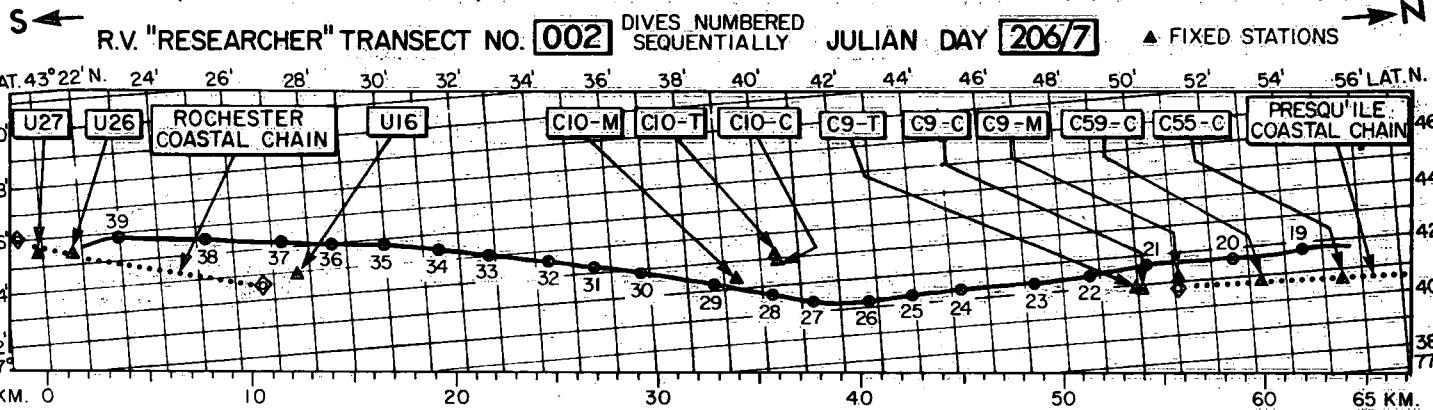
‡ No data from C10-T for Transects 14 to 21.

IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

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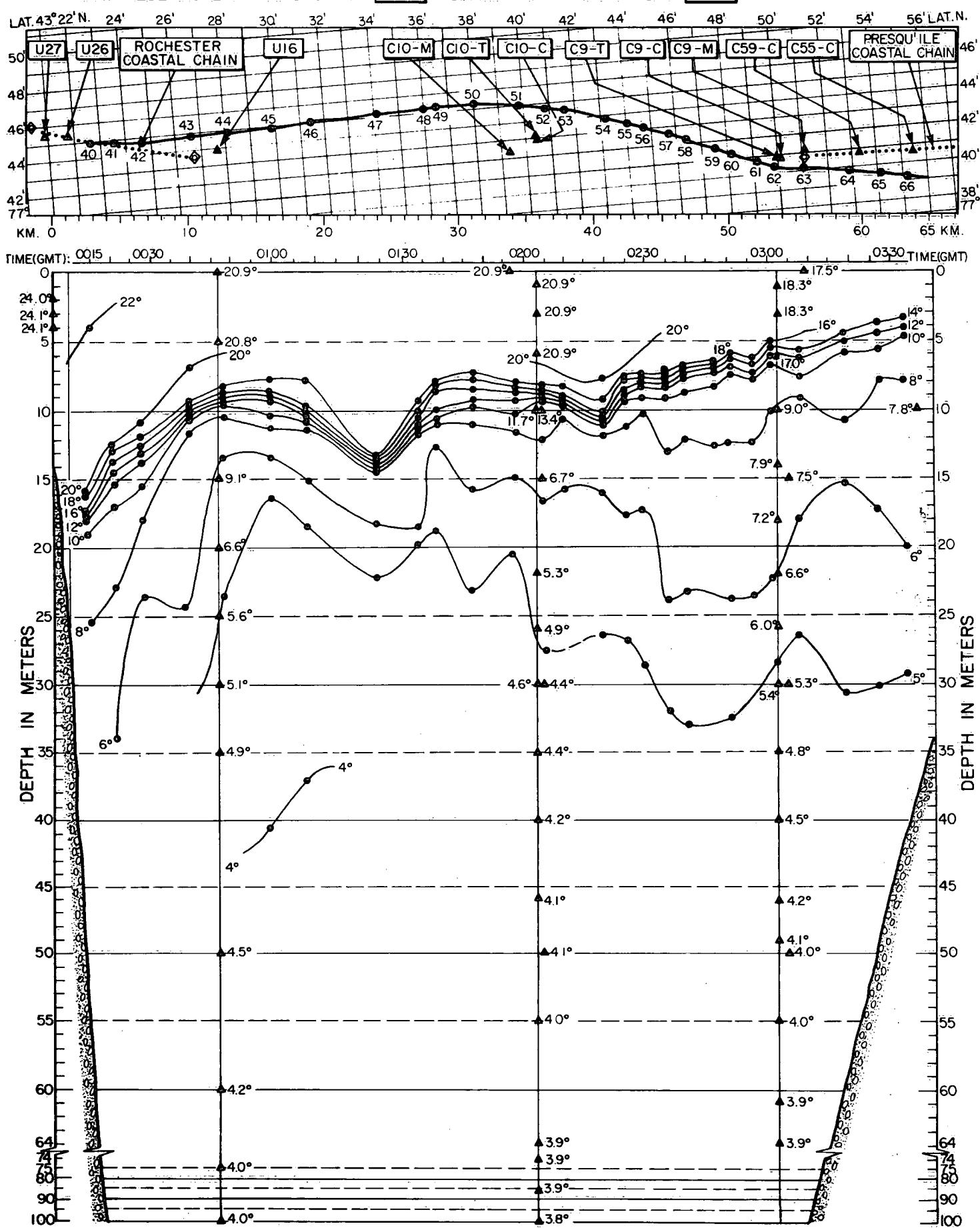


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IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N).

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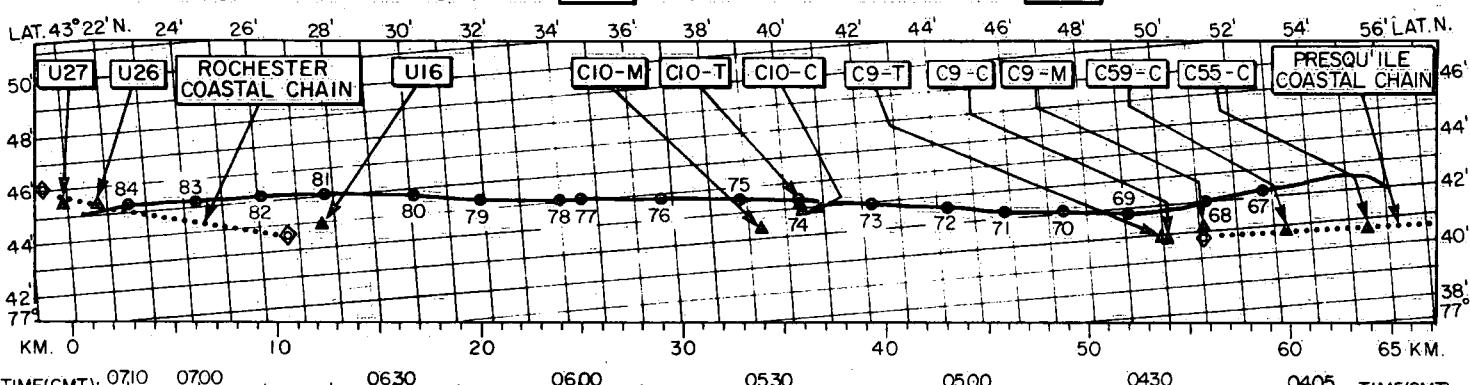
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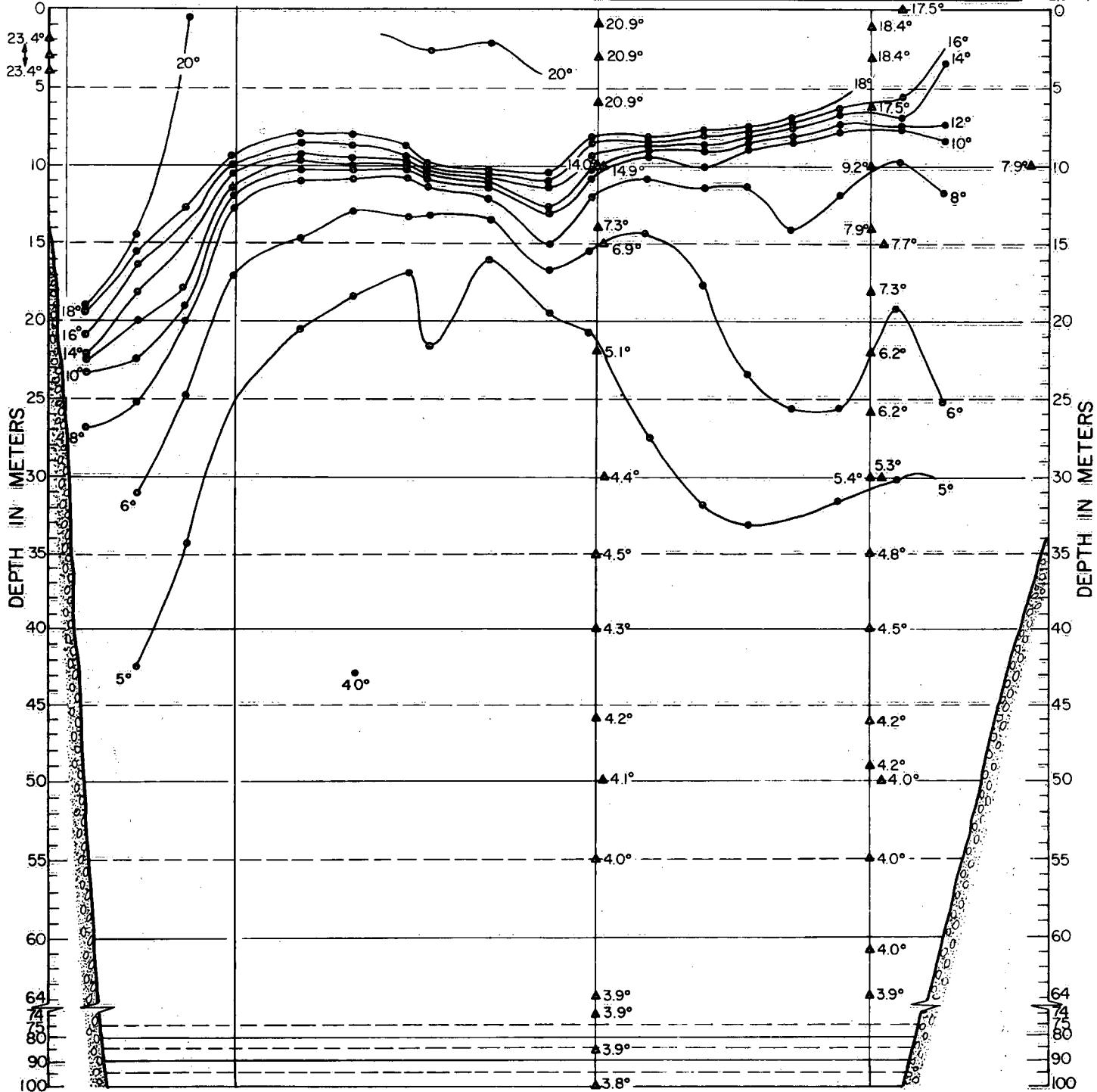
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JULIAN DAY 207

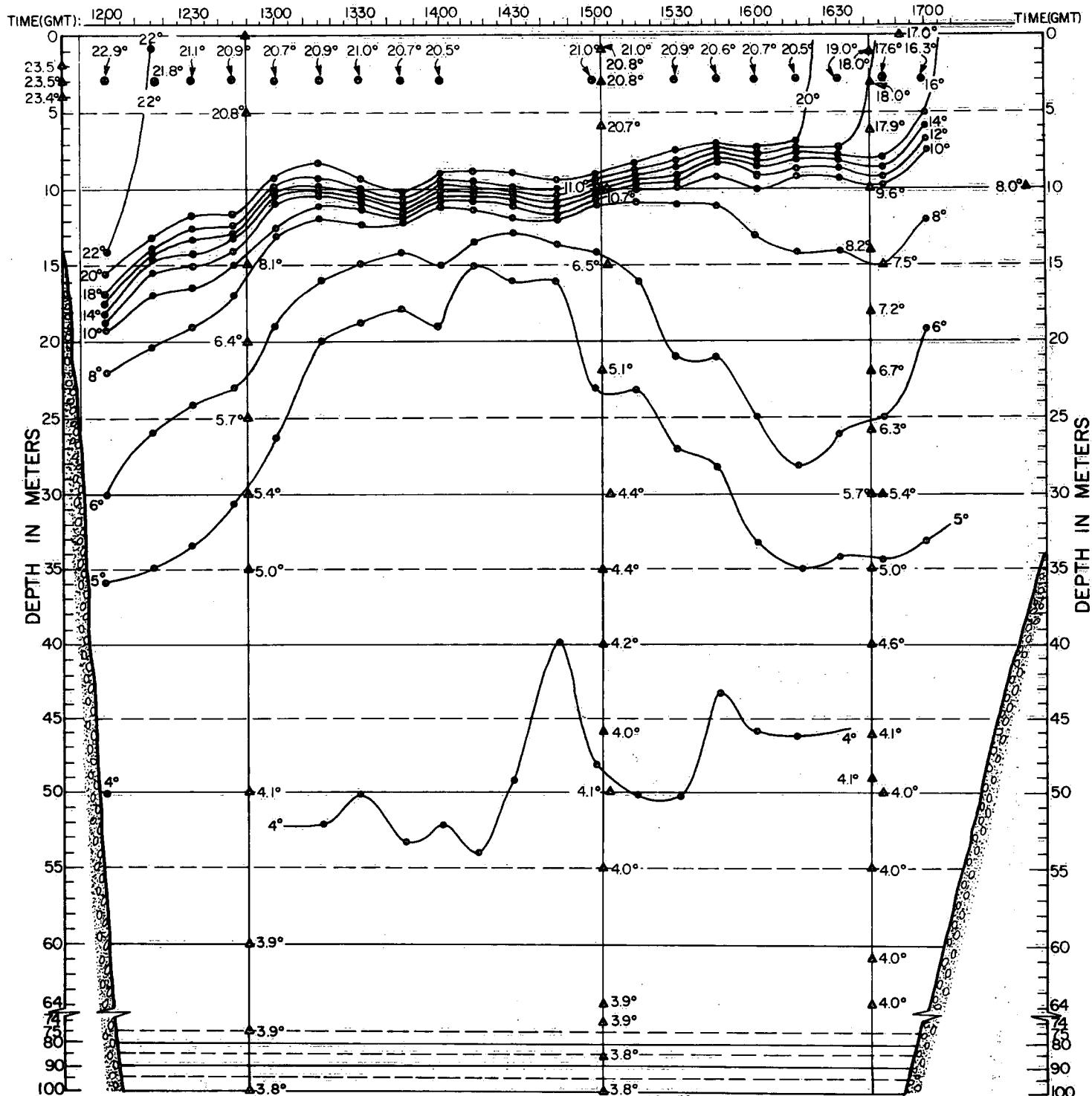
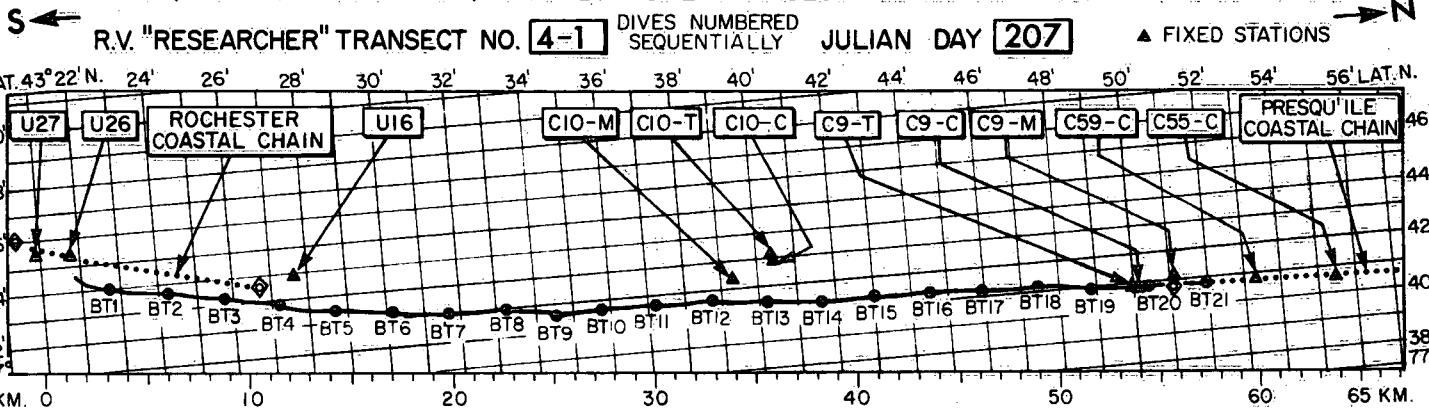
▲ FIXED STATIONS N →



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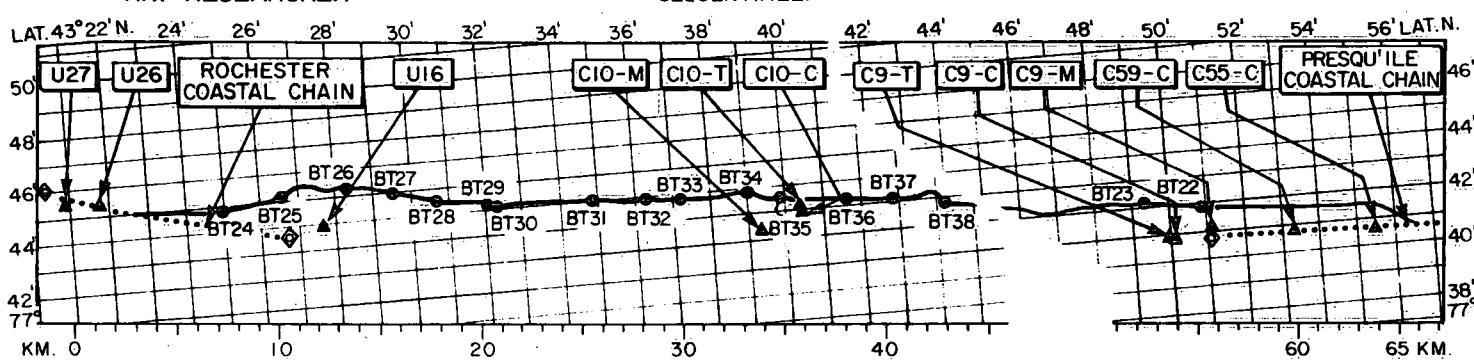


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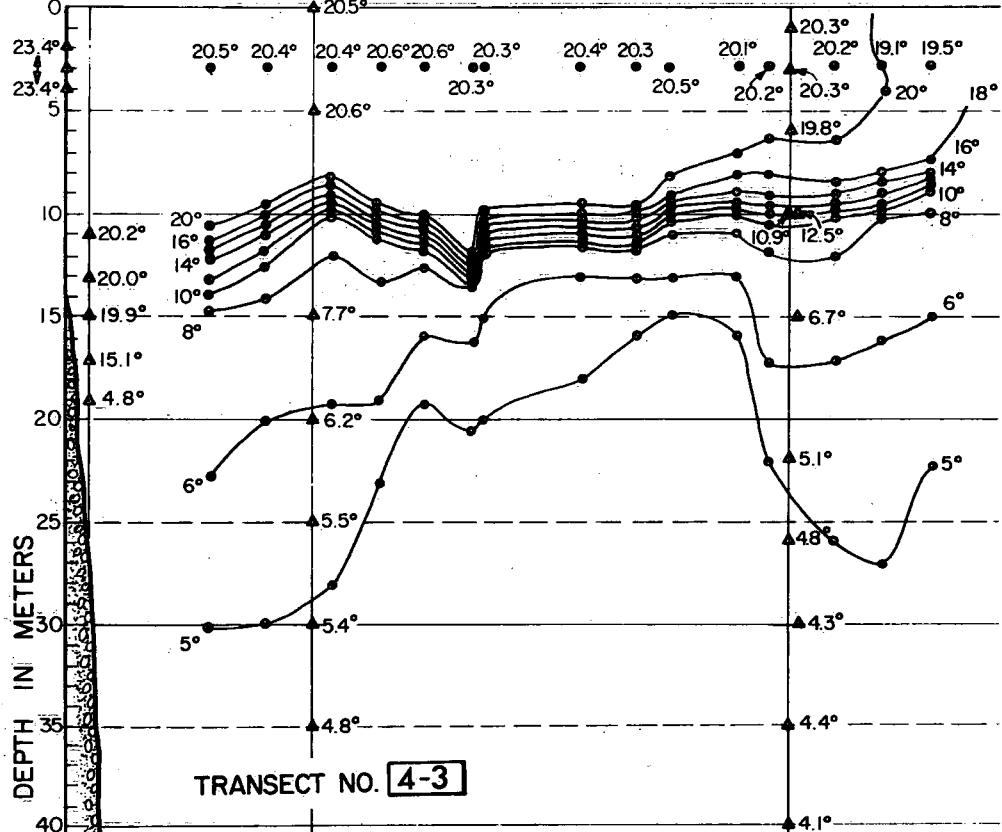
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DIVES NUMBERED  
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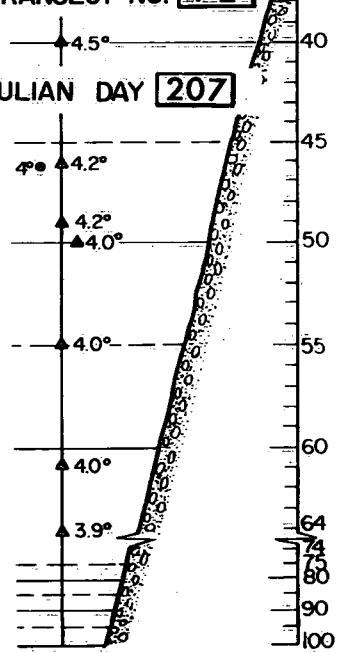
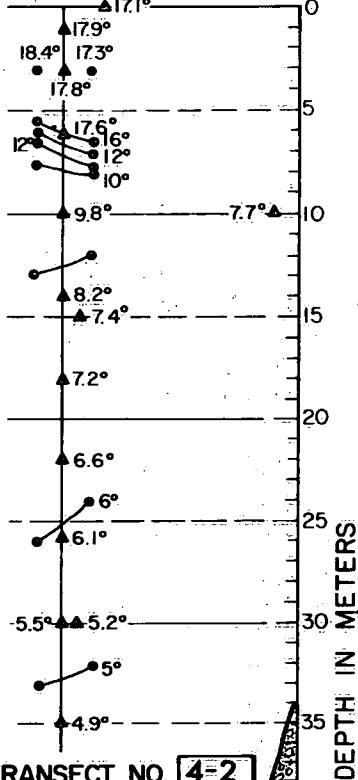
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1830 1800 TIME(GMT)



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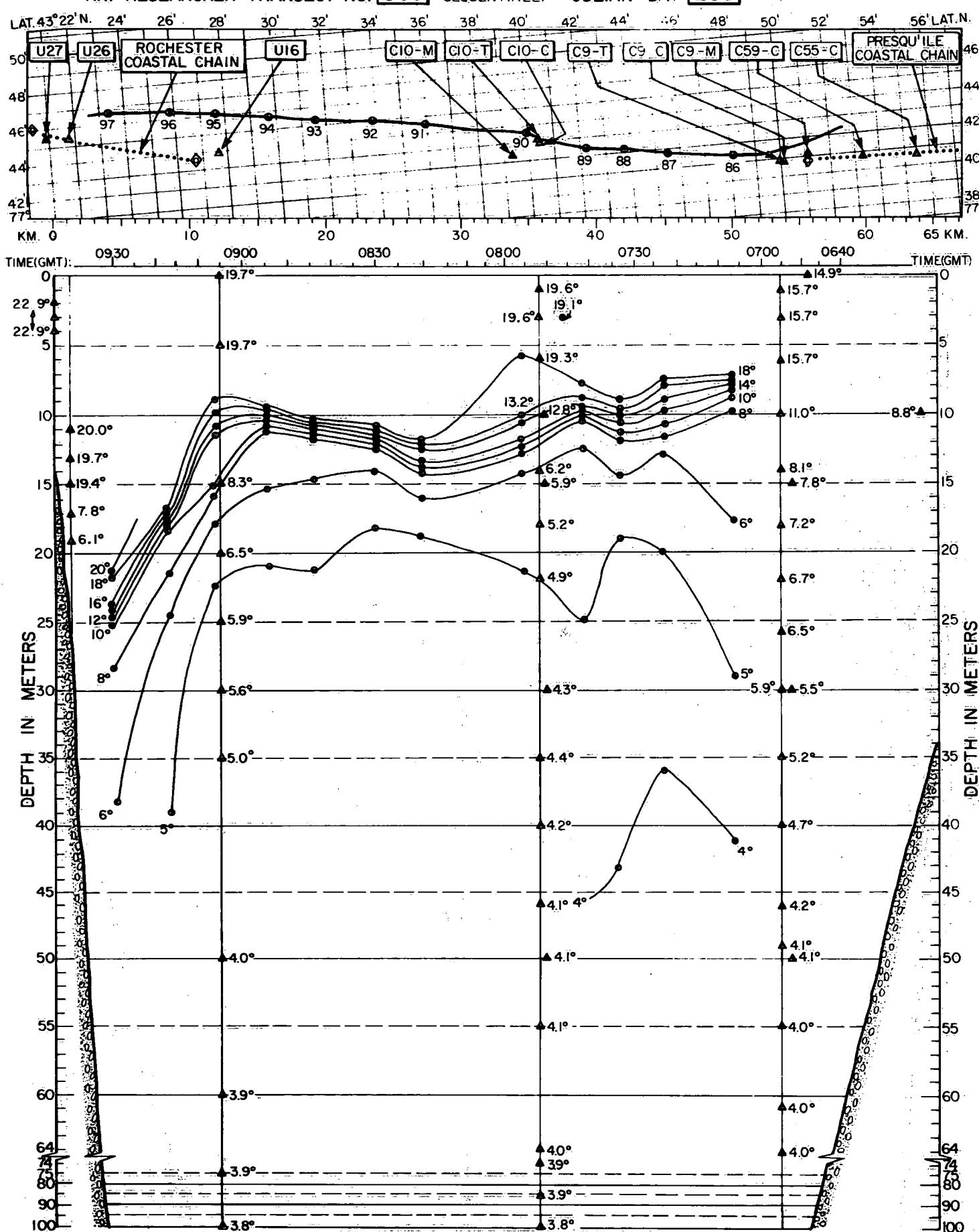
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JULIAN DAY 208

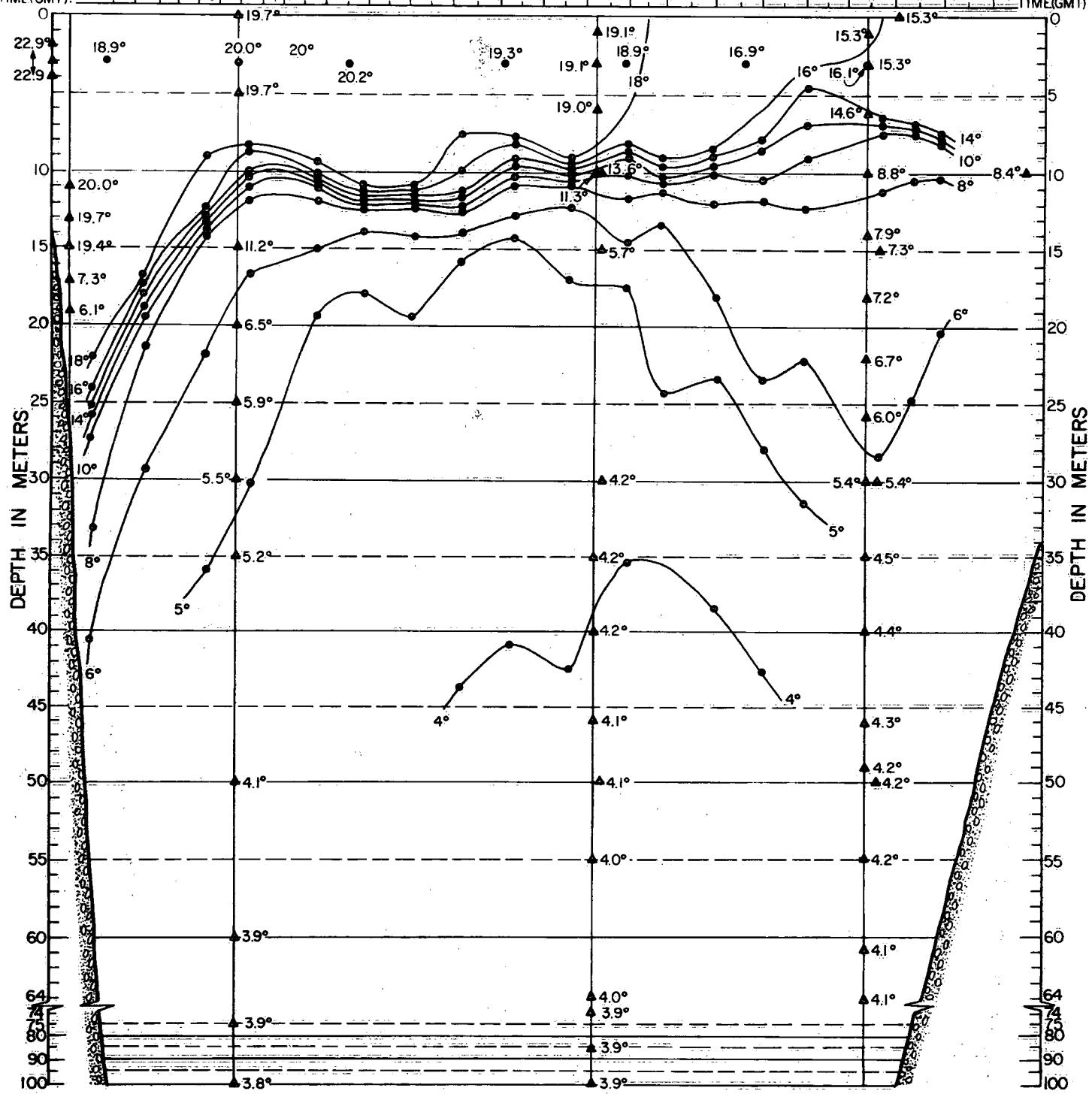
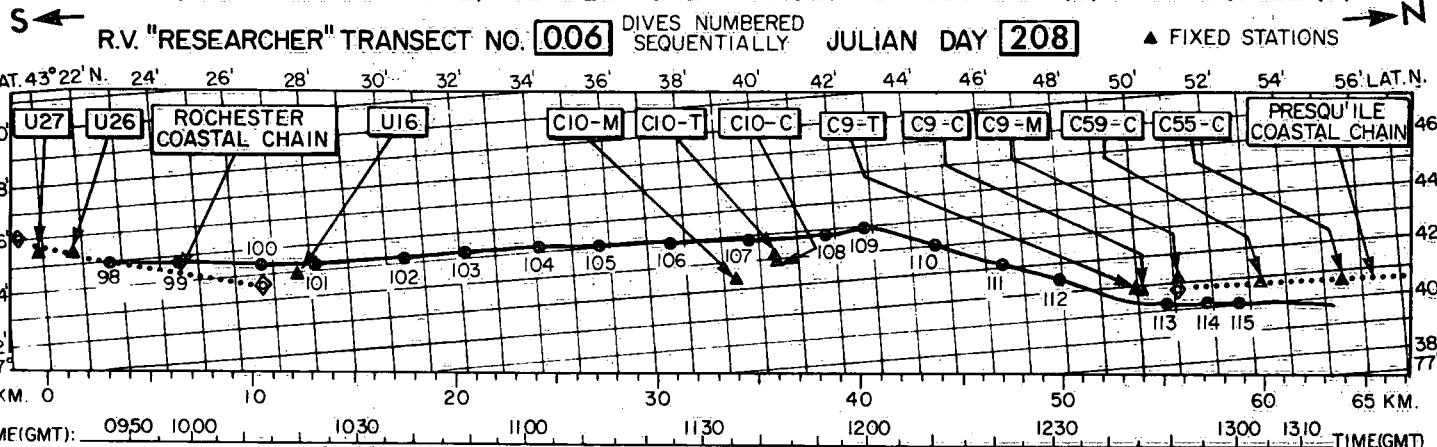
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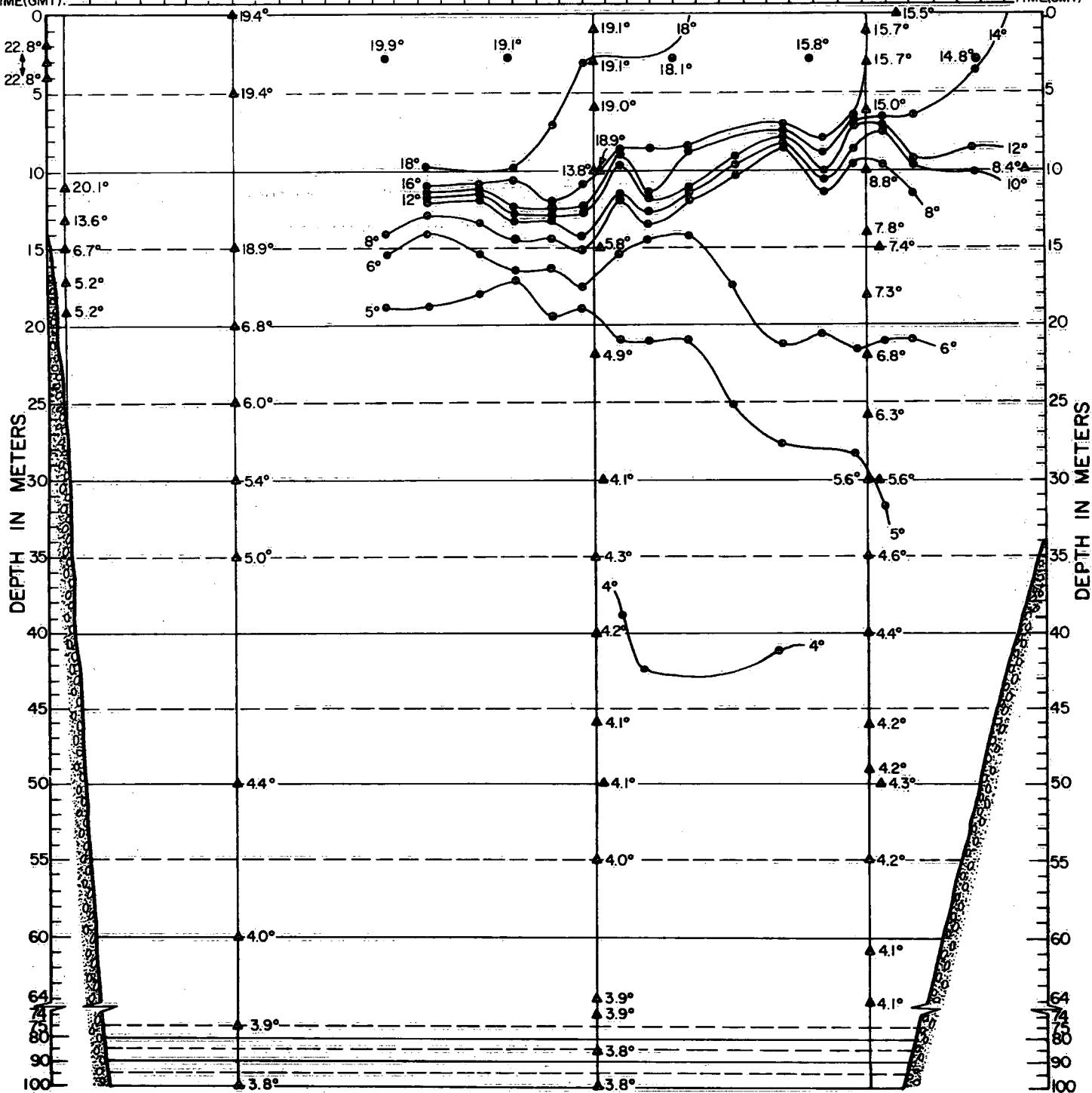
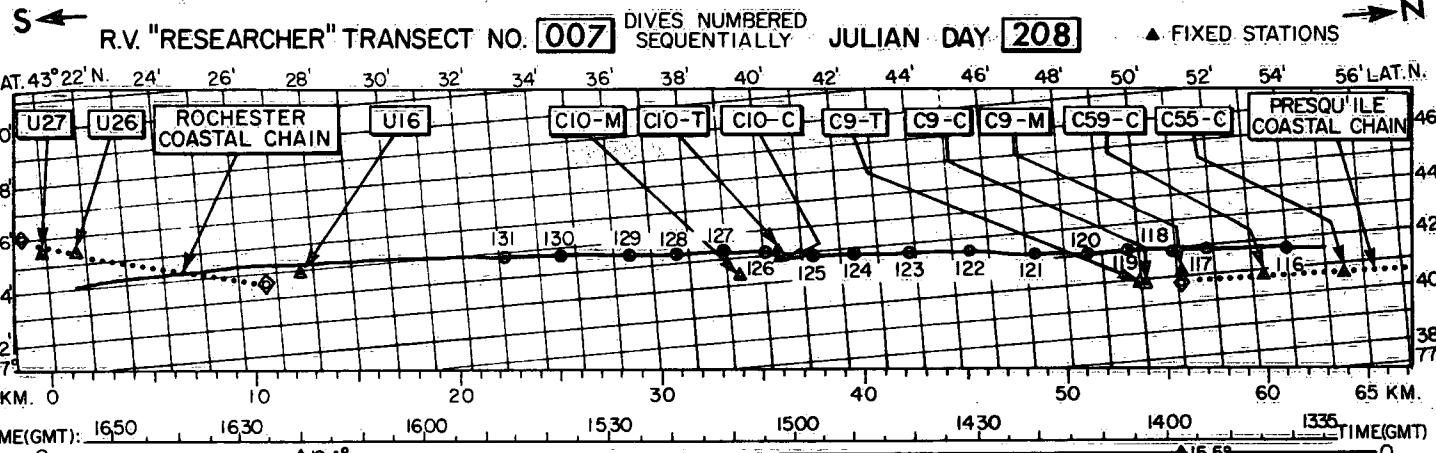
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## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



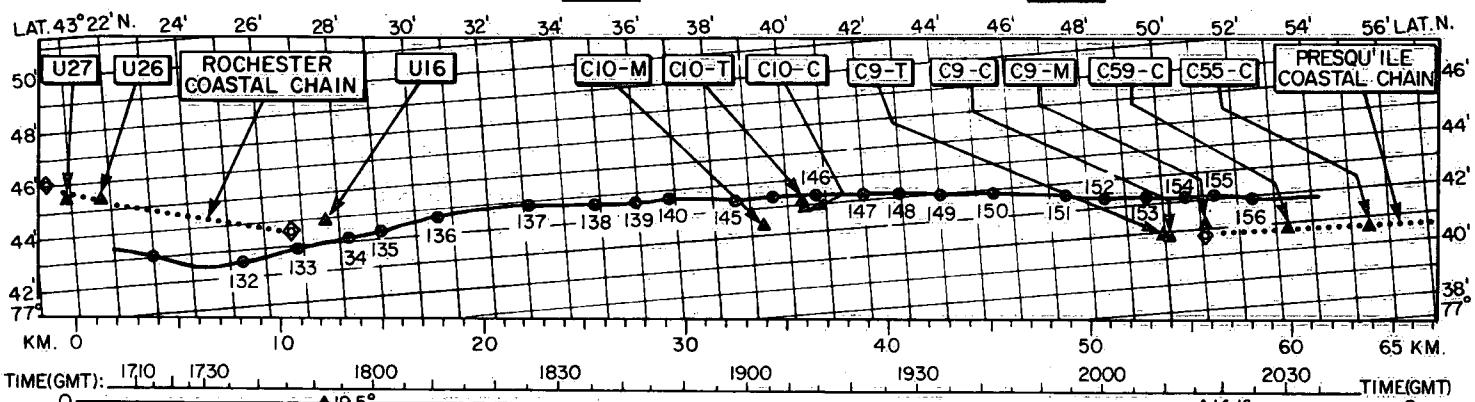
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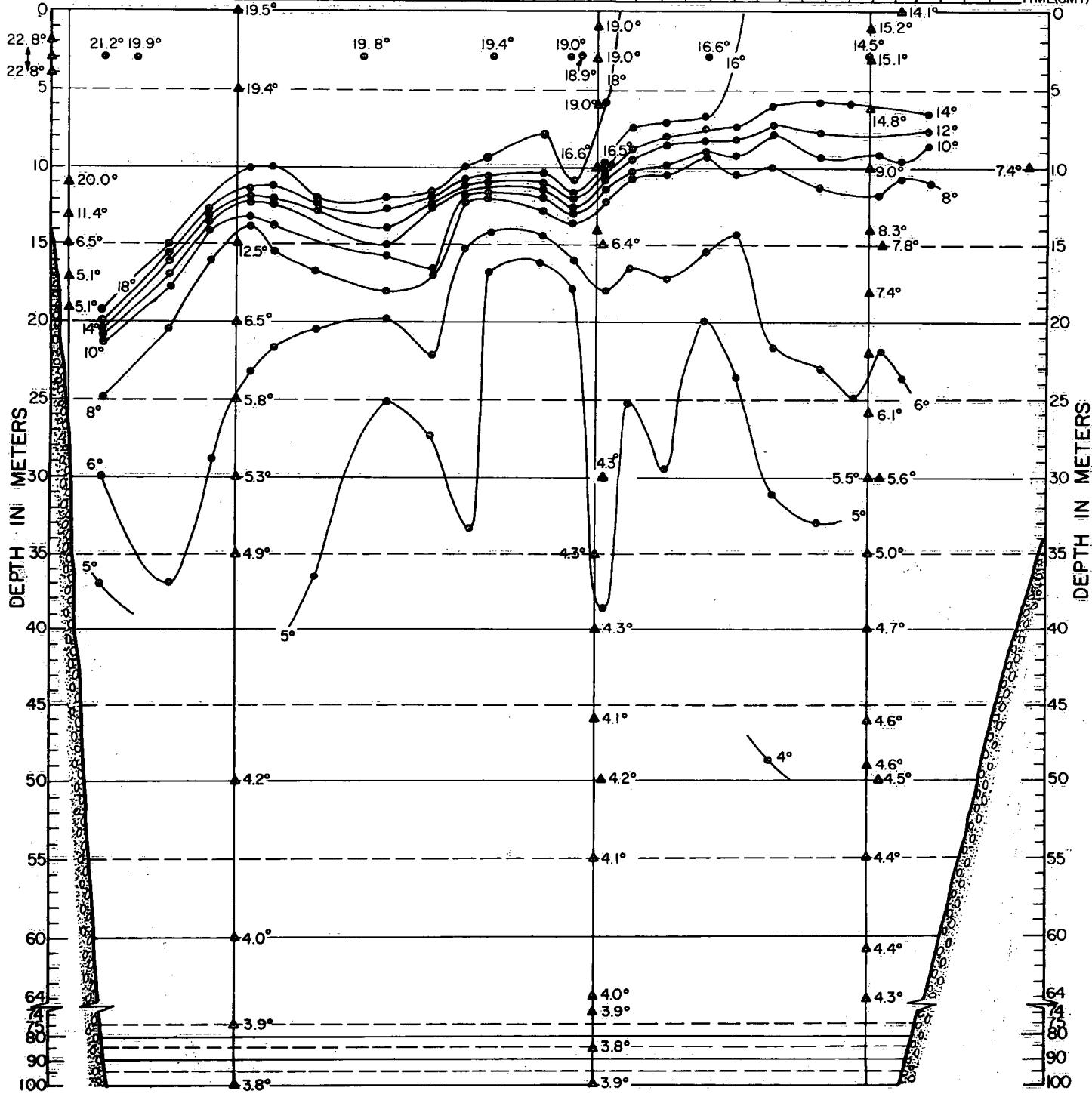
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JULIAN DAY 208

▲ FIXED STATIONS N →

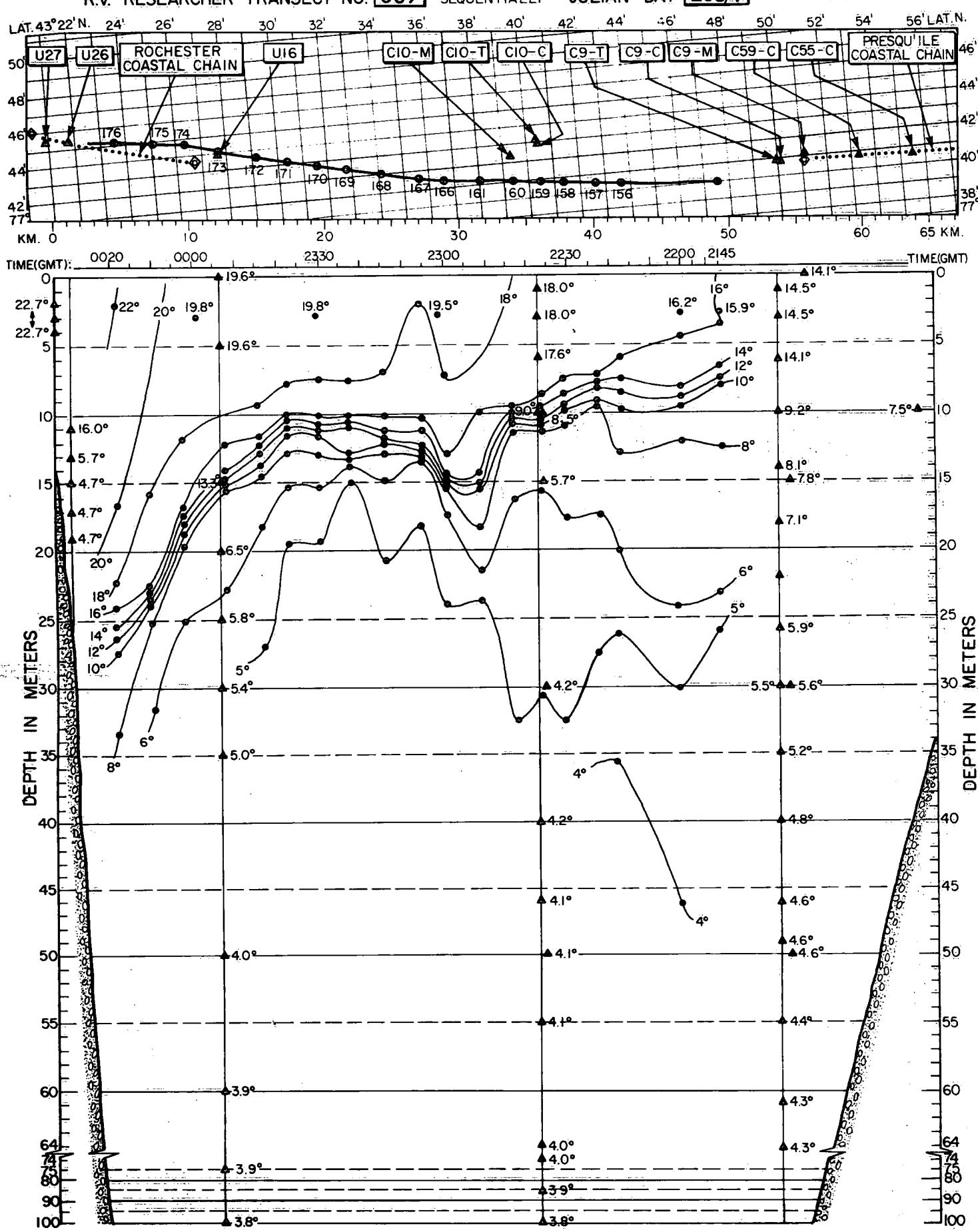


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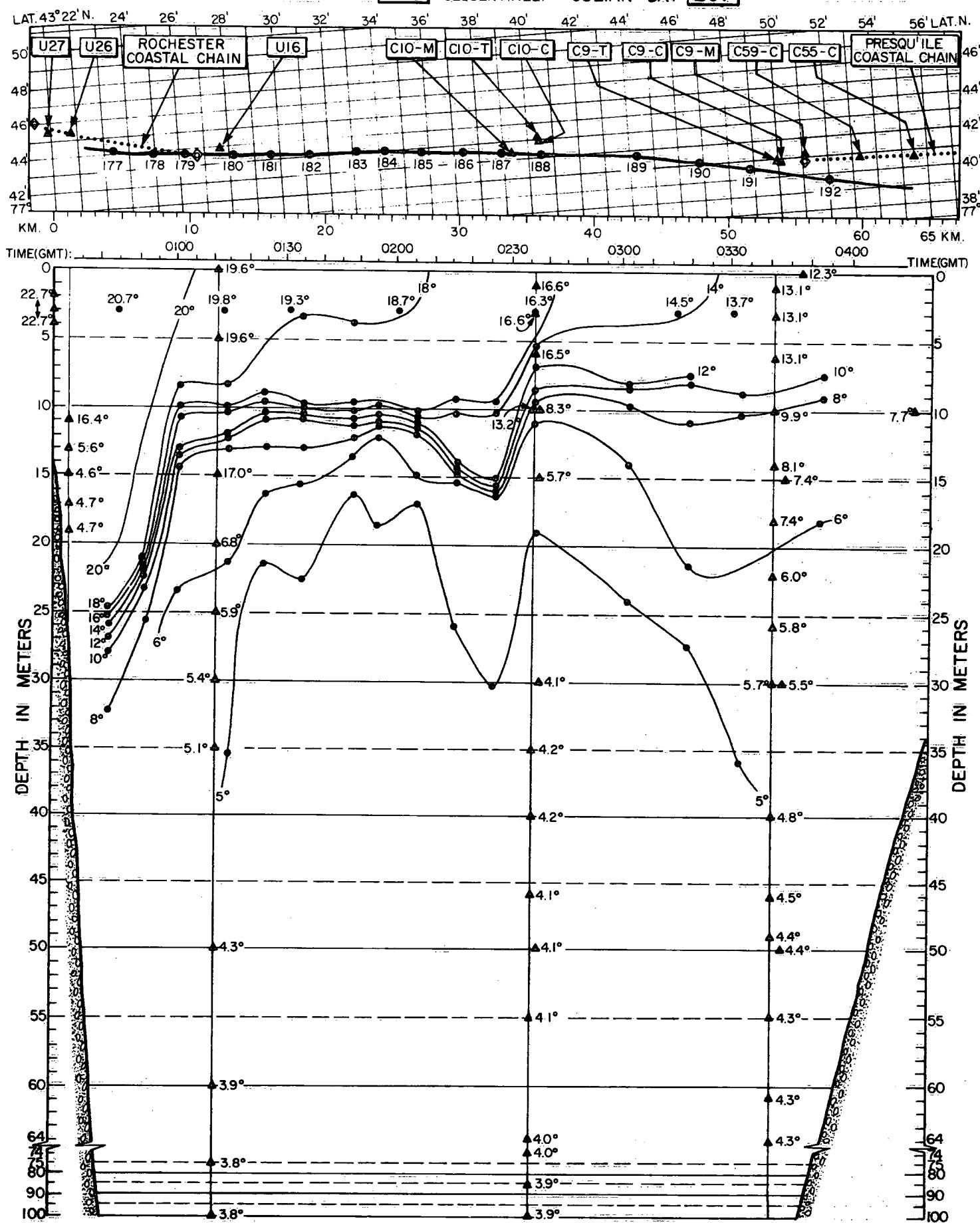
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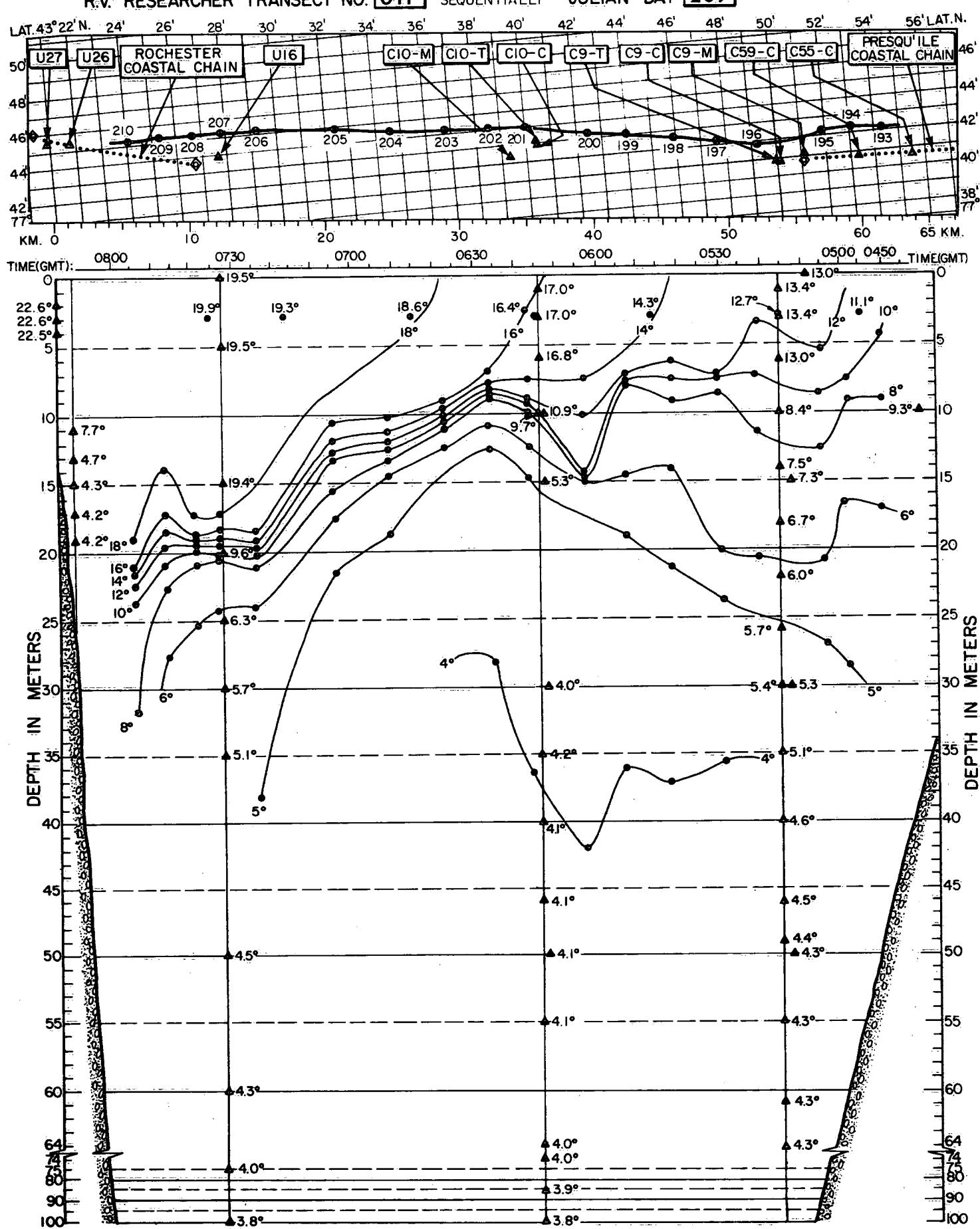
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▲ FIXED STATIONS



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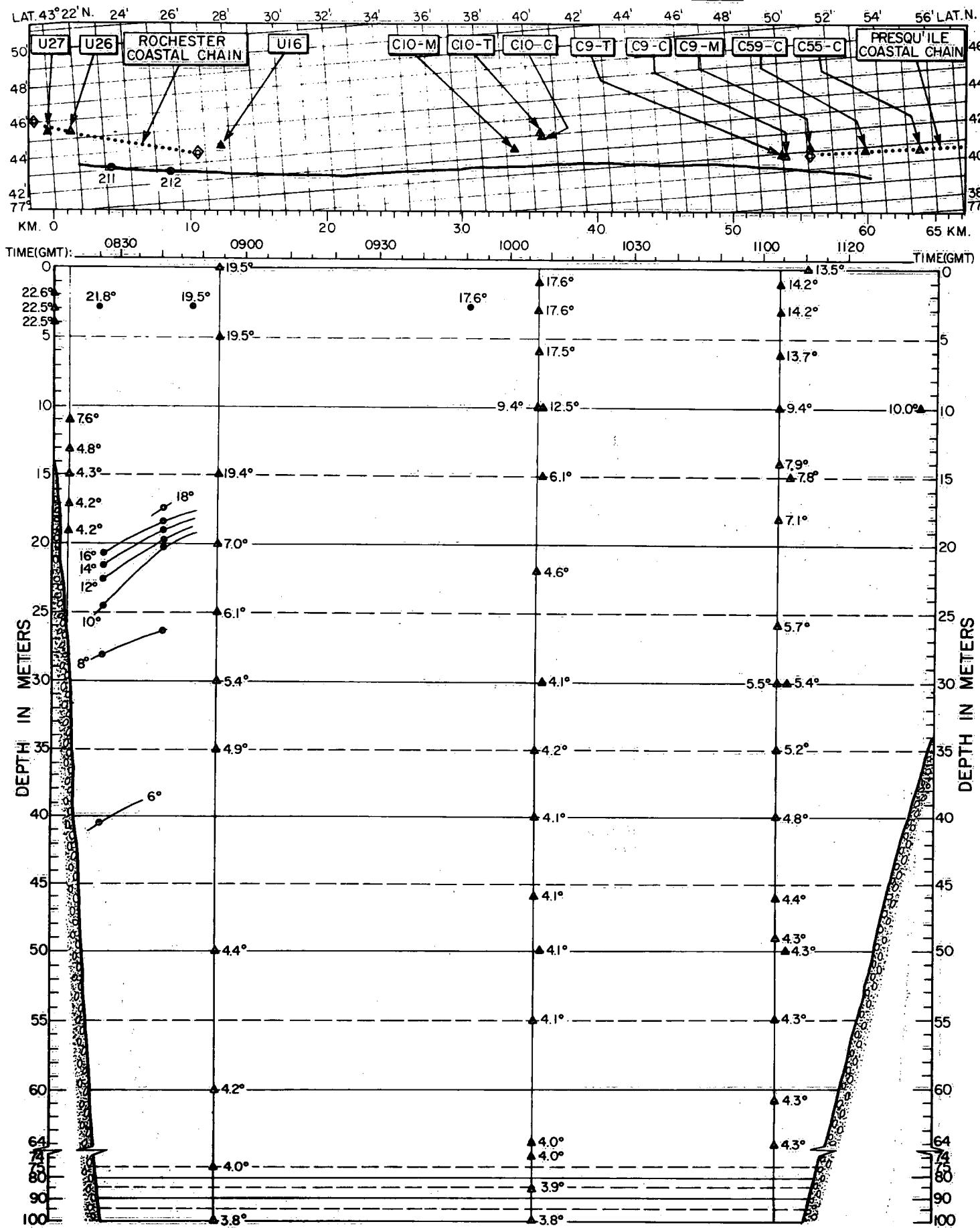
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DIVES NUMBERED  
SEQUENTIALLY

JULIAN DAY 209

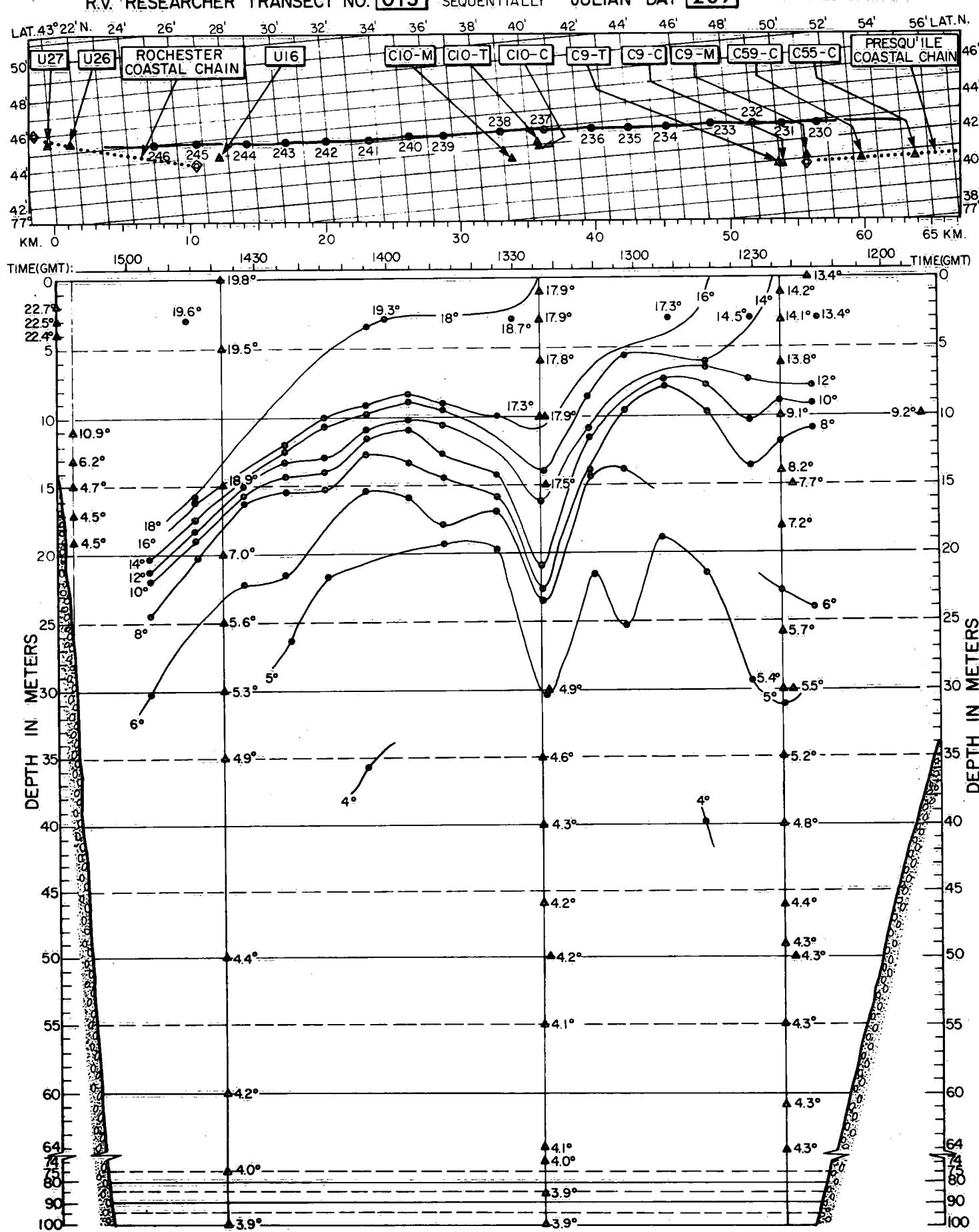
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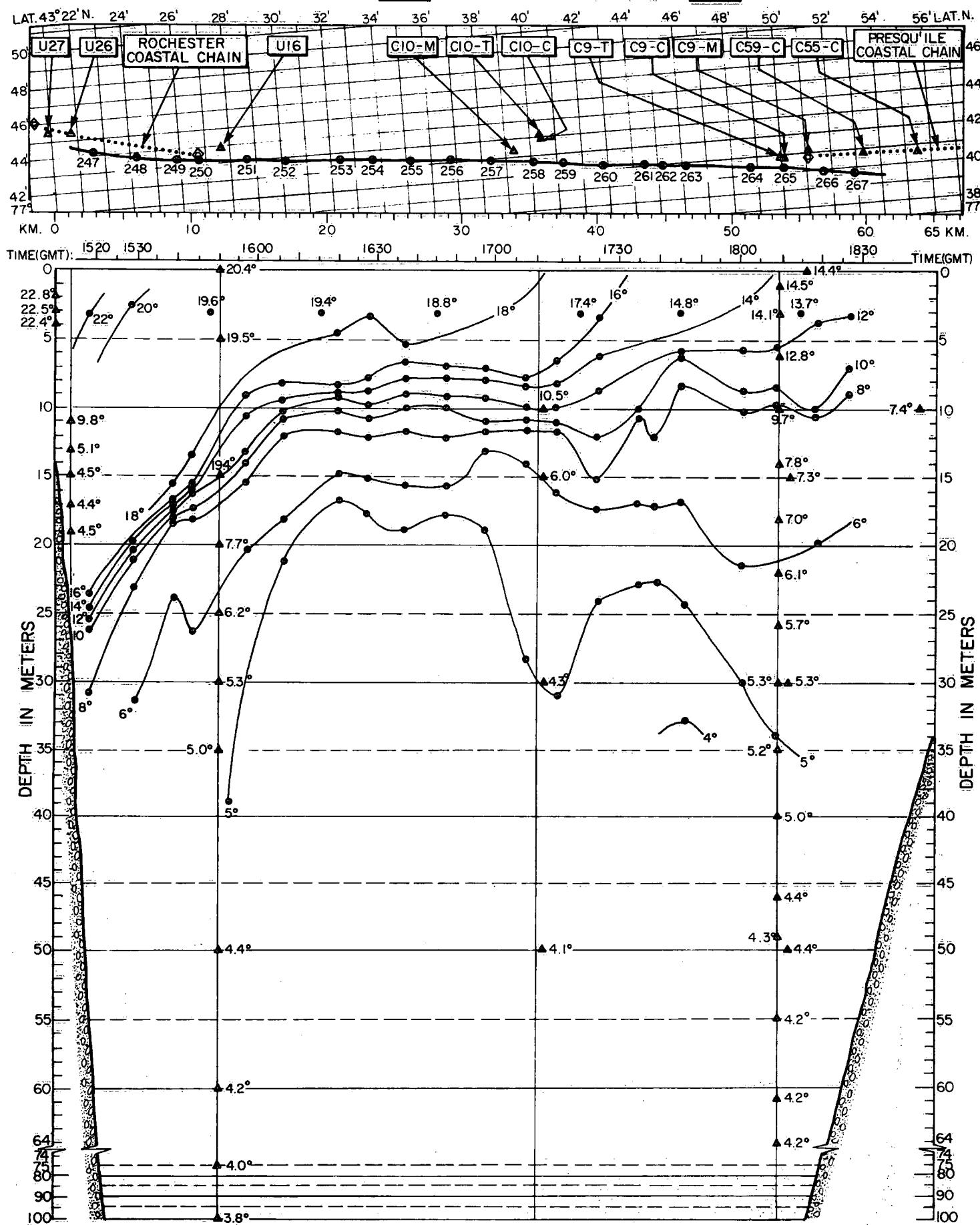
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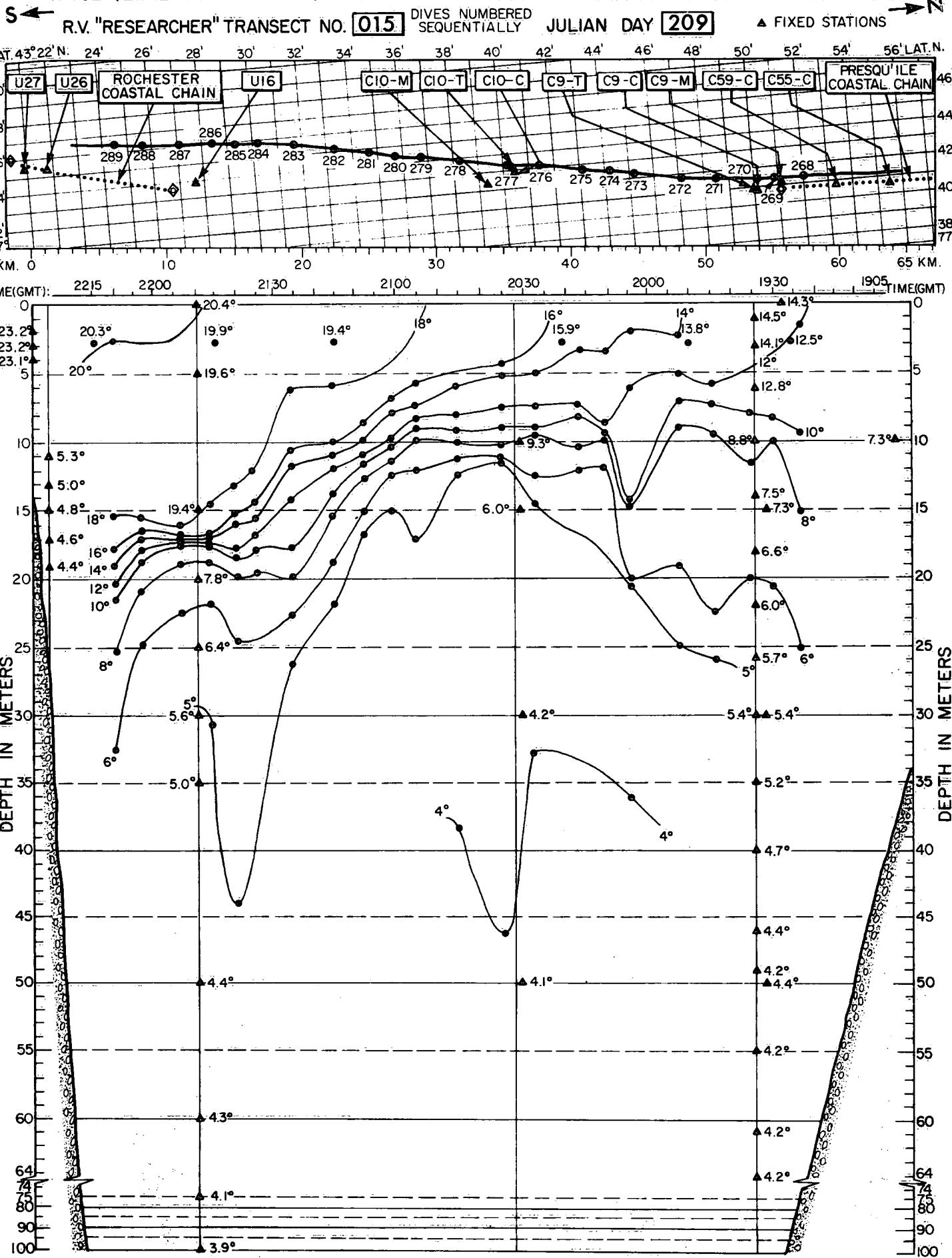


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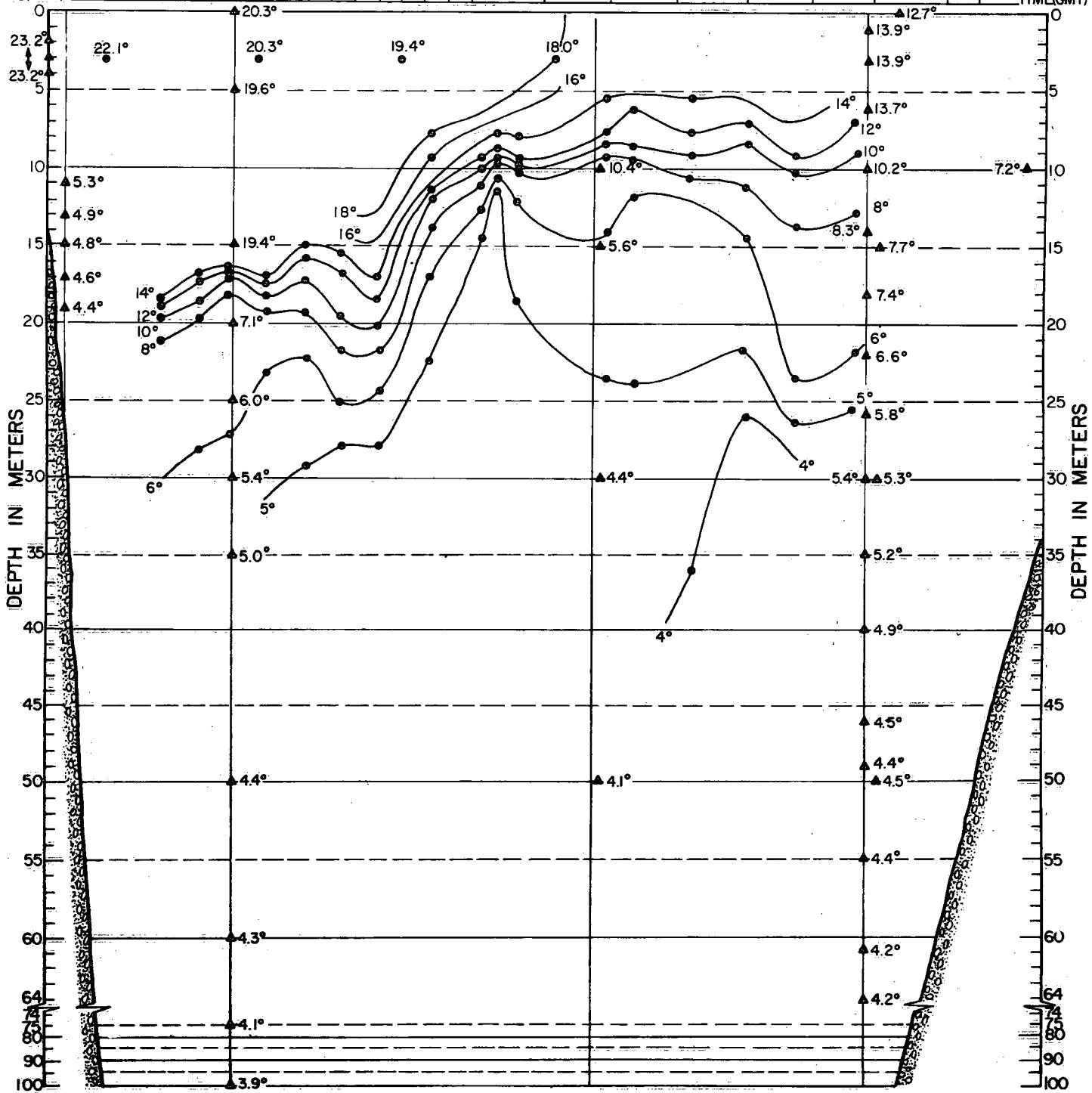
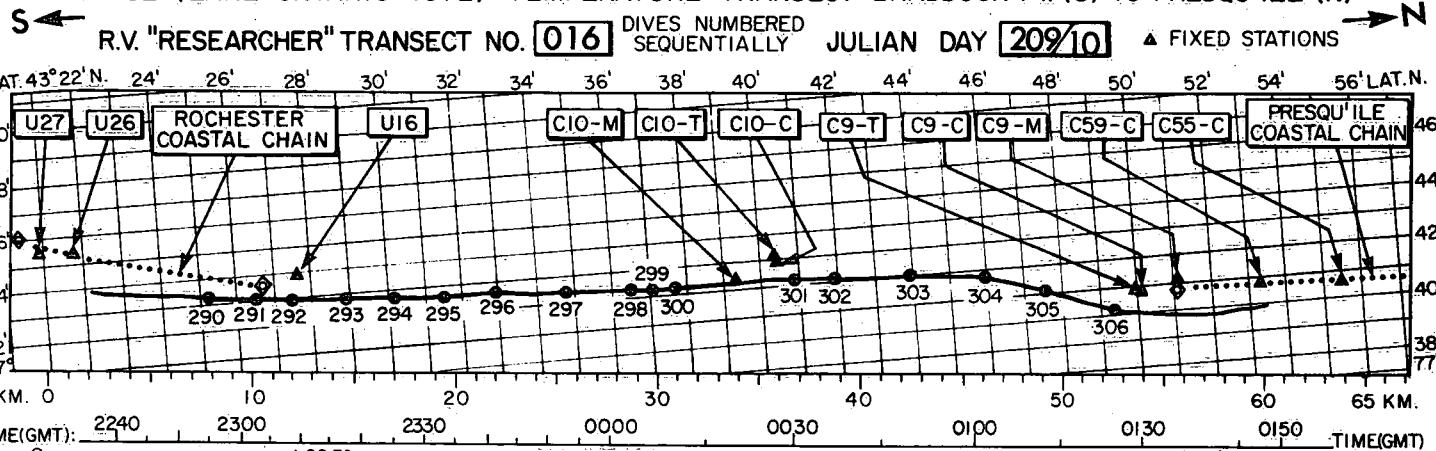
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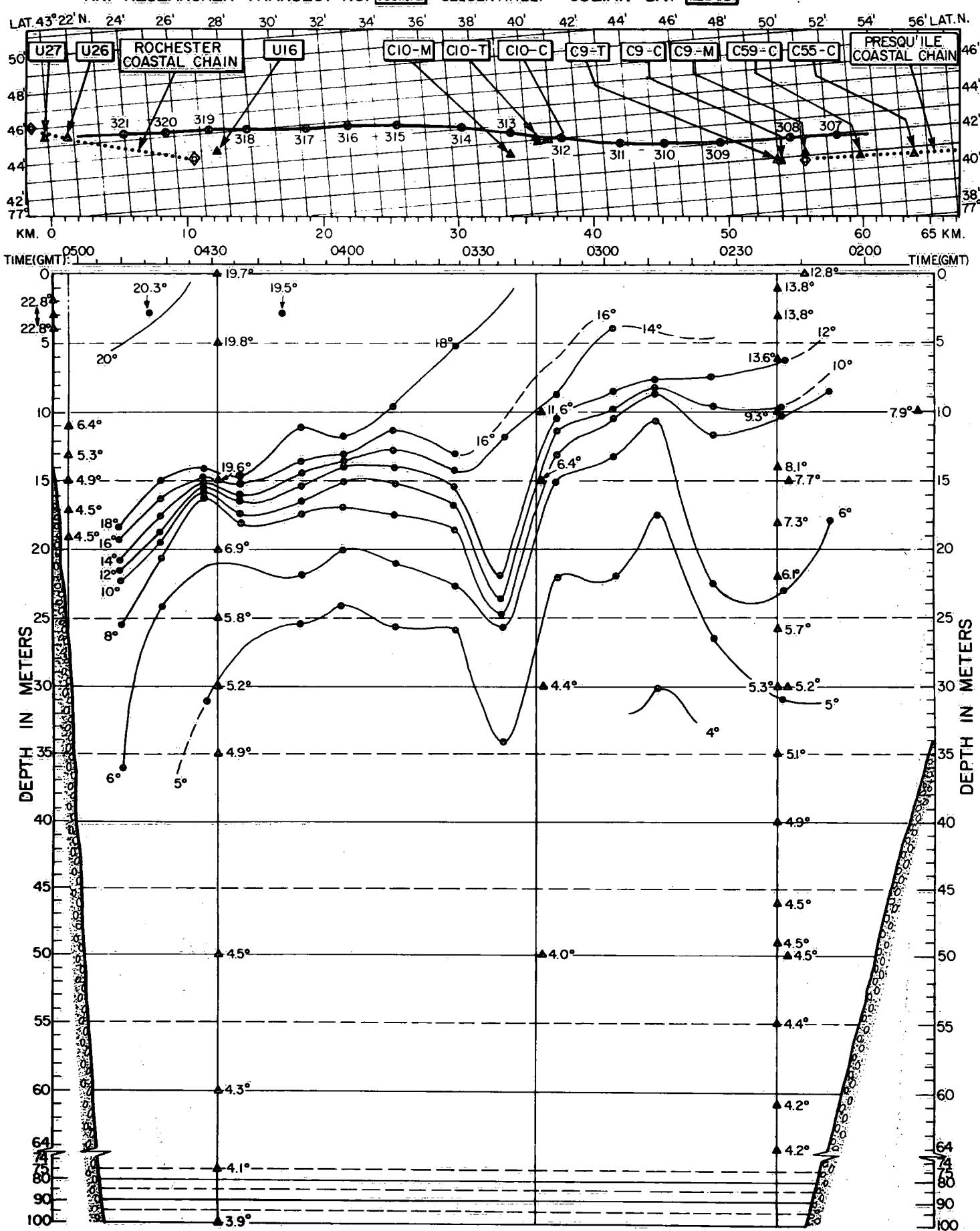


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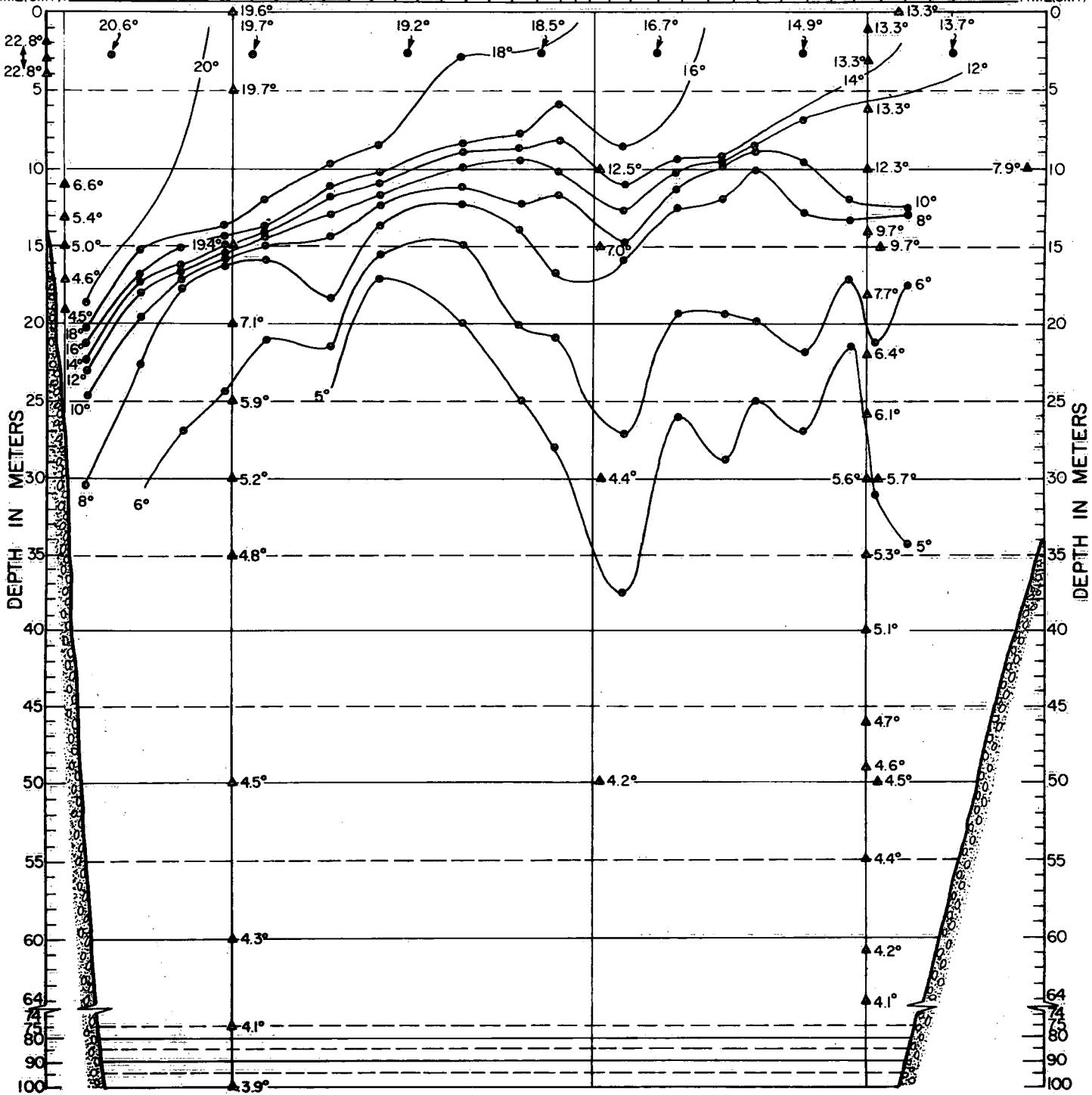
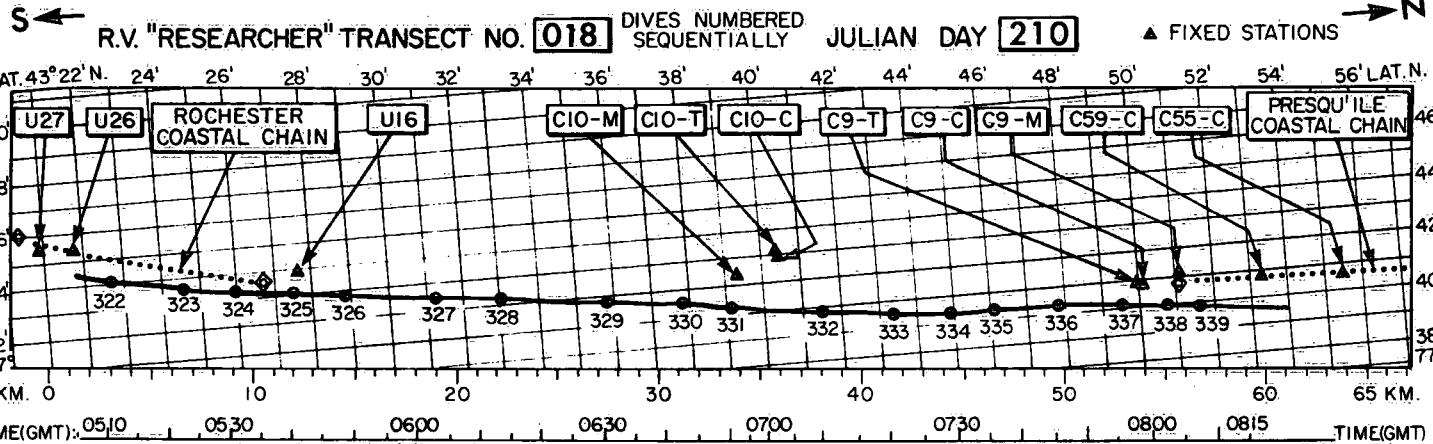


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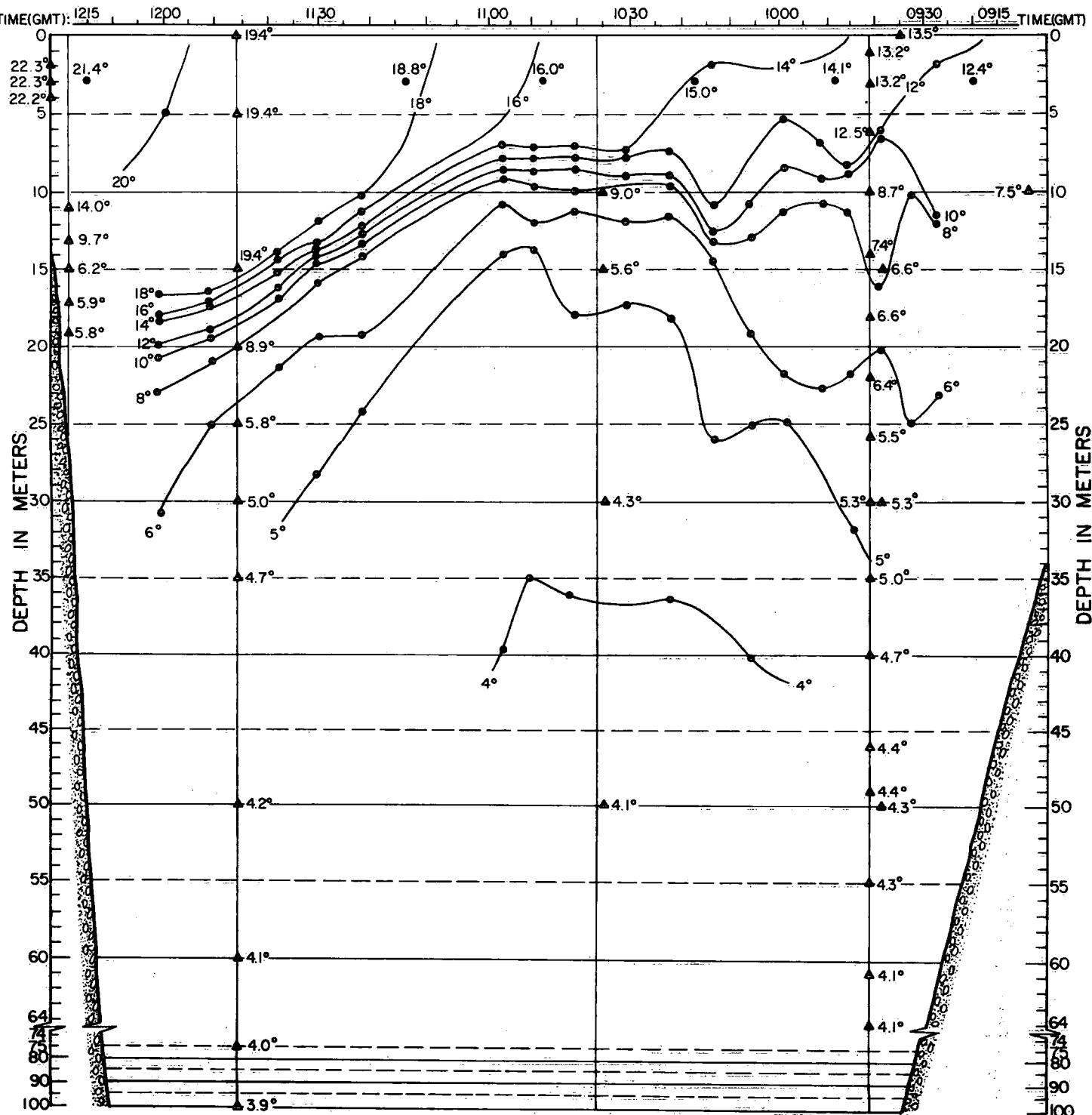
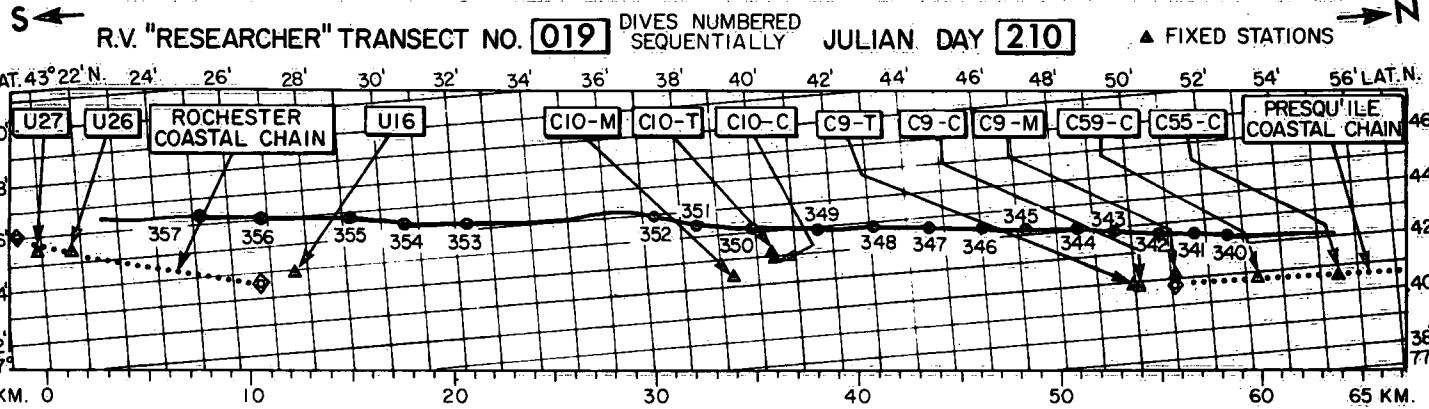
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▲ FIXED STATIONS



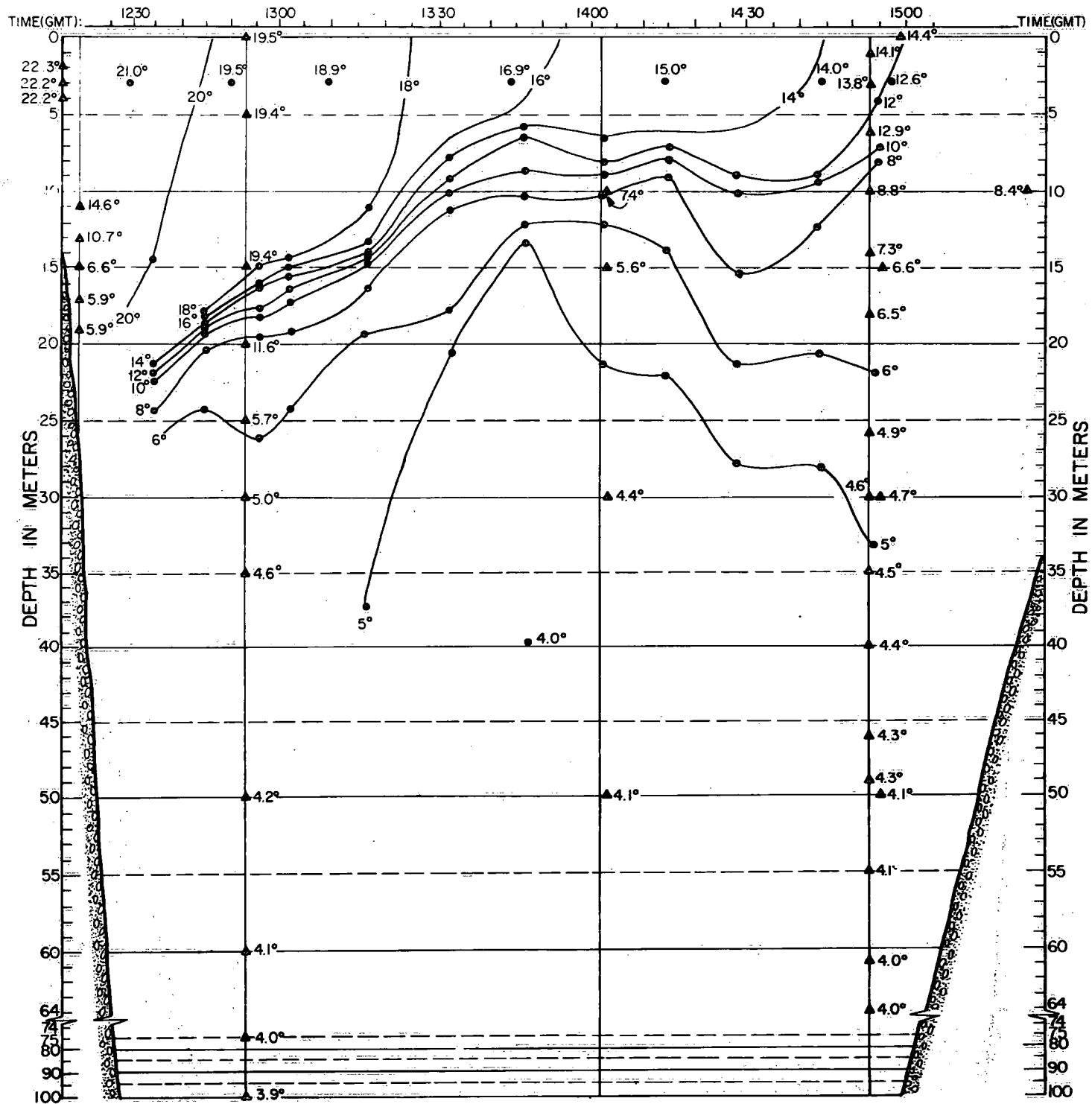
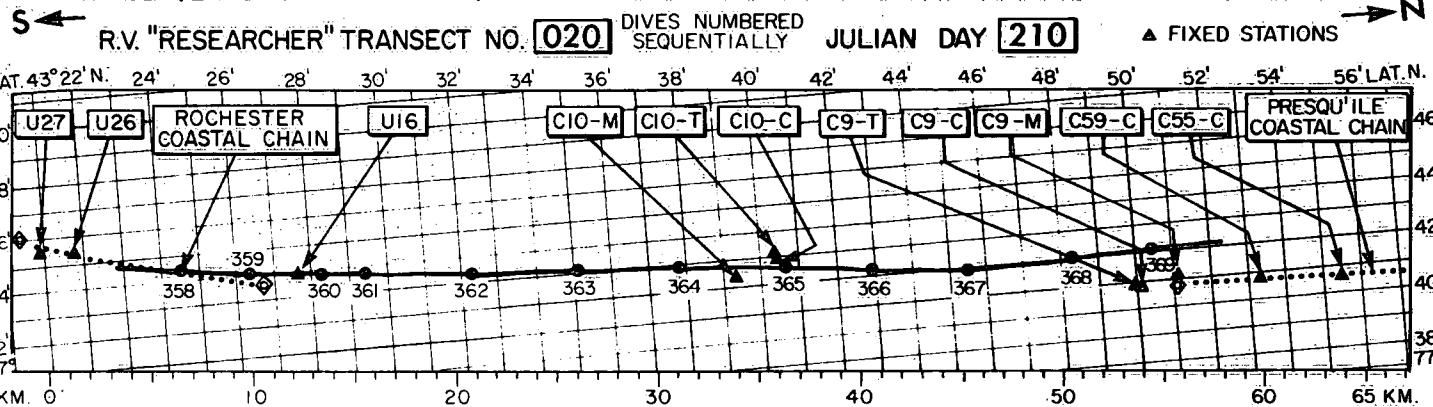
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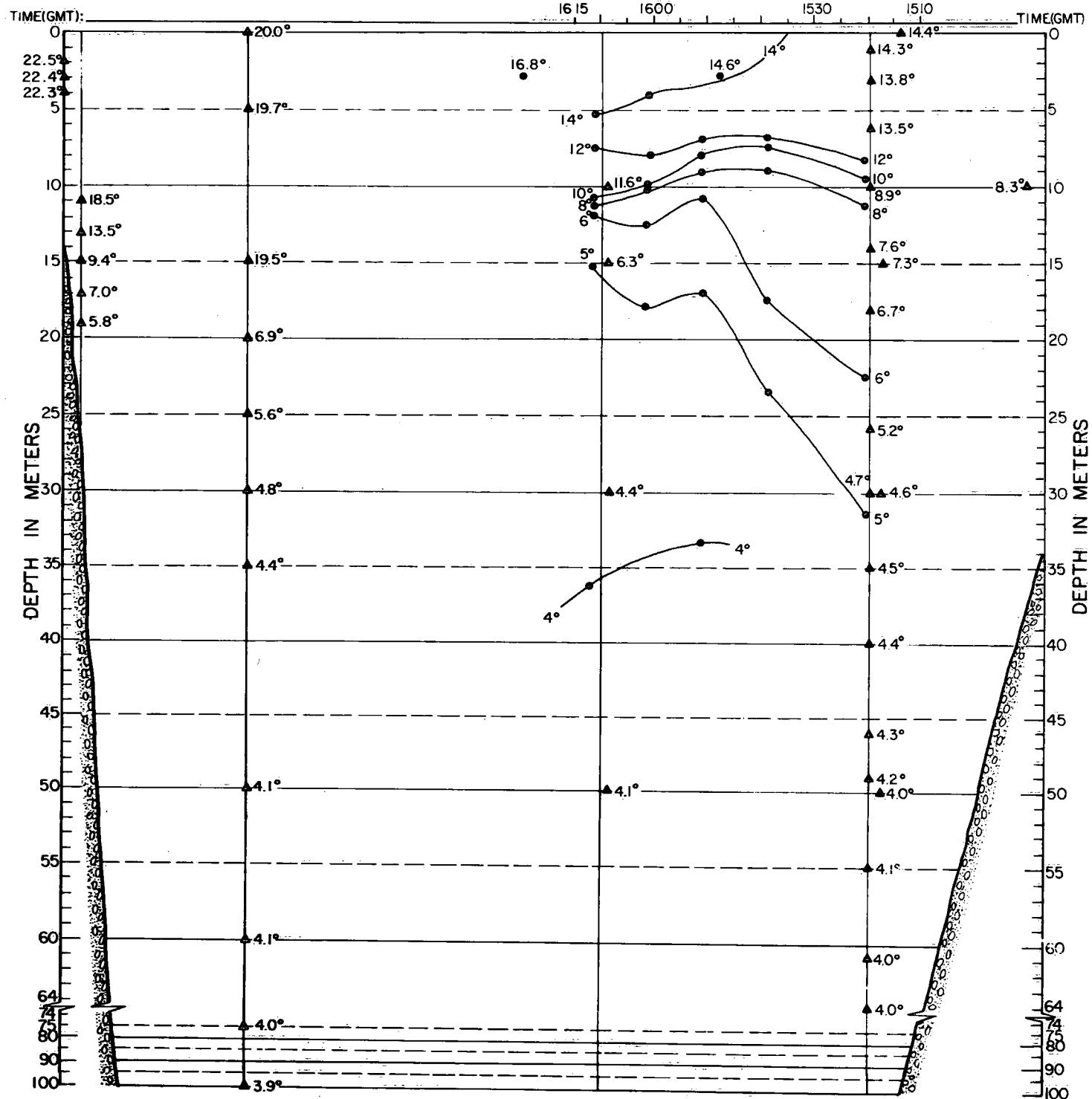
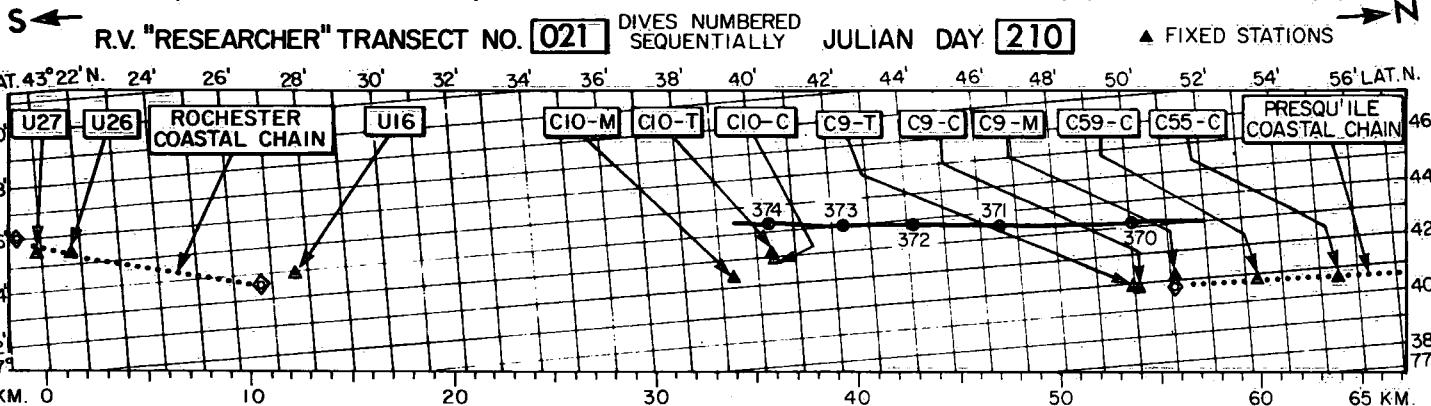
## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



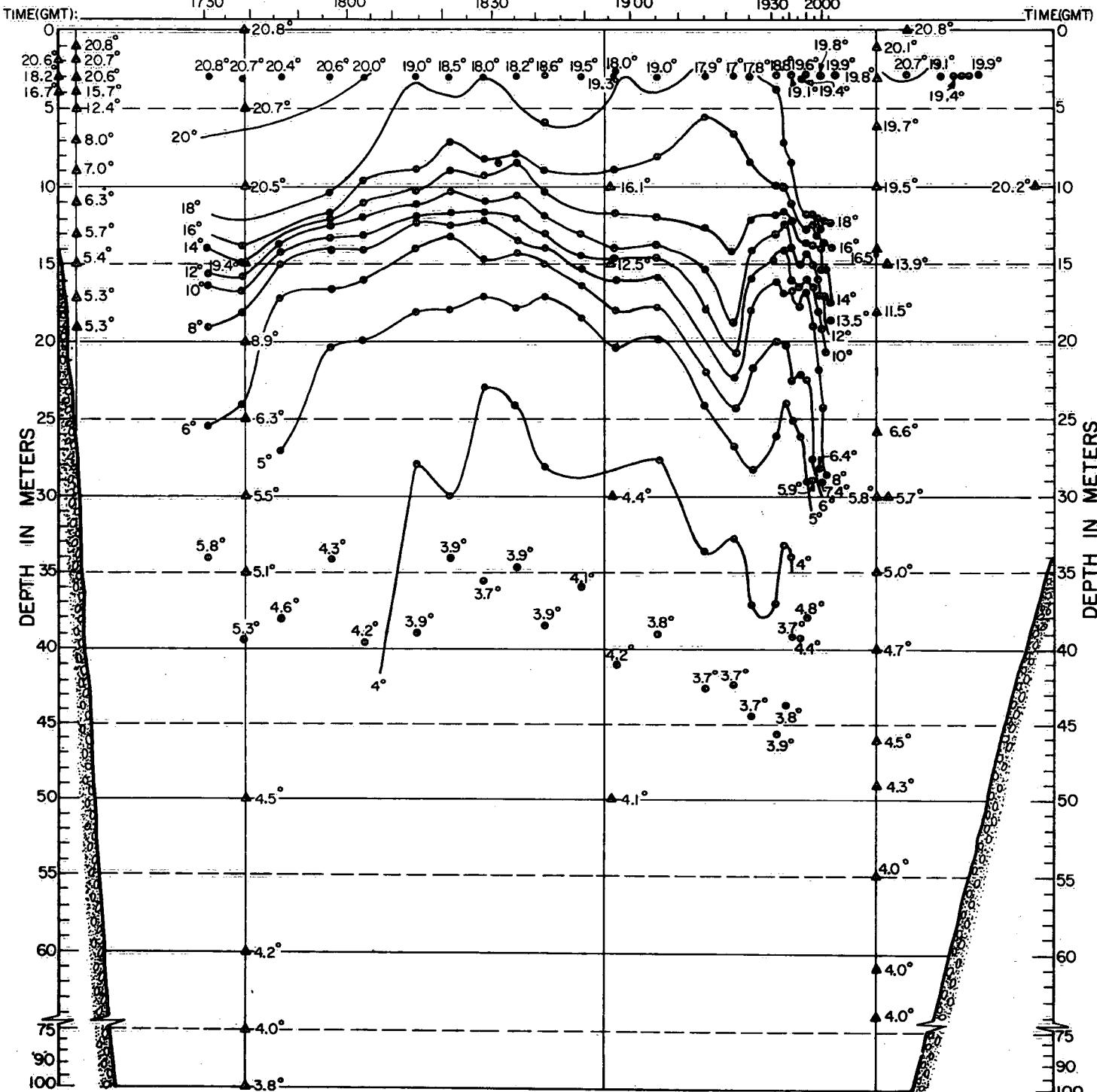
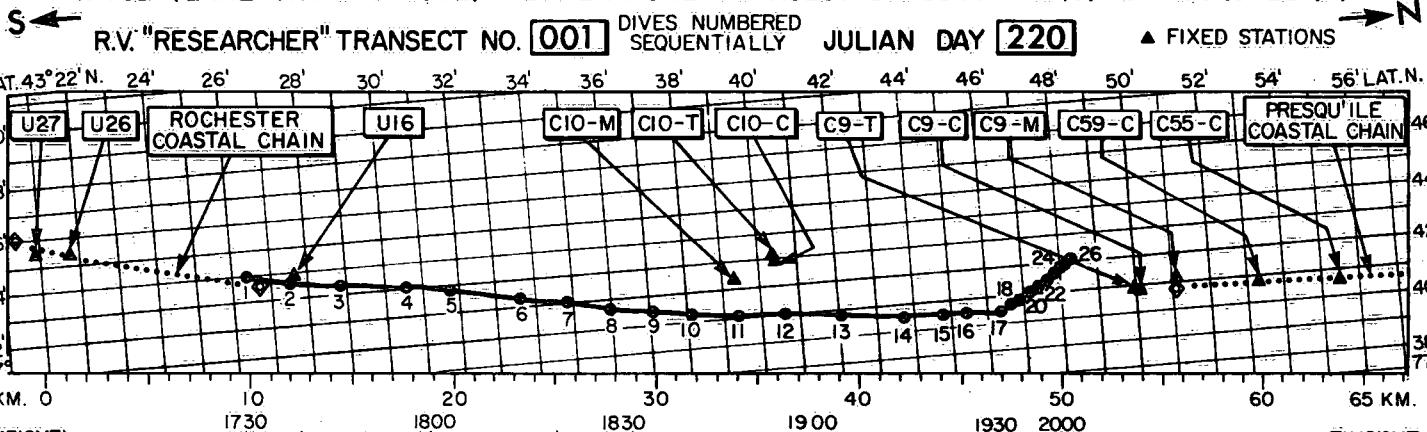
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



**Table 5.3. Times (GMT) of Temperature Readings at Fixed Stations and Depths (Fig. 5.1) Entered on the  
Braddock Pt. to Presqu'ile Transect Diagrams: 7-11 August (Julian Days 220-224, see Diagrams)**

Transect No.	U27, U26	U16	C10-C	C9-T, C9-C	C9-M	C55-C
1	1736	1736	1850	2010	2010	2010
2	2142	2142	2150	2130	2120	2120
3	0000	0000	0110	0210	0220	0230
4	0548	0518	0400	0310	0300	0250
5	0554	0642	0800	0900	0900	0910
6	1200	1142	1030	0940	0930	0930
7	1224	1300	1430	1520	1530	1550
8	1848	1824	1710	1610	1600	1600
9	1906	1930	2100	2200	2210	2220
10	0142	0106	2350	2250	2240	2230
11	0148	0224	0340	0430	0440	0500
12	0812	0730	0610	0510	0500	0500
13	0818	0848	1010	1110	1120	1130
14	1500	1430	1300	1200	1150	1140
15	1518	1548	1840	1950	1950	2000
16	2306		2130	2030	2020	2020
17	0118		0310	0410	0410	0410
18	0742		0600	0500	0450	0440
19	0806		1000	1100	1110	1110
20	1424		1240	1140	1130	1130
21	1430		1620	1710	1710	1720
22	2000		1820	1740	1730	1730
23	2024		2220	2320	2320	2330
24	0300		0110	2350	2350	2340
25	0318		0520	0620	0630	0650
26	1042		0830	0730	0720	0700

## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



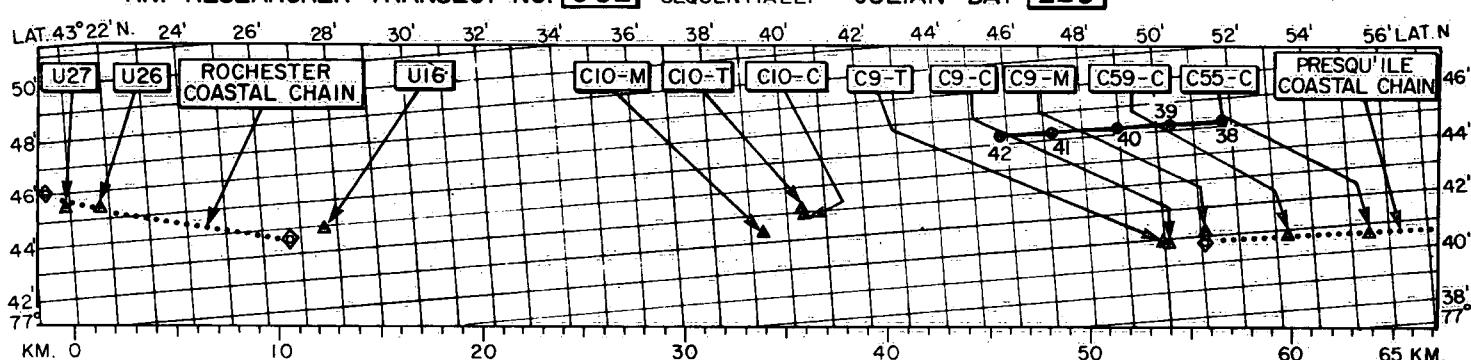
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ←

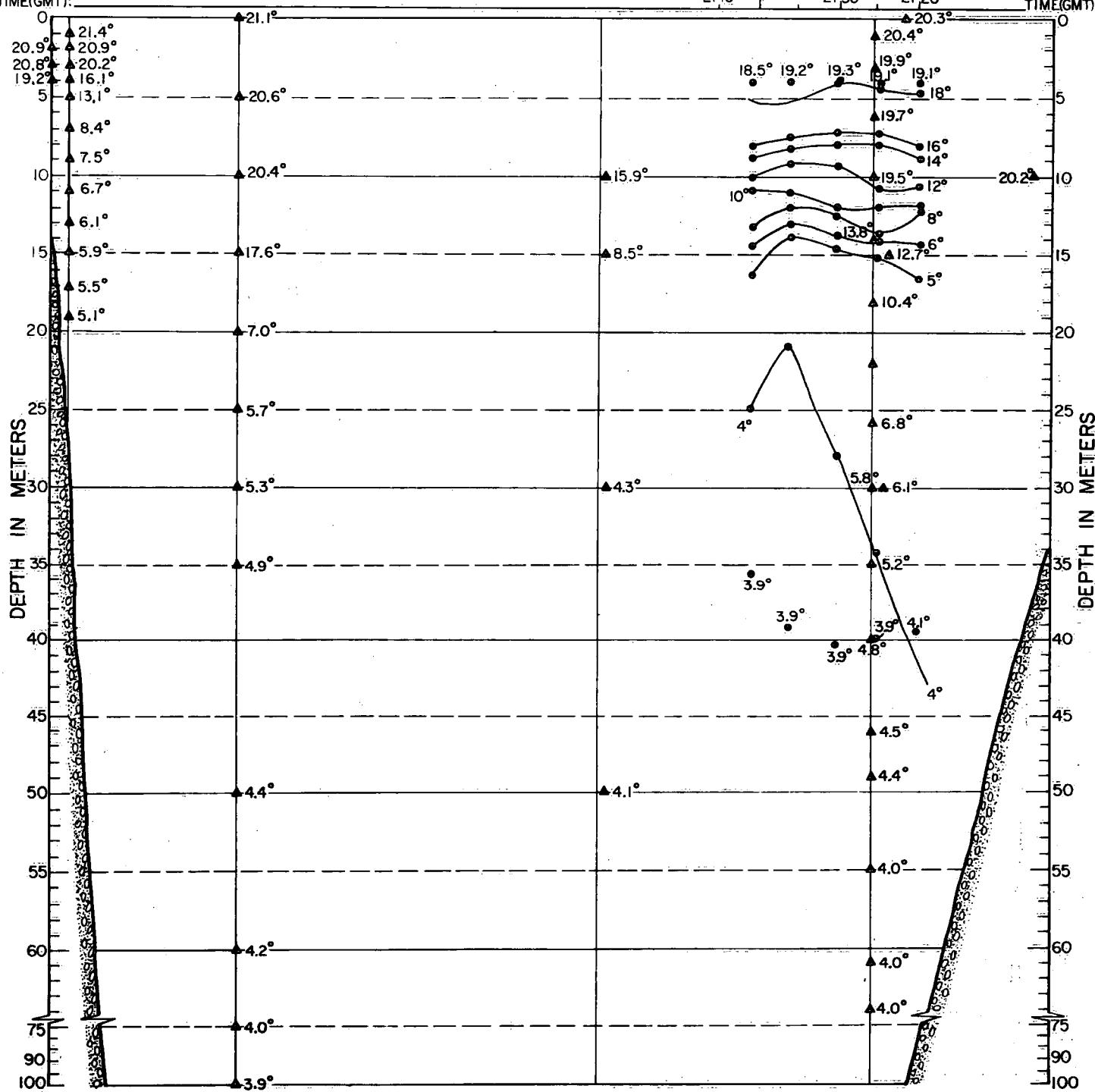
R.V. "RESEARCHER" TRANSECT NO. 002 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 220

→ N

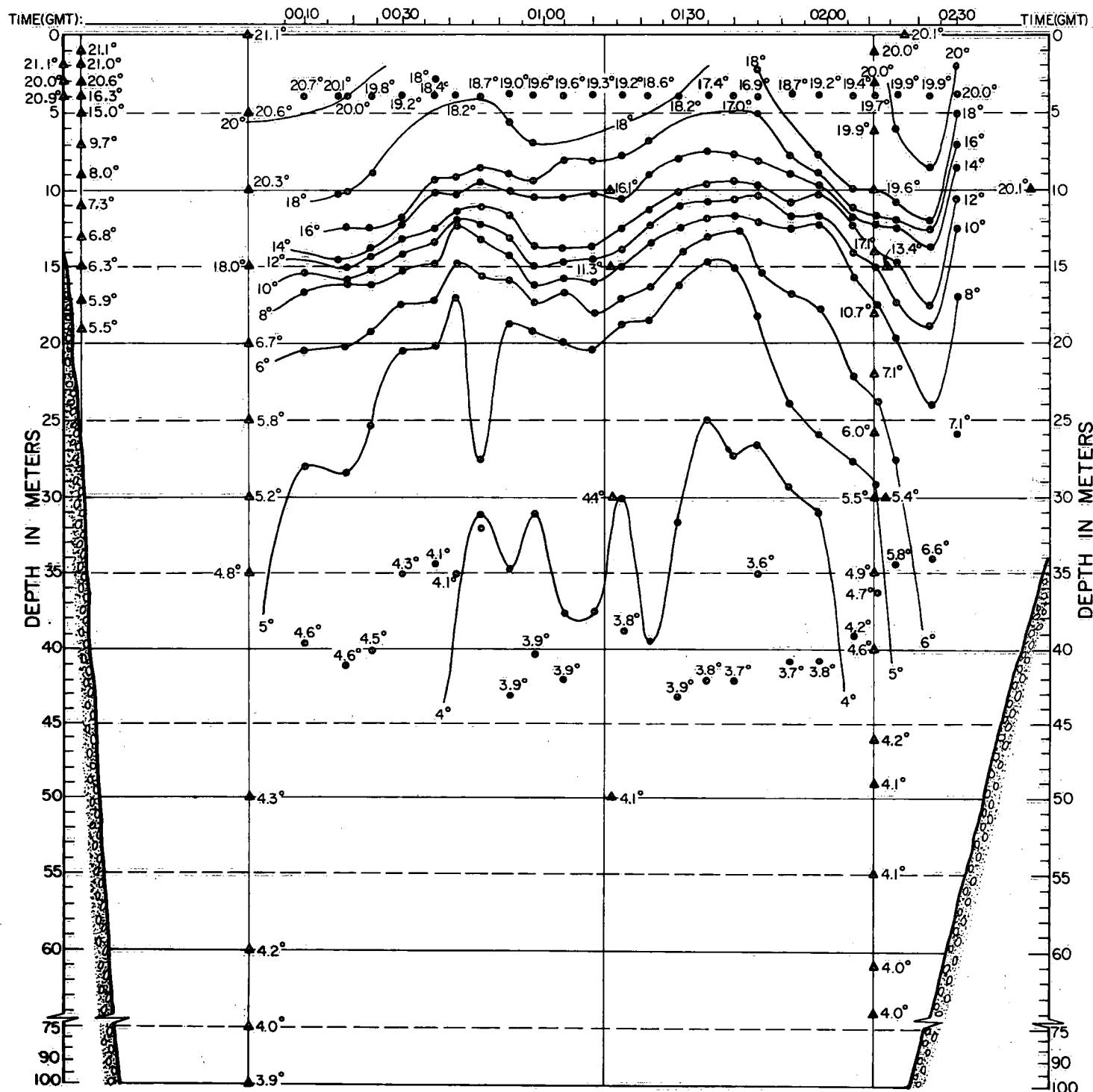
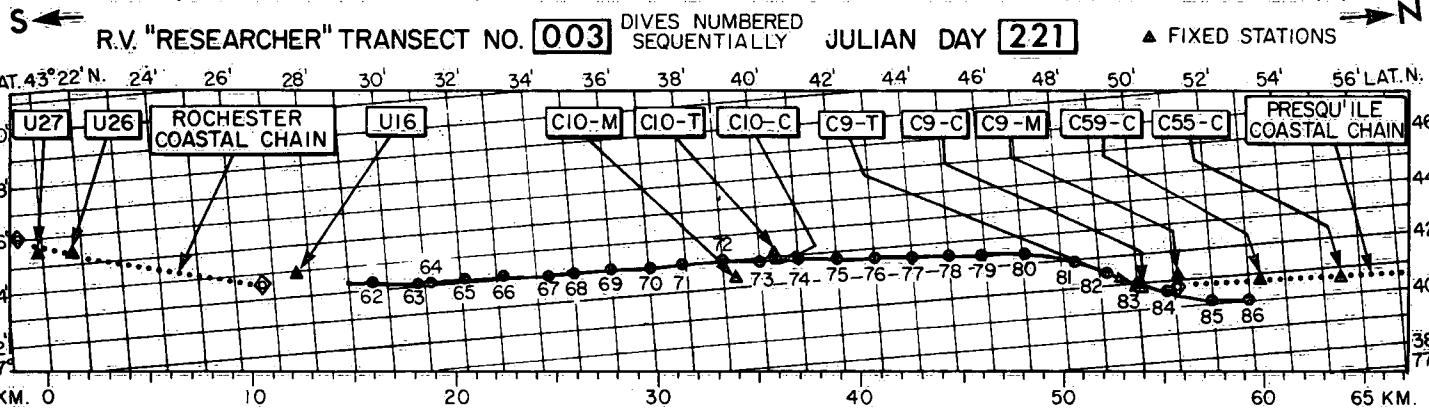
▲ FIXED STATIONS



TIME(GMT):



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT (S) TO PRESQU'ILE (N)

S →

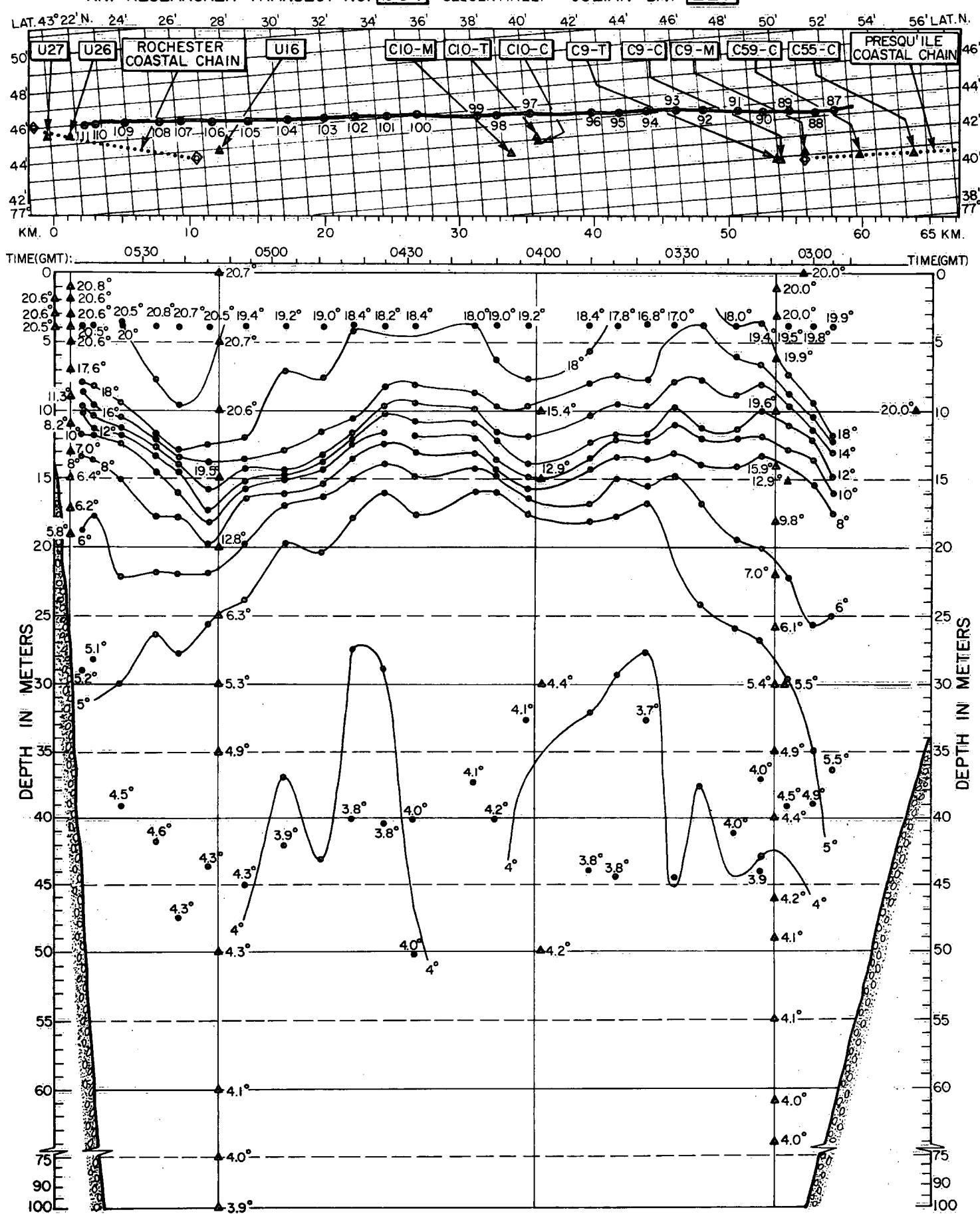
R.V. "RESEARCHER" TRANSECT NO. **004** DIVES NUMBERED SEQUENTIALLY JULIAN DAY **221**

DIVES NUMBERED

JULIAN DAY 221

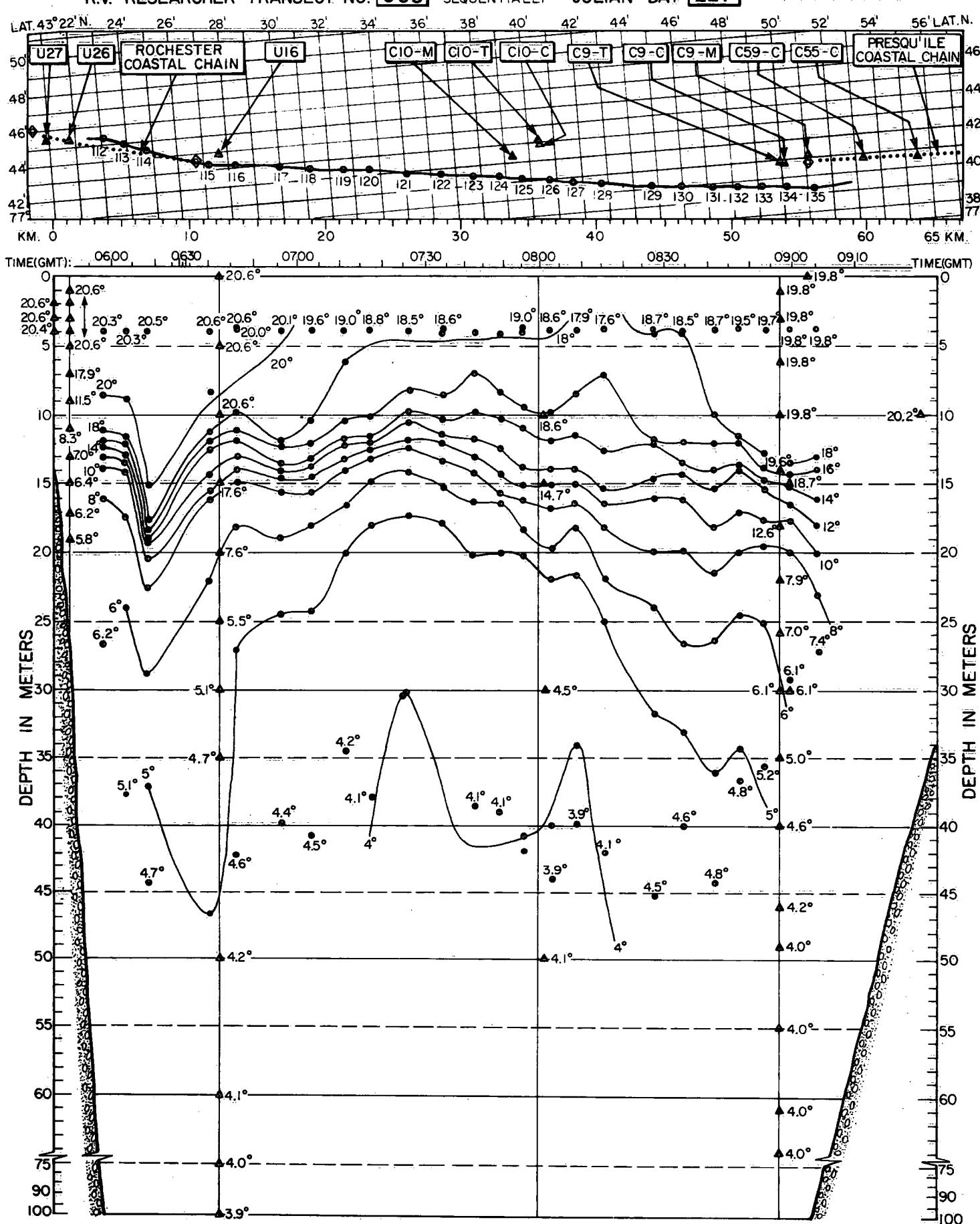
#### ▲ FIXED STATIONS

N



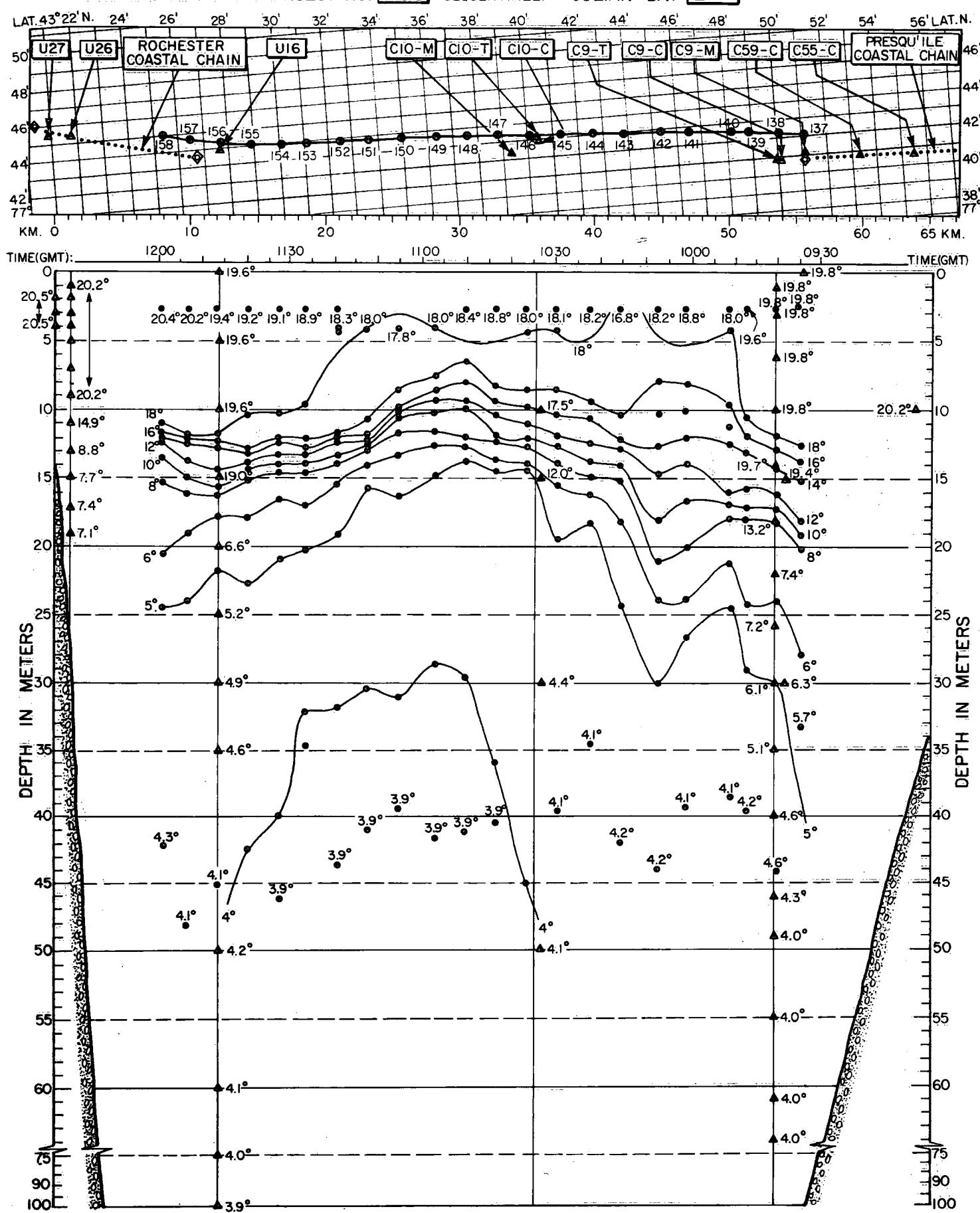
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R/V "RESEARCHER" TRANSECT NO 005 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 221 N → ▲ FIXED STATIONS



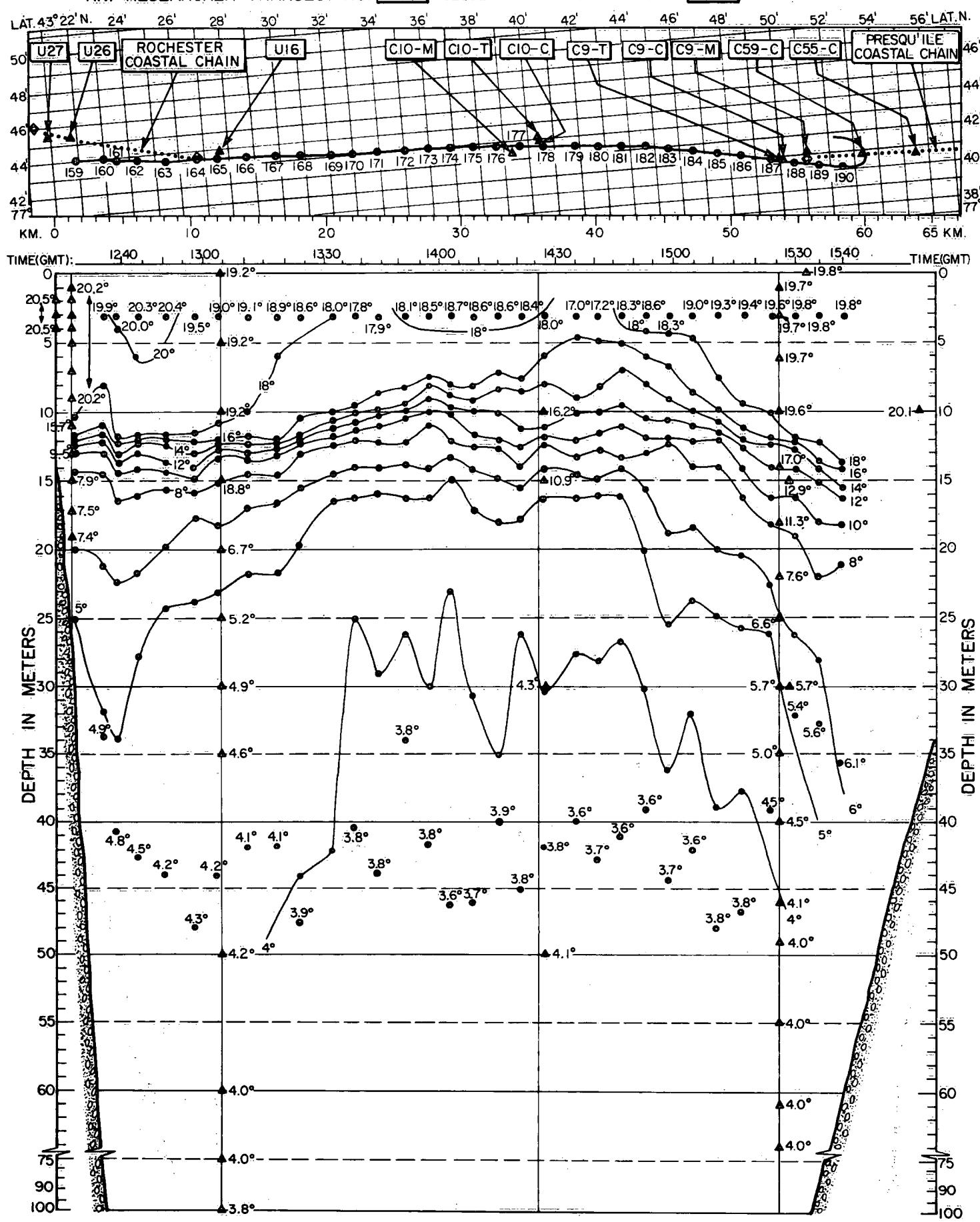
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 006 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 221 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 007 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 221 ▲ FIXED STATIONS → N



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S

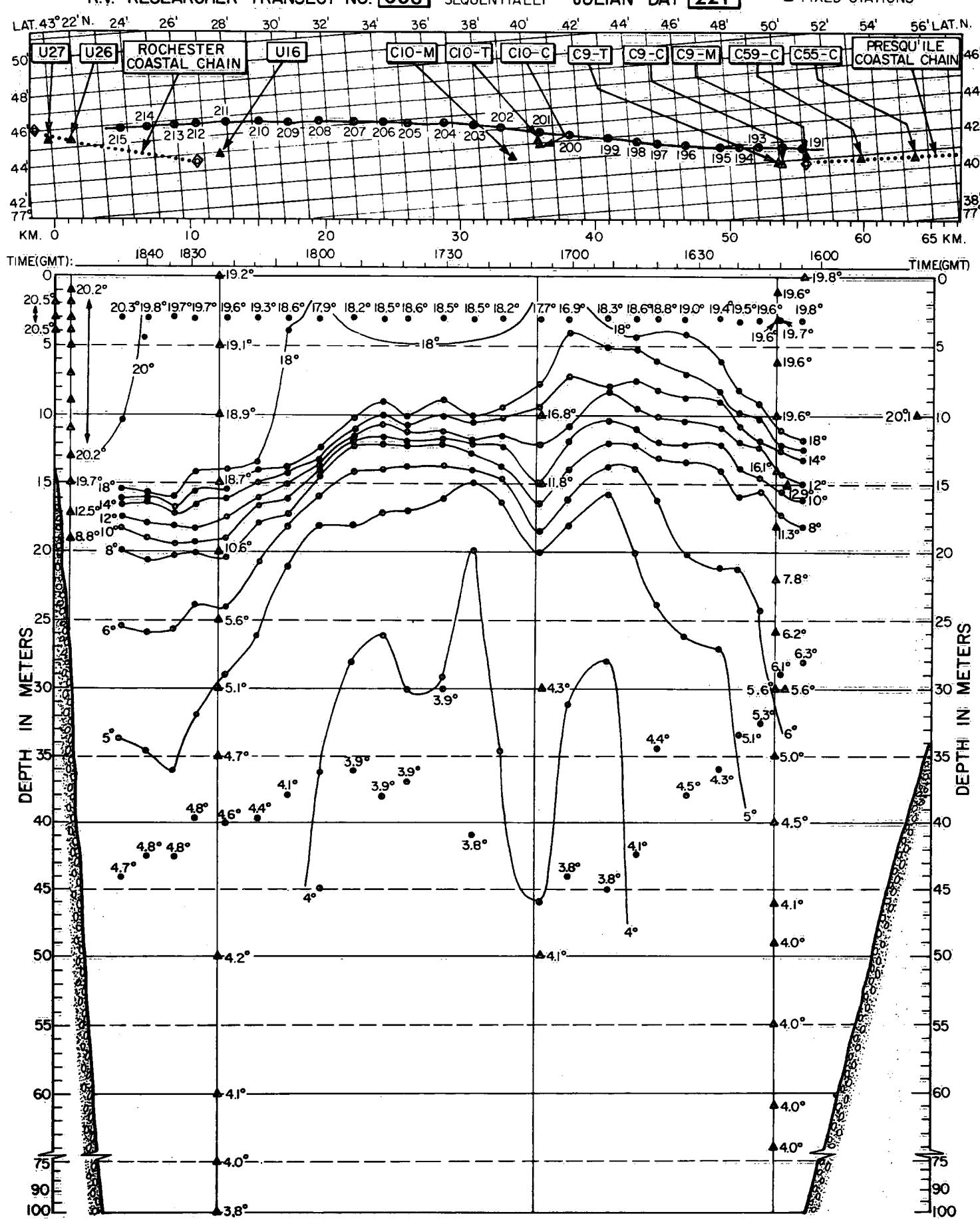
R.V. "RESEARCHER" TRANSECT NO. 008

DIVES NUMBERED  
SEQUENTIALLY

JULIAN DAY 221

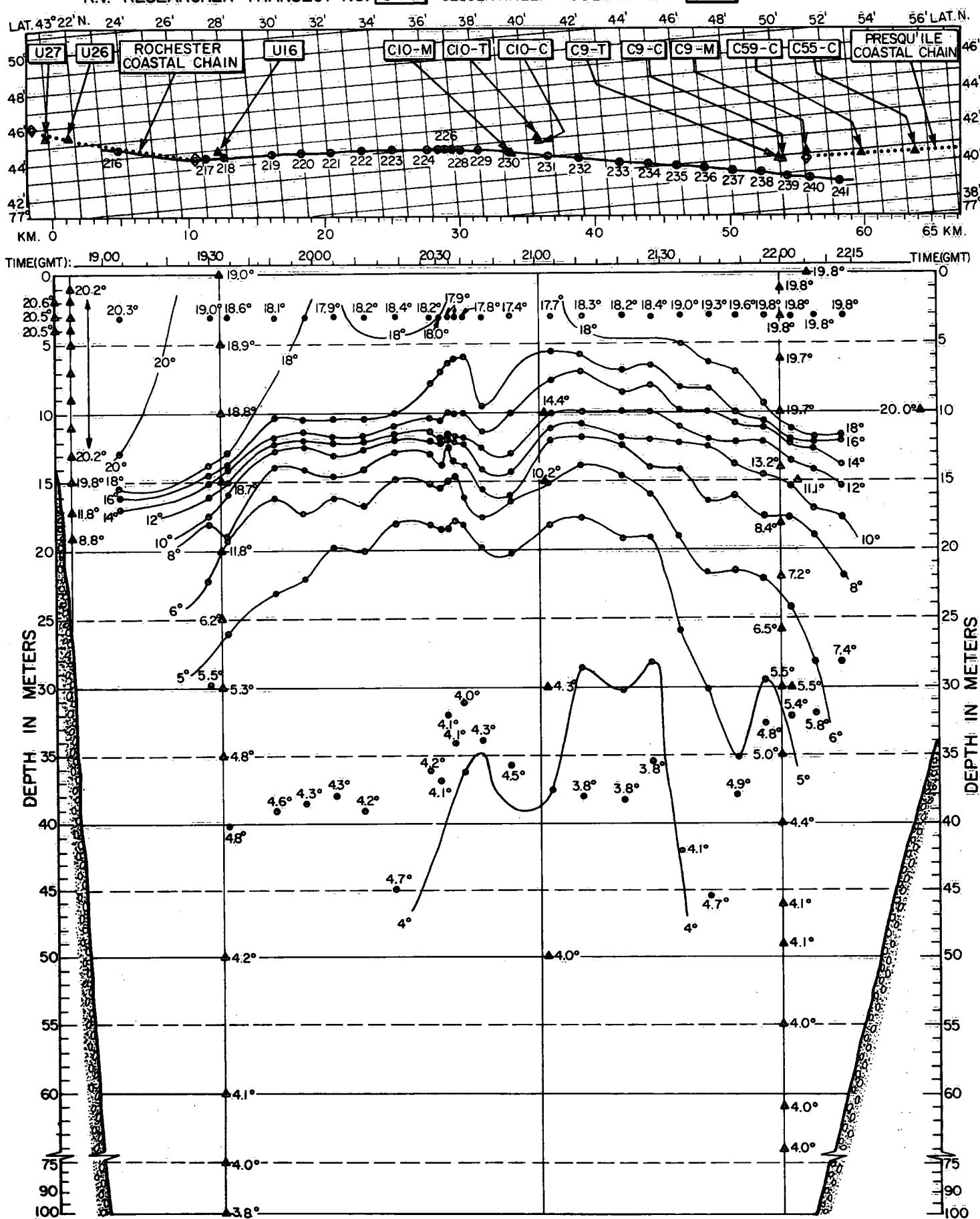
▲ FIXED STATIONS

N



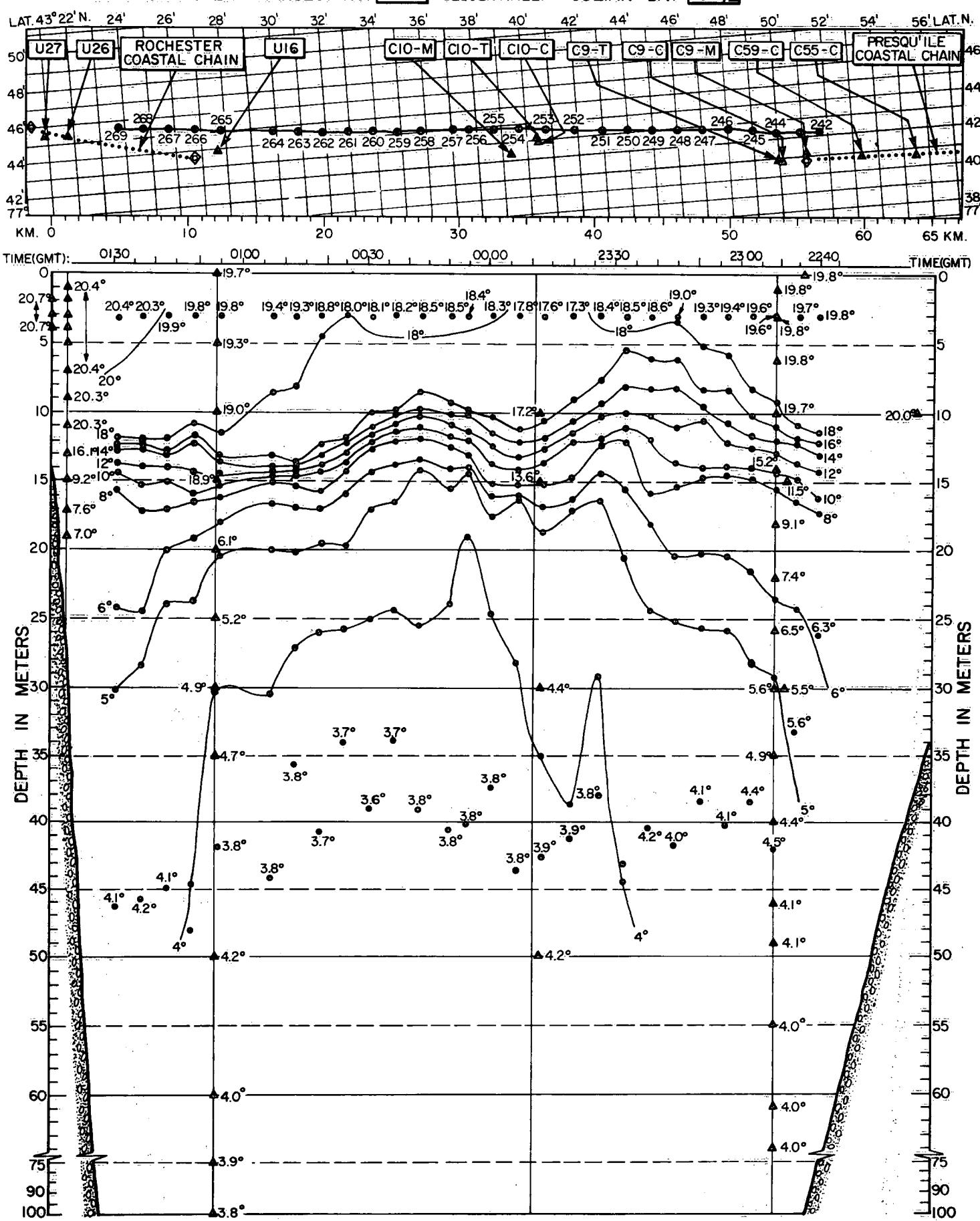
## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT.(S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 009 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 221 N →

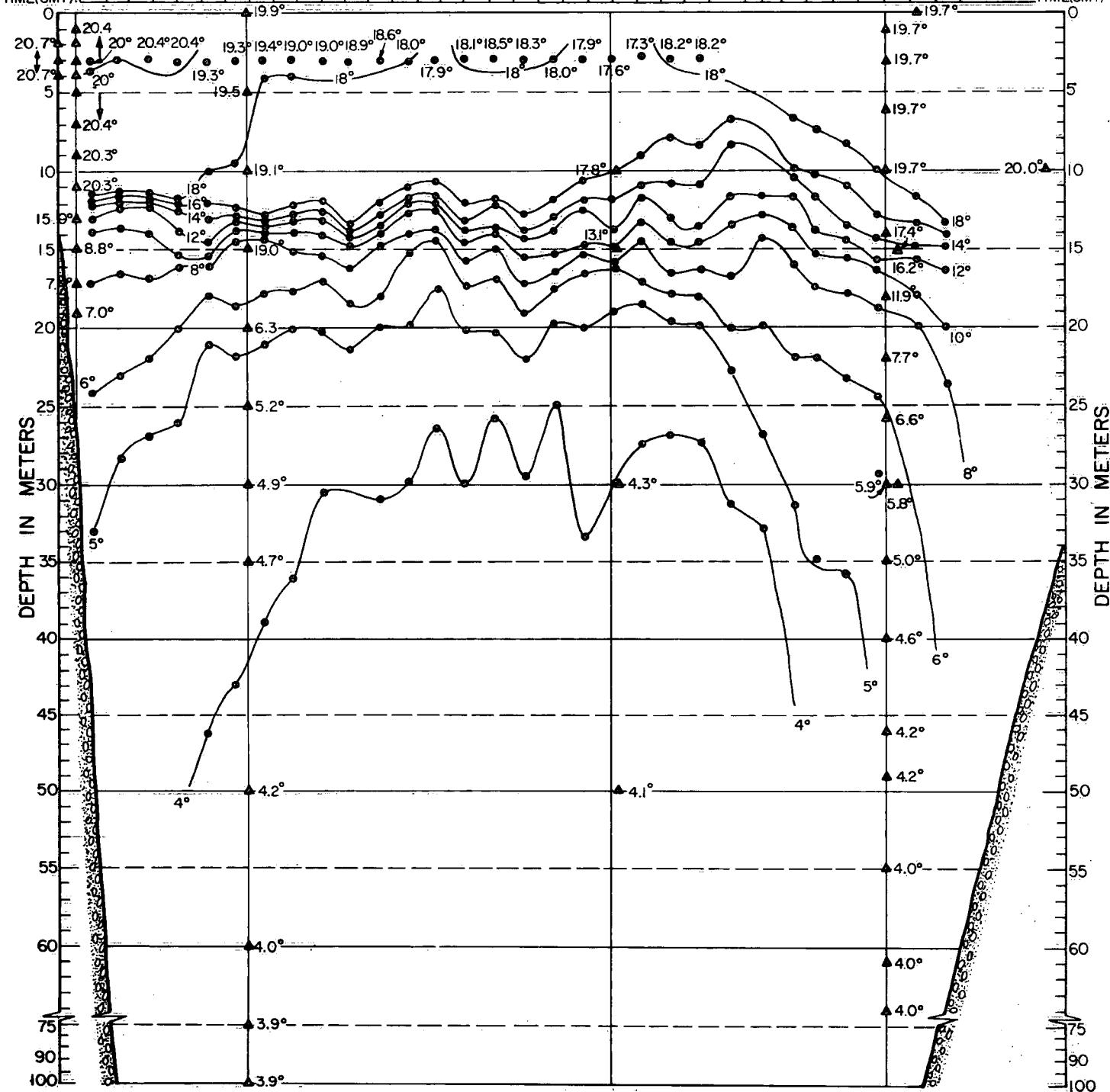
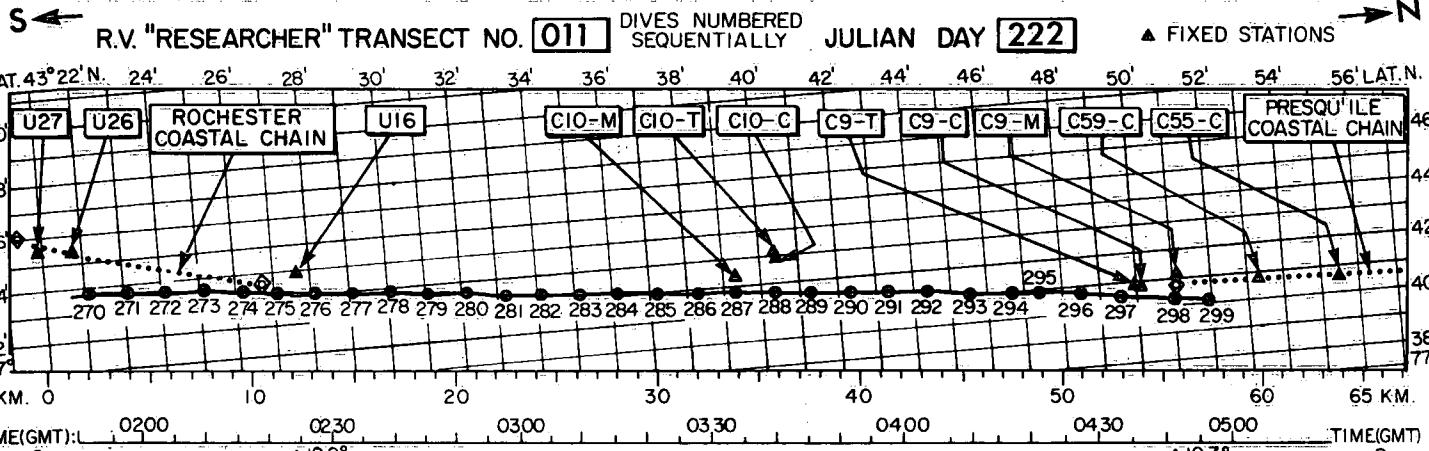


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

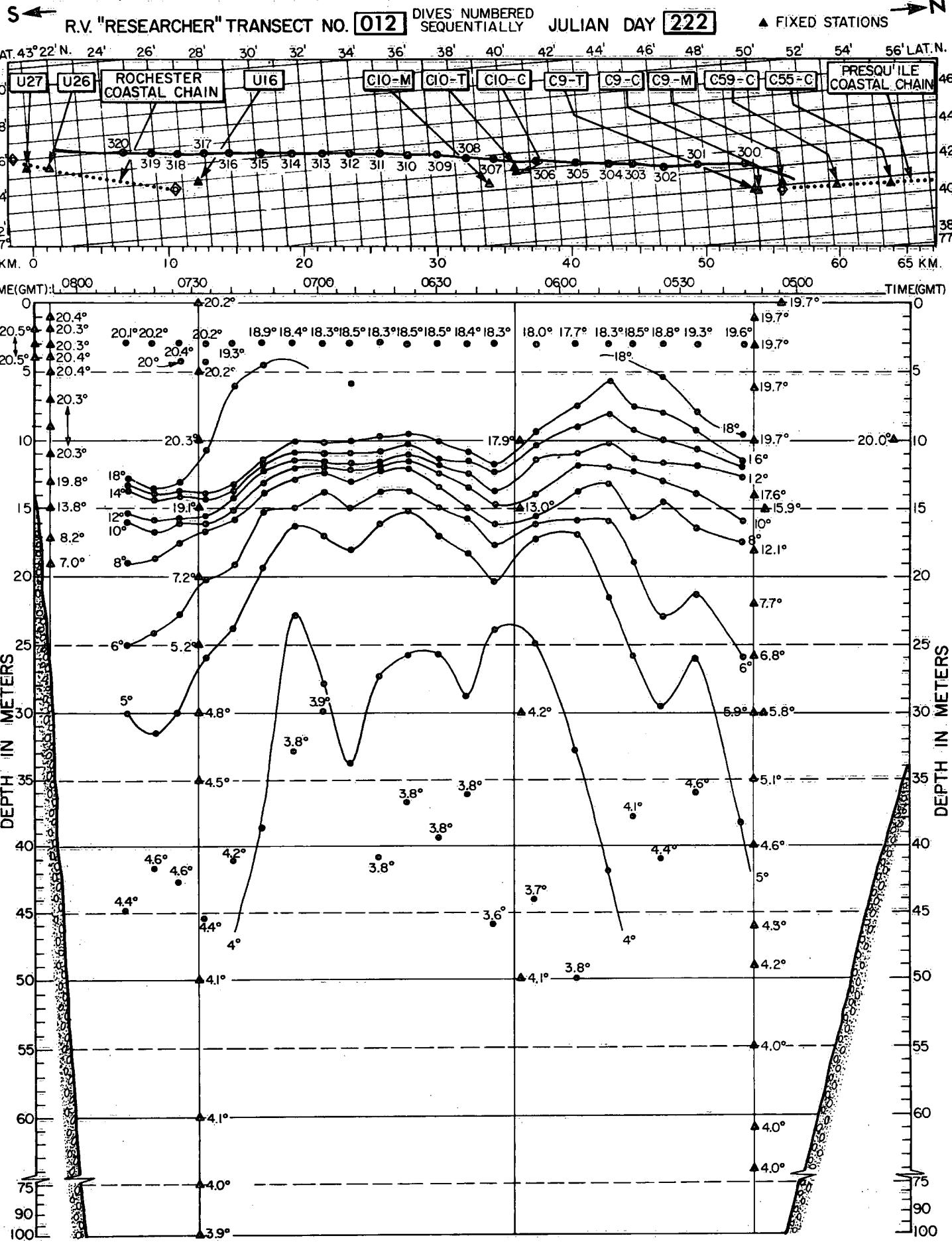
S ← R.V. "RESEARCHER" TRANSECT NO. 010 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 221 1/2 ▲ FIXED STATIONS → N



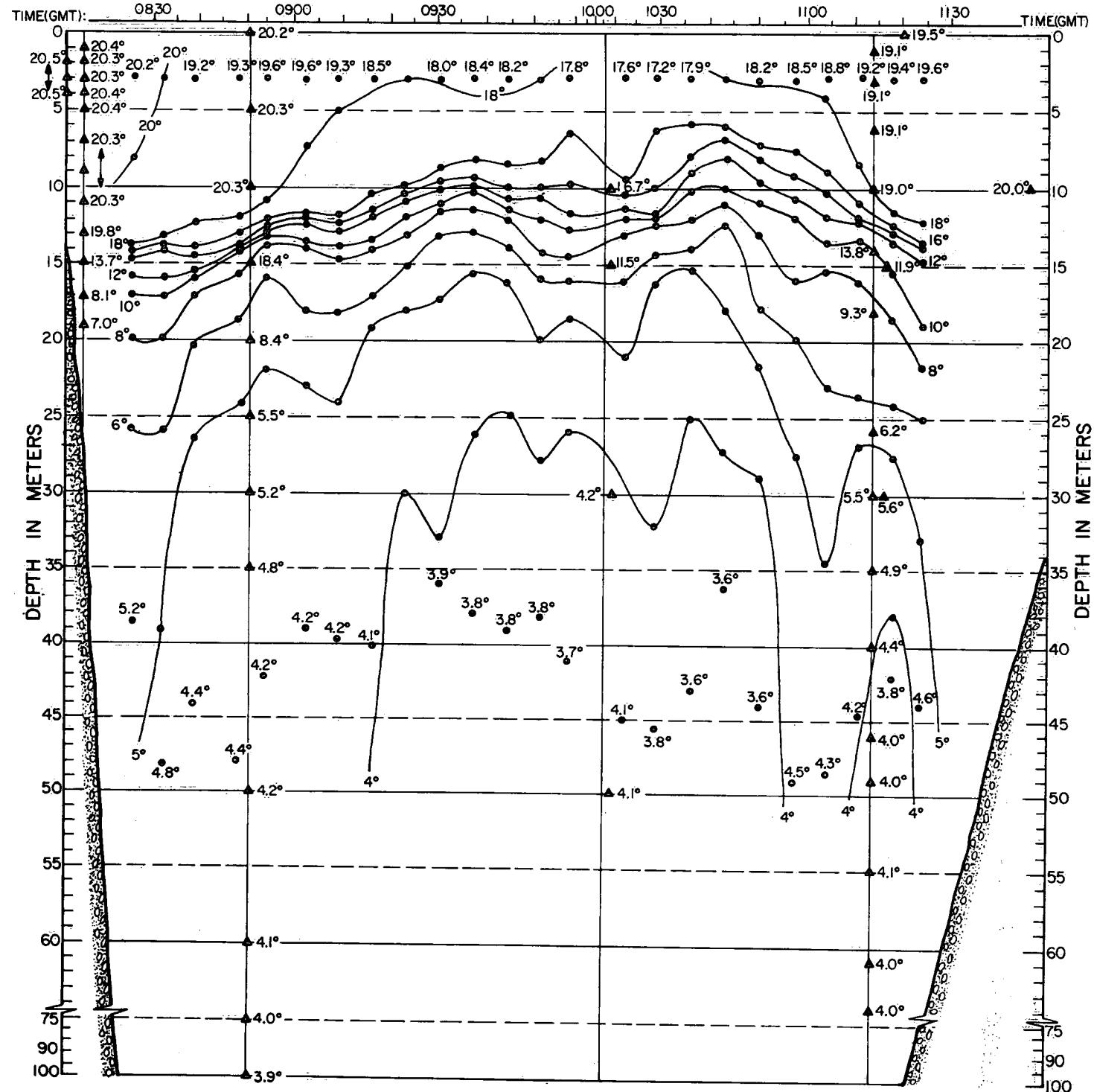
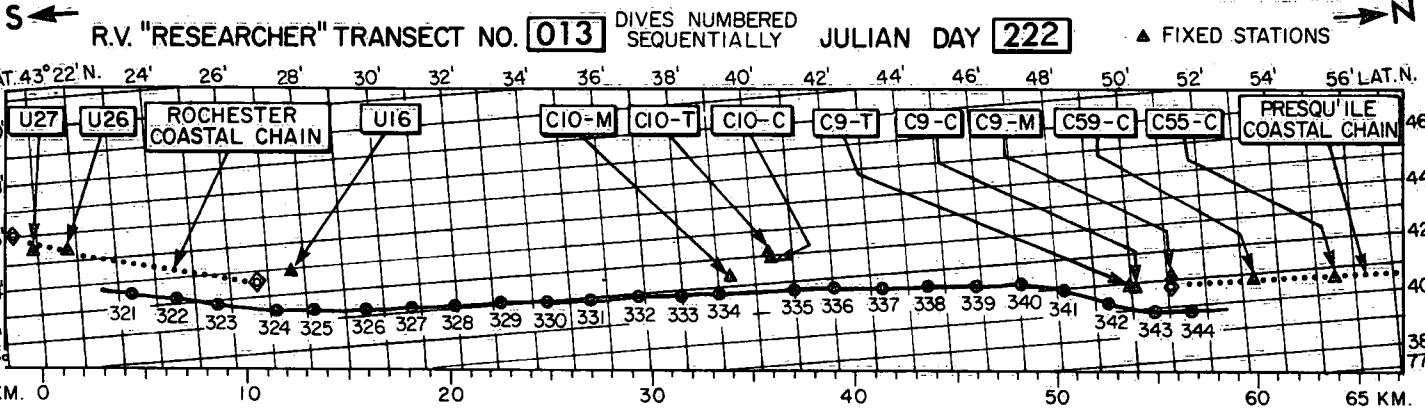
## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

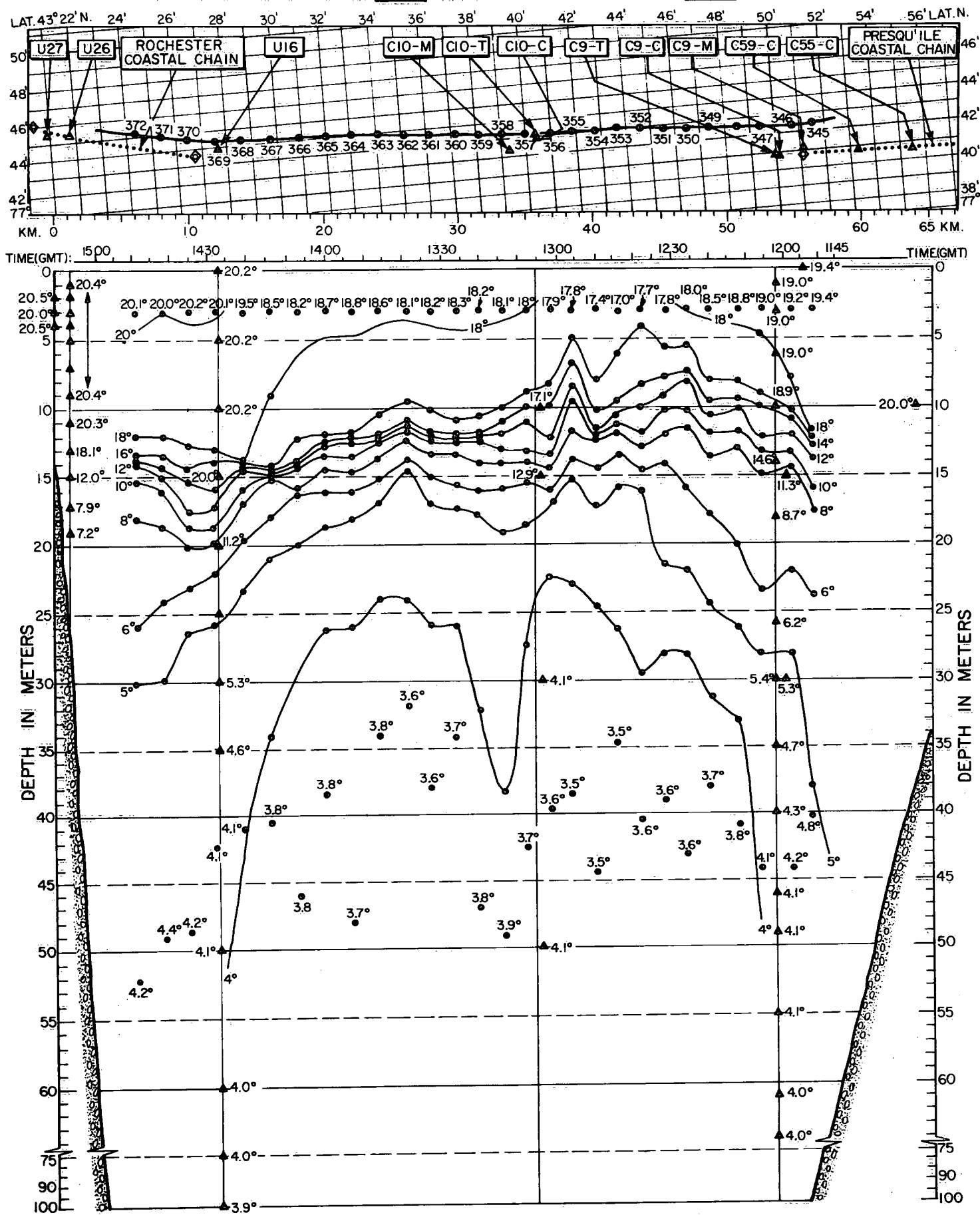


## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



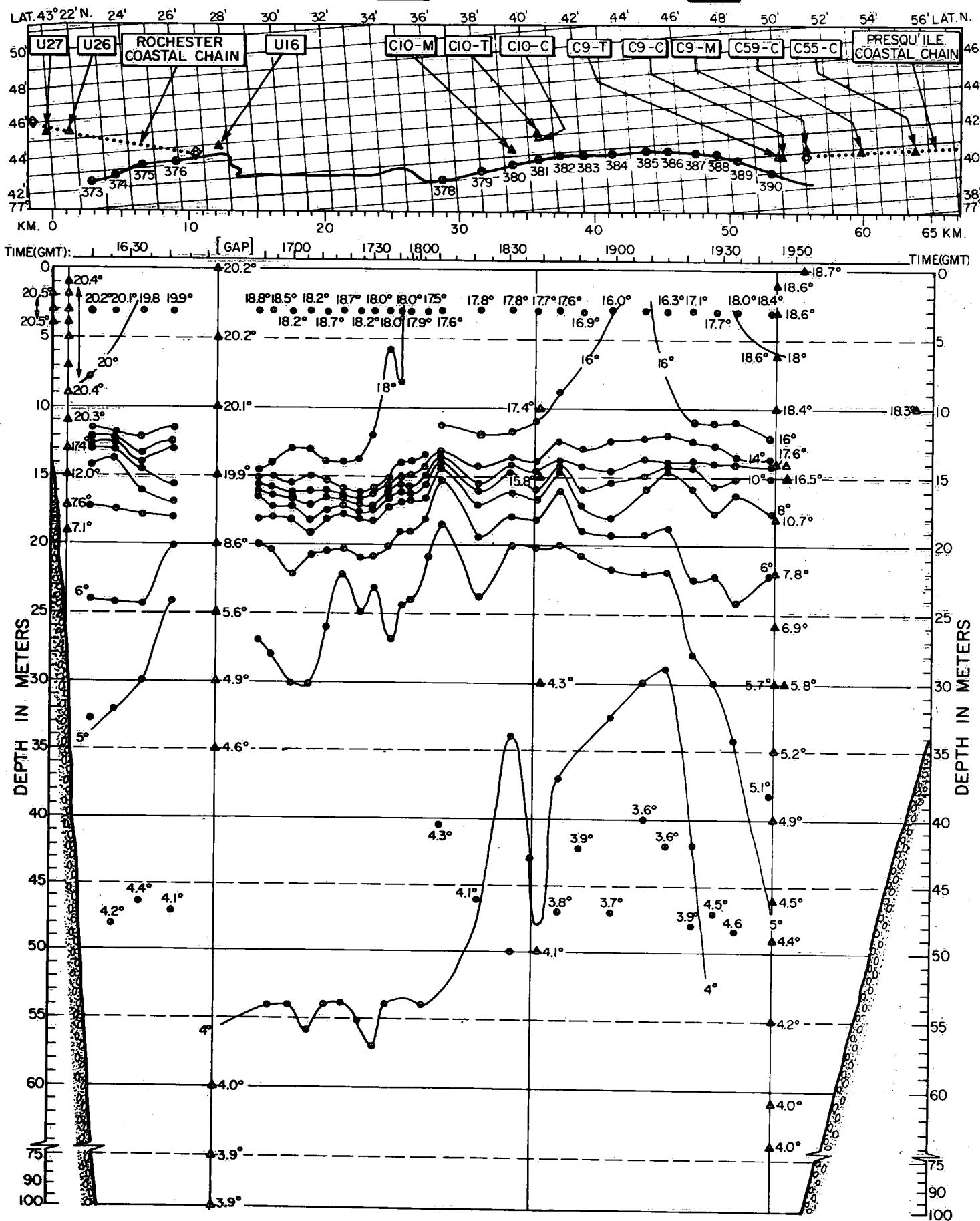
| FYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 014 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 222 ▲ FIXED STATIONS N →



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 015 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 222 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

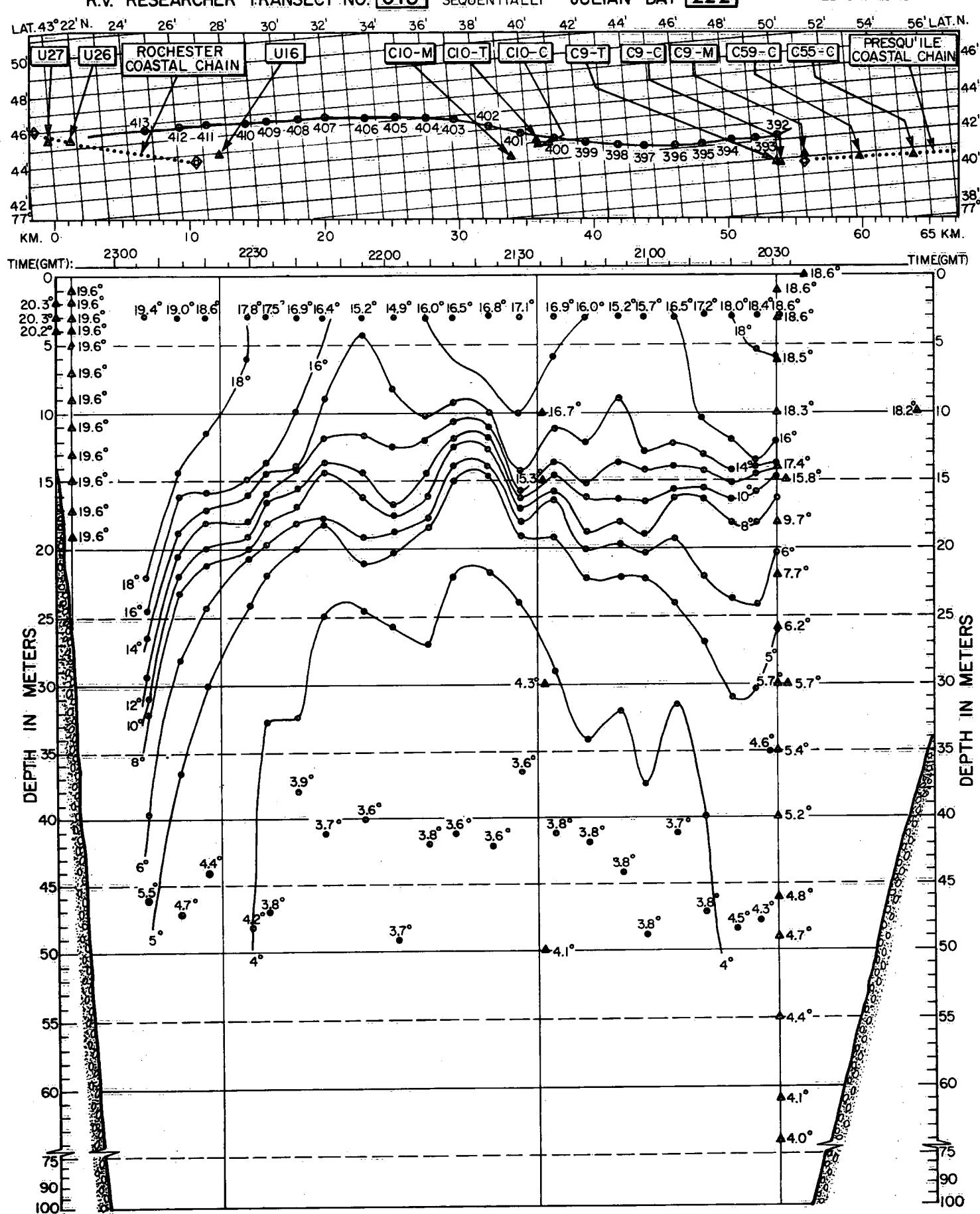
S ←

## R.V. "RESEARCHER" TRANS.

DIVES NUMBERED  
SEQUENTIALLY

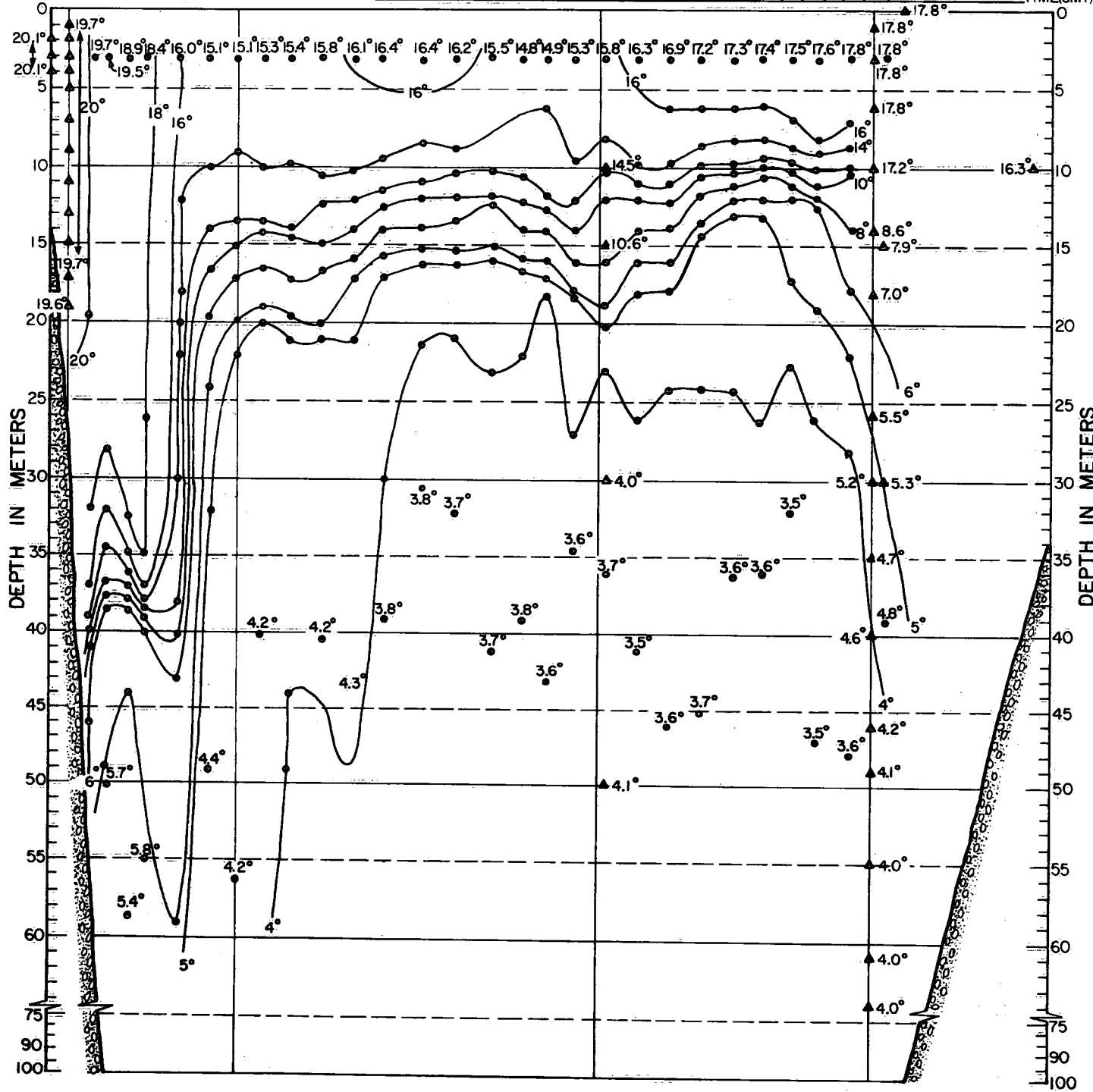
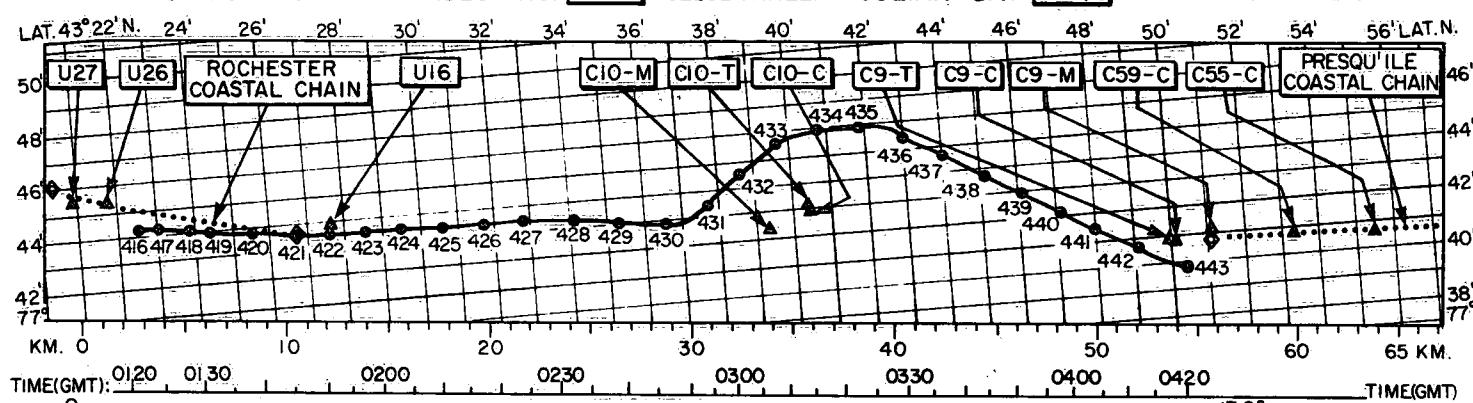
JULIAN DAY 222

## ▲ FIXED STATIONS



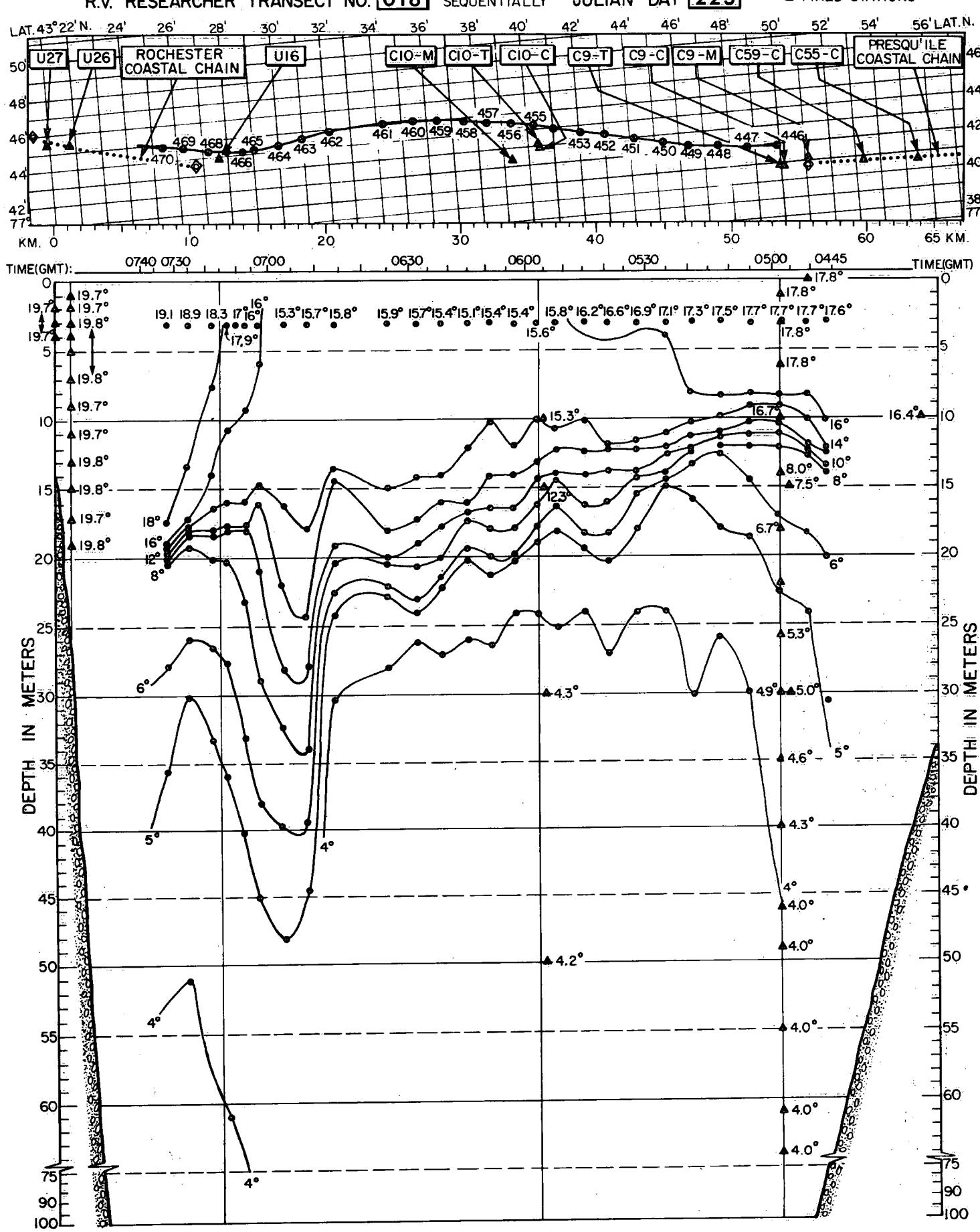
## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 017 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 222/3 N →



LEYGI (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← B.V. "RESEARCHER" TRANSECT NO 018 DIVES NUMBERED  
SEQUENTIALLY JULIAN DAY 223 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

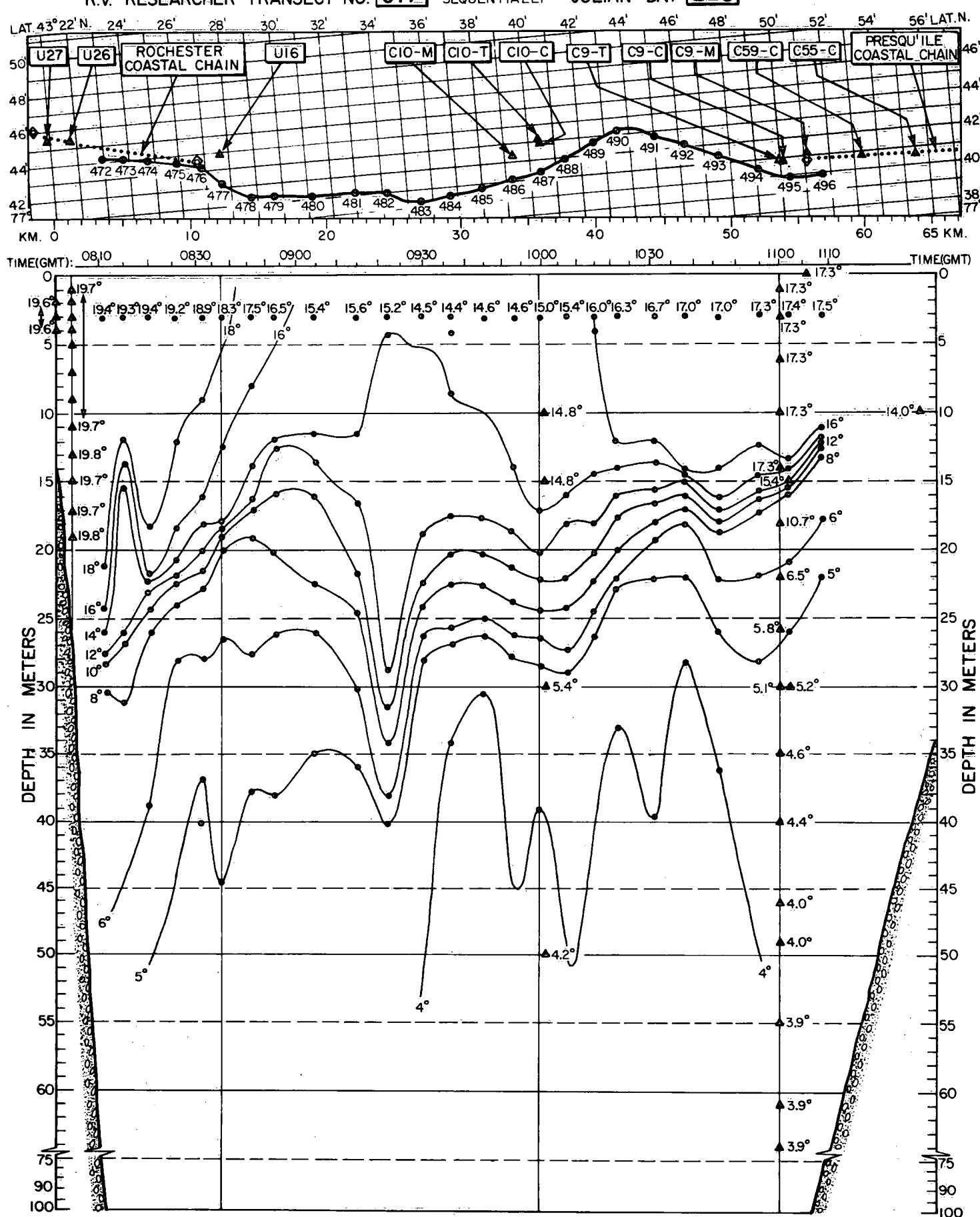
S →

R.V. "RESEARCHER" TRANSECT NO. **019** DIVES NUMBERED  
SEQUENTIALLY

JULIAN DAY 223

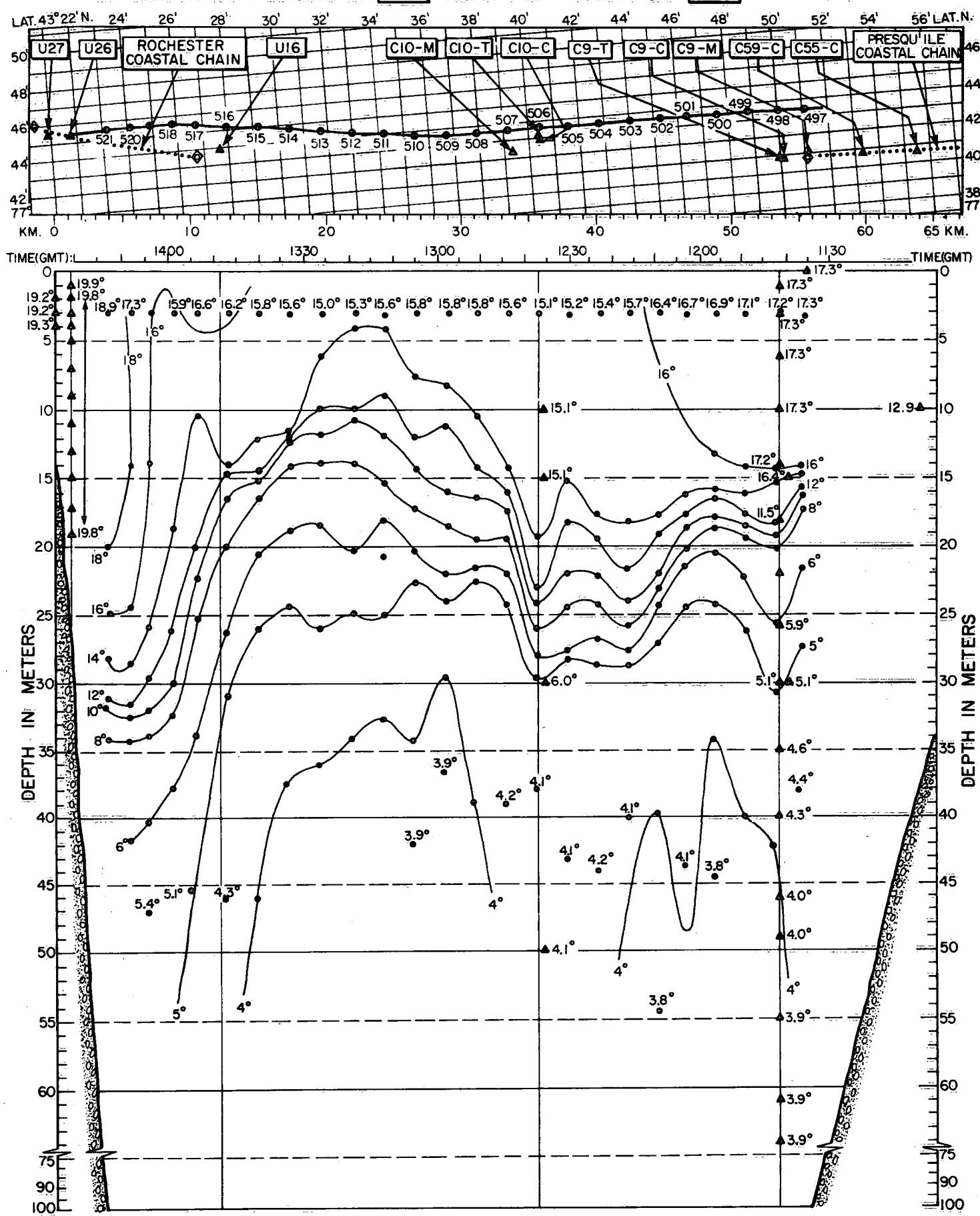
#### ▲ FIXED STATIONS

1



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT.(S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 020 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 223 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

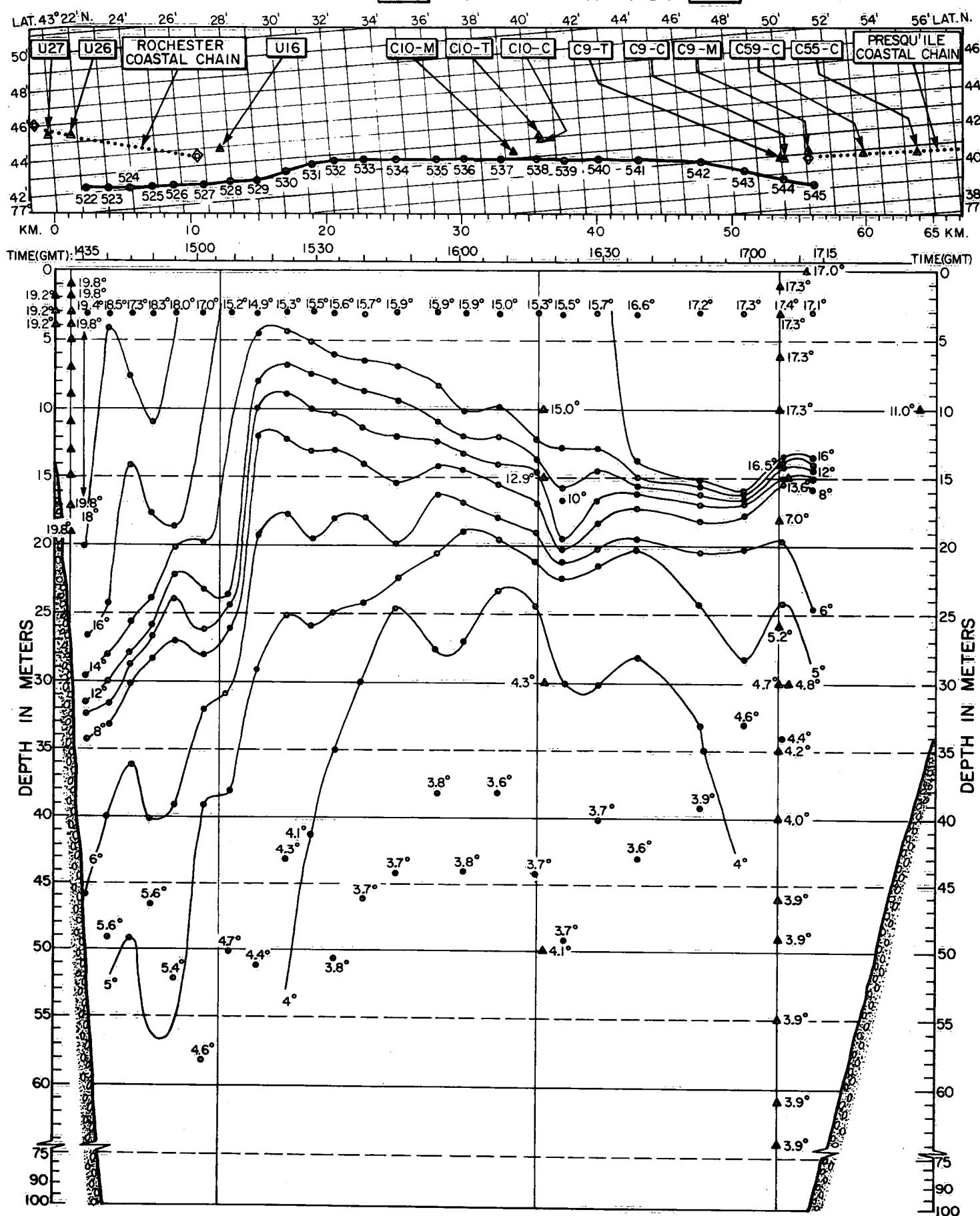
S →

R.V. "RESEARCHER" TRANSECT NO. 021 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 223 ▲ FIXED STATIONS 

DIVES NUMBERED  
SEQUENTIALLY

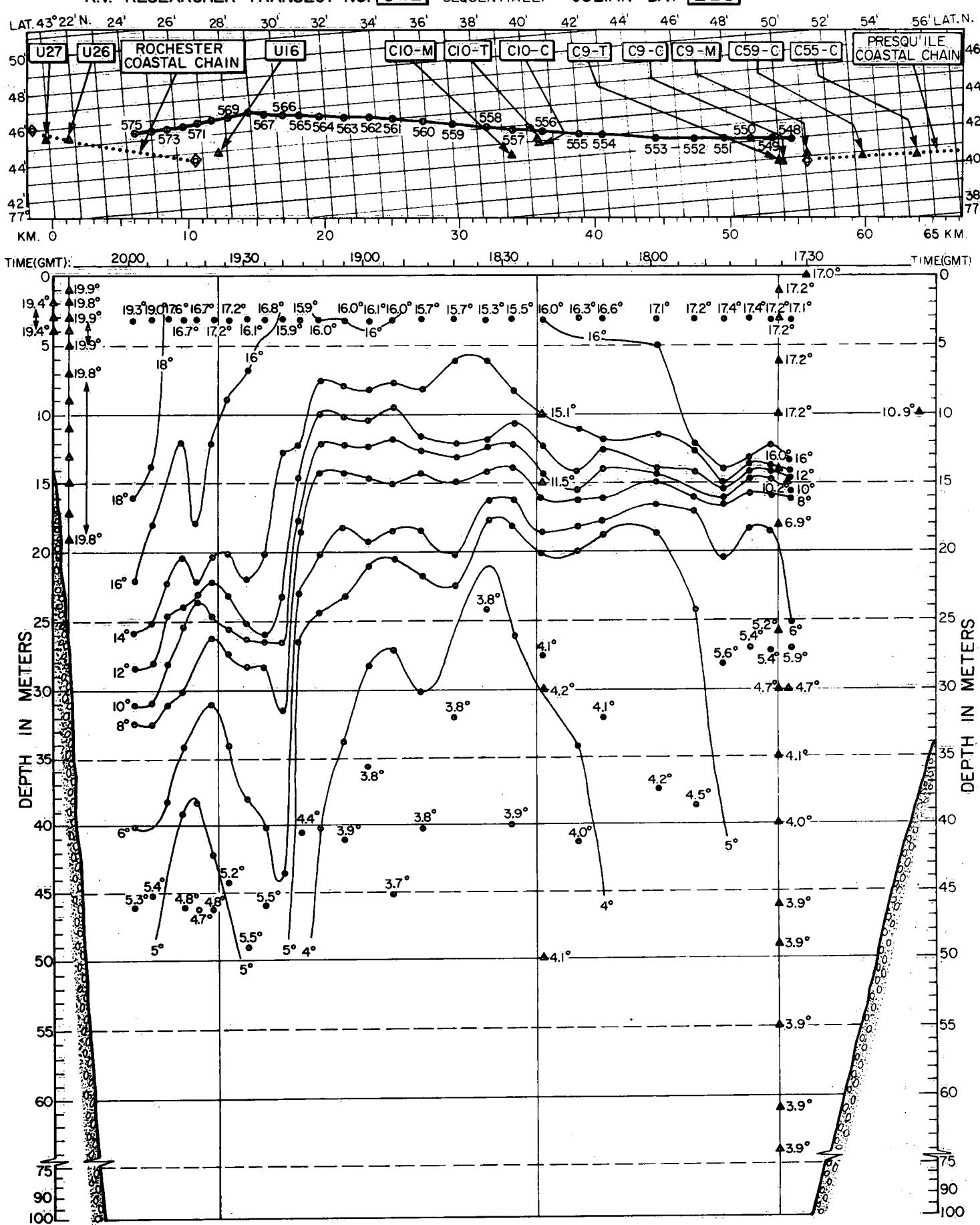
JULIAN DAY 223

**▲ FIXED STATIONS**



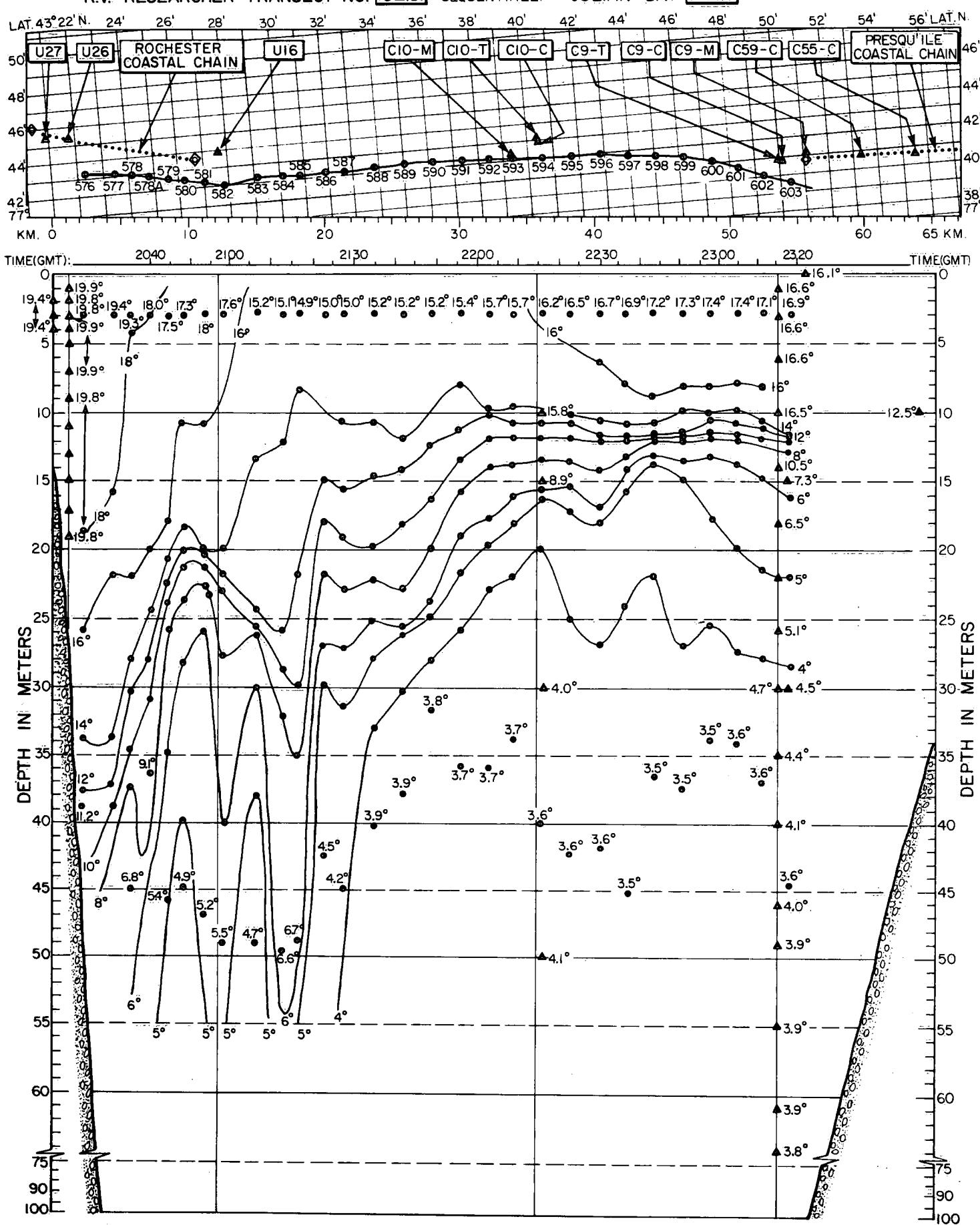
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO 022 DIVES NUMBERED  
SEQUENTIALLY JULIAN DAY 223 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT: BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R/V "RESEARCHER" TRANsect NO 023 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 223 N → ▲ FIXED STATIONS



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

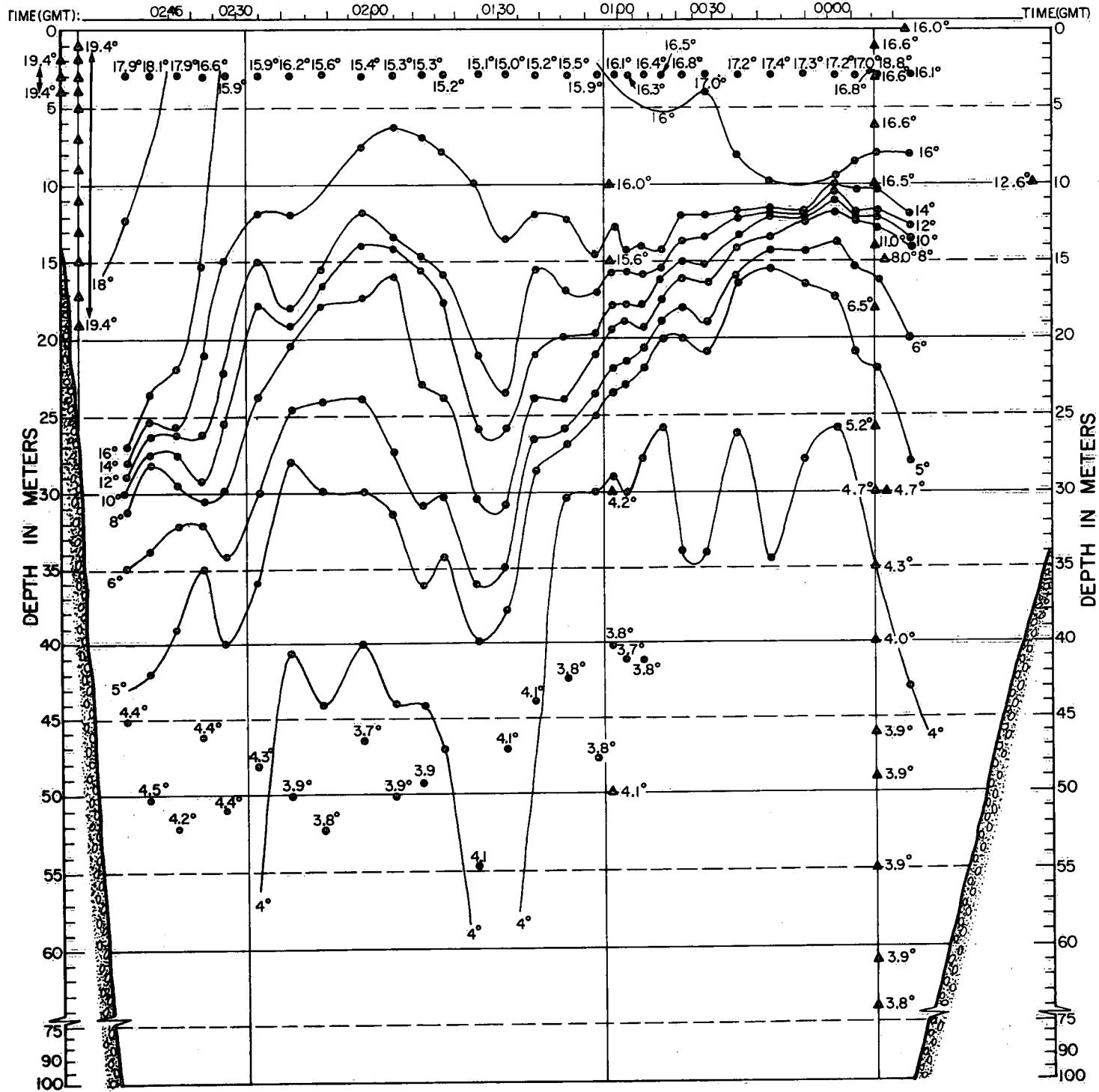
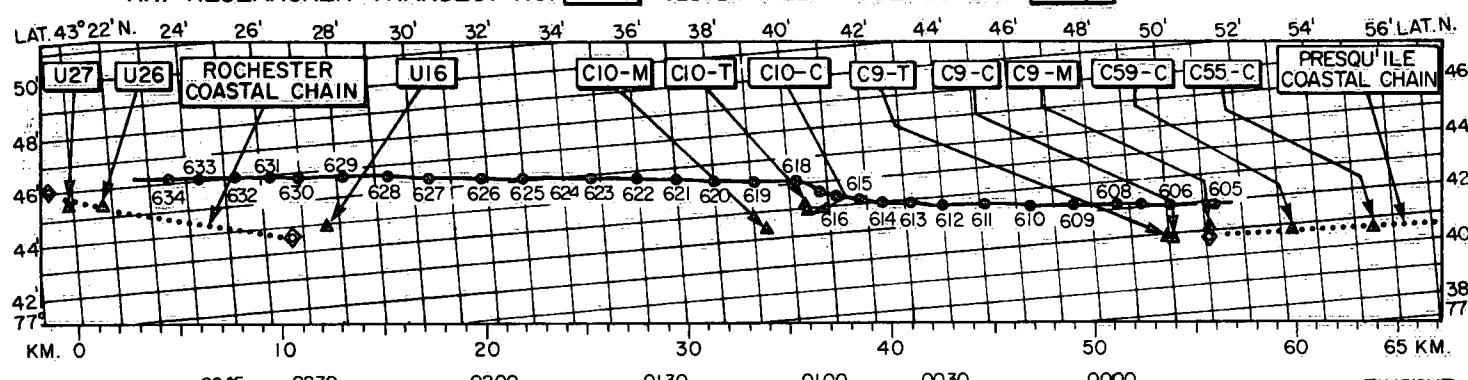
S ←

R.V. "RESEARCHER" TRANSECT NO. 024 DIVES NUMBERED SEQUENTIALLY

JULIAN DAY 223/4

▲ FIXED STATIONS

N →



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ←

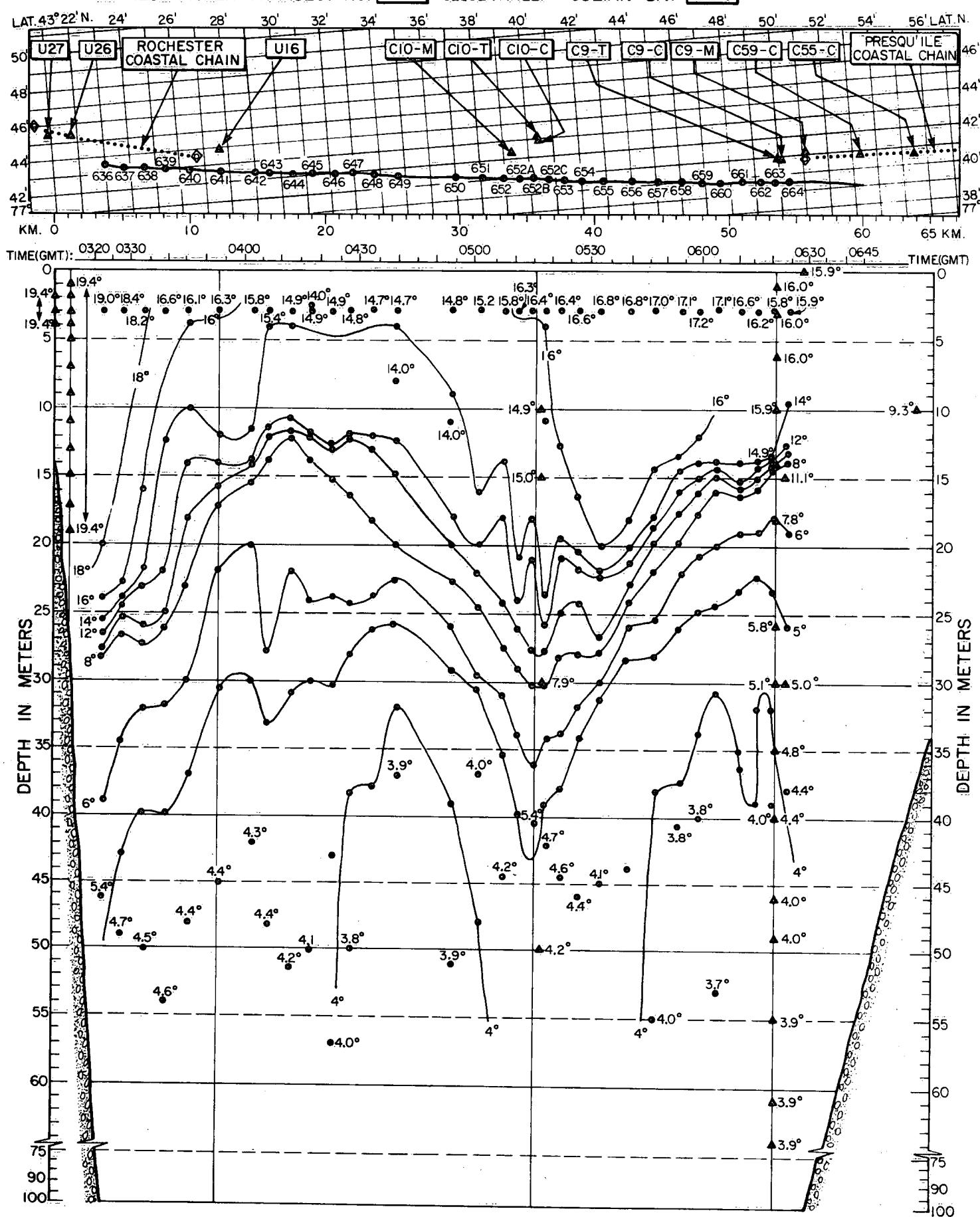
R.V. "RESEARCHER" TRANSECT NO. 025 DIVES NUMBERED  
SEQUENTIALLY JULIAN DAY 224

DIVES NUMBERED  
SEQUENTIALLY

JULIAN DAY 224

▲ FIXED STATIONS

N



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

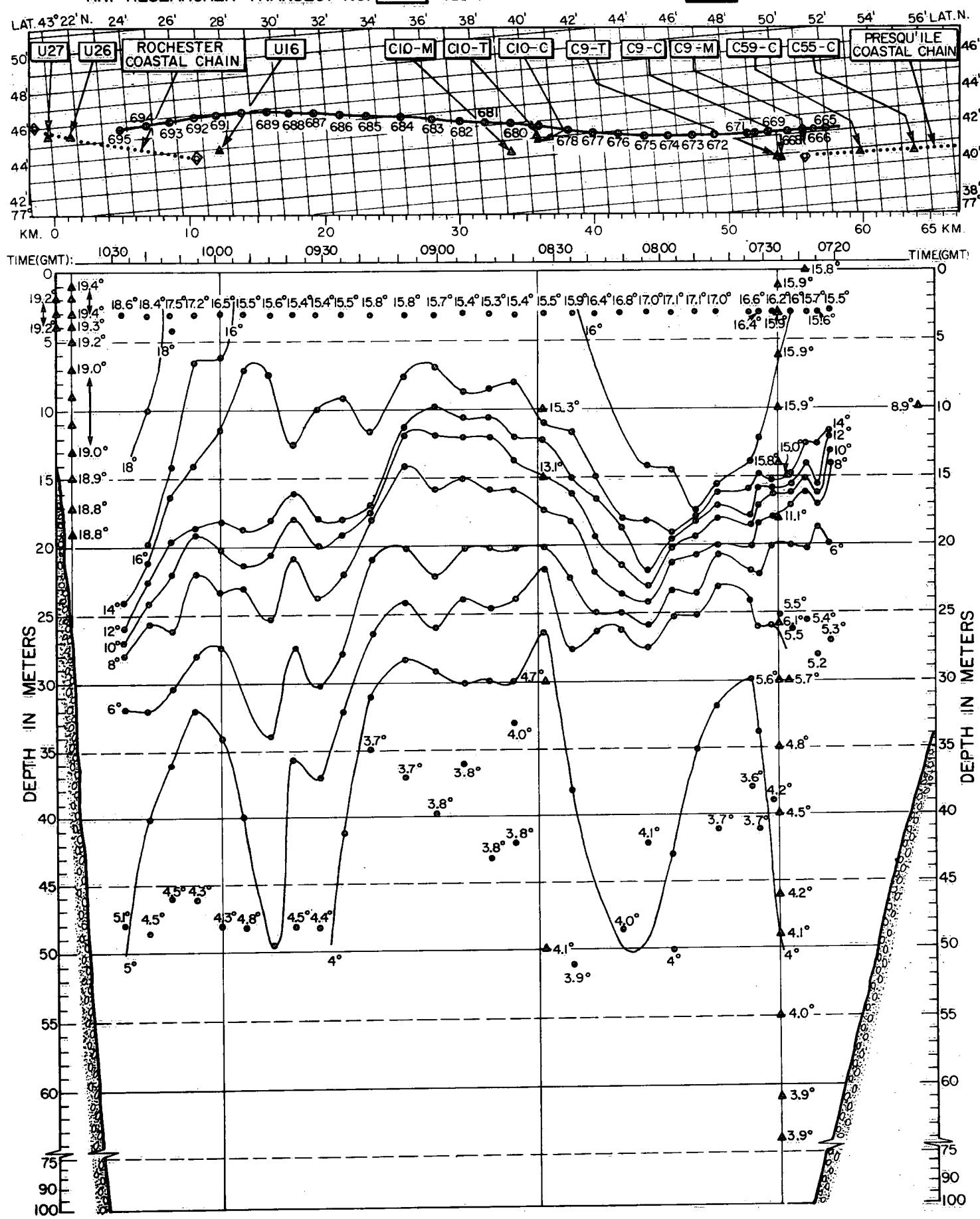
S

R.V. "RESEARCHER" TRANSECT NO. 026 DIVES NUMBERED SEQUENTIALLY

JULIAN DAY 224

▲ FIXED STATIONS

N



**Table 5.4. Times (GMT) of Temperature Readings at Fixed Stations and Depths (Fig. 5.1) Entered on the Braddock Pt. to Presqu'ile Transect Diagrams: 2-6 October (Julian Days 276-280, see Diagrams)**

Transect No.	U27, U26	U16	C10-T	C10-M	C9-T, C9-C	C9-M	C55-C, C59-C
1	1924	2012	2200	2150	2310	2310	2330
2	0324	0242	0110	0120	0000	2350	2340
3	0330	0406	0630	0550	0740	0740	0740
4	1142	1106	0930	0940	0820	0810	0800
5	1154	1224	1400	1350	1510	1520	1520
6	1906	1830	1700	1710	1550	1550	1530
7	2048	2124	2250	2250	0000	0010	0010
8	0400	0330	0150	0200	0040	0030	0030
9	0430	0500	0630	0620	0740	0750	0750
10	1136	1100	0930	0940	0820	0810	0810
11	1200	1224	1410	1400	1520	1530	1530
12	1936	1900	1720	1730	1600	1600	1600
13	1954	2018	2140	2130	2250	2300	2310
14	0400	0330	0200	0200	2340	2330	2320
15	0424	0500	0640	0630	0750	0750	0800
16	1200	1124	0940	0950	0820	0820	0810
17	1224	1300	1430	1420	1540	1550	1600
18	1954	1912	1740	1750	1630	1620	1610
19					Bathythermograph Transect		
20	0442	0400	0230	0230	0110	0110	0110
21	0500	0530	0700	0650	0800	0810	0810
22	1154	1130	1000	1010	0850	0850	0840

IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S →

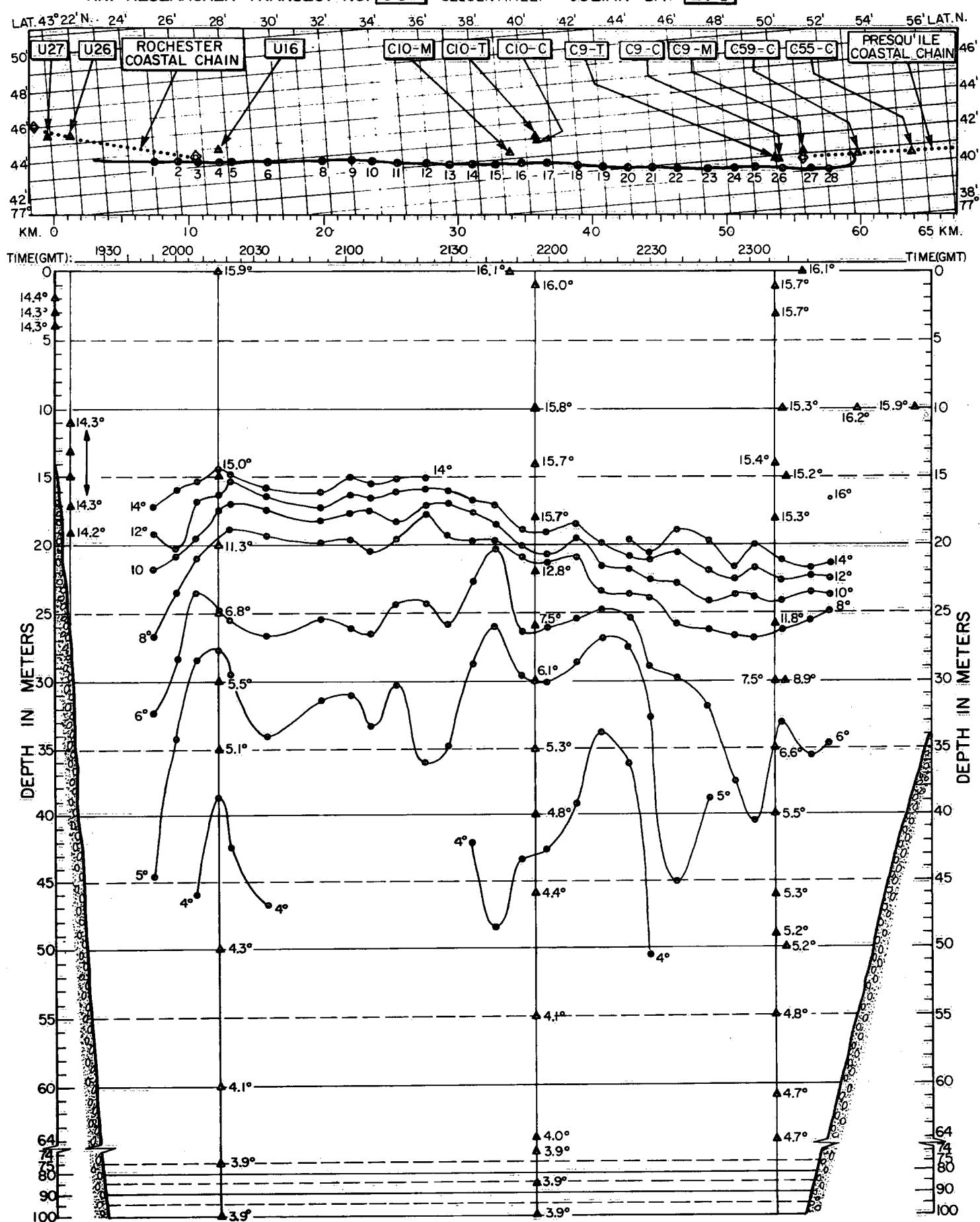
R.V. "RESEARCHER" TRANSECT NO. **001** DIVES NUMBERED SEQUENTIALLY JULIAN DAY **276**

DIVES NUMBERED

JULIAN DAY 276

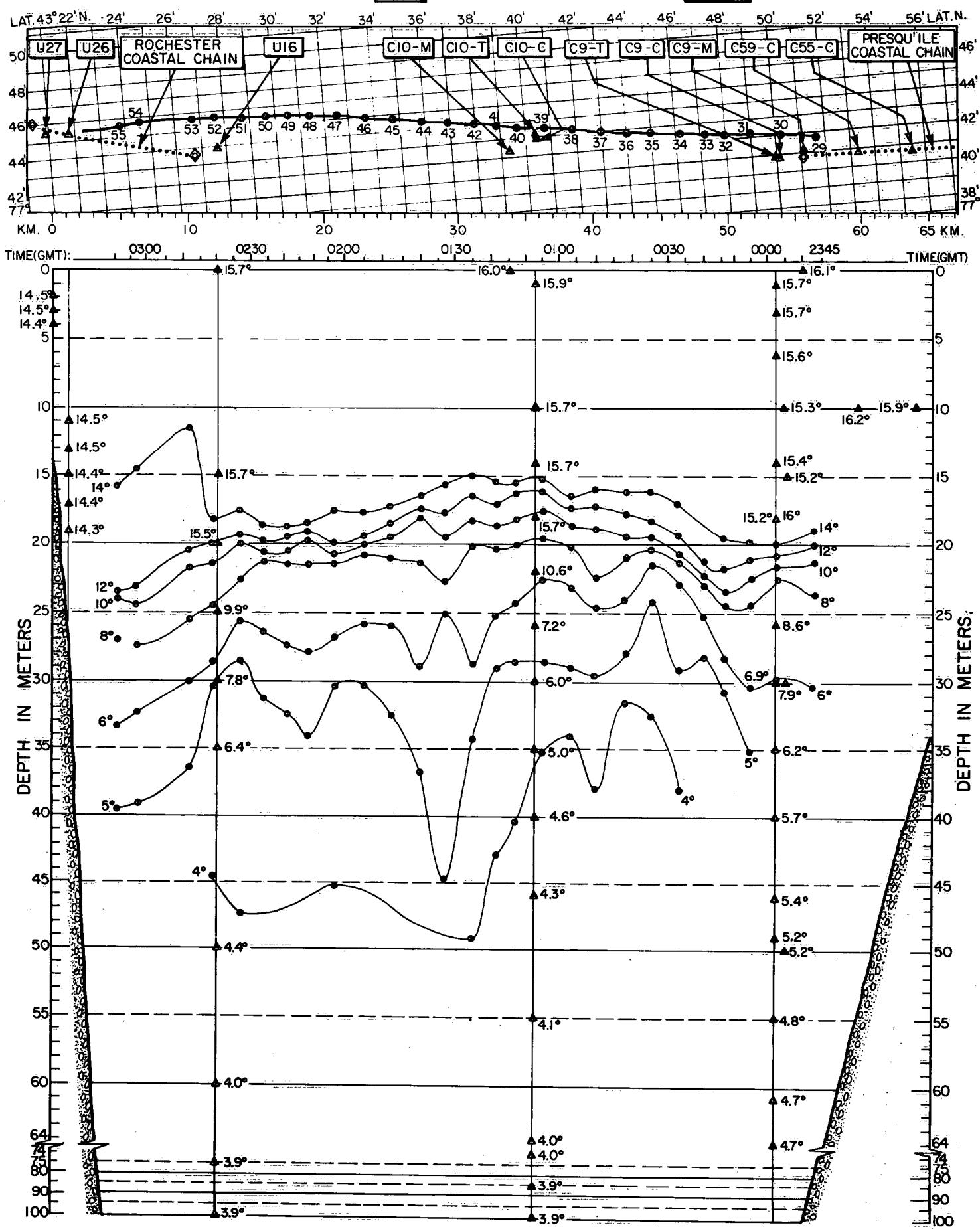
## **FIXED STATIONS**

N



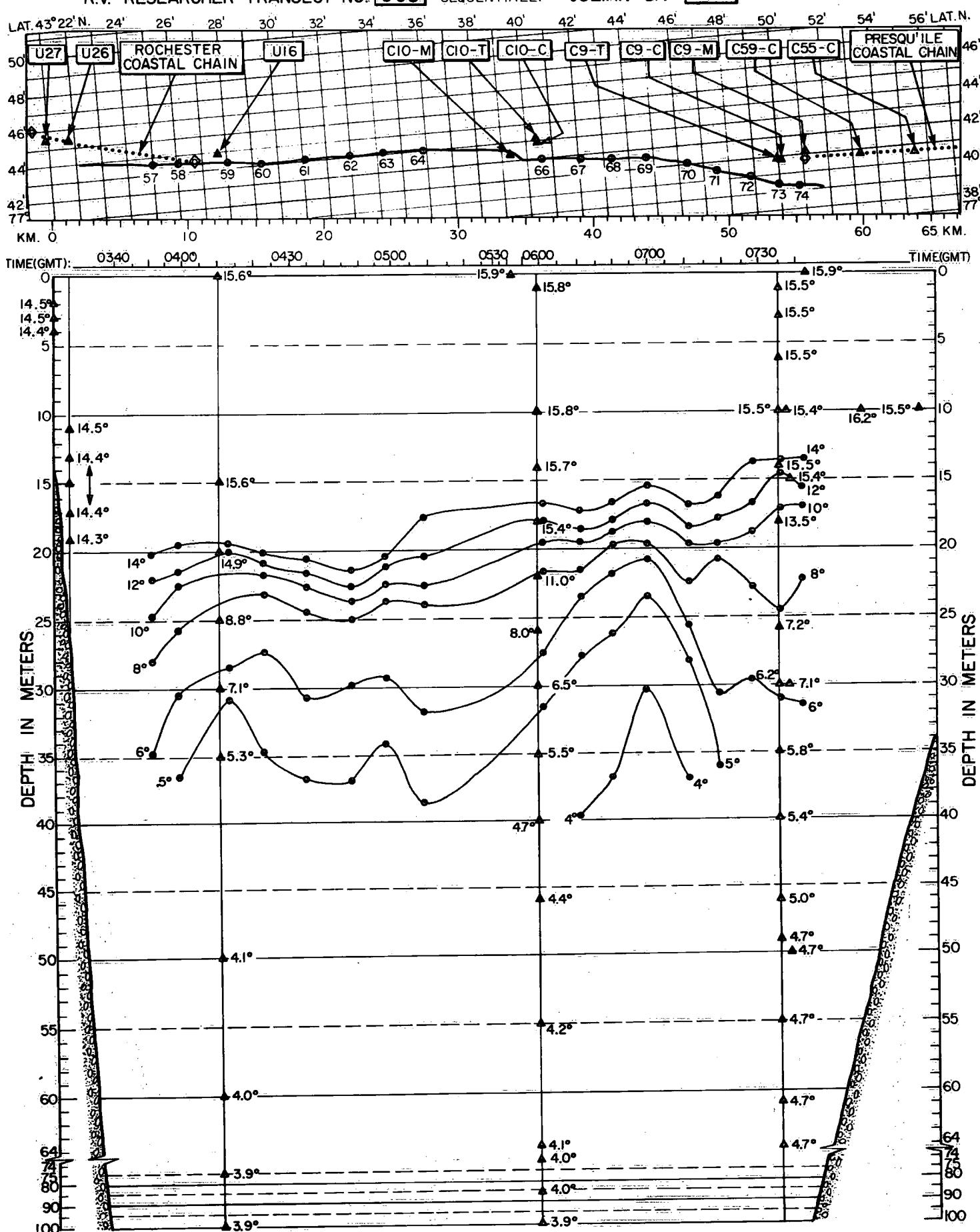
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S R.V. "RESEARCHER" TRANSECT NO. 002 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 276/7 N ▲ FIXED STATIONS



LEYGI (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 003 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 277 ▲ FIXED STATIONS →



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S-1

R.V. "RESEARCHER" TRANSECT NO. 004

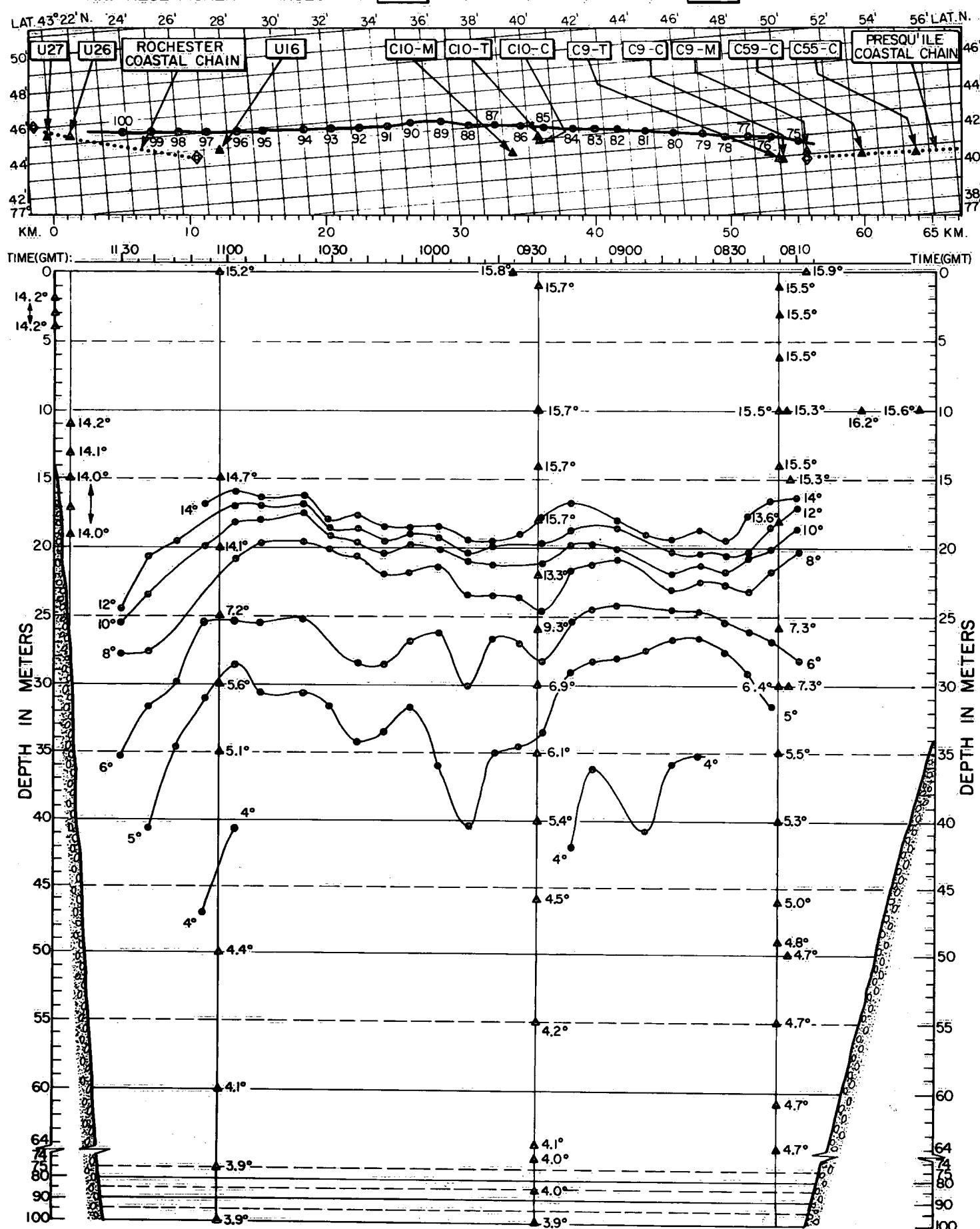
DIVES NUMBERED

11

AN DAY 277

#### **▲ FIXED STATIONS**

1



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ←

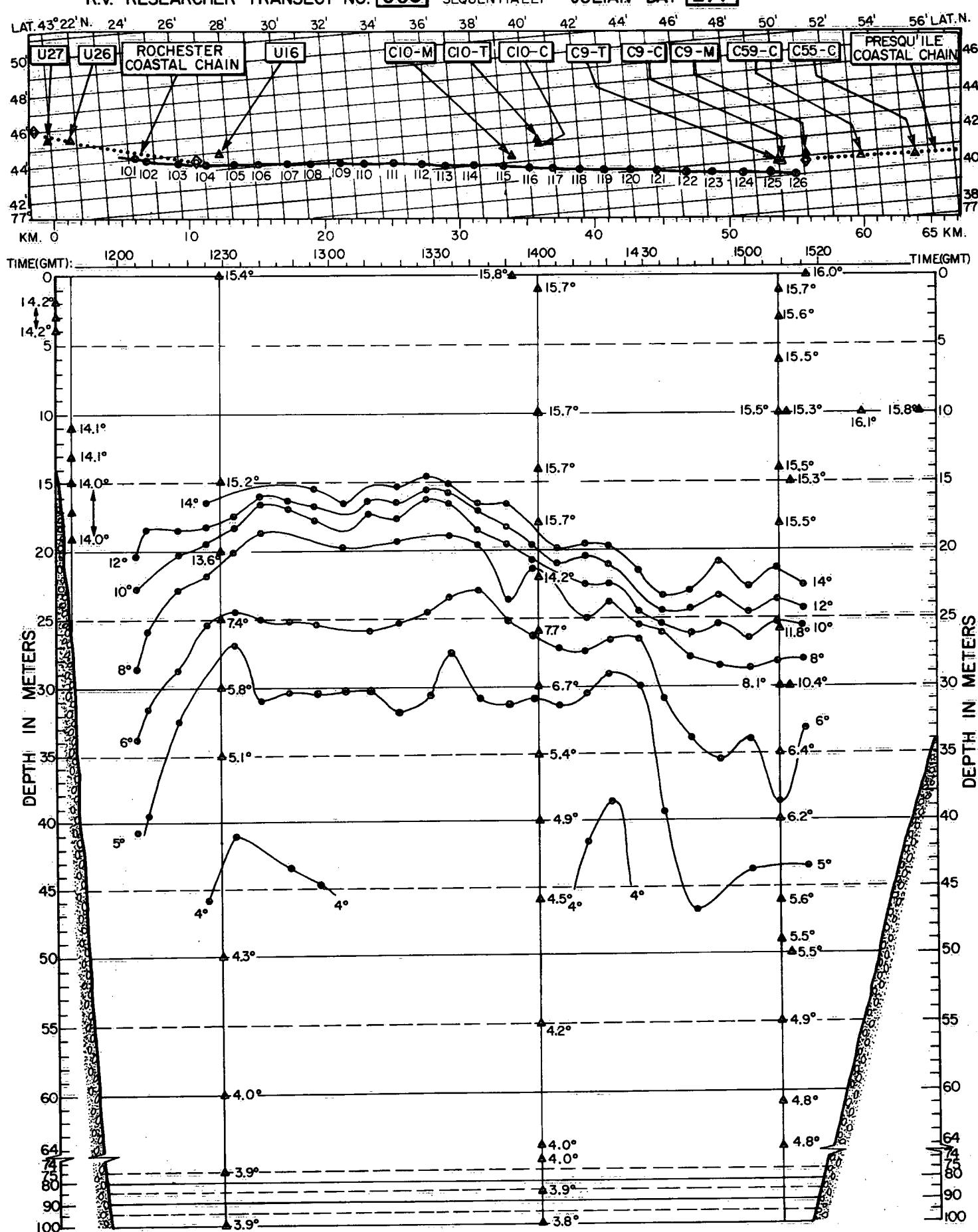
R.V. "RESEARCHER" TRANSECT NO. 005 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 277

DIVES NUMBERED

JULIAN DAY 277

## ▲ FIXED STATIONS

→ N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

5

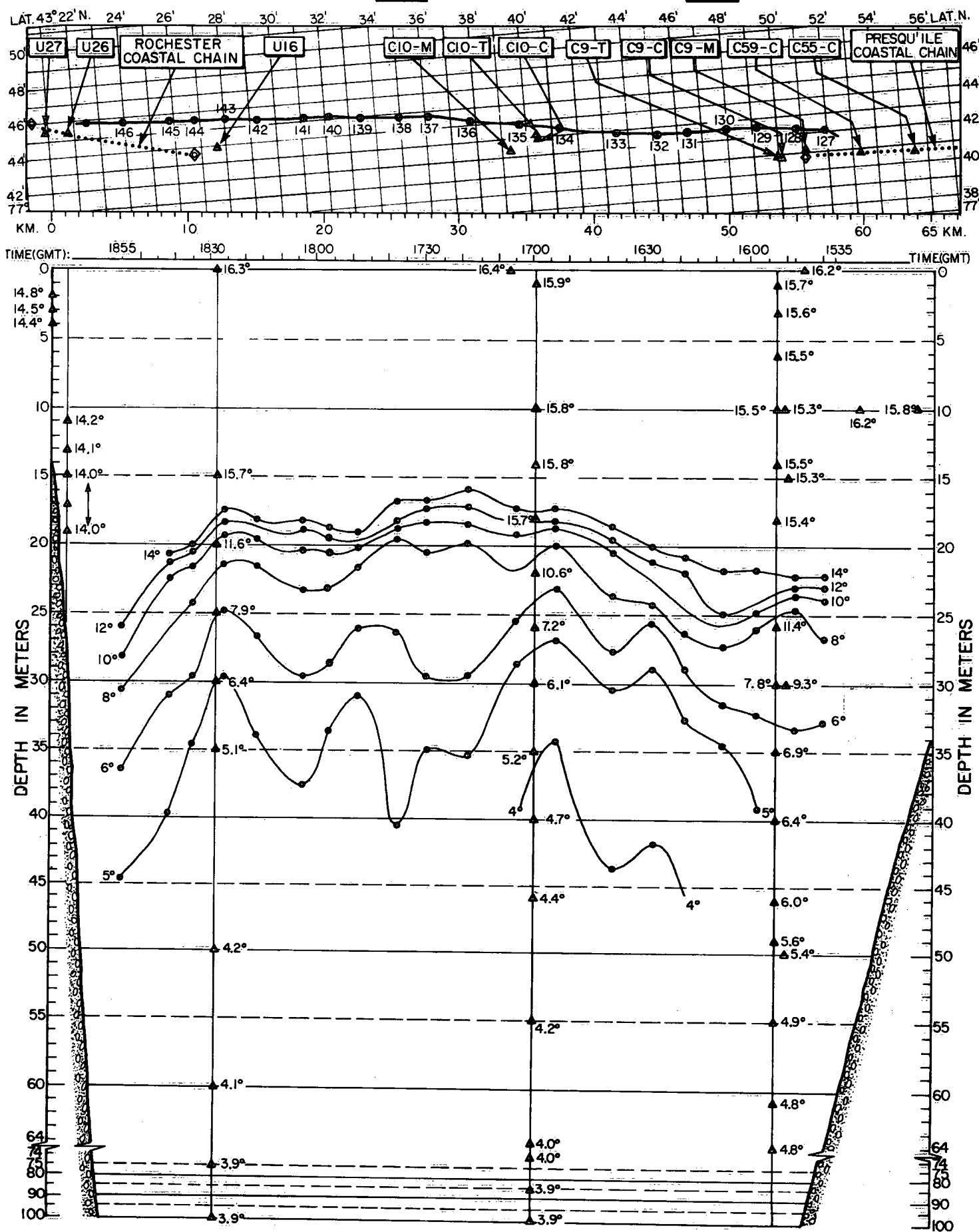
R.V. "RESEARCHER" TRANSECT NO. **006** DIVES NUMBERED  
SEQUENTIALLY JULIAN DAY **277**

DIVES NUMBERED  
SEQUENTIALLY

JULIAN DAY 277

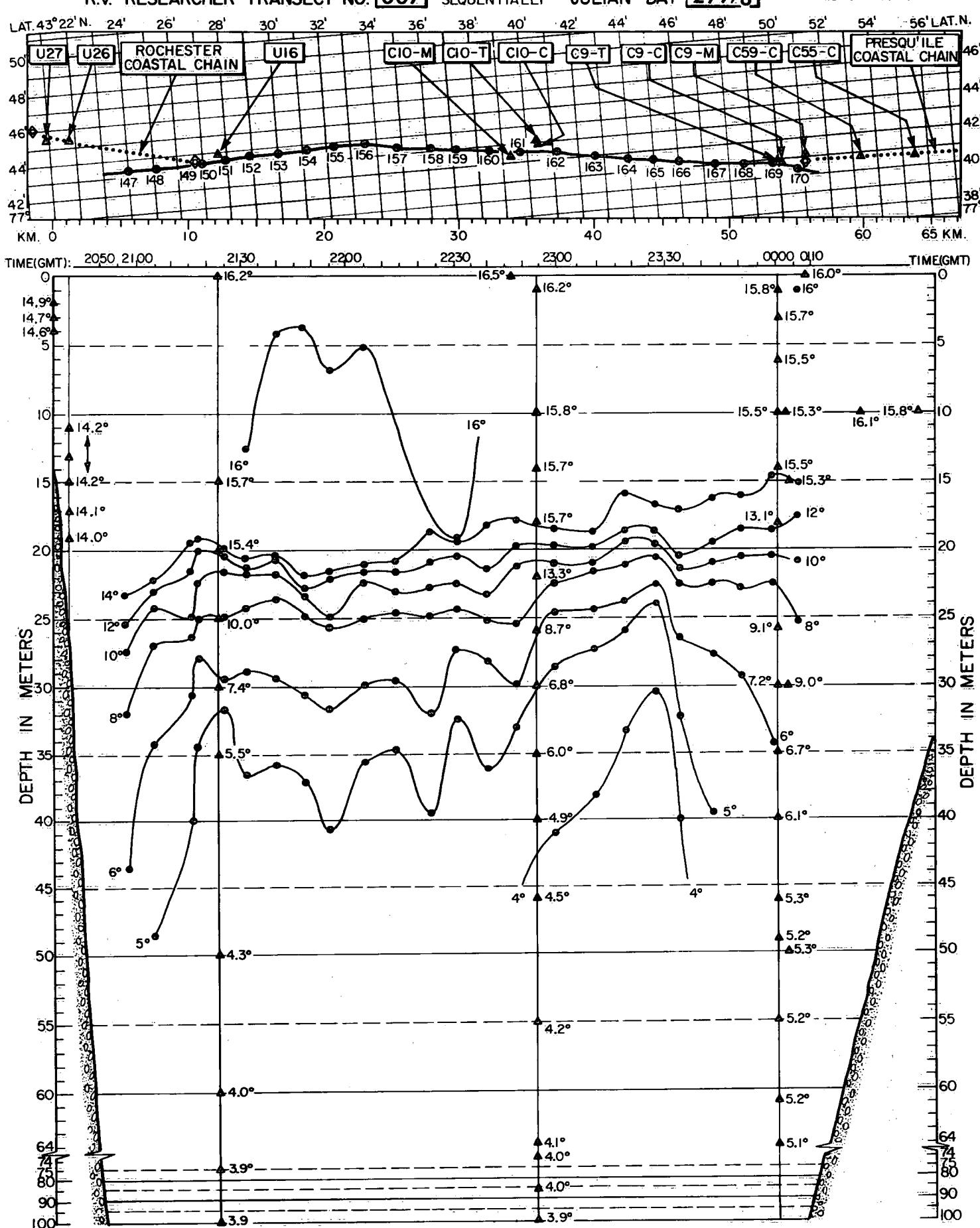
## ▲ FIXED STATIONS

N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← B.V. "RESEARCHER" TRANSECT NO 007 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 277/8 ▲ FIXED STATIONS → N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S →

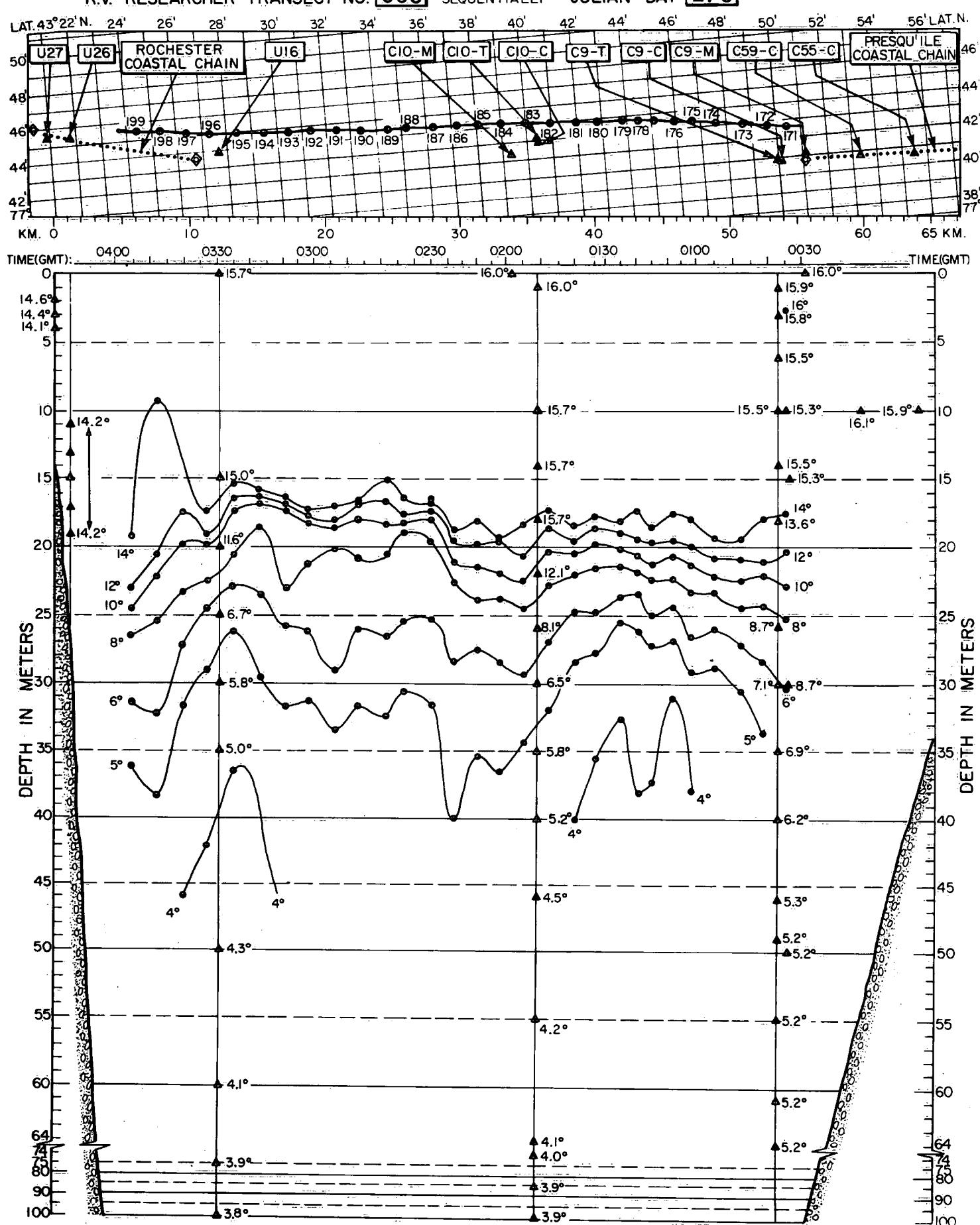
R.V. "RESEARCHER" TRANSECT NO. 008

DIVES NUMBERED

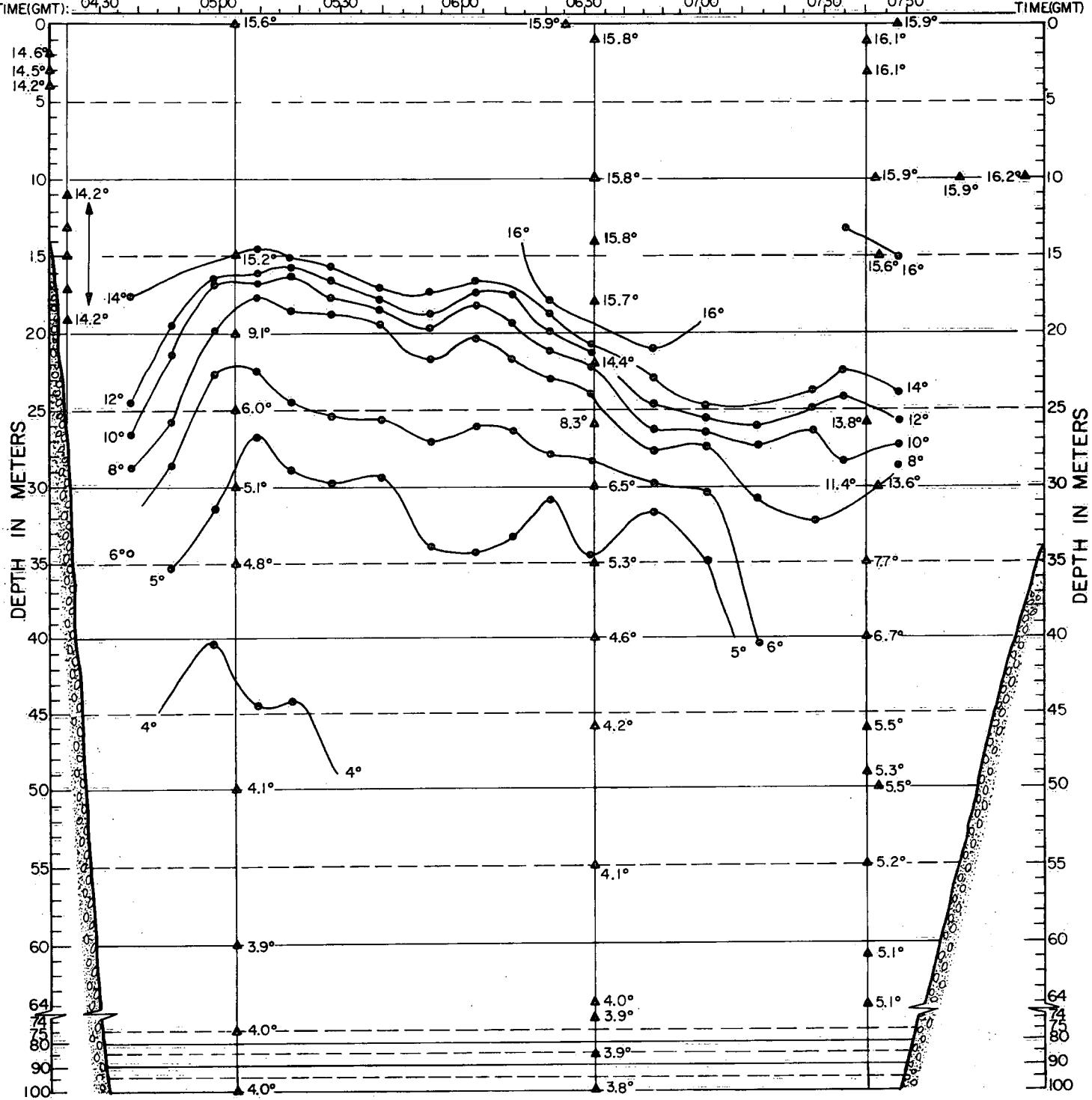
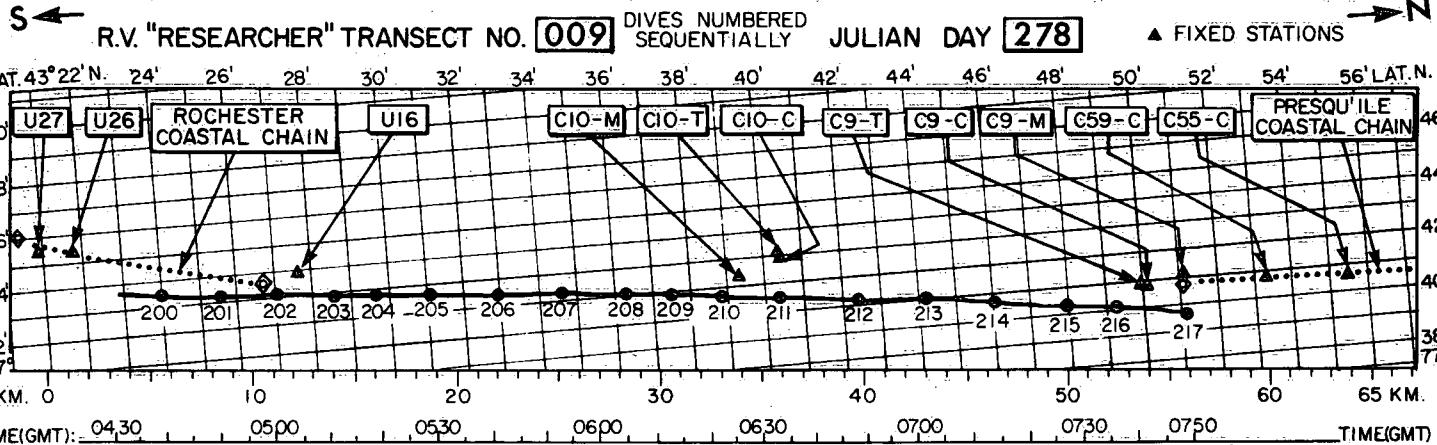
JULIAN DAY 278

## ▲ FIXED STATIONS

→ N



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)



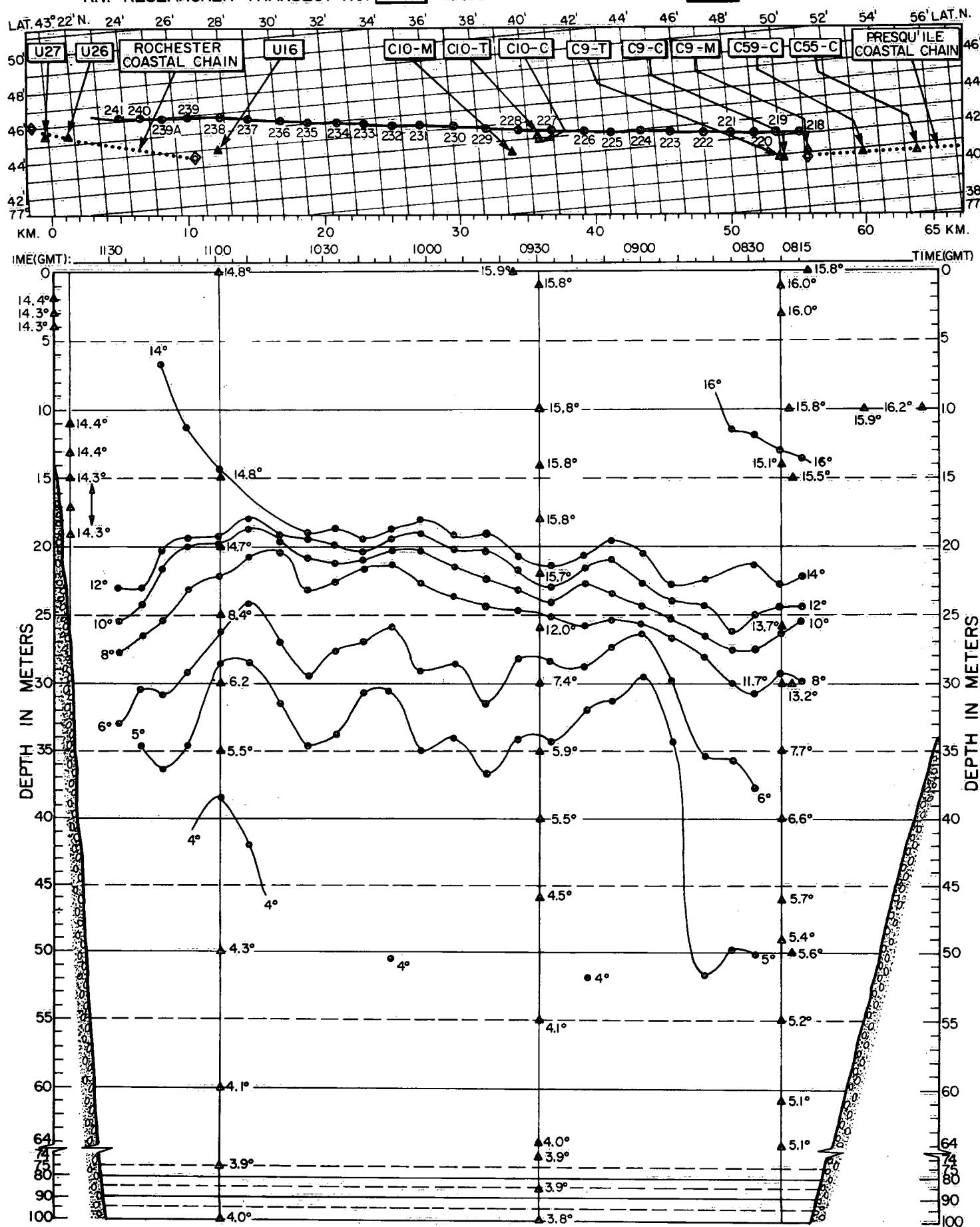
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 010 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 278 ▲ FIXED STATIONS → N

DIVES NUMBERED

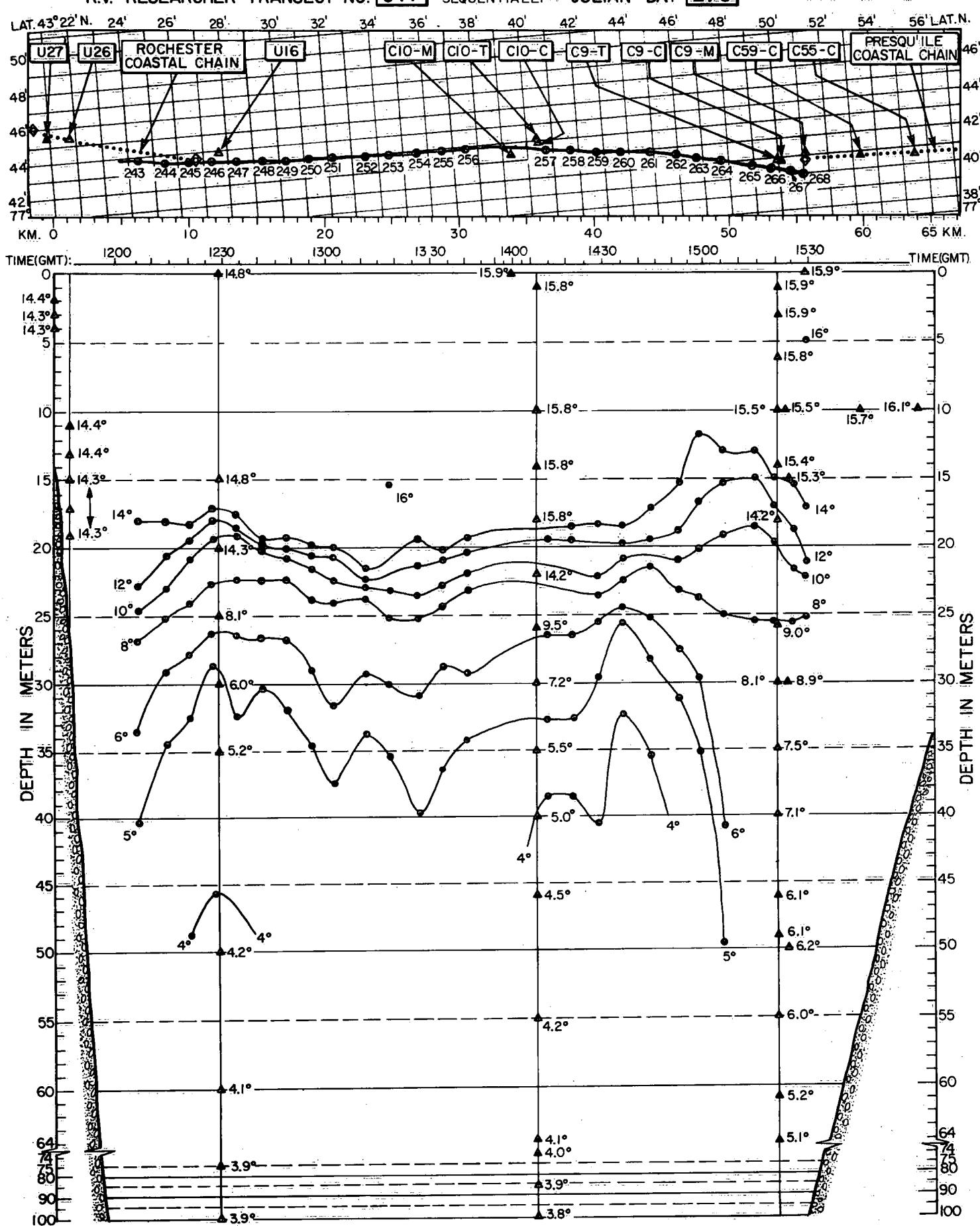
JULIAN DAY 278

#### **▲ FIXED STATIONS**



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 01 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 278 N → ▲ FIXED STATIONS



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

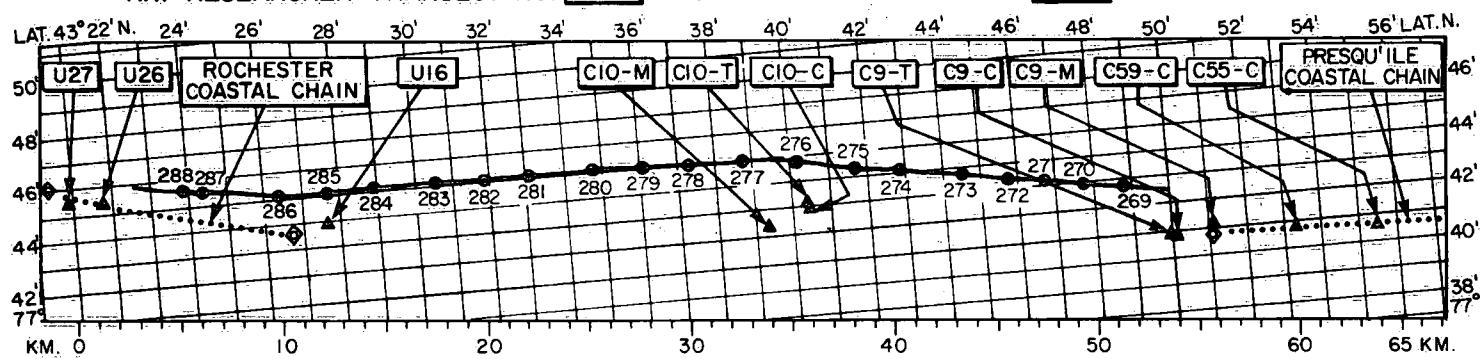
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DIVES NUMBERED  
SEQUENTIALLY

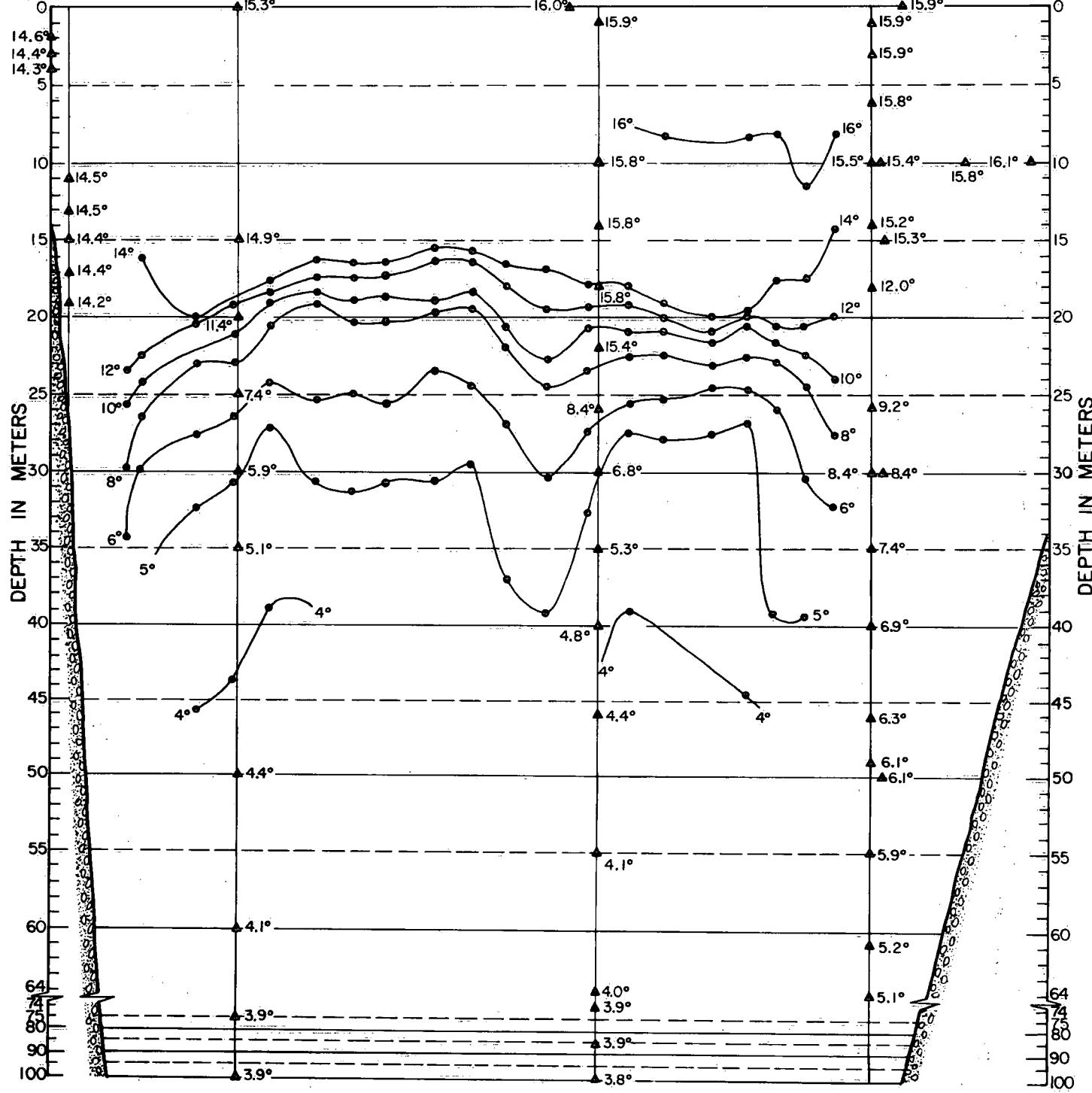
JULIAN DAY 278

#### ▲ FIXED STATIONS



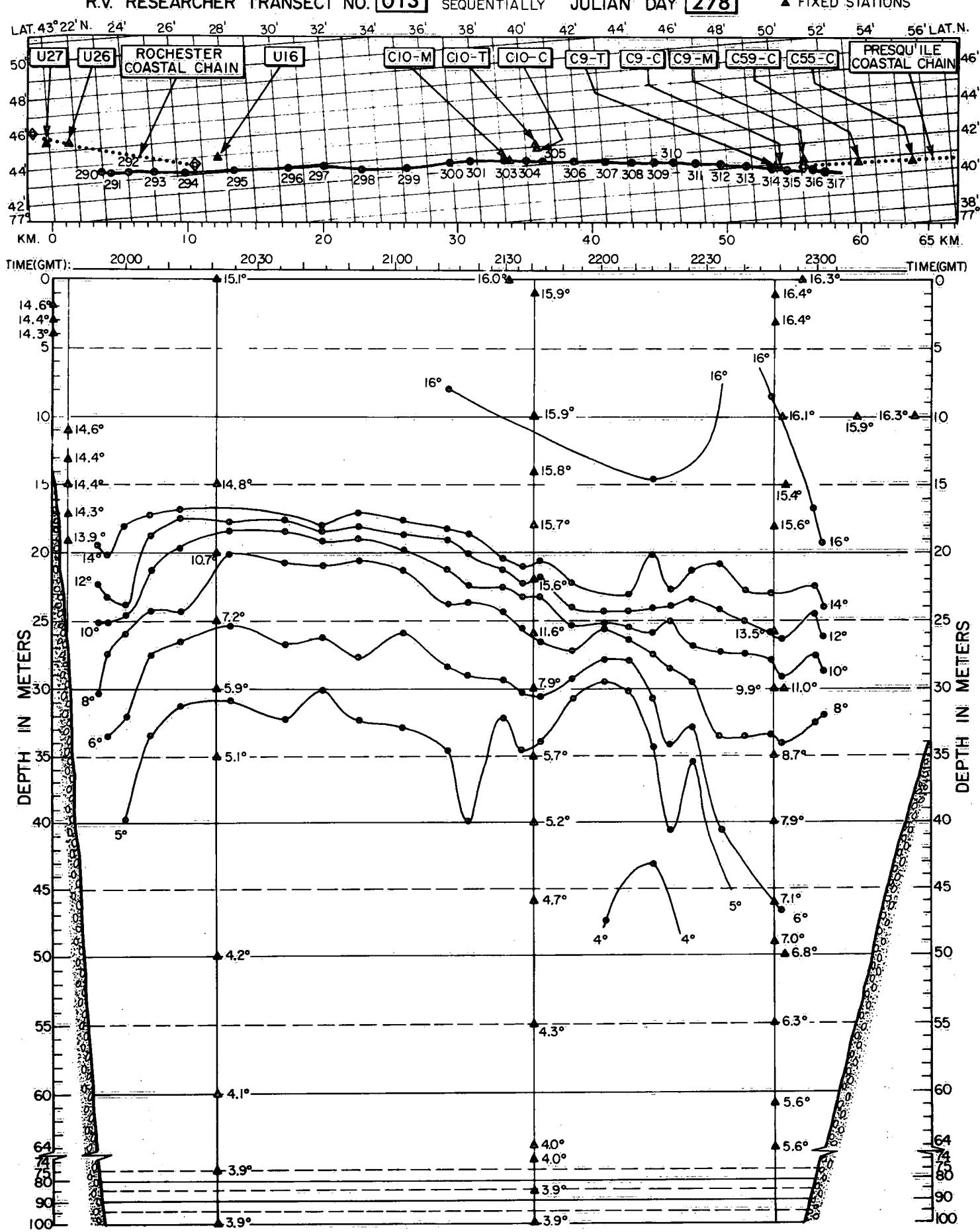
TIME(GMT):

TIME(GMT):      TIME(GMT)



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 013 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 278 N →



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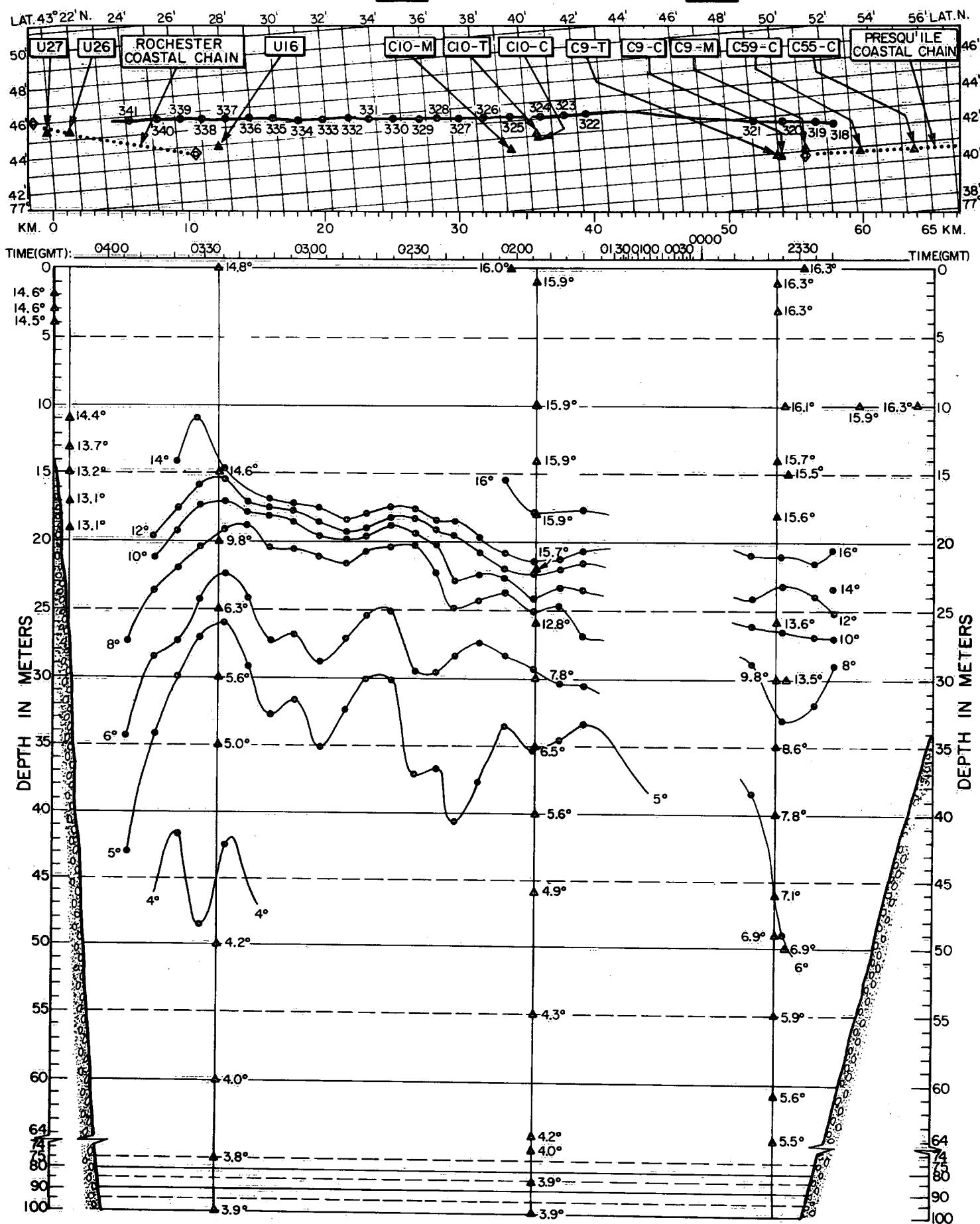
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R.V. "RESEARCHER" TRANSECT NO. 014 DIVES NUMBERED SEQUENTIALLY

JULIAN DAY 278

▲ FIXED STATIONS

N



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

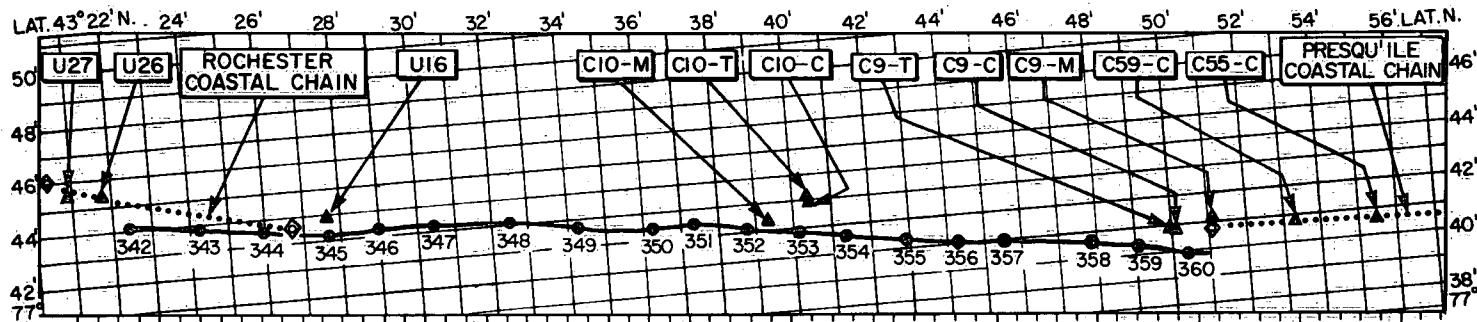
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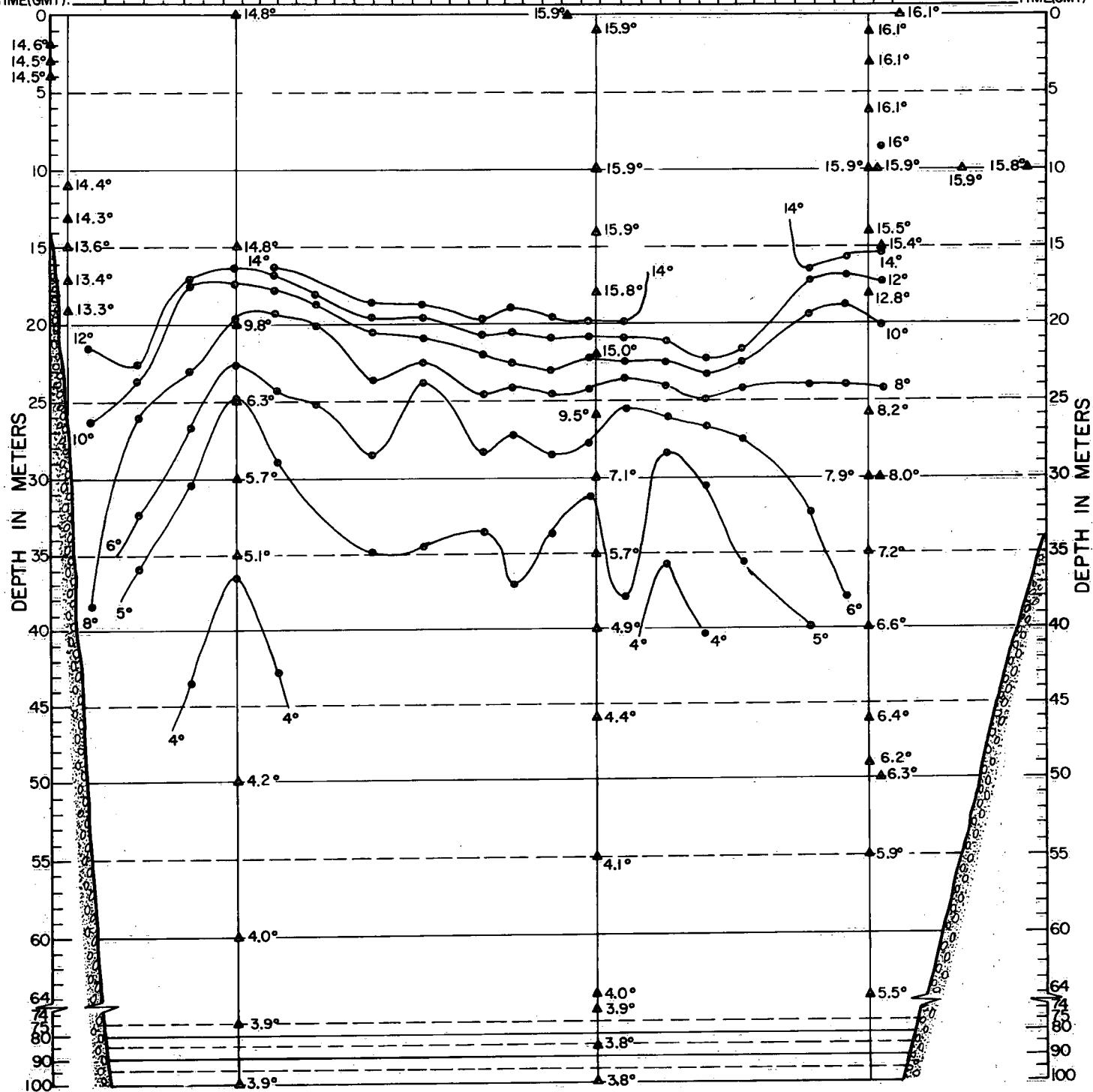
JULIAN DAY 279

▲ FIXED STATIONS

N

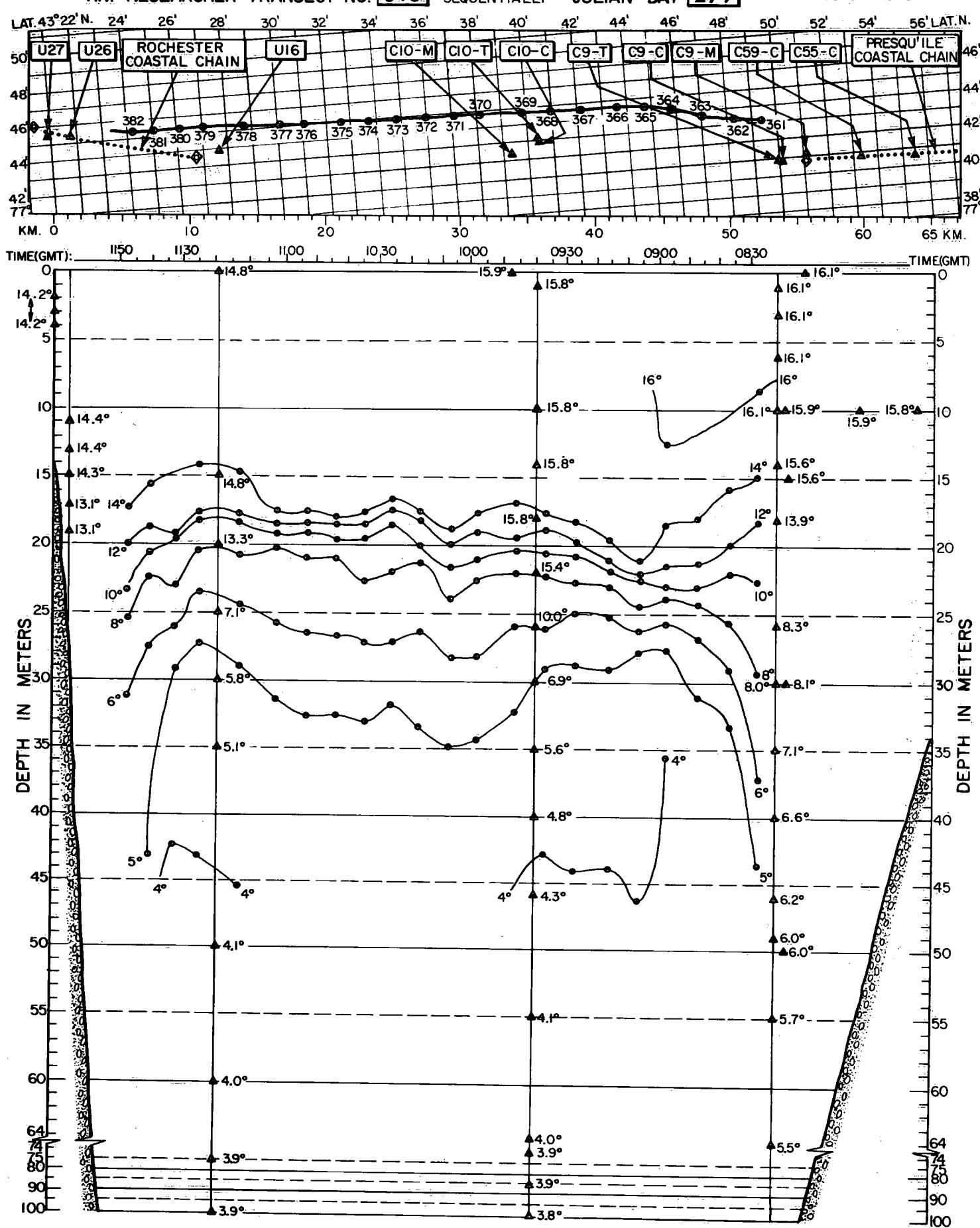


TIME(GMT): 0430 0500 0530 0600 0630 0700 0730 0755 TIME(GMT)



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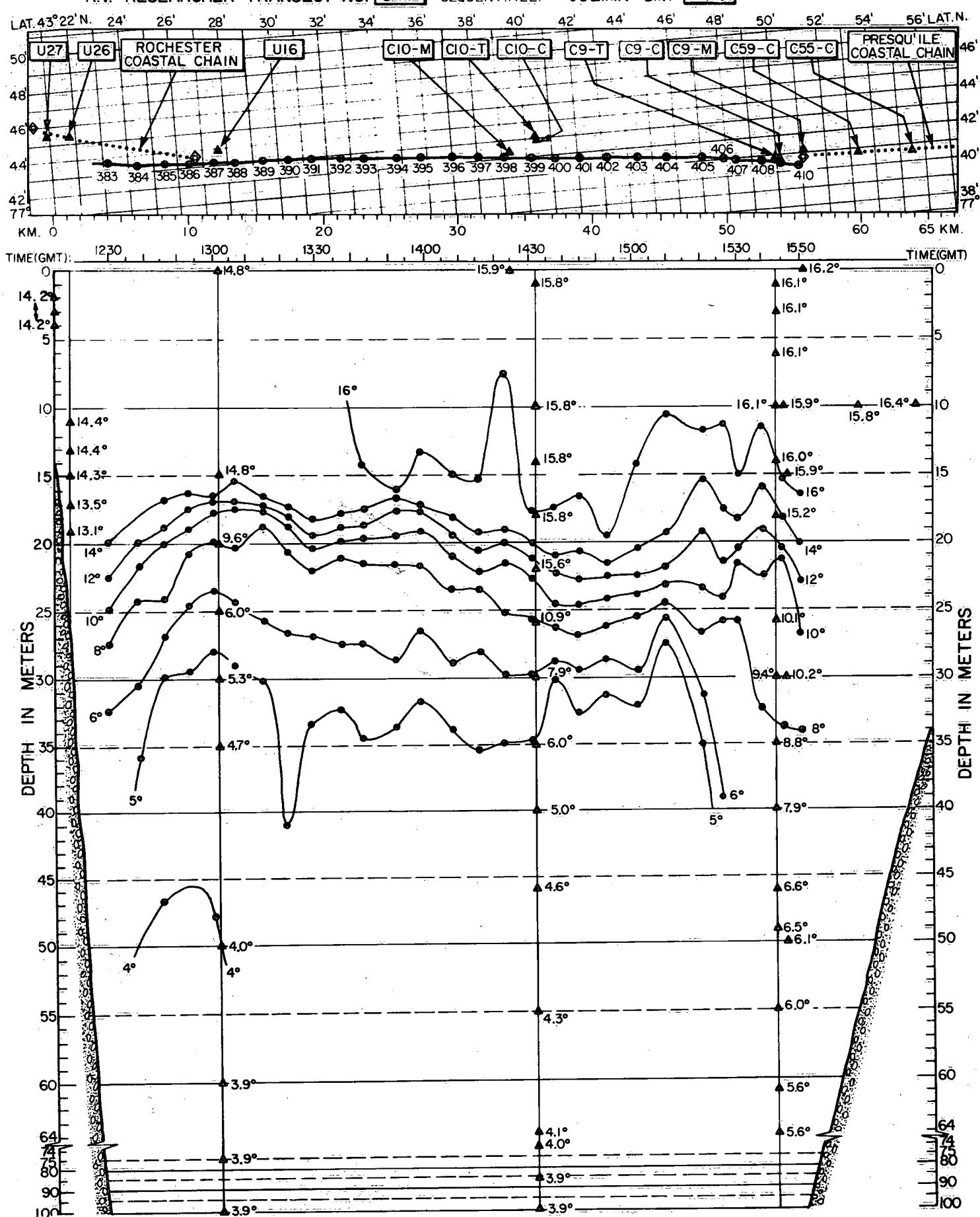
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R.V. "RESEARCHER" TRANSECT NO. 017 DIVES NUMBERED SEQUENTIALLY

JULIAN DAY 279

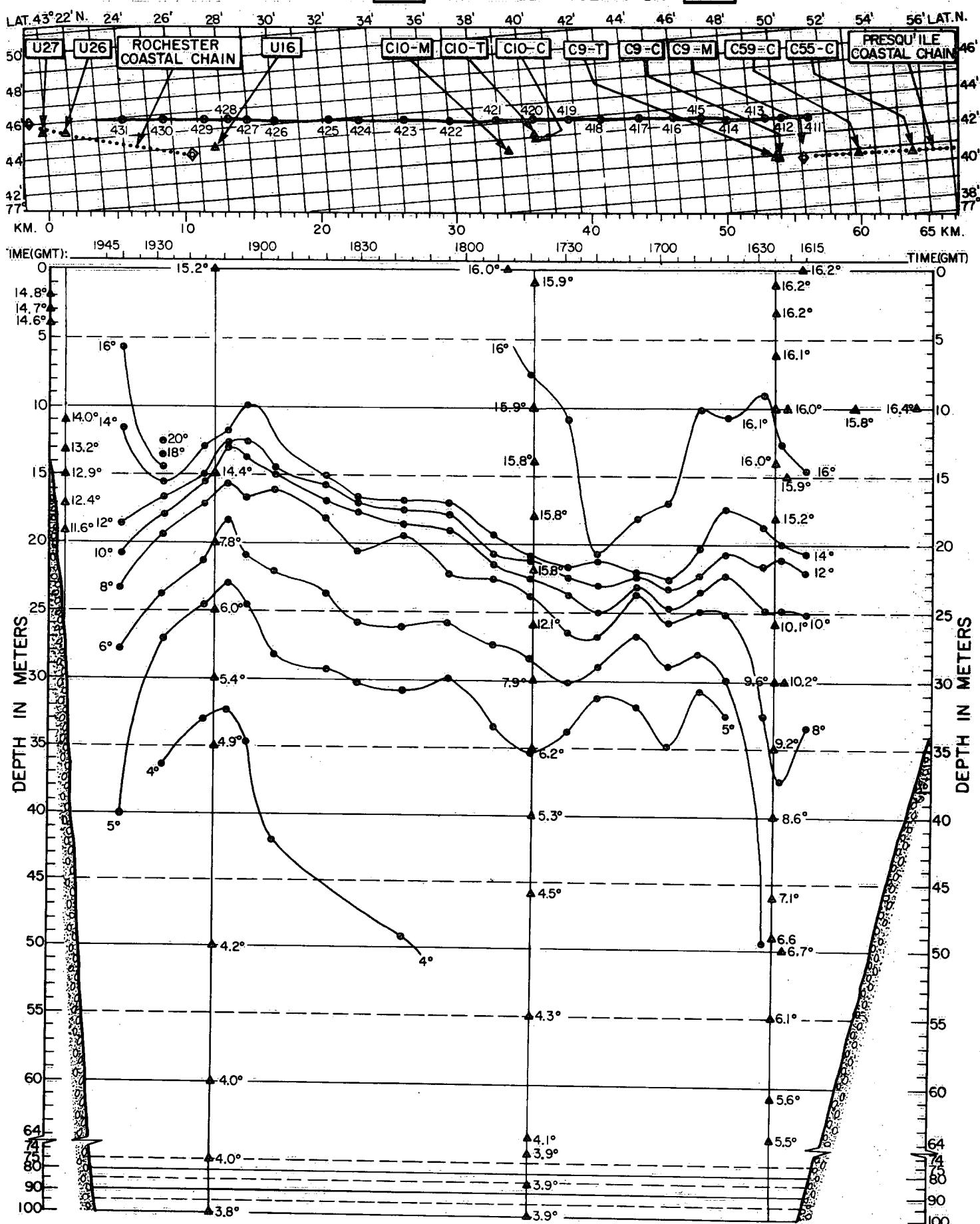
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▲ FIXED STATIONS



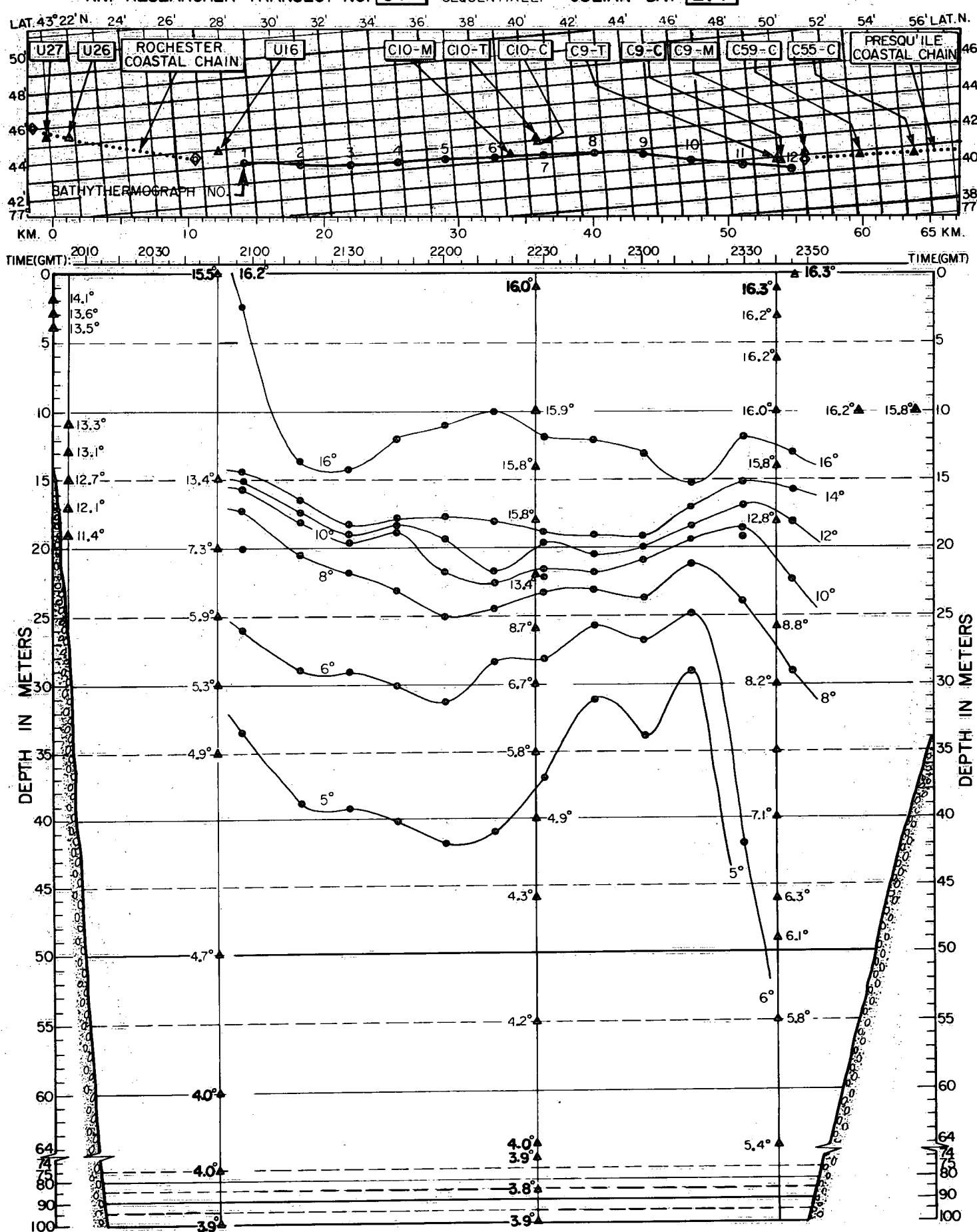
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 018 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 279 N → ▲ FIXED STATIONS



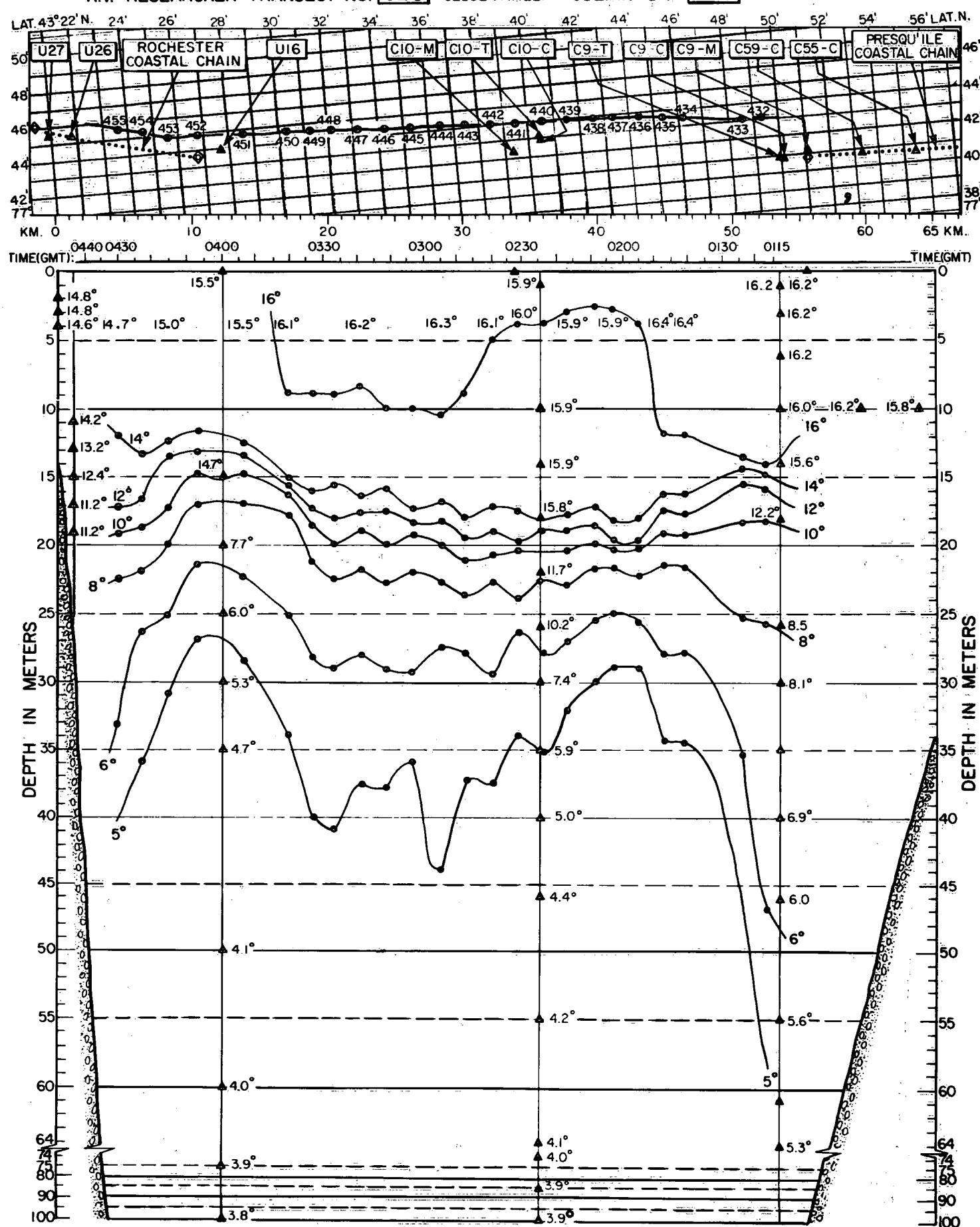
FYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 019 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 279 ▲ FIXED STATIONS N →



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT.(S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 020 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 280 → N  
▲ FIXED STATIONS



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

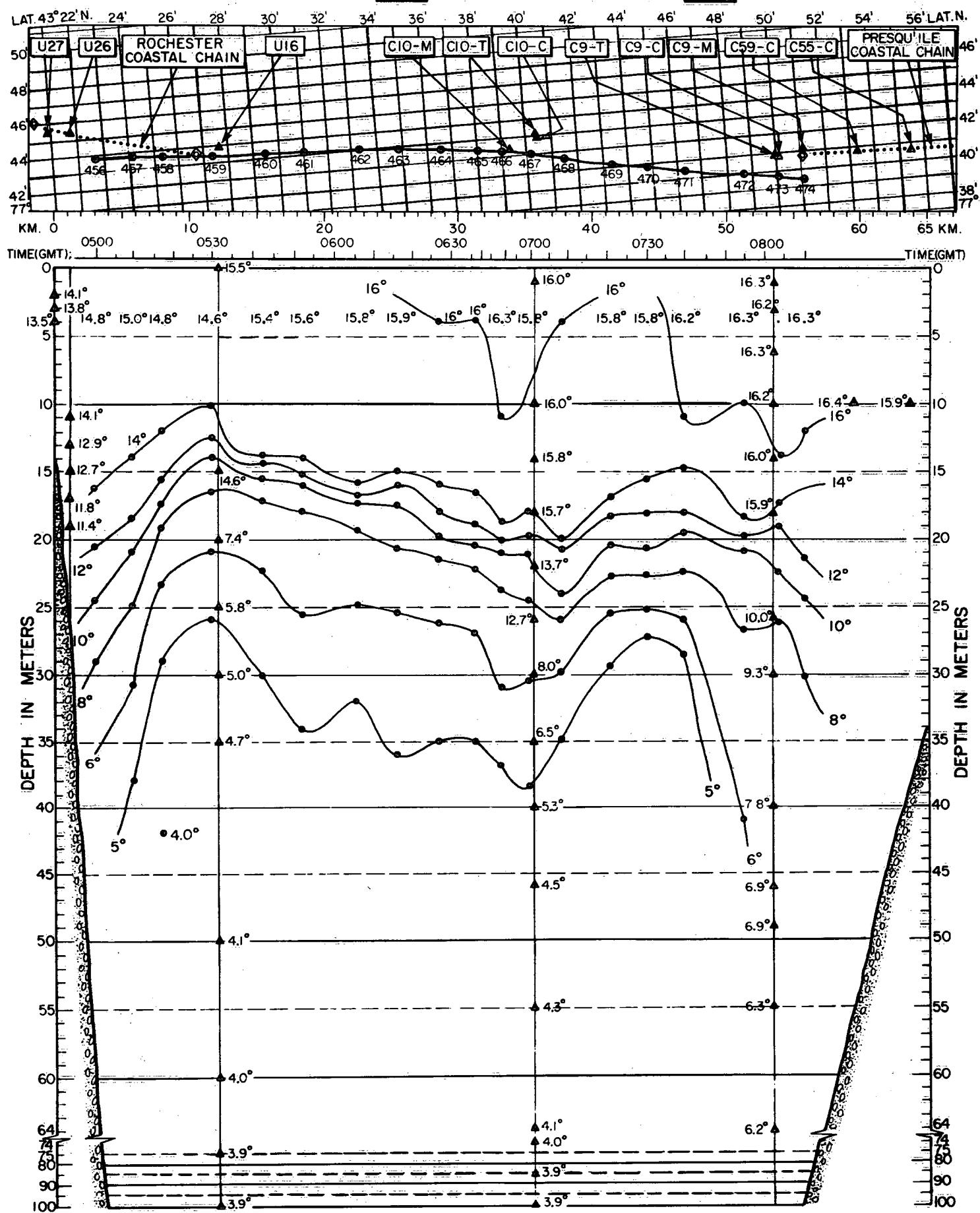
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R.V. "RESEARCHER" TRANSECT NO. 021 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 280

DIVES NUMBERED

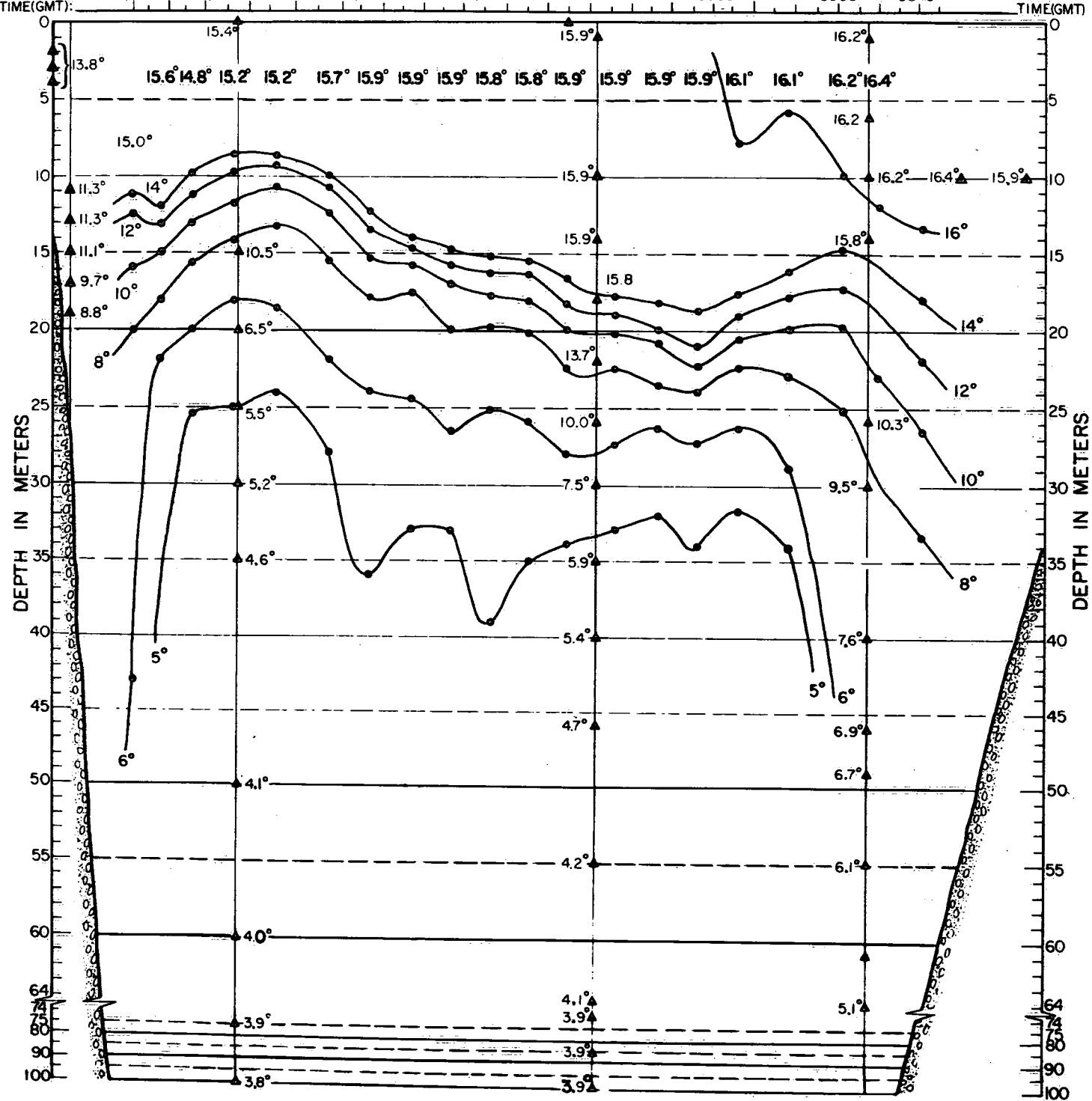
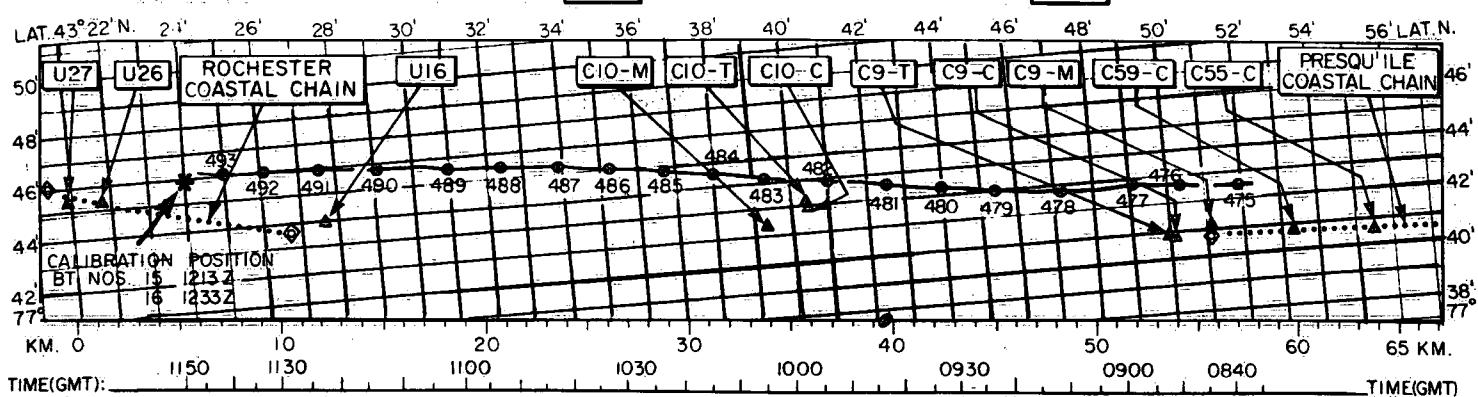
JULIAN DAY 280

2



## IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT BRADDOCK PT. (S) TO PRESQU'ILE (N)

S ← R.V. "RESEARCHER" TRANSECT NO. 022 DIVES NUMBERED SEQUENTIALLY JULIAN DAY 280 N →



# Intercomparisons of the Braddock Point to Presqu'ile Temperature Transects and Contemporary Measurements at "Coastal Chains" and Fixed Recording Stations

## 6.1. THERMOCLINE DEPTHS ESTIMATED BY THE UNDULATOR COMPARED WITH ESTIMATES FROM FIXED STATIONS

On the Braddock Pt. to Presqu'ile section the vessel track passed close to three U.S. stations (towers U27, U26, mooring U16) and eight Canadian stations (C9-T, C9-C, C9-M, C10-C, C10-T, C10-M, C59-C, C55-C), the positions of which are shown at the head of the transect diagrams in Chapter 5 and in Figure 6.3. The temperature data from various depths (Table 5.1) at these fixed stations are entered, as explained in Chapter 5, on the transect diagrams at times (Tables 5.2, 5.3 and 5.4) coinciding as closely as possible with the times of the vessel's passage. It is therefore possible to compare temperatures or, more specifically, thermocline depths determined by the Undulator and by the fixed thermographs at the stations along the transect, i.e. principally at U16, C9-T, and C10-T. This comparison is made in Figure 6.1 for all three cruises and for all cases in which a temperature data point from a fixed station lies at or close to a thermocline isotherm, as determined by the Undulator. Only those cases where close comparison is possible have been selected, but even so some scatter is to be expected, because the fixed station readings were only available at 6-min intervals at U16 and at 10-min intervals at the Canadian stations. Also distances of the vessel tracks from the fixed stations ranged from less than 100 m to 4 km in the exceptional case of C10-T and Transect 17 (day 223). Usually the station-to-track distances were about 1 km. Even at such small distances, short internal waves could be expected to produce occasional differences of a metre or so in thermocline depth between the station and the nearest transect point. Scatter must therefore be expected in the Figure 6.1 comparisons. However, if the Undulator showed no bias in estimating isotherm depth, relative to the estimates from fixed-station readings, the best-fit regression line through the points in Figure 6.1 should fall on the 45° lines, shown broken. But the actual regression lines (unbroken) lie roughly parallel to but above the 45° lines by 1 m or

less in July, 2 m in August, and 1.5 to 2.5 m in October. If the measured temperatures and the assumed sensor depths at the fixed stations are taken as correct, the conclusion from Figure 6.1 is that the Undulator underestimated thermocline depths by 1 or 2 m. On the assumption that this was the consequence of the undesirably long thermal lag in the response of the Undulator's sensor as mounted in its epoxy resin support, the following analysis was carried out.

For this analysis the following experimental results are relevant. First, the thermal time constant of the thermistor, as mounted, was determined in the laboratory to be about 5 s in well-stirred water. Second, when the Undulator was made to dive in Lake Ontario following the procedure described in Chapter 2 and with a well-developed thermocline present, the profiles plotted from data obtained during the rapid descent and the slower ascent showed thermoclines differing in depth by about 5 m (examples in Figure 6.2). We assumed that the thermal lag of the Undulator sensor led to a large overestimate of thermocline depth during the rapid descent; and we therefore used the ascent data only in preparation of the transect diagrams in Chapter 5. The question is, to what extent do those transects underestimate thermocline depth? In one attempt to answer this question, we compared Undulator data from specific dives with contemporary profiles obtained with O.S.S. Researcher's XBT (Expendable Bathymeterograph, Sippican Corporation). Two typical comparisons are illustrated in Figure 6.2, made during transect No. 22, 10 August, when a thermocline of moderate gradient deepened as the vessel approached the southern shore. The expected differences in estimate of isotherm depths from the descent and the ascent of the Undulator are evident; but the surprising result is that, although the XBT temperature-depth trace lies between the descent and ascent traces of the Undulator, it is closer to the descent trace. Looking at all the evidence, including that presented in Figure 6.1 and later figures, we must conclude that during its very rapid descent that particular XBT also overestimated Lake Ontario thermocline depth by several metres.

## 6.2. RESPONSE OF SENSORS ASCENDING THROUGH MODEL THERMOCLINES

To analyze further the Undulator response to changes in ambient temperature during the slower ascending phase, the following model was considered. Three temperature sensors of respective thermal time constants of 5, 10, and 20 s are assumed to ascend at a uniform rate through the model "thermoclines" illustrated by thick lines in Figure 6.3. The computed responses at the sensors are shown by thin lines in that figure. The rate of rise chosen in Figure 6.3 is 10 cm s<sup>-1</sup>, representative for the Undulator as used in Lake Ontario, where the rates ranged from 5.3 to 6.2 m min<sup>-1</sup> (see Fig. 2.8).

The hypothetical thermoclines in Figure 6.3 possess uniform temperature gradients, shown as thick lines separating a "hypolimnion" of uniform temperature 6° from an "epilimnion" of uniform temperature 16°. Reading from the bottom of the figure, the thermocline thickness (and temperature gradients) are: zero (infinite); 1.25 m (8° m<sup>-1</sup>); 2.50 m (4° m<sup>-1</sup>); 5 m (2° m<sup>-1</sup>); 10 m (1° m<sup>-1</sup>); and 20 m (0.5 m<sup>-1</sup>). It is assumed that, rising through the "hypolimnion", all three temperature sensors have had time to equilibrate to 6°. When they pass through the "thermocline" of zero thickness, the sensor temperatures rise exponentially, as shown, at rates determined by the time constant. The other model thermoclines possess finite thicknesses; and the exponential phase of the sensor temperature rise does not begin until the sensor has risen to the top of the thermocline and enters the "epilimnion", i.e. to the levels indicated by horizontal broken lines in the figure. Below these levels and within the thermocline, the rise in sensor temperature lags behind the rise in true ambient temperature. That lag, initially small at the bottom of the thermocline, approaches a constant value in the upper portion, so that the temperature-depth profile, as indicated by the sensor, parallels the true thermocline in slope but is raised above it by a distance equal to the vertical distance travelled by the sensor during an interval equal to its own time constant. This result, as Figure 6.3 shows for the more realistic thermocline models illustrated near the top of the figure, is independent of thermocline slope. In other words, for the middle of linear thermocline slope, the error in thermocline depth estimated by a sensor of time constant C seconds rising at a speed of x cm s<sup>-1</sup> will be Cx cm. Near the bottom of the thermocline the error is less than Cx; near the top it is greater than Cx.

For a temperature sensor of time constant C, the general equation for the sensor temperature T<sub>s</sub>(t) as a

function of time is

$$T_s(t) = T_w(t) - C(dT_s/dt) \quad (1)$$

in which T<sub>w</sub> is the (true) ambient temperature as a function of time. For linear variation of T<sub>w</sub>, assumed for Figure 6.3, T<sub>w</sub>(t) = kt, and Equation 1 yields

$$T_s(t) = kt + kC(e^{-t/C} - 1) \quad (2)$$

It follows from Equation 1 that T<sub>w</sub>(t) can be derived from T<sub>s</sub>(t) and dT<sub>s</sub>/dt. This we attempted to do; but the unsmoothed T<sub>s</sub>(t) record from the Undulator was too "noisy" to permit a reliable estimate of dT<sub>s</sub>/dt. We did not resort to a laborious smoothing procedure because, as we conclude below, the Undulator error in estimation of thermocline depth is acceptable for most purposes and the order of magnitude of the correction is known.

Figure 6.3 shows that, under the conditions of that model, a sensor with a 5-s time constant would underestimate thermocline depth by 0.5 m. This result is in agreement with the findings for July in Figure 6.1, but not with the findings for August and October, which are consistent with an error of 2 m. If Figure 6.3 is representative of the Lake Ontario thermoclines, the thermal time constant of the Undulator as used may therefore have been greater than the 5 s estimated for the mounted thermistor bead in the laboratory. The position of the bead and/or the cooling effect of the Undulator casing may have had some influence. Also to be considered in future designs is the intensity of turbulence around the temperature sensor during descent and ascent.

## 6.3. ADDITIONAL TRANSECT - FIXED STATION COMPARISONS

A further source of evidence is to be found in intercomparisons of temperature-depth distributions determined by transects and at fixed stations. Therefore, isotherm depths were interpolated from hourly averaged temperature readings at various depths (see Table 5.1) at U16 (6-min intervals), C9-T, and C10-T (10-min intervals). Those three stations lay close to the Braddock Pt. to Presquile transect (see Fig. 6.4). Interpolated (hourly mean) isotherm depths are also included for two nearby stations, U14 and U15, respectively 24 and 20 km from the transect. On the figures which follow (as listed in Table 6.1), the times of nearest passage of the transect vessel are marked with vertical lines. It should be noted that vertical hatching on isotherms in the diagrams

**Table 6.1. Numbering of the Hourly Mean Isotherm Depth Diagrams According to Station and Cruise Dates; see Figures 6.5 – 6.16**

Station No.	Cruise dates			
	Jul 10-14*	Jul 24-28	Aug 7-11	Oct 2-6
U14		6.7	6.11	6.13
U15		6.8		
U16		6.9	6.11	6.14
C9-T	6.5	6.10	6.12†	6.15
C10-T	6.6			6.16

\*Dates of C.S.S. *Limnos* July cruise.

†8-12 August, concurrent with the C.S.S. *Limnos* cruise.

from C9-T and C10-T indicates that interpolation extended over a range greater than 4°C, which occasionally occurred, for example when data were missing from one or more thermistor channels. The hourly averaged isotherm depth diagrams are listed according to station number and cruise dates in Table 6.1.

#### 6.4. TRANSECT - COASTAL CHAIN COMPARISONS

The remaining category of checks on Undulator accuracy are direct comparisons between temperature profiles obtained independently by the Undulator and by surveys along the Rochester and Presqu'ile Coastal Chains, when there was coincidence in space and time. We have arbitrarily defined coincidence to be within 3 km in space and 20 min in time. The comparisons are shown in the following figure pairs: Figures 6.17 and 6.18, 6.24 and 6.25, 6.26 and 6.27, 6.28 and 6.29, 6.30 and 6.31. The coincident Transect and Chain temperature profiles are shown on the right; the isotherm distributions in the whole Chain section and in a larger corresponding portion of the Transect are shown, on the same distance and depth scales, on the left.

##### Coincident Comparisons with the Rochester Chain

There was only one coincidence for the Rochester Chain: 2110 GMT at 12 km on the Coastal Chain and 2120 GMT at 11 km on Transect 7, Julian day 277, 3 October 1972 (Fig. 6.17). With data available at 2124 GMT (Table 5.4) from the fixed mooring U16 at 12 km, it is therefore possible to compare three independent estimates of the temperature-depth profile in Figure 6.18. The agreement is remarkably close. The transect profile (dots) would fit the other points better if it were moved down 1 m.

There was near-coincidence on 27 July (Julian day 209, Transect 14, Fig. 6.19). Both the Coastal Chain and the Transect, although an hour or more apart, show strong downwelling in the region 3 to 13 km, with the Transect thermocline showing a steeper gradient and lying a little higher than the Chain thermocline, but with a similar slope. Very near shore (not traversed by the Transect) there was a narrow band of upwelling, also shown on the fixed thermographs at U27. This is an example of the way in which Chain and Transect information can be combined to provide a more complete picture of the whole section. The same statement applies to the comparisons in Figures 6.20 to 6.23.

##### Coincident Comparisons with the Presqu'ile Chain

If, for the Presqu'ile Coastal Chain, we again define a Transect-Chain coincidence as falling within a time limit of 20 min and a distance limit of 3 km, we have three such coincidences and one near-coincidence. In each case, data from the moored thermistor chain C9-T fortunately also fall within or nearly within the coincidence limits, so that three independent estimates of the temperature profile can be made. In the first example (Figs. 6.24, 6.25) the C9-T points show divergence near the top and in the lower part of the profile. Note, however, that there was a 30-min time difference between the C9-T and Chain observations. The Transect and Coastal Chain profiles show close agreement in the thermocline region; again this agreement would be closer if the Transect profile were lowered by 1 m.

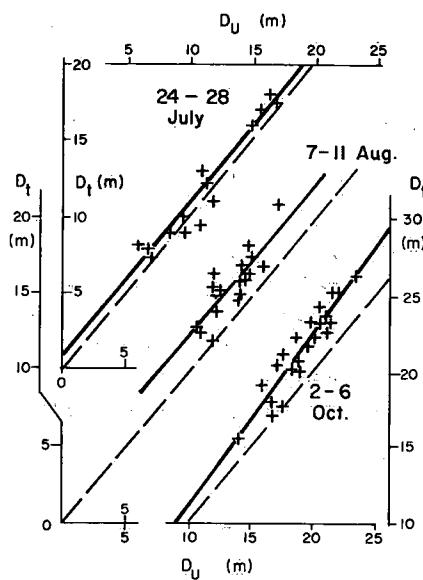
In the second example (Figs. 6.26, 6.27) all three profiles coincide closely in space and time, and apart from one aberrant point on the Transect profile, excellent agreement would again be obtained if that profile were lowered by 1 m. The third example (Figs. 6.28, 6.29) shows the Transect and Chain thermocline profiles running fairly close together with no systematic offset, but with a divergence at 30 m. In the near-coincidence (Figs. 6.30, 6.31) there is coincidence in distance, but the Chain measurements were made an hour later than those in the Transect and at C9-T. Lowering the Transect profile by 1.5 m would produce a better fit with the Chain and C9-T data points. It may be noted that had Figure 6.31 been drawn to produce the best time coincidence rather than space coincidence, the Transect-Chain discrepancy would have been much greater, because of the pronounced dip in the Chain isotherms between 12 and 16 km, a situation reminiscent of that found in the Figure 4.10 comparison referred to in Chapter 4.

## Near-Coincident Transect-Chain Comparisons

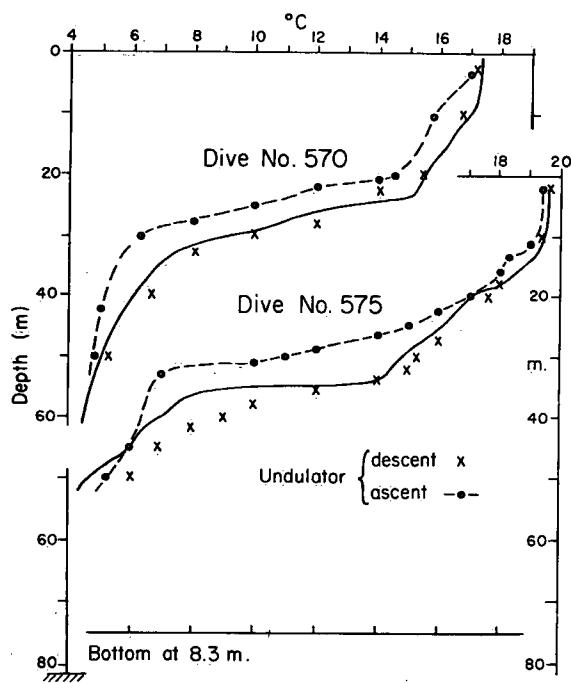
The near-coincident Transect-Chain comparisons in Figures 6.32 to 6.42 help, as in Chapter 4, to complete the transects and connect the offshore and nearshore pictures of isotherm distribution. However, in making these connections, attention must be paid to relative timing. Although there is a spatial overlap in the region 16 to 19 km from shore, the time gap is sometimes great enough to allow large changes in isotherm depth to occur; the 3-hr gap in Figure 6.36 is an example. In Figure 6.40, on the other hand, there is almost coincidence in time and space, but the Transect shows a thermocline which is much narrower than that shown by the Chain, with only a 4-km gap between them.

## 6.5. CONCLUSIONS FROM ALL INTERCOMPARISONS

Combining all the evidence from the Transect - fixed station comparisons in Figure 6.1, from the model in Figure 6.3, and from the Transect - Coastal Chain "coincidences" (Figs. 6.17, 6.18, and 6.24 to 6.31) we conclude that *the transect diagrams in Chapter 5 generally underestimate thermocline depths by 0.5 to 2.5 m, with 1.5 m as the most probable difference*. Where oscillation in thermocline depth is the main interest, this error is not important. Where precise thermocline depth is the prime consideration, in heat budget studies for example, a correction of 1.5 m should be applied.



**Figure 6.1.** Comparisons of thermocline depth estimates made on selected occasions when the Undulator (producing a depth estimate,  $D_U$ ) passed close to a fixed station (producing a depth estimate,  $D_t$ ). A group of crosses, each cross representing an individual estimate pair, is plotted for each of the three cruises; best-fit regression lines are drawn (unbroken) through each group. The significance of the broken line is explained in the text.



**Figure 6.2.** Comparisons of temperature-depth profiles obtained (i) during the descent, (ii) during the subsequent ascent of the undulator on two particular dives\*, and (iii) from a contemporary XBT cast (see text).

\*Dive No. 570, 1938 GMT (bottom at 135 m, temp.  $3.9^{\circ}\text{C}$ ) and dive No. 575, 1958 GMT, Julian day 223, 10 August 1972, both on Transect No. 22.

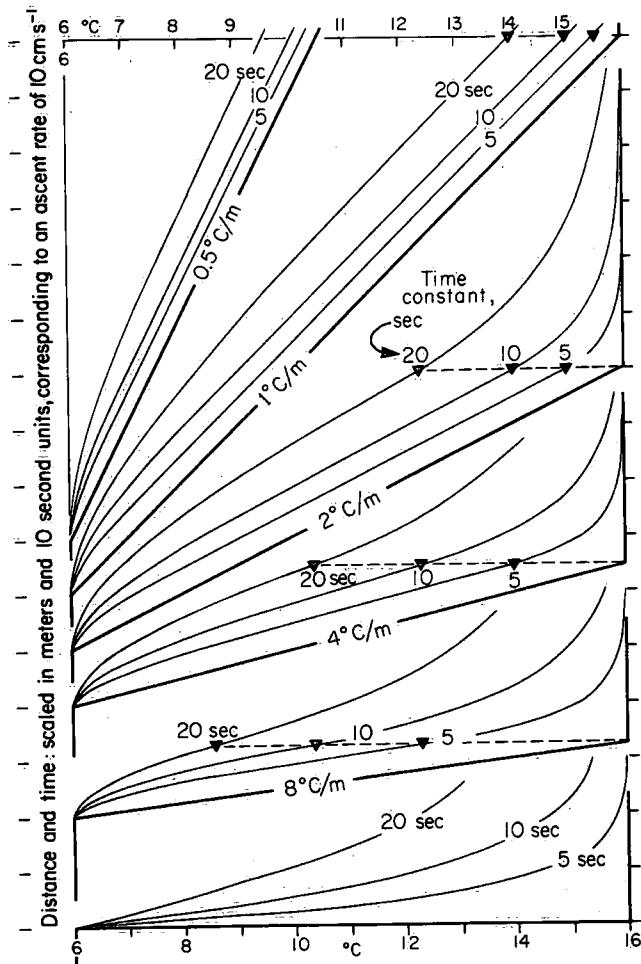


Figure 6.3. Responses of three temperature sensors while ascending at a rate of  $10 \text{ cm s}^{-1}$  through model thermoclines (see text).

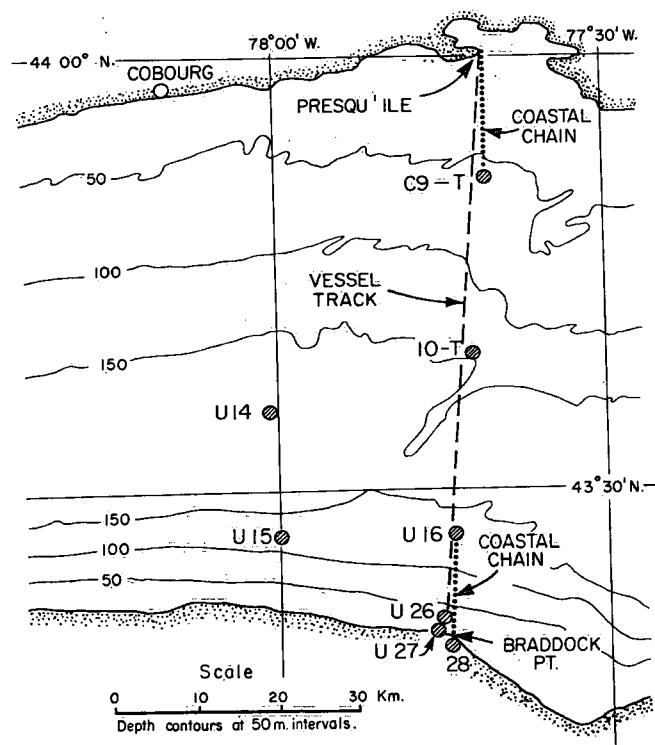
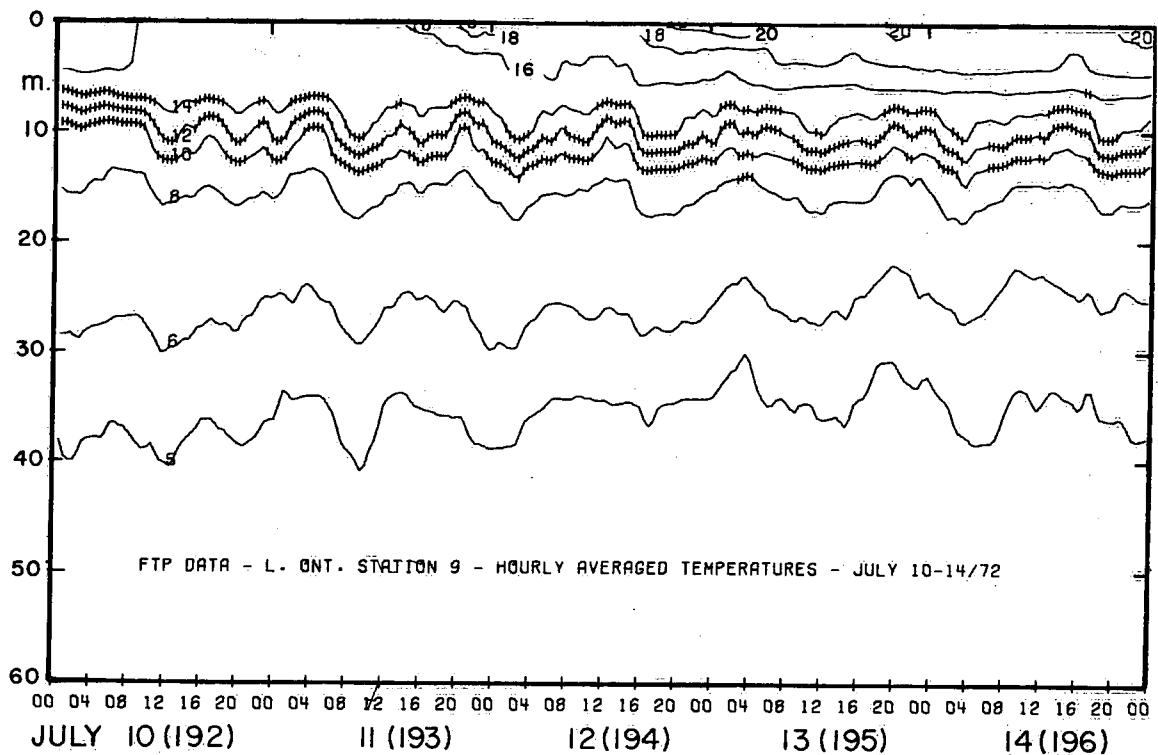
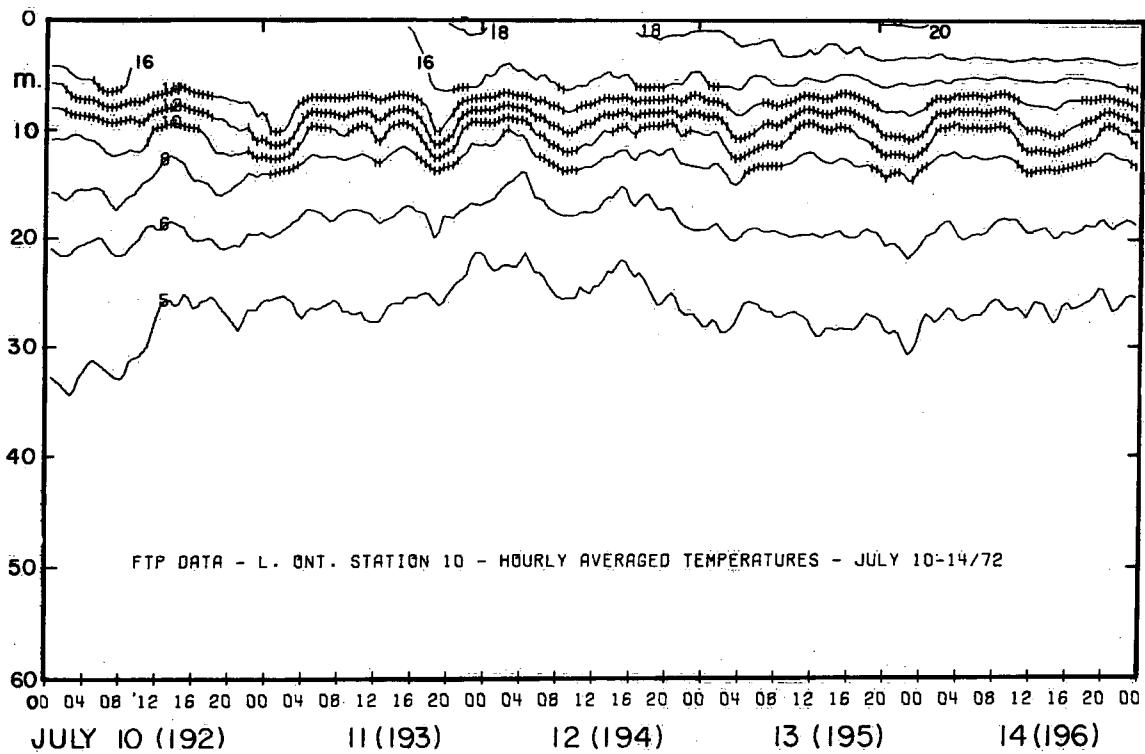


Figure 6.4. Lake Ontario 1972: positions of fixed measuring stations relative to the Braddock Pt. to Presqu'ile Transect (broken line) and to the Coastal Chains (dotted lines).



**Figure 6.5** Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C9-T, Lake Ontario, 10-14 July 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.



**Figure 6.6.** Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C10-T, Lake Ontario, 10-14 July 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.

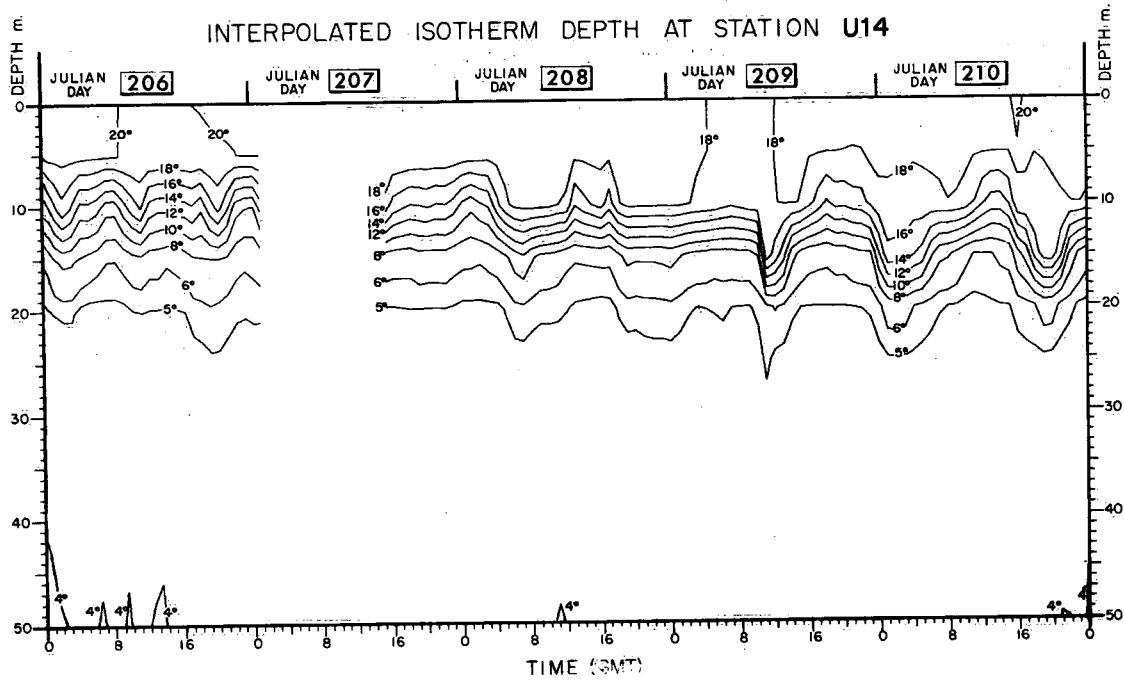


Figure 6.7. Isotherm depths at station U14, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 5.1.

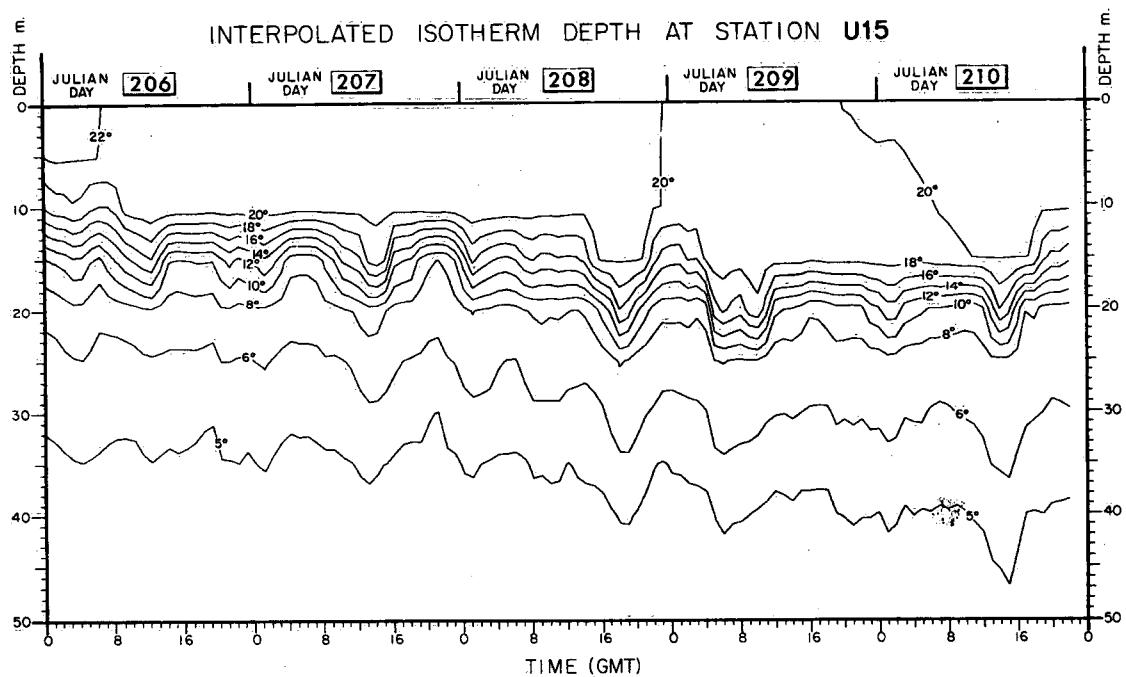
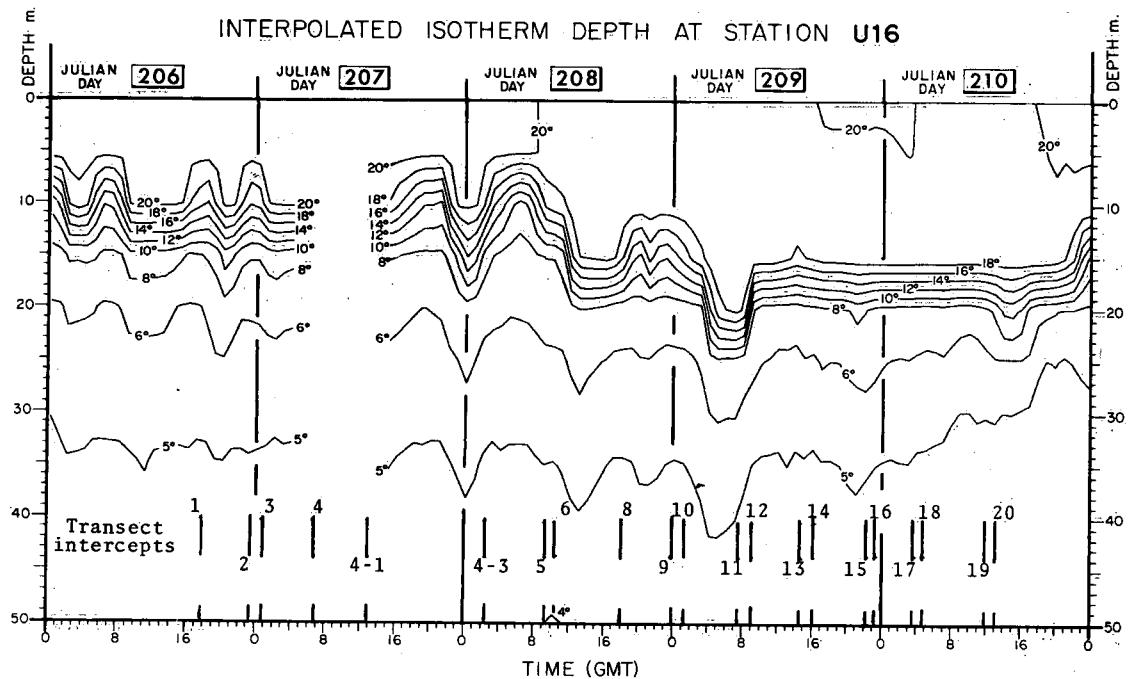
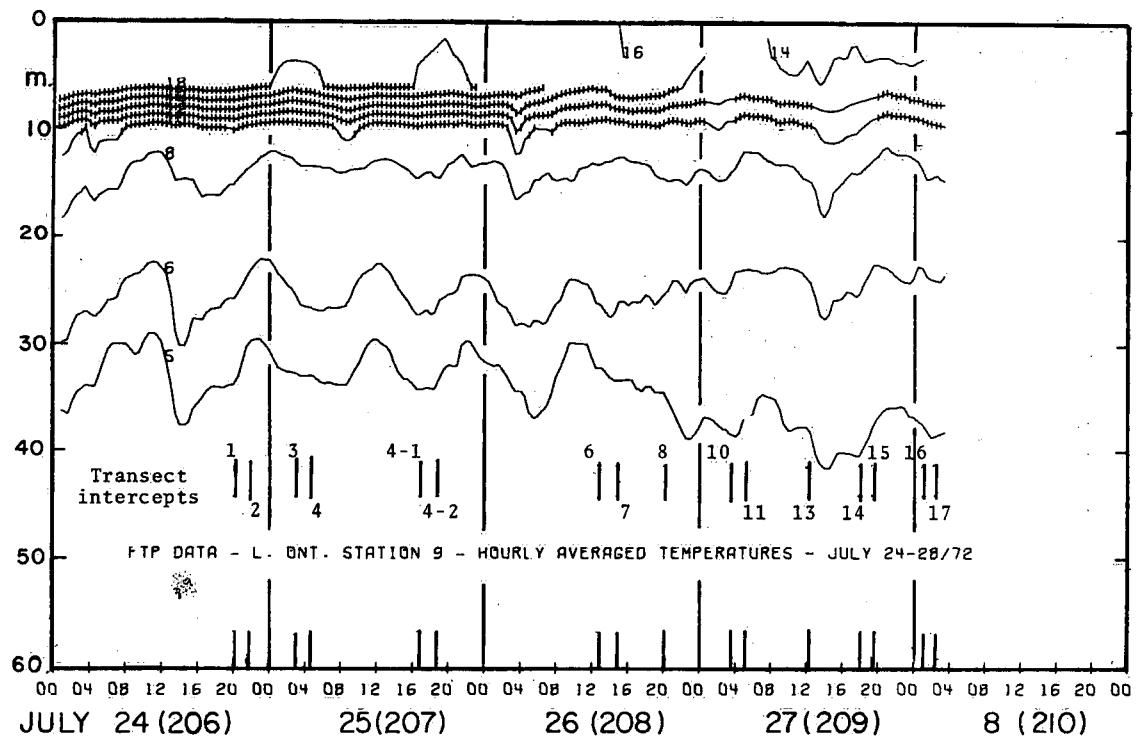


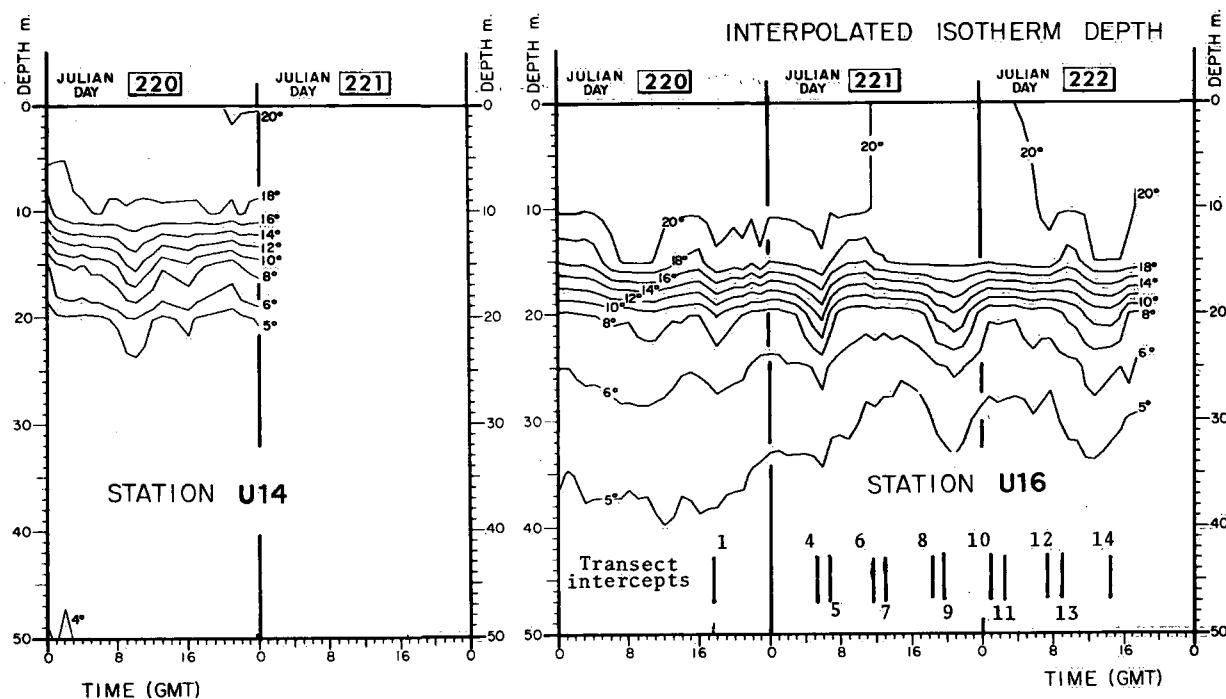
Figure 6.8. Isotherm depths at station U15, Lake Ontario, 22-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 5.1.



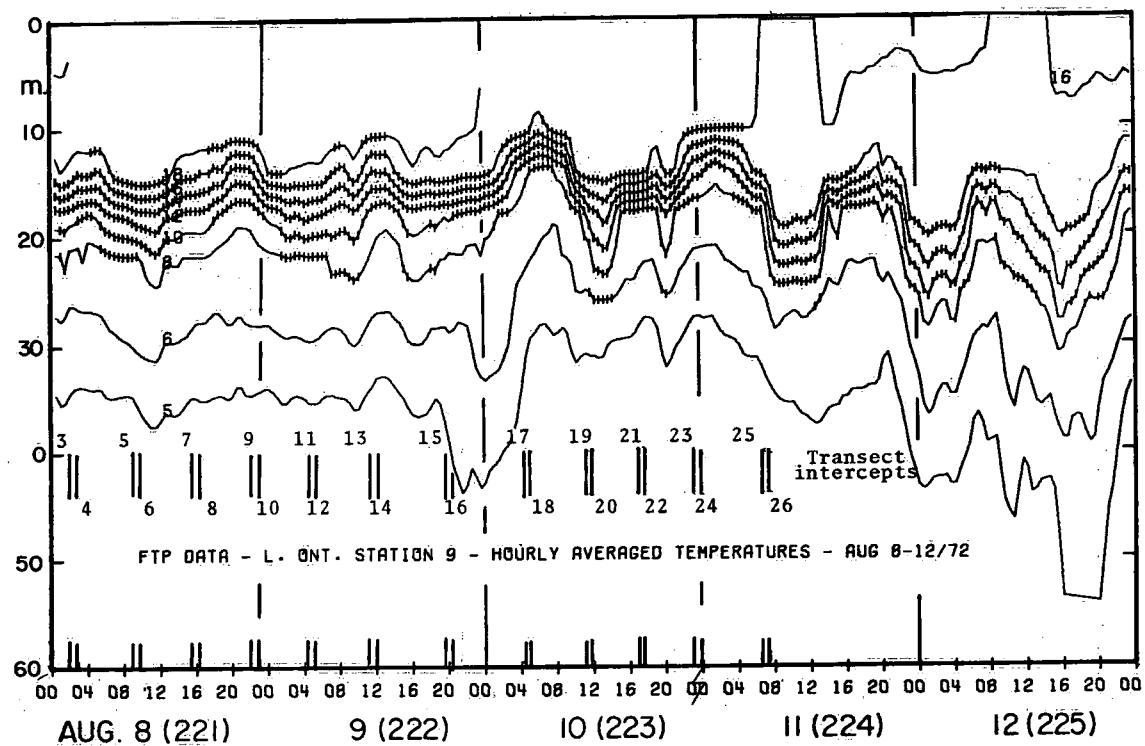
**Figure 6.9.** Isotherm depths at station U16, Lake Ontario, 22-28 July 1972, interpolated from hourly averaged temperatures listed in Table 5.1.



**Figure 6.10.** Isotherm ( $^{\circ}$ C) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C9-T, Lake Ontario, 24-28 July 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.



**Figure 6.11.** Isotherm depths at stations U14 and U16, Lake Ontario, 7-9 August 1972, interpolated from hourly averaged temperatures at depths listed in Table 5.1.



**Figure 6.12.** Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C9-T, Lake Ontario, 8-12 August 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.

INTERPOLATED ISOTHERM DEPTH AT STATION U14

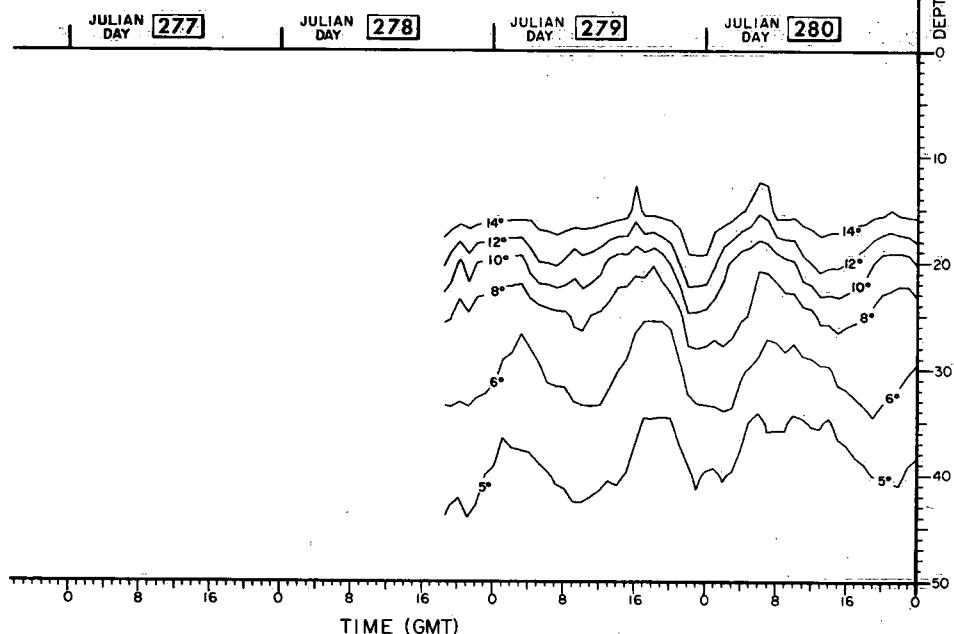


Figure 6.13. Isotherm depths at station U14, Lake Ontario, 4-6 October 1972, interpolated from hourly averaged temperatures at depths listed in Table 5.1.

INTERPOLATED ISOTHERM DEPTH AT STATION U16

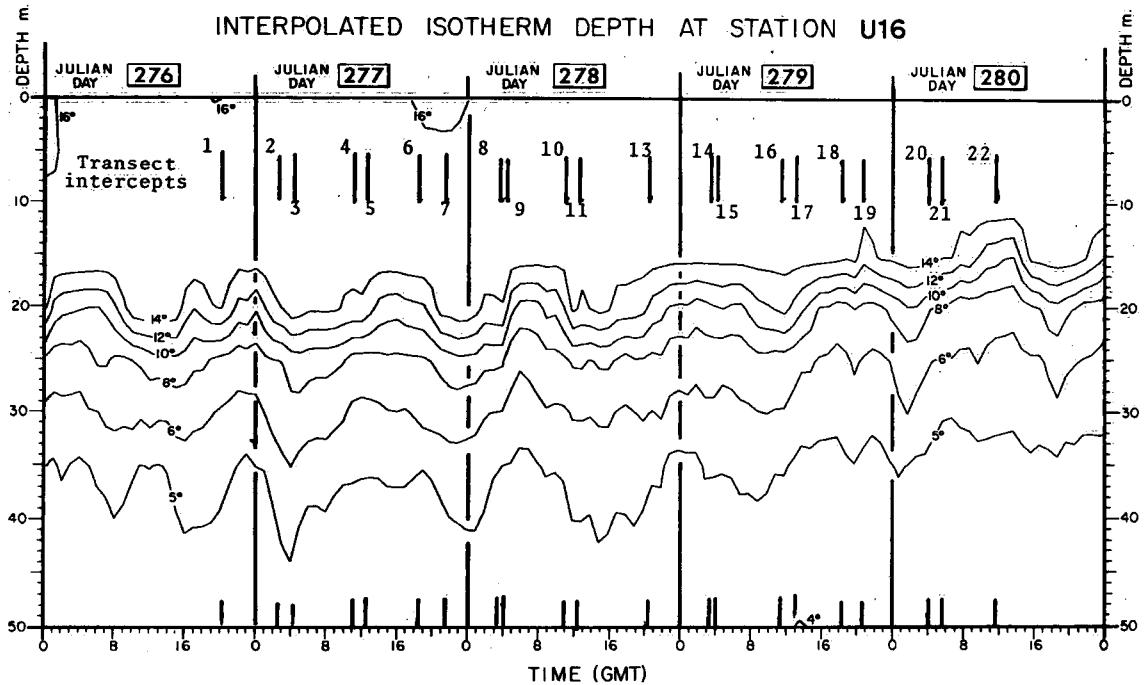
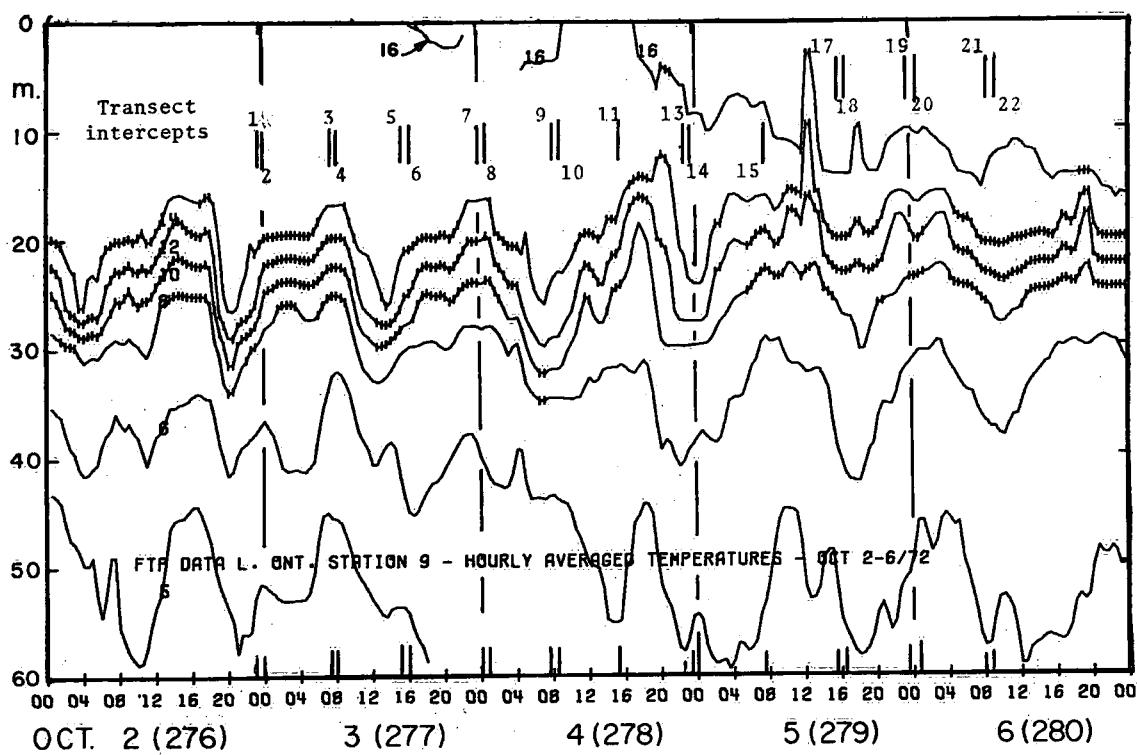
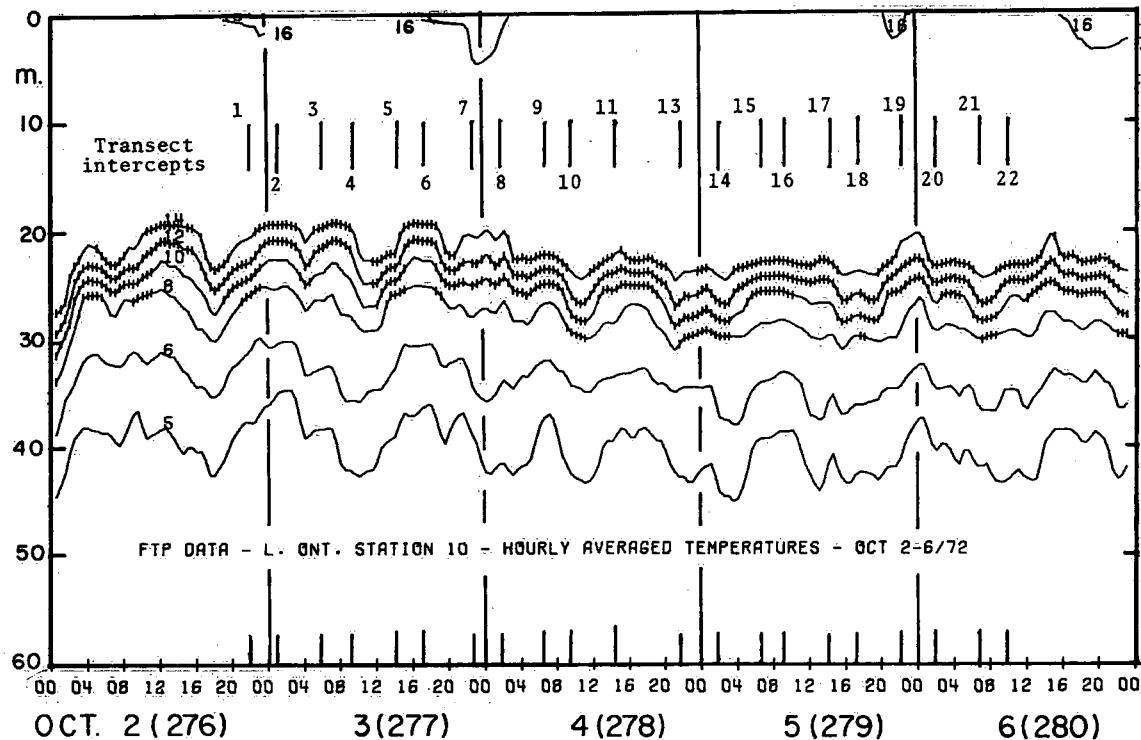


Figure 6.14. Isotherm depths at station U16, Lake Ontario, 2-6 October 1972, interpolated from hourly averaged temperatures at depths listed in Table 5.1.



**Figure 6.15.** Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C9-T, Lake Ontario, 2-6 October 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.

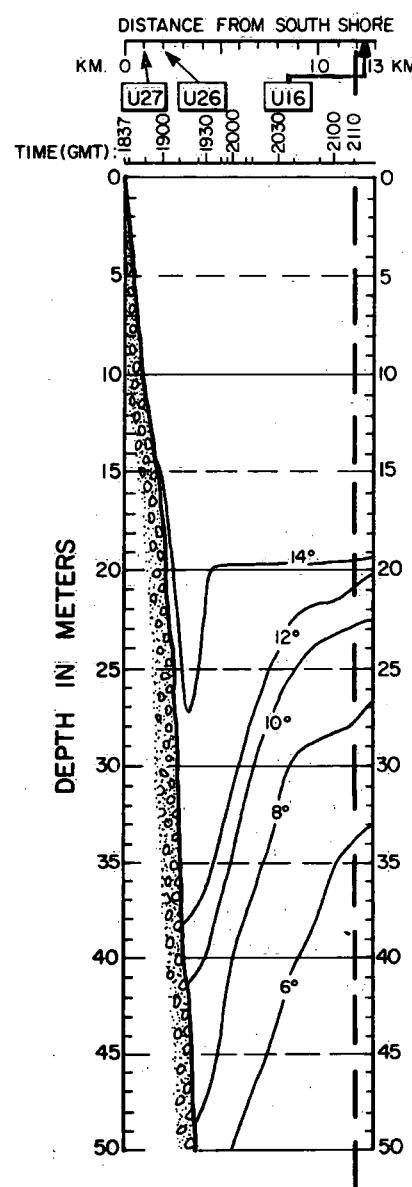


**Figure 6.16.** Isotherm ( $^{\circ}\text{C}$ ) depths interpolated from hourly averaged temperatures at various fixed depths (listed in Table 5.1) at station C10-T, Lake Ontario, 2-6 October 1972. The time scale is GMT and the Julian day number is in parentheses after the date. The significance of the vertical hatching on some isotherms is explained in Figure 4.5.

IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

ROCHESTER COASTAL CHAIN



JULIAN  
DAY  
**277**

TRANSECT NO. **007** FROM  
BRADDOCK POINT TO PRESQU'ILE

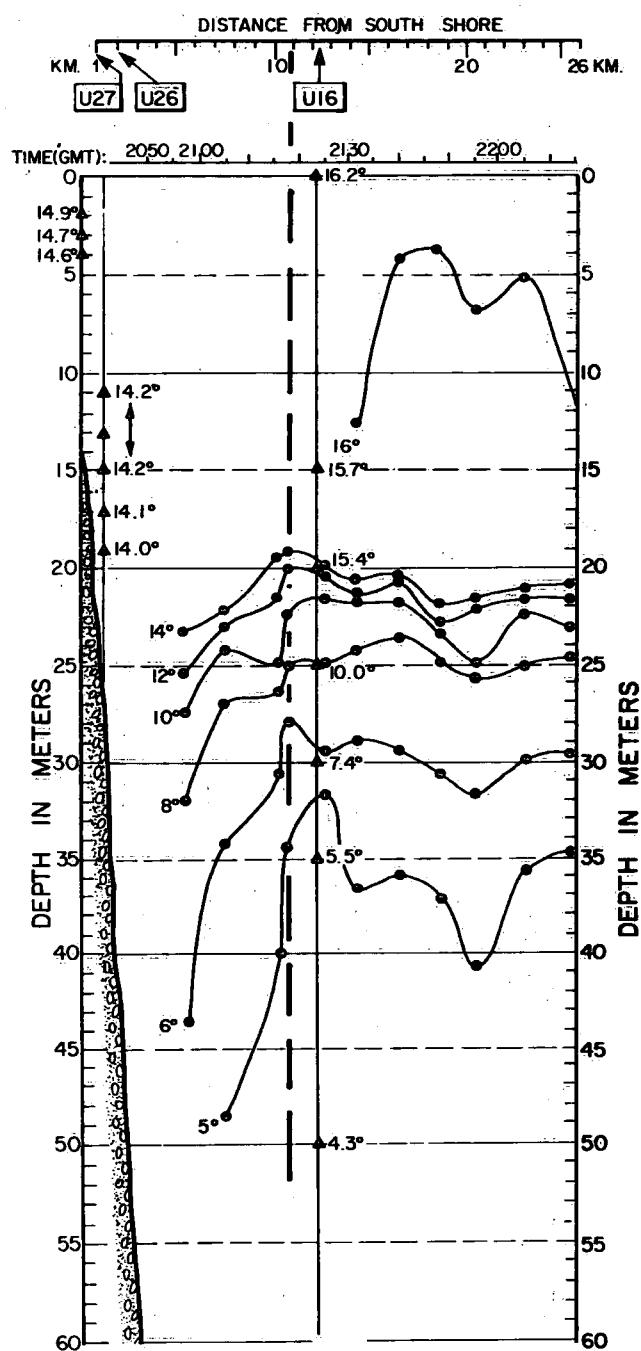
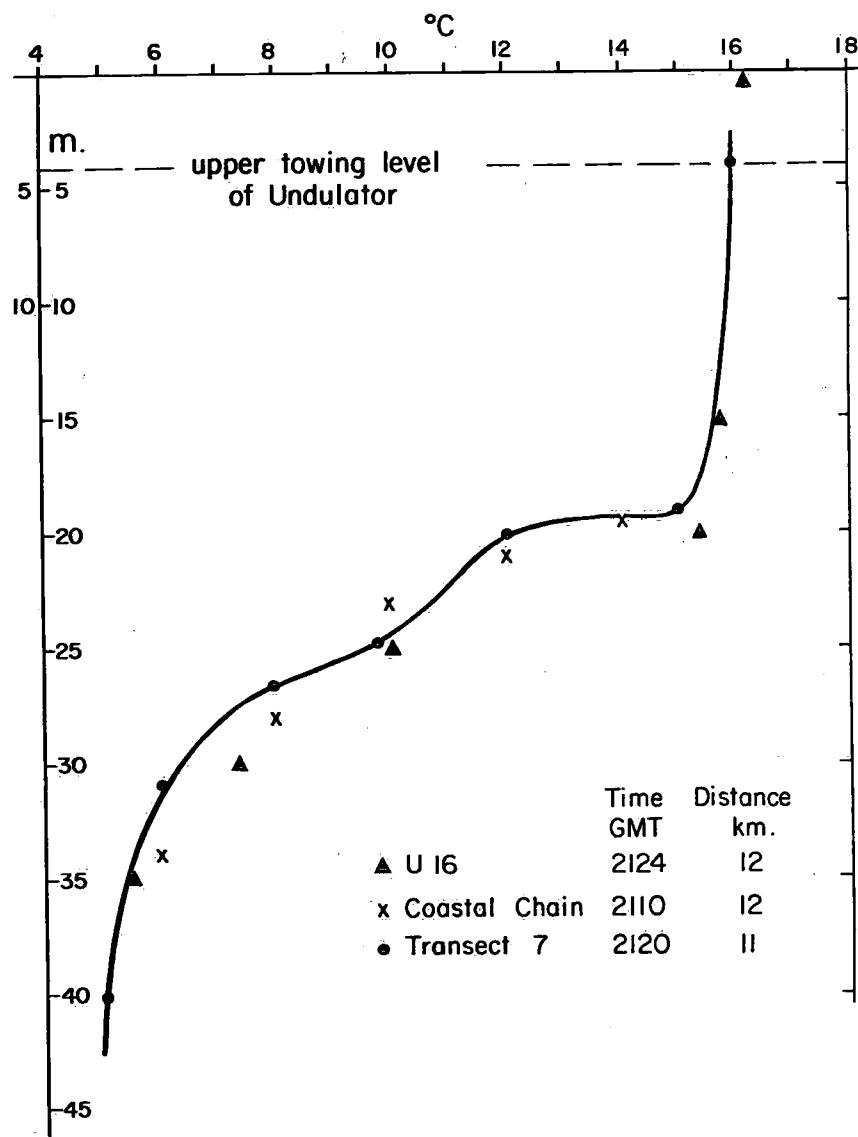


Figure 6.17. Isotherm depths in the Rochester Coastal Chain section, 3 October, and in the corresponding portion of the contemporary Transect 7. The coincidence point is shown, in each section, by a vertical broken line.

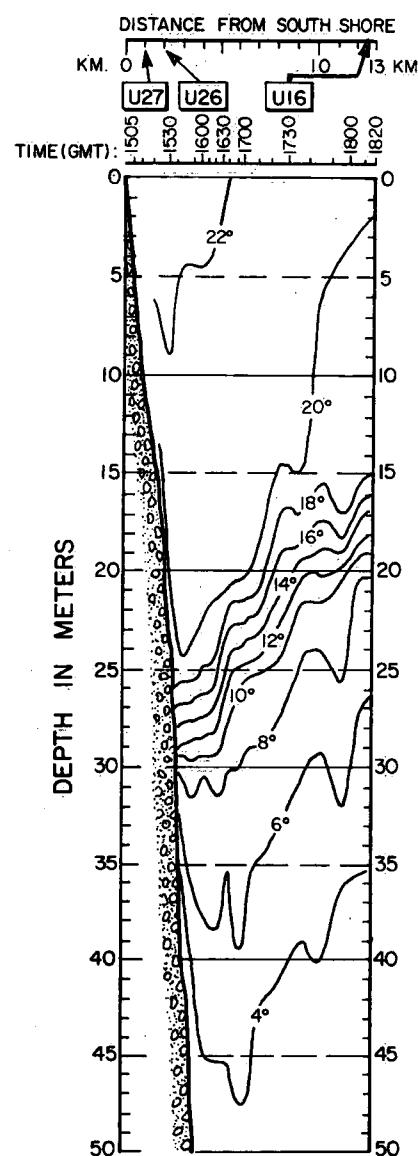


**Figure 6.18.** Comparison of "coincident" temperature-depth profiles derived independently from O.S.S. *Researcher* Transect 7, 3 October, and from the Rochester Coastal Chain at the indicated times and distances from shore (see Fig. 6.17). Also shown is the coincident profile at station U16.

# IFYGL (LAKE ONTARIO 1972)

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS

### ROCHESTER COASTAL CHAIN



JULIAN  
DAY  
**209**

### TRANSECT NO. 014 FROM BRADDOCK POINT TO PRESQU'ILE

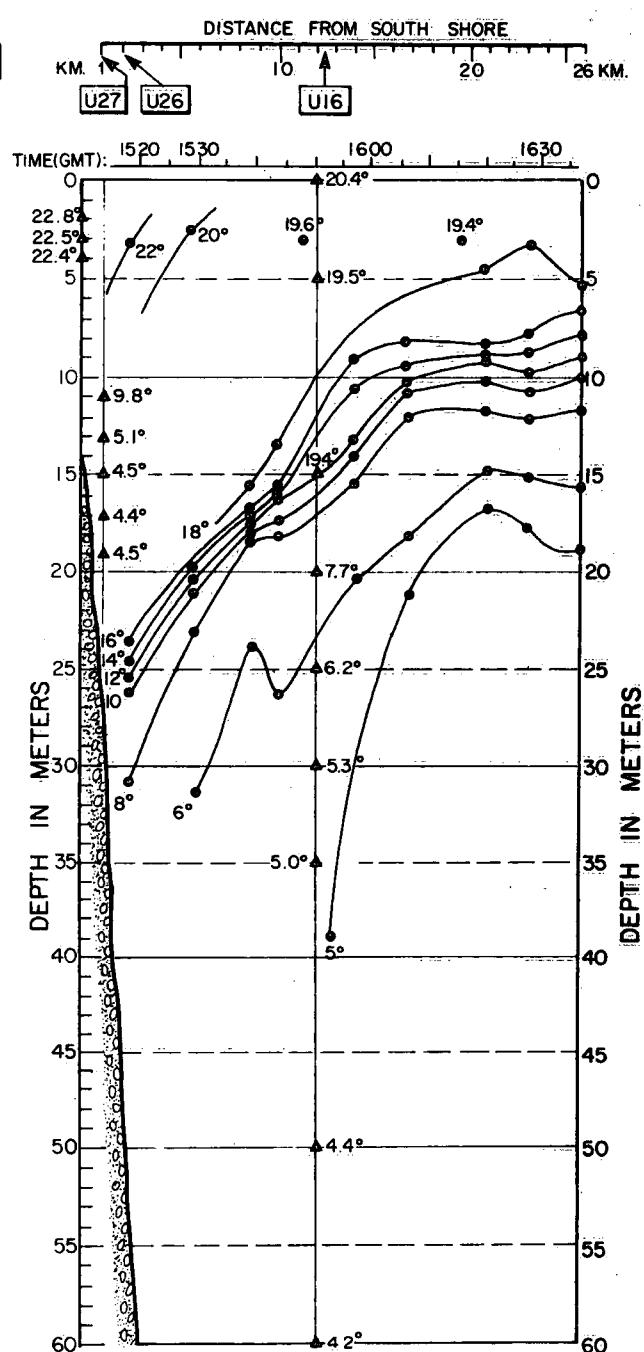
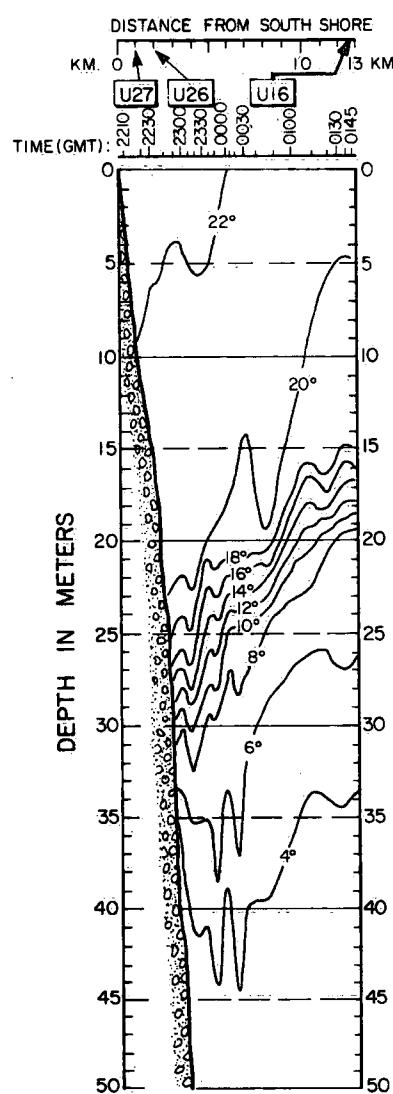


Figure 6.19. Isotherm depths in the Rochester Coastal Chain section, 27 July, and in the corresponding portion of the contemporary Transect No. 14.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## ROCHESTER COASTAL CHAIN



## TRANSECT NO. 016 FROM BRADDOCK POINT TO PRESQU'ILE

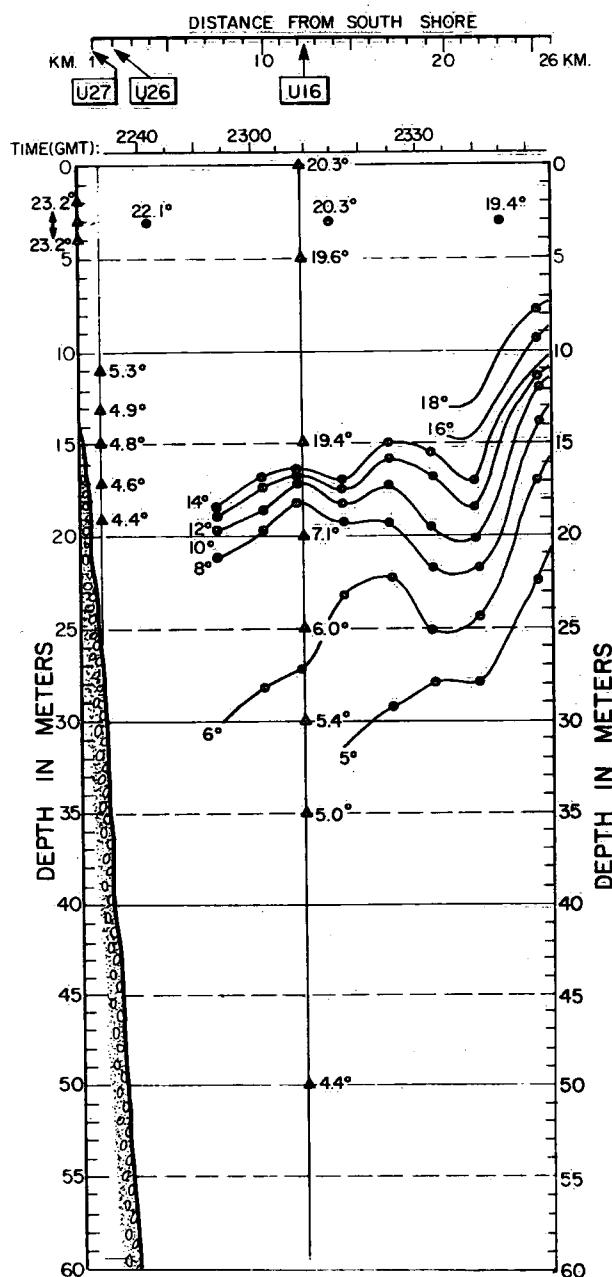
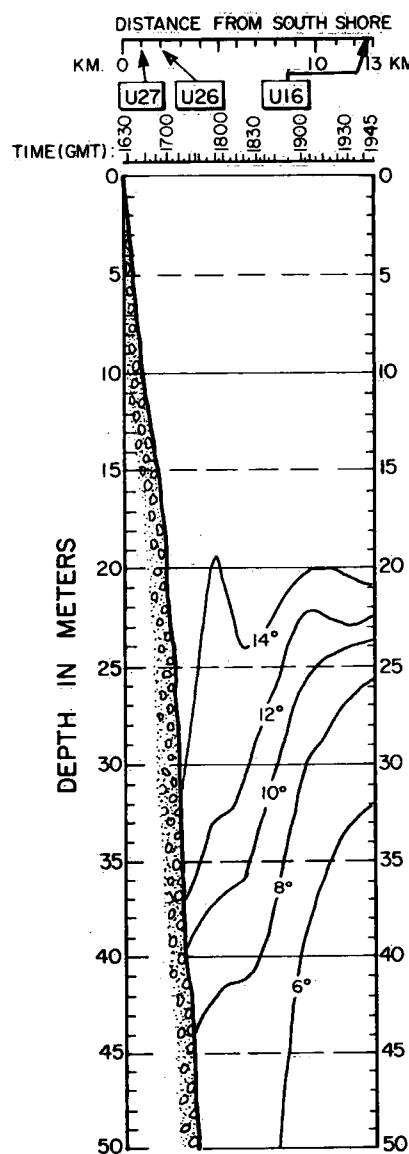


Figure 6.20. Isotherm depths in the Rochester Coastal Chain section, 27 July, and in the corresponding portion of the contemporary Transect 16.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## ROCHESTER COASTAL CHAIN



## TRANSECT NO. 001 FROM BRADDOCK POINT TO PRESQU'ILE

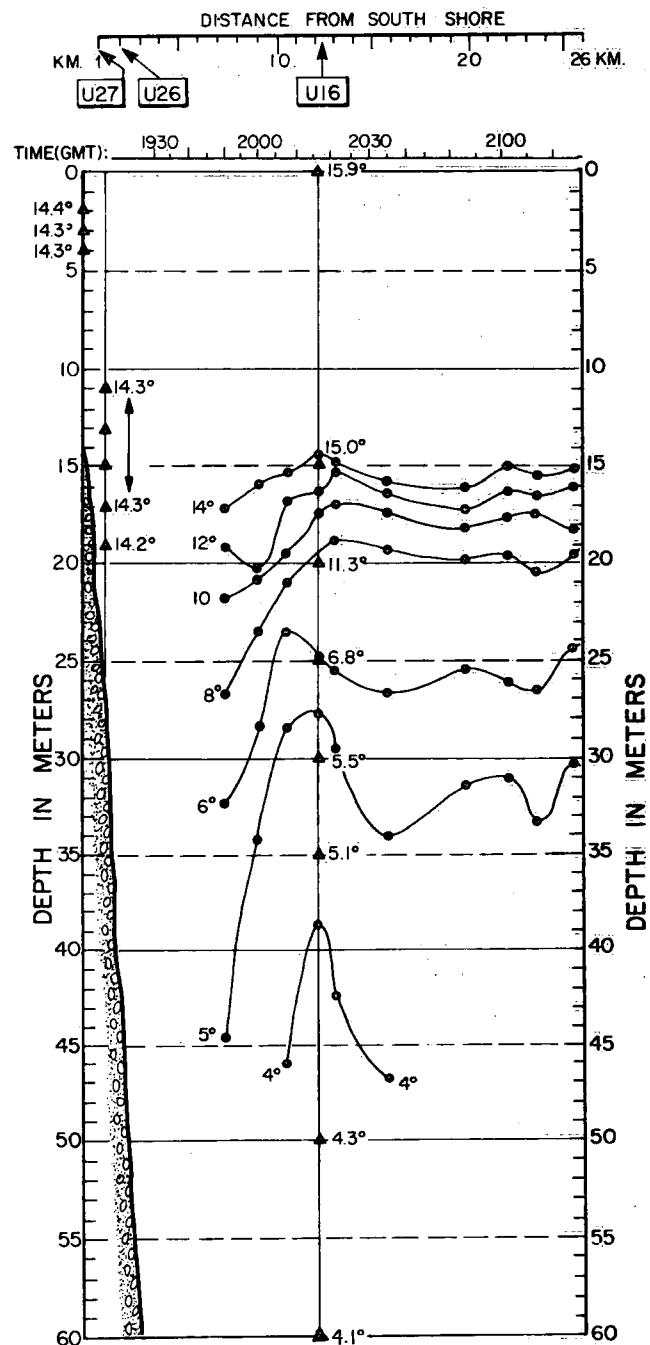
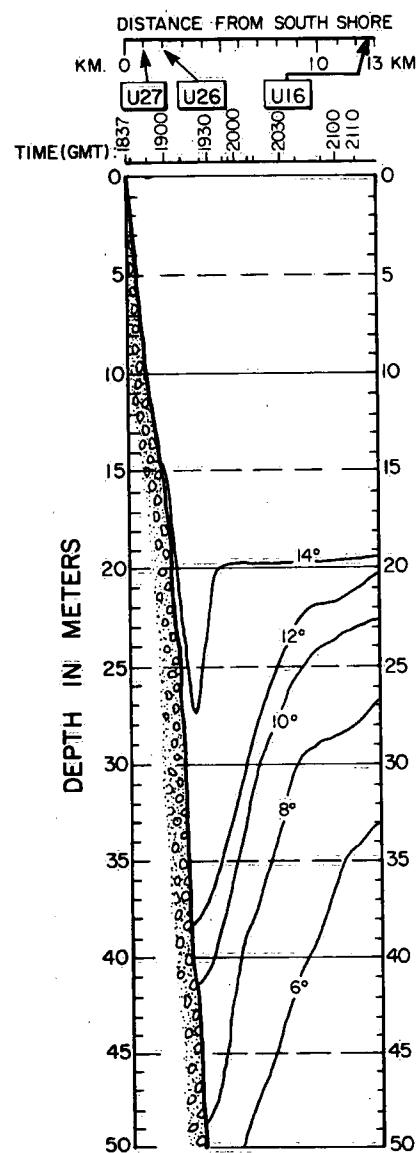


Figure 6.21. Isotherm depths in the Rochester Coastal Chain section, 2 October, and in the corresponding portion of the contemporary Transect 1.

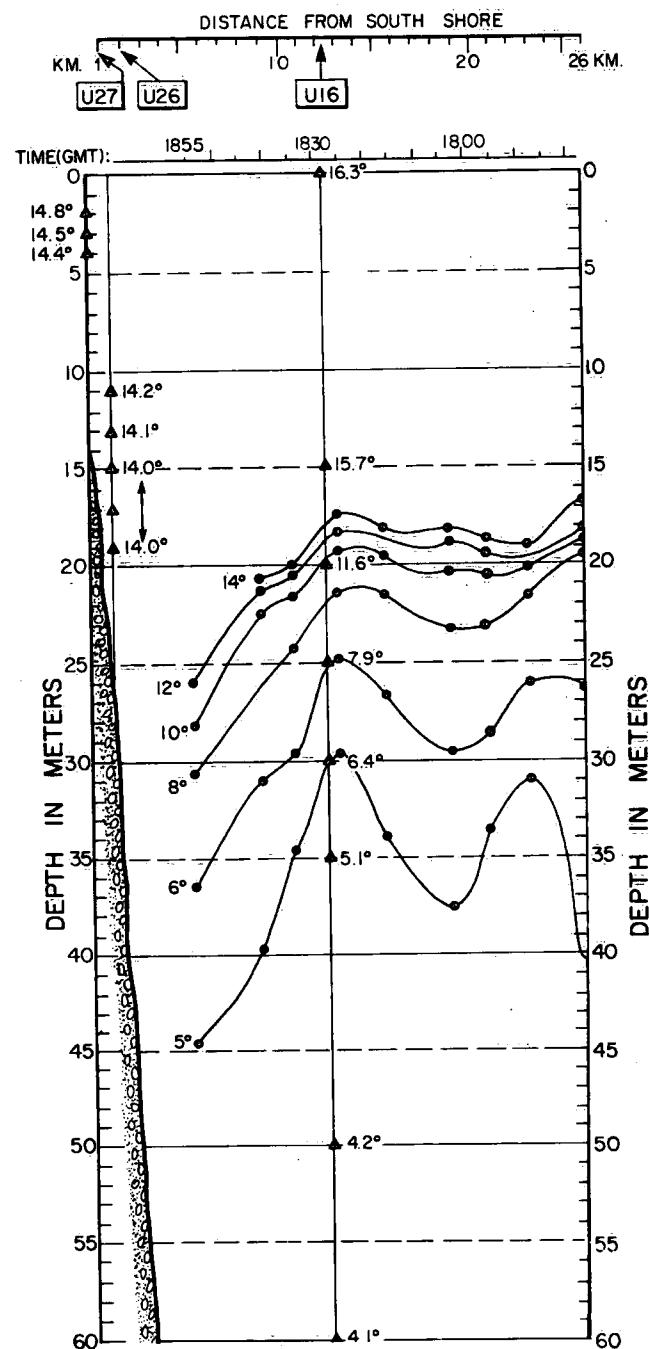
# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## ROCHESTER COASTAL CHAIN



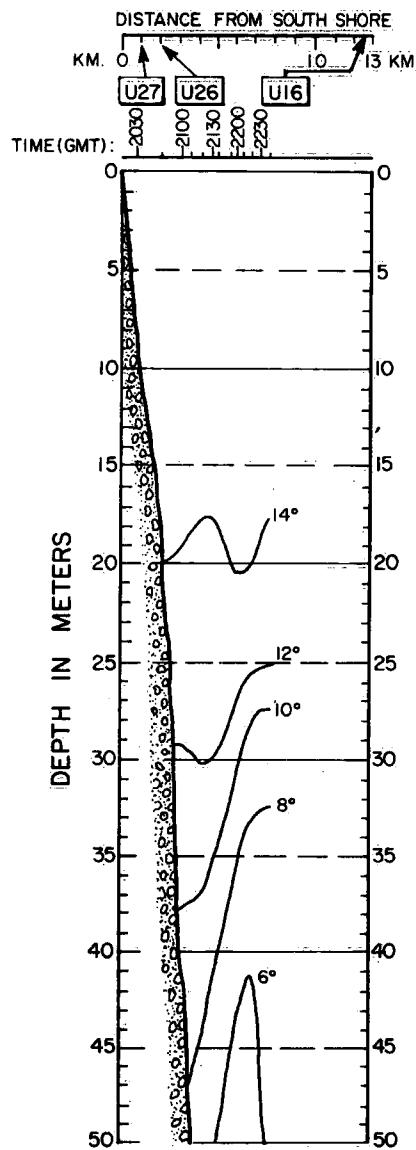
## TRANSECT NO. 006 FROM BRADDOCK POINT TO PRESQU'ILE



# IFYGL (LAKE ONTARIO 1972)

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS

### ROCHESTER COASTAL CHAIN



### TRANSECT NO. 013 FROM BRADDOCK POINT TO PRESQUE ISLE

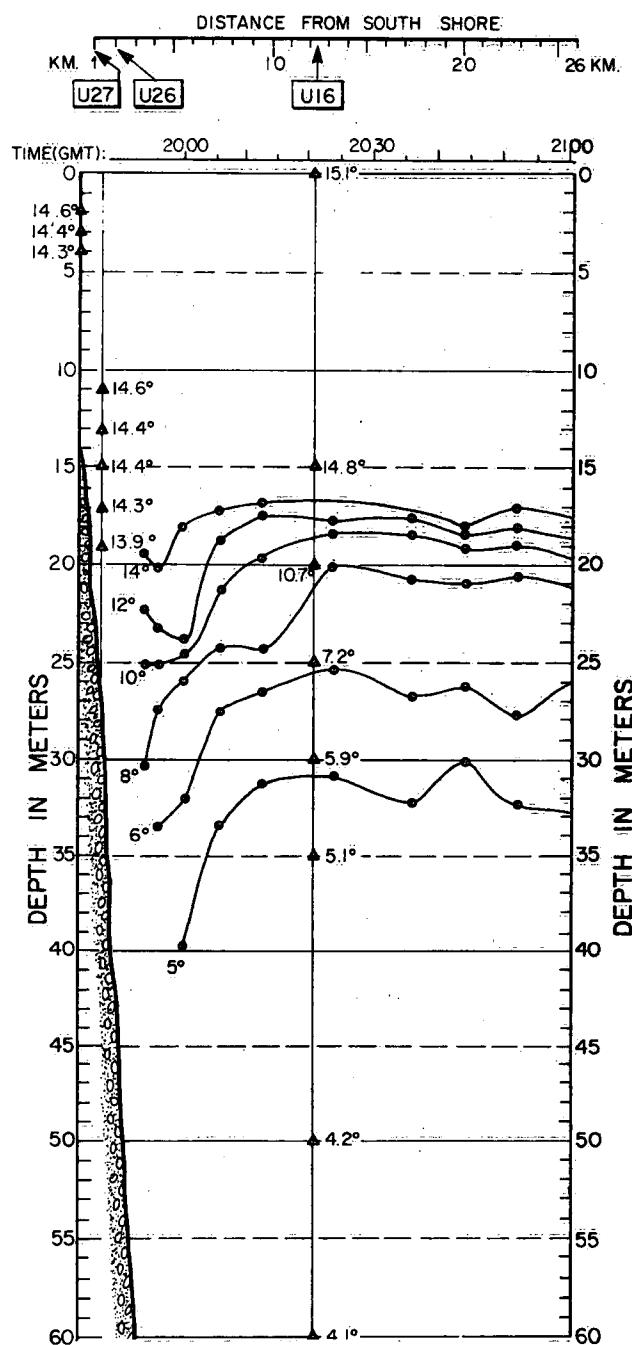


Figure 6.23. Isotherm depths in the Rochester Coastal Chain section, 4 October, and in the corresponding portion of the contemporary Transect 13.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

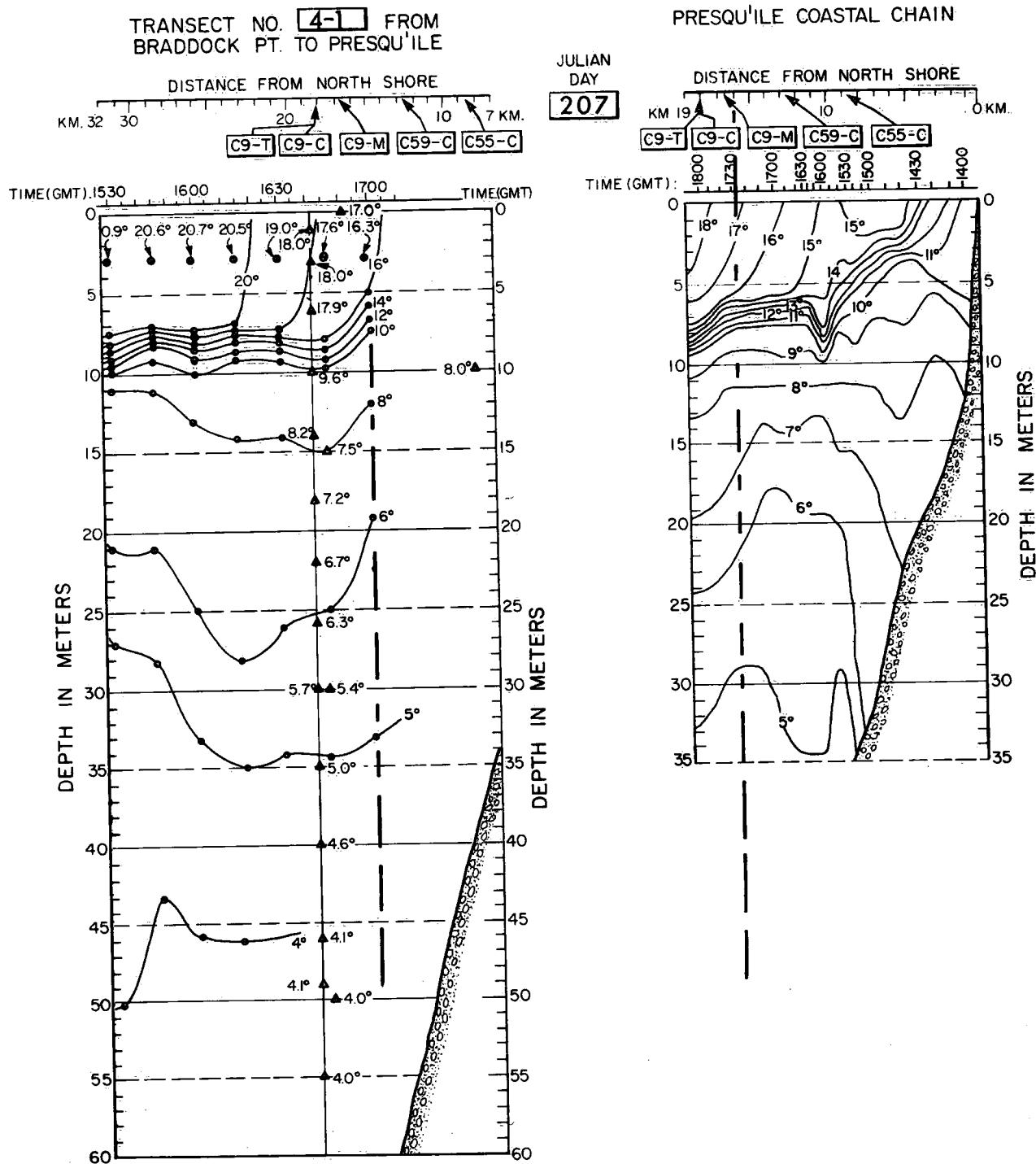
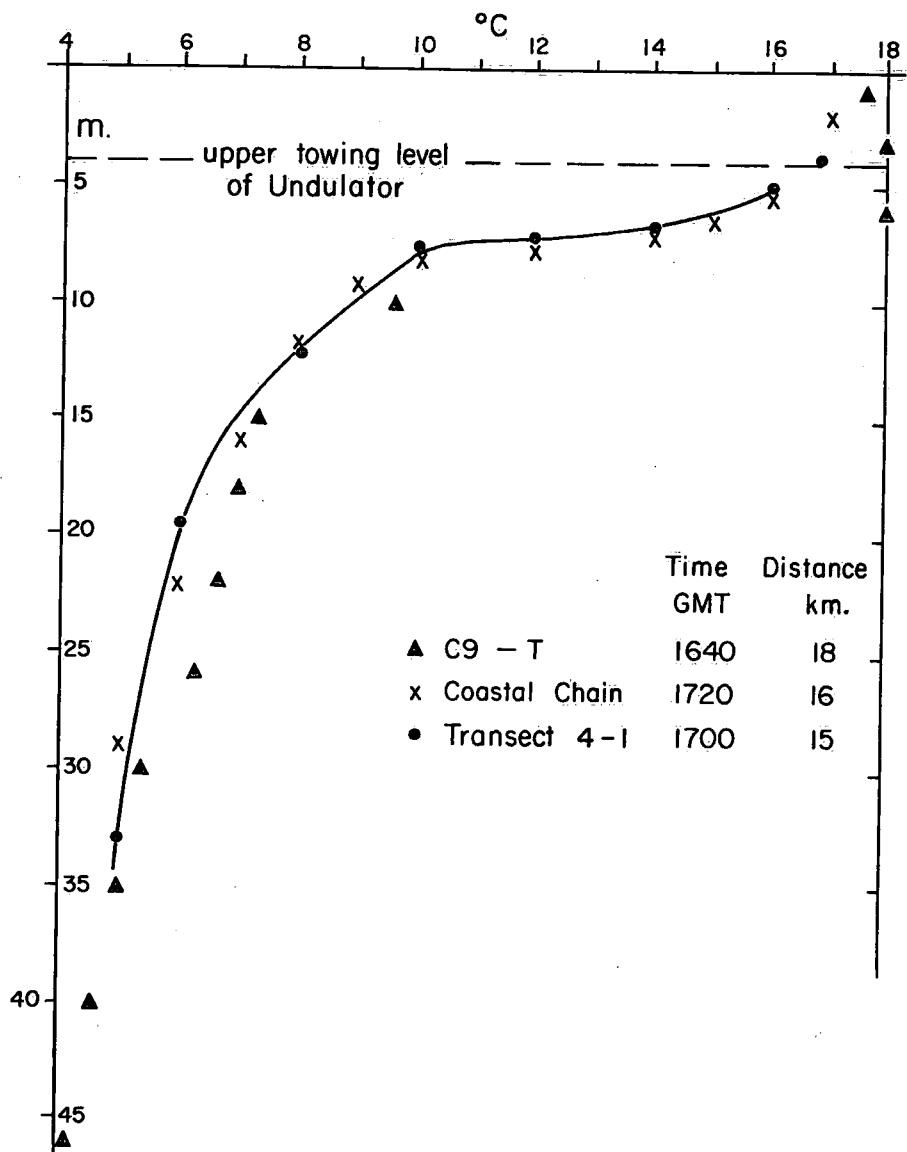


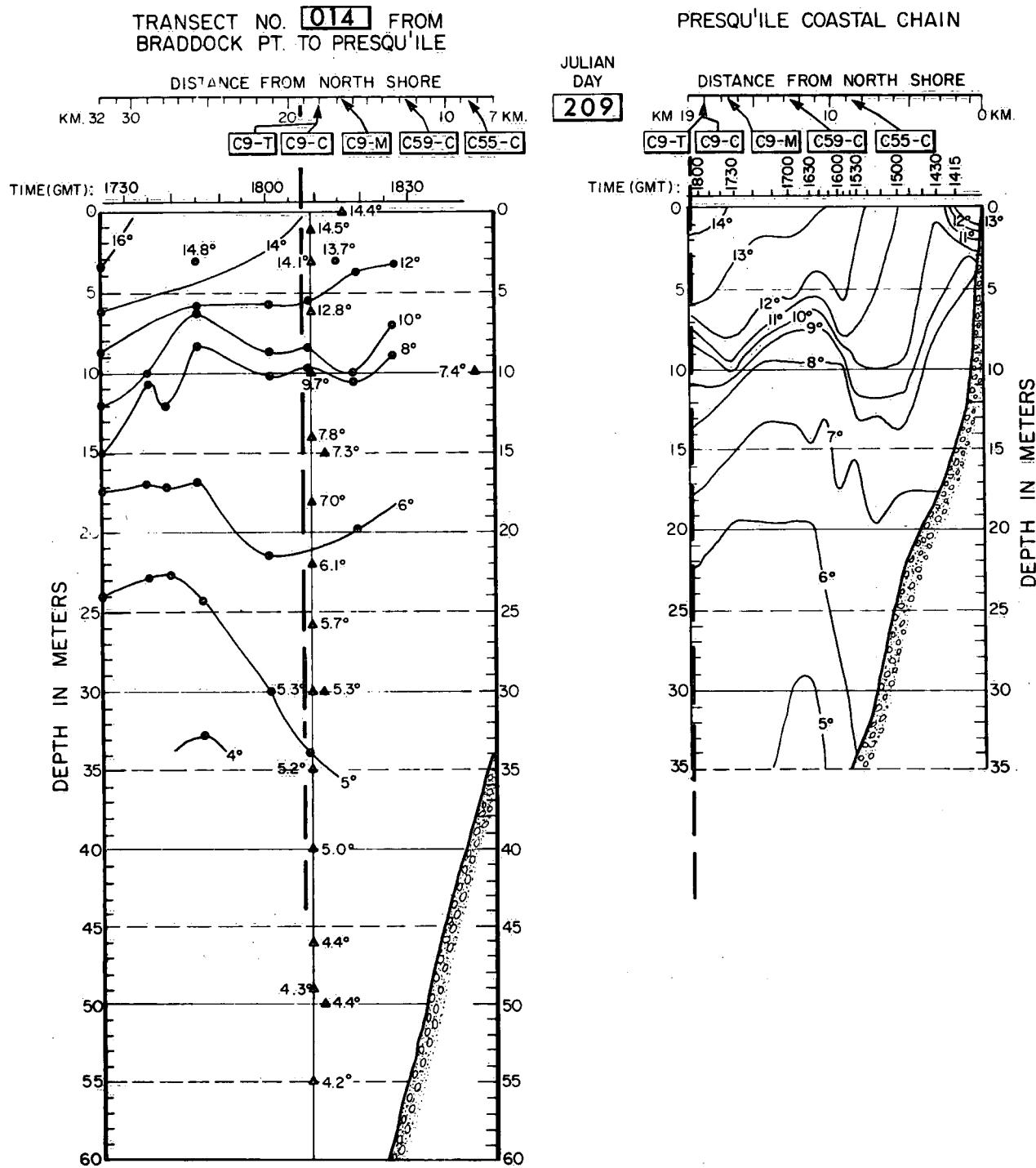
Figure 6.24. Isotherm depths in the Presqu'ile Coastal Chain section, 25 July, and in the corresponding portion of the contemporary Transect 4-1. The coincidence point is shown, in each section, by a vertical broken line.



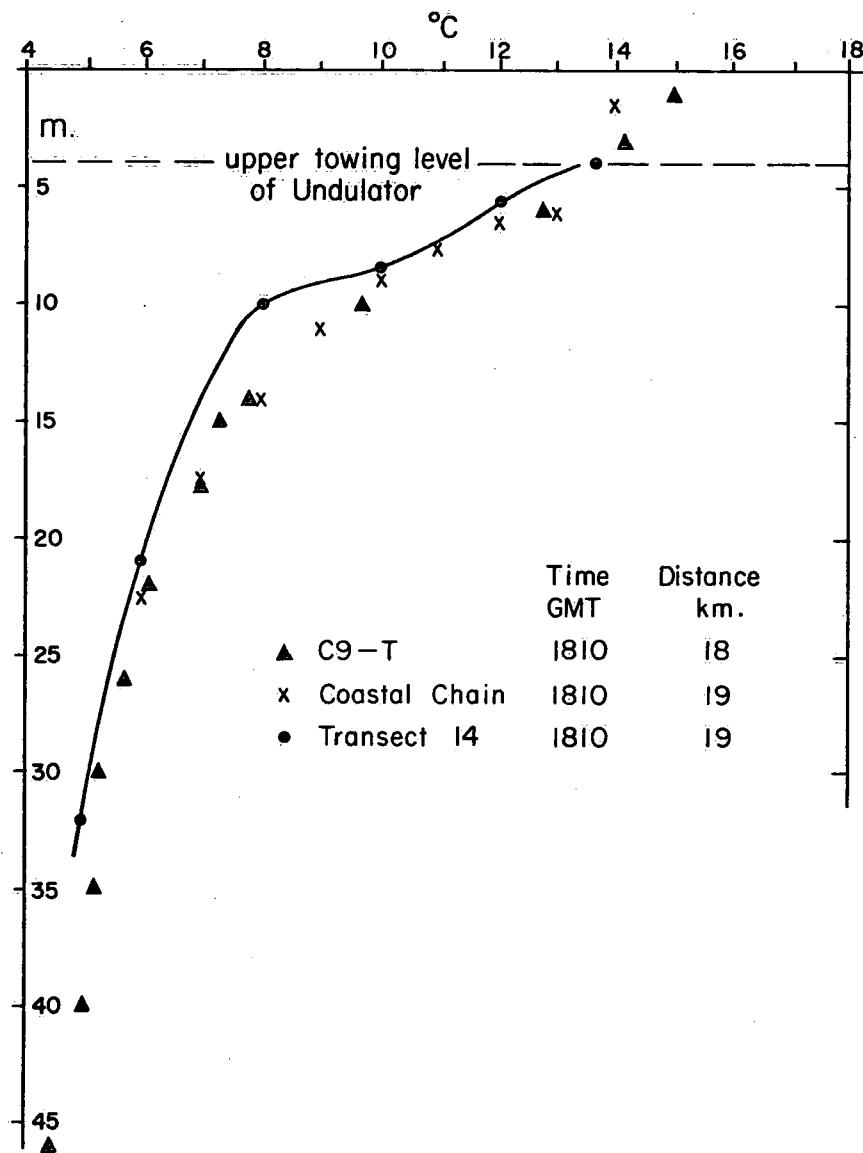
**Figure 6.25.** Comparison of "coincident" temperature-depth profiles derived from O.S.S. *Researcher* Transect 4-1, 25 July, and from the Presquile Coastal Chain at the indicated times and distances from shore (see Fig. 6.24). The coincident profile from station C9-T is also included.

**IFYGL (LAKE ONTARIO 1972)**

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS



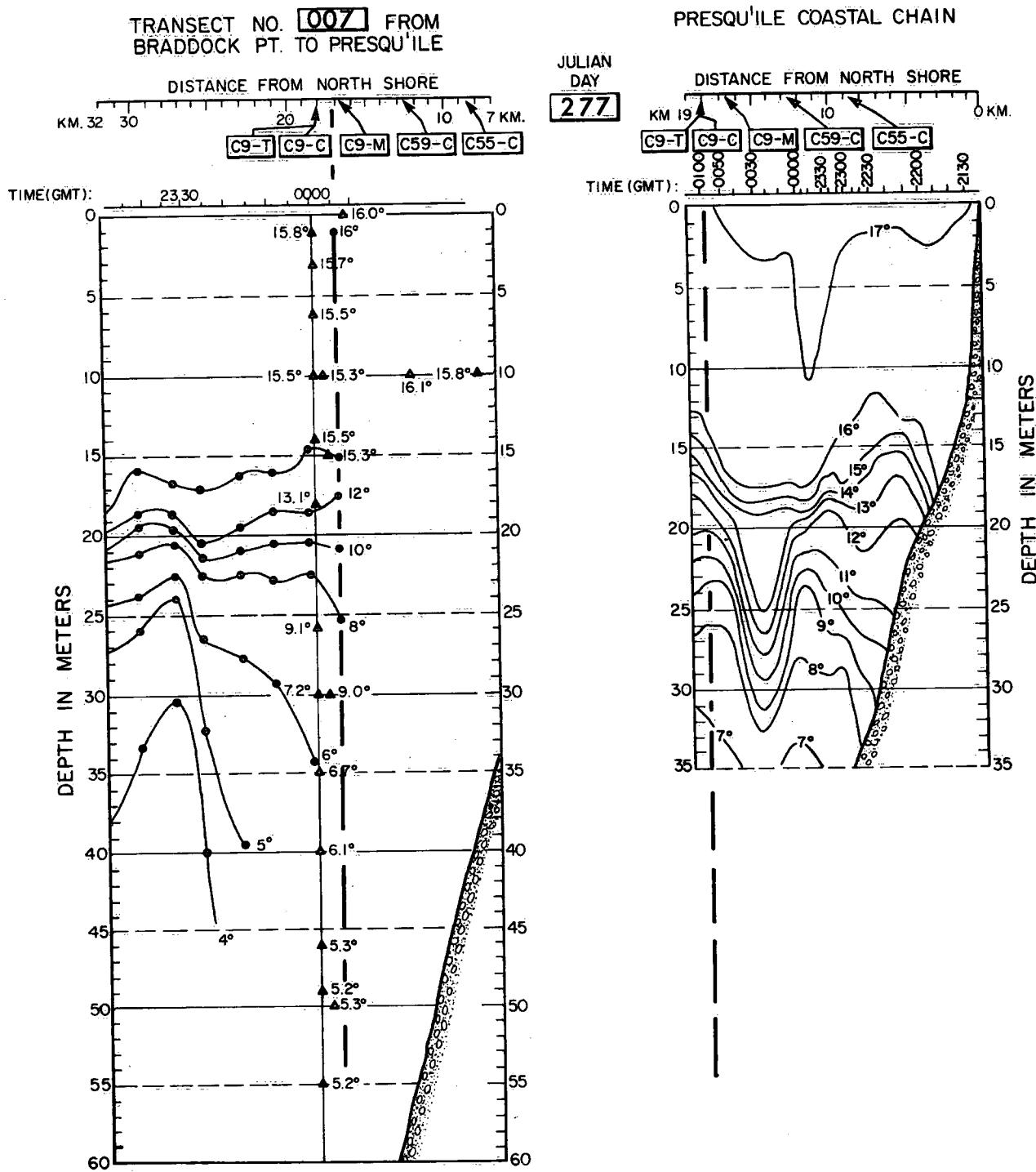
**Figure 6.26.** Isotherm depths in the Presqu'ile Coastal Chain section, 27 July, and in the corresponding portion of the contemporary Transect 14. The coincidence point is shown, in each section, by a broken vertical line.



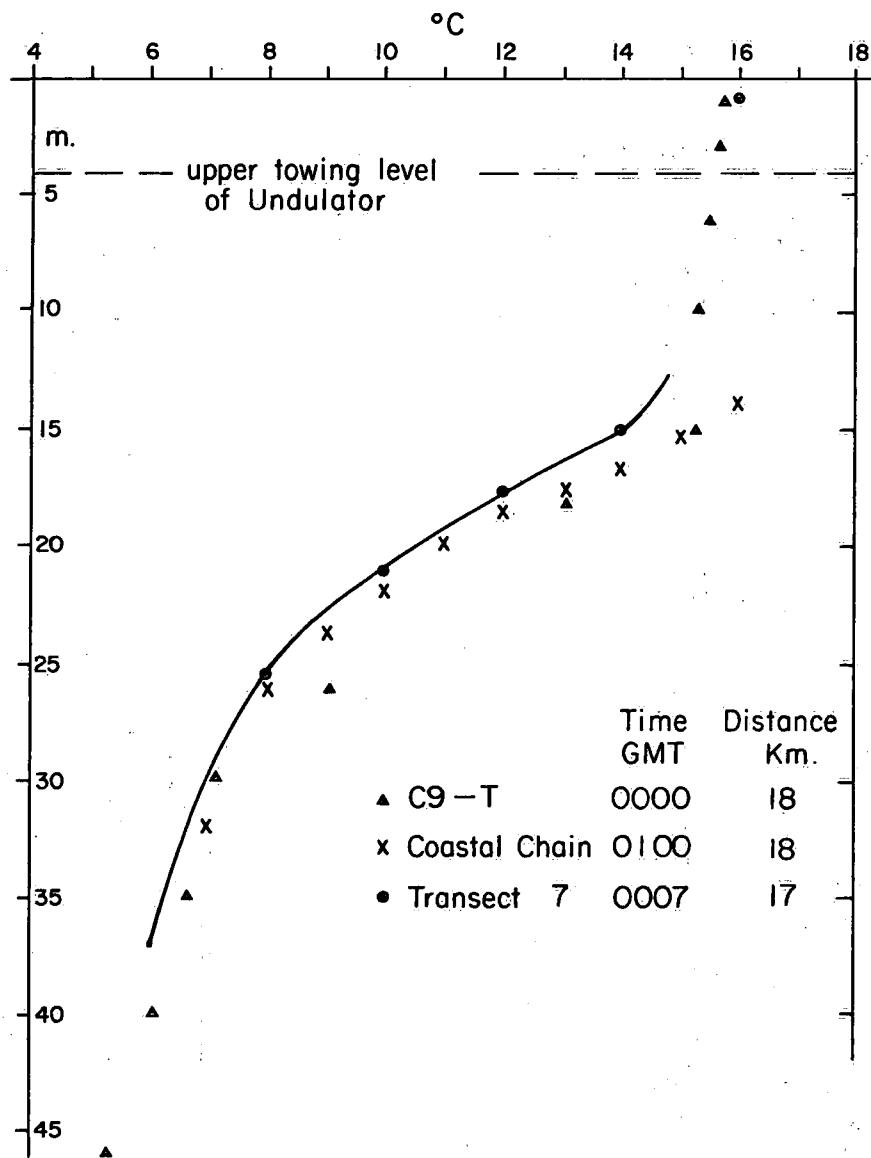
**Figure 6.27.** Comparison of "coincident" temperature-depth profiles derived from O.S.S. *Researcher* Transect 14, 27 July, and from the Presqu'ile Coastal Chain at the indicated times and distances from shore (see Fig. 6.26). The coincident profile from station C9-T is also included.

**IYGL (LAKE ONTARIO 1972)**

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS



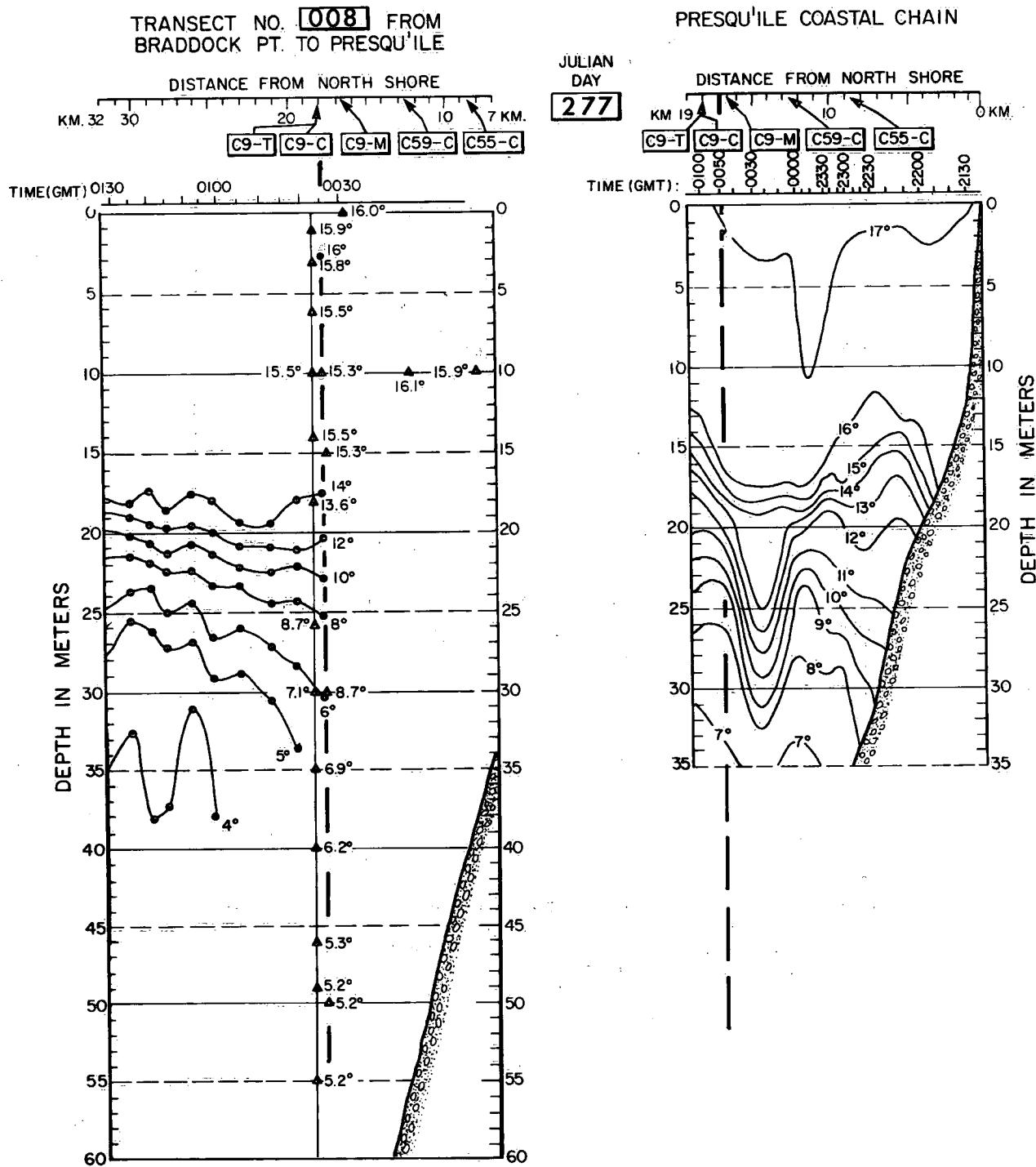
**Figure 6.28.** Isotherm depths in the Presqu'ile Coastal Chain section, 3 October, and in the corresponding portion of the contemporary Transect 7. The coincidence point is shown, in each section, by a vertical broken line.



**Figure 6.29.** Comparison of "coincident" temperature-depth profiles derived from O.S.S. *Researcher* Transect 7, 3 October, and from the Presqu'ile Coastal Chain at the indicated times and distances from shore (see Fig. 6.28). The coincident profile from station C9-T is also shown.

IIFYGL (LAKE ONTARIO 1972)

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS



**Figure 6.30.** Isotherm depths in the Presquile Coastal Chain section, 3 October, and in the corresponding portion of the contemporary Transect 8. The coincidence point is shown, in each section, by a vertical broken line.

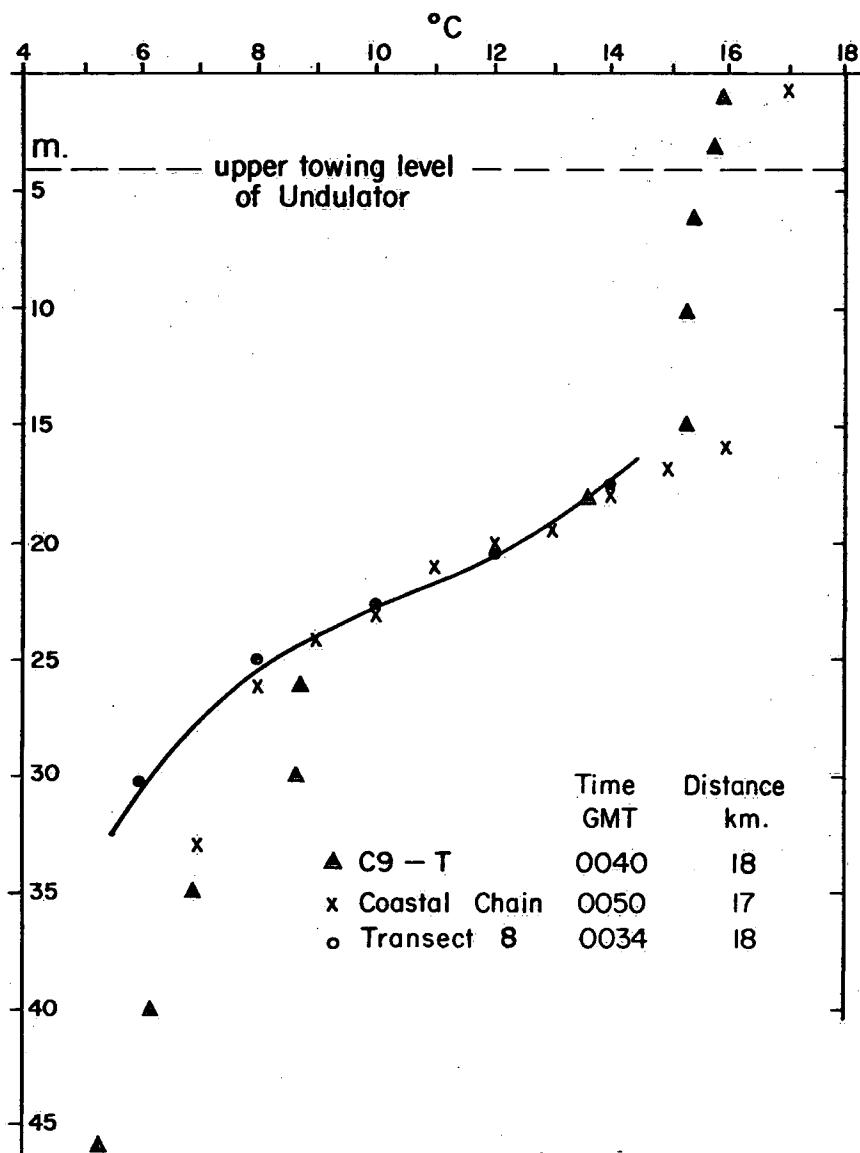


Figure 6.31. Comparison of "coincident" temperature-depth profiles derived from O.S.S. *Researcher* Transect 8, 3 October, and from the Presqu'ile Coastal Chain at the indicated times and distances from shore (see Fig. 6.30). The coincident profile from station C9-T is also shown.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

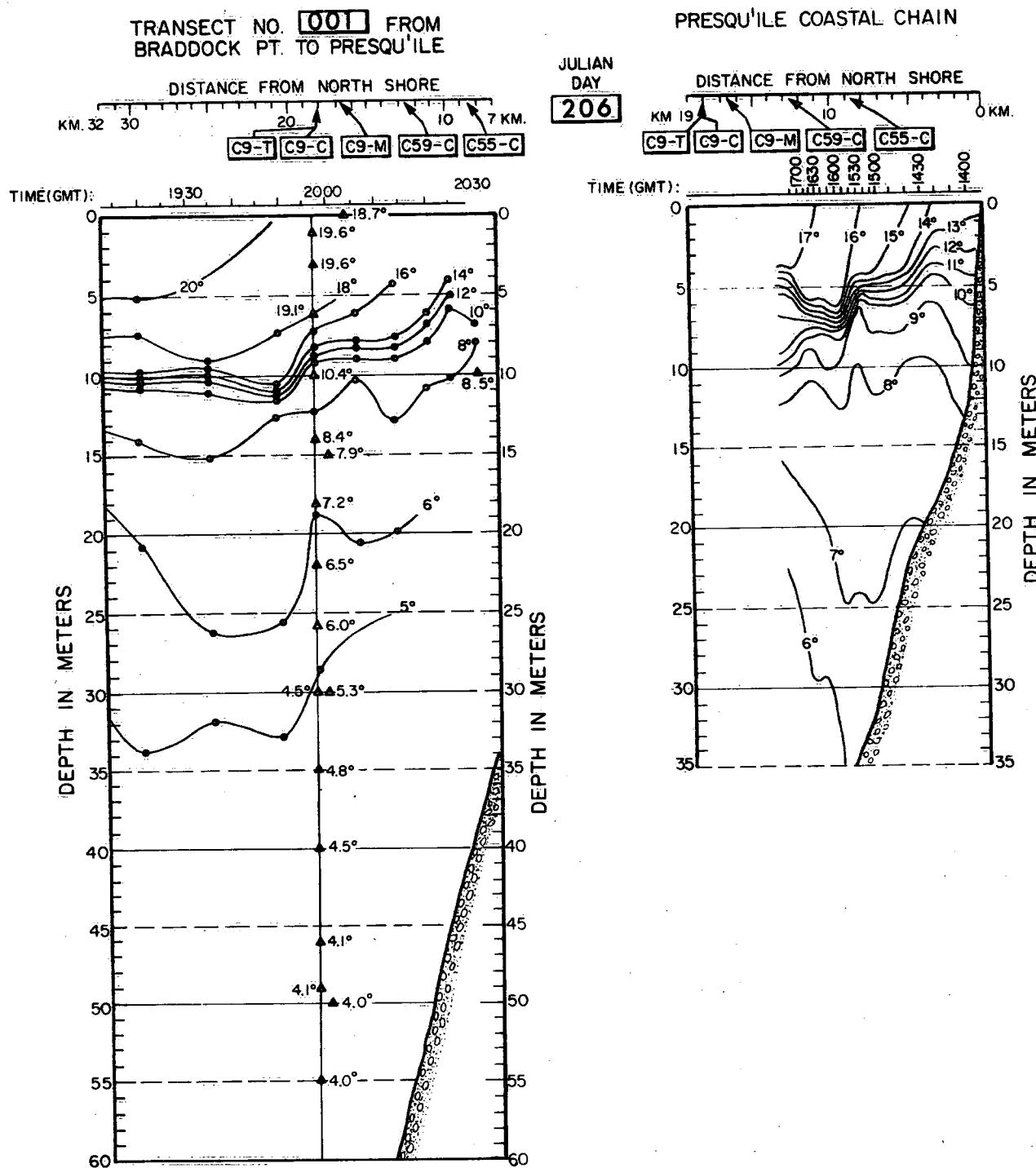


Figure 6.32. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 1, 24 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

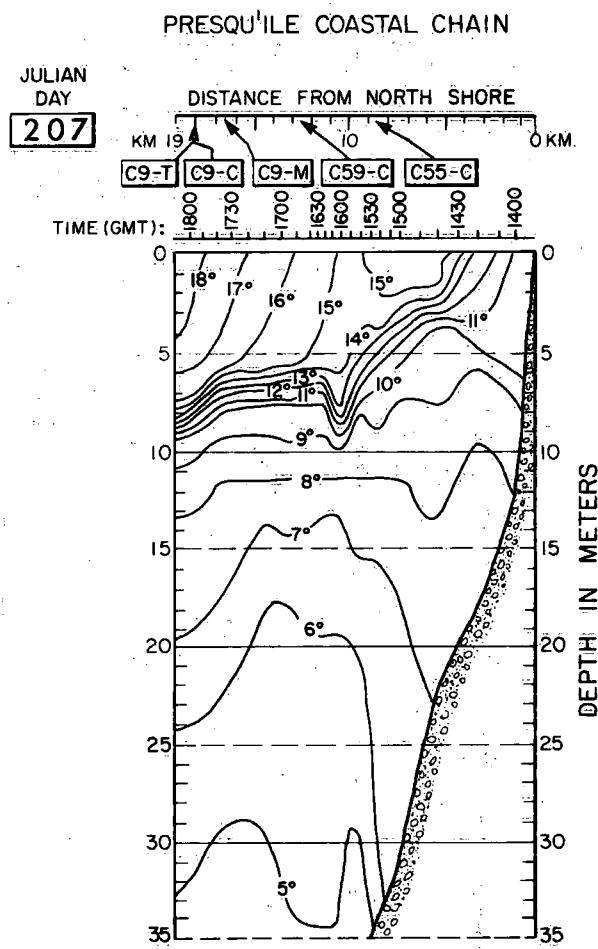
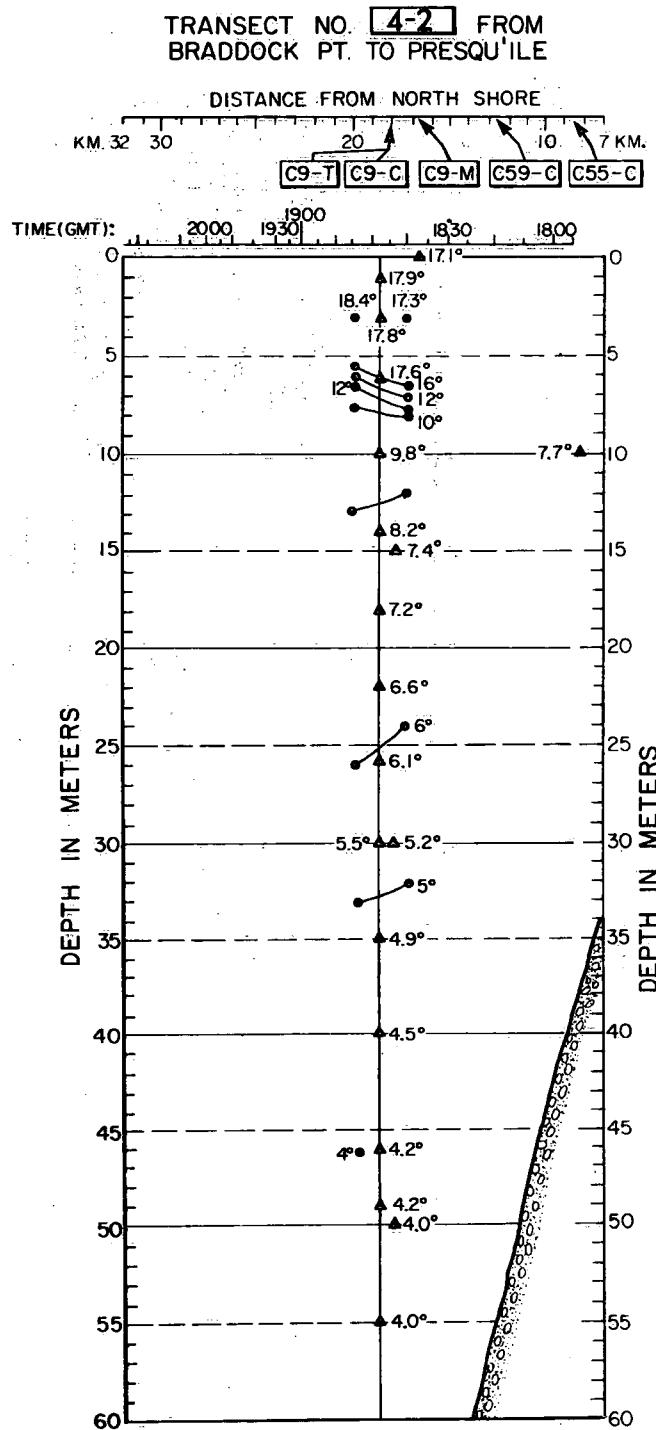


Figure 6.33. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 4-2, 25 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

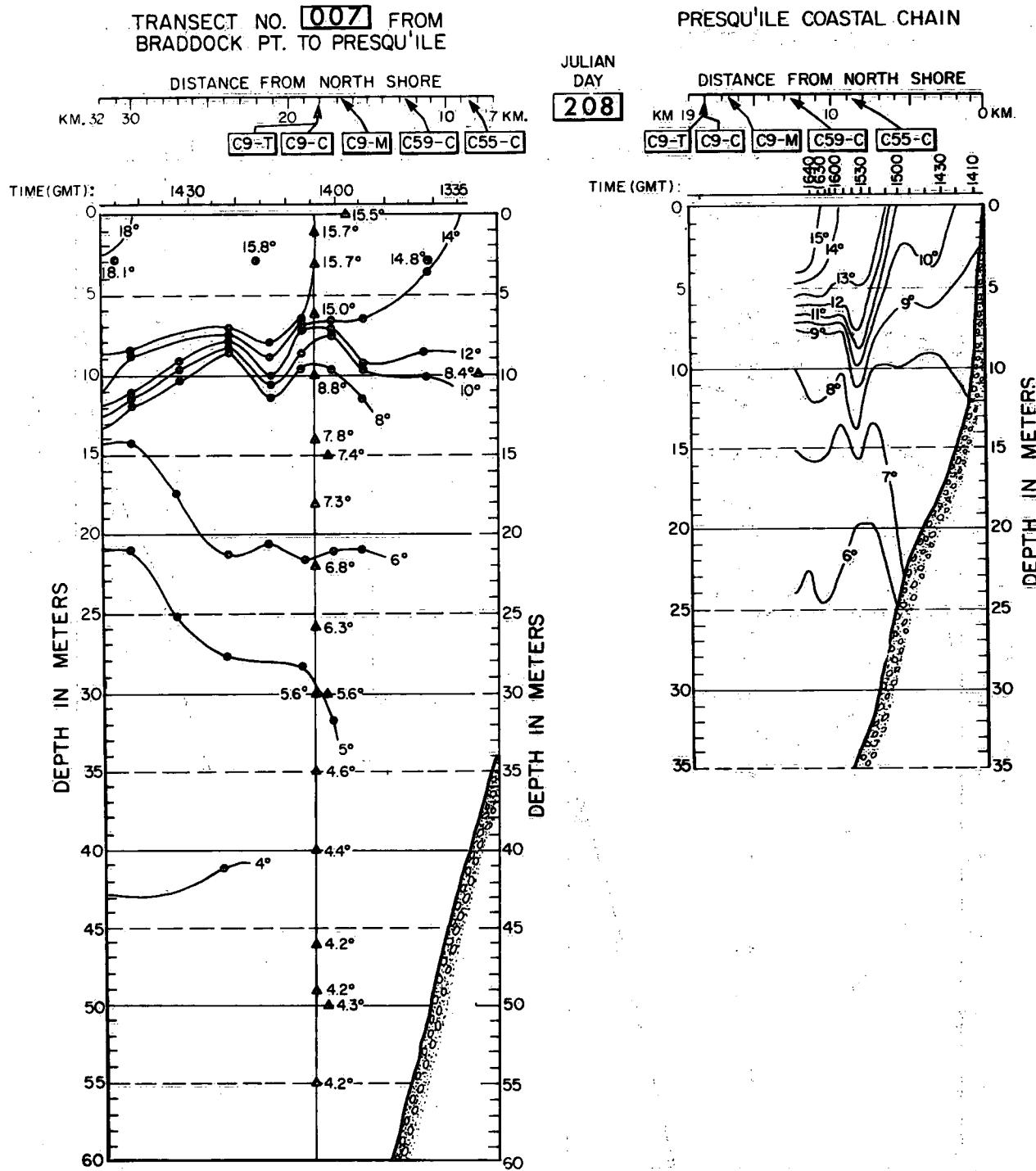


Figure 6.34. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 7, 26 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

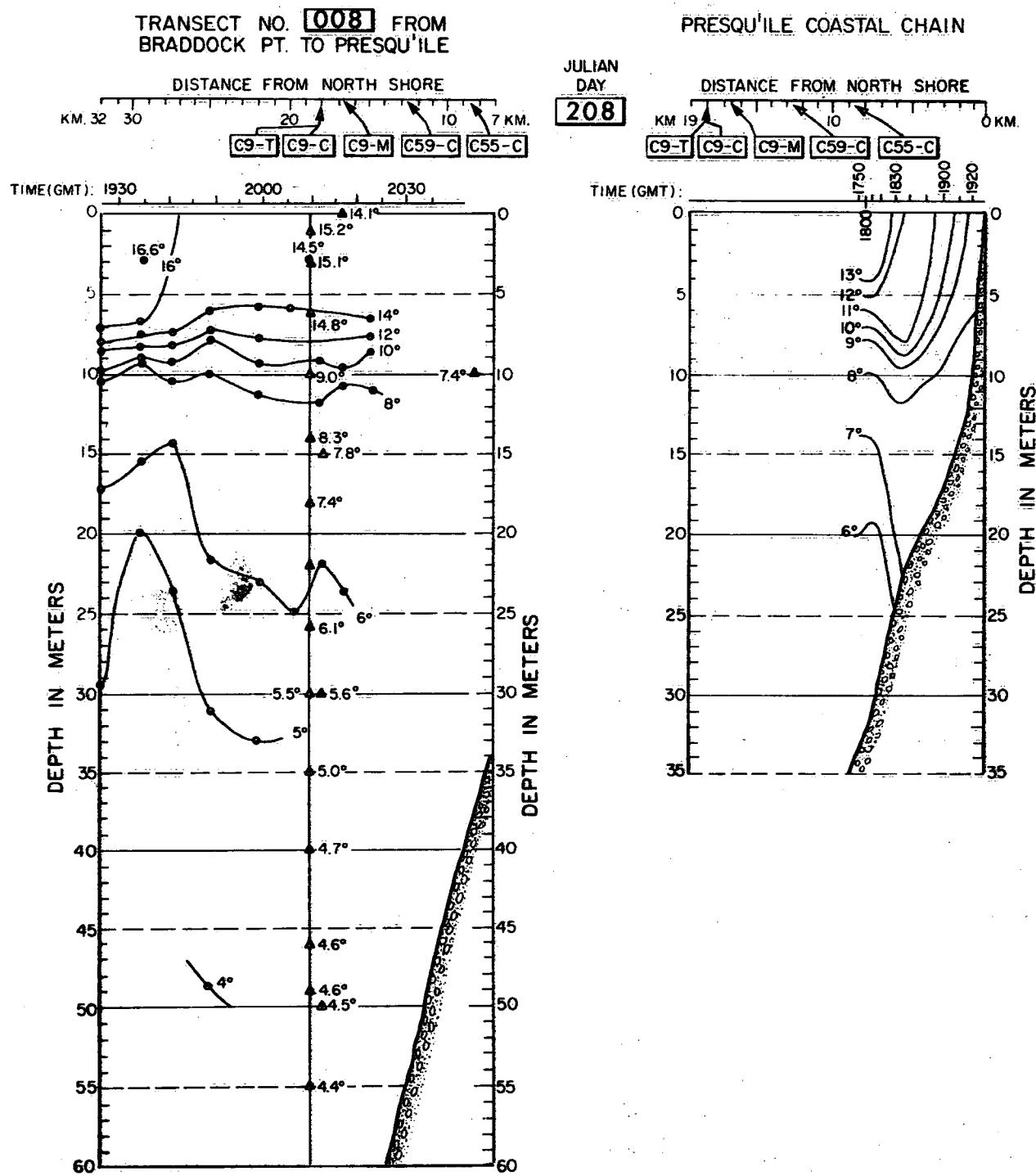


Figure 6.35. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 8, 26 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

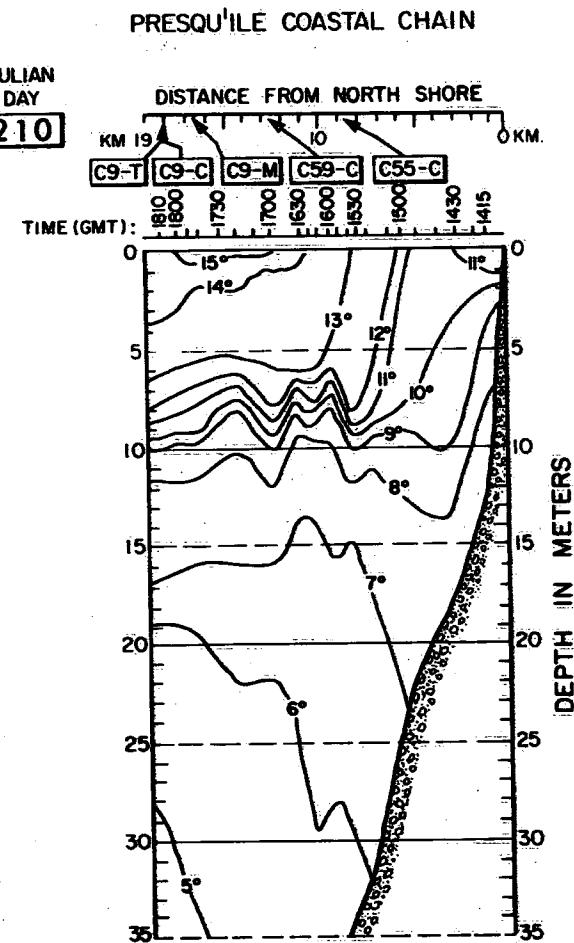
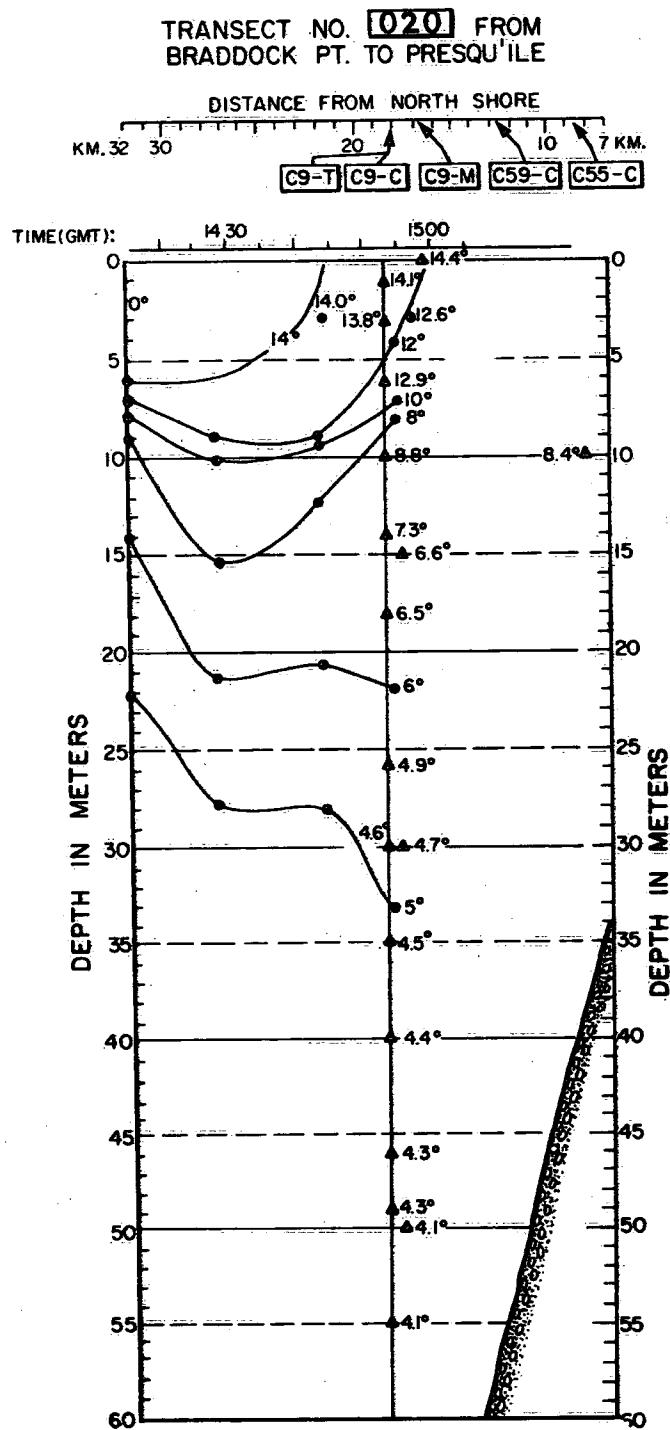


Figure 6.36. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 20, 28 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

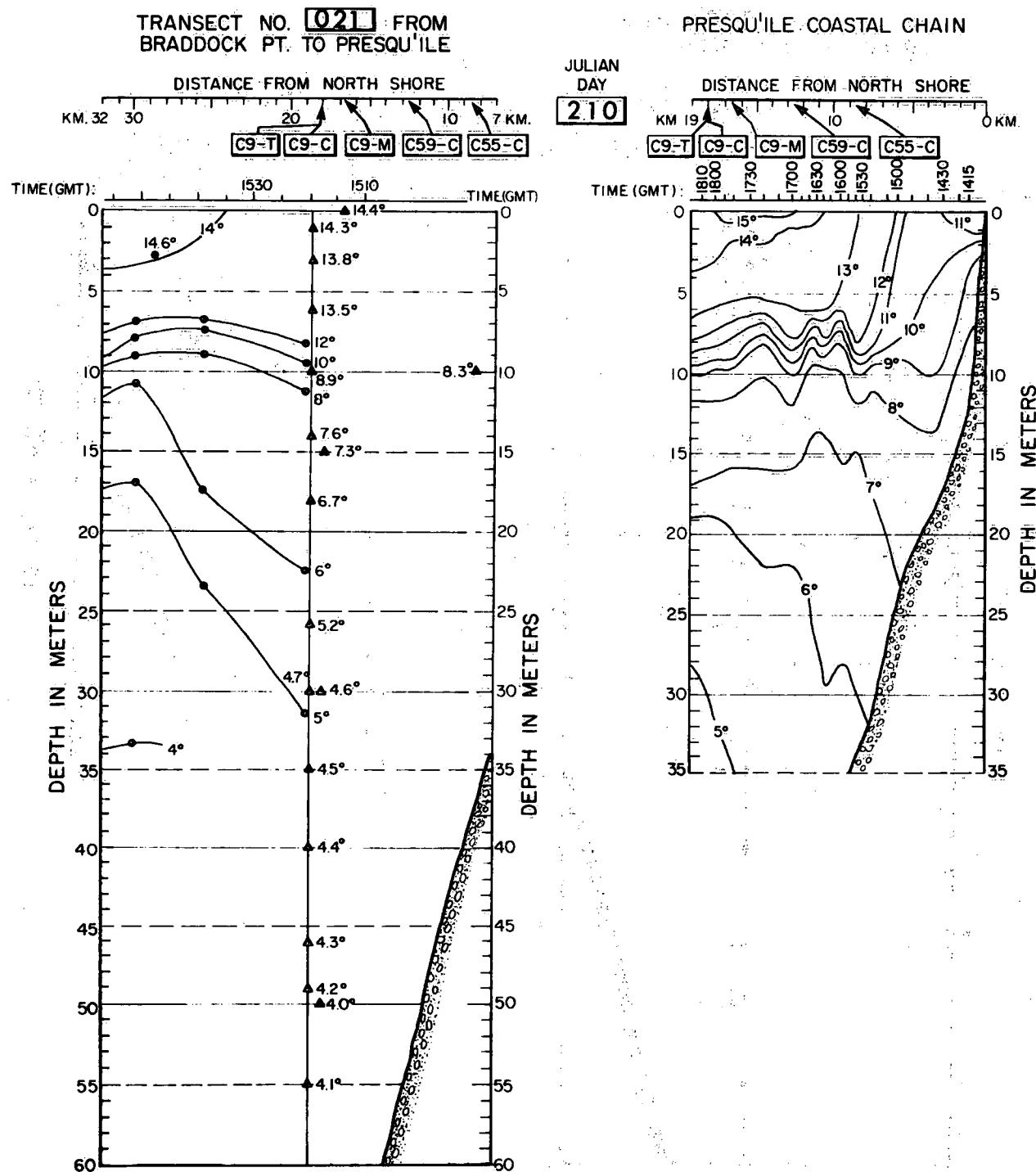


Figure 6.37. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 21, 28 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

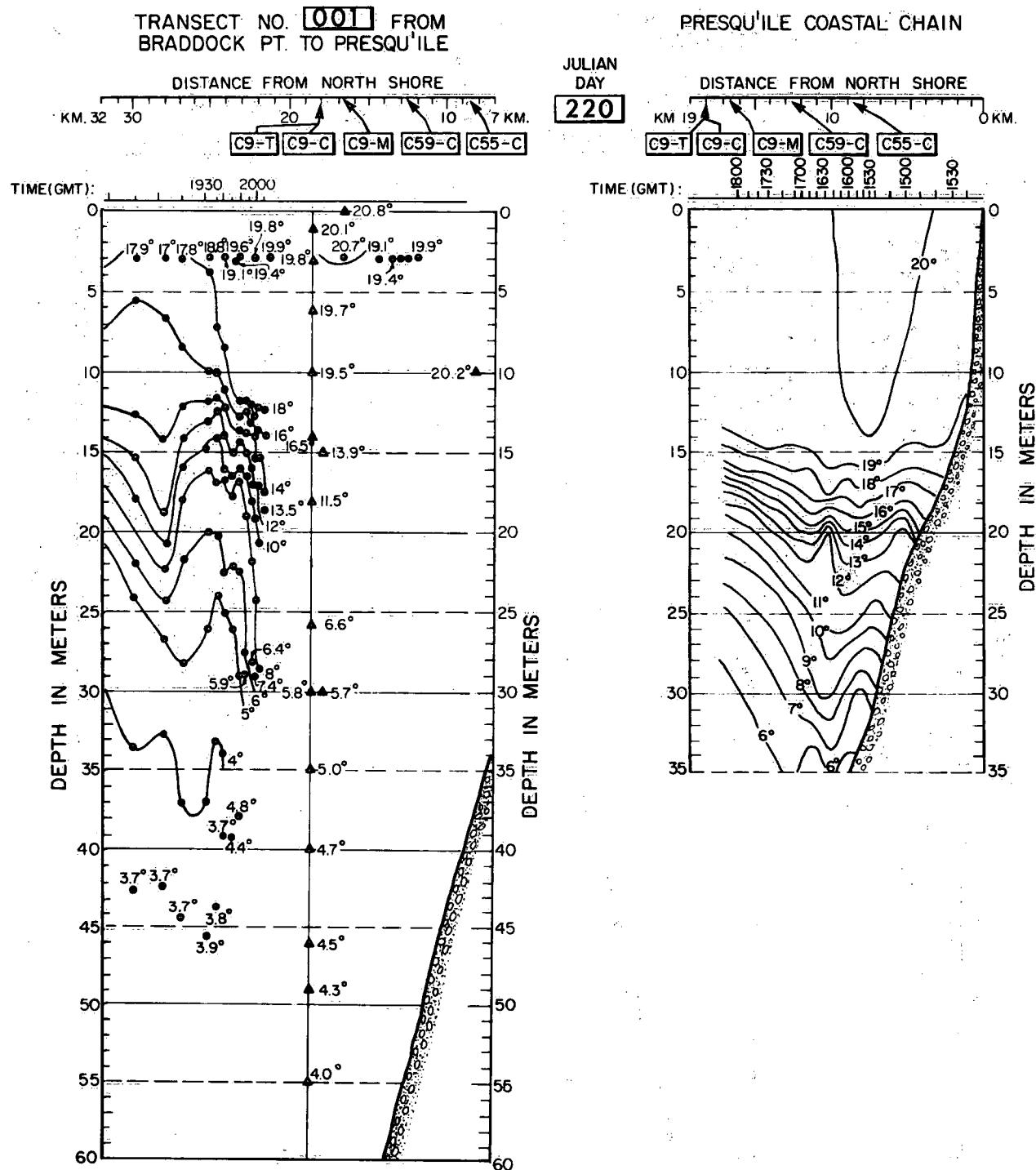


Figure 6.38. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 1, 7 August.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

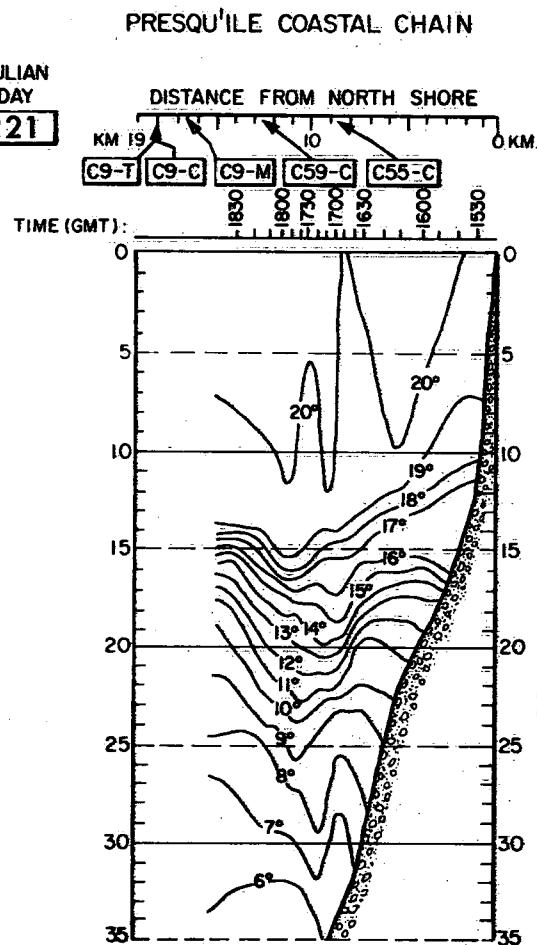
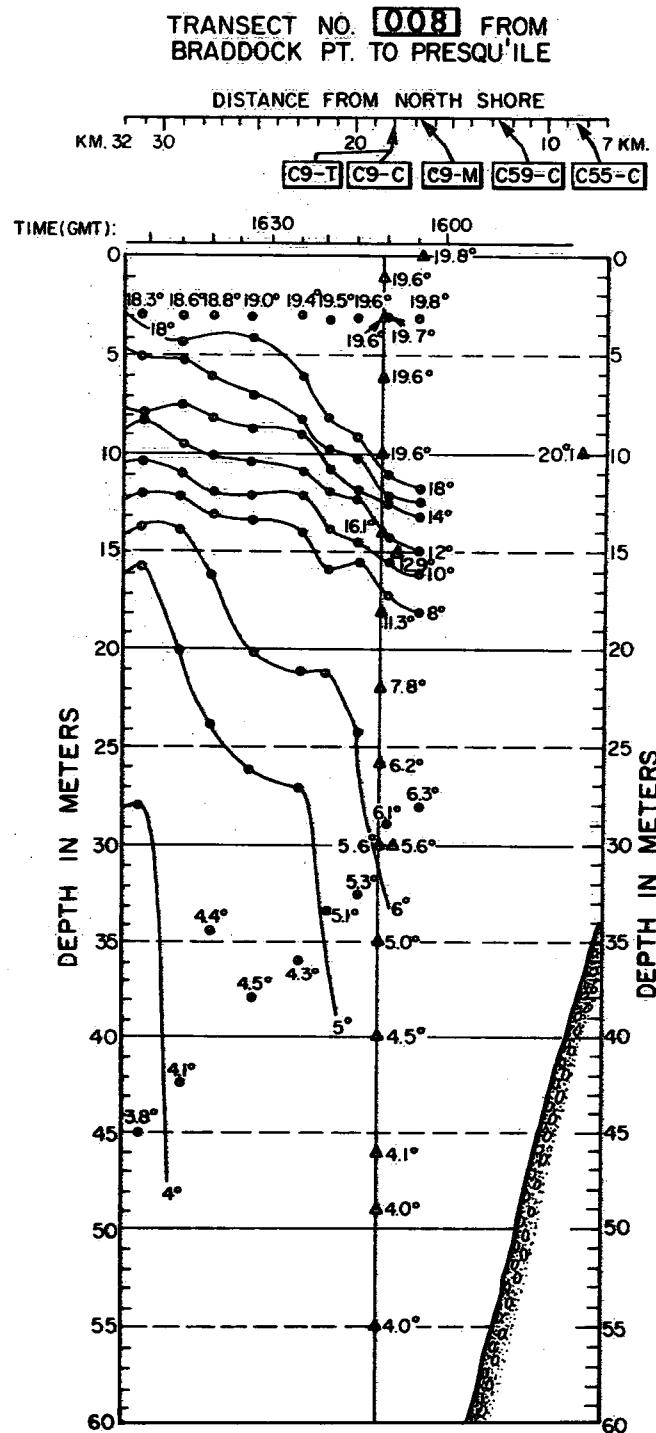


Figure 6.39. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 8, 8 August.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

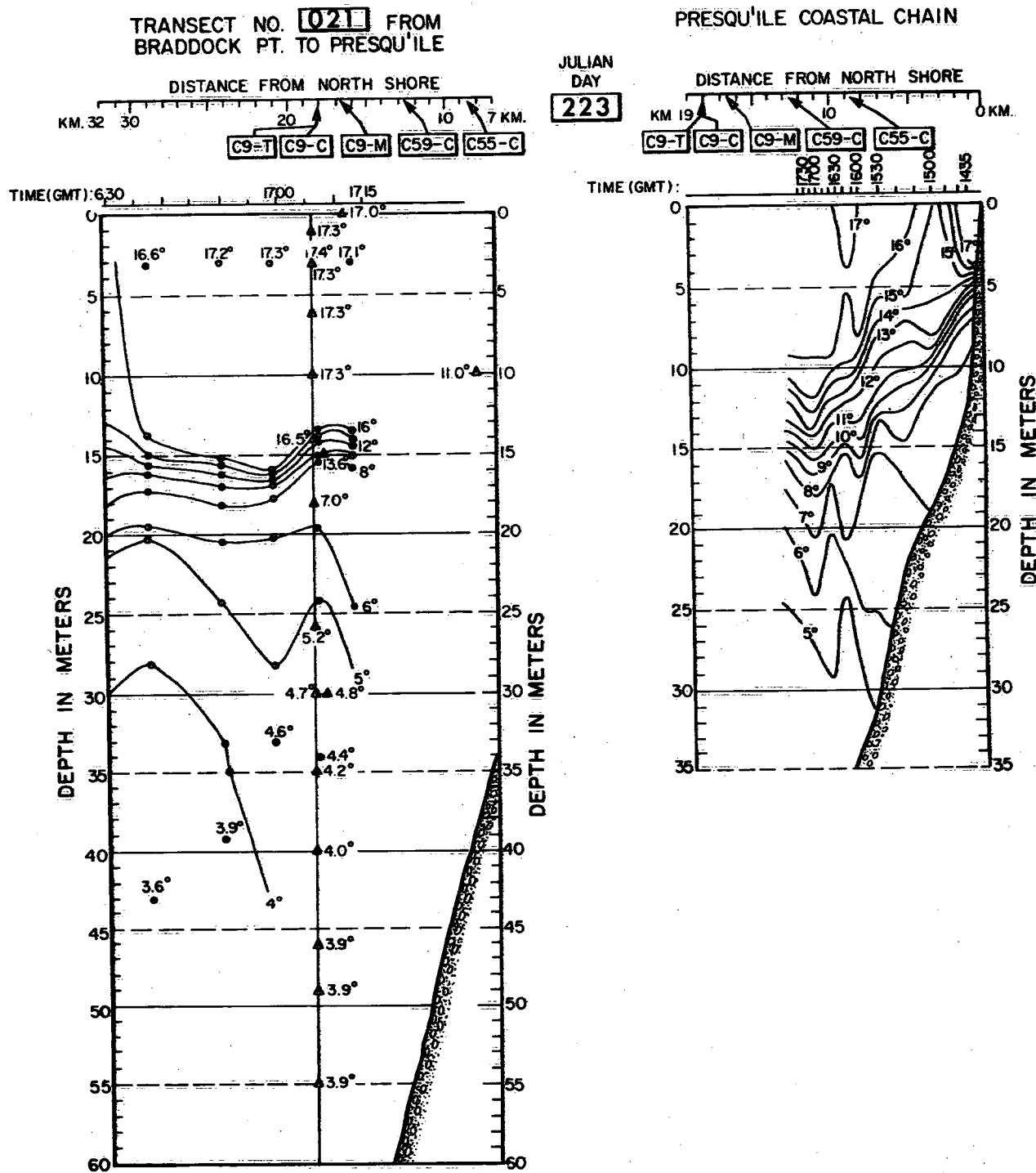


Figure 6.40. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect No. 21, 10 August.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

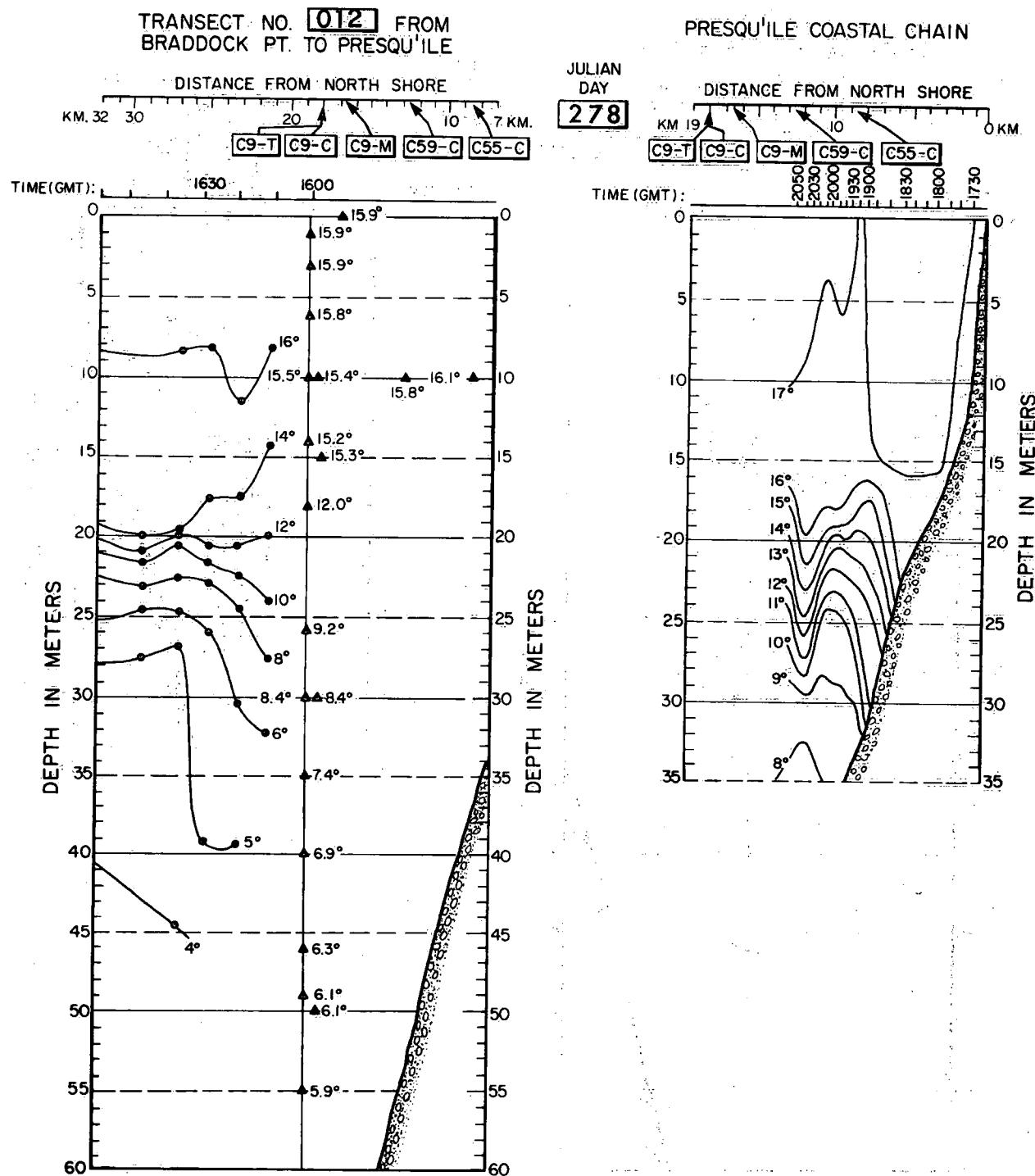
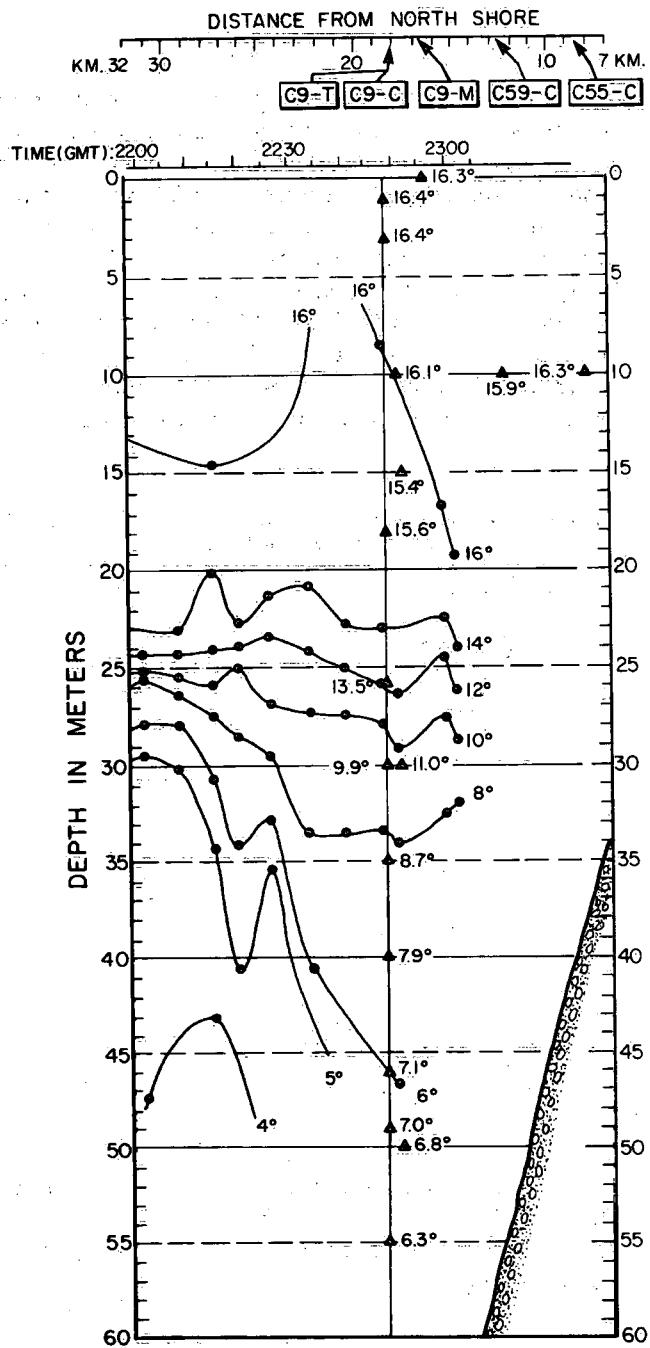


Figure 6.41. Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 12, 4 October.

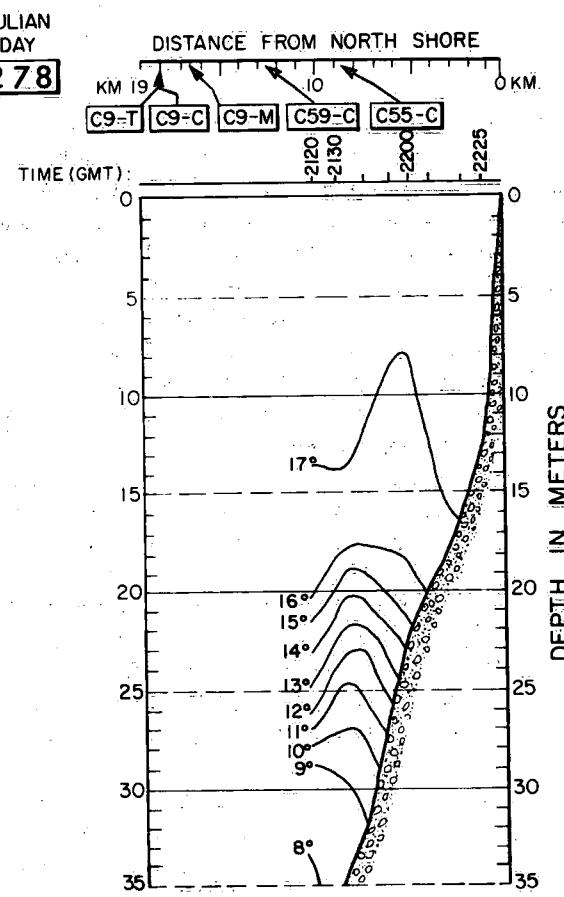
# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## TRANSECT NO. 013 FROM BRADDOCK PT. TO PRESQU'ILE



## PRESQU'ILE COASTAL CHAIN



**Figure 6.42.** Isotherm depths in the Presqu'ile Coastal Chain section and in the corresponding portion of the contemporary Transect 13, 4 October.

## Temperature Distribution in the Oswego to Prince Edward Point Transect

While the Braddock Pt. to Presquile Undulator tows were in progress during July, August, and October (see Chapter 5), temperature distribution in a section near the eastern end of the basin was explored on a continuous to-and-fro shuttle by S.S. *Advance II*: 24-28 July (16 transects); 7-11 August (17 transects); 2-6 October (22 transects). The vessel occupied (slowed down at) 18 stations (positions shown in Figures 1.1 and 7.1) to obtain temperature profiles with a mechanical bathythermograph (BT). From these the following transect isotherm diagrams were prepared with a vertical exaggeration of 1000:1. As each diagram is identified by transect number and Julian day, no additional figure numbering is necessary. At the head of each diagram are shown (i) the vessel track with the 18 stations shown as dots; (ii) the positions of fixed measuring stations, i.e., instrumented moorings located on or near the transect route; (iii) the line (dotted) occupied by the Oswego Coastal Chain (Scott *et al.*, 1973); and (iv) the GMT time scale for the particular transect. Official IFYGL numbering is shown for the fixed stations, but we have found it convenient to adopt the prefix C for Canadian instruments (for which the suffixes -T, -C, and -M signify moored thermistor chains, current meters, and meteorological buoys, respectively), and U for the United States moorings U19 and U20. The depths of the 4°, 5°, 6° and all even-numbered isotherms above 6°C were determined from each BT cast and entered as a dot at the corresponding depth and horizontal distance on the diagram. Surface temperatures, measured by a mercury thermometer in a dip bucket, were entered for each BT station. Smoothed isotherms were then drawn in by hand.

To provide a more complete temperature picture for each transect and to aid comparison between the BT profiles and those obtained from the moored recorder instruments, *all* available fixed-station temperature data (Table 7.1) were extracted from the IFYGL data files, for

the times when the vessel's track "coincided" with a station, and entered as triangles at appropriate depths on the transects which follow. However, isotherms on those transects are derived solely from the BT profiles and do not take fixed-station measurements into account. Station sensor depths are listed in Table 7.1; and the times of vessel-station coincidences — to the nearest 6 min for mooring U19 and U20 and to the nearest 10 min for C11-C — are assembled, for all three cruises, in Table 7.2. Comparisons between transect (BT) and fixed-station temperature profiles are made in Chapter 8.

**Table 7.1. Depths (m) of Temperature Sensors\* at Fixed Stations in or near the Oswego to Prince Edward Point Section**

U.S. stations, 6-min intervals	Canadian station, 10-min intervals
Moorings U19, U20	Mooring C11-C†
surface	
5	
10	10
15	15
20	
25	
30	30
35	
50	50
60	
75	
100	

\*Data from those sensors are entered, as triangles in the transect diagrams, according to availability and as shown in the timetable, 7.2.

†Surface temperature also measured at C11-M.

The transect diagrams appear on the following pages: 227-242 (24-28 July, 16 transects); 243-259 (7-11 August, 17 transects); 260-281 (2-6 October, 22 transects).

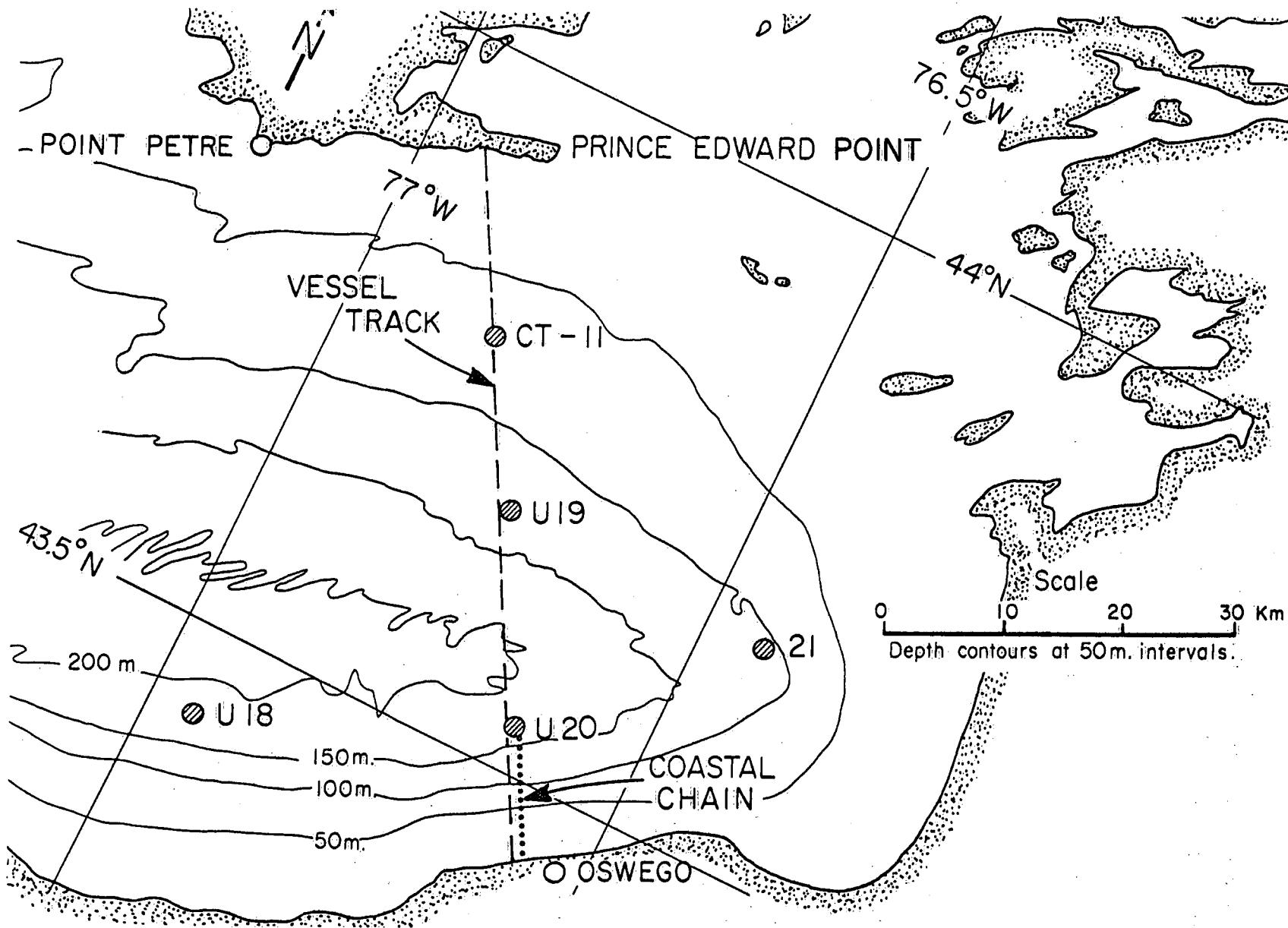


Figure 7.1. Positions of fixed measuring stations relative to the Oswego to Prince Edward Point transect (broken line) and to the Oswego Coastal Chain (dotted line).

**Table 7.2. Times (GMT) of Temperature Readings at Fixed Stations and Depths\***  
**Entered on the Oswego to Prince Edward Point Transect Diagrams**  
**(see these for dates)**

Transect No.	Cruise and day (J)						
	24-28 July, 206-210		7-11 August, 222-224		2-6 October, 276-280		
	U19	C11-C†	U20	C11-C†	U20	U19	C11-C†
1	2342‡	0240		2300	1918	2148	2240
2		0600	0448	0150	0448	0248	0140
3	1306	1410	0636	0920	0600	0736	0830
4	1754	1650	1412	1200	1342	1212	1120
5	2224	2320	1536	1750	1542	1724	1810
6	0306	0150	2212	1940	2218	2054	2010
7	1318	1430	2336	0240	2324	0106	0230
8	1748	1700	0730	0530		0554	0510
9	2236	0030	0848	1110	0812		1050
10	0430	0330	1624	1350	1530	1348	1310
11	0900	1000	1724	1800	1642	1818	1850
12	1336	1240	1454	1800	2254	2130	2040
13	1854	1950	2248	2010	0012	0206	0300
14	2248	2150	0018	0320	0830	0718	0620
15	0418§	0520	0724	0530	0954	1118	1200
16	0824§	0730	0836	1126	1618	1454	1410
17			1530	1320	1712	1830	1920
18					2318	2200	2130
19						0236	0340
20						0624	0550
21						1036	1120
22						1412	1320

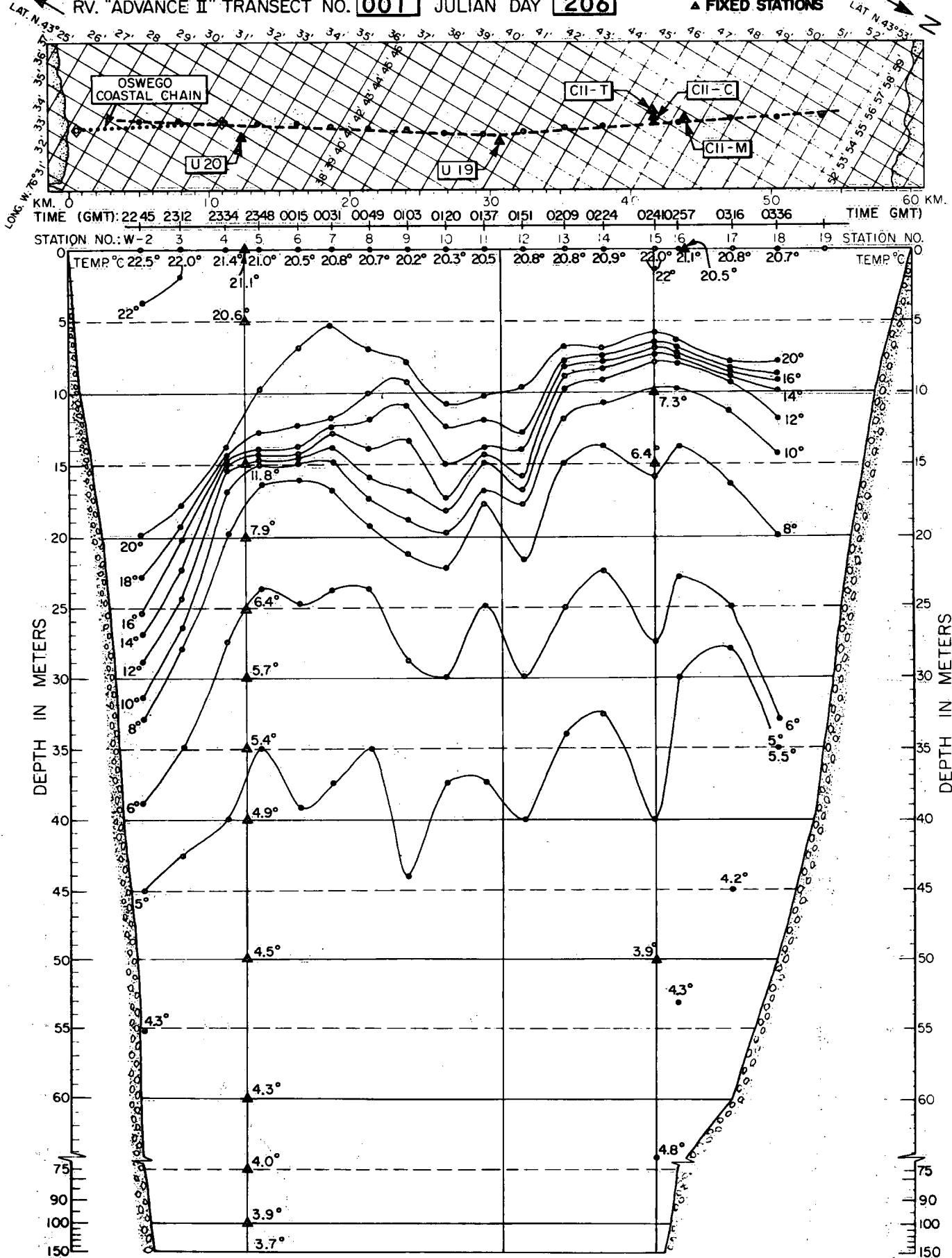
\* Depths entered in Table 7.1.

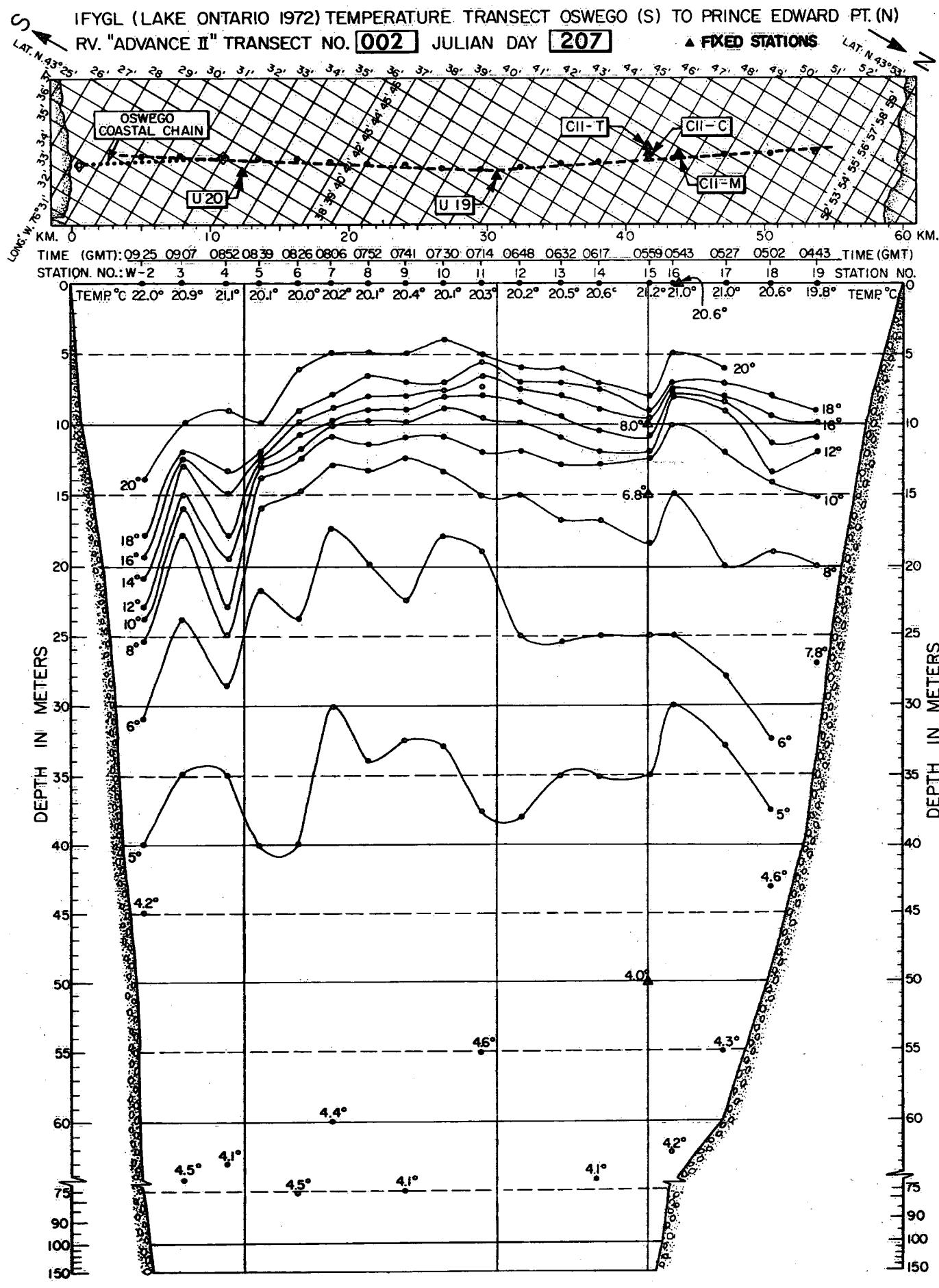
† Surface temperature also entered for C11-M at times within 20 min of those shown for C11-C.

‡ Station U20, Transect 1.

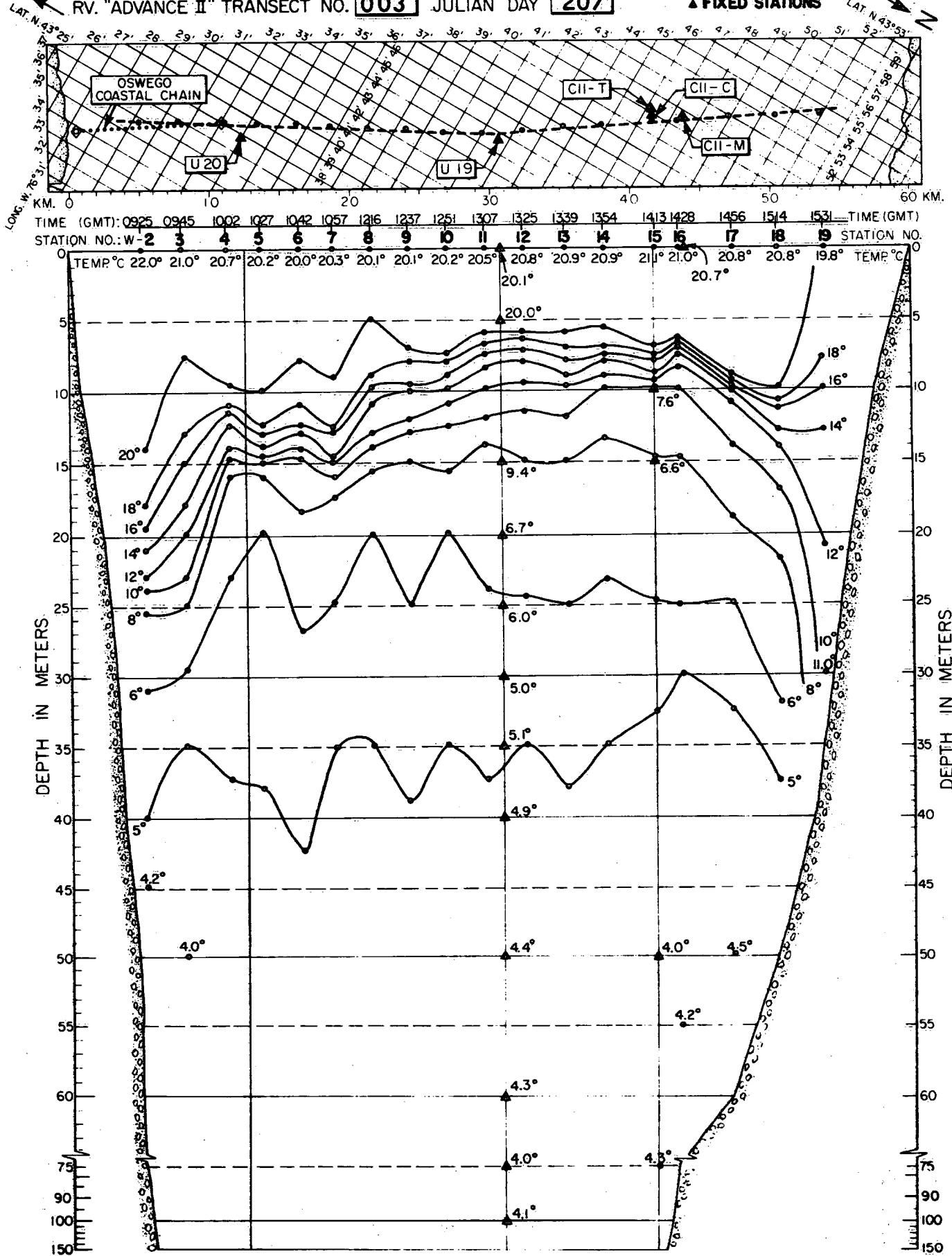
§ For Transects 15 and 16 the U20 readings were for 0206 and 0954 GMT, Julian day 220, respectively.

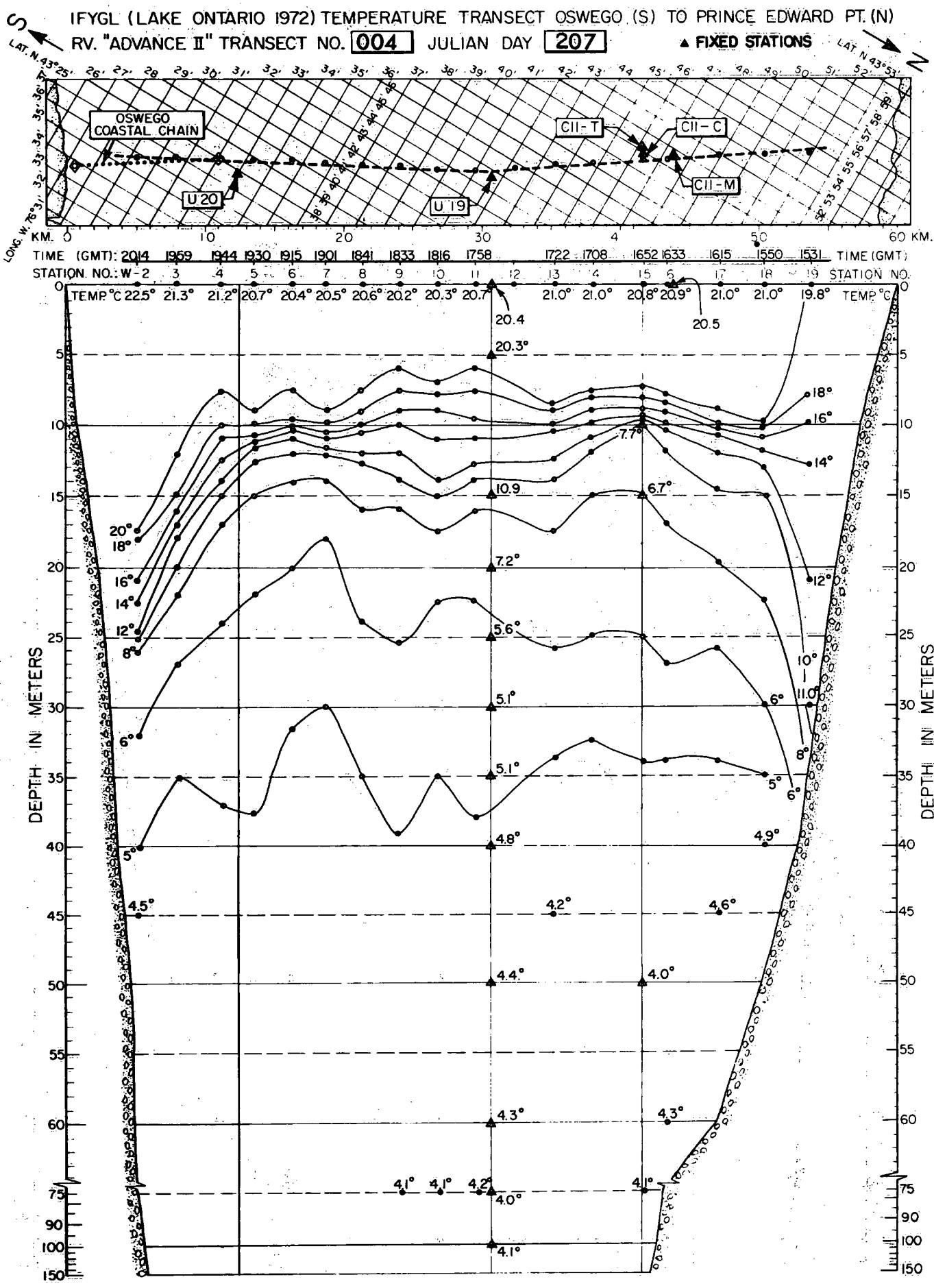
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 001 JULIAN DAY 206





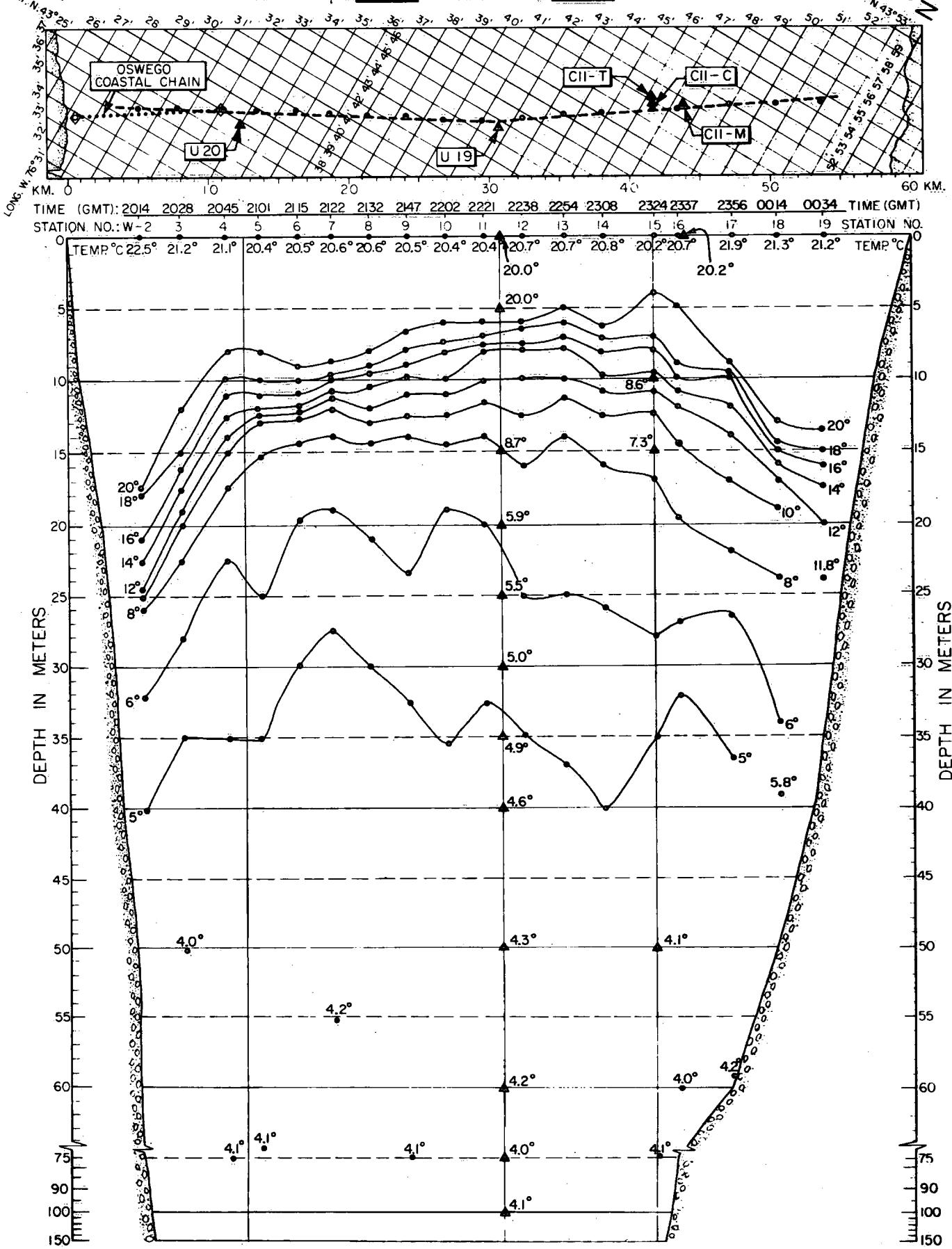
6 IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV. "ADVANCE II" TRANSECT NO. 003 JULIAN DAY 207 ▲ FIXED STATIONS LAT. N.

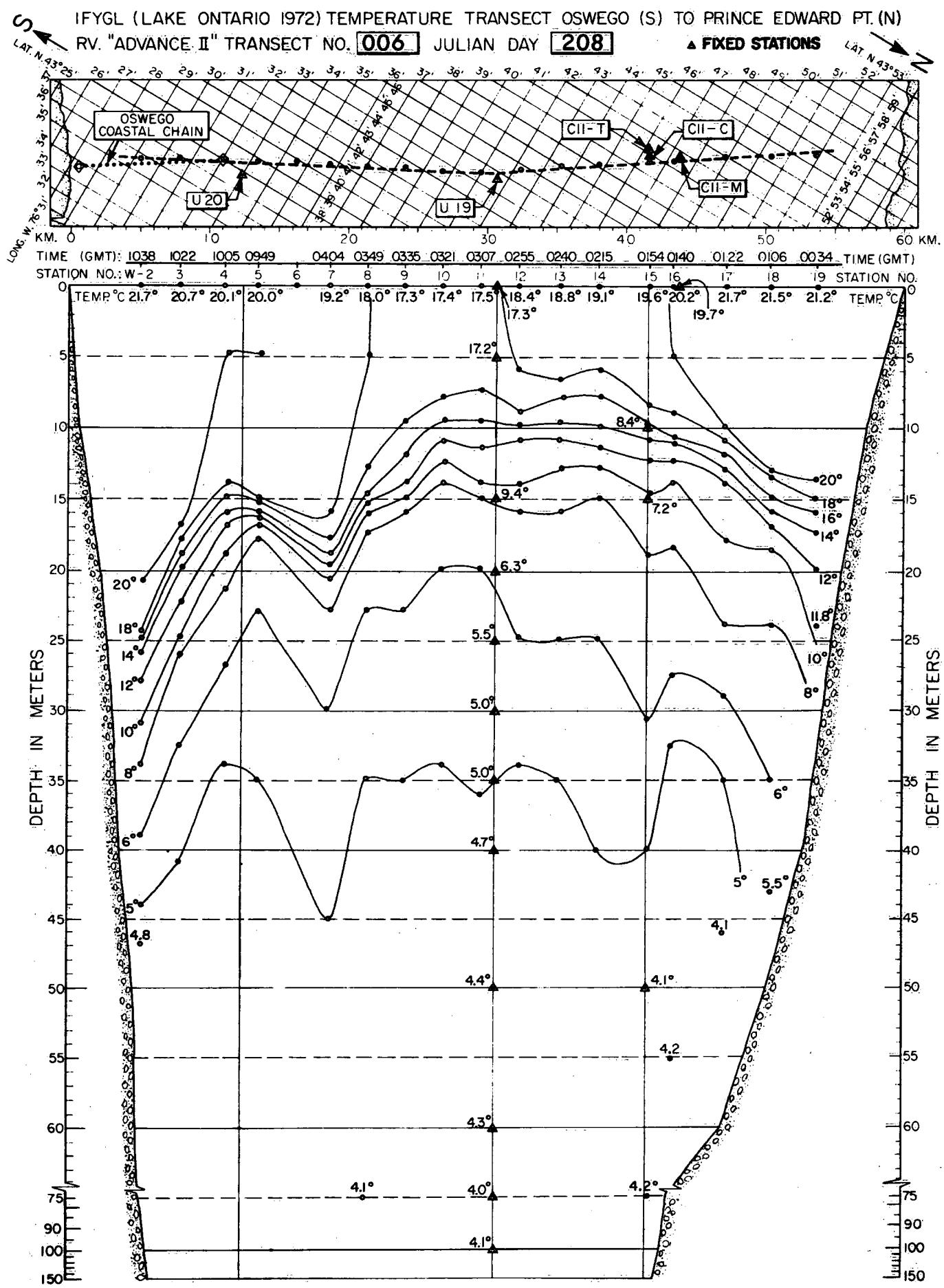




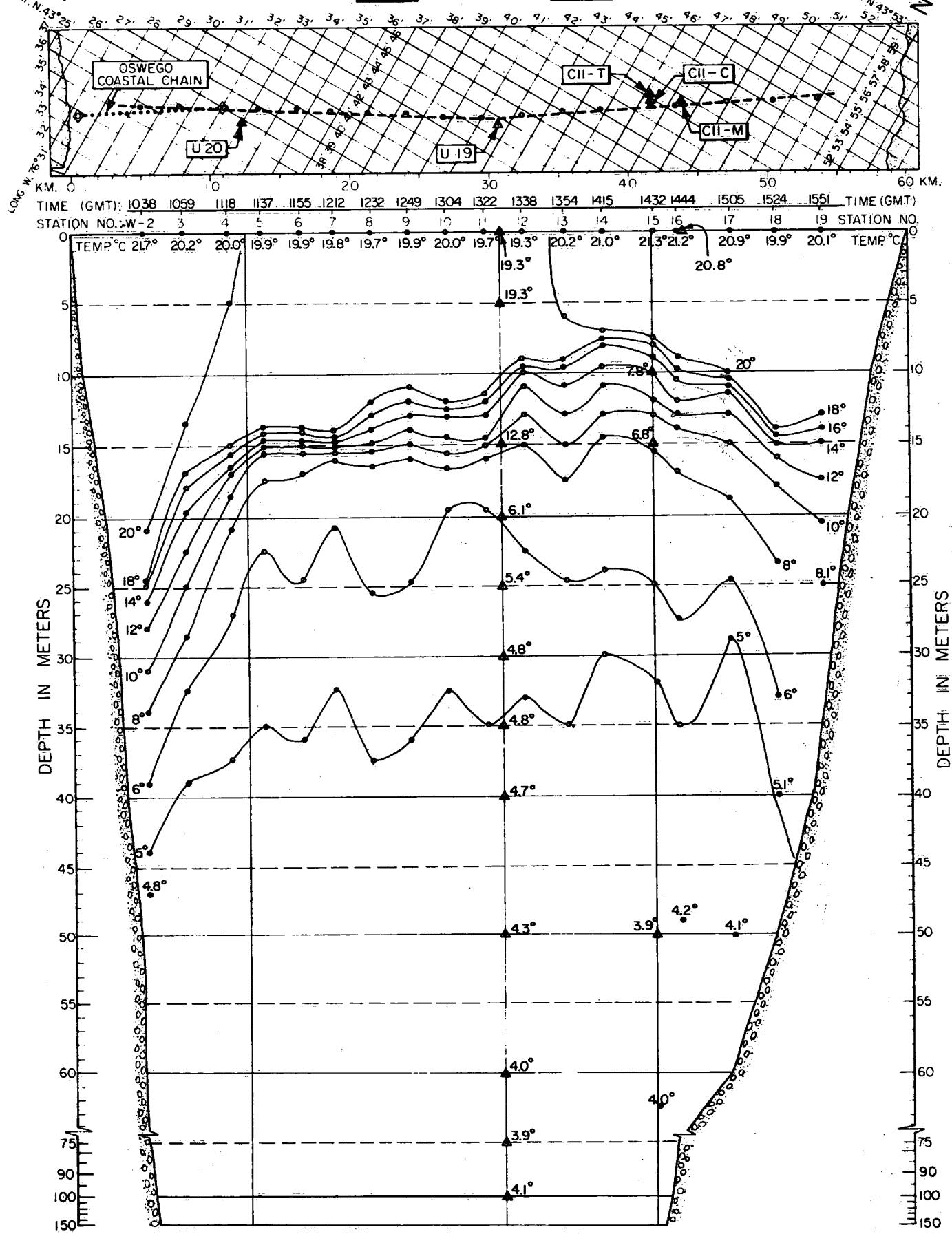
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 005 JULIAN DAY 207

▲ FIXED STATIONS

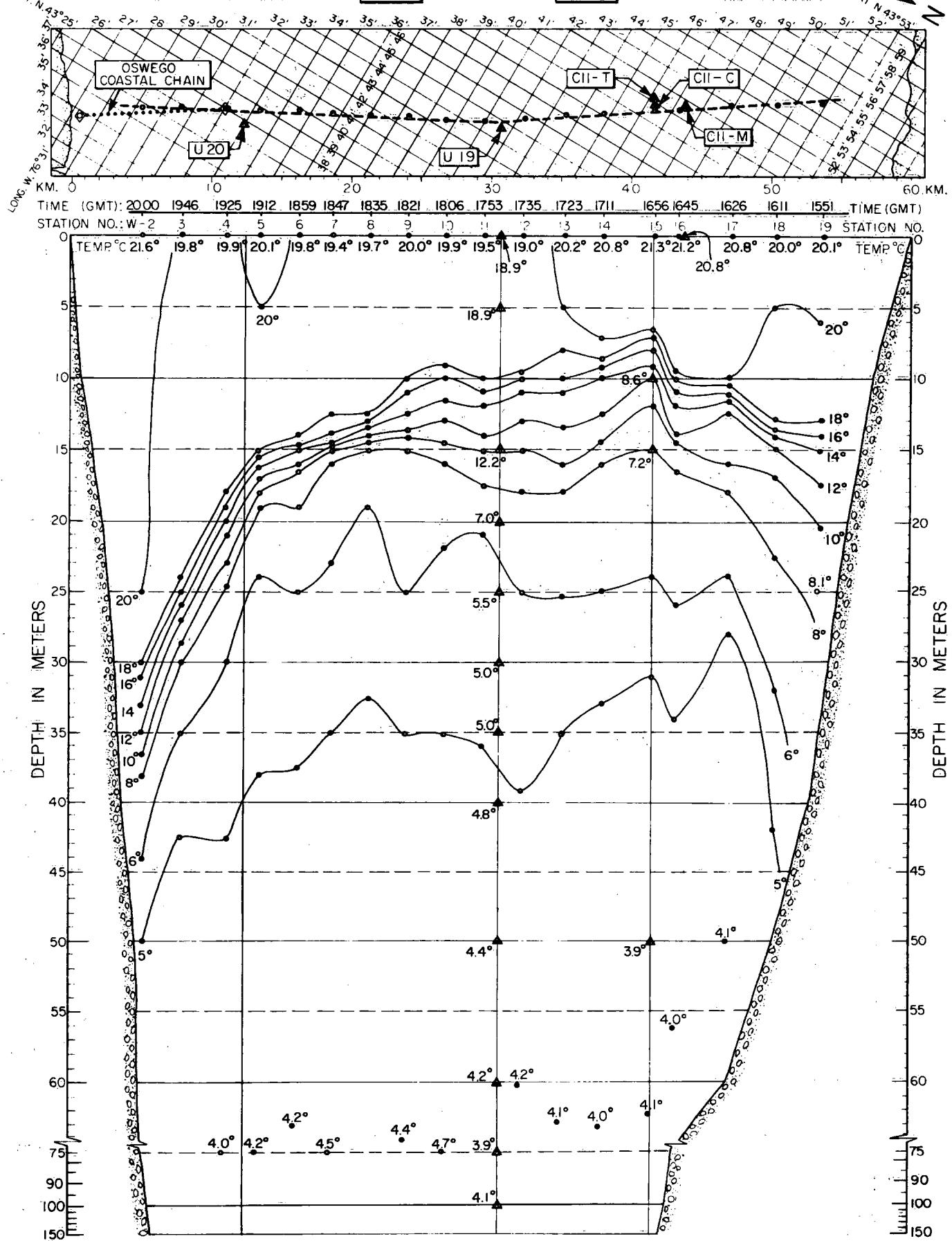




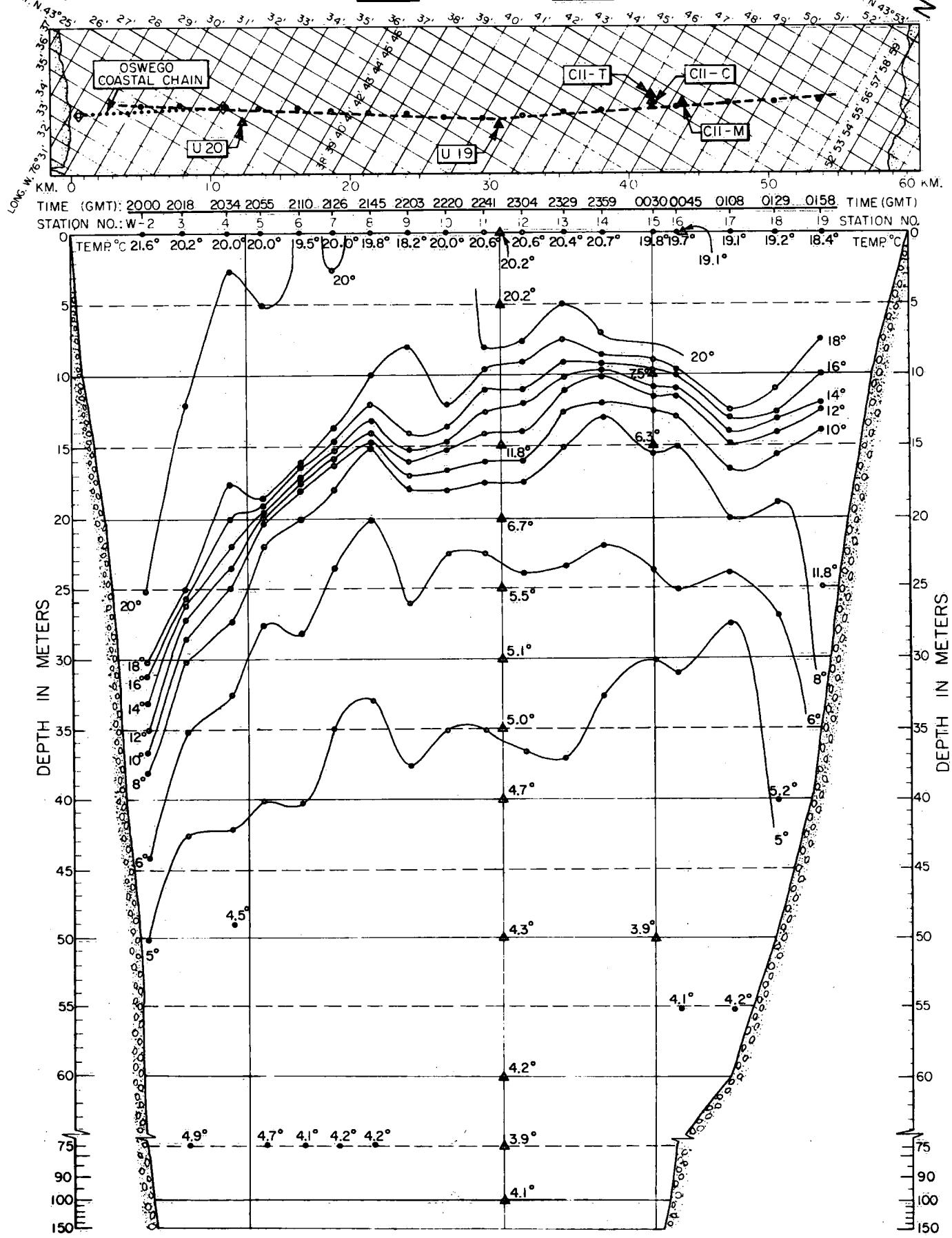
S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT (N)  
RV. "ADVANCE II" TRANSECT NO. 007 JULIAN DAY 208 ▲ FIXED STATIONS LAT N 43°  
LAT N 43°  
5



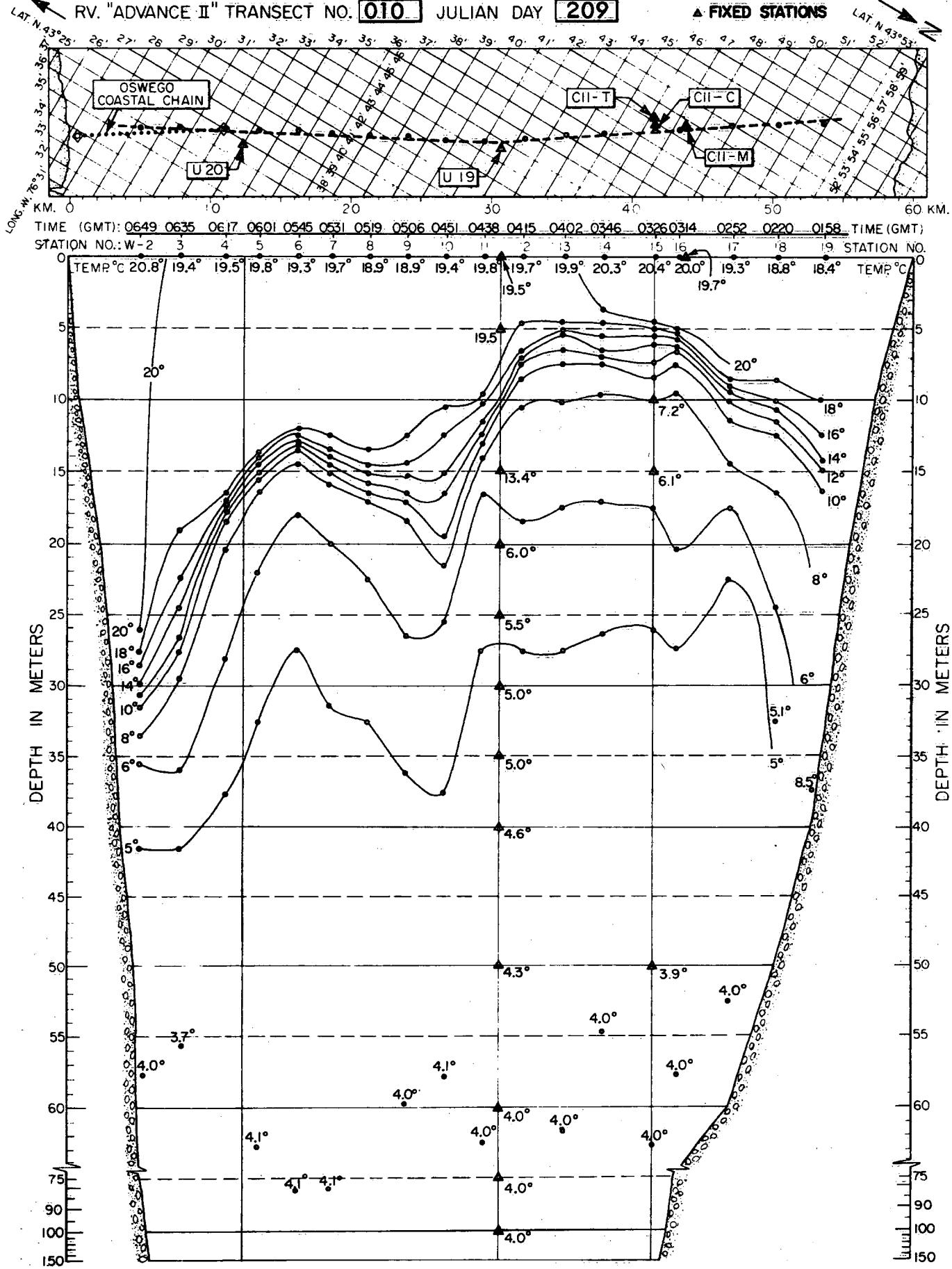
*S* 1FYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
*L47* RV. "ADVANCE II" TRANSECT NO. **008** JULIAN DAY **208** ▲ FIXED STATIONS *L47*



S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. 009 JULIAN DAY 208 ▲ FIXED STATIONS N

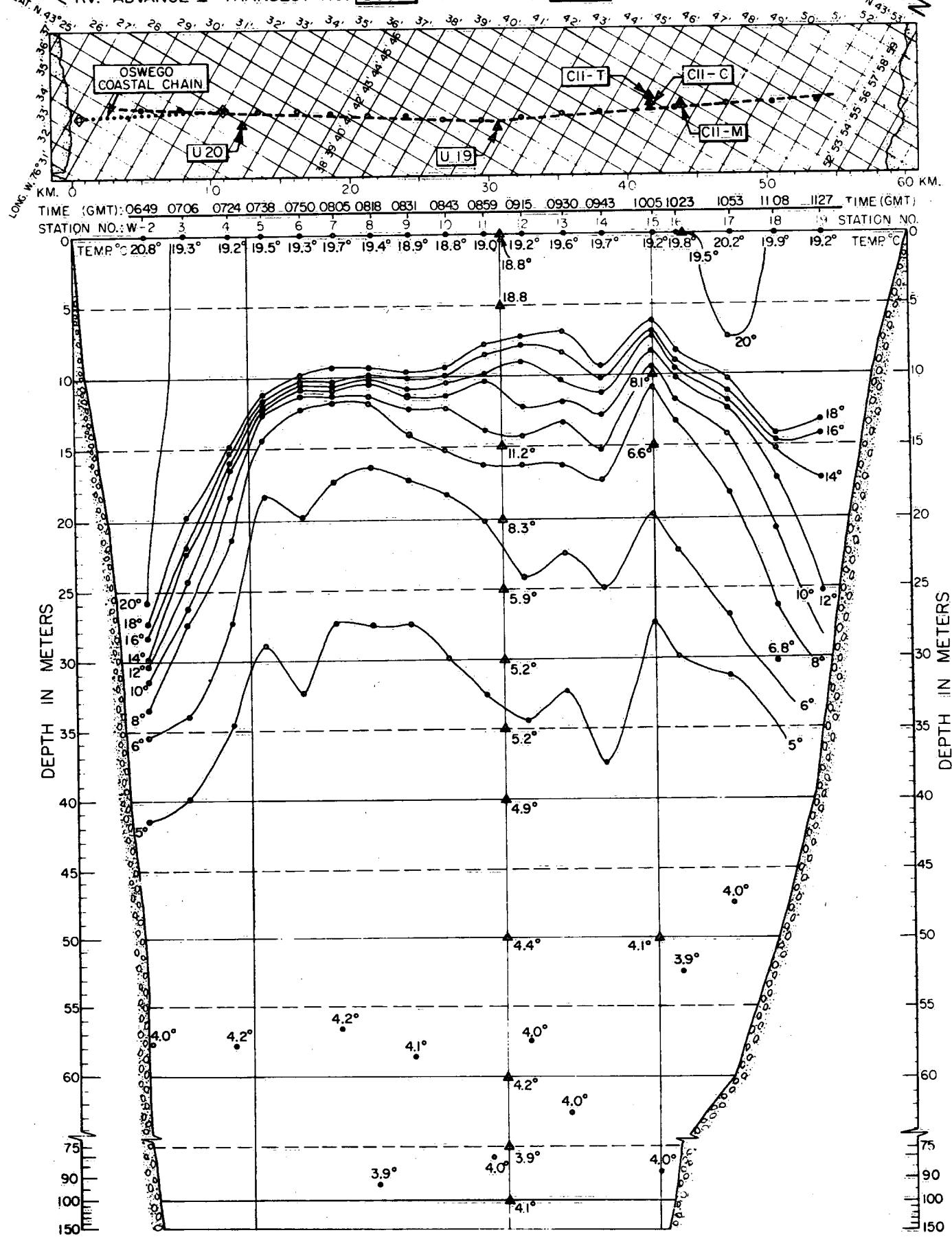


S. IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV. "ADVANCE II" TRANSECT NO. 010 JULIAN DAY 209 ▲ FIXED STATIONS L4T N L4T N

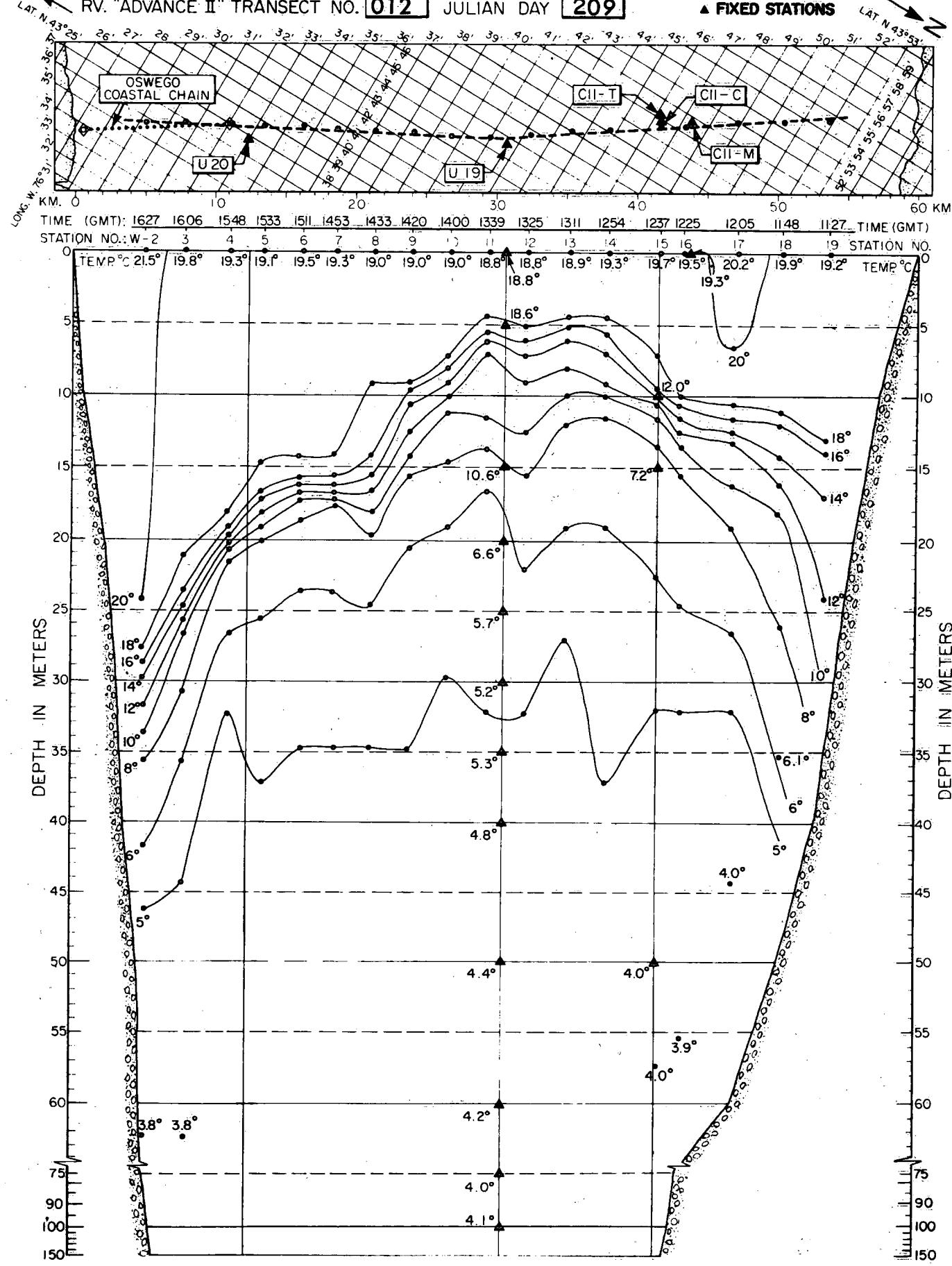


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **011** JULIAN DAY **209**

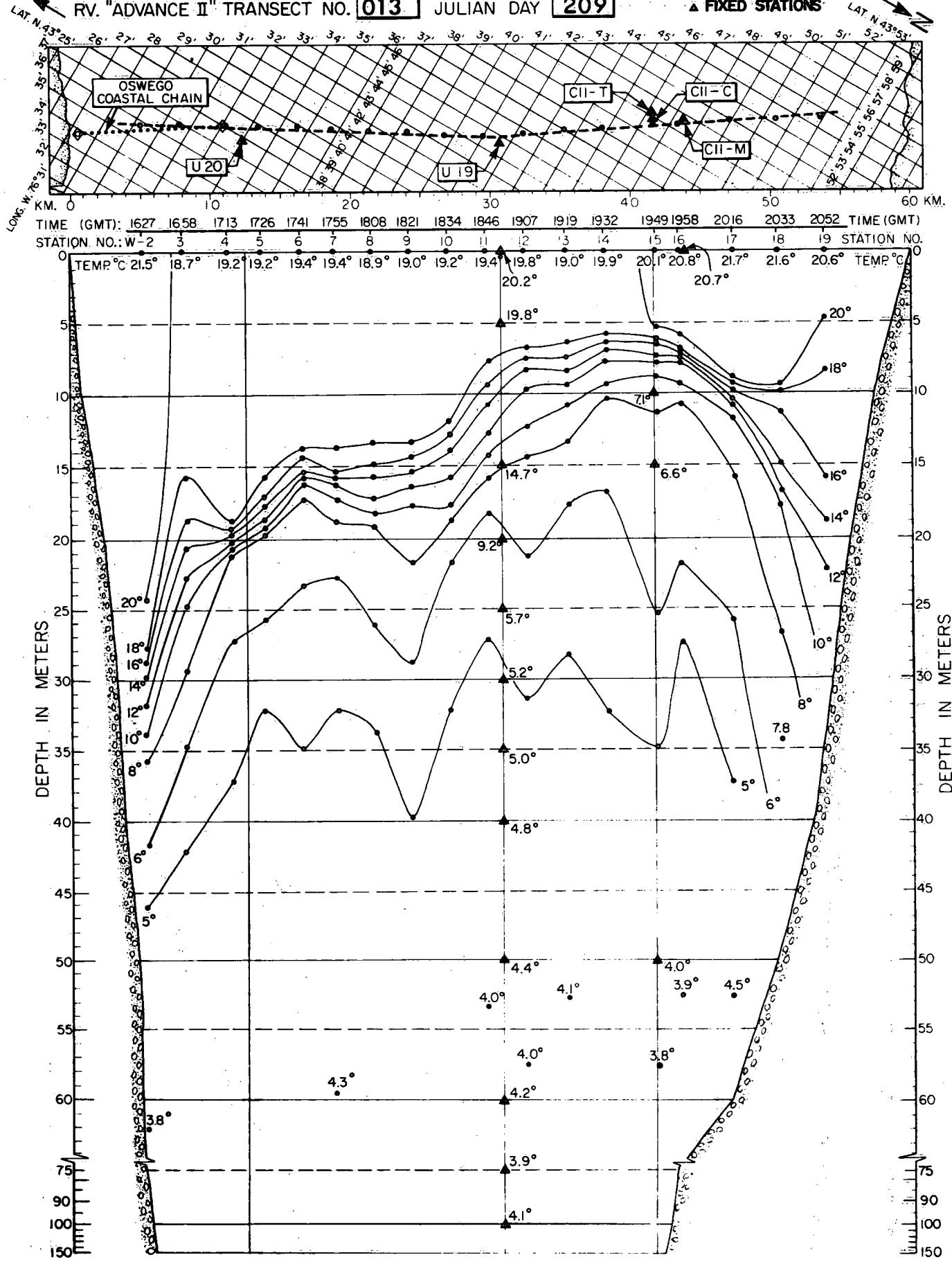
▲ FIXED STATIONS



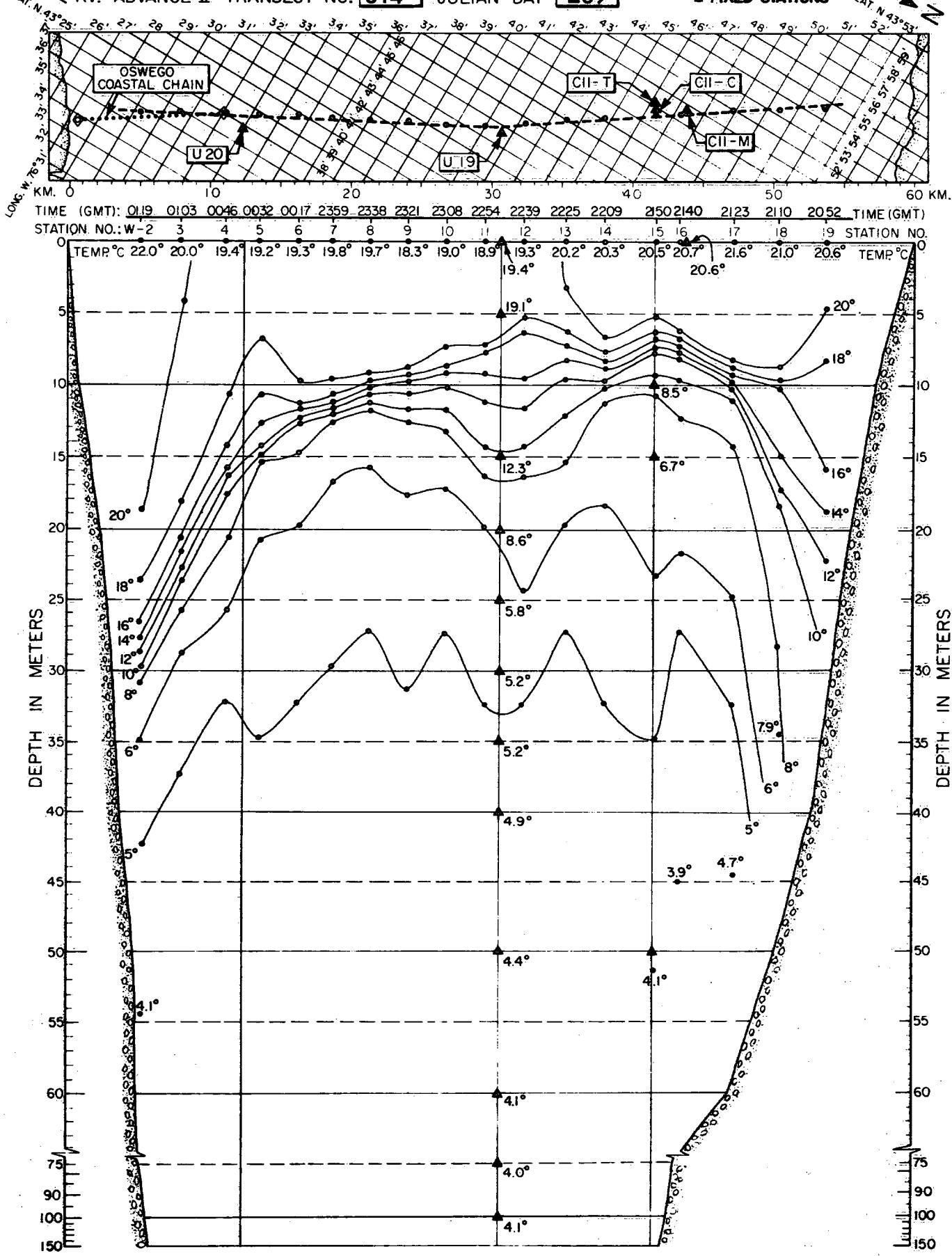
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 012 JULIAN DAY 209



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 013 JULIAN DAY 209

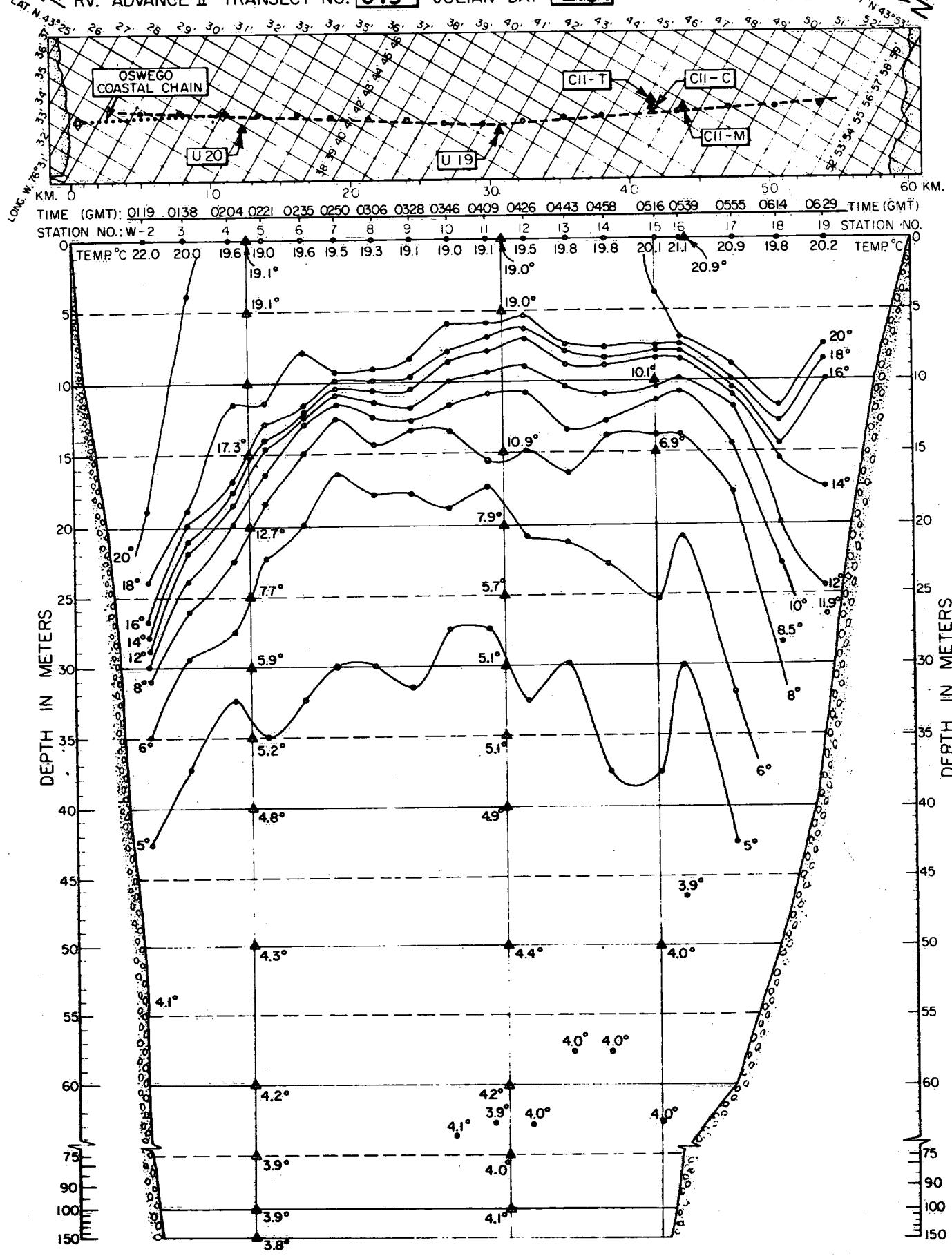


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 014 JULIAN DAY 209

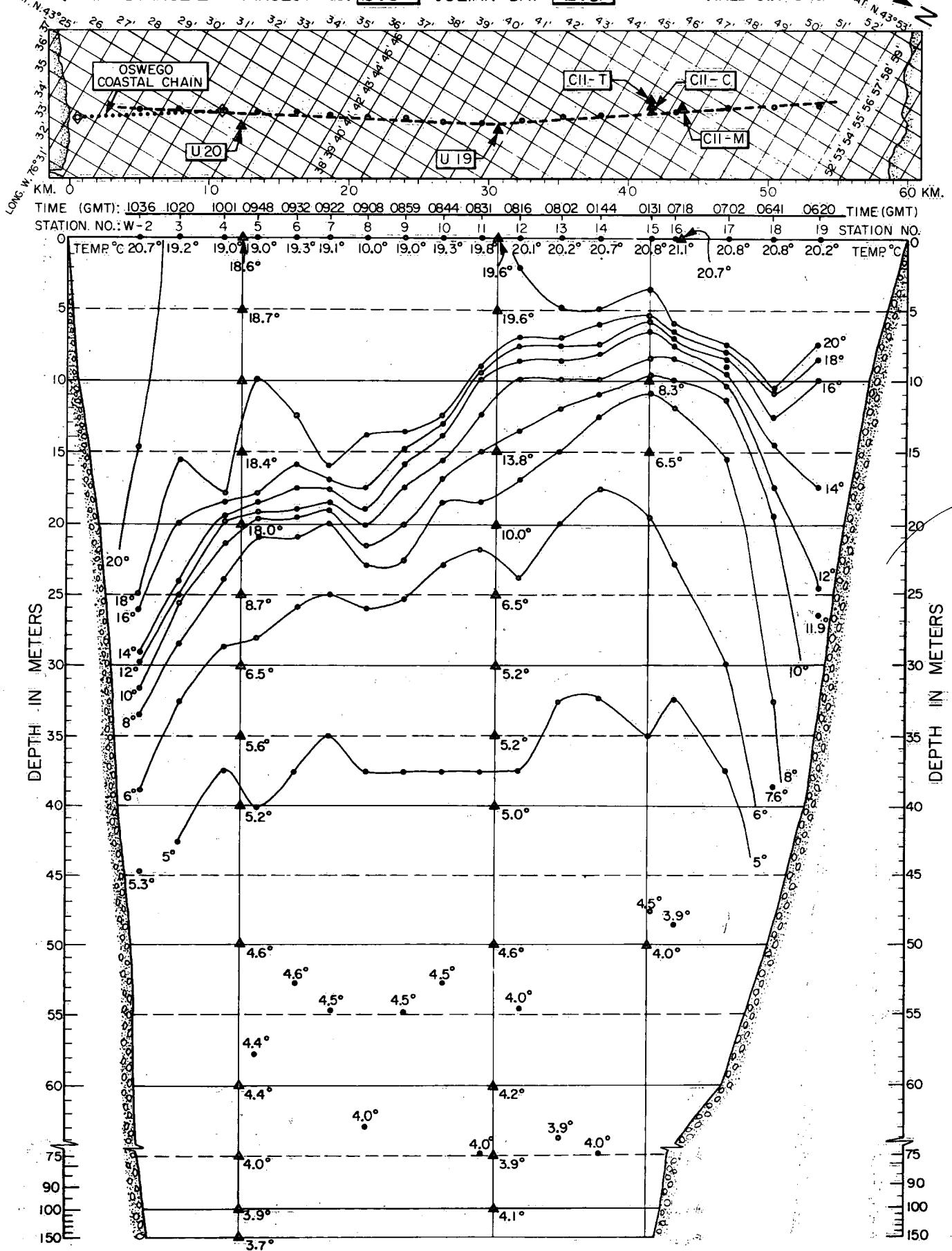


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **015** JULIAN DAY **210**

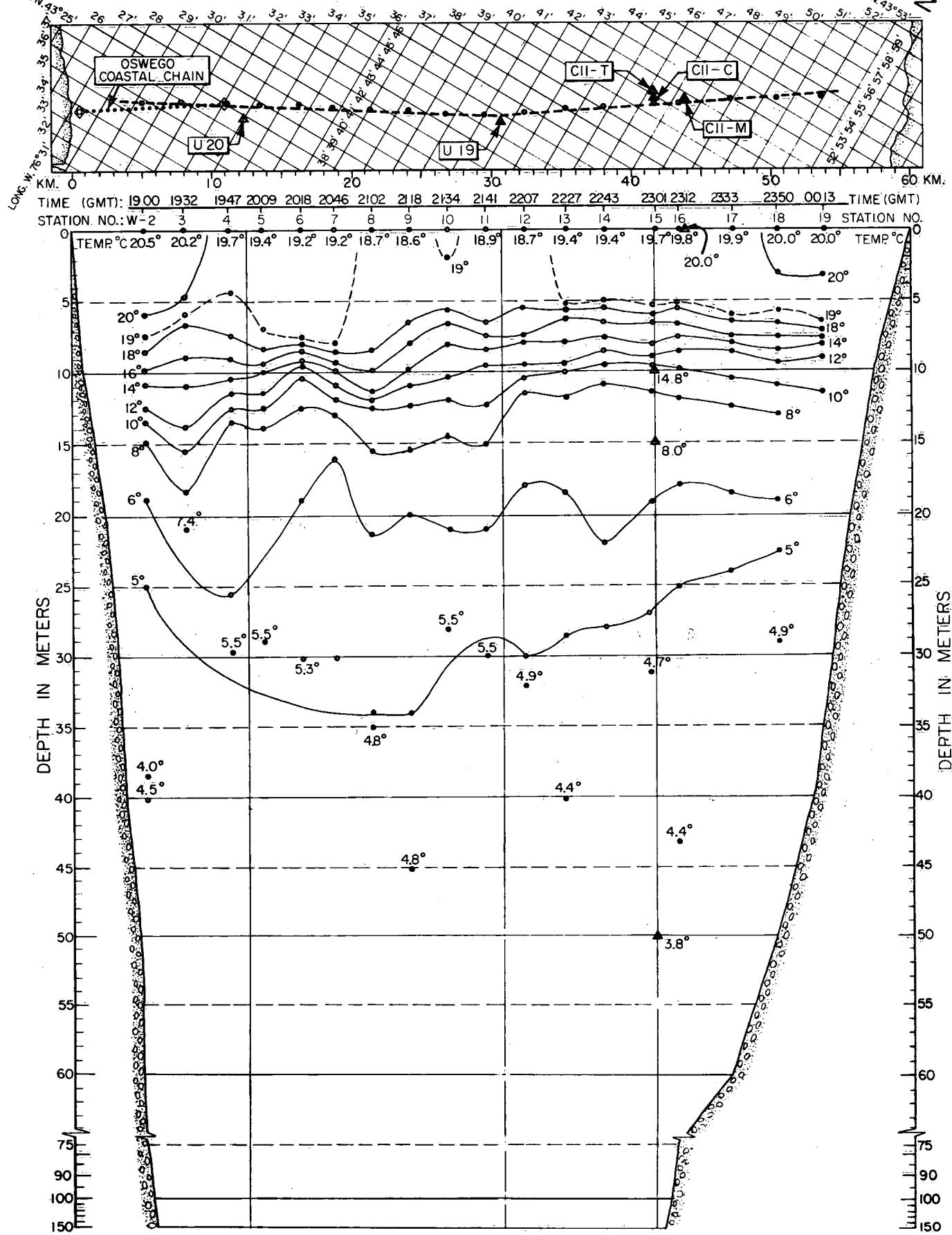
▲ FIXED STATIONS

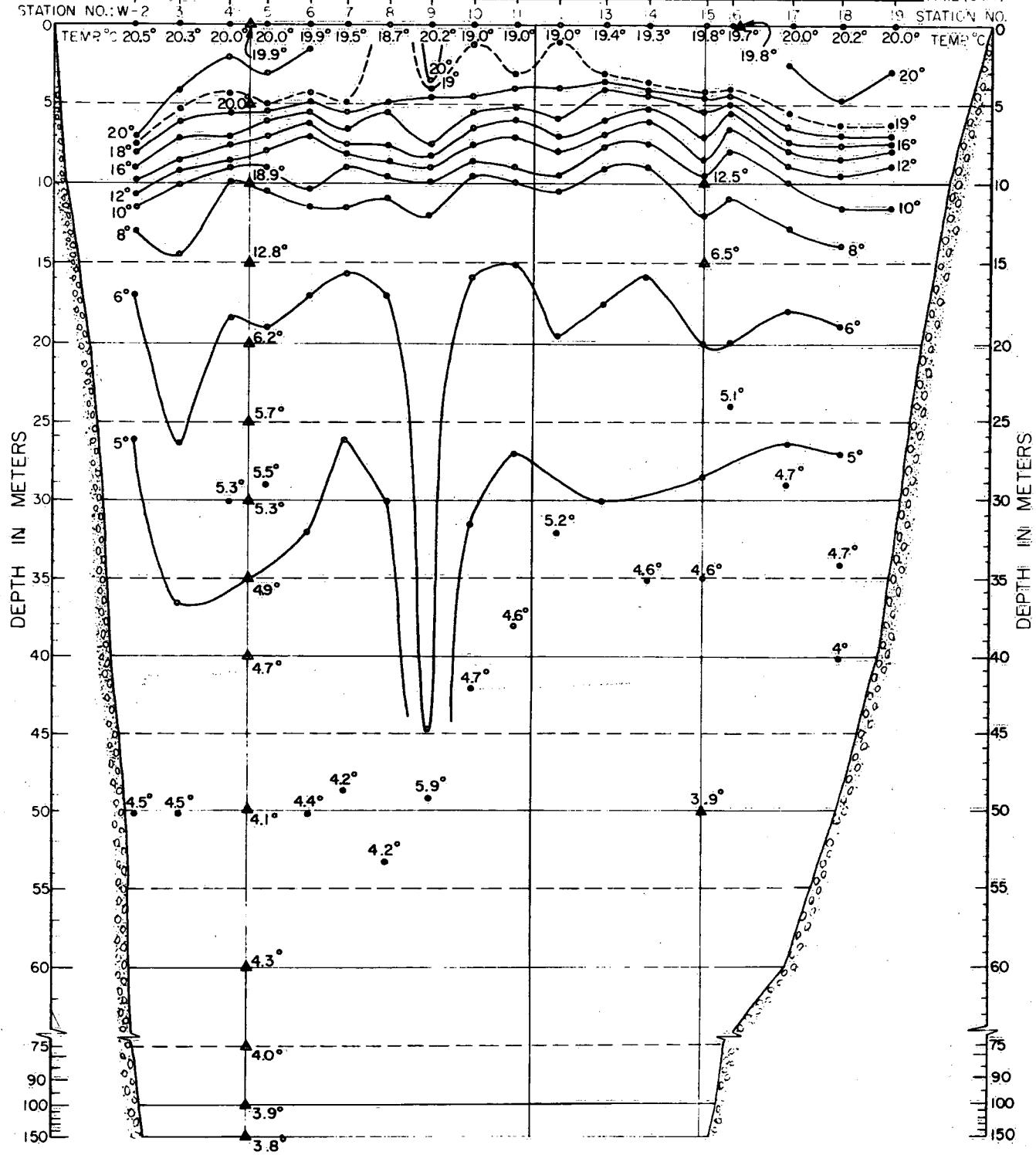
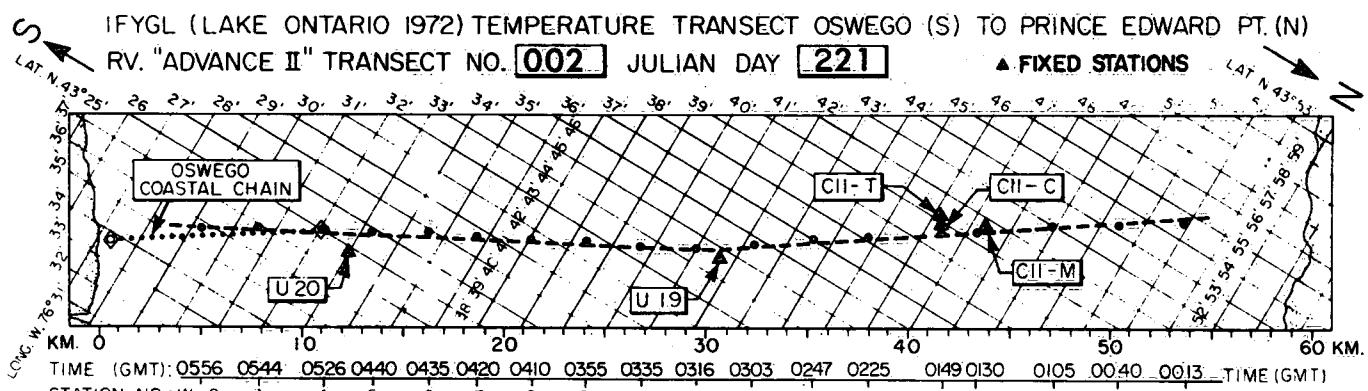


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **016** JULIAN DAY **210**



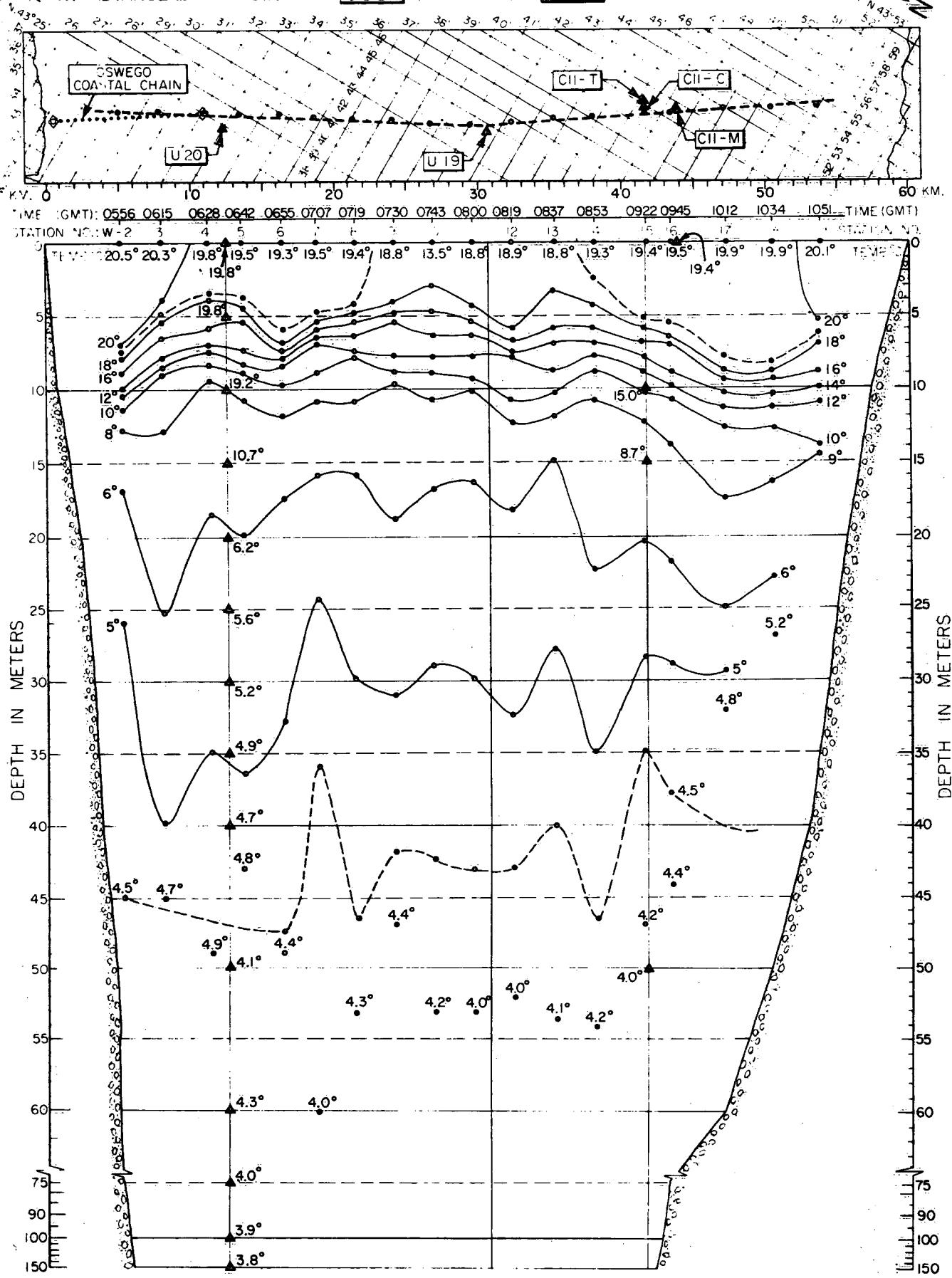
S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. 001 JULIAN DAY 220 ▲ FIXED STATIONS LAT. N 43°55' S 43°55'

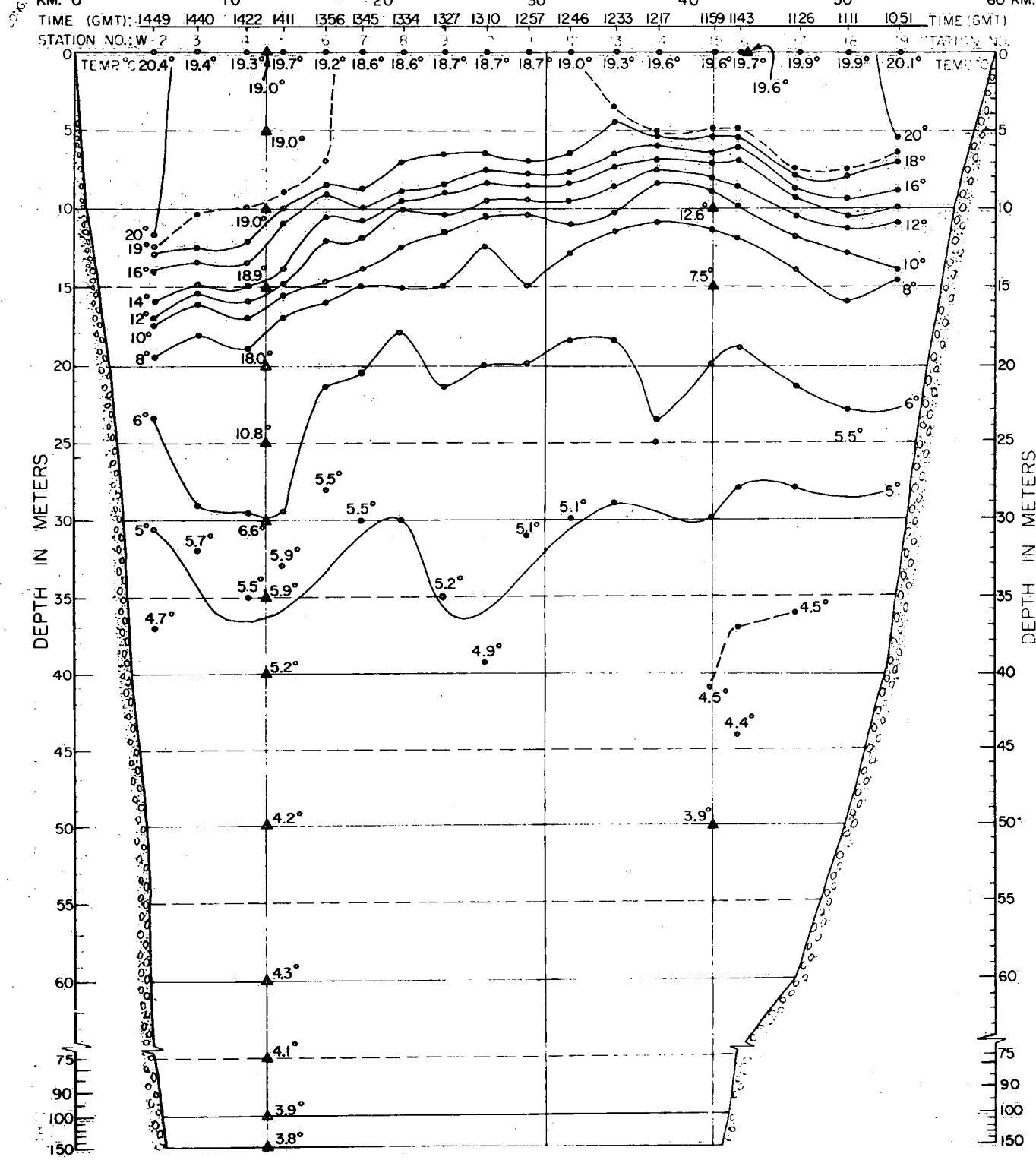
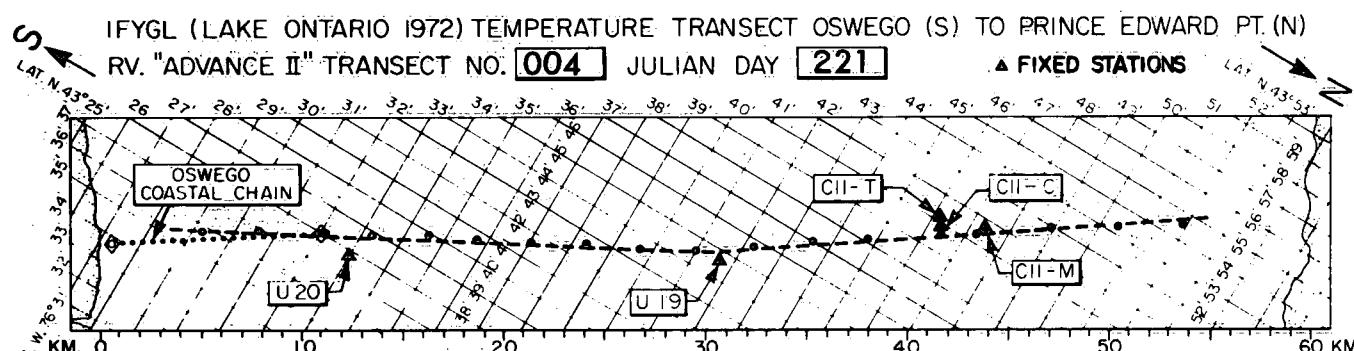




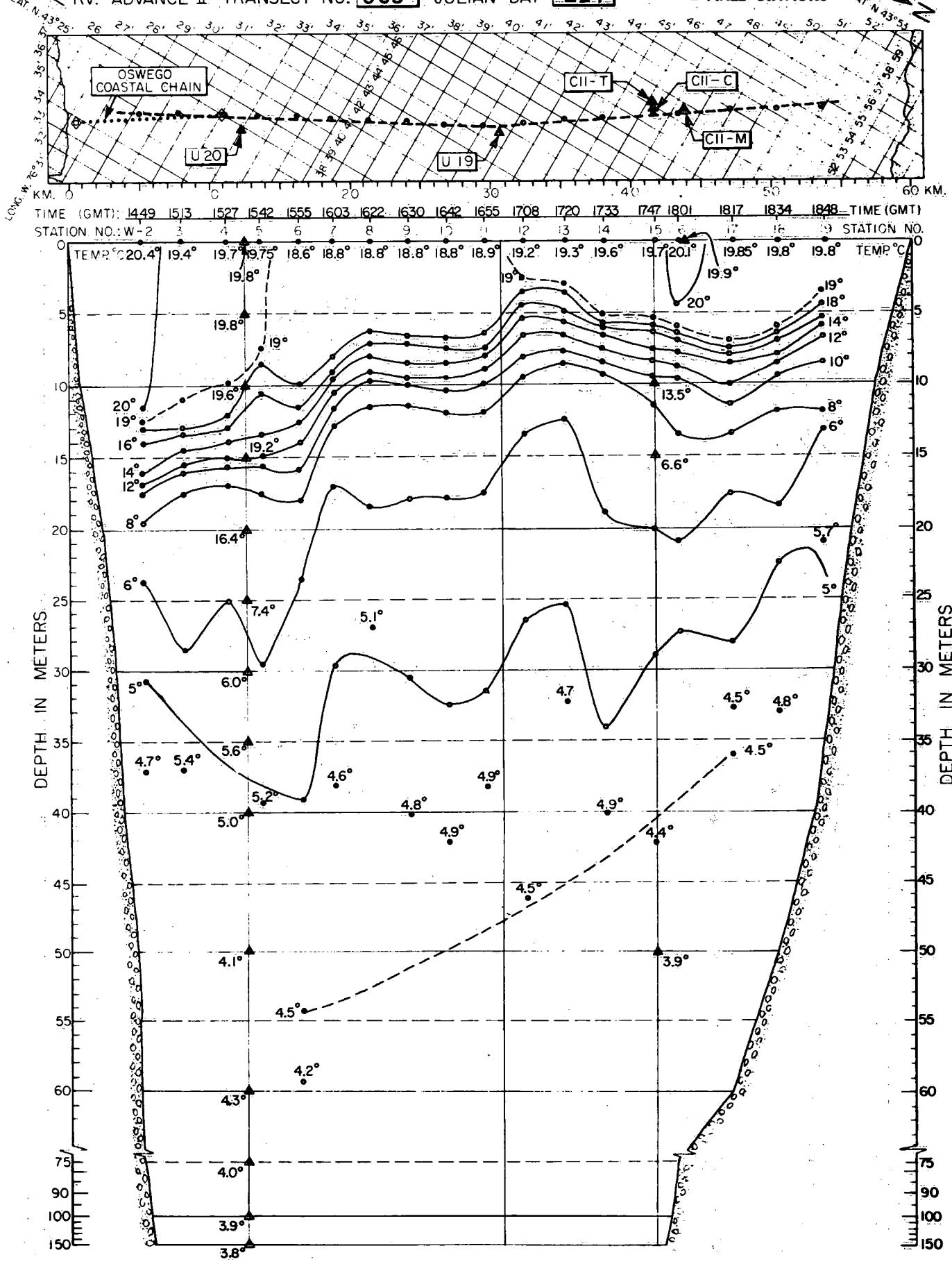
S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **003** JULIAN DAY **221**

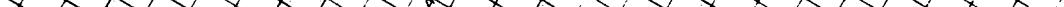
▲ FIXED STATIONS

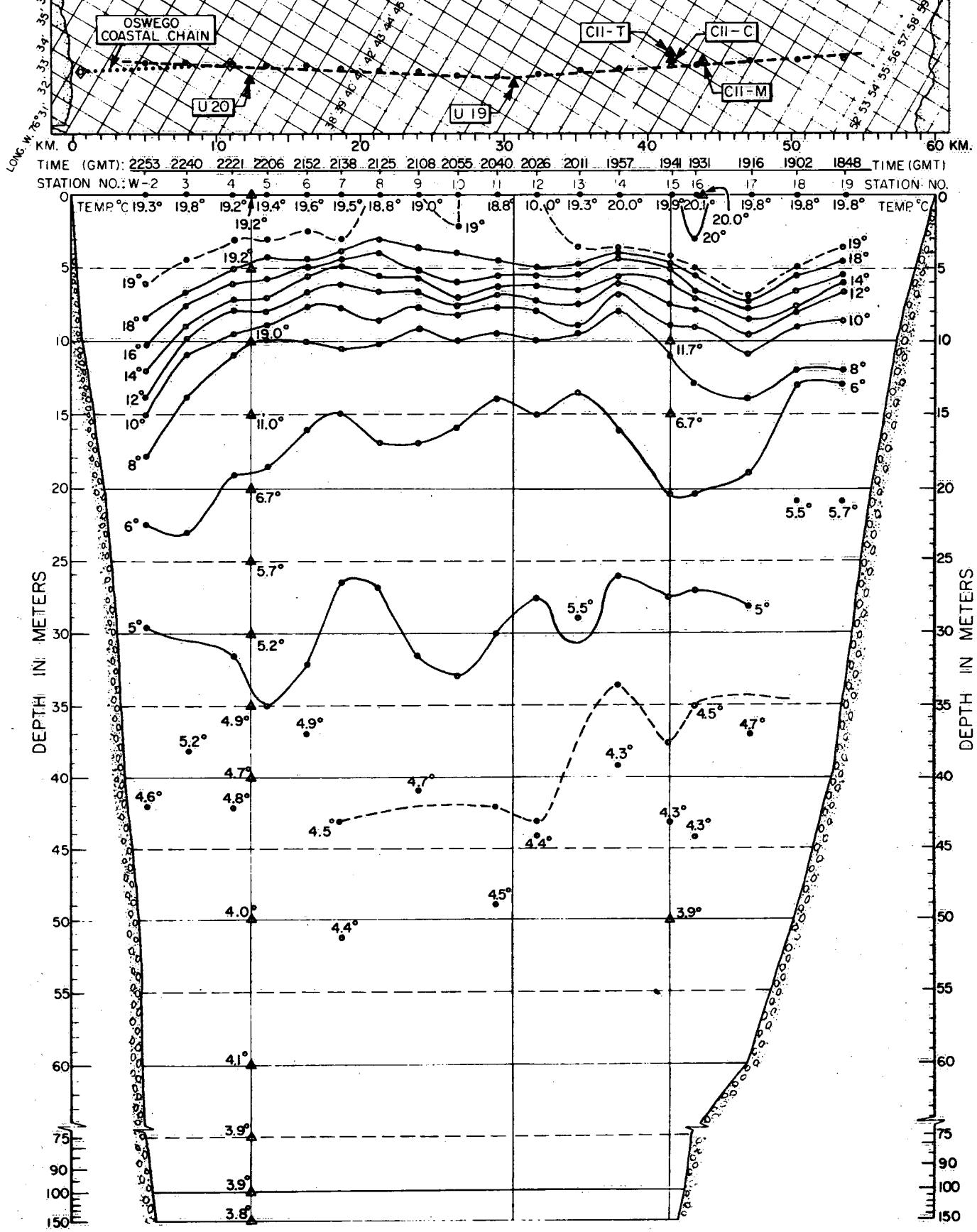




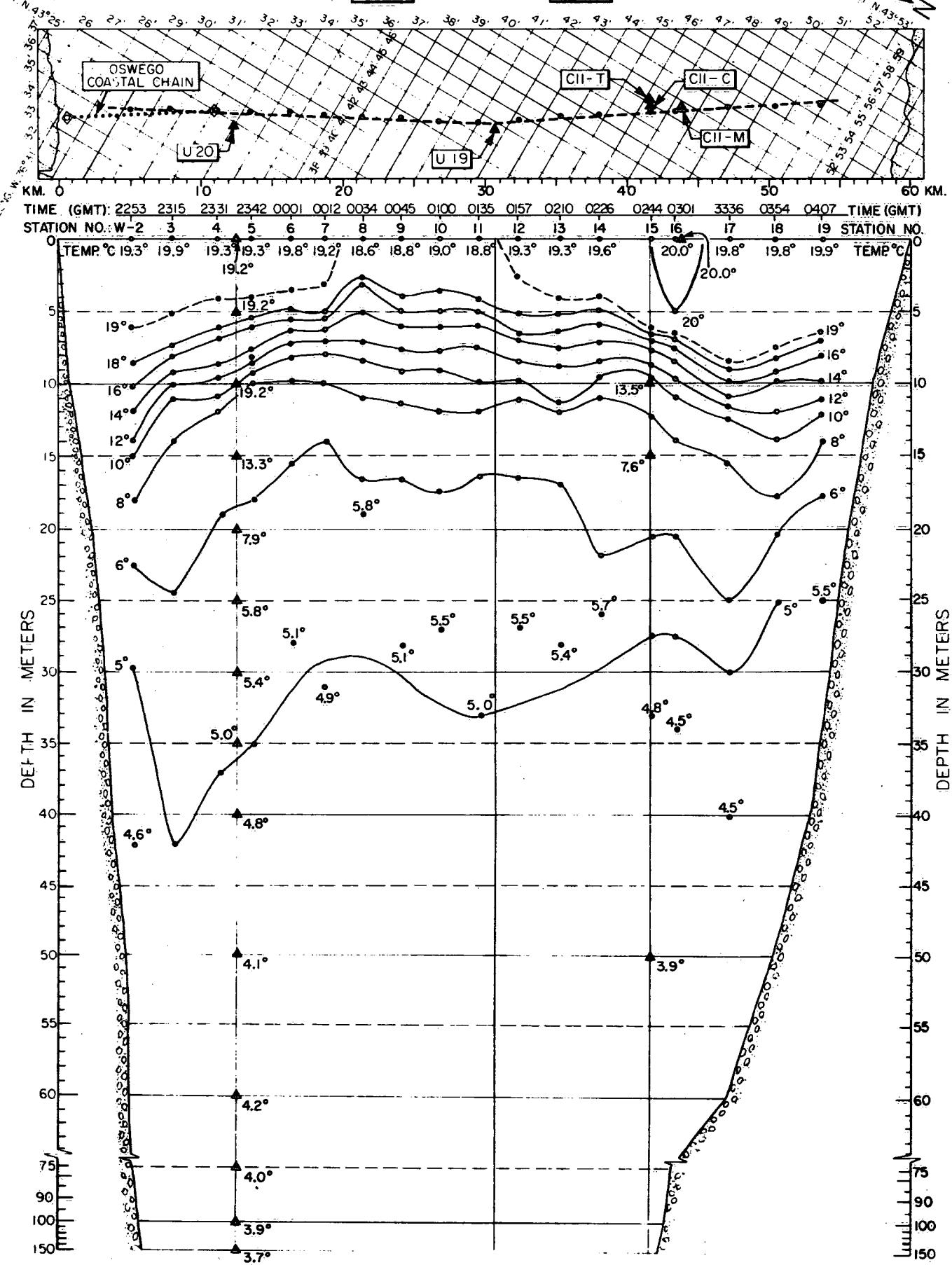
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **005** JULIAN DAY **221**

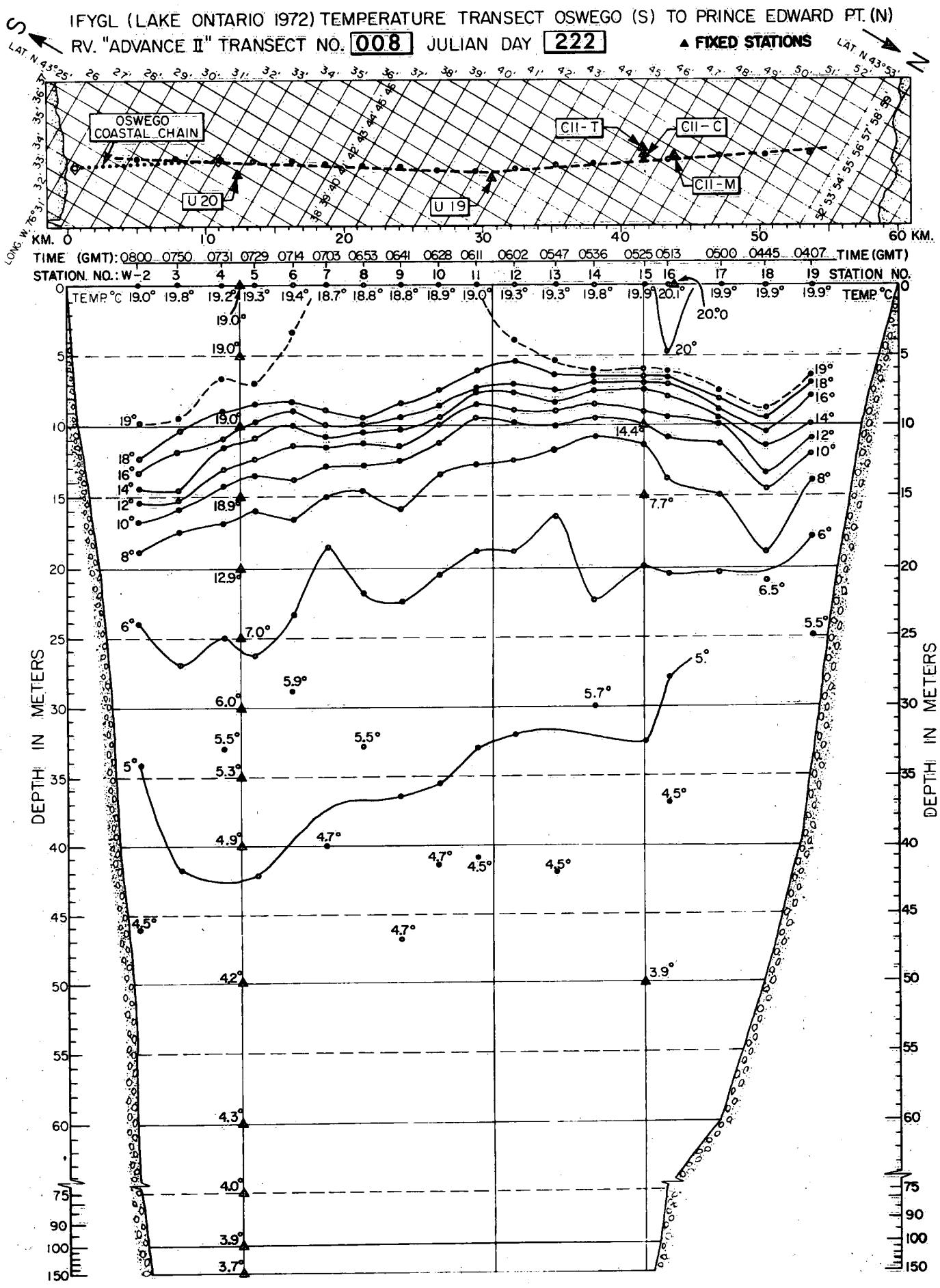


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **006** JULIAN DAY **221** ▲ FIXED STATIONS  
 LAT. N 43° 53' 41" N 43° 53' 52" S 43° 53' 52"  


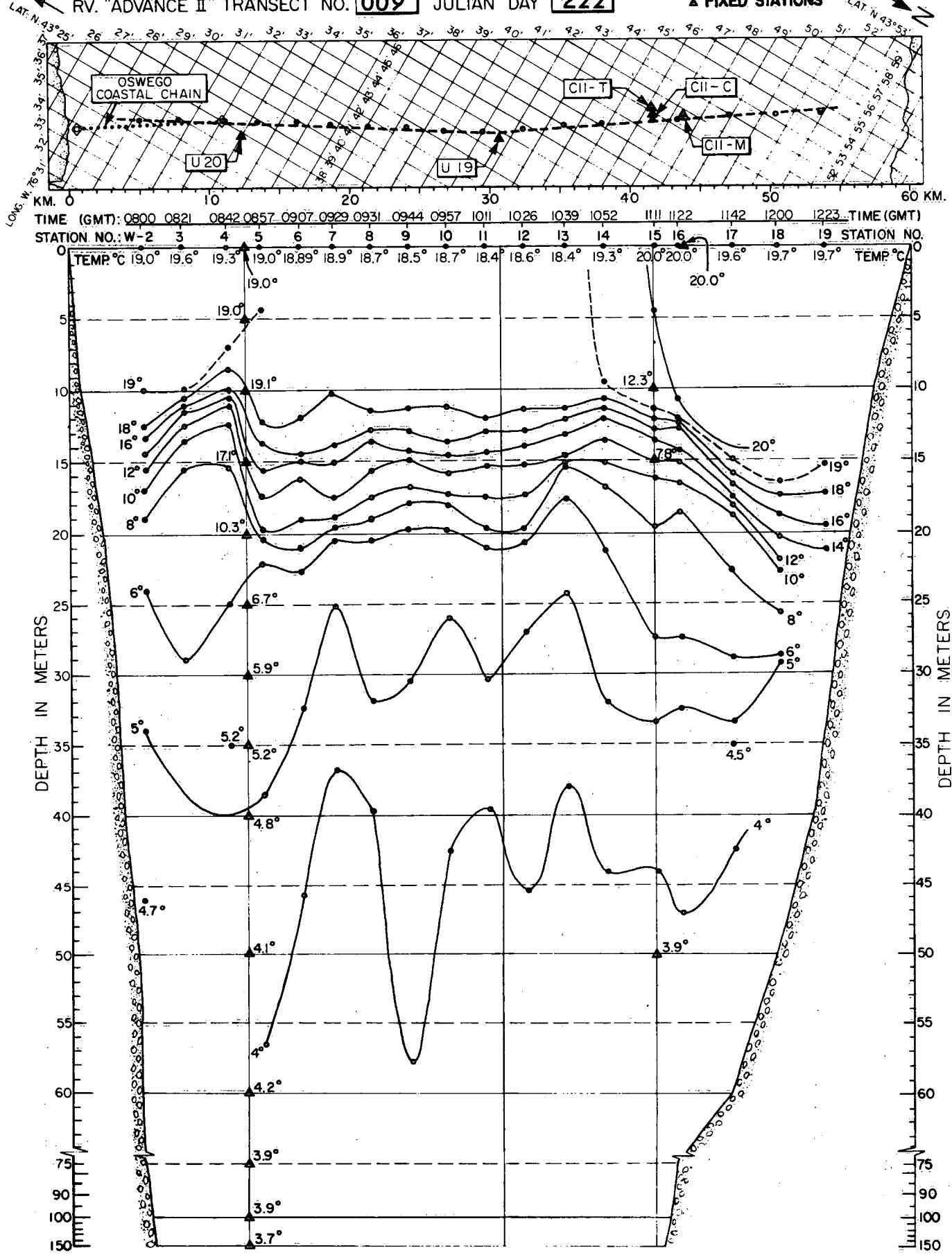


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. 007 JULIAN DAY 221 ▲ FIXED STATIONS LAT N

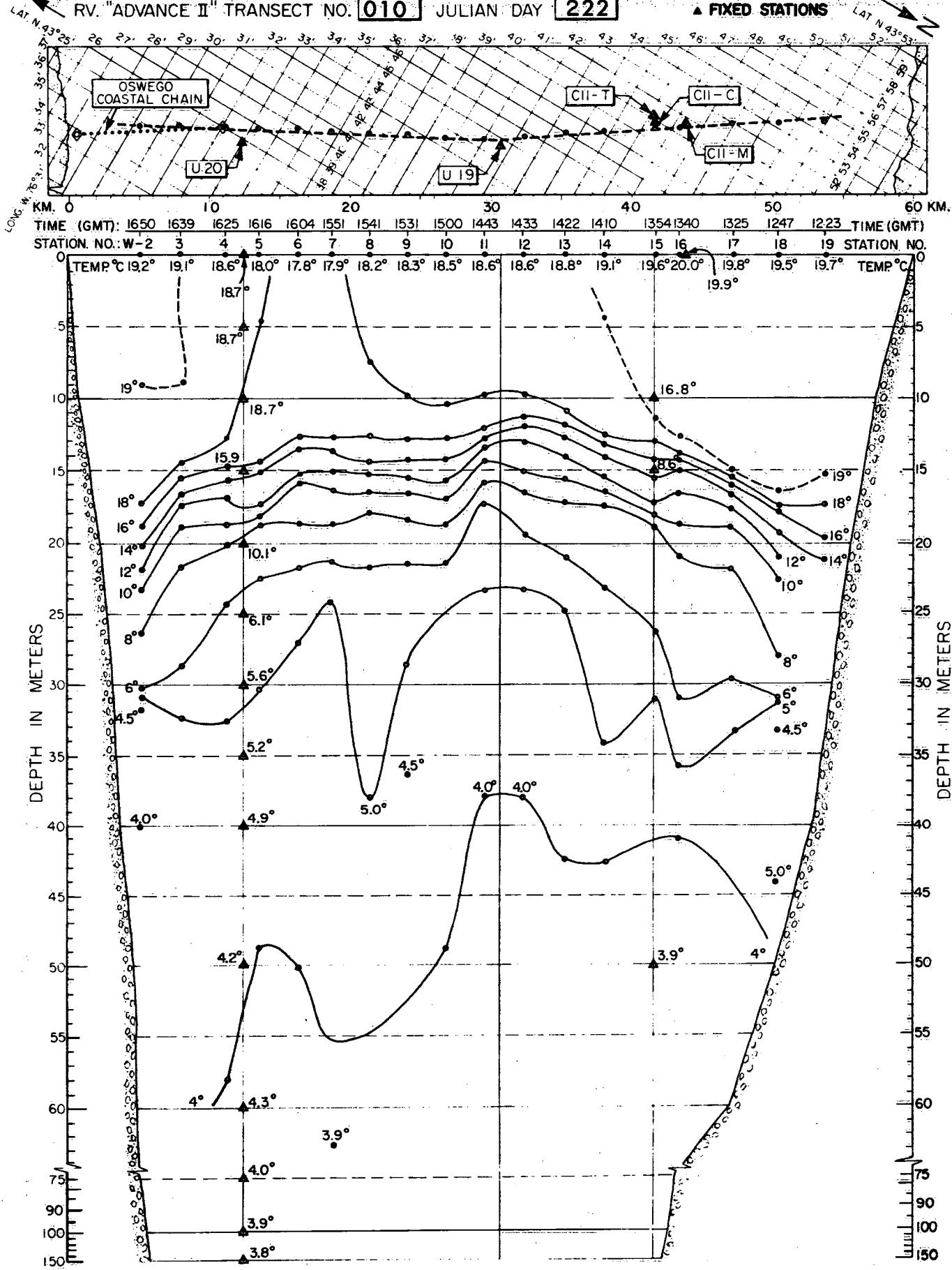




IF YGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **009** JULIAN DAY **222**



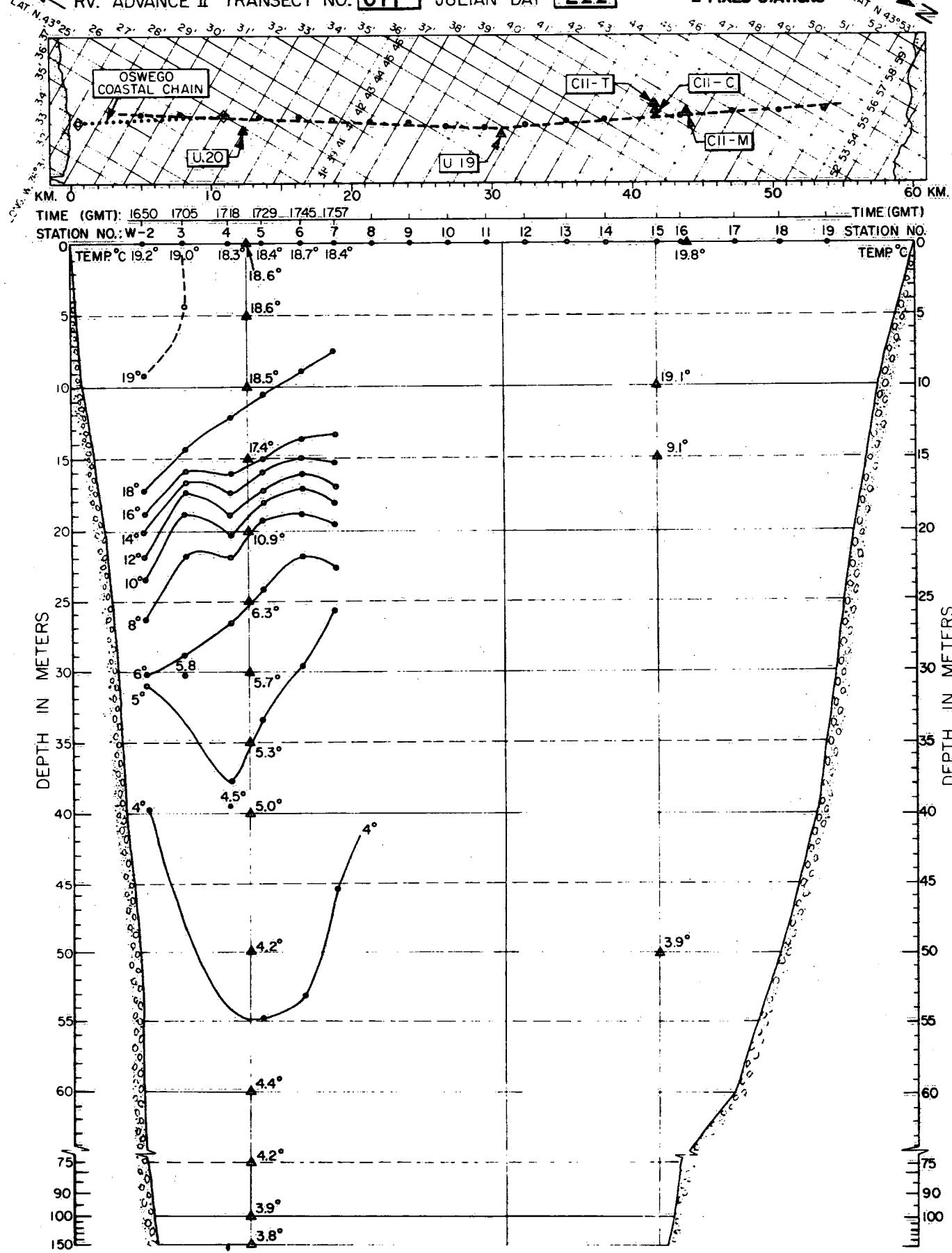
S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV "ADVANCE II" TRANSECT NO: 010 JULIAN DAY 222 ▲ FIXED STATIONS



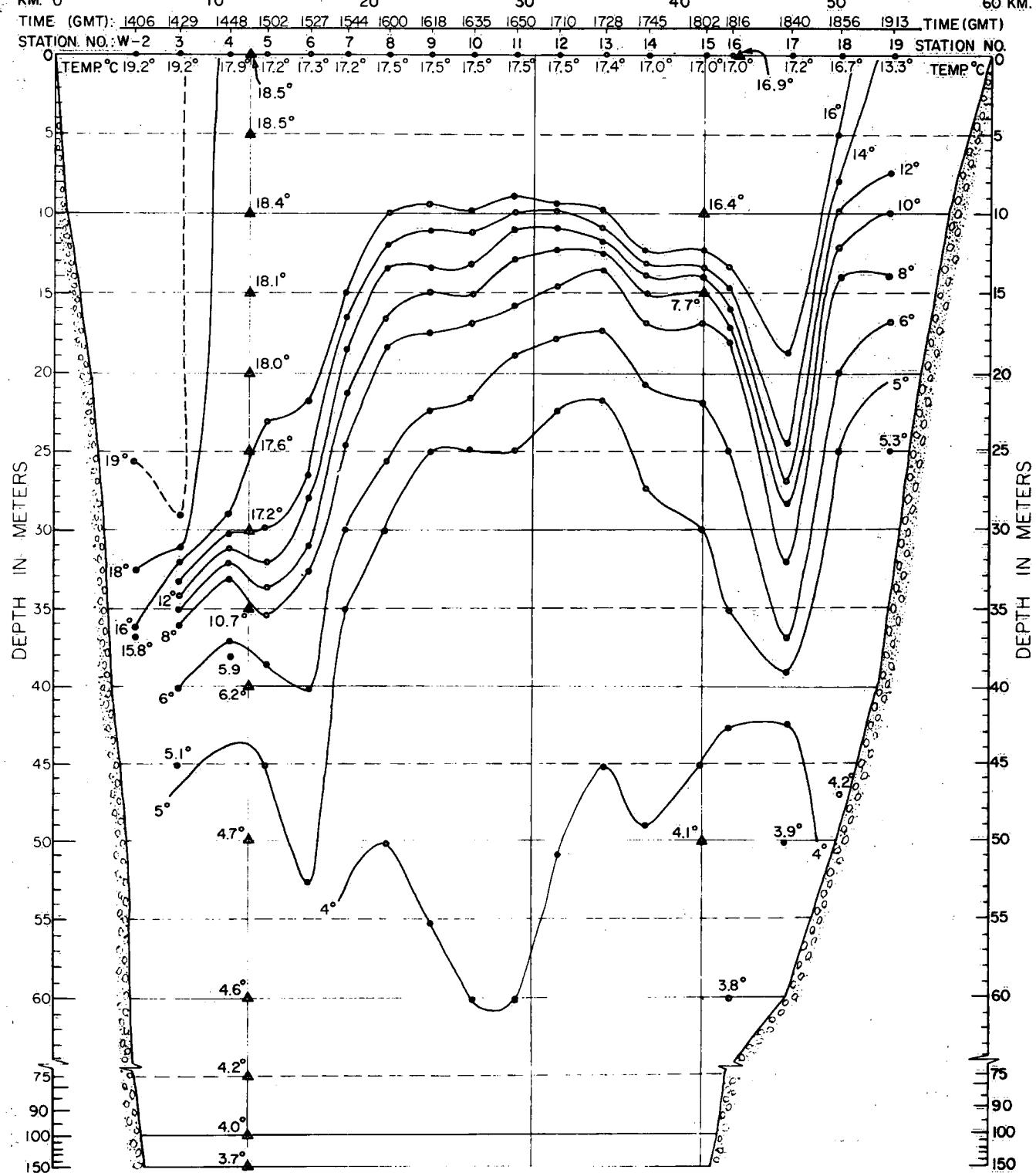
IIFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT (N)

RV. "ADVANCE II" TRANSECT NO. 011 JULIAN DAY 222

▲ FIXED STATIONS



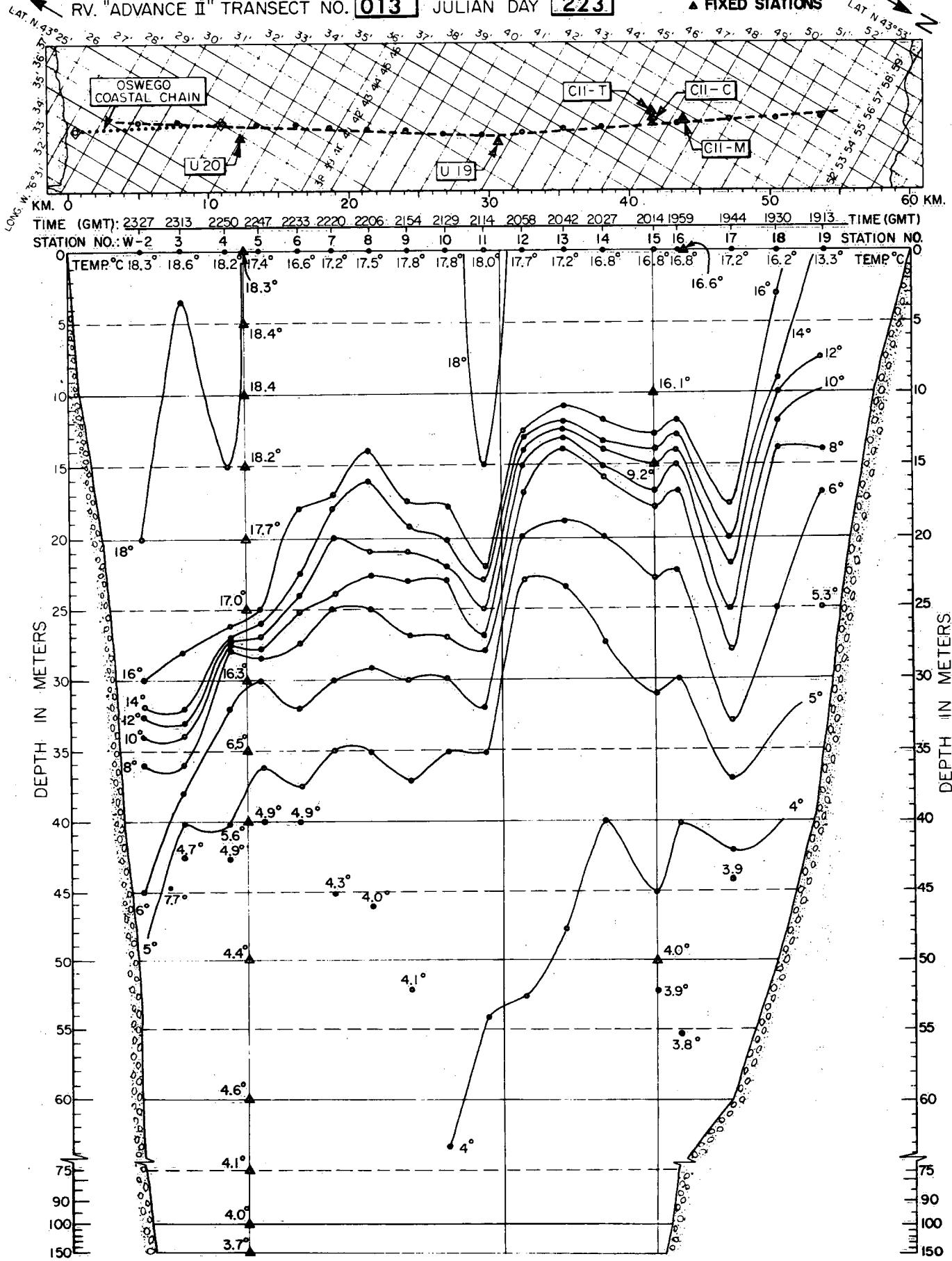
Map showing transect routes from Oswego to Prince Edward Point. The map includes latitude and longitude coordinates, a scale bar, and labels for fixed stations CII-T, CII-C, and CII-M.



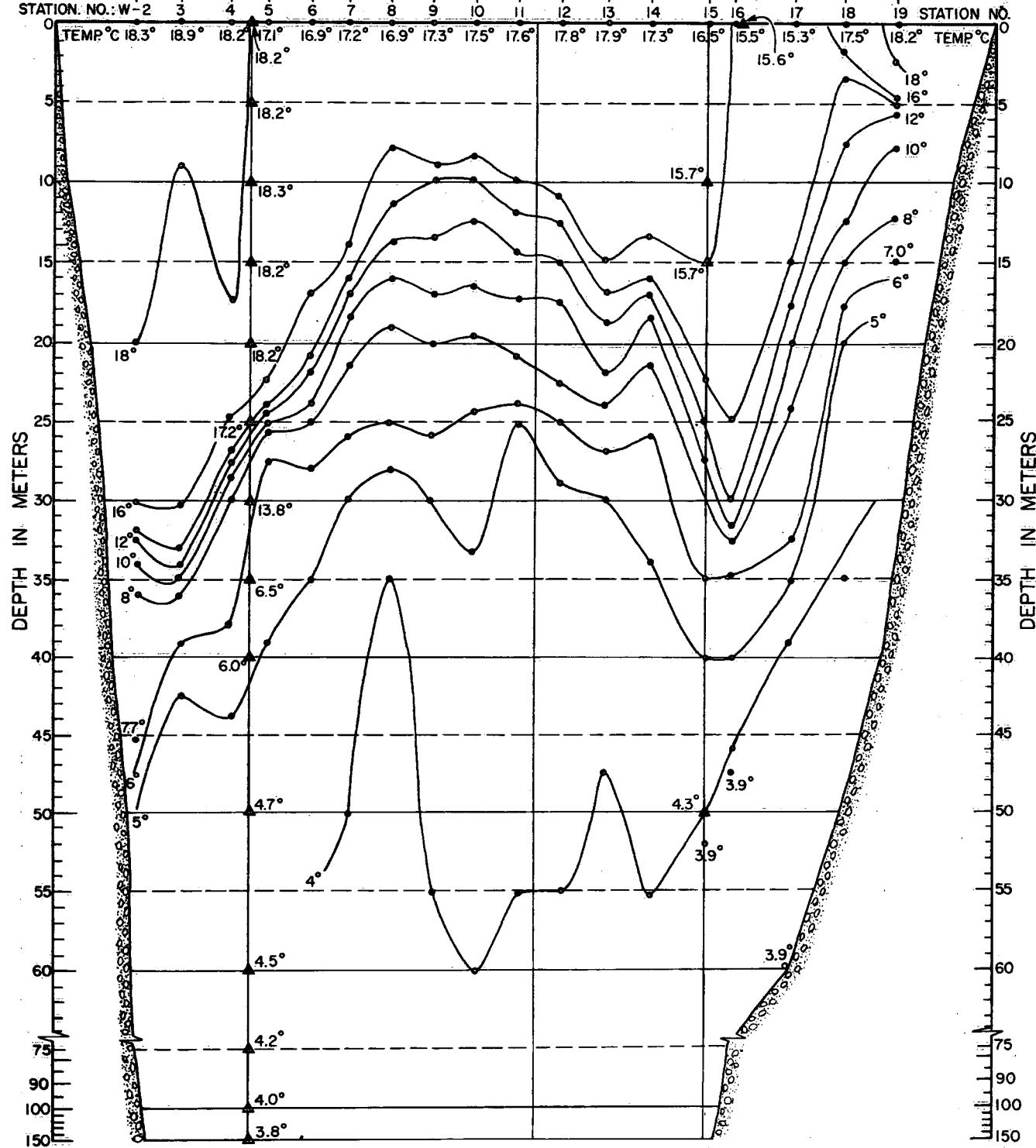
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)

RV. "ADVANCE II" TRANSECT NO. **013** JULIAN DAY **223**

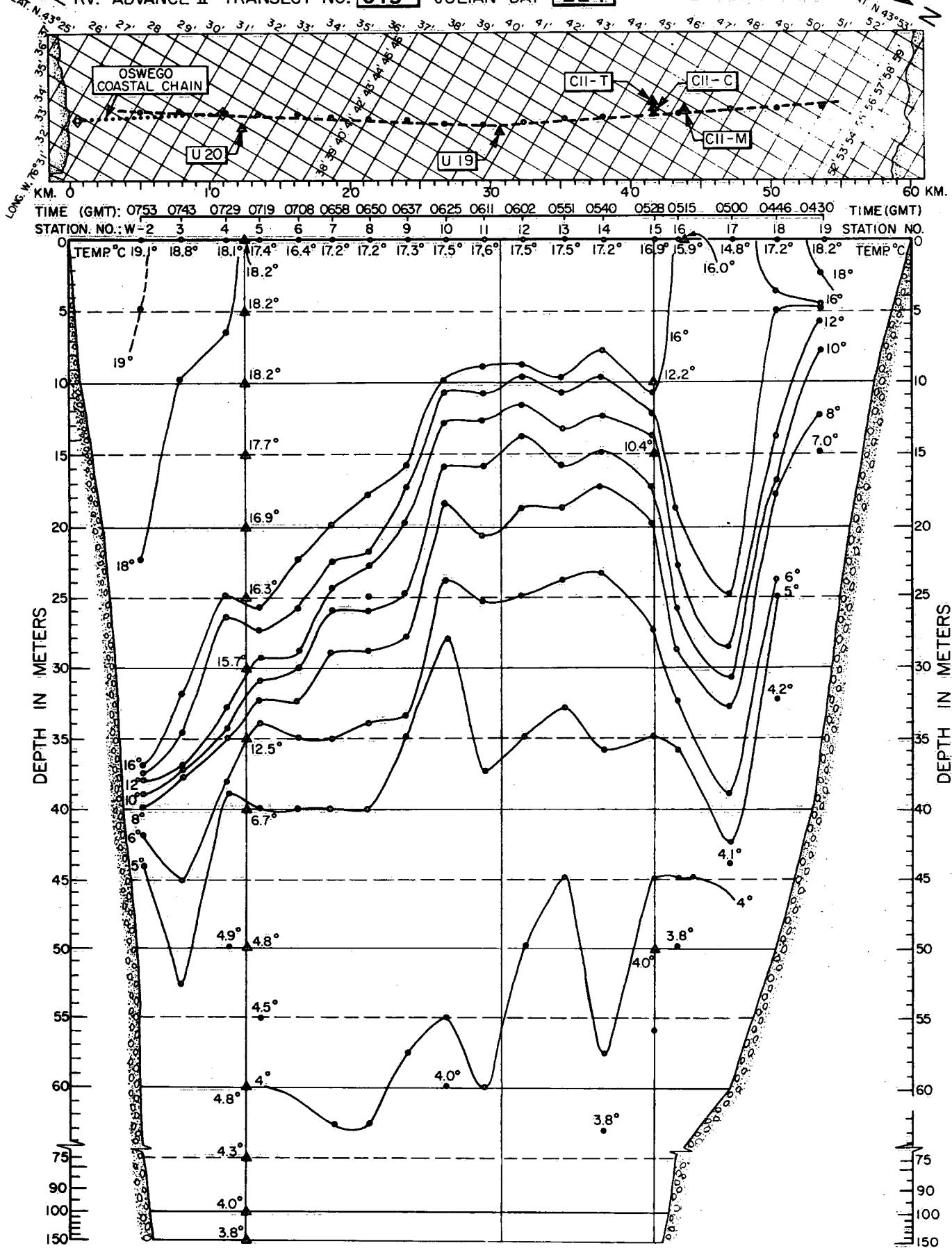
▲ FIXED STATIONS

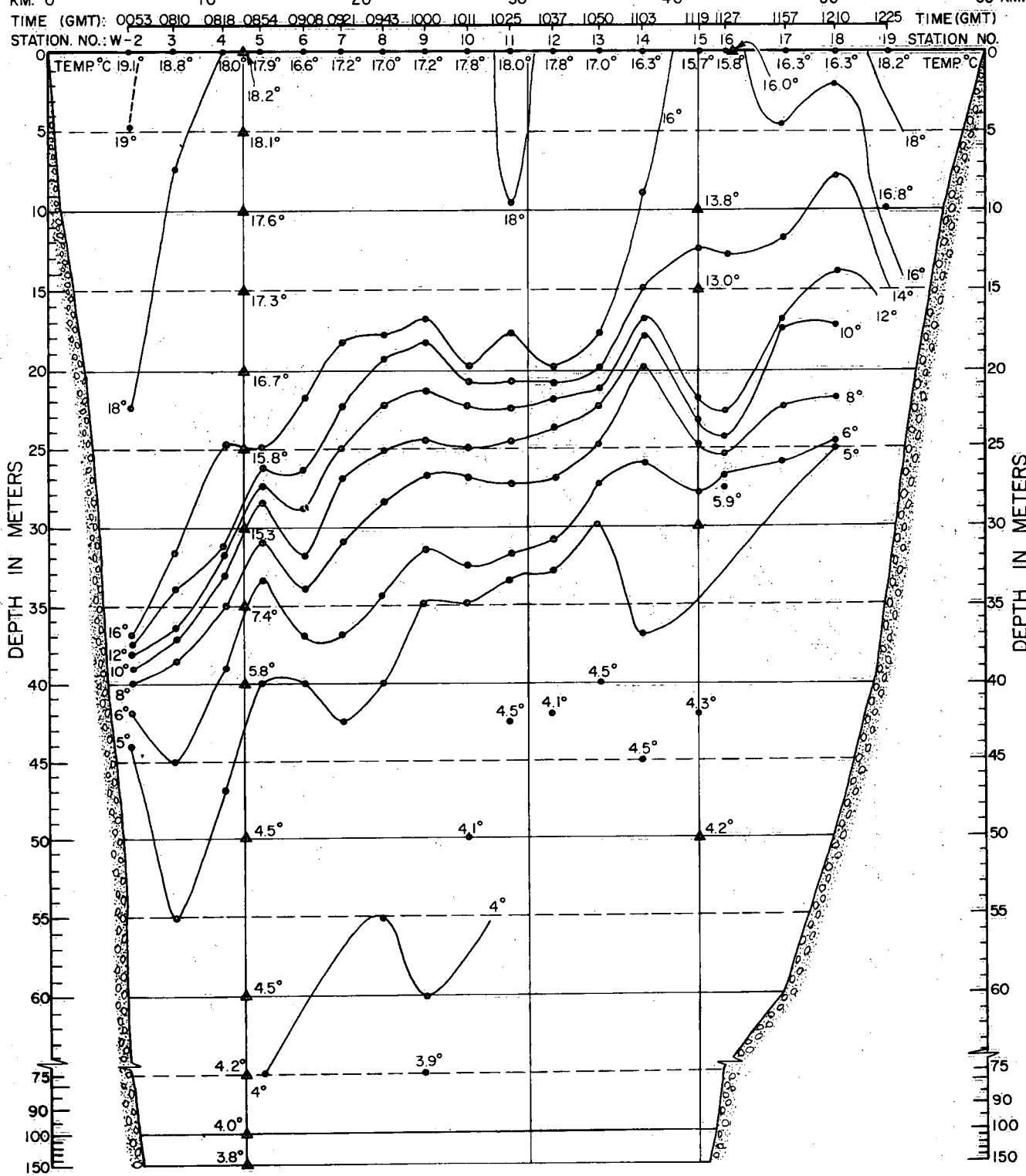
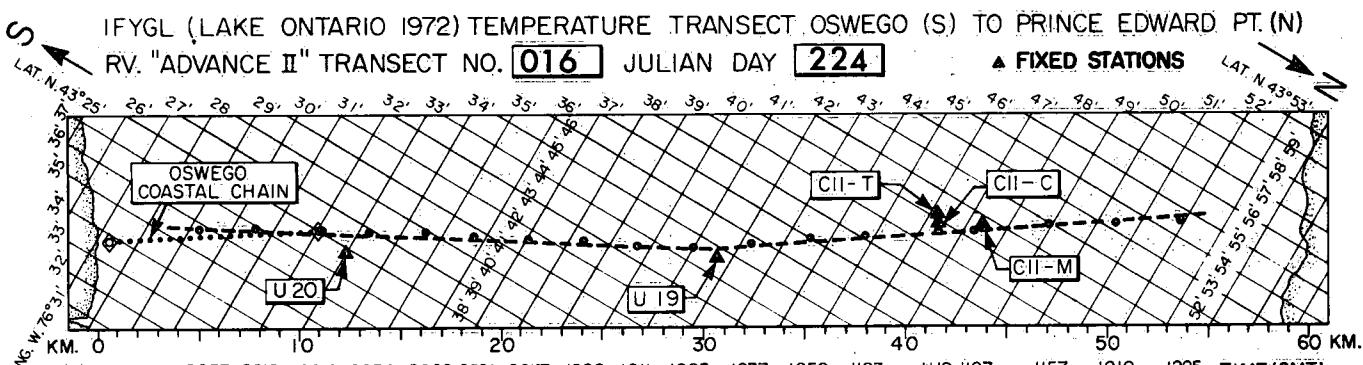


Map showing the IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N). The map displays a grid of latitude (43° 30' N to 43° 55' N) and longitude (75° 30' W to 75° 55' W). A dashed line represents the transect route, starting at U20 near Oswego and ending at CII-T, CII-C, and CII-M near Prince Edward Pt. Fixed stations are marked along the route. The map also includes labels for the Oswego Coastal Chain and various station identifiers like U19, U20, CII-T, CII-C, and CII-M.



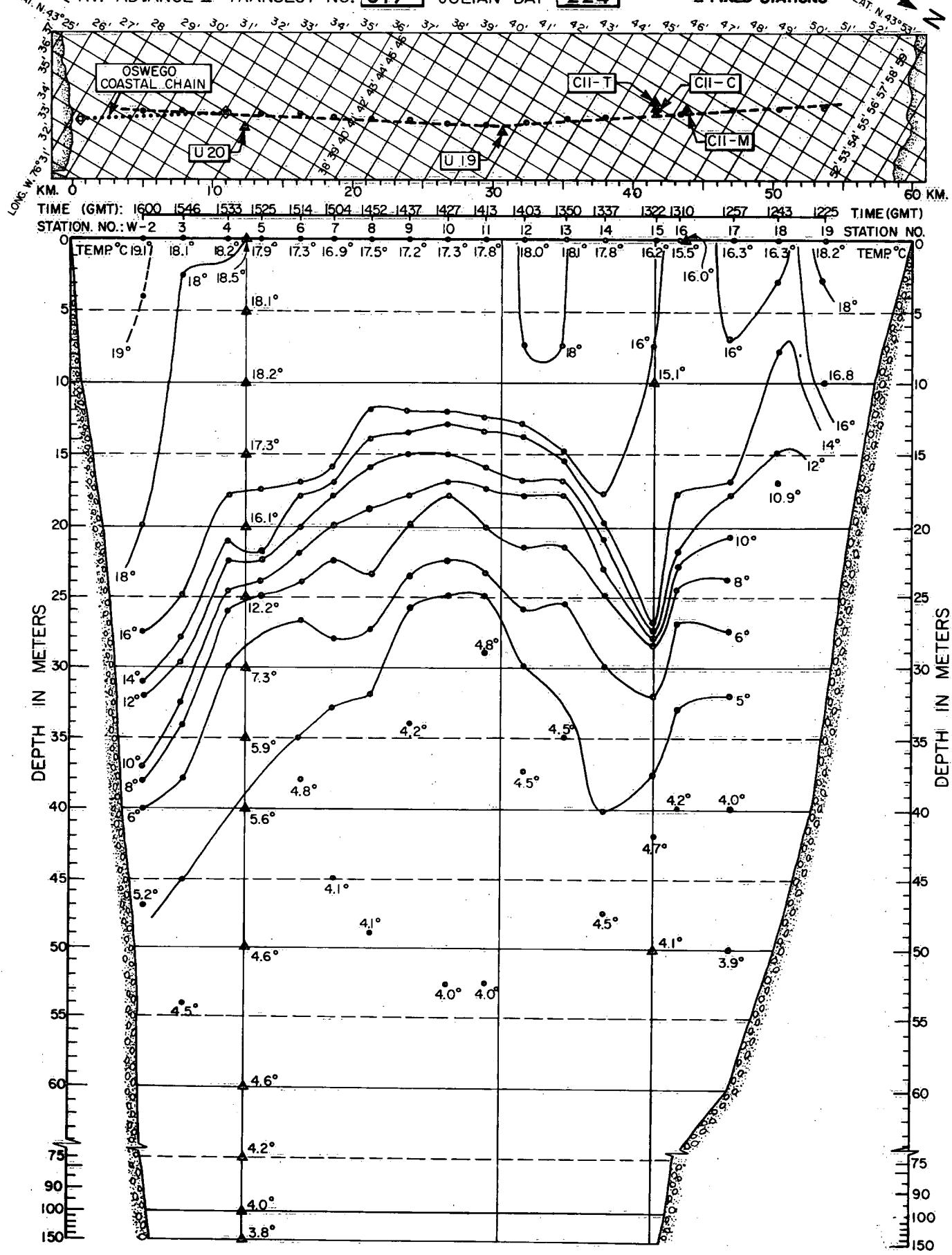
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 015 JULIAN DAY 224



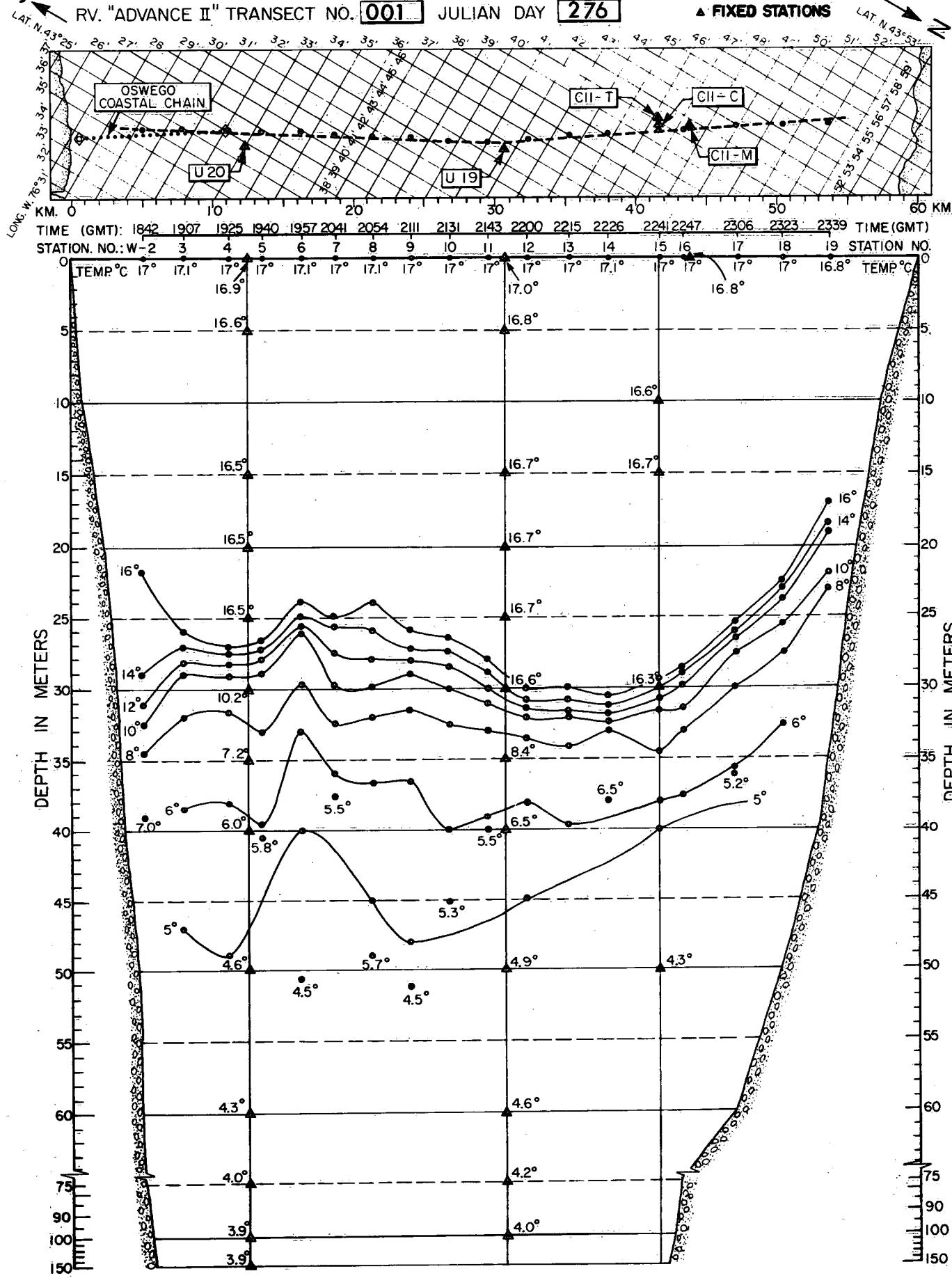


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 LAT. N 43° 25' 26' 27' 28' 29' 30' 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47' 48' 49' 50' 51' 52' 53'  
 RV. "ADVANCE II" TRANSECT NO. 017 JULIAN DAY 224

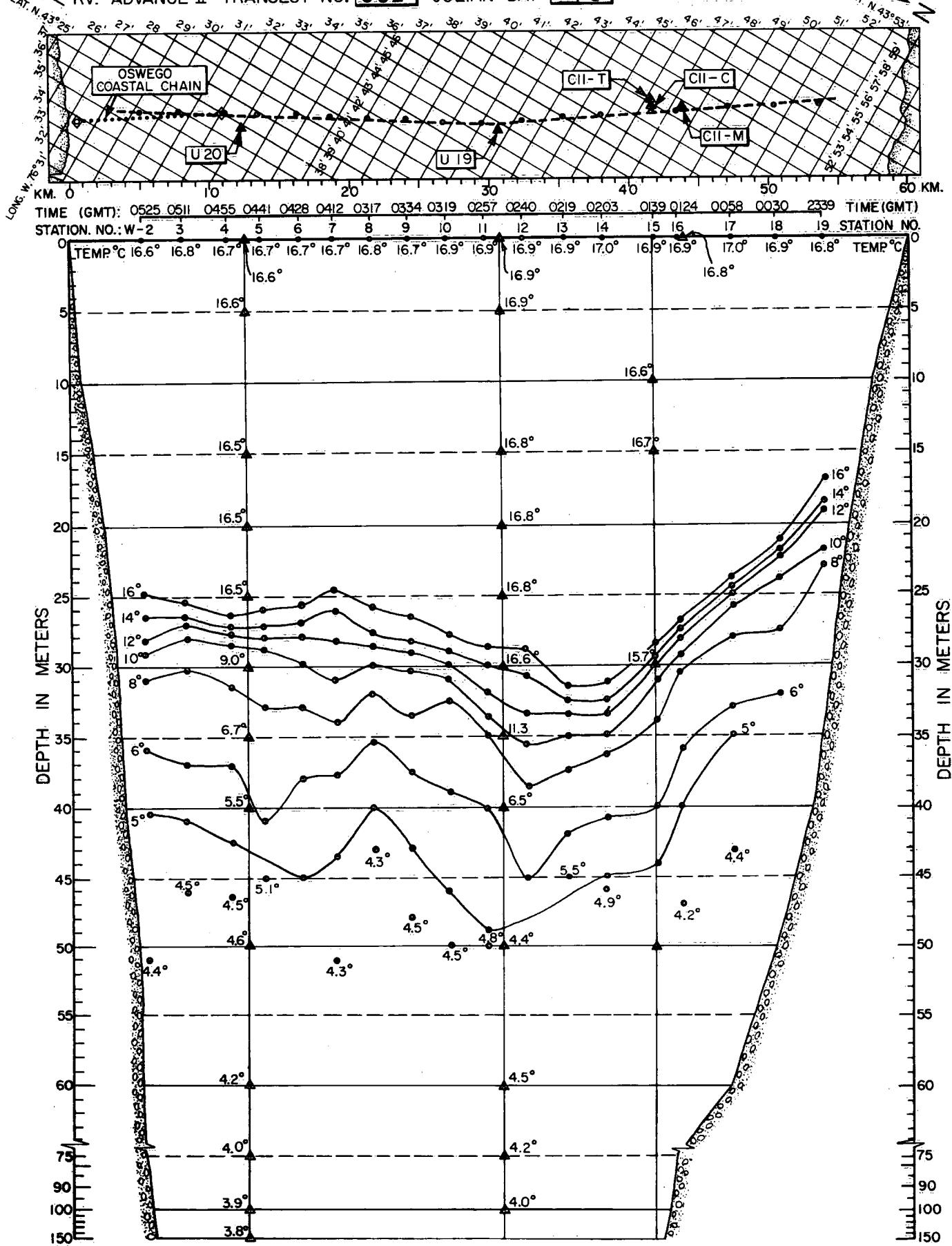
▲ FIXED STATIONS

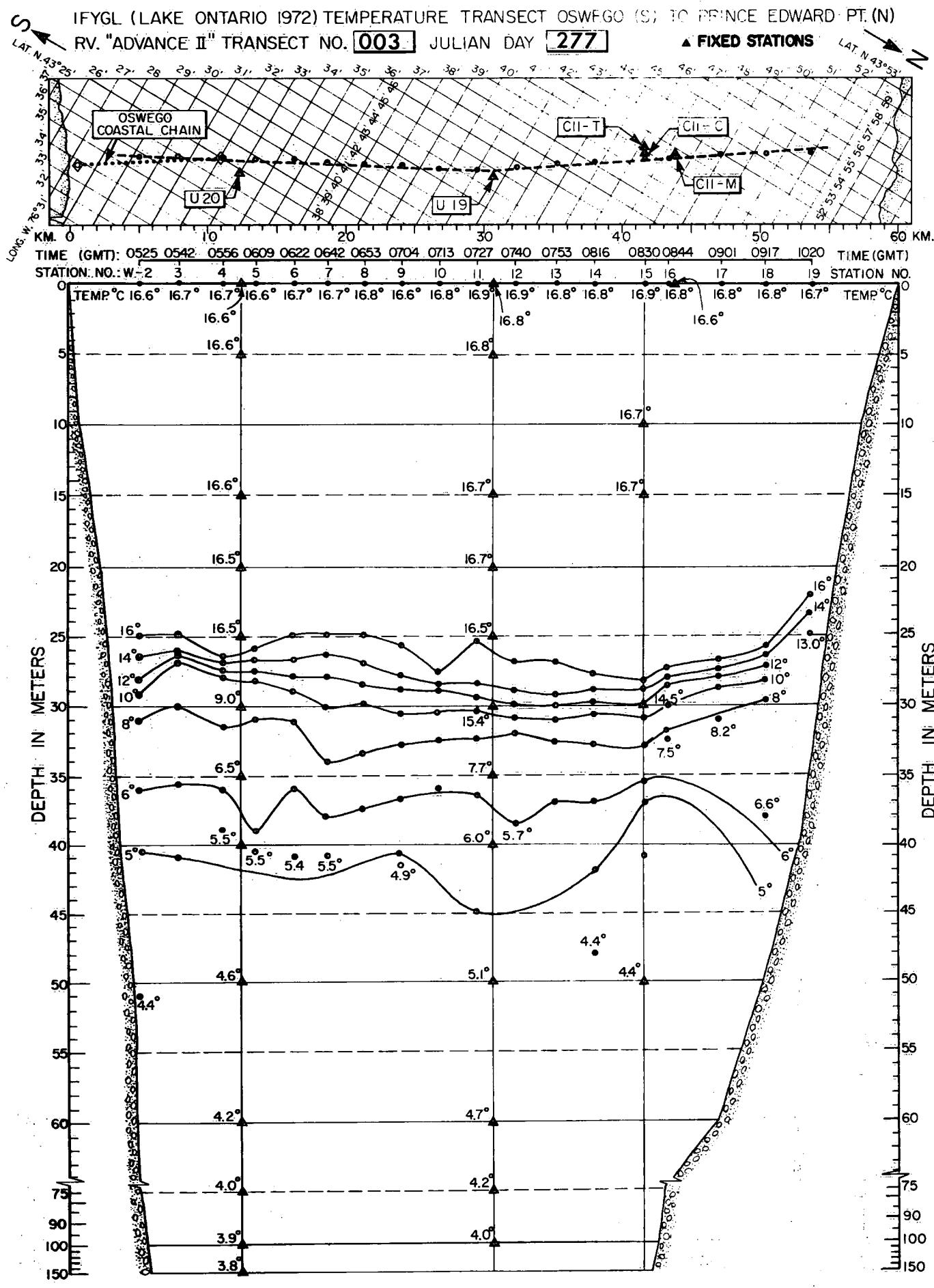


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)

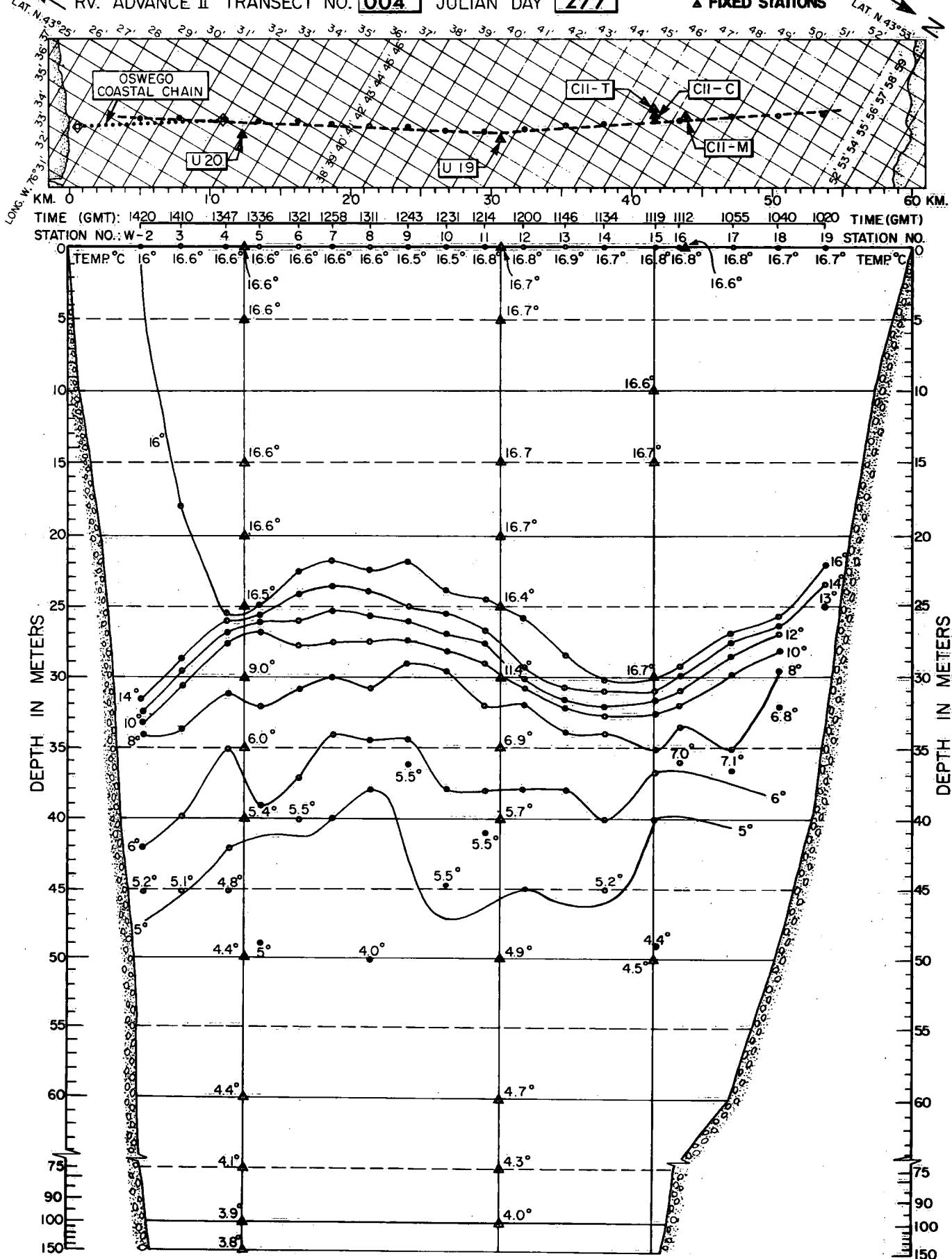


S  
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. 002 JULIAN DAY 276

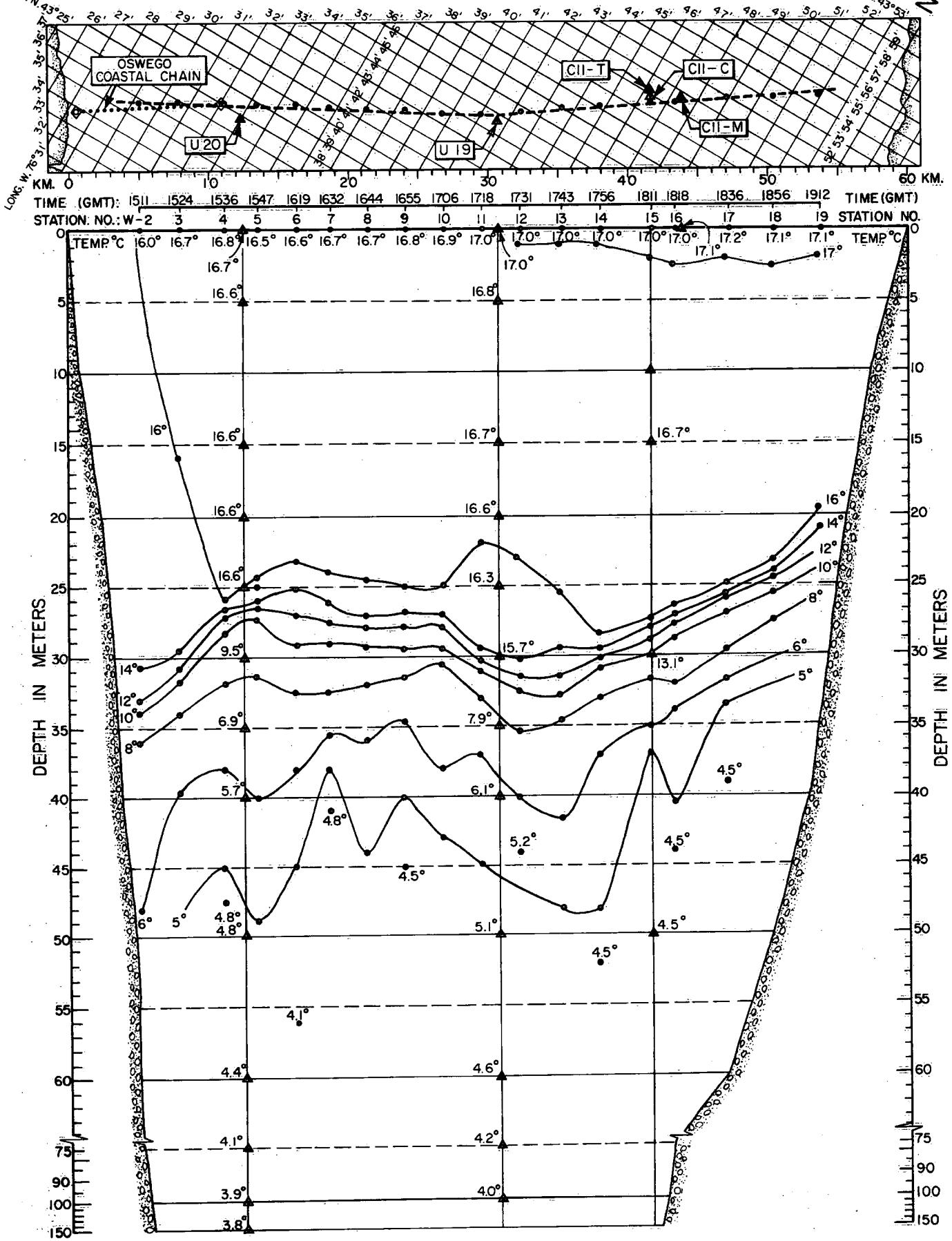




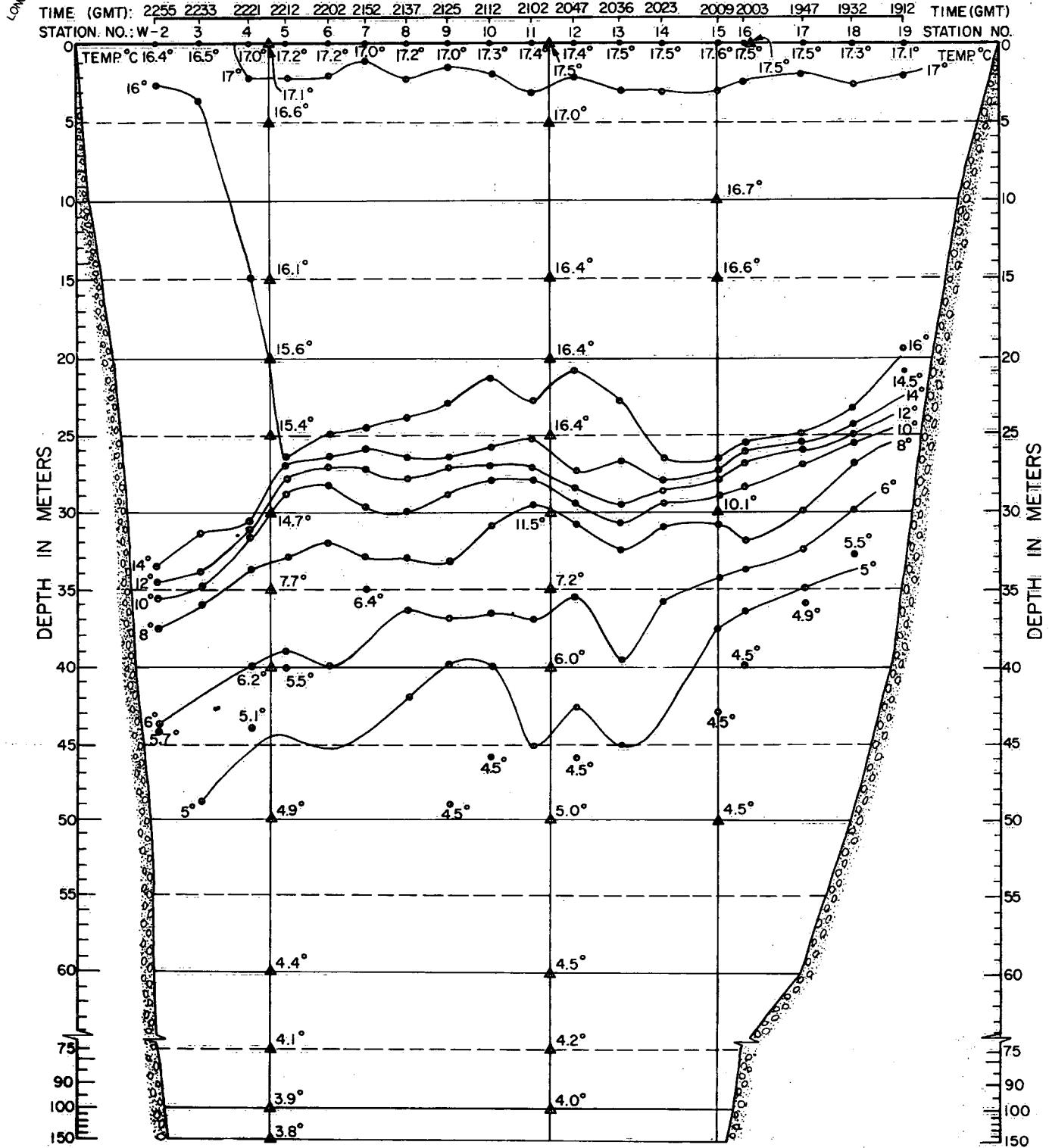
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 004 JULIAN DAY 277

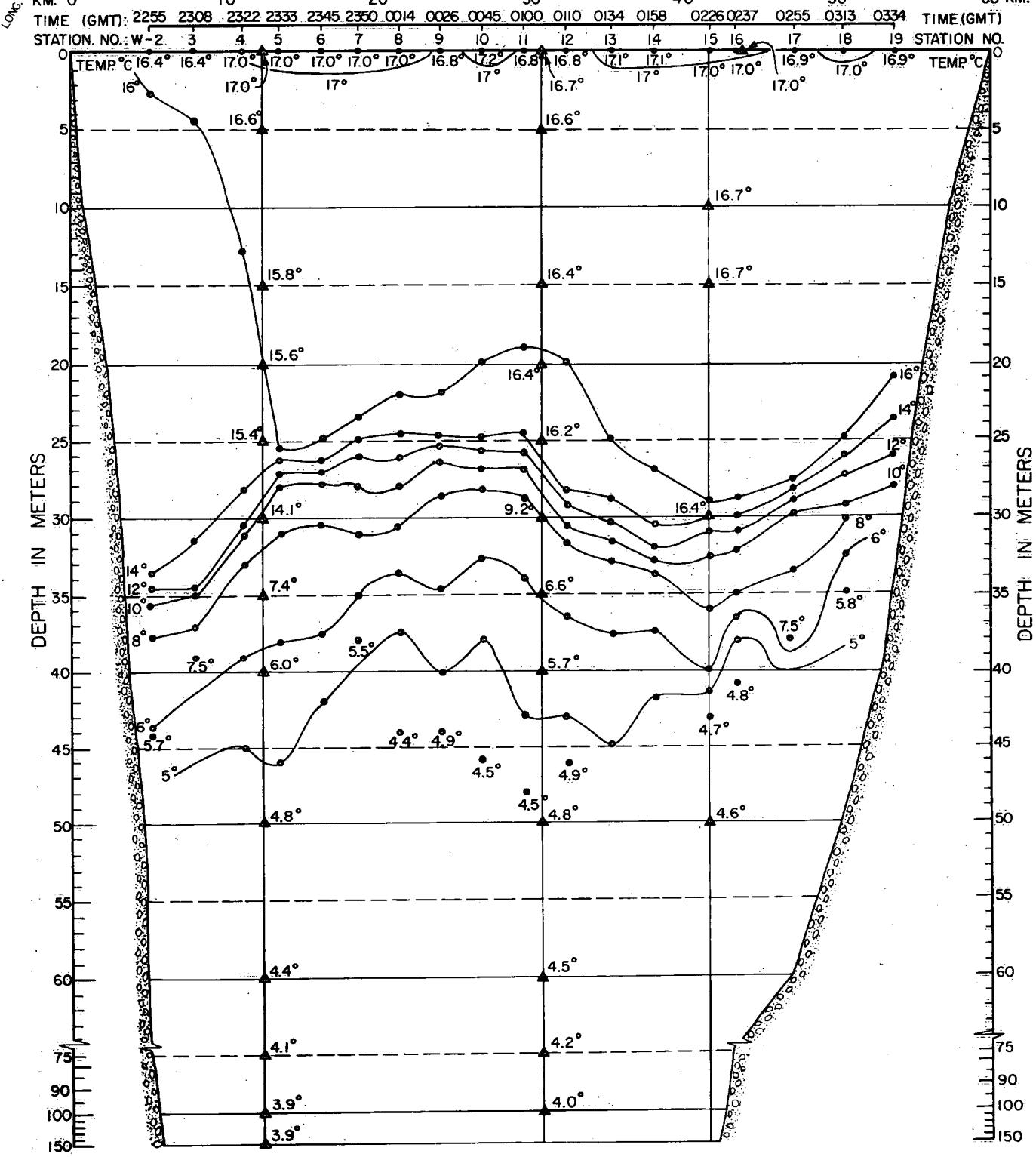
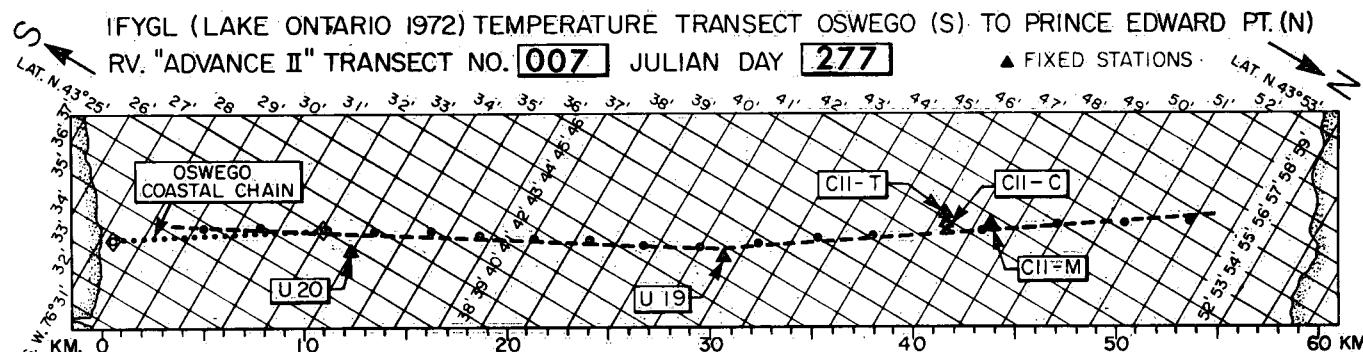


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV. "ADVANCE II" TRANSECT NO. 005 JULIAN DAY 277 ▲ FIXED STATIONS LAT. N. 43° 20' S



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **006** JULIAN DAY **277** ▲ FIXED STATIONS  
 LAT. N 43° 25' 26' 27' 28' 29' 30' 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47' 48' 49' 50' 51' 52' 53'  
 LONG. W 76° 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47' 48' 49' 50' 51' 52' 53' 54' 55' 56' 57' 58' 59'  
 KM. 0 10 20 30 40 50 60 K.M.  
 OSWEGO COASTAL CHAIN  
 U20 U19 CII-T CII-C CII-M



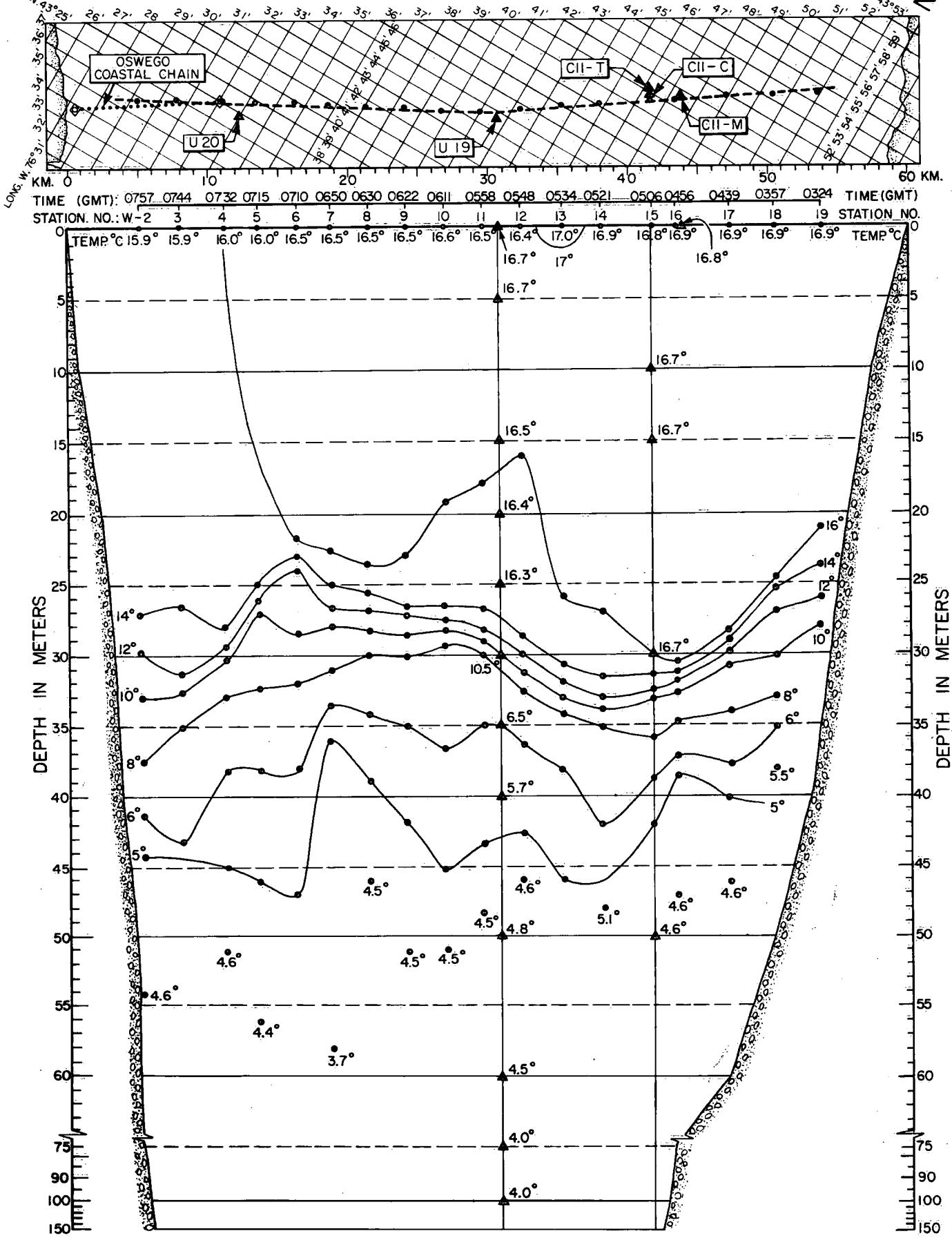


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV. "ADVANCE II" TRANSECT NO. **008** JULIAN DAY **278** ▲ FIXED STATIONS LAT. N. **44° 45' 00"**

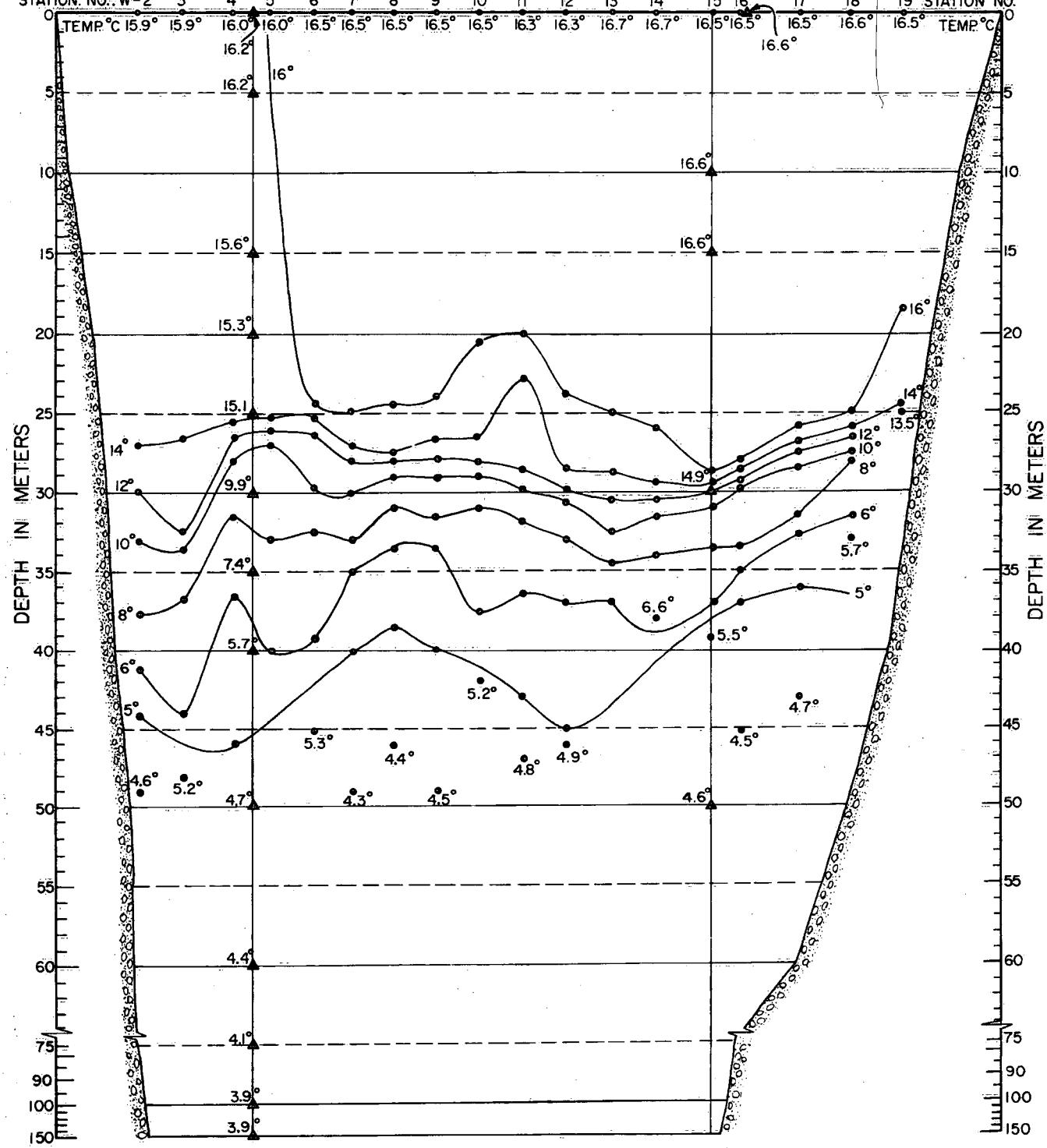
AT N RV. "ADVANCE II" TRANSECT NO. 008 JULIAN DAY 278

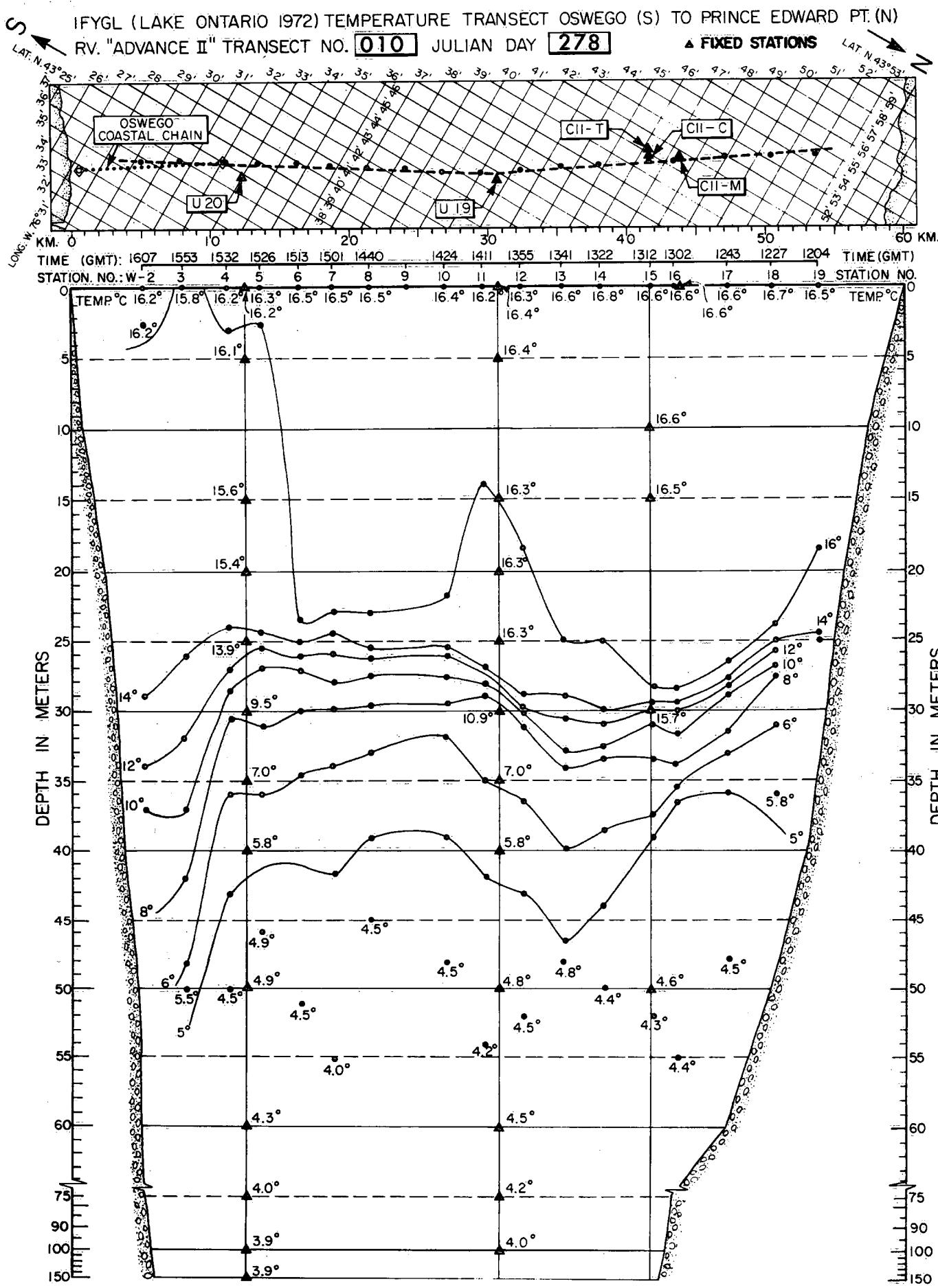
N 43°26' 20" E 2°22' 20" S 20°30' 30" E 11°32' 32" S 2°35' 35" E 1°37' 38" S 0°39' 40" E 0°41' 42" S 0°43' 43"

▲ FIXED STATIONS



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 009 JULIAN DAY 278 ▲ FIXED STATIONS  
 LAT. N. 43° 25' 26' 27' 28' 29' 30' 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45'  
 LONG. W. 76° 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47' 48' 49' 50' 51' 52' 53'  
 KM. 0 10 20 30 40 50 60  
 TIME (GMT): 0757 0816 0834 0844 0857 0907 0921 0934 0946 1000 1015 1028 1040 1054 1101 1126 1140 1204 TIME (GMT)  
 STATION NO.: W-2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 STATION NO.

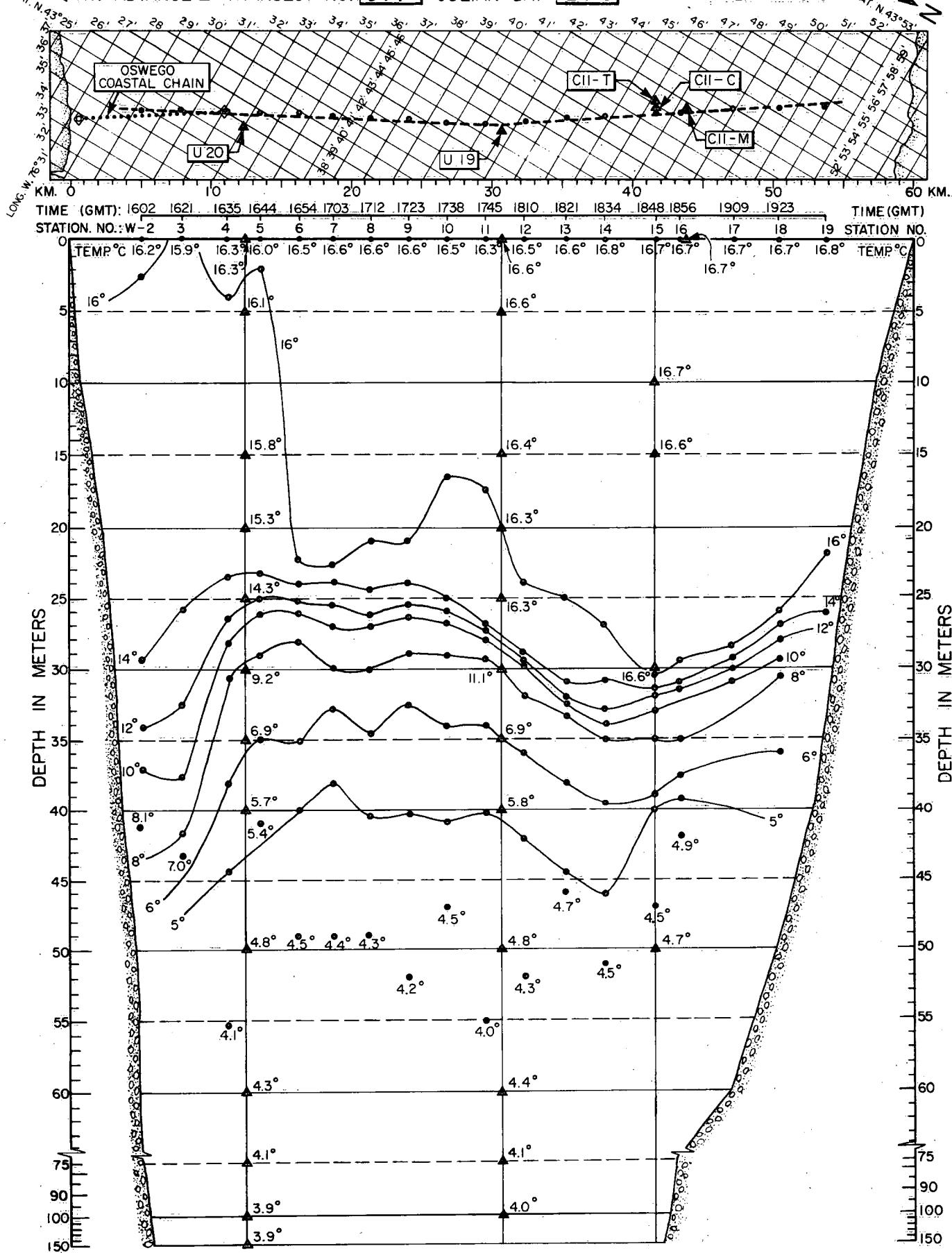




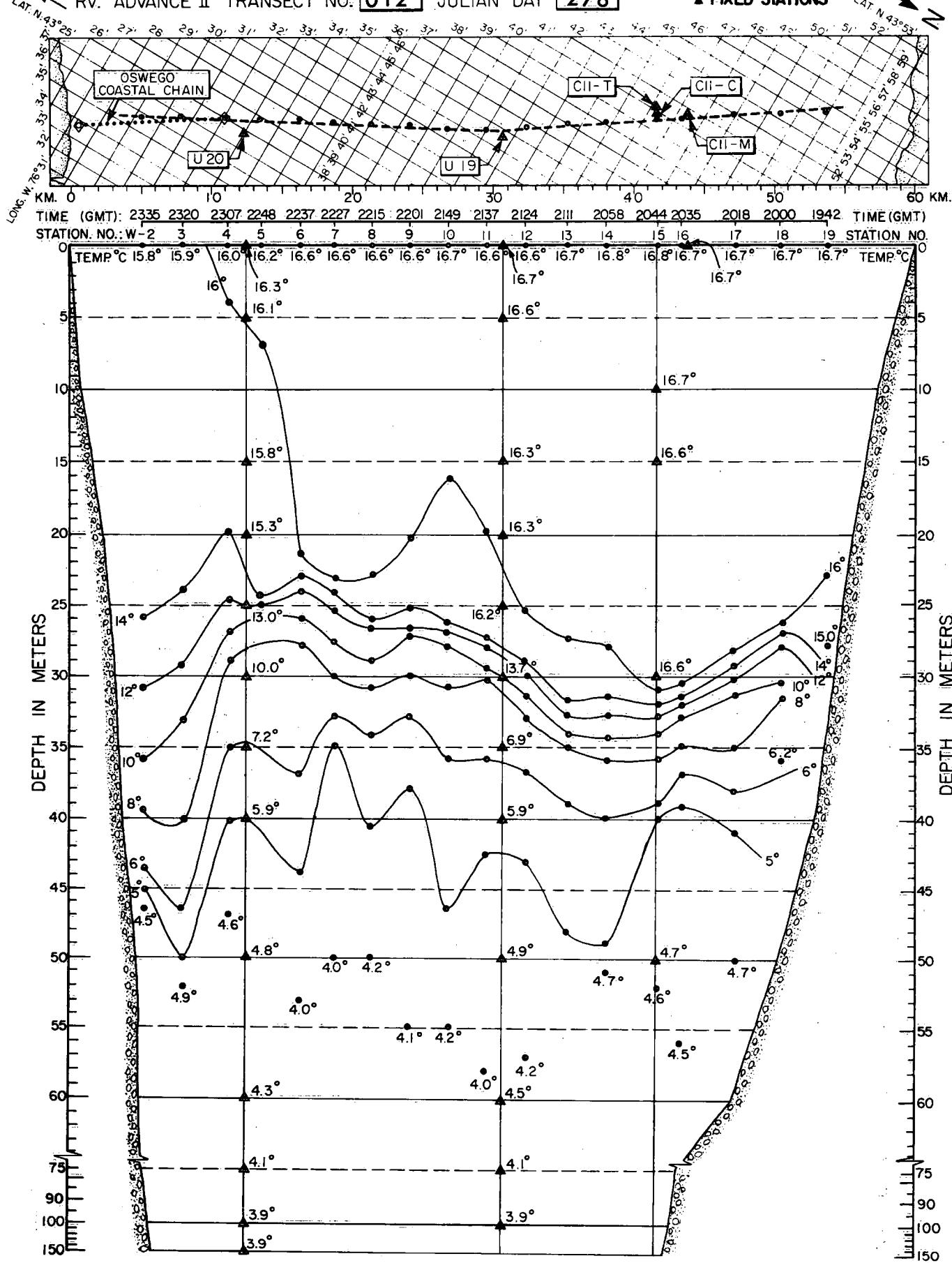
1FYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)

RV. "ADVANCE II" TRANSECT NO. 011 JULIAN DAY 278

▲ FIXED STATIONS



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. 012 JULIAN DAY 278



IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)

RV. "ADVANCE II" TRANSECT NO. **013** JULIAN DAY **278** ▲ FIXED STATIONS

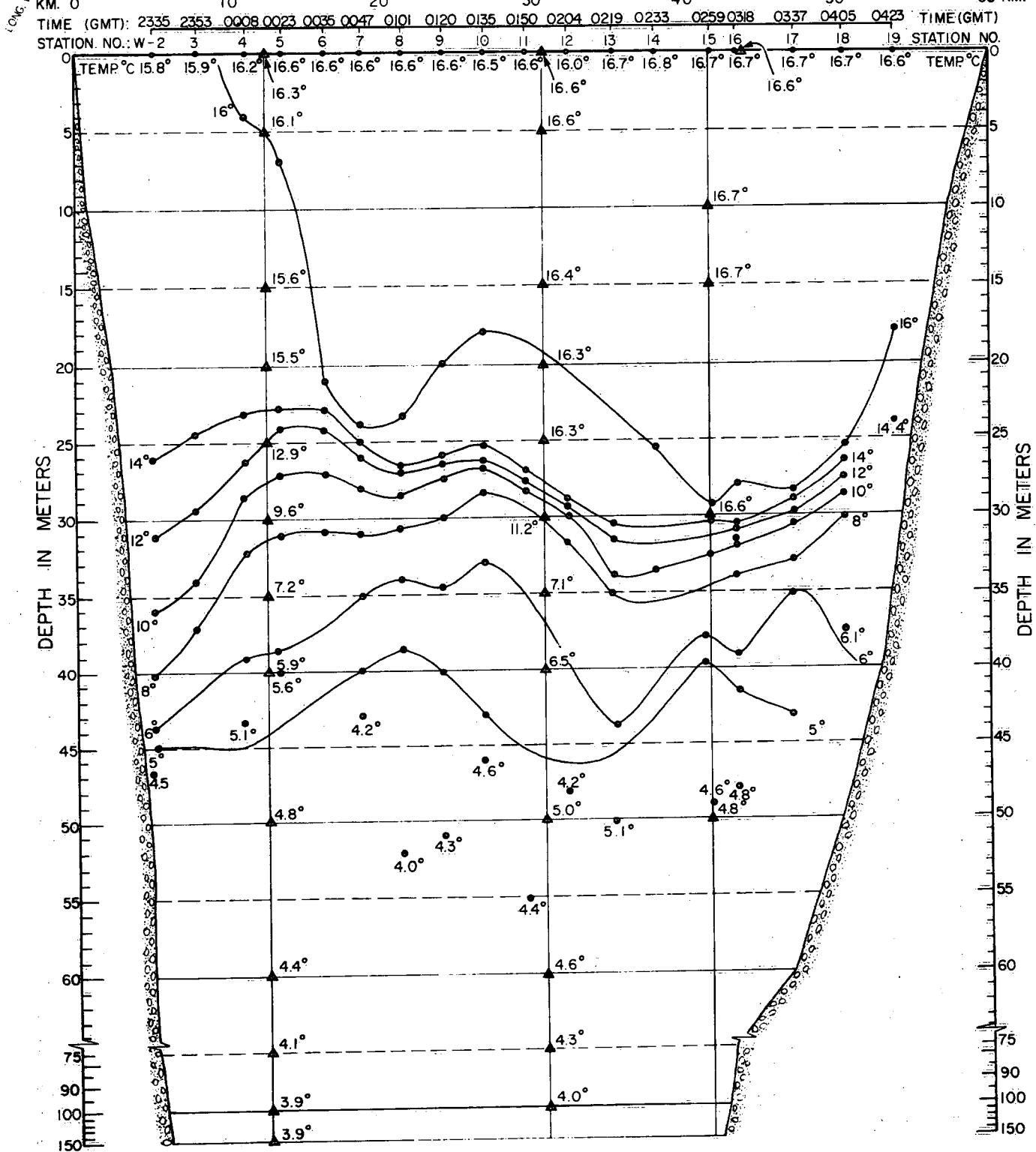
LAT. N 43° 51' 52' 53' 54' 55' 56' 57' 58' 59'

LONG. W 76° 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44'

OSWEGO COASTAL CHAIN

U 20 U 19 CII-T CII-C CII-M

0 10 20 30 40 50 60 KM

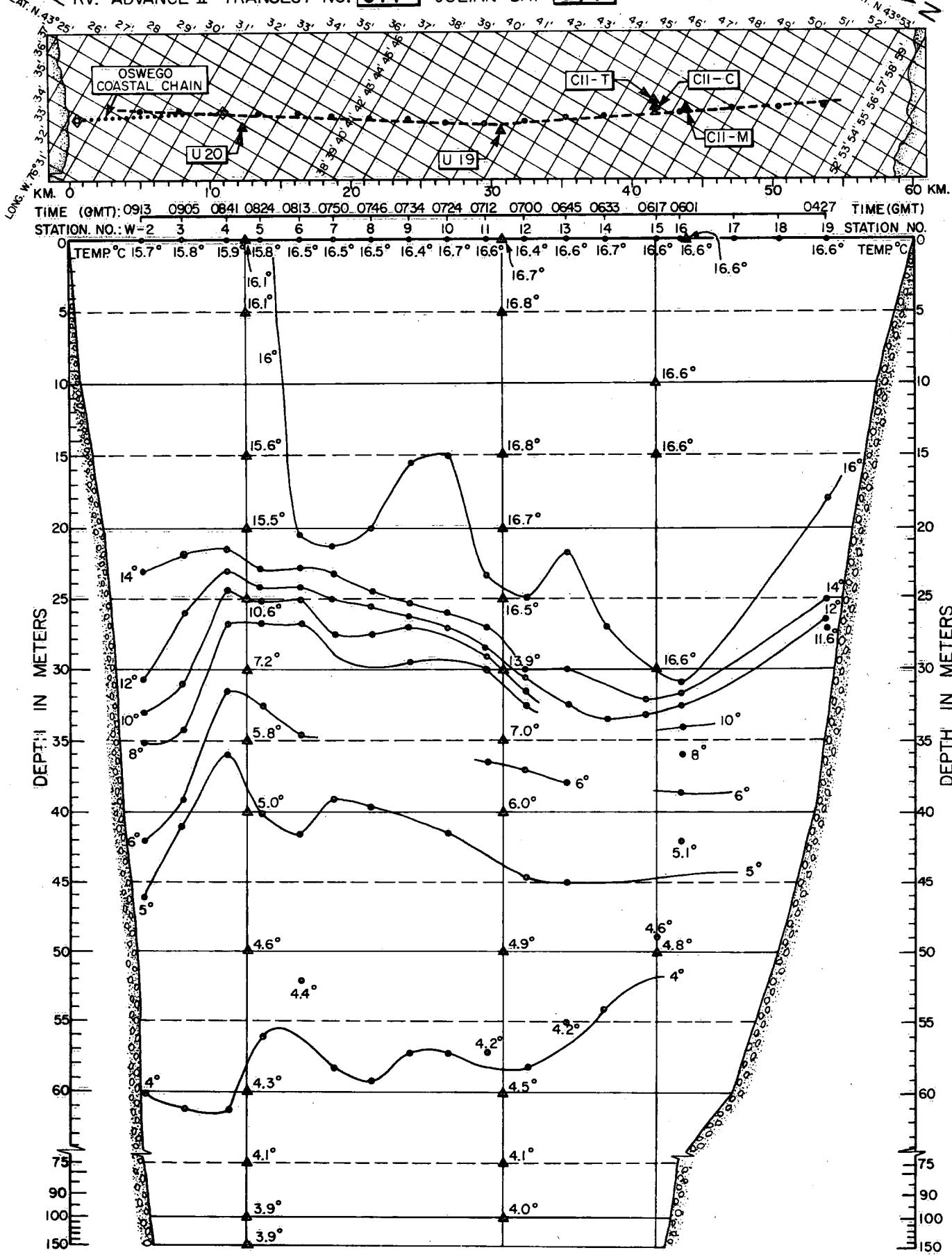


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)

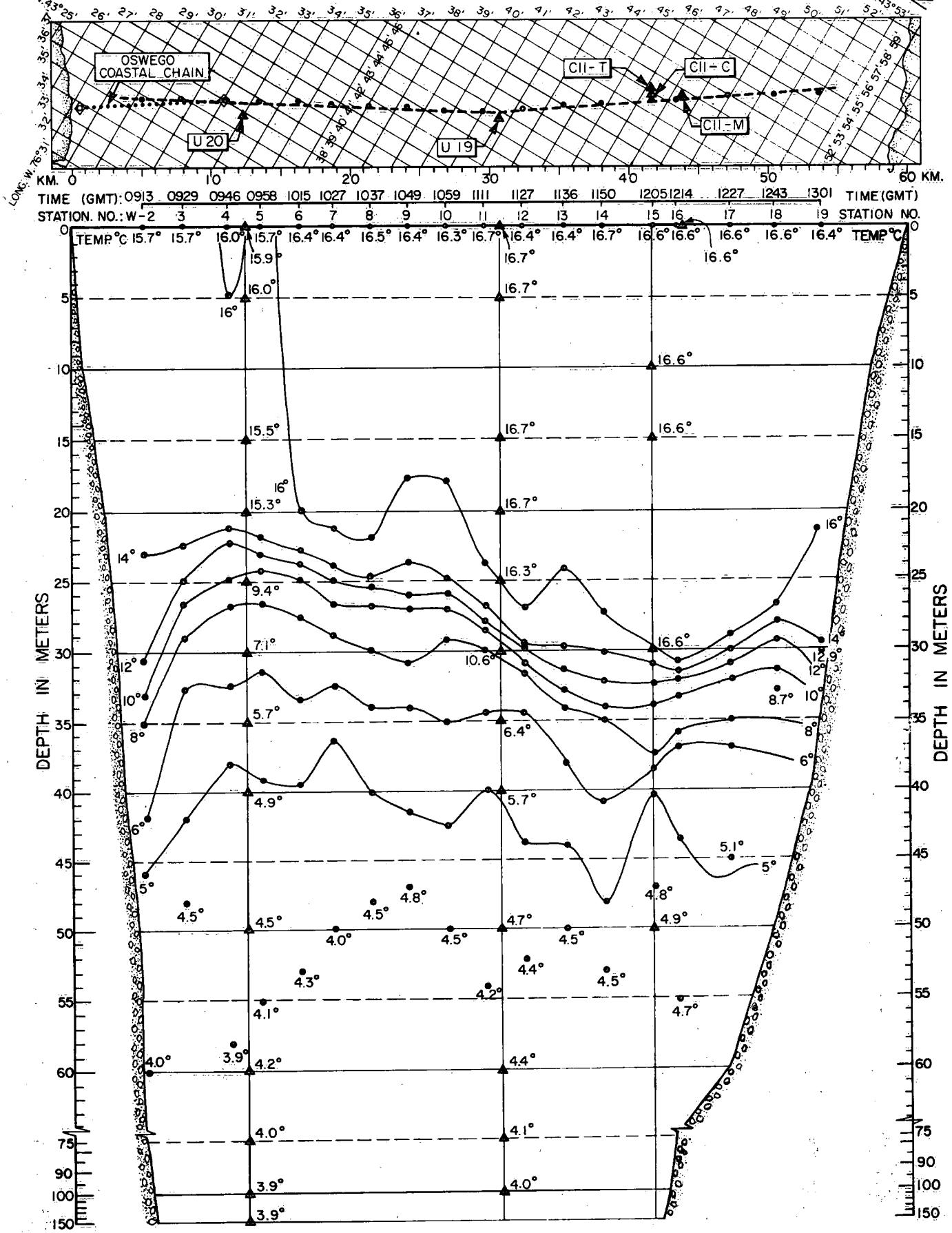
RV. "ADVANCE II" TRANSECT NO. 014

JULIAN DAY 279

▲ FIXED STATIONS



6 IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. 015 JULIAN DAY 279 ▲ FIXED STATIONS LAT N 43° 45' 30"

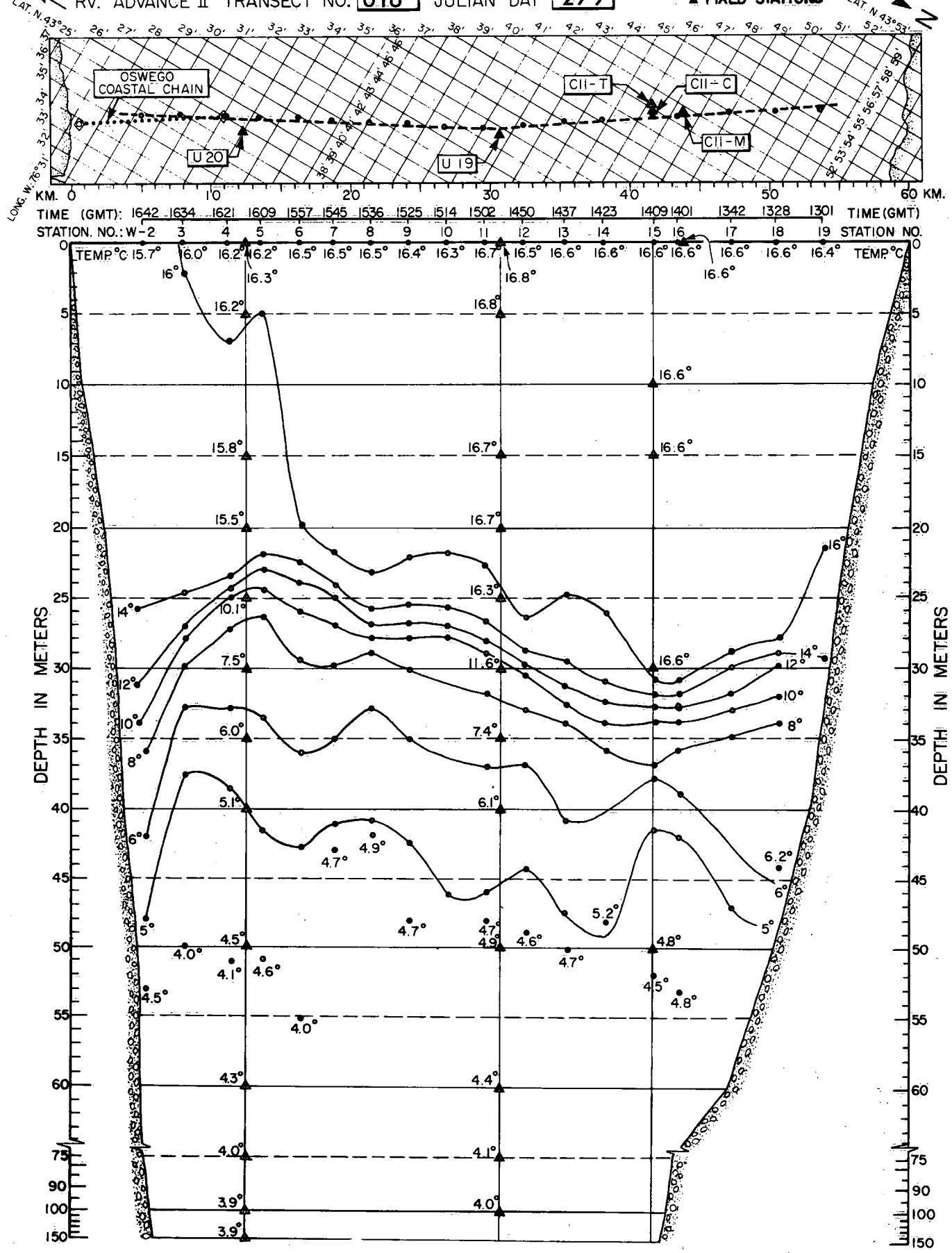


S JFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
BY "ADVANCE II" TRANSECT NO 016 JULIAN DAY 279 ▲ FIXED STATIONS

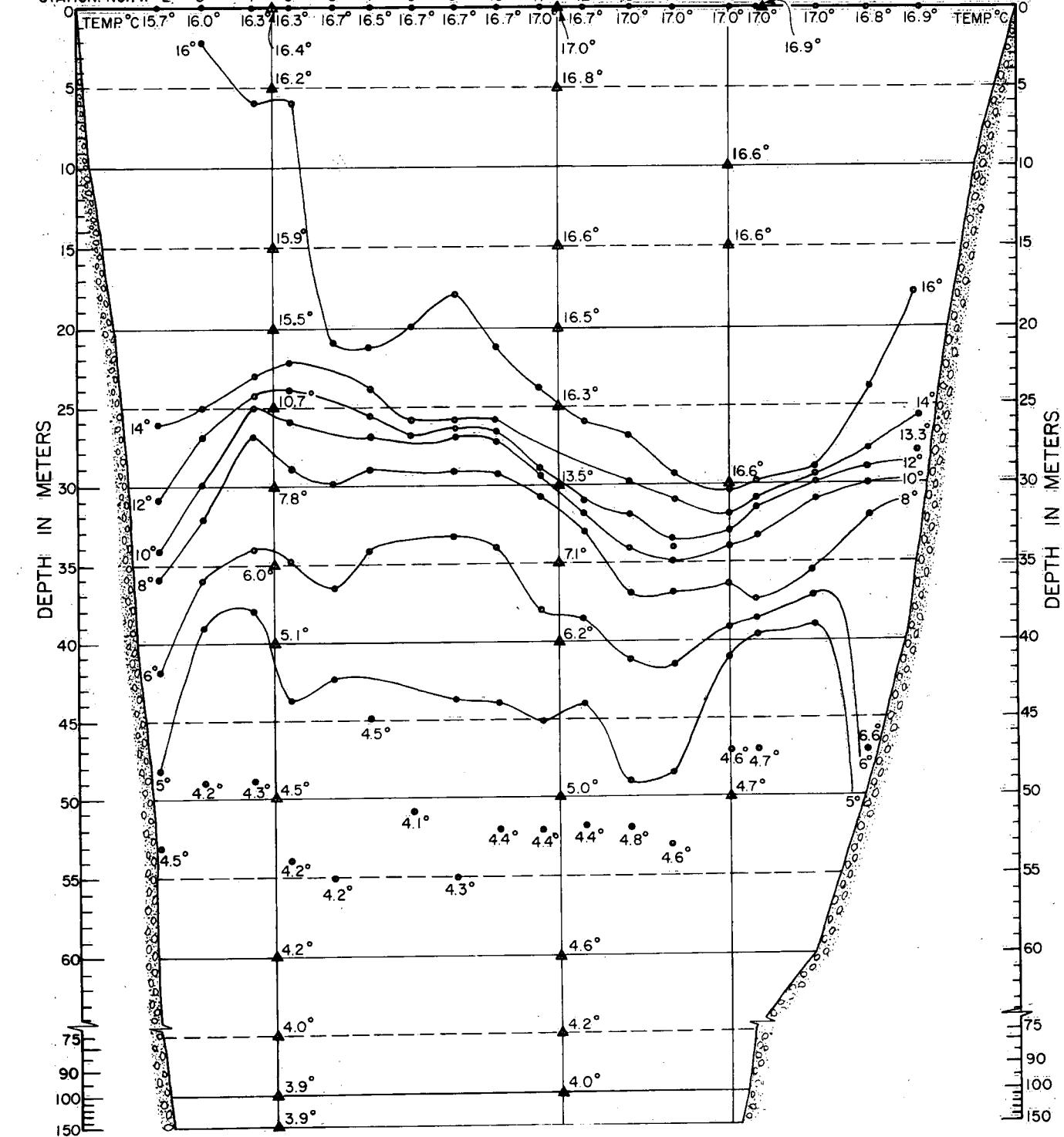
RV. "ADVANCE II" TRANSECT NO. **016** JULIAN DAY **279**

279

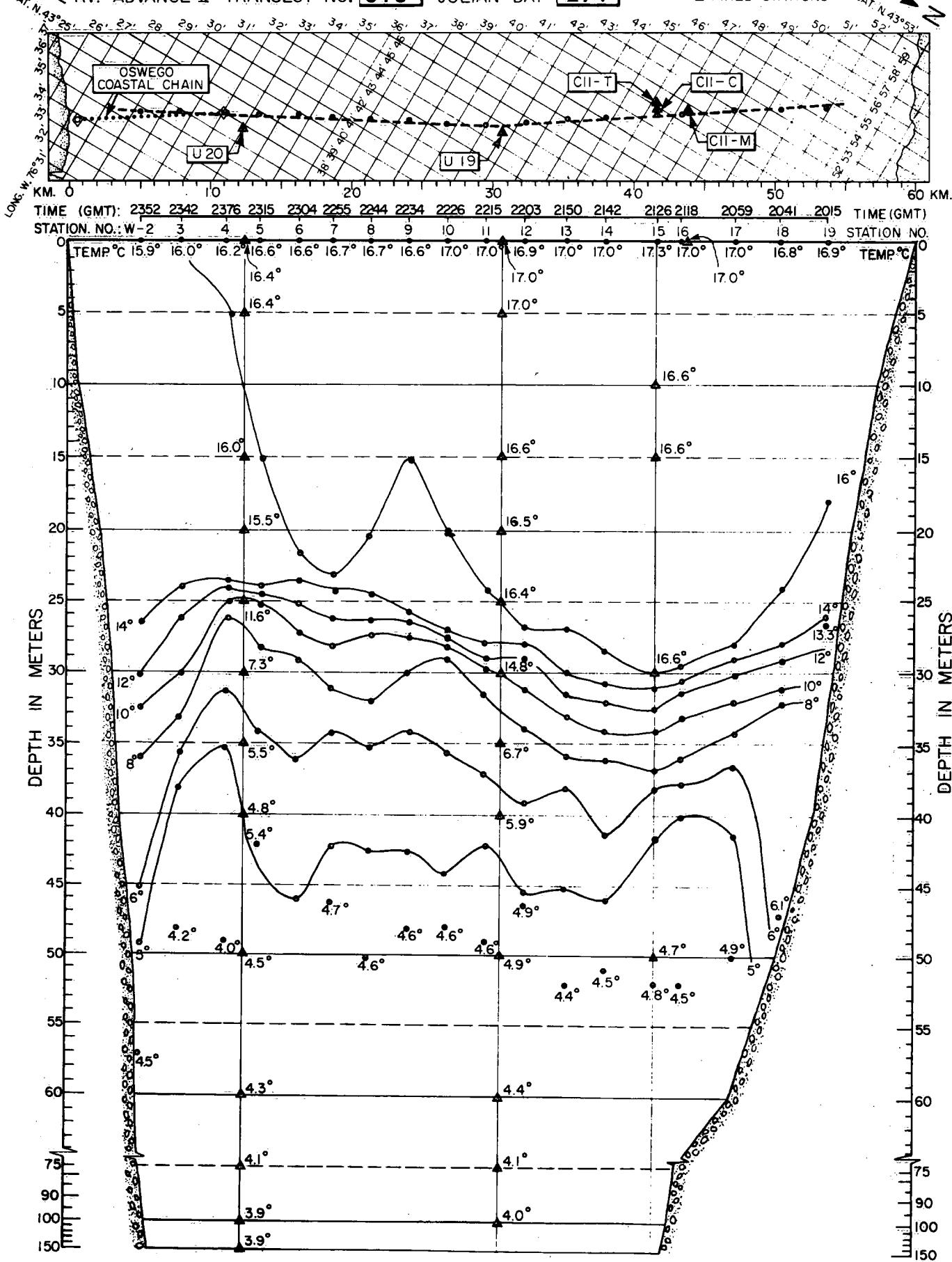
#### **▲ FIXED STATIONS**



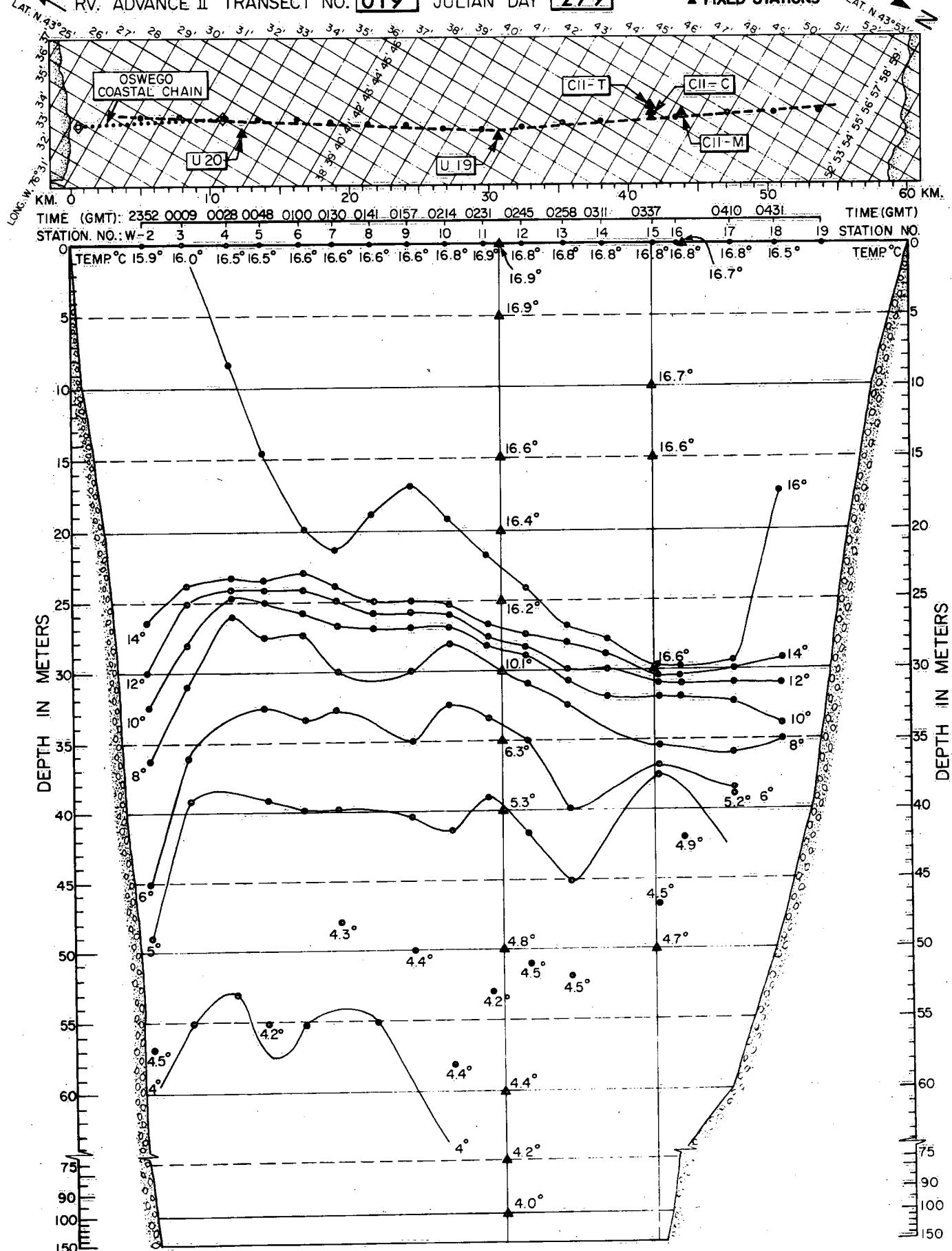
This figure is a map of a lake transect route. The lake is oriented horizontally, with its southern shore at the top. A dashed line represents the transect path, starting at station U20 near Oswego and ending at station CII-M near Prince Edward Point. Several fixed stations are marked along the path: CII-T, CII-C, and CII-M. The map includes a grid with latitude and longitude coordinates. Latitude ranges from 43°25'N to 43°52'N, and longitude ranges from 76°30'W to 75°52'W. A scale bar indicates distances up to 60 km. A legend box labeled 'OSWEGO COASTAL CHAIN' is located in the upper left area of the lake.

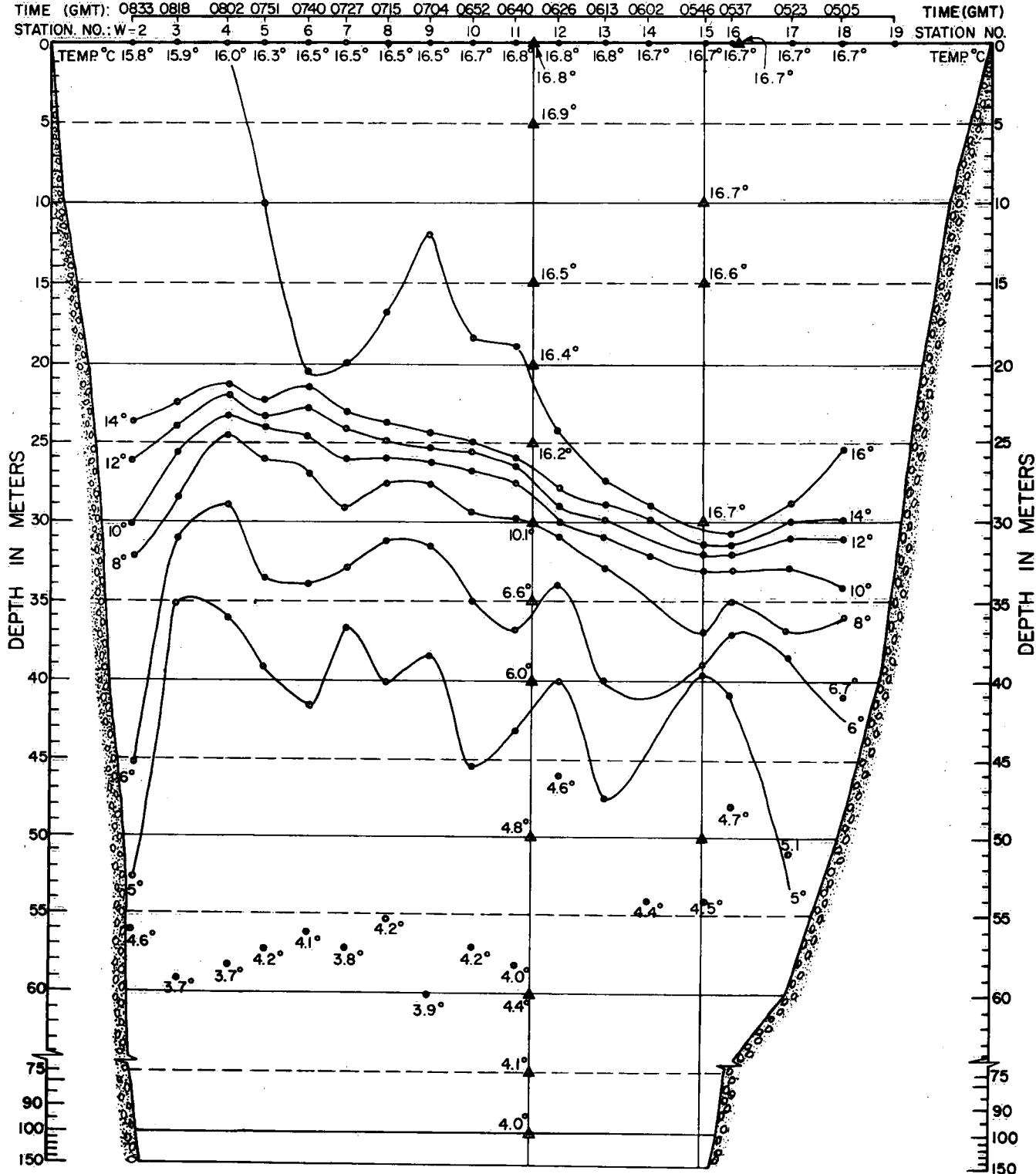
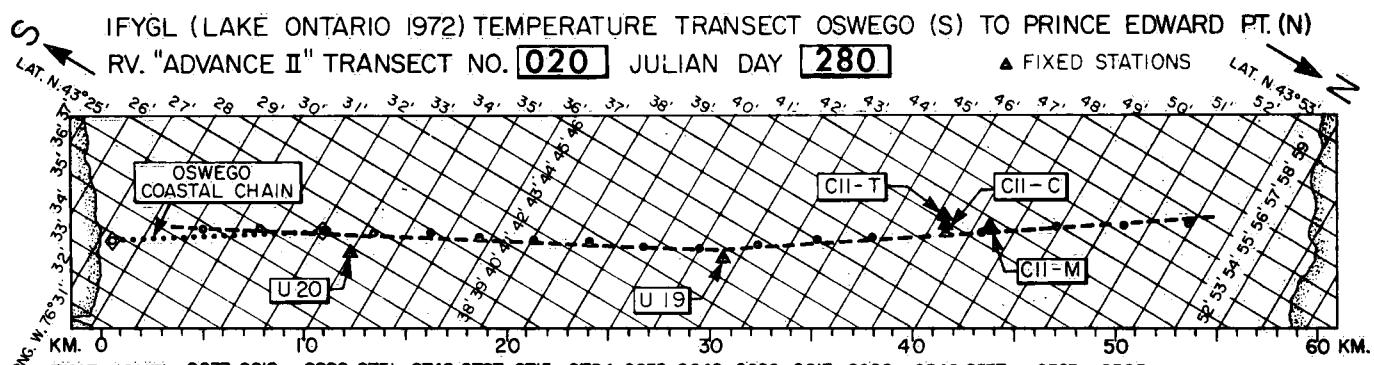


IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
 RV. "ADVANCE II" TRANSECT NO. **018** JULIAN DAY **279**

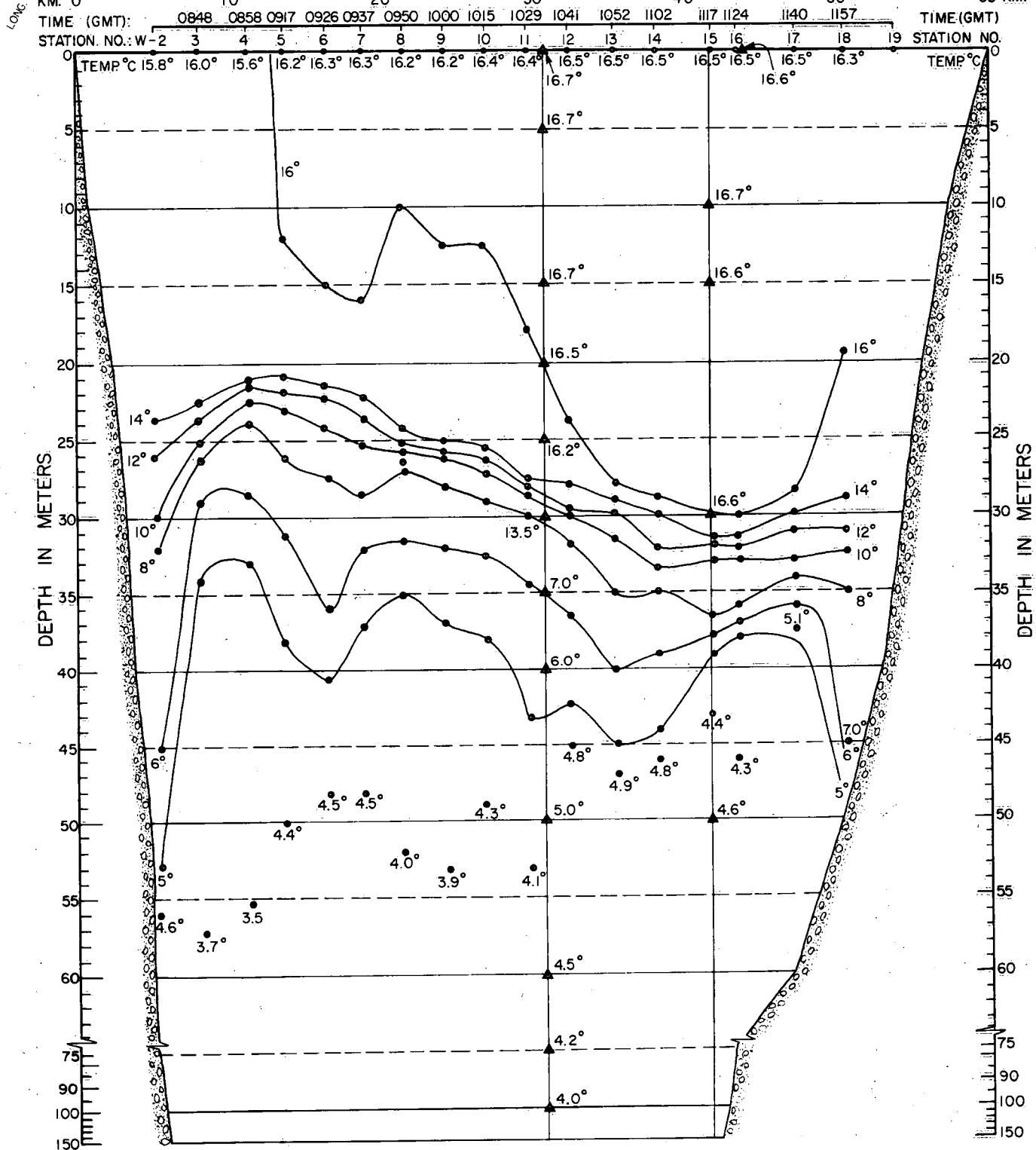


S IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV "ADVANCE II" TRANSECT NO. 019 JULIAN DAY 279 ▲ FIXED STATIONS 47





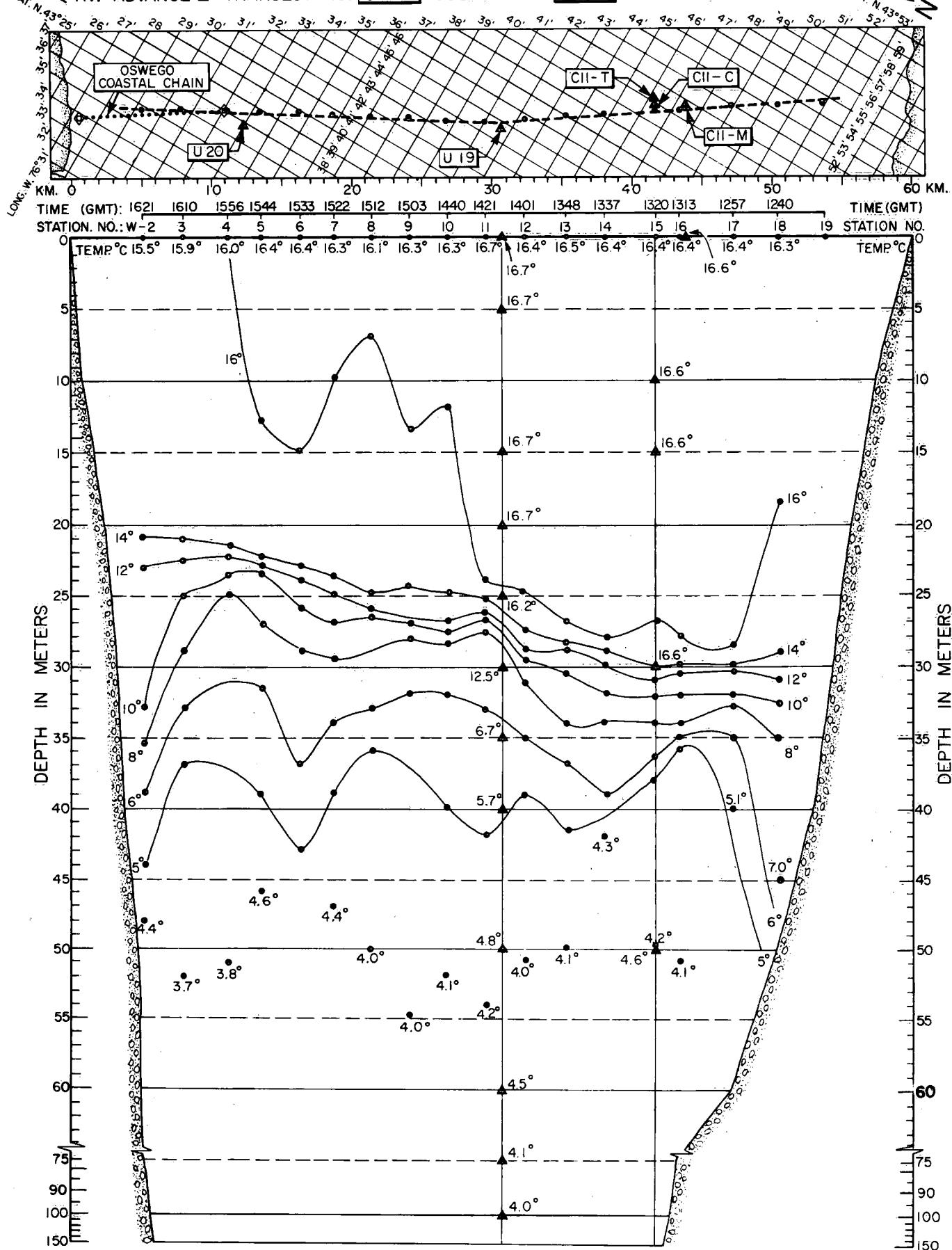
5  
FYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT.(N)  
RV. "ADVANCE II" TRANSECT NO. **021** JULIAN DAY **280** ▲ FIXED STATIONS  
LAT. N 43° 53' 50' 51' 52' 53'  
LAT. N 43° 25' 26' 27' 28' 29' 30' 31' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47'  
OSWEGO COASTAL CHAIN  
U 20 U 19 CII-T CII-C CII-M  
W 76° 3' 32' 33' 34' 35' 36' 37' 38' 39' 40' 41' 42' 43' 44' 45' 46' 47' 48'  
KM 0 10 20 30 40 50 60  
LAT. N 43° 53' 54' 55' 56' 57' 58' 59'  
LAT. N 43° 25' 26' 27' 28'



S  
IFYGL (LAKE ONTARIO 1972) TEMPERATURE TRANSECT OSWEGO (S) TO PRINCE EDWARD PT. (N)  
RV. "ADVANCE II" TRANSECT NO. **022** JULIAN DAY **280**

▲ FIXED STATIONS

LAT. N 43° 53' 52'



# Intercomparisons of the Oswego to Prince Edward Point Temperature Transects and Contemporary Measurements at the Oswego Coastal Chain and at Fixed Recording Stations

## 8.1. THERMOCLINE DEPTHS ESTIMATED BY BATHYTHERMOGRAPH COMPARED WITH ESTIMATES FROM FIXED STATIONS

On the Oswego to Prince Edward Point section the vessel track passed close to two U.S. stations (moorings U19 and U20) and two Canadian stations (C11-C and C11-M<sup>3</sup>), the positions of which are shown at the head of the transect diagrams in Chapter 7 and in Figure 7.1. The temperature data from various depths (Table 7.1) at these fixed stations are entered, as explained in Chapter 7, on the transect diagrams at times (Table 7.2) coinciding as closely as possible with the times of the vessel's passage. It is therefore possible to compare temperatures, or more specifically thermocline depths, determined by the bathythermograph and by the fixed thermographs at the stations along the transect, i.e. principally at U20, U19, and C11-C in south to north sequence. This comparison is made in Figure 8.1 for all three cruises and for all cases in which a temperature datum point from a fixed station lies at or close to a thermocline isotherm, as determined by the bathythermograph. Only those cases where close comparison is possible have been selected; but some scatter is to be expected, because the fixed-station readings were only available at 6-min intervals at U19 and U20 and at 10-min intervals at C11-C. The distances of the vessel tracks from the fixed stations were usually less than 1 km; but even at such small distances, short internal waves could occasionally produce isotherm slopes large enough to appear as differences in thermocline depth between a station and the nearest point on the transect.

If we assume that the temperatures were measured correctly at each station and the sensors were in fact at the depths indicated in Table 7.1, then Figure 8.1 suggests that the bathythermograph underestimated thermocline depth by about 2 m (with scatter) during the July and August cruises, but that the discrepancy was

<sup>3</sup>The thermistor chain C11-T was not in operation during any of the transect cruises.

1 m or less during the October cruise. For July and August, there are too few points for a definite conclusion, while the October results appear to justify a correction of +1 m to the thermocline depths as shown in the transects in Chapter 7. The reason for this difference, if real, is not obvious. When, as was often the case, the BT slide showed two traces (ascent and descent) the mean of the two was taken, which should have minimized any effect of thermal lag.

## 8.2. ADDITIONAL TRANSECT - FIXED-STATION COMPARISONS

Additional comparisons, between isotherm depths on transects and the time variation of isotherm depths interpolated from hourly averages of 6-min readings at stations U19 and U20, are provided by Figures 8.2 to 8.9. The positions of the fixed stations are shown in Figure 7.1. Two of those stations (U19 and U20) lie on the vessel track, and the times of vessel passage are indicated by vertical lines for the July cruise (Figs. 8.2 and 8.3), the August cruise (Fig. 8.4) and the October cruise (Figs. 8.5 and 8.6).

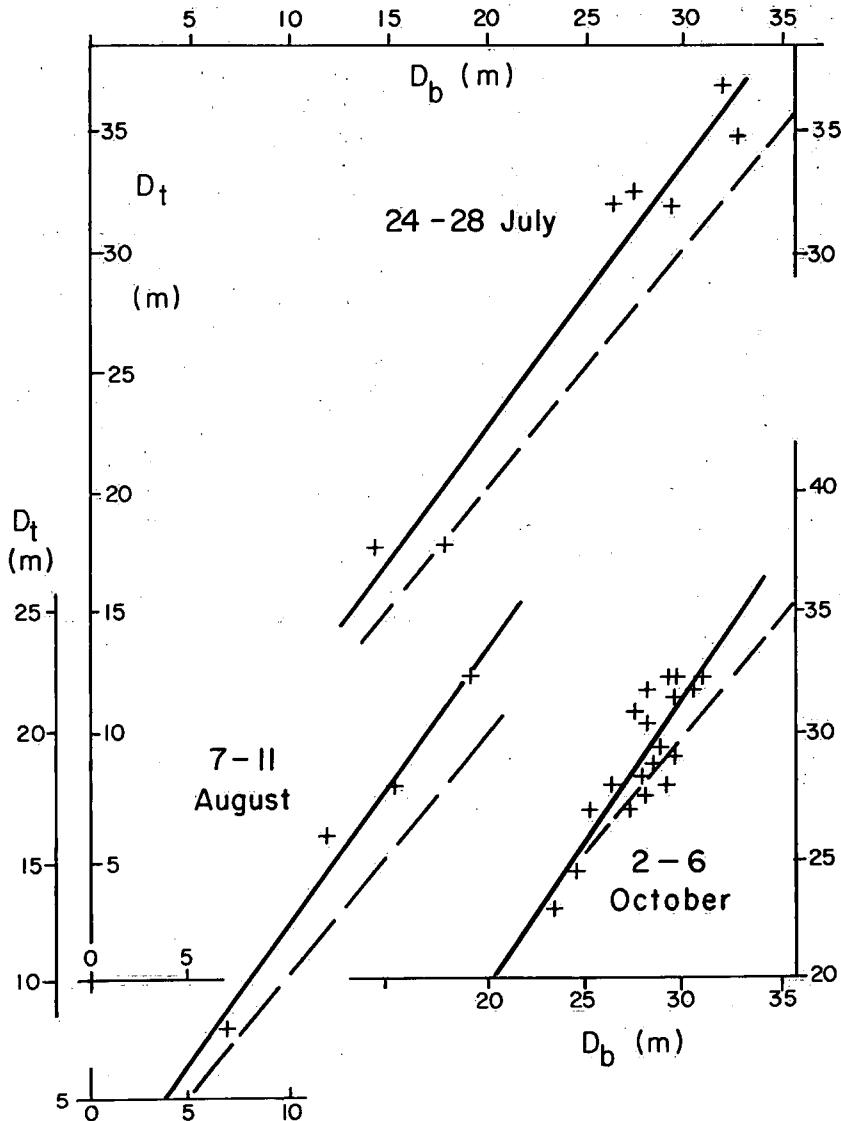
Interpolated hourly averaged isotherm depths are also illustrated (in Figs. 8.7 to 8.9) for two nearby stations, U18 and U21 (see Fig. 7.1), respectively 27 and 22 km from the section.

## 8.3. OSWEGO COASTAL CHAIN AND TRANSECT COMPARISONS

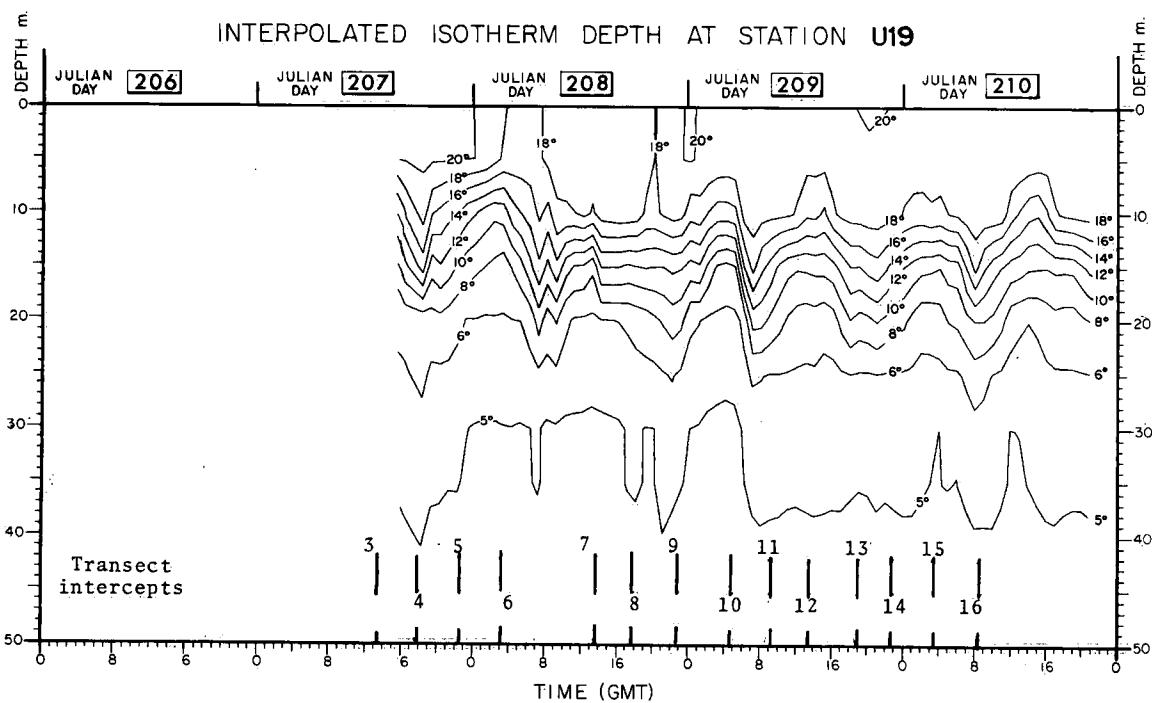
The other two transect sections, Olcott to Oshawa and Braddock Pt. to Presqu'ile, provided several Coastal Chain and Transect "coincidences", for which independently determined temperature profiles could be compared. For the Oswego to Prince Edward Point section only one Coastal Chain (Oswego) was available; and in only one case was there coincidence in space and time (Figs. 8.10, 8.11). In that case, and in more than three-

quarters of the transects presented in Chapter 7, there was strong downwelling of the isotherms near the Oswego shore, evidence of a strong eastward-going coastal current for most of the time of the cruises. Using a Whitney thermometer and estimating depth from length of cable payed out under these circumstances, it is possible that the Chain investigators overestimated isotherm depths. That is speculation, but in the single Transect-Chain coincidence presented here (Figs. 8.10, 8.11) isotherms derived from the Chain profiles were estimated to be about 5 m deeper than those derived from the Transect. The same is true of the near-coincidences on the same Julian day (209, July, Figs. 8.12, 8.13) and in an August case (Fig. 8.14) that shows a Transect-Chain time separation of 1 to 3 hr. The agreement between Transect and Chain estimates of isotherm depth was better in October (Figs. 8.15 to 8.17) when the thermocline was deeper and the coastal downwelling weaker. Figure 8.1 also shows better Transect - fixed station agreement in October (with many points) than in July and August (with few points).

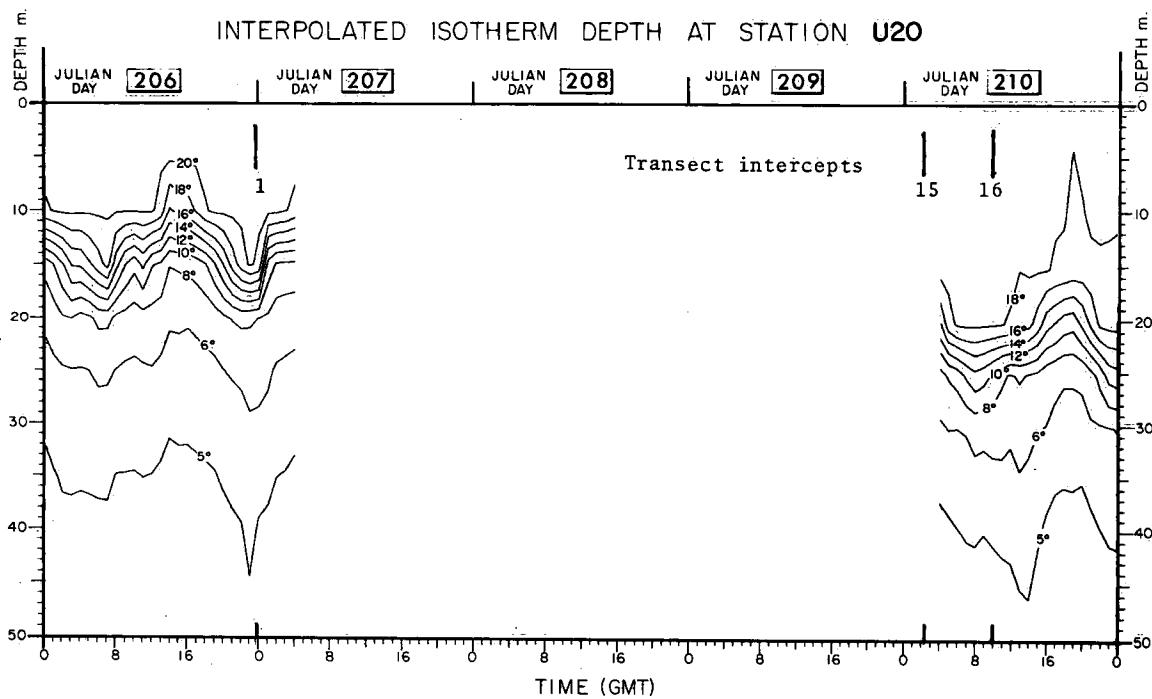
Measured against the Transect - fixed station and Transect - Coastal Chain comparisons made in Chapter 6, the material presented in this section is much less extensive, and some of the results are influenced by the presence of strong downwelling at Oswego. We do not feel able, therefore, to recommend any systematic correction to the thermocline depths estimated by bathythermograph on the Oswego to Prince Edward Point section. It will be noted (Figs. 8.1, 8.15 to 8.17) that, in the absence of strong downwelling at the Oswego end of the section, agreement between Transect and fixed station or Coastal Chain results was on average fairly close. The large discrepancies (for example, Figs. 8.10, 8.11) appeared, in the form of lower Chain-estimated isotherms, during periods of strong downwelling. Errors in depth estimation, arising when the cable was not vertical in the Chain measurements, were likely to be greatest when the thermocline was deep and when there was a strong current running. Therefore, it appears likely to us that the Transect measurements can serve to correct the Chain measurements, rather than vice versa.



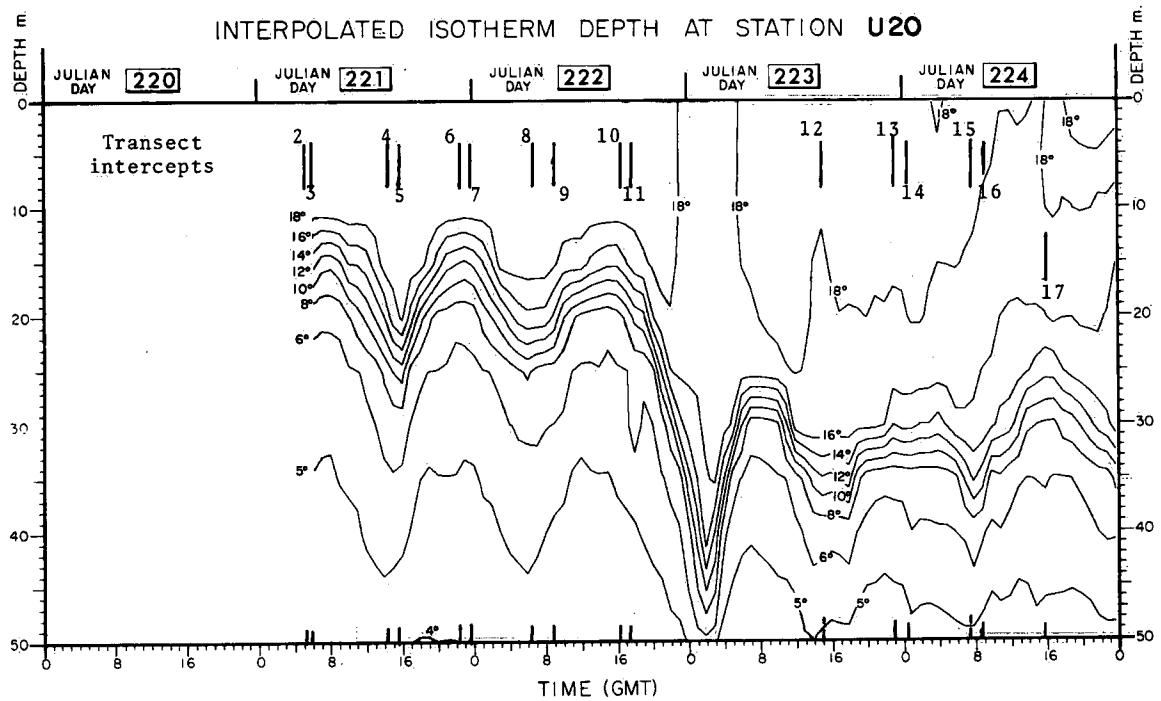
**Figure 8.1.** Comparison of thermocline depth estimates made on selected occasions when the vessel's bathythermograph (producing a depth estimate  $D_b$ ) was cast close to a fixed station (which produced an independent depth estimate  $D_t$ ). A group of crosses, each cross representing an individual estimate pair, is plotted for each of the three cruises; and best-fit regression lines are drawn (unbroken) through each group. The significance of the broken line is explained in section 6.1.



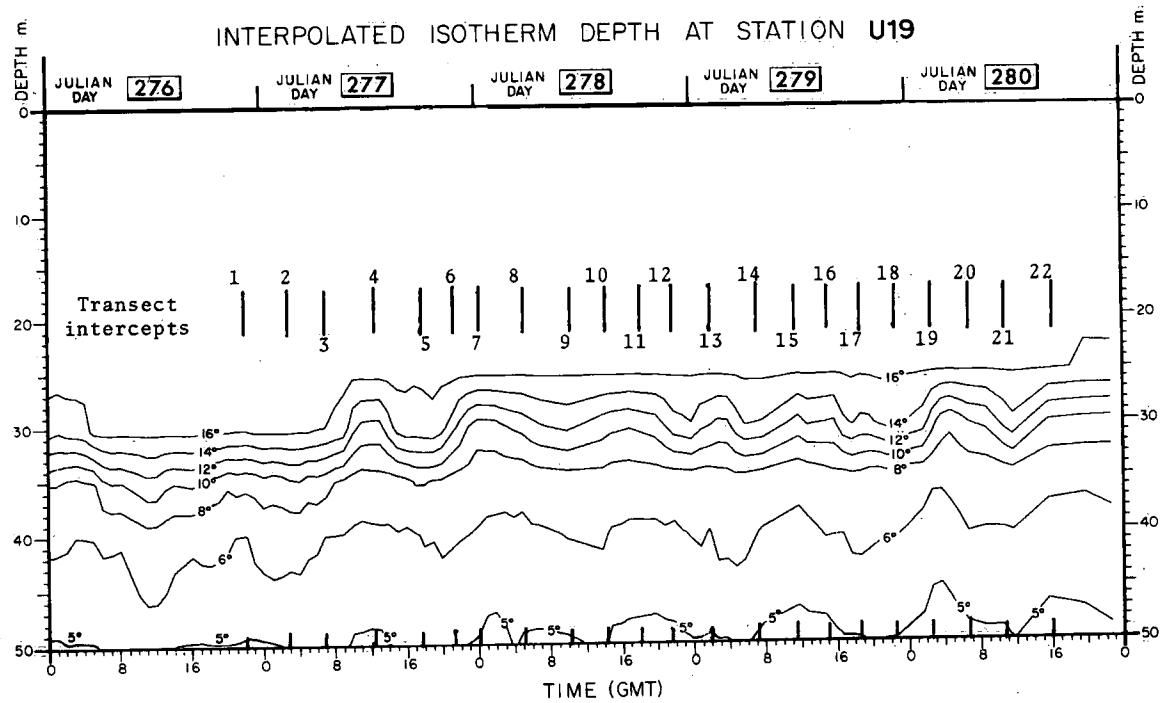
**Figure 8.2.** Isotherm depths at station U19, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.



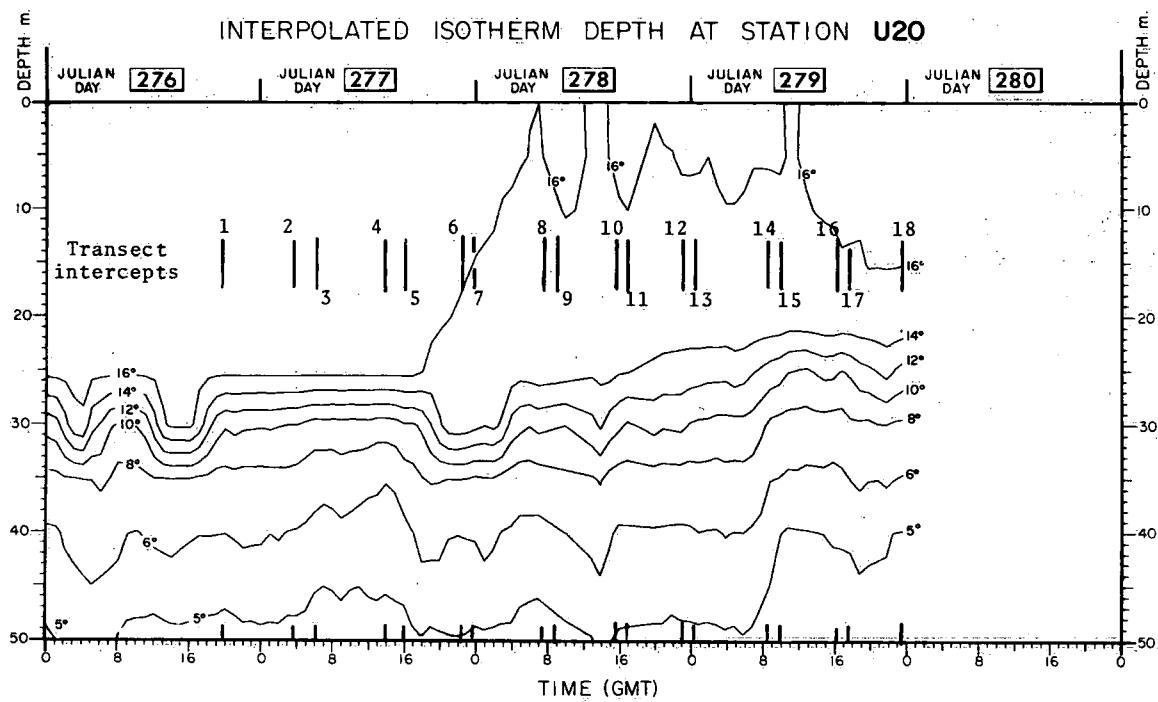
**Figure 8.3.** Isotherm depths at station U20, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.



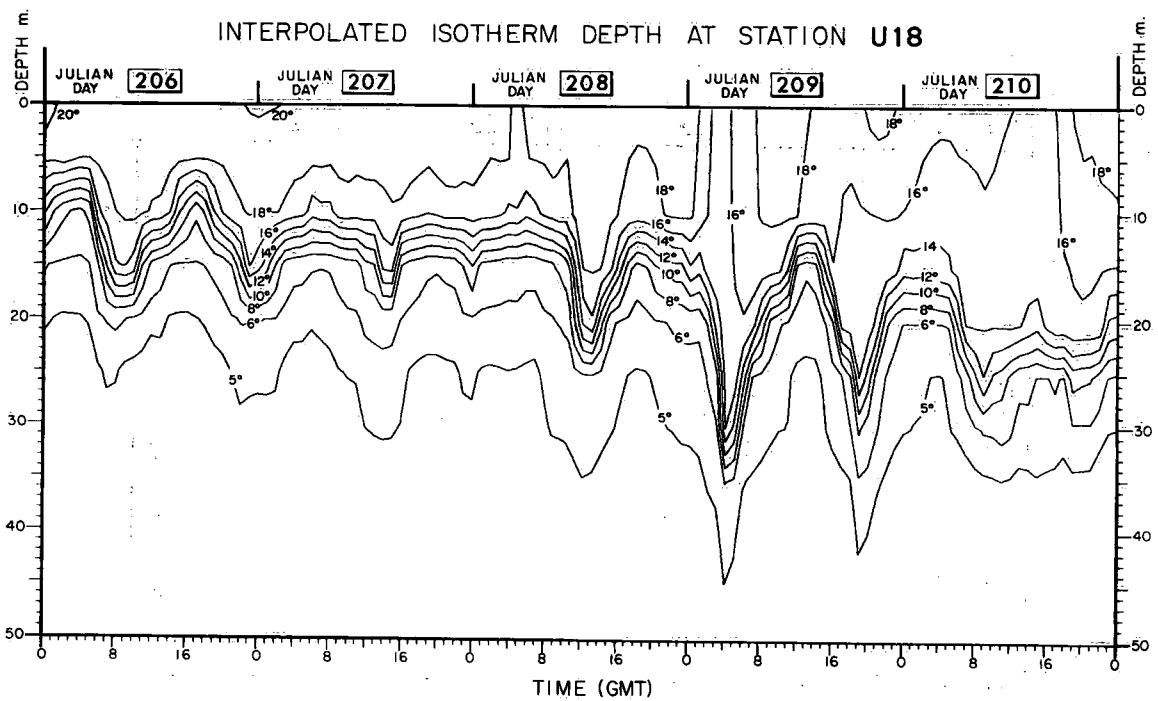
**Figure 8.4.** Isotherm depths at station U20, Lake Ontario, 7-11 August 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.



**Figure 8.5.** Isotherm depths at station U19, Lake Ontario, 2-6 October 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.



**Figure 8.6.** Isotherm depths at station U20, Lake Ontario, 2-6 October 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.



**Figure 8.7.** Isotherm depths at station U18, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.

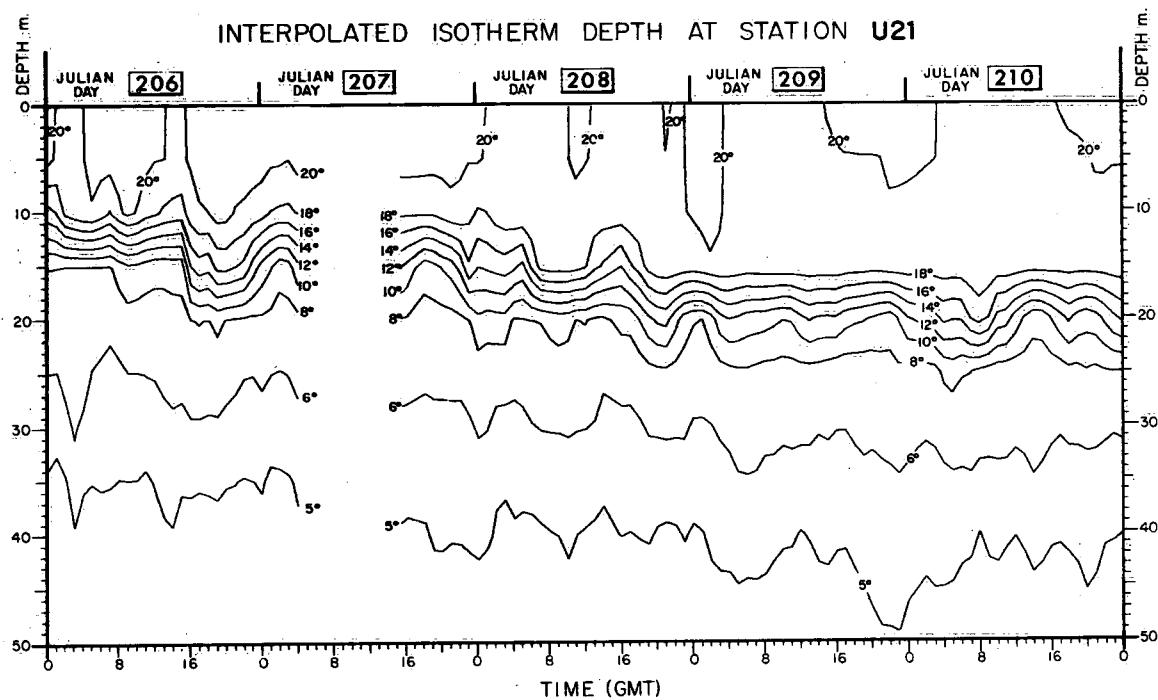


Figure 8.8. Isotherm depths at station U21, Lake Ontario, 24-28 July 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.

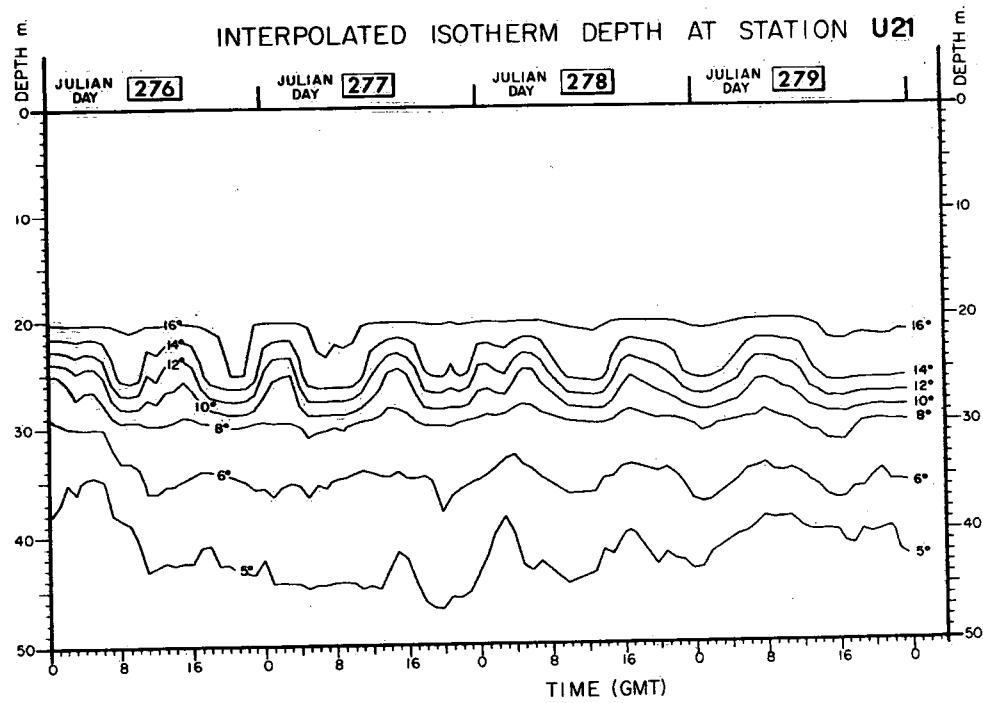


Figure 8.9. Isotherm depths at station U21, Lake Ontario, 2-5 October 1972, interpolated from hourly averaged temperatures at depths listed in Table 7.1.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

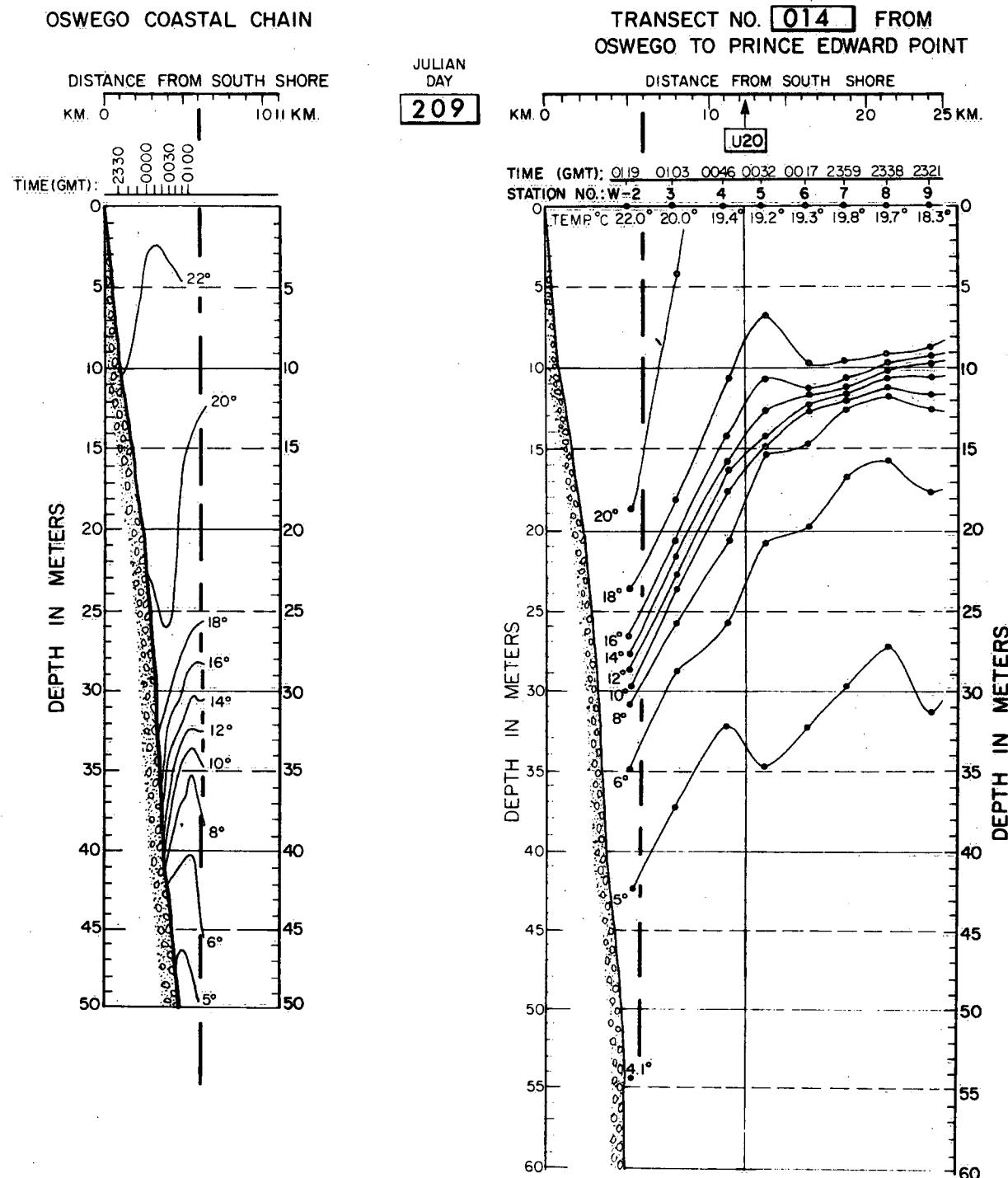
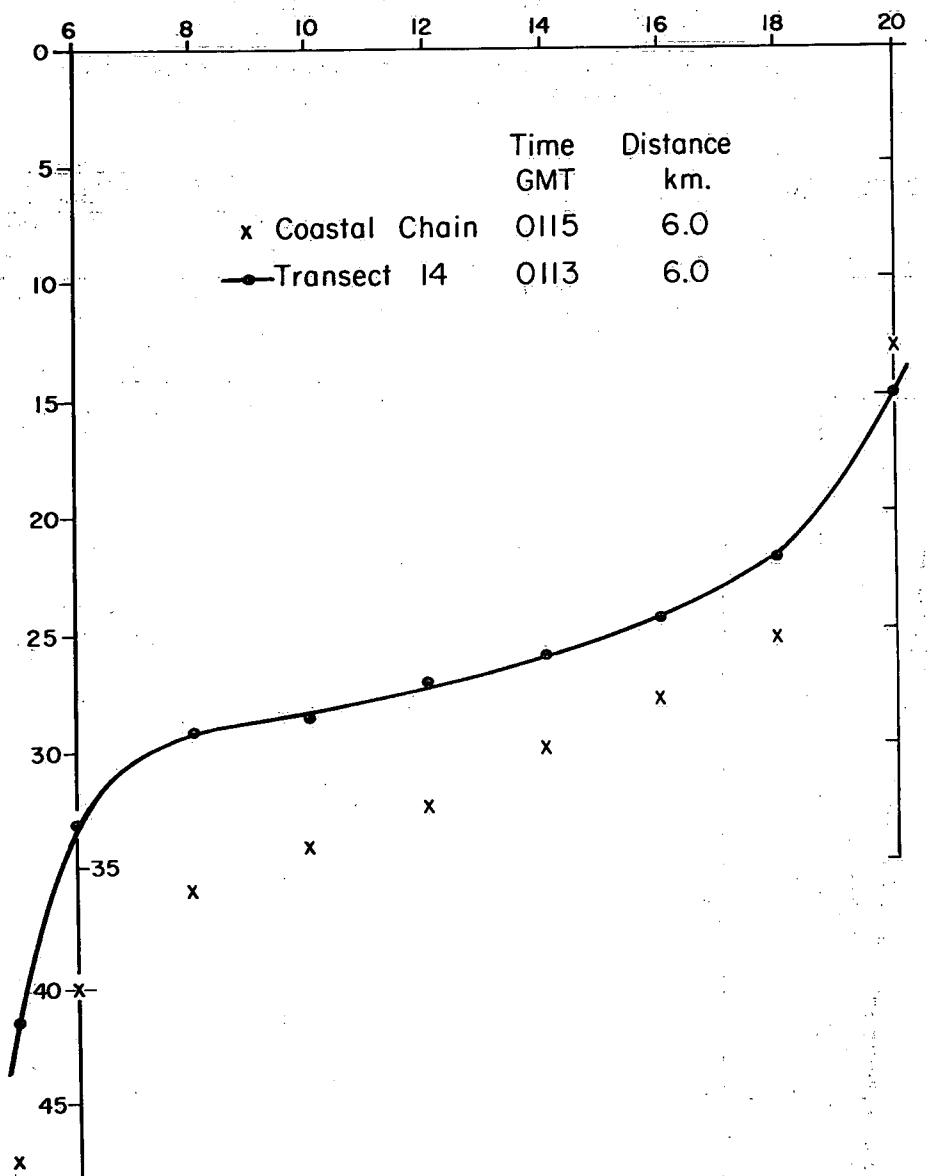


Figure 8.10. Isotherm depths in the Oswego Coastal Chain section, 27 July, and in the corresponding portion of the contemporary Transect 14. The coincidence point is shown in each section by a vertical broken line.



**Figure 8.11.** Comparison of "coincident" temperature-depth profiles derived independently from S.S. *Advance II* Transect 14, 27 July, and from the Oswego Coastal Chain at the indicated times and distances from shore (see Fig. 8.10).

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

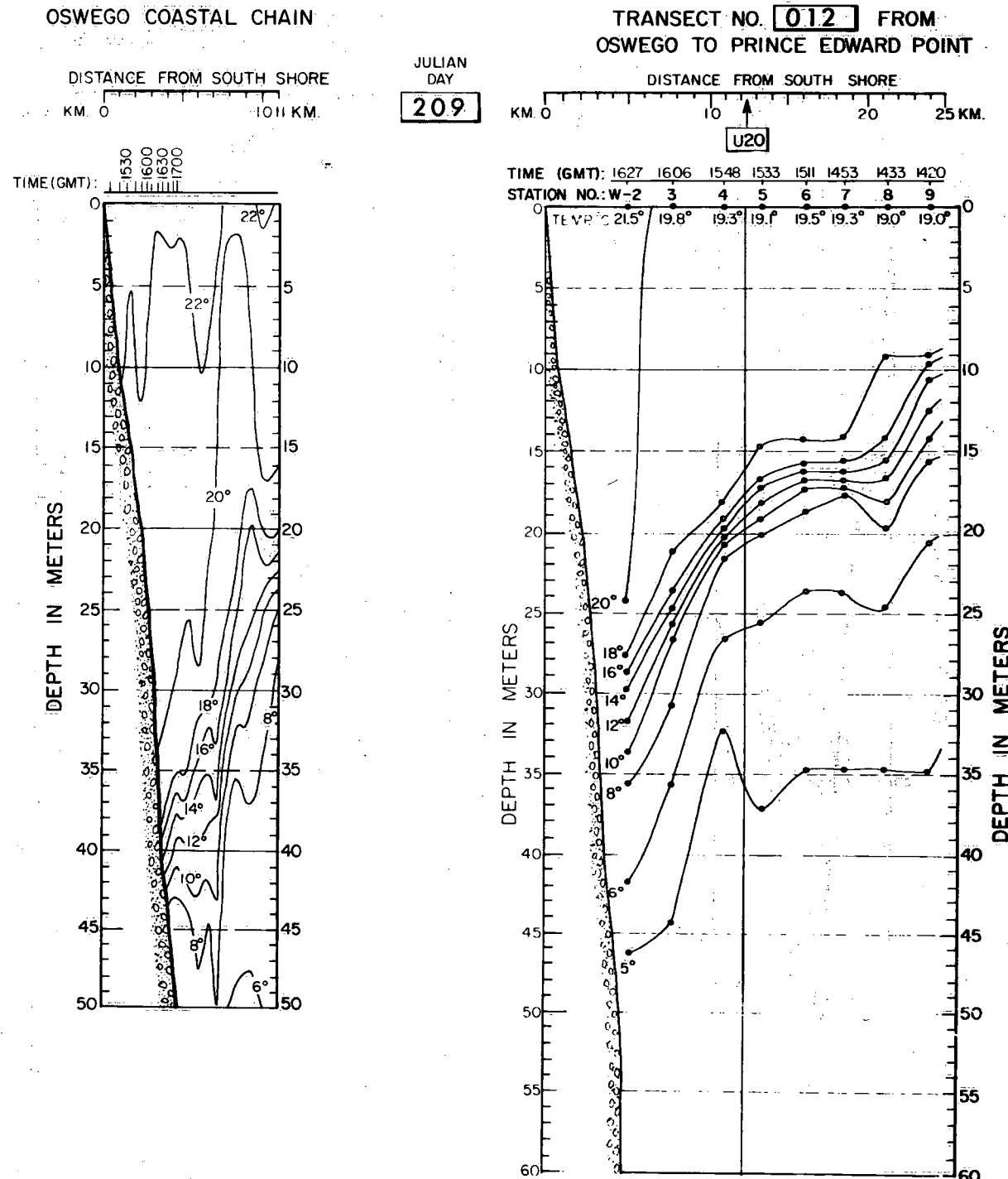


Figure 8.12. Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 12, 27 July.

IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

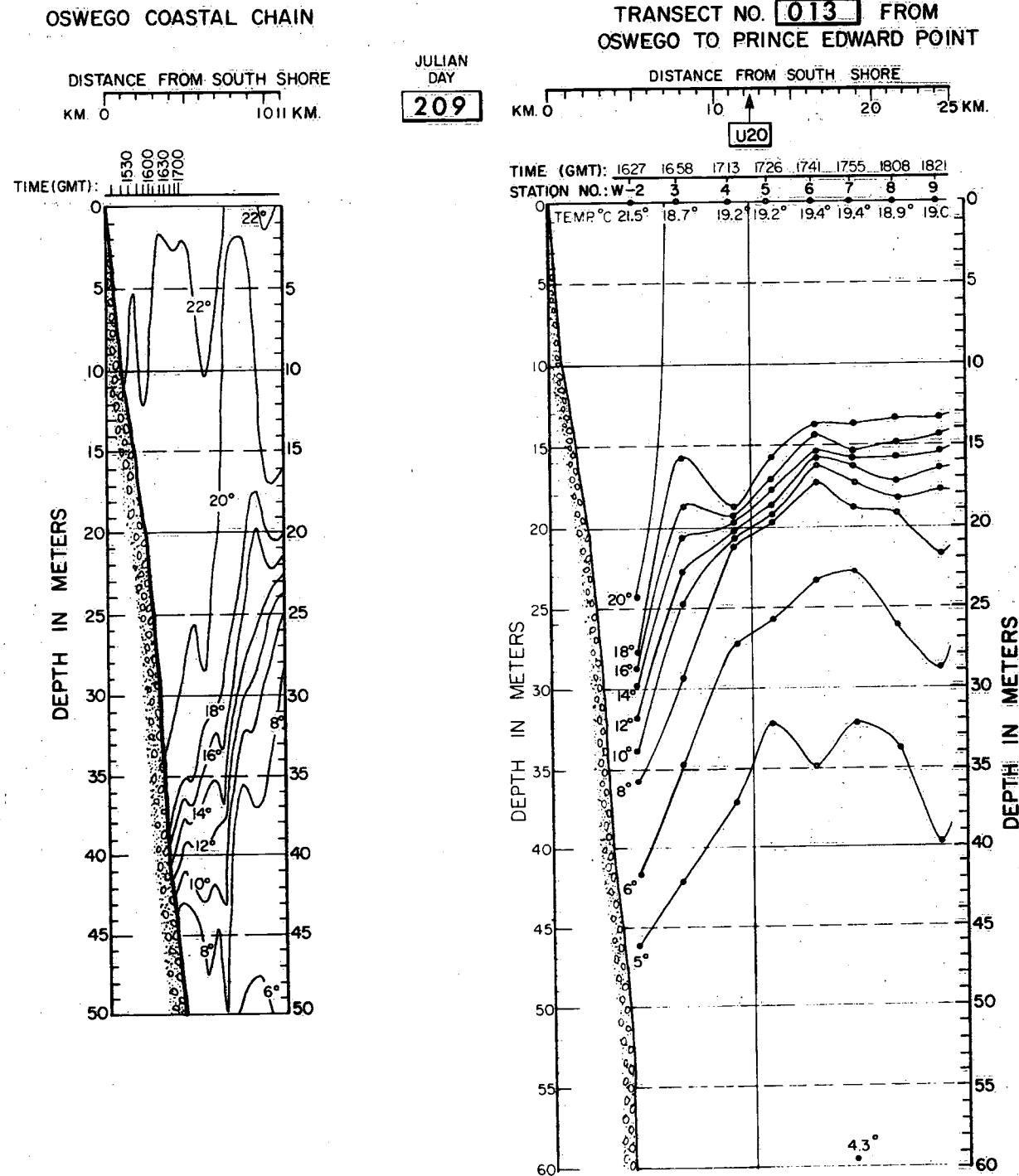
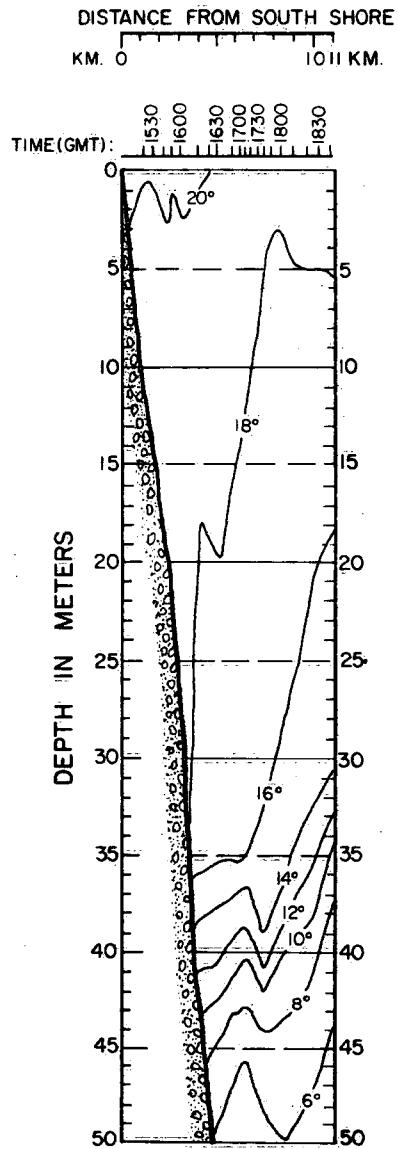


Figure 8.13. Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 13, 27 July.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## OSWEGO COASTAL CHAIN



## TRANSECT NO. 017 FROM OSWEGO TO PRINCE EDWARD POINT

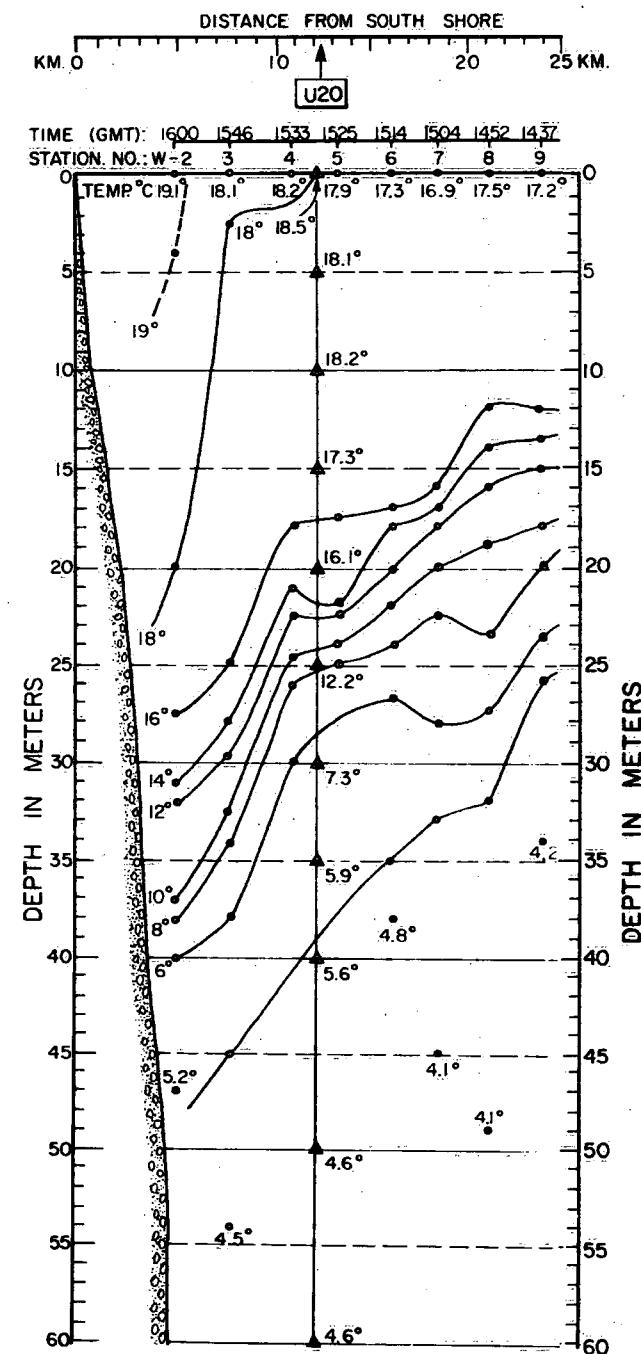
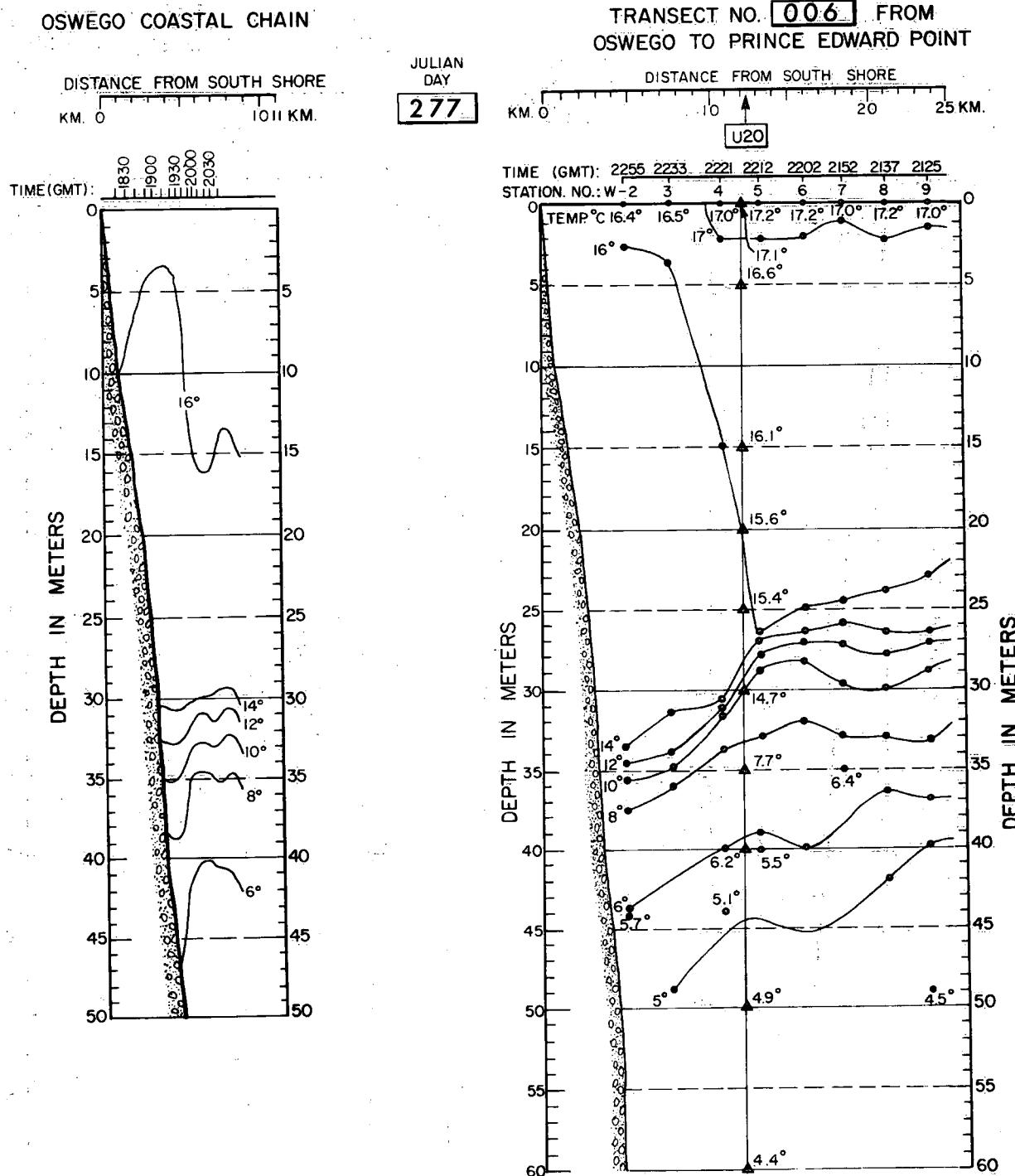


Figure 8.14. Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 17, 11 August.

IFYGL (LAKE ONTARIO 1972)

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS

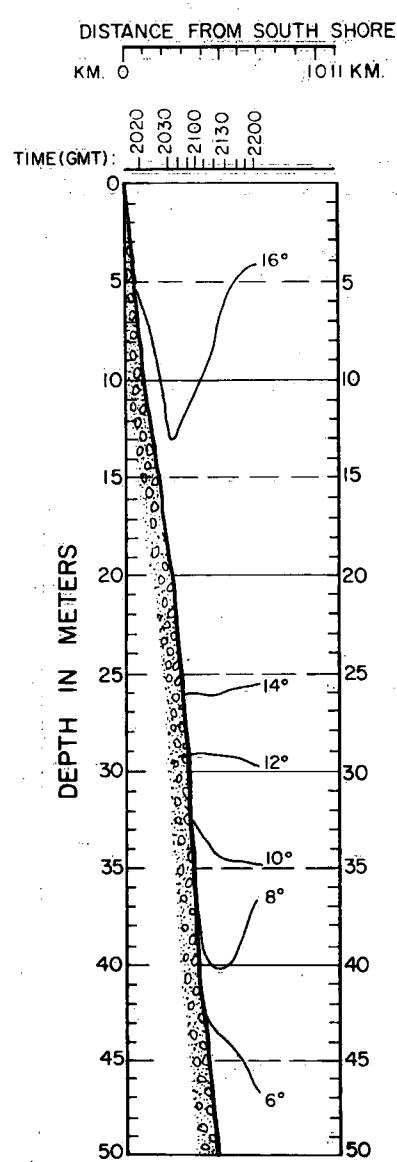


**Figure 8.15.** Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 6, 3 October.

# IFYGL (LAKE ONTARIO 1972)

COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS  
AND COASTAL CHAIN OBSERVATIONS

## OSWEGO COASTAL CHAIN.



JULIAN DAY  
**278**

## TRANSECT NO. 012 FROM OSWEGO TO PRINCE EDWARD POINT

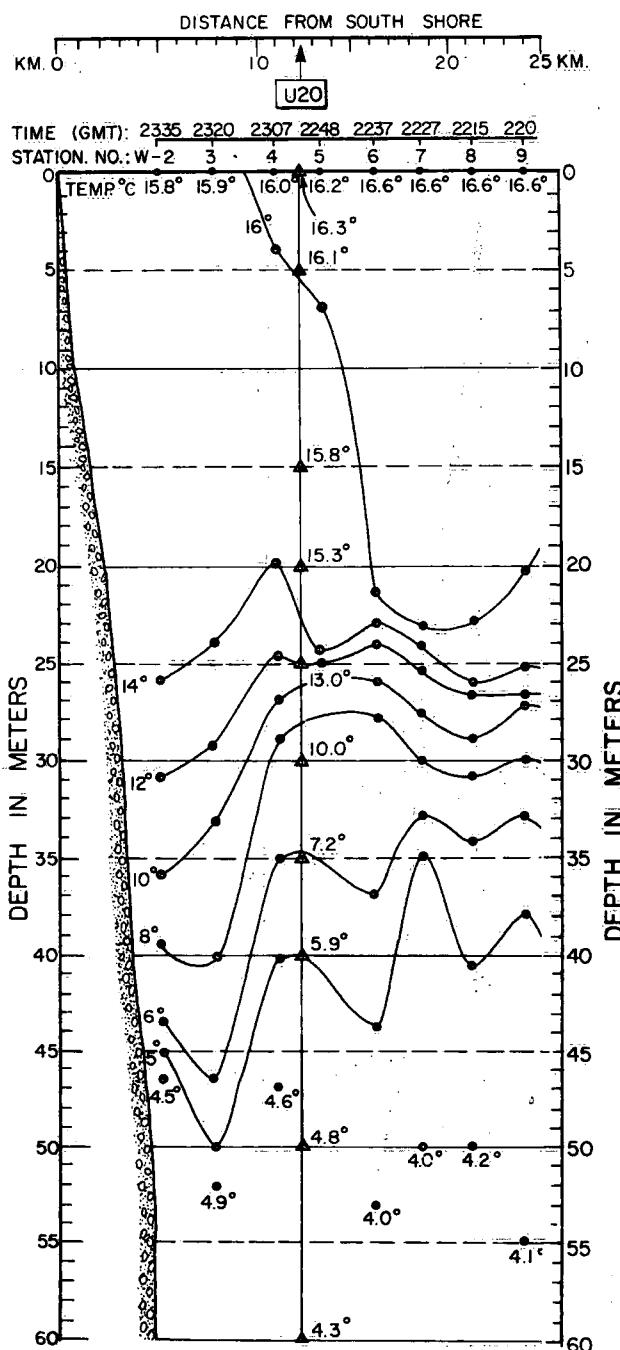
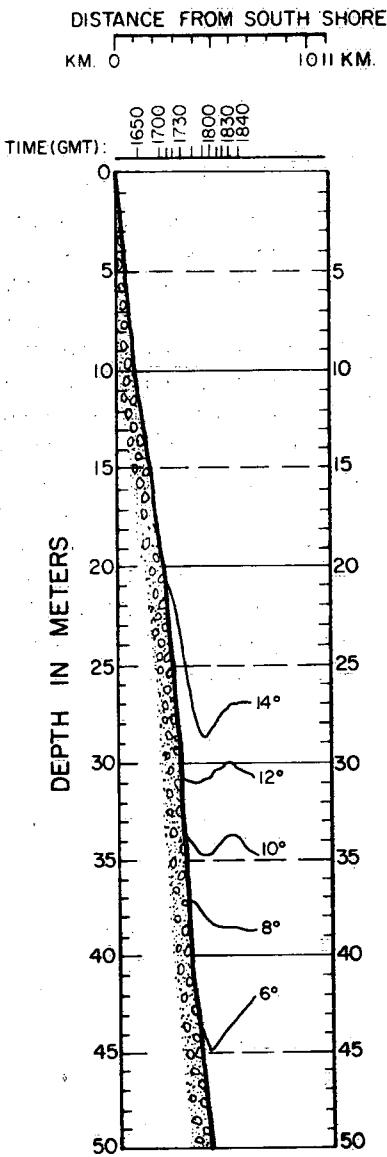


Figure 8.16. Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 12, 4 October.

# IFYGL (LAKE ONTARIO 1972)

## COMPARISON OF TEMPERATURE DISTRIBUTIONS DETERMINED FROM VESSEL TRANSECTS AND COASTAL CHAIN OBSERVATIONS

### OSWEGO COASTAL CHAIN



### TRANSECT NO. **017** FROM OSWEGO TO PRINCE EDWARD POINT

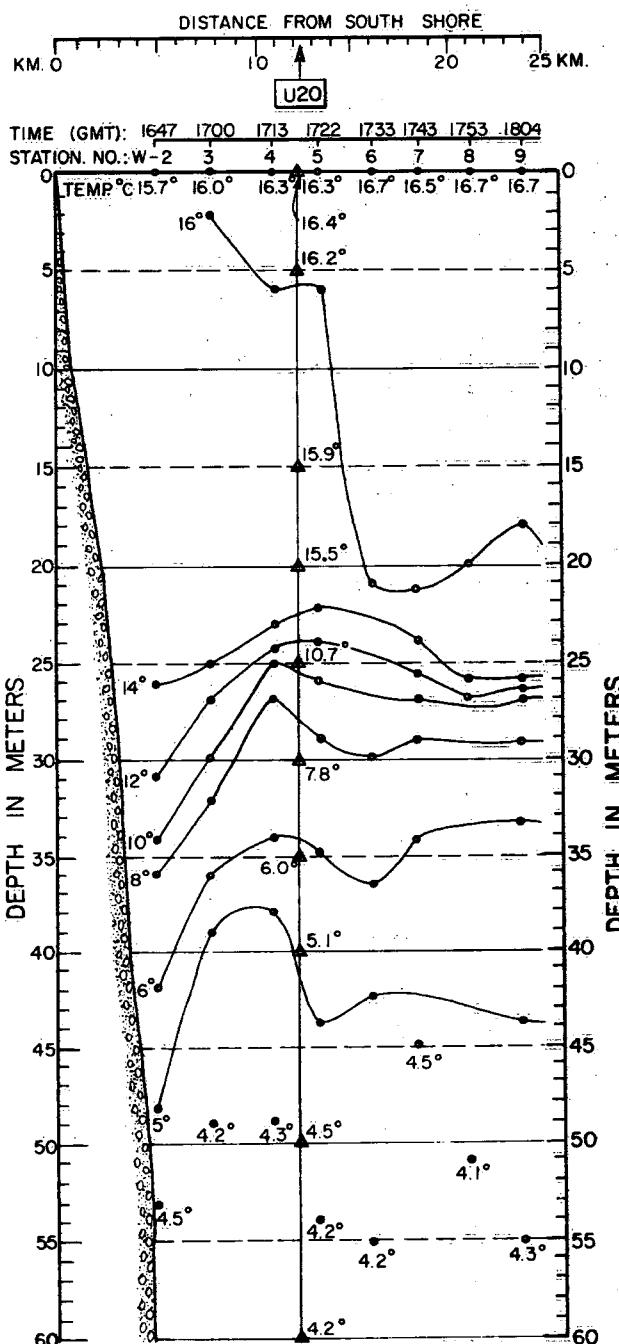


Figure 8.17. Isotherm depths in the Oswego Coastal Chain section and in the contemporary Transect 17, 5 October.

## **Objectives and Anticipated Uses of This Report**

Of the physical variables measured in Lake Ontario during IFYGL, water temperature was the one explored most intensively by various methods and for different purposes. Research vessels devoted most of their effort to a lake-wide monitoring (90 stations occupied at two-weekly intervals) of the slow seasonal changes in heat distribution. Aircraft equipped with infrared radiation thermometers obtained truly synoptic and very detailed pictures of surface skin temperature over the whole lake, giving clues to subsurface motions, the nature of which was explored by other methods.

One such method, described in Chapter 2, was based on continuously repeated scans of temperature distribution in three selected cross-lake Transects (Fig. 1.1, Olcott to Oshawa, Braddock Pt. to Presqu'ile, and Oswego to Prince Edward Point) simultaneously occupied for five-day periods during July, August, and October 1972. The results of those scans are assembled

as 126 transect diagrams in Chapters 3, 5, and 7, respectively.

Painstaking editing of the transect results—through comparison with all available contemporary data from recording instruments moored in or near the transects, and (in Chapters 4, 6, and 8) from the Coastal Chain surveys made by other investigators for other purposes at the inshore ends of each Transect—has delayed publication of the report. But this complete edited assemblage of all temperature data pertaining to the three cross-lake sections enables the user to interpret the "continuous" records at fixed stations (Chapters 4, 6, and 8) and to follow internal motions on time scales of hours or days, i.e. short enough for water temperature to be accepted as a conservative label of water masses. The report will serve, with the Coastal Chain reports, as a data bank for the study of upwelling-downwelling events, quasi-geostrophic flow, and internal waves.

## References

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- Mortimer, C.H., 1968. Internal waves and associated currents observed in Lake Michigan during the summer of 1963. Univ. Wisconsin—Milwaukee, Center for Great Lakes Studies, Spec. Rep., No. 1, mimeo, 24 p., 120 figs.
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Chain; (lc) Basic data for the Olcott Coastal Chain. State Univ. New York, Albany, Atmos. Sci. Res. Center Rep. Nos. 227a, 279 p; 227b, 232 p; 227c, 306p.

(b) Background and Information Sources

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- Mortimer, C.H., 1971. Large-scale oscillatory motions and seasonal temperature changes in Lake Michigan and Lake Ontario. Pt. I, text, 111p., Part II, illustrations, 106 p., with the collaboration, in Chapter III on internal wave theory, of M.A. Johnson. Center for Great Lakes Studies, Univ. Wisconsin—Milwaukee, Spec. Rep., No. 12.
- Sweers, H.E., 1969. Structure, dynamics and chemistry of Lake Ontario. Mar. Sci. Branch, Dep. Energy, Mines and Resources, Ottawa, Canada, Ms. Rep. Ser. No. 10, 227 p.

## Detailed Specifications and Description of the CGLS Undulator

The towed temperature-depth recording system, as used on the Braddock Pt. to Presquile Transect, was a modified version of the instrument reported on by Mortimer (1972). A general description of the system and its operation is to be found earlier in this report (section 2.2, including Figs. 2.4 to 2.8). Detailed specifications and descriptions of particular components of the system are assembled in this appendix.

### WINCH, CABLE, AND TERMINATIONS

The winch (W) was a modified Hydro-Products model HR-60, gasoline-powered winch. The gasoline engine was replaced by a 5 h.p., three-phase, a.c. electronic motor fitted with a fixed centre, variable diameter pulley transmission system. A simple hand-operated level wind device (L) was placed above the winch drum in easy reach of the winch operator, to facilitate cable handling (see Fig. 2.4).

The cable used was 1000 m of 3-mm-diameter, counterspiral wound, armored steel with a single insulated centre conductor. It was terminated at the towed unit (fish) end by a swivel connector with a watertight rotating contact, from which a watertight connection was made into the fish. In spite of the counterspiral construction of the cable armoring, torque changes occurred at the fish end when large changes in tension occurred during the dive cycle. The swivel, specially constructed at the Center for Great Lakes Studies, was therefore necessary to prevent breakage of the connection between the cable end and the fish (see Fig. A.2).

The 3-mm-diameter steel cable with a single centre conductor not only provided the mechanical link between the control system on the towing vessel and the fish, but it also constituted the electrical link. The inner conductor and the spiral-wound outer armoring were used to conduct power from the on-deck power supply to the sensor electronics and as the transmission medium for transmitting data from the fish to the on-deck monitoring and recording equipment.

To complete the electrical connections for power and data transmission, a slip-ring commutator was provided

on the winch. This particular model possessed seven rings each with a bronze brush. In an attempt to minimize slip-ring noise, four ring-brush sets were connected in parallel for the ground and three sets were connected in parallel for the data and power.

### THE TOWED SENSOR HOUSING (THE FISH)

The sensor housing or fish is shown in Figures A.1 and A.2 (see also the photograph in Figure 2.6). Specifications are given in Table A.1. This housing served as a vehicle for the temperature and pressure sensors, and their associated electronics.

Table A.1. Sensor Housing Measurements

Body	Steel tubing, $\frac{1}{4}$ in. wall, $3\frac{1}{2}$ in. o.d., nickel plated, wt. 25 lb, length (with nose) 22 in.
Nose piece	Machined steel, $3\frac{1}{2}$ in. diameter, $6\frac{1}{2}$ in. long, nickel plated, wt. $16\frac{1}{4}$ lb
Fins (three)	Steel plate, $\frac{1}{4}$ in. thick, nickel plated, welded to body, all fins demountable to permit pressure testing of the body in an available vessel

The towing cable was attached to the housing just forward of the vertical fin. Several attachment holes were provided; the best one for towing was chosen by trial and error.

At the front of the sensor housing there was a solid bulkhead with a hole drilled and threaded to receive a Marsh-Marine RM-4-FS-P, watertight connector. Over this connector was fitted a heavy nose piece, attached to the front of the housing by four set screws.

#### Pressure Sensor

The specifications of the pressure transducer (Statham Instruments, model PA505-200,  $3 \times 1$  in.) were as follows (data supplied by manufacturer):

Range: 0-200 psi (maximum overload, 400 psi)

Transduction: resistive, balanced, fully active strain gage bridge

**Power requirements:** 28  $\pm$  4 V d.c. (25 mA at 28 V d.c.)

**Output voltage:** 0.1 to 5 V d.c. nominal. Output noise: < 5 mV rms

**Non-linearity and hysteresis:** less than  $\pm$  0.75% full scale

**Compensated temperature range:** 0-65°C

The pressure sensor (Statham Instruments) was housed inside the fish, connected to the ambient environment via a tube emerging through the rear cover cap, passing upward along the rear edge of the vertical fin, and terminating at a hole drilled in the fin edge (P in Figs. 2.4 and 2.6). That hole was also connected to several other holes, drilled in the fin and directed perpendicular to the direction of water flow over the fin. This arrangement was designed to ensure that the effect of variation in towing speed on the measured (hydrostatic) pressure could be neglected.

#### Temperature Sensor

The temperature sensor was a composite thermistor bead (Yellow Springs Instruments No. 44204) with linear response. The accuracy guaranteed by the manufacturer was  $\pm 0.15^\circ\text{C}$ , with a time constant in stirred oil of 1 s. The bead was mounted in epoxy resin at the end of a  $\frac{1}{4}$ -in. galvanized iron U-shaped pipe, the other end of which carried the electrical connection, through a watertight seal in the end-cap, into the fish body. The thermistor end of the pipe was bent, under the fish body, to face forward into the water flow, so that the partially exposed thermistor bead would respond as quickly as possible to temperature changes. The surface of the bead was reduced to about one-half by the method of mounting in epoxy cement; the actual time constant of that component was increased by a factor of approximately five. As explained in section 2.2, the unduly large time constant of this particular instrument meant that the data acquired during the rapid descent portion of the dive had to be discarded entirely and care had to be exercised in interpreting data obtained during the slower ascent (see Chapter 6).

#### Electronic Sections and Data Flow within the Fish

The electronic sections within the towed fish are displayed in Figure A.3. Three parameter voltages—temperature, pressure (depth), and a reference voltage—were time multiplexed according to the format illustrated

in Figure A.4, and converted into digital form for transmission to the on-deck recorders via the towing cable. The analog multiplexer used field effect transistors which were turned on individually to sequentially select the three analog inputs.

The analog-digital convertor was a linear ramp comparator (gated oscillator) design. Under logic control it generated a burst of pulses, the number of which was proportional to the voltage being selected by the analog multiplexer. The pulse burst was converted by the line driver into current pulses, which were detected at the other end of the line by the on-deck electronics.

#### ON-DECK ELECTRONICS AND RECORDERS

All data generated by the system were recorded on magnetic tape by a Precision Instrument tape recorder, model PI-1177 (R in Fig. 2.4). The recorder generated internally the required IBM-compatible loadpoint gaps, inter-record gaps, longitudinal redundancy check characters and end-of-file marks.

Each character was recorded on the tape as a parallel seven-bit byte, according to the standard IBM seven-track EBCID code. The Inter-Record gap command was generated by the on-deck electronics as the IRG signal. The End-of-File command was generated by a manual push-button on the tape deck.

The on-deck system performed the following functions (see Fig. A.5):

- (a) detected serial pulse trains from the submerged sensor and converted the pulse train into parallel binary coded decimal (BCD) data;
- (b) formatted the BCD data and recorded it on 0.5-in. computer-compatible magnetic tape with proper blocking;
- (c) converted and demultiplexed the BCD data into three analog channels for display and analog recording purposes (e.g. with the depth and temperature analog outputs applied to an X-Y recorder);
- (d) sampled the analog depth data and generated information on high-low depth limits for use by the winch operator; and
- (e) provided for manual entry of miscellaneous data and insertion of such data between sampled sensor data on tape.

The detected and conditioned pulse trains were used to generate timing signals, with which the system synchronized its operations. The pulse train was also accumulated in a three-digit BCD counter. Under control of the central control logic, the three-digit BCD data were multiplexed, one digit at a time, through the character encoder, where a beginning-of-word character was added. The central control logic also gave synchronous commands to the "write sequence" control, to enable each encoded character to be written onto magnetic tape.

Logic and external controls (Run/Hold switch) were provided to stop the system manually in one of two modes: (i) at the end of a sampling sequence, and (ii) when the block length counter initiated an inter-record gap sequence. The second mode (ii) was used prior to the end-of-file sequence generated by the manual controls on the tape deck. A third manual input (Sample Frequency Select switch) selected recording rates of four, two, and one data points per second. For each of these recording rates the towed sensors continued to sample at a fixed rate of four samples a second.

A block-length counter accumulated the number of write cycles and, at a predetermined number, stopped the write cycle and commanded the tape deck to generate

an inter-record gap. Upon completion of gap generation, a signal from the tape deck permitted the system to return to the write sequence.

The data (parameter-serialized and bit-parallel) was converted to an analog voltage and demultiplexed by a three-channel sample-and-hold circuit. The three analog data channels were then displayed on panel meters and could be used to drive X-Y or other strip-chart recorders.

The depth analog channel was monitored to give warning to the operator when preselected high and low limits were exceeded. As an additional safeguard, the towing cable carried a projection which triggered the "end-of-cable" warning switch E on the towing sheave (E in Fig. 2.5), described in the legend of Figure 2.5.

An external data entry system was incorporated, which could insert on the tape a record of navigational information, time and other miscellaneous data. These data were entered and stored in a memory from the panel keyboard. Upon operator command, the data were read from memory and written onto the magnetic tape without stopping or interrupting the data sampling process.

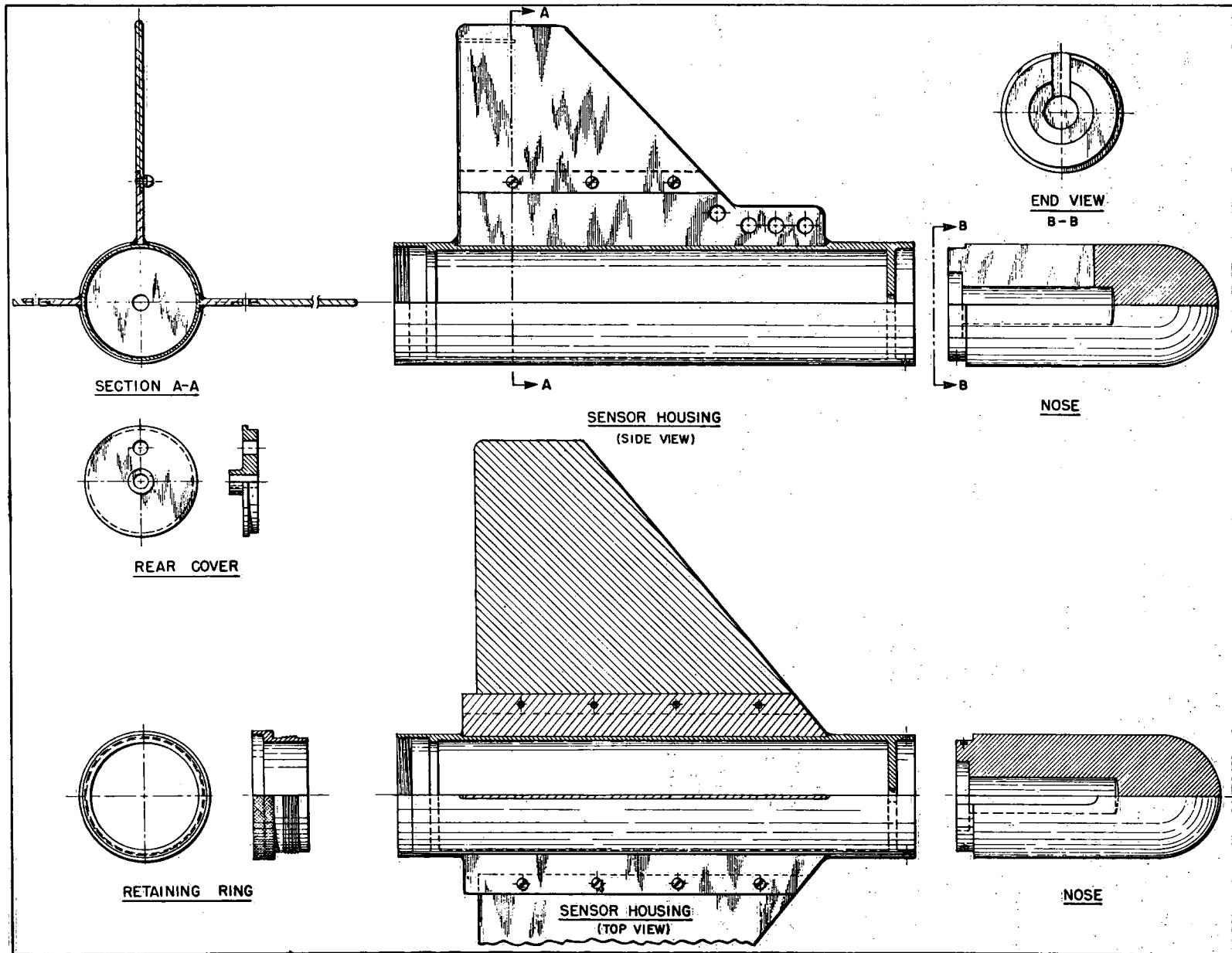


Figure A.1. Details of sensor housing (1 / 4 full-size).

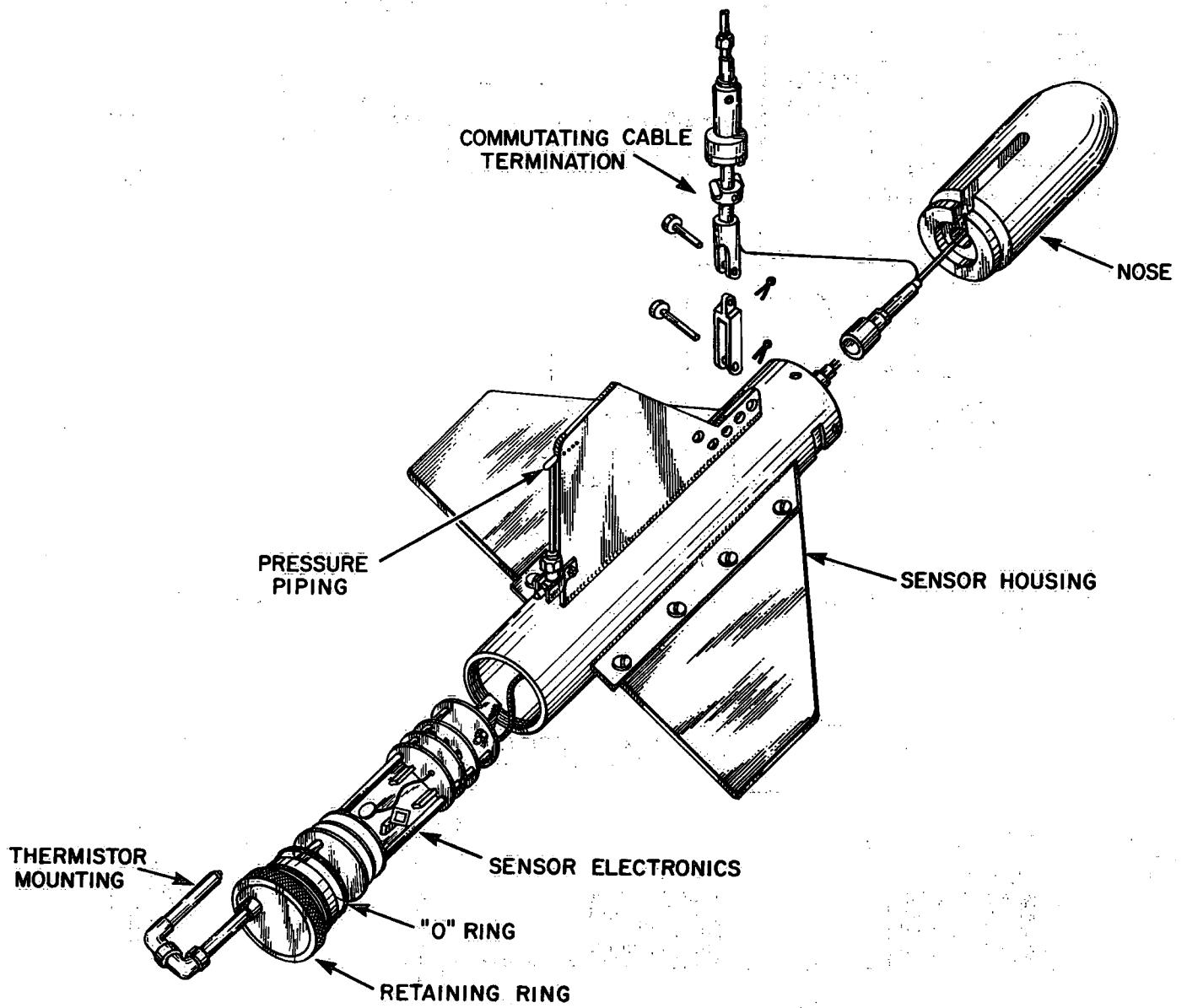


Figure A.2. Exploded view of the sensor housing, contents, and attachment (1/6 full size).

## UNDULATING SENSOR ELECTRONICS

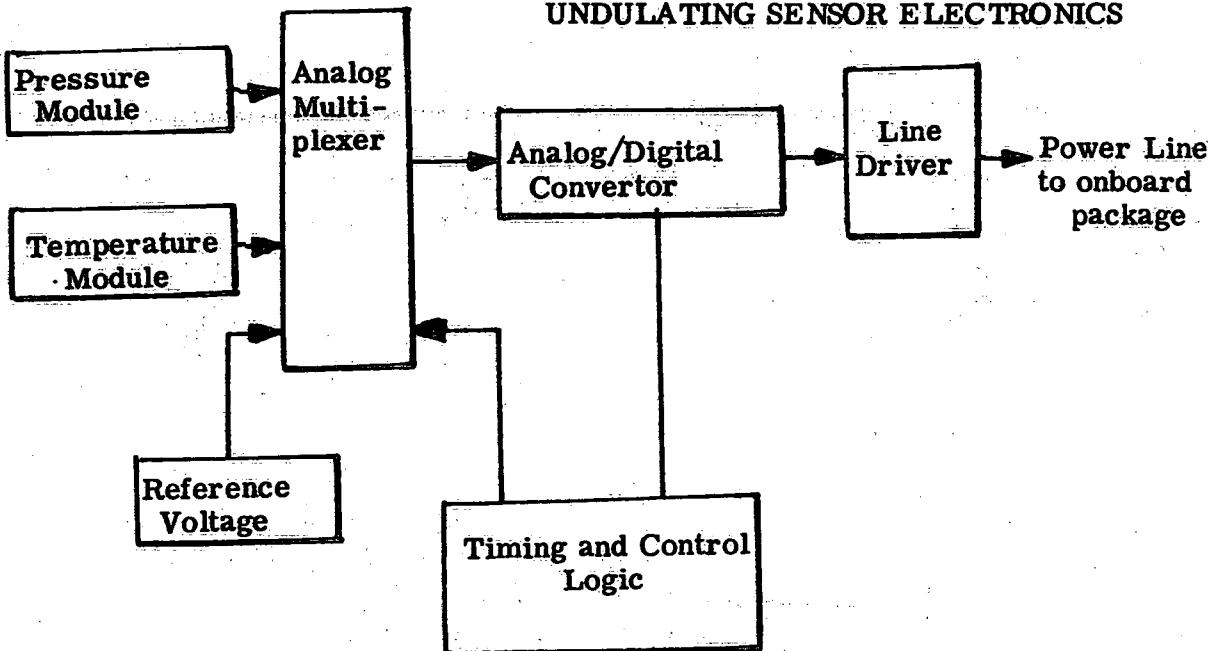


Figure A.3. Block diagram of major electronic sections and data flow within the towed sensor package (fish).

## DATA TRANSMISSION FORMAT

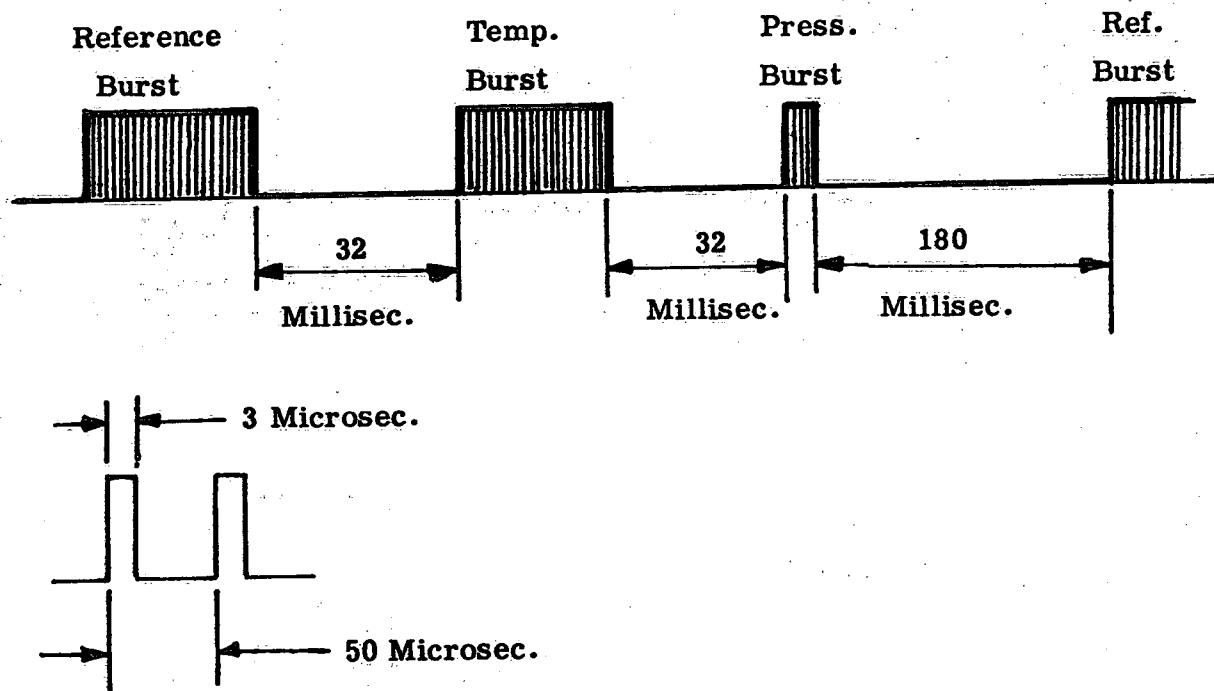


Figure A.4. Format of data transmitted from the sensor package, as burst of pulses, through the towing cable to the on-deck recorders.

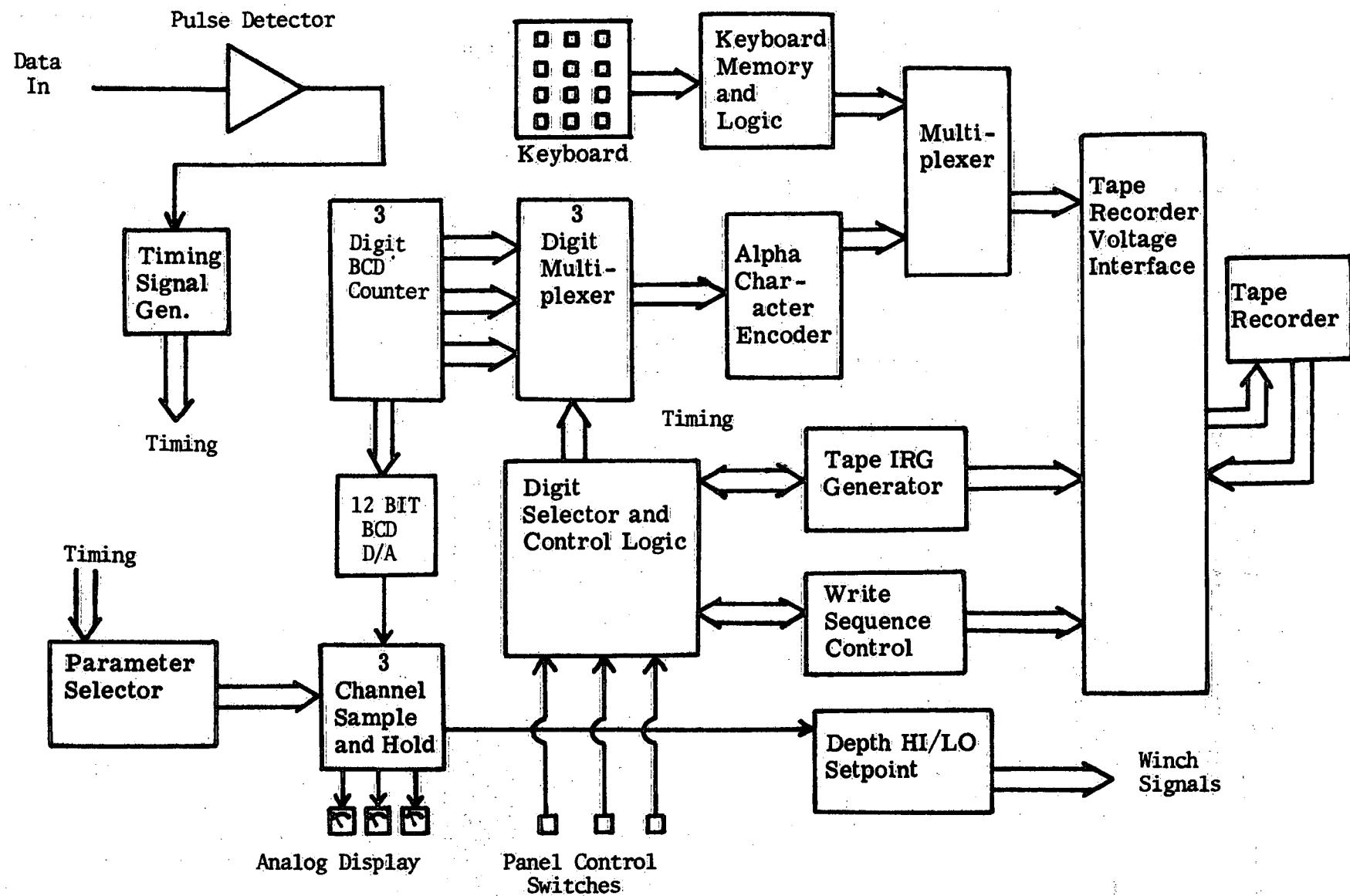


Figure A.5. Block diagram of electronic sections, recording components, and data flow in the on-deck recording system.

## Specifications of CCIW Batfish System and Description of Data Reduction Techniques

### BATFISH SYSTEM—DESCRIPTION AND SPECIFICATIONS

Section 2.1 contains brief descriptions of the Batfish, the towed array and the SBT systems together with their modes of operation. However, the CCIW transect data presented in this report were collected entirely with the Batfish system, and for this reason a more complete description is appended.

The system may be broken down into the following components: (1) Batfish vehicle; (2) sensors; (3) tow cable; (4) winch; (5) analog data display; (6) analog to digital convertor and recorder.

#### Batfish Vehicle (Table B.1)

The Batfish vehicle was developed at the Atlantic Oceanographic Laboratory (Bedford Institute of Oceanography, Dartmouth, N.S.) and manufactured by Hermes Electronics of Dartmouth, N.S.<sup>1</sup> The fish is made of reinforced plastic (Fig. B.1). A main fuselage contains the sensor payload and elements of the control system. On this fuselage are attached two active lifting surfaces (hydrovanes), stabilizing fins, a roll-stabilizing rudder, and a rotating impeller. Depth control is achieved through varying the angle of attack of the hydrovanes; very little of the downward force required to oppose the lift generated by the tow cable is obtained from the weight of the vehicle and load.

The angle of attack of the hydrovanes is varied by means of a hydraulic system comprising a pump driven by the impeller, a small hydraulic ram, and an electrically operated servo-valve. The valve controls both the direction and rate of change of the hydrovane angle of attack.

The electrical commands to the servo-valve are provided by a control unit which consists of a vehicle-mounted pressure sensor arranged to output a d.c.

voltage (0-2.5 V) proportioned to vehicle depth, and a shipboard electronic command device. The command signal is a d.c. voltage of the same range and polarity as the output from the pressure transducer, and this voltage is proportional to the desired or command depth of the vehicle. The difference between the command voltage and the pressure transducer output (desired depth and vehicle depth) forms an error signal, which, suitably amplified, activates the hydraulic servo-valve. A small alternating "dither" signal is added to the error signal to overcome a tendency of the valve to stick and thus improves the response of the vehicle to small changes in the error signal. When the command voltage is held constant, the vehicle seeks to fly at a constant depth. Because the dynamic response characteristics of the system depend on the depth of tow and the amount of cable streamed, the gain and bias of the error amplifier must be adjusted manually to ensure stability of flight. Correct adjustment is a matter of trial and error, but is rapidly achieved by an experienced operator.

Table B.1. Batfish Vehicle Specifications

Dimensions:	Height	0.9 m
	Length	1.3 m
	Wingspan	0.7 m
	Weight (in air)	70 kgf
	Weight (in water)	50 kgf
Range of towspeeds		3-14 knots
Range of depths attainable with faired cable at 10-knot tow speed		0-200 m
Maximum dive rate		1 m/s at 10 knots
Maximum ascent rate		5 m/s at 10 knots
Payload		Interior of the vehicle will accommodate a cylindrical case of 12.5 cm in diameter, and 62 cm in length

The command voltage may be varied manually or introduced via a signal generator. In the latter case, a sawtooth wave form is generated, the analog of the desired flight path of the vehicle. Controls provide for variation of the maximum and minimum of the oscillating command voltage (maximum and minimum depth), and for the rates of change between the two (rates of ascent

<sup>1</sup> The Batfish system is now manufactured and marketed by Guildline Ltd. of Smiths Falls, Ontario.

and descent). Because of the complexity of the system transfer function (essentially non-linear), the vehicle does not follow exactly the command signal, but can nevertheless be made to oscillate between selected depths, at rates consistent with the collection of reliable data. The presence of an operator is required to ensure that the vehicle flies correctly, since the adjustments are somewhat unstable in time. His presence is particularly required in shoaling water, since the maximum command depth must be reduced progressively to avoid collision with the bottom. The instantaneous depth of the vehicle is displayed at all times to the operator.

A third control mode exists wherein the command voltage alone is fed to the servo-amplifier (open feedback loop mode). Depending on polarity, a maximum-rate dive or ascent is produced. This mode can be used to initiate an emergency ascent when collision with the bottom seems imminent.

A novel gravity-operated rudder maintains stability of the vehicle about its roll axis, making unnecessary the carrying of heavy ballast. A small vertically hinged rudder is attached to the rear of the fuselages, and from the rudder a pendulum projects horizontally and rearwards. If, while under tow, the vehicle starts to roll off the vertical, the pendulum swings the rudder in the direction which produces a righting moment. With the vehicle on the surface of the water, this mechanism no longer acts, and the fish tends to assume a large roll angle and to yaw or paravane to one side or other of the ship's track. Since the direction of yaw seems to be very consistent with a particular vehicle, the tow point on the ship can be arranged so that the vehicle yaws clear of the ship's wake when on the surface. In this way, the dive cycle of the flight carries the vehicle through water which is undisturbed by the presence of the ship.

#### Sensors (Table B.2)

The vehicle sensor package is a Guildline (Smiths Falls, Ontario) model 8250 B electronic bathythermograph (Fig. B.2). This unit carries a pressure sensor in the form of a diaphragm strain-gauge type transducer and a temperature sensor consisting of a Formel copper element spirally wound inside an oil-filled stainless steel tube. Through a synchronous switching device, the sensors and their amplifiers operate with an alternating square wave signal, while the output is a d.c. voltage from a relatively low source impedance. The switching circuitry and amplifiers are carried in a pressure case aboard the vehicle, while the power supply and control panel remain in the ship's laboratory space.

Table B.2. Sensor Specifications

Vehicle sensors	Model 8250B EBT Guildline, Smiths Falls, Ontario. Modified to permit remote mounting of the temperature sensor
Temperature	Resistance thermometer using Formel copper wire spiral inside stainless steel tubing. Thermometer element wound into 5-cm-diameter spiral about 7 cm long. Signal level 0-3 V d.c.; 150 ohm output impedance Linear output at 100 mV/°C. Range 0-30°C. Accuracy $\pm 0.01^\circ\text{C}$ $\pm 0.1\%$ reading. Nominal accuracy: $\pm 0.05^\circ\text{C}$ . Time constant 0.1s in still water.
Pressure	Strain gauge diaphragm type. Viatran model PTB-207C-1
Range	0-100 mH <sub>2</sub> O
Output	0-2.5 V d.c.; output impedance of 150 ohms
Accuracy	$\pm 1\%$ of reading
Nominal accuracy	$\pm 1 \text{ mH}_2\text{O}$
Tension	Woods model 1912-5K strain gauge type transducer. 0-2300 kgf (0-5000 lb) Daytronics model 870 strain gauge bridge and amplifier 0-10 V d.c. output: linear response Output impedance: 50 ohms Accuracy $\pm 1\%$ full scale

Since the Batfish vehicle is designed to accommodate plankton samples, fluorometers, etc. requiring a flow of water, the nose of the vehicle terminates in a scoop, and a water tunnel passes through the centre of the fuselage. The temperature sensor is remotely mounted from the aluminum pressure case and is located at the entrance to the water tunnel, where it receives the full flow of undisturbed water. A strain-gauge type tension transducer is incorporated into a sling which ties the flange of the winch drum to the frame. This link is attached once the tow cable has been payed out, whereupon the winch motor and brakes are disengaged, allowing the cable tension to be measured by the transducer.

#### Tow Cable (Table B.3)

The tow cable serves four functions: (1) mechanical support of vehicle; (2) transmission of power to vehicle sensors and amplifiers; (3) transmission of pressure and temperature signals to the ship; (4) transmission of commands to servo-valve. The cable chosen is composed of a central core containing seven copper conductors, individually insulated, upon which are wrapped two layers of galvanized steel wire. The outer wrapping is designed to minimize the tendencies for the cable to twist or to crush the inner conductors when a load is applied. The overall diameter of the cable is 0.75 cm (0.3 in.).

**Table B.3. Cable of Fairing Specifications**

Cable	Amergraph (U.S. Steel) type 7J30SB Two-layer armour wrap of galvanized steel Seven No. 22 AWG tinned copper conductors with polypropylene insulation Overall diameter 0.75 cm Resistance of individual conductor 0.06 ohms/m Total breaking strength: 3000 kgf Weight of cable in air: 0.20 kgf/m
Fairing	Fathom Flexnose (Fathom Oceanology), Port Credit, Ontario. Nylon leading edge with plastic tailpiece Chord length: 4.4 cm Individual module length: 10 cm Thickness: 1.25 cm (Frontal) Drag coefficient: 0.10
Winch to lab cable	Belden 8426, 6 conductors (18 AWG) plus shield (used as 7th conductor). Rubber insulation neoprene jacket. 30 m long

The water drag on the cable must be held to limits dictated by the negative lift characteristics of the vehicle, and to reach depths of 60 m at tow speeds of 10 knots with less than 100 m of cable streamed, it is imperative that the cable be faired (Fig. B.3). Moreover, the strumming induced by the vortex shedding from an unfaired cable accelerates the deterioration of the cable and the mechanical integrity of the sensor package. Accordingly, the tow cable is faired with "Flexnose" fairing developed by Fathom Oceanology (Port Credit, Ontario). This fairing is applied in 10-cm-long elements, each element comprising a rigid plastic tailpiece and a flexible nylon leading edge. Plastic fairing stops are moulded on the cable itself at approximately 3-m intervals to oppose the component of drag force acting along the cable. The tolerance of fit between tow cable and fairing permits free rotation of the fairing about the cable. The leading edge of the fairing sections joins the tailpiece via a longitudinal groove. Thus by overlapping the leading edges so that they link up adjoining tailpieces, the fairing is applied in continuous modules of length equal to the gap between fairing stops (3 m). This linking is adopted primarily to reduce damage to the fairing caused by winching the cable over pulley blocks. Out of the water, the fairing tends to rotate about the cable so that the tailpieces hang downward. As the fairing passes over a pulley it must rotate so that the leading edge lies against the surface of the wheel. There is a possibility that a piece of fairing approaching a sheave with its tail downward may jam momentarily with enough force to shatter the plastic of the tailpiece. By joining the individual fairing sections into longitudinal modules, this risk is confined to the first fairing section to encounter the pulley in any such module.

**Winch (Table B.4)**

The winch was made in the CCIW shop and is intended to accommodate a single wrap of large-diameter faired cable (Fig. B.4). The winch is hydraulically operated via a motor and gear box originally intended for a gill-net drum. The drive permits rotation in either direction under power, a free wheeling mode, and is also equipped with a locking friction brake. A manually operated level-wind device is attached. The tow cable is mechanically terminated at the drum surface, while the electrical conductors lead to a set of slip rings allowing electrical communication with the vehicle to be maintained while the winch is operating.

**Table B.4. Winch Specifications**

Drum diameter: 76 cm (30 in.)
Drum length: 76 cm (30 in.)
Gear Matic Hydraulic Drum Drive (Gearmatic Co., North Surrey, B.C.)
Pull of 450 kgf (1000 lbs) when driven by 8250 kPa (1200 psi)
Speed: 0-1 m/s
Slip rings: Guildline (Smiths Falls, Ontario)
Oil-soaked steel wool brush on brass commutator
Sheave: 90 cm diam. magnesium wheel with throat diameter of 10 cm. Pulley surface lined with polyurethane plastic (Timberland and Elliott, Woodstock, Ontario)

The cable is led over a large-diameter pulley attached to the tow point. The pulley wheel groove is relatively wide to avoid damage to the fairing.

#### Analog Data Display

The pressure-depth signal and the temperature signal (d.c. voltages in the ranges 0-2.5 V and 0-3 V, respectively) are recorded in analog form on a two-channel strip-chart recorder (Table B.5). This record is intended as a backup measure in the case of failure of the digital recording system. The signals are also fed to an X-Y recorder which serves as both a visual monitor of the system performance and a means of obtaining a further analog record. In the latter mode, the recorder pen is

**Table B.5. Specifications of Analog Recorders**

Two-channel strip chart recorder: Hewlett Packard Model 7100B electric writing; input impedance >1 Mohm
X-Y recorder: Hewlett Packard model 7005B ink writing 28 x 43 cm (11 x 17 in.) table includes Hewlett Packard 17005A chart advance accessory
Input impedance >1 Mohm Accuracy ±0.2% full scale Lineally ±0.1% full scale

engaged as the Batfish begins a dive and disengaged at the attainment of maximum depth. A temperature-depth profile is produced along a slanting trajectory encompassing a horizontal distance of one-half the Batfish wavelength (500 m).

The tension signal is not usually recorded but is displayed on a dial readout voltmeter.

#### Analog to Digital Convertor and Digital Recorder (Table B.6)

The final repositories of temperature-depth information are reels of computer-compatible ½-in. magnetic tape. To this end, the analog voltage signals are input to a scanner-recorder system manufactured by The Analog Digital Data Systems Company of Rochester, New York. A digital clock paces the operation and provides time information. On receipt of a pulse from the clock, a serializer-controller initiates a sequential scan of up to 20 input channels, connecting each of them in turn to an A/D converter. A sequence of binary decimal-encoded words is produced for each scan, starting with a four-character time word (day, hour), the number of the first

channel sampled, and continuing with a three-character word for each input channel (three significant figures). This sequence is written on magnetic tape in a common seven-track BCD code. The sampling interval is variable from 0.1 s to 1 hr, and any sequentially ordered block of channels from the 20 inputs available may be recorded. If required, an additional manually coded 12-character word may be inserted ahead of the first time word. This word is composed via a set of thumbwheel switches, and is used to insert coded information concerning tape identification, format specifications, channel identification, calibration data, time information, and navigation parameters. A provision is made for the blocking of the data into records of suitable length for subsequent computer processing.

The sampling interval used for all the transect cruises was 1 s. This is long compared with the time constant of the Batfish temperature sensor, so that some aliasing of higher frequencies into the record is inevitable. The sampling interval was chosen to minimize the amount of data collected while still retaining good-quality records from the towed array. The high-frequency aliasing of the Batfish data is thought to add a noise level which is small compared with that incurred by the 500-m spatial sampling interval.

**Table B.6. Specifications of Automatic Data Logging System\***

Inputs	Up to 20 d.c. voltage signals in range 0-10 V non-floating, plus a manually encoded 12-character word
Input impedance	Alternates between open circuit and 4000 ohms when connected to the A/D convertor.
Resolution	(least significant figure) $\pm 100$ mV or $\pm 0.1\%$ full scale
Sampling Interval	0.1 s to 1 hr in several discrete steps
Output	12-character manual word (optional), time word (hour, minute), first channel number, one 3-character word for each channel sampled. Output repeated for each scan and blocked into records. Record length variable.
Output format	BCD encoded 7-track ½-in. magnetic tape. Records separated by ¼-in. blank inter-record gaps. End-of-file marks are manually initiated

System assembled in modular form

1. Digital clock (ADDS, model 015012)
2. Serializer-controller (ADDS, model 016020)
3. Reed-relay scanner (ADDS, model 012126)
4. A/D convertor voltmeter (ADDS, model 013012)
5. Analogue amplifiers (CCIW) and filters
6. Tape recorder (Digi Data, model 135F Incremental)
7. Fan unit (ADDS)

and is mounted in standard 19-in. relay rack 6 ft high.

\*Manufactured by Analog Digital Data Systems, Inc. of Rochester, New York to specifications prepared by CCIW.

#### BATFISH SYSTEM PERFORMANCE

##### Mechanical Performance

With three exceptions, to be explained below, the mechanical components of the system gave excellent service throughout the experiments.

The tow cable fairing became disarrayed with time, necessitating interruptions at about 12-hr intervals to straighten it out. The fairing elements, which were joined by overlapping nose-pieces, tended to separate, to ride up on one another, and thus to destroy the hydrodynamically smooth performance. This deterioration caused an increasingly erratic behaviour of the vehicle, requiring frequent adjustment of the servo gain and bias controls to maintain the desired operating cycle. The deterioration of the fairing occurred mostly in the lower one-third of the cable (portion nearest the vehicle). It is thought that the damage occurs when the vehicle is on the water surface and the flow past the fairing is mainly along the cable, rather than at right angles to it. Under these conditions, the orientation of the fairing is unlikely to be steady, and one can envisage situations where two adjoining elements tend to counter-rotate once they are forced apart at the tail. The nose-piece alone must resist this torque,

and since the grooves into which the nose-pieces fit are relieved over a portion of their length to ease passage of the cable over pulleys, it is not surprising that the fairing begins to separate. The performance of the fairing would be improved by joining the links at the tail (flexibly) and by eliminating the relief of the tailpiece grooves. Subsequent versions of the fairing incorporate both features with success.

The second fault was the repeated failure of the rubber expansion nipple placed over the hydraulic oil reservoir port on the vehicle control mechanism. When this occurred, water entered the hydraulic circuits and formed a thick emulsion, which in turn affected the operation of the servo-control valve. The failure seemed to be due mainly to incompatibilities between the oil and the material of the expansion nipple. A finger from a neoprene rubber glove worked better than anything else tried, and this small but important item is now checked regularly.

The Batfish vehicle struck bottom at least twice during the experiments despite careful attention to the maximum dive depth and the depth of water indicated by the ship's echo sounder. On both occasions, damage was slight but could easily have been total. The problem arises because the depth indicated by the echo sounder when the maximum depth control is adjusted does not always correspond with the depth found below the Batfish on the next dive. Some form of active bottom avoidance device is highly desirable for use in coastal waters. At the time of this writing, such a device has been constructed at the Bedford Institute.

#### **Electrical Performance**

All sensors worked reliably throughout. Some initial difficulties were encountered with electrical grounding as a result, in part of the ship's electrical system, which provides 110 V, 60 cycle d.c. via two oppositely phased 55-V supplies instead of the usual single 110-V supply and a neutral conductor. One side of the inputs of the ADDS is at instrument ground (non-floating). Isolating amplifiers were required for some of the inputs to the scanner.

#### **Data Logging**

The collection of analog temperature-depth profiles proved to be very valuable not only as a backup to the digital recording system, but also for the information they contain on the vertical thermal structure of the water

column, information that is less well-documented in the digital record because of the finite sampling interval.

The ADDS system is prone to operator errors mostly in the maneuvers required to introduce coded manual data via the thumbwheels. This was not discovered until the data processing stage, where the errors caused much initial confusion. It was concluded that only a tape-identifying code need be entered, and that all additional information was more accurately retained in a written log book.

The ADDS system now represents a somewhat antiquated technology, and while still serviceable, could profitably be replaced by more reliable and flexible equipment.

#### **DATA REDUCTION TECHNIQUES**

The analog data have been used in conventional ways in preliminary cruise reports and need not be discussed further.

The main body of data can be viewed as two streams of information, one consisting of temperature-depth samples recorded as their voltage analogs together with time information on magnetic tape, and the other comprising the ship's position at fixed time, format specifications, and calibration information, written originally in laboratory notebooks and the ship's log. Each crossing of the lake constitutes a "file" of data which forms the input to the process generating a transect diagram. We shall briefly describe this process.

In a first stage the data are run through program T0WPR1, a program which decodes raw data from the ADDS system tape and prints out selected records for verification. Any inconsistencies with that which is expected to be on the tape are revealed at this point (parity errors, faulty data, errors in formation or coding, etc.) and decisions can be made on how to process further or to delete doubtful passages.

In the next stage, the data are fed to program T0WPR0 together with information on punched cards concerning calibration information, formatting specifications, records to be deleted, and ship's position. The ADDS values (voltages) are now converted into physical variables (temperatures and depths) and the ship's position along the transect line is computed for each scan time. In this last operation, the series of navigational fixes made on the crossing of the lake (latitudes and longitudes) are converted into rectangular coordinates

(origin at the Olcott shoreline) X and Y, with X being the distance along the transect line from Olcott (positive northwards), and Y being distance to the west of the line. The Y values were checked to make sure that the ship had not strayed significantly from the intended path but were otherwise discarded. Given the X values and times of the fixes, the X values for each of the scans were computed by linear interpolation. The output from TØWPRØ was stored on a separate magnetic tape.

A third program, PLØBAT, operated with the converted data produced by TØWPRØ, calculated the isotherm depths for each transect. The family of even-degree Celsius isothermal surfaces is chosen for this representation. The isothermal surfaces are defined by the sequence of triplets of temperature  $\theta$ ,  $(Z_\theta, X_\theta, t_\theta)$ , where  $Z_\theta$  is the depth of encounter of the surface at distance  $X_\theta$  along the transect line, and at time  $t_\theta$ . These triplets are constructed by scanning the sequence of temperature, depth, time, and distance quadruplets of the primary data,  $(\theta_i, Z_i, t_i, X_i)$ , and determining the points at which the vehicle runs through the isothermal surface in question, an event signalled by

$$\theta_{i-1} \leq \theta \leq \theta_i \text{ or } \theta_{i-1} \geq \theta \geq \theta_i$$

The values of  $Z_\theta$ ,  $X_\theta$ , and  $t_\theta$  are then determined by straightforward linear interpolation. The output of PLØBAT comprises a sequence of triplets for each desired isothermal surface and is committed to another magnetic tape.

Finally, a simple routine driving the CALCOMP plotter reads data from the PLØBAT output tape and plots the trace of each isothermal surface along the transect line. The plot is achieved by drawing straight lines between adjacent points of encounter as defined by the  $Z_\theta$ ,  $X_\theta$  values of the triplets  $(Z_\theta, X_\theta, t_\theta)$ . Recognizing that the horizontal distance between successive encounters of an isothermal surface may be as large as 1000 m (Batfish "wavelength") and thus introduce considerable aliasing

of the shorter wavelength thermal features, we feel this display to be more informative than an artificially smoothed curve. A jagged, uneven trace of an isothermal surface is then to be considered indicative of the presence of horizontal scales of variation of thermal structure improperly resolved by the Batfish system but effectively resolved by the towed array system. This substructure is to be the topic of a future report.

## OVERALL ACCURACY OF THE BATFISH SYSTEM

The individual temperature and depth readings are thought to be accurate to within  $\pm 0.1^\circ\text{C}$  and  $\pm 1.0$  m. The errors introduced in digitizing the signals and in interpolating between pairs of temperature depth points are likely to be much smaller so that the error in computing an isotherm depth is essentially

$$\delta_z \xrightarrow{\Delta\bar{\theta}(d\bar{\theta}/dz)^{-1}}$$

where  $\delta_z$  is the depth error,  $\Delta\bar{\theta}$  the temperature error, and  $d\bar{\theta}/dz$  is the mean vertical temperature gradient. The arrow over the plus sign indicates that quantities are combined as the root of a sum of their squares. Taking  $d\bar{\theta}/dz$  to be  $1^\circ\text{C/m}$ , the total depth error is about  $\pm 1.5$  m in the thermocline region. Any regular bias due to the finite time-response of the instruments should be much smaller than this.

The uncertainty in horizontal location is difficult to estimate. The navigational fixes were made with a Decca System and should be accurate to within 200 m. However, individual fixes are located some 10 km apart or  $1/2$  hr in time. As long as the ship made steady progress along the line, the uncertainty in estimating its absolute position at any instant should not exceed a radius of 1000 m, an acceptable accuracy for displaying the major features of the thermal structure across a 60 km transect line.

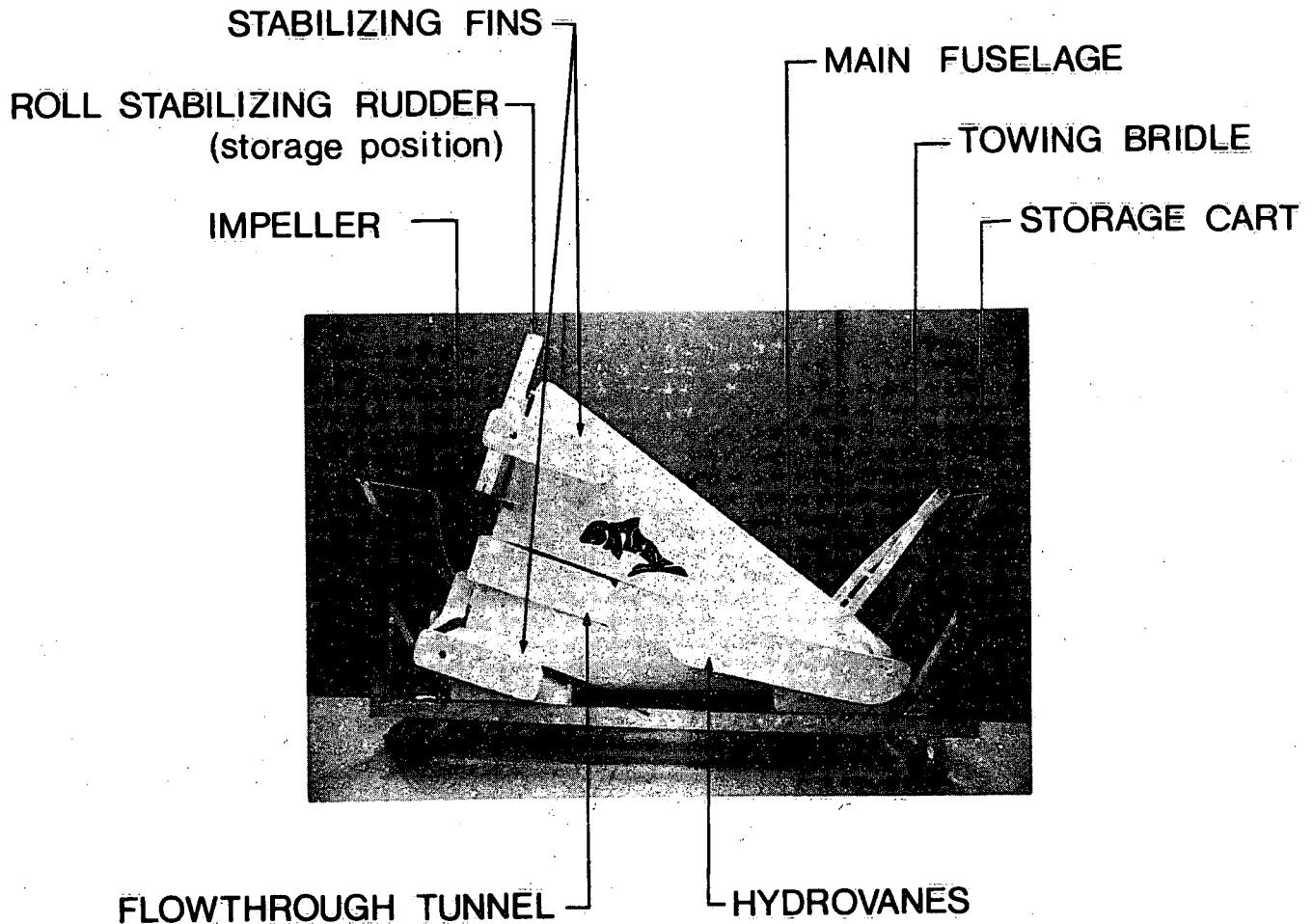


Figure B.1. The Batfish vehicle as seen from the side in its storage cart. The entrance to the tunnel is at the nose of the vehicle (right side of photograph) and is obscured by the starboard hydrovane. The bar referred to as the roll stabilizing rudder and which is positioned perpendicularly to the plane of the stabilizing fins, is rotated into the plane of the fins while the vehicle is under tow.

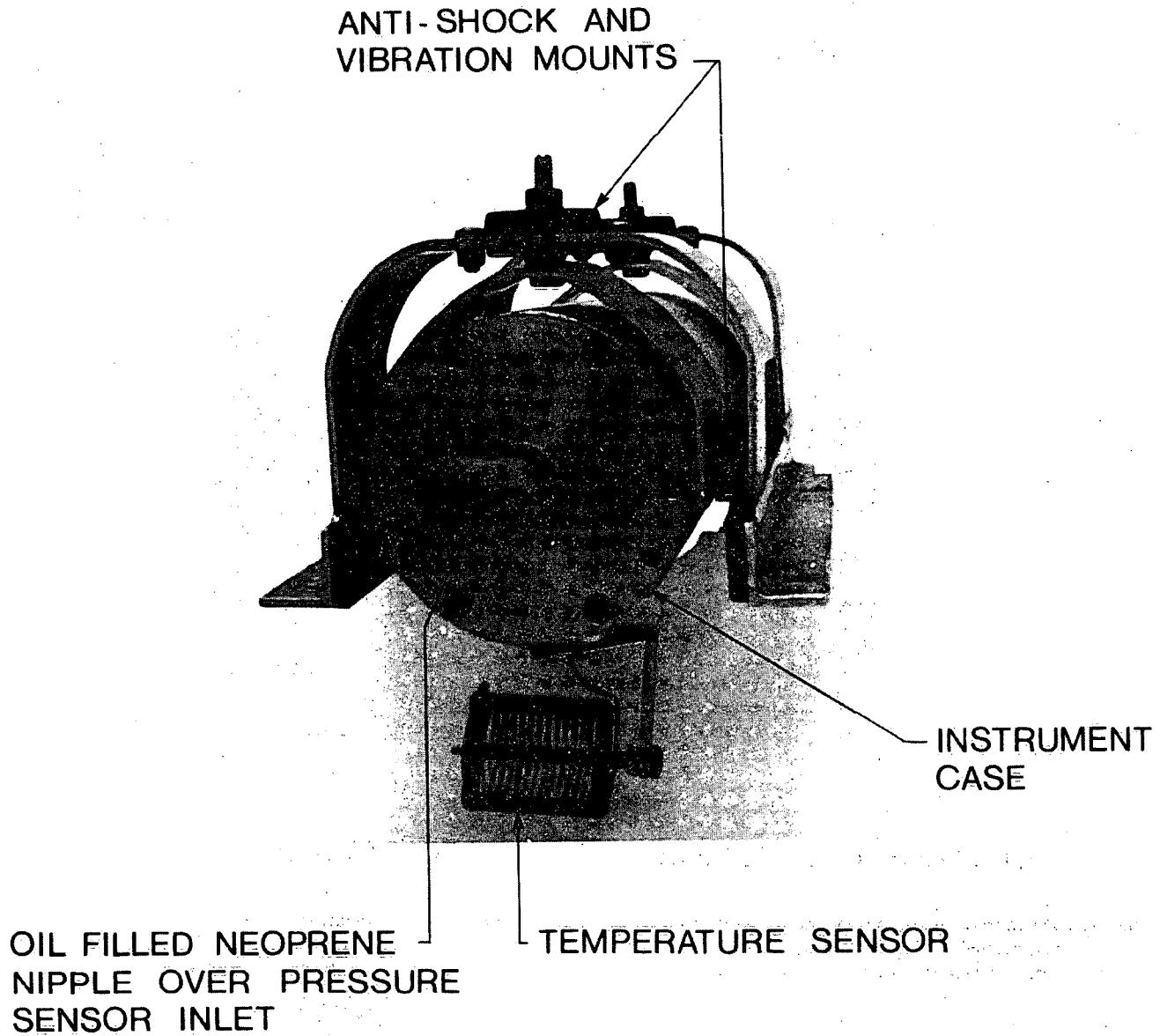
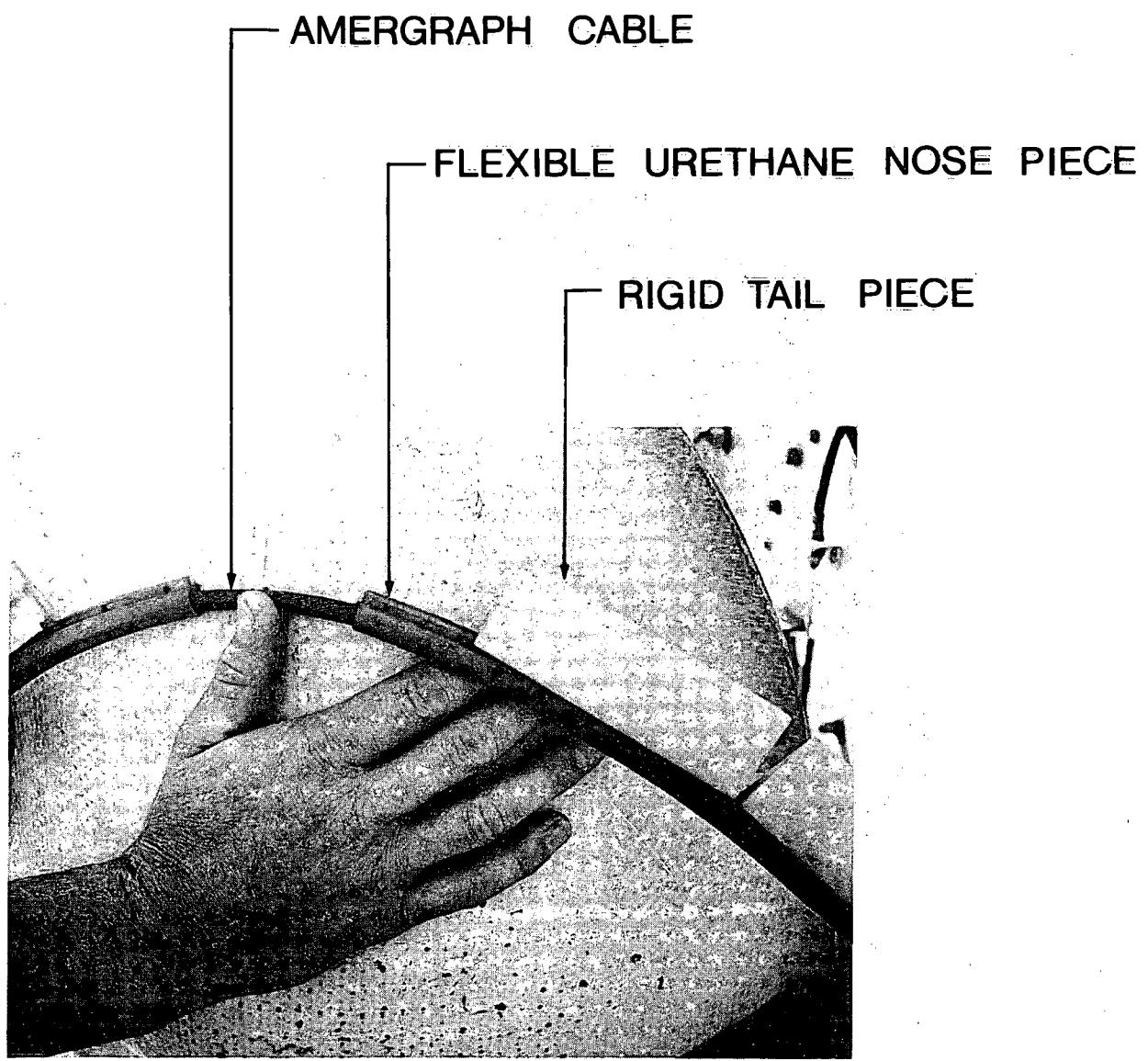


Figure B.2. Front three-quarters view of the sensor package and its shock-proof mounting. This package is installed above the flow-through tunnel with the temperature sensor projecting into the tunnel. On some installations, the temperature sensor is mounted remotely from the sensor package and near to the entrance of the tunnel.



**Figure B.3.** A view of the tow cable and fairing. Some fairing has been removed to show the central Amergraph cable. Note the staggered application of nose and tail pieces.

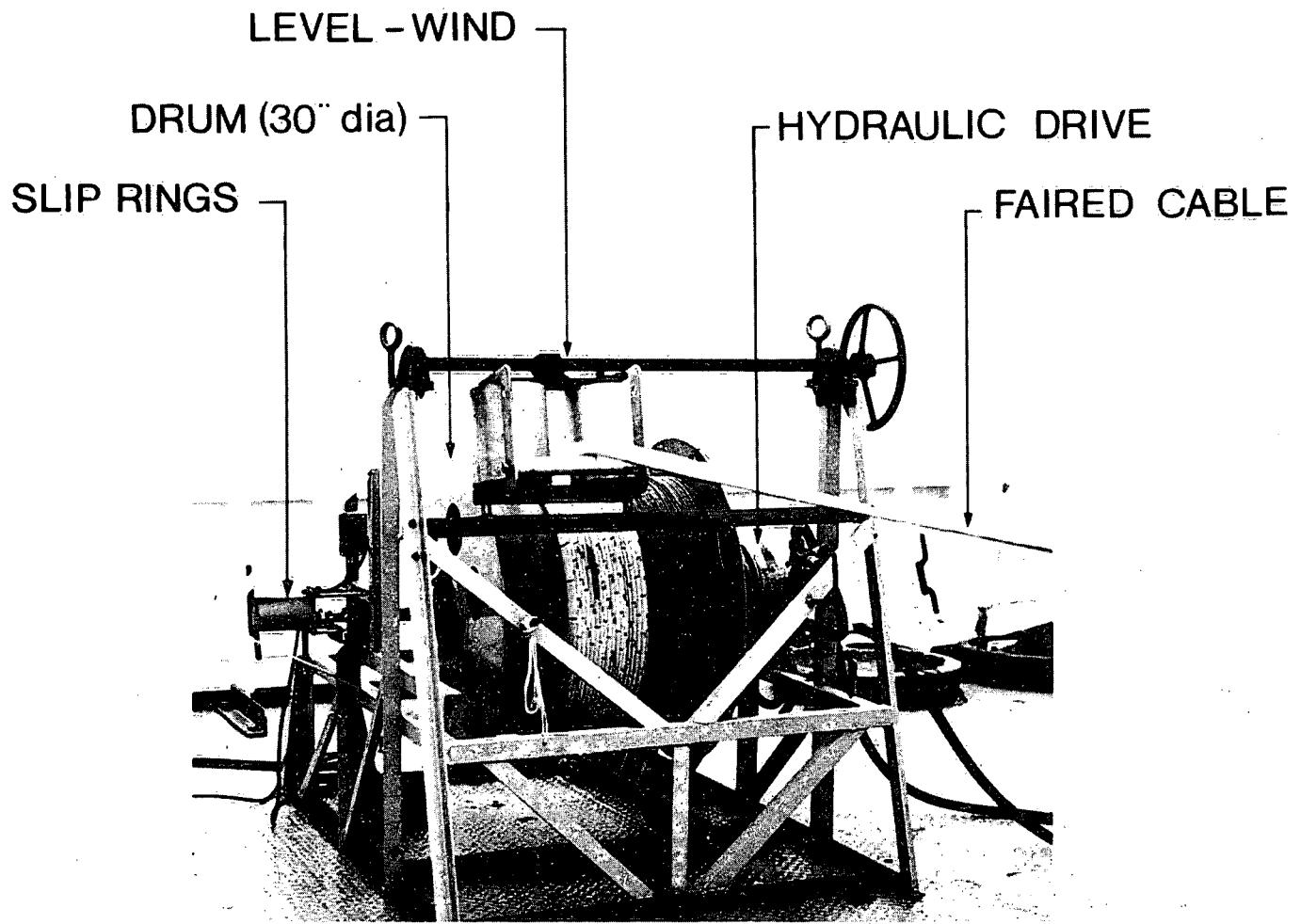


Figure B.4. A simple towing winch developed for faired cables. Note the manually operated level-wind device.

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