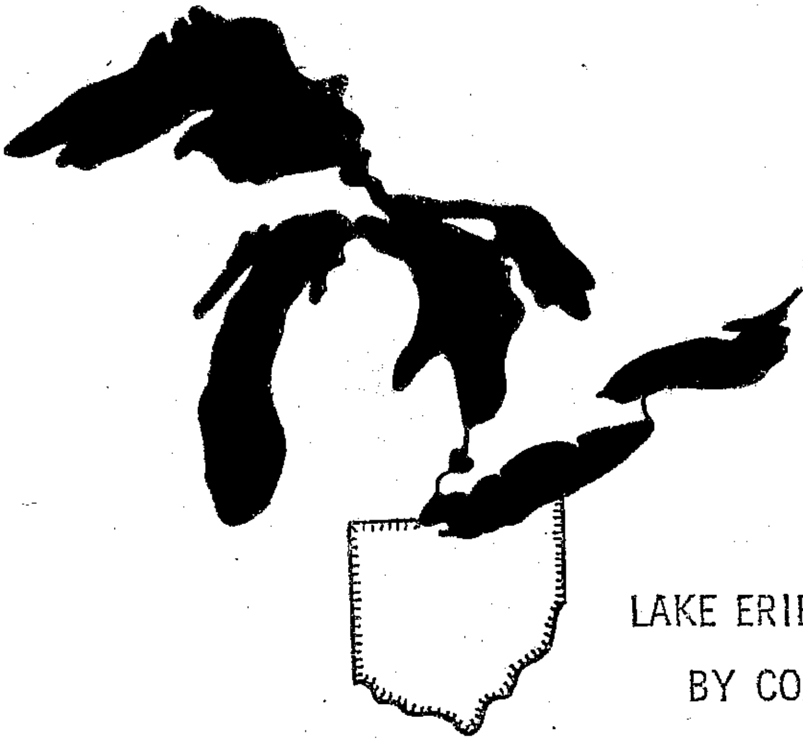

CONTOURING LAKE ERIE WATER QUALITY DATA BY COMPUTER GRAPHICS

Prepared for

Grosse Ile Laboratory
U.S. Environmental Protection Agency
Grosse Ile, Michigan

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CENTER FOR LAKE ERIE AREA RESEARCH
THE OHIO STATE UNIVERSITY
COLUMBUS, OHIO

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CONTOURING OF LAKE ERIE WATER QUALITY DATA BY COMPUTER GRAPHICS

INTRODUCTION

Purpose

The purpose of this project was to develop a system that could accurately construct a large number of illustrations of water quality data in a short period of time. On each of nine separate cruises the Center for Lake Erie Area Research had collected data from Lake Erie on approximately sixteen physical, chemical, and biological parameters. Before most of the data could be effectively analyzed, it needed to be illustrated or presented pictorially, such as by contours.

Background

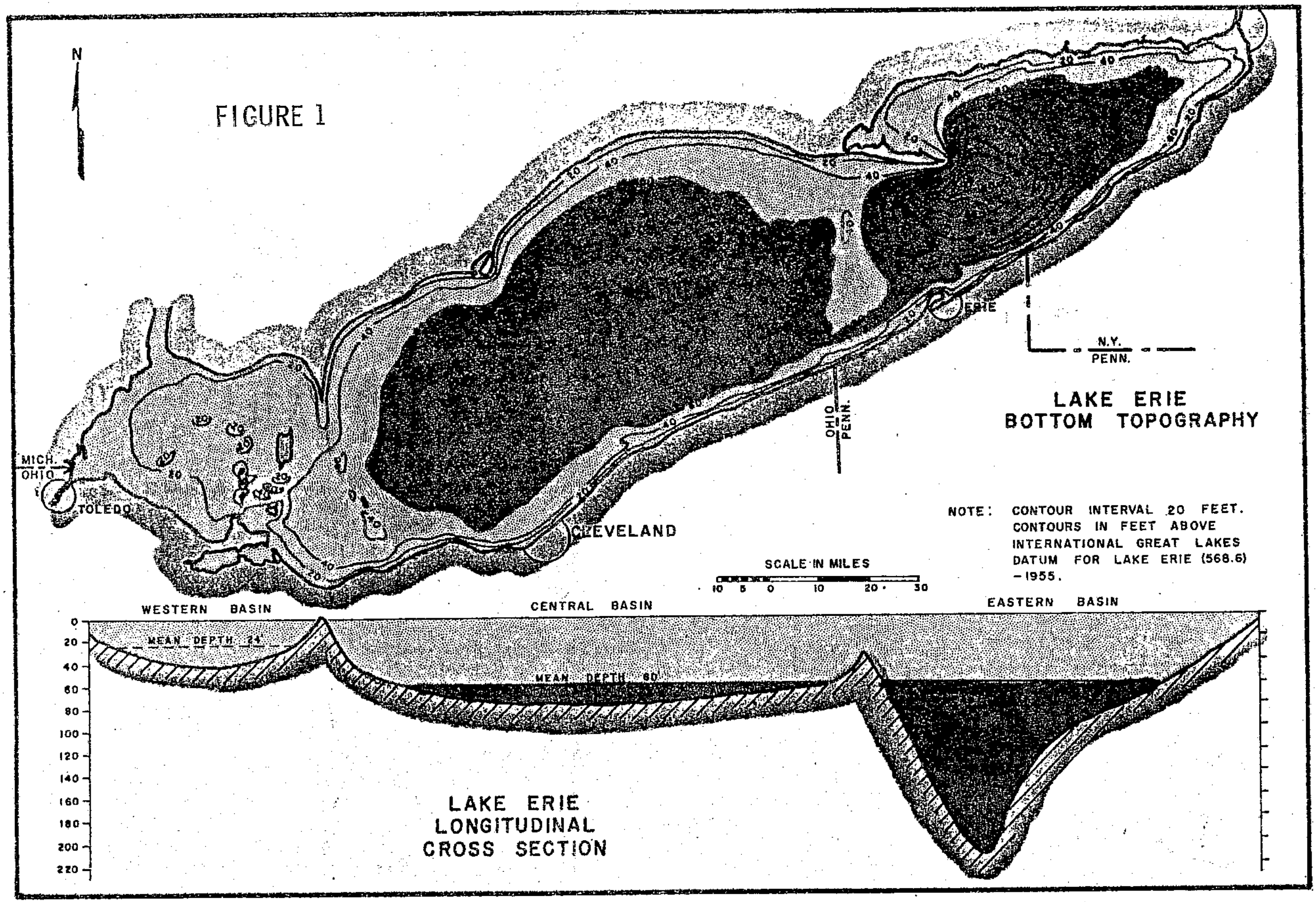
Physical Description of Lake Erie. Lake Erie, the shallowest of the Great Lakes, is located at 42°15' north latitude and 81°15' west longitude. It is approximately 386 kilometres long and 80 kilometres wide, with the major axis oriented in a northeast to southwest direction along an azimuth of approximately 70 degrees.

Natural barriers divide the lake into three basins. The large, flat bottomed Central Basin is separated from the small, shallow Western Basin by a chain of islands and a pointed peninsula. On the other end it is separated from the Eastern Basin by a low, flat ridge. The average depth is 9 metres in the Western Basin and 18 metres in the Central Basin. In contrast to this, the maximum depth of the Eastern Basin is 64 metres. The Central Basin has a surface area of approximately 14,900 square kilometres and fifty nine per cent of the total lake volume (Figure 1).

The Eastern and Central Basins undergo thermal stratification from mid-June to mid-September, but the Western Basin is shallow enough to remain mixed all year. Dominant southwest and northeast winds frequently cause the lake surface to tilt along its major axis and create internal seiches or rockings of the thermal layers.

During the last few years the lake level has been approximately one metre above normal which has caused occasional severe flooding

FIGURE 1


N
MICH.
OHIO
TOLEDO
CLEVELAND
ERIE
OHIO
PENN.
N.Y.
PENN.
LAKE ERIE
BOTTOM TOPOGRAPHY
NOTE: CONTOUR INTERVAL 20 FEET. CONTOURS IN FEET ABOVE INTERNATIONAL GREAT LAKES DATUM FOR LAKE ERIE (568.6) –1955.
SCALE IN MILES
10 5 0 10 20 30
WESTERN BASIN
CENTRAL BASIN
EASTERN BASIN
MEAN DEPTH 24
MEAN DEPTH 60
0 20 40 60 80 100 120 140 160 180 200 220
LAKE ERIE
LONGITUDINAL
CROSS SECTION

along the southwest shoreline. These physical characteristics of the lake create some of the conditions which lead to its water quality problems.

Thermal Stratification. As applied to lakes, thermal stratification is the formation of two or more distinct layers of water at different temperatures. In most lakes, this phenomena produces a warm layer over a cold layer during the summer and possibly the reverse during the winter. In the spring, the sun begins to warm the upper part of the lake. Turbulence from wind stirs up the lake to replace the warm water with cooler water from below. However, the cool water is heavier than the warm water and the turbulence is frequently not strong enough to stir up the cold water from the bottom portion of the lake. This creates the condition of a freely circulating warm upper layer, called the epilimnion, over-riding a stagnant cold layer, called the hypolimnion, separated by a thin zone called the mesolimnion, where the temperature changes drastically. This is depicted in Figure 2. This condition usually exists from early summer

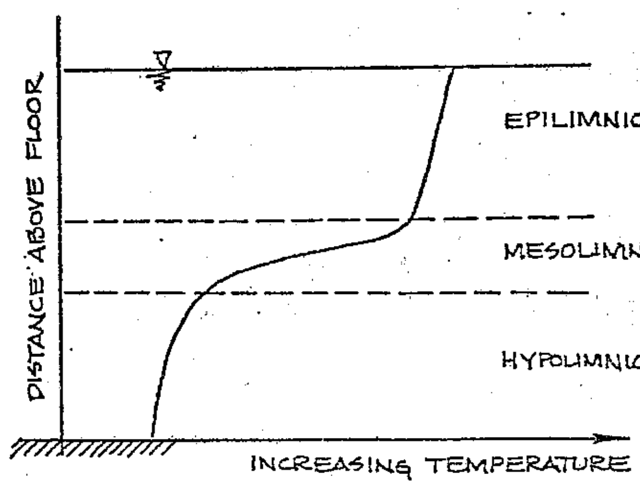


FIGURE 2. Thermal Profile of a Stratified Lake.

to early fall. In the fall the cold air cools the surface of the lake. Since this cool water is heavier than the water just below, it begins to sink causing the mixing of the layers called the fall overturn. Occasionally a stable cold layer can be created during the winter causing an inverse stratification which becomes mixed by a spring overturn. In some very deep lakes the stratification can become very complex with three or more layers forming such as in the Eastern basin of Lake Erie.

The nature of these layers can cause severe water quality problems. Because the cold hypolimnion lays the bottom of the lake stagnat, it does not get reoxygenated by contact with the atmosphere. Only limited oxygen comes from interface mixing with the mesolimnion. Therefore, normal biodegredation on the lake bottom as well as consumption by animal life depletes the oxygen in the hypolimnion. If the biodegredation is severe enough, as would be the case after a large algae bloom sinks to the bottom to rot, the hypolimnion becomes anoxic, ie. without oxygen. This kills or drives away the oxygen dependent organisms and stimulates the activity of anaerobic organisms which can cause the production of the foul-smelling hydrogen sulfide and turn the water black.

For this reason, the extent and duration of thermal stratification is an important item of consideration in environmental lake surveys.

Lake Erie Pollution Problems. Over the years Lake Erie has been subjected to an increasing load of municipal, industrual, and agricultural wastes. Detroit, Toledo, and Cleveland have been the major sources of the municipal and industrial wastes, while the agricultural activities around the shoreline have been sources of nutrients from fertilizer runoff or animal wastes.

The result of these nutrient loads has been increased phytoplankton activity and more extensive oxygen depletion of the water, especially in the hypolimnion. This has reduced the quality of the water, impairing sports activities, such as fishing and swimming, and eliminating some areas as drinking water sources.

If the condition of the lake deteriorates to a certain point, anoxic areas may cause nutrients to be released by the sediments creating a self-fertilization process leading to worse conditions. Thus, the pollution of Lake Erie is not only a problem, but one of increasing concern and in need of an urgent plan of control.

Recent Research on Lake Erie. In response to increasing evidence of premature eutrophication of Lake Erie, Canada and the United States signed an agreement in 1970 to conduct studies to determine the causes of the increasing pollution of the Great Lakes. These studies were to be supervised by an International Joint Commission to coordinate the data. From 1970 through 1972 a scientific team from the Canadian Centre for Inland Waters collected and analyzed data from Lake Erie. During 1973 and 1974 the Center for Lake Erie Area Research (CLEAR) collected data from the Central and Western Basins of Lake Erie while the Great Lakes Laboratory of the New York State University College at Buffalo Collected data from the Eastern

Basin. Both will also be collecting data in 1975.

CLEAR is an environmental research organization affiliated with The Ohio State University. They have offices and labs at the main campus in Columbus, Ohio and the Stone Lab branch on Gibraltar Island on Lake Erie. Their primary function is to collect and analyze data from Lake Erie and the surrounding area. Most of this work is funded by the United States Environmental Protection Agency as part of the joint agreement.

The data that was collected by CLEAR was obtained during a series of nine cruises from June to December. Using a research vessel, CLEAR collected samples from fifty stations in the Western and Central basins (see Figure 3) analyzed them for sixteen physical, chemical, and biological parameters. These included temperature, dissolved oxygen, alkalinity, soluble and total phosphate, nitrate and nitrite, chlorophyll, methane production, benthos. Once the data was analyzed, it was recorded on data sheets according to sampling depth and parameter name, one station per sheet. Dissolved oxygen and temperature were measured every metre from surface to floor while other parameters were only measured at the surface, the lower interface of the epilimnion, the upper interface of the hypolimnion, and the floor.

To evaluate the data CLEAR was interested in illustrations of the parameter values at the lake surface, the lower epilimnion surface, the upper hypolimnion surface, and the floor, or just at the surface and floor during unstratified periods. For ten parameters from nine cruises this amounted to 200 to 300 diagrams. In addition, the areal extent of the hypolimnion and the anoxic zone, the volume of the thermal layers, and the average heat and dissolved oxygen contents in the thermal layers was important for quantitative calculations of the changing condition of the lake. Since this work presented a formidable task by conventional hand methods, the project detailed in this report was established to develop a high speed system, possibly by the use of computers, to produce the desired diagrams and accessory information.

CONCEPT FORMULATION

Goals and Objectives

Since this project was somewhat unique, it required a significant amount of original design. Therefore, the work was broken into three phases. These phases were the formulation of the initial concepts, the development of a procedure from the selected concept, and, finally,

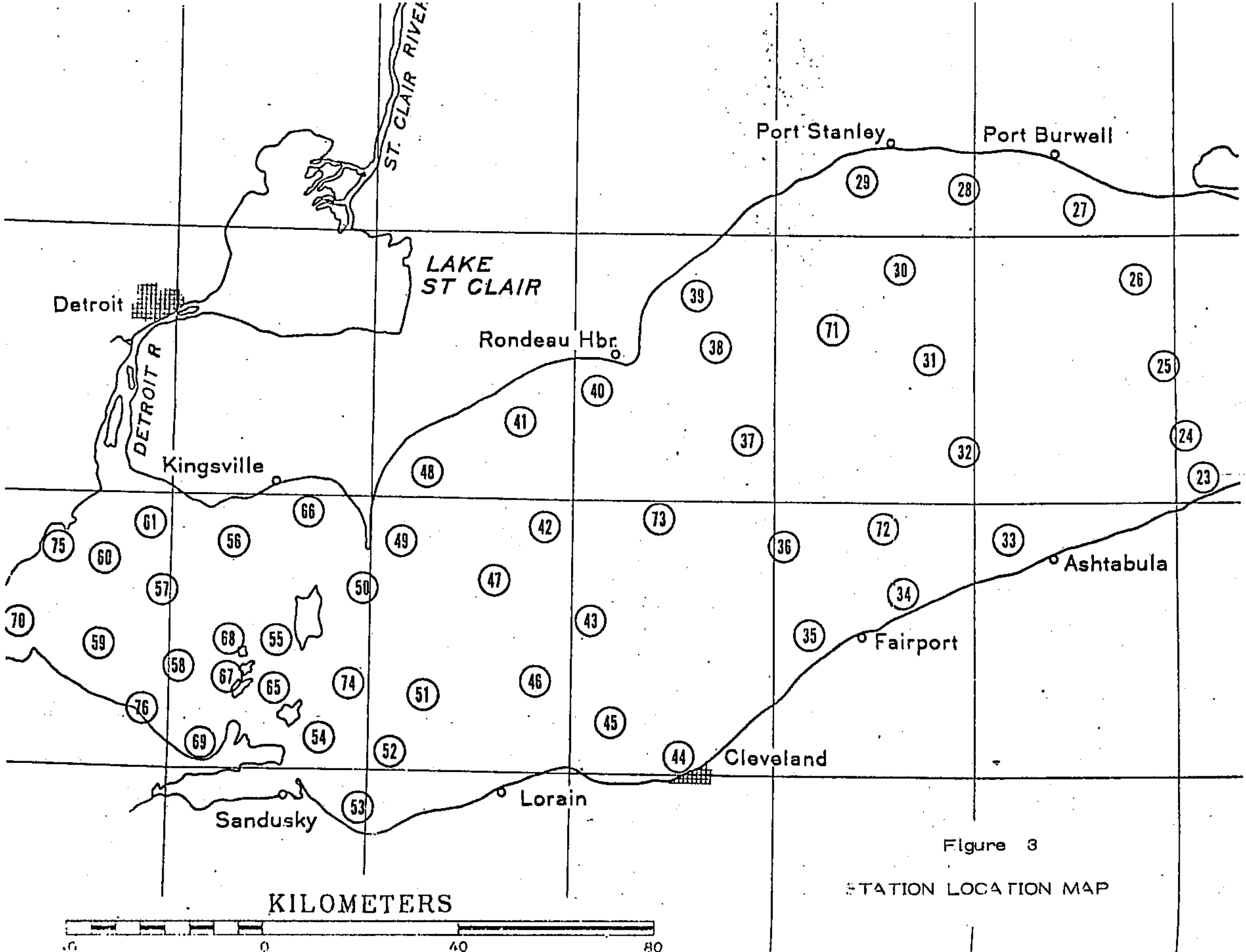


Figure 3

STATION LOCATION MAP

the testing and improvement of the procedure. This and the following two sections cover these three project phases.

To effectively analyze a collection of water quality data from many sampling points and detect correlations, one must present the data in a fashion that links together the results from the scattered points. Contouring, the process of constructing lines of constant value between locations assigned differing values, is one of the most satisfactory methods of accomplishing this goal. For this reason it was selected as the means of presenting the CLEAR data from Lake Erie.

Before ideas could be evaluated, the objectives of the project had to be established. An examination of the data, the goals of CLEAR, and the time and budget constraints yielded the following basic objectives for the final solution.

1. To use survey data in its existing recorded form
2. To be fast
3. To be simple to set up and operate
4. To have a reasonable cost (approximately $2 per diagram)
5. To work for all types of parameters - physical, chemical, and biological
6. To produce contours at a constant depth or varying depths below the lake surface
7. To produce diagrams that are sufficiently clear, accurate, and complete to be used without retouching
8. To have the flexibility of producing different scale diagrams and different contour intervals
9. To compute volumes, areas, and volume weighted averages. (A volume weighted average is an average of values which were weighted according to the volume of water registering each value.)

General Approach

With the knowledge that extensive computer facilities were available, three options were considered. One was to draw the contours by hand from blank maps of the lake marked with the appropriate parameter values at the sampling station locations. The second was to draw the contours by hand from a computer printout of a closely spaced network of parameter values interpolated from station values. The values would be printed on a scaled lake outline at the locations where they were calculated. This method was used by the Canadian Centre for Inland Waters in some of their studies on the Great Lakes. The third method was to have a computer both calculate and draw the contours. From the standpoint of objectives 2, 4, 7, and 9, the third option was the best approach. All three methods met the other objectives equally well, so, the complete computer analysis method was selected.

Equipment Plan

The Ohio State University has one of the largest research and instruction computer facilities in the United States. Their equipment included large, late model computers such as the IBM 370, 4 remote job submittal terminals, over twenty IBM 29 keypunch machines, magnetic tape, disc, and card input devices, small computers, such as the IBM 1130, to control auxiliary equipment, and others. From the counseling of computer course advisors and facility directors, the equipment considered most applicable to the problem was the IBM 370 computer using either batch-type job submittals or time-share job submittal on a typewriter (IBM 2741) terminal and the small IBM 1130 or 1620 computers in conjunction with the drum plotter or cathode display screen. Since objective 7 stressed the importance of clarity and perminence of results, the various means of computer graphic display were evaluated in the light of this objective as well as objective 4 (the cost). The Omnitab language had several package programs that could construct plots on the printer from original data input to the program. However, these plots were not as smooth and neat as those produced by the drum plotter and the cathode display screen. The cost of the screen displays as well as the inconvenience of having to be at the computer center to study the displays dictated the final selection of the drum plotter. This drum plotter, the IBM 1621, consisted of a drum over which passed a long roll of paper mounted like a scroll. A pen was mounted to travel along a rod parallel to the centerline of the drum. The pen shifted laterally in response to changes in x coordinates, and the drum rotated in response to changes in y coordinates.

The IBM 1620 computer directing this plotter did not contain sufficient storage for the analyses required to calculate the contours for this problem. Therefore, the plotter commands had to be generated by another computer doing the contour calculations. The IBM 370 computer had the most storage and was the least expensive. Also, batch-type job submittal was less expensive than typewriter terminal input, even though the latter was faster. These considerations led to the adoption of the basic plan depicted in Figure 4. As shown, data is inserted to the 370 via a program containing the proper algorithms for contour calculations and data manipulations. The computer outputs the result of the data manipulations as well as a set of commands for the plotter. With these commands, the 1627 directs the drum plotter to draw the contours.

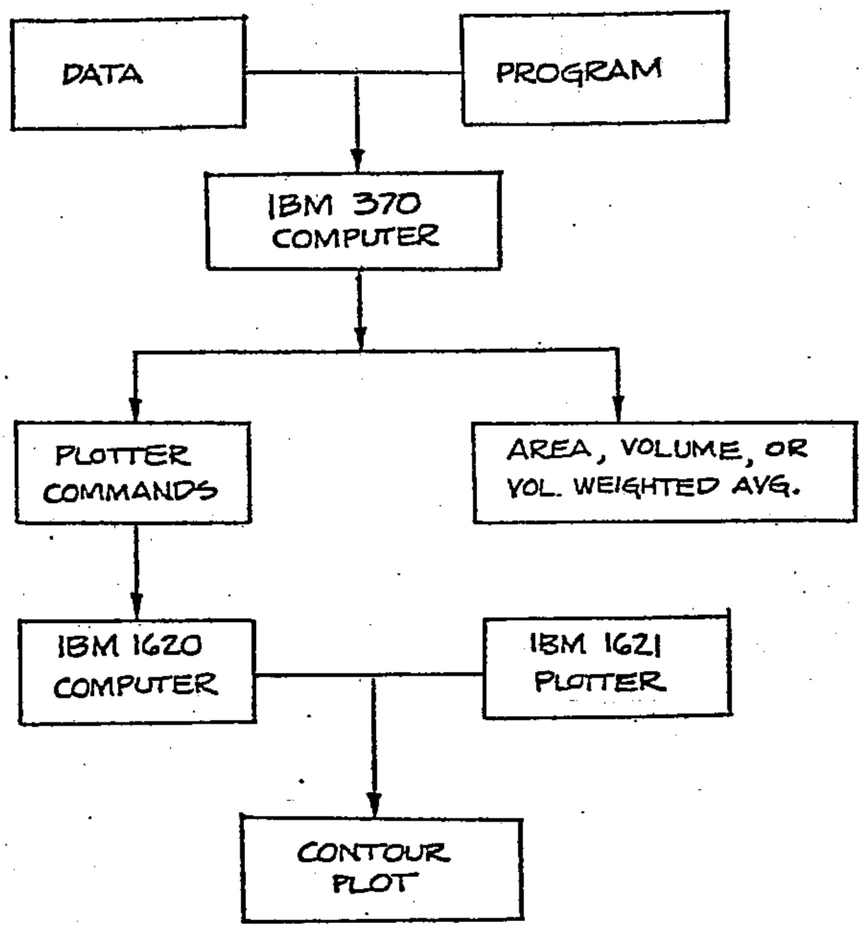


FIGURE 4. Computer Equipment Utilization

Program Framework

Once the equipment plan was established, the scheme for setting up the algorithm was developed. Some extensive research turned up two readily available programs for calculating contours. The first was a Fortran program called CNTOUR which was part of the General Plotting Package (GPP) stored in The Ohio State University Fortran Library. The second was an unpublished Fortran program called CGTOUR written by John W. Snowden. Unfortunately, neither program could be easily revised to compute areas enclosed within the parameter contours, which was a necessary step for figuring volume weighted averages, areas, and volumes (data manipulation). Therefore, the first idea considered was to calculate the contours segment by segment on a grid superimposed on the lake. These segments were to be calculated in sequence along the contour trace. From the end point coordinates of all the segments, the area could be calculated by the surveyors technique of double meridian distances. Thus it was important that all contour traces form a closed tract. All calculations and plotter instructions were to be generated by one program. After several weeks of development this approach had become a complicated, storage-consuming mess and was discarded in favor of a new approach. This new approach, born from ideas brought forth in a discussion at the Canadian Centre for Inland Waters, centered around a concept of prismatic unit cells. If the area and volume could be calculated from a sum of whole and partial unit cells created by a grid, the existing contour programs would be used to calculate the contours. A volume weighted value could also be computed by multiplying the unit cell volume by the value assigned to the center of the cell location. From this evolved the three program concept. For area and volume calculations the first program would figure out the number of unit cells in each layer of depth. Since the sampling station locations were too sparse to compute more than rough contours the second program would interpolate the given parameter station values onto a smaller grid. These grid points would coincide with the cell locations in Program I to produce a data format suitable for use by the third program, the contouring program. The contouring program would then produce the plotter command cards for the plots.

A preliminary study indicated that this would be a reasonable approach, and it was pursued successfully through the development and other remaining stages.

PROGRAM DEVELOPMENT

Selection of Contouring Program

Once the three-program concept was selected, these programs had to be developed to satisfy the requirements of the most suitable existing contouring program. Both the GPP and the Snowden contouring programs required an input of a three dimensional array containing the two coordinates of each point location and the parameter value assigned to that point. In the GPP the points could be located at random, but in the Snowden program the points had to be divided into rows containing equal numbers of points. However, these rows did not have to be straight or uniformly spaced. Figure 5 shows an example of this warped grid. Both programs were written as subprograms and both produced the command cards which directed the 1621 plotter to draw the contour diagrams.

From conversations with advisors and graduate students at the computer center it was determined that the Snowden program produced

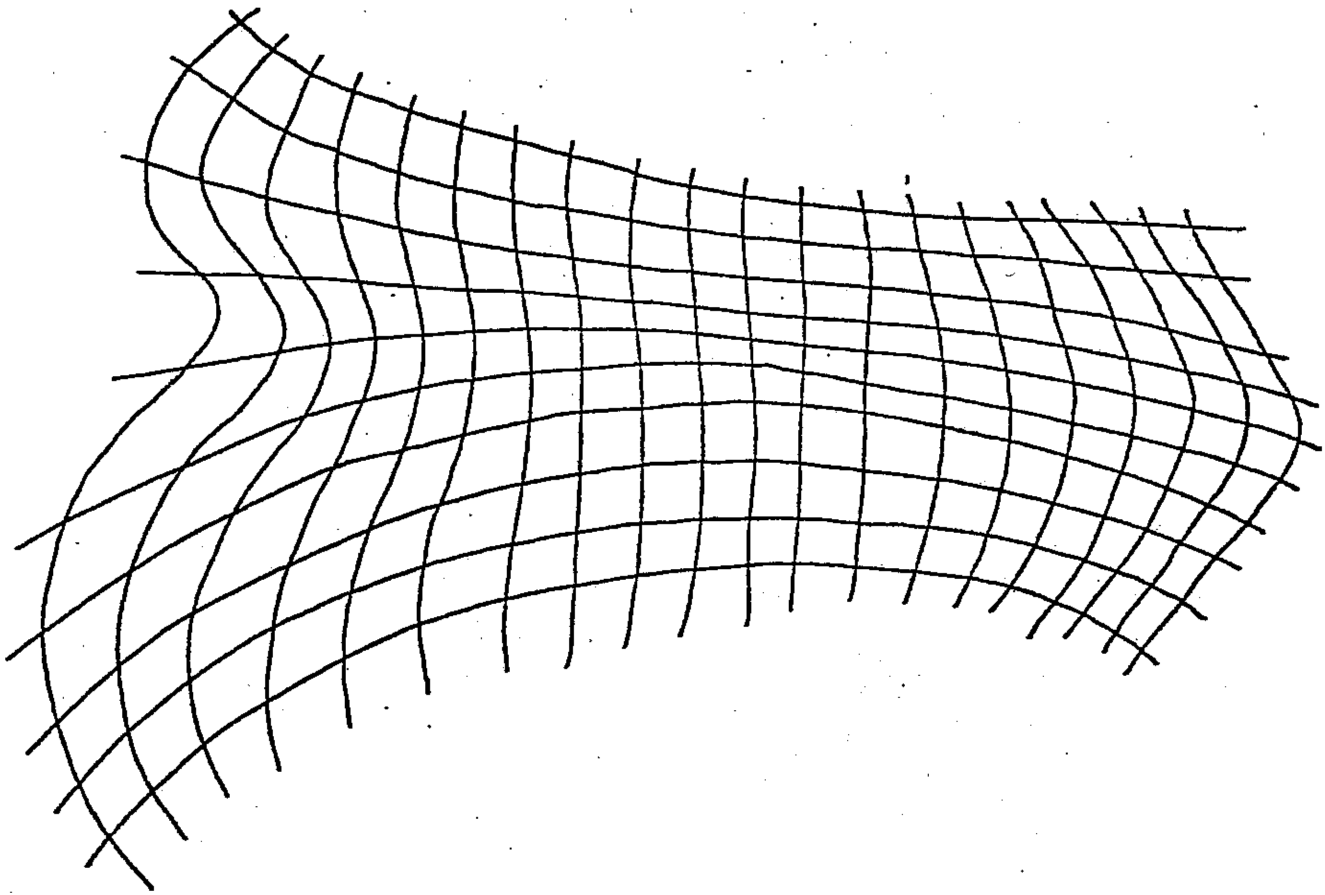


FIGURE 5. Warped Grid for Snowden Contouring Program

more accurate contours in less time than the GPP program and would, therefore, be the better one to use in this project.

Establishment of Grid

Since a more uniform point distribution produced better plots, a rectangular grid of points was the optimum arrangement. This fell right in line with the grid requirement for volume and area calculations. Hence, a three-dimensional rectangular grid was constructed on an outline of the Lake Erie floor. Since the major axis of the central basin of the lake runs from southwest to northeast at an azimuth of approximately 63 degrees so that the X axis coincided with the major axis. This reduced the size of the grid required to enclose the lake and, thus, reduced the number of grid points to be processed. Since the average sampling point spacing on the CLEAR study was twenty to twenty-five kilometres, five kilometres was selected as the initial grid point spacing. This produced a grid of 55 units by 23 units to enclose the central and western basins. However, the option to change the grid point spacing was designed into the program should further experimentation have indicated that a larger or smaller grid would have been more appropriate. Figure 6 shows a ten kilometre grid similar to the five kilometre grid actually used.

Development of Program I - The Boundary Program

Definitions. Once the grid was established, a sequence of calculations was laid out and nomenclature assigned to the lines and volumes used most frequently. A cell was a block of the grid having a length of one unit along each edge and centered around a grid point. A partial cell was a cell within the lake whose Y dimension (NW to SE) was cut short by a strip boundary. A strip was a row of cells running northwest to southeast along a horizontal grid line, and a series of strips side by side made up a layer. The total number of cells and partial cells within a certain boundary was used to approximate the area or volume within that boundary. This was calculated one strip at a time and one layer at a time, moving from south to north along each strip. The repetitive nature of these computations made it ideally suited to a computer analysis. A strip boundary was a point where the grid line along the center of a strip intersected the lake floor. These boundaries were designated as minimums when the floor depth was increasing while moving northward, or as maximums when the depth was decreasing. A diagram of these items is shown in Figure 7.

Computation of Strip Boundaries. Strip boundary values were necessary to calculate the number of full and partial cells in each strip. This task was assigned to Program I. From a recent Canadian Nautical Map, floor depths at 916 different locations were recorded on data cards. These lake floor data points were then used in this program to compute probable depths at each of the grid points by interpolating between the three data points closest to the grid point. This interpolating was an application of the concept of a line intersecting a plane defined by 3 points. As each new grid point in a strip was assigned a value, that depth value and the previous depth value in the strip were compared, and the locations of any intermediate integral depths were determined by simple interpolation. These locations were the strip boundaries for the depth that equaled the contour value and were stored by grid coordinates. Figure 8 shows a typical cross-section of a lake strip and the locations of the strip boundary values that would be calculated. To compute boundary values

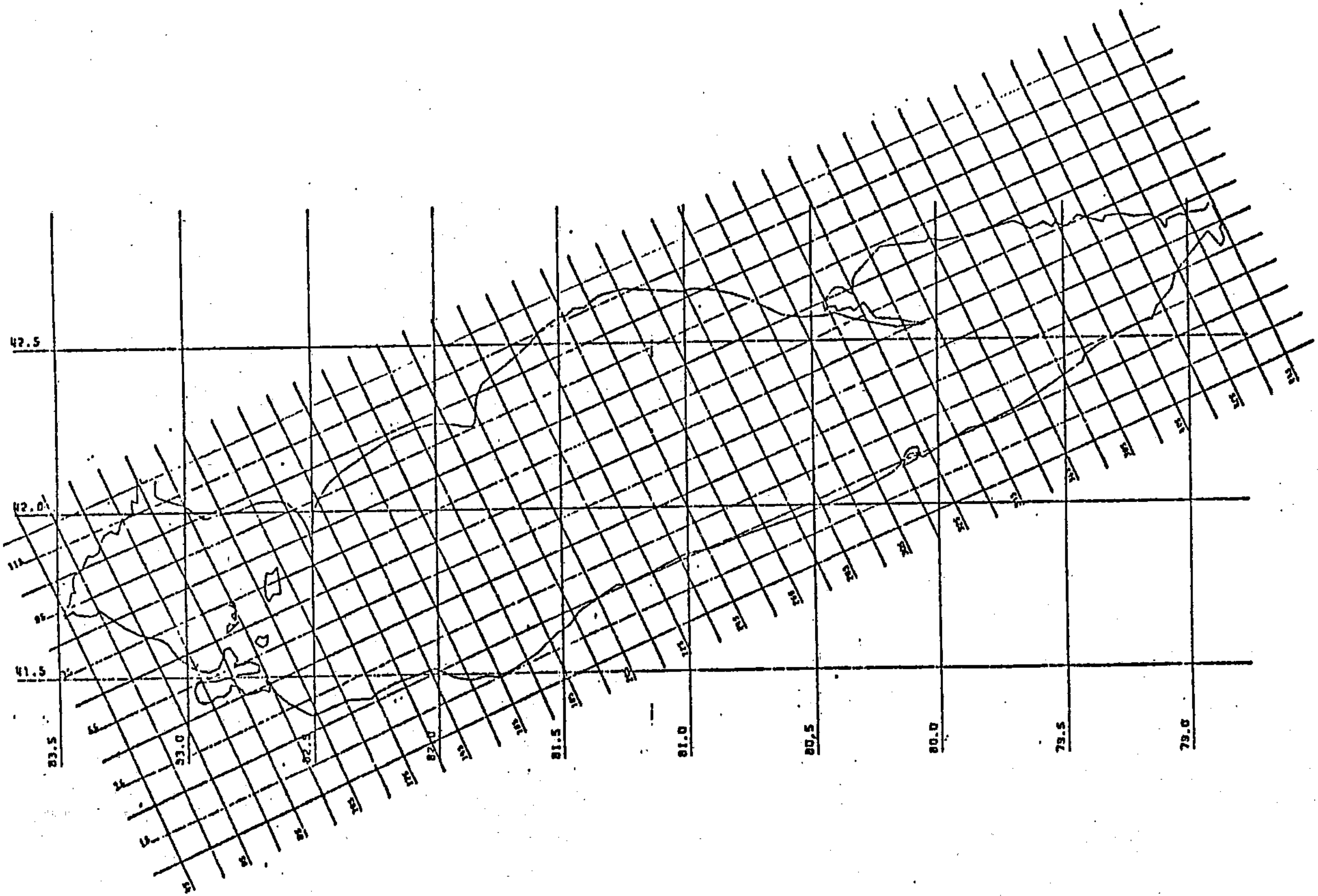


FIGURE 6. A Ten-kilometre Grid for Lake Erie Analysis

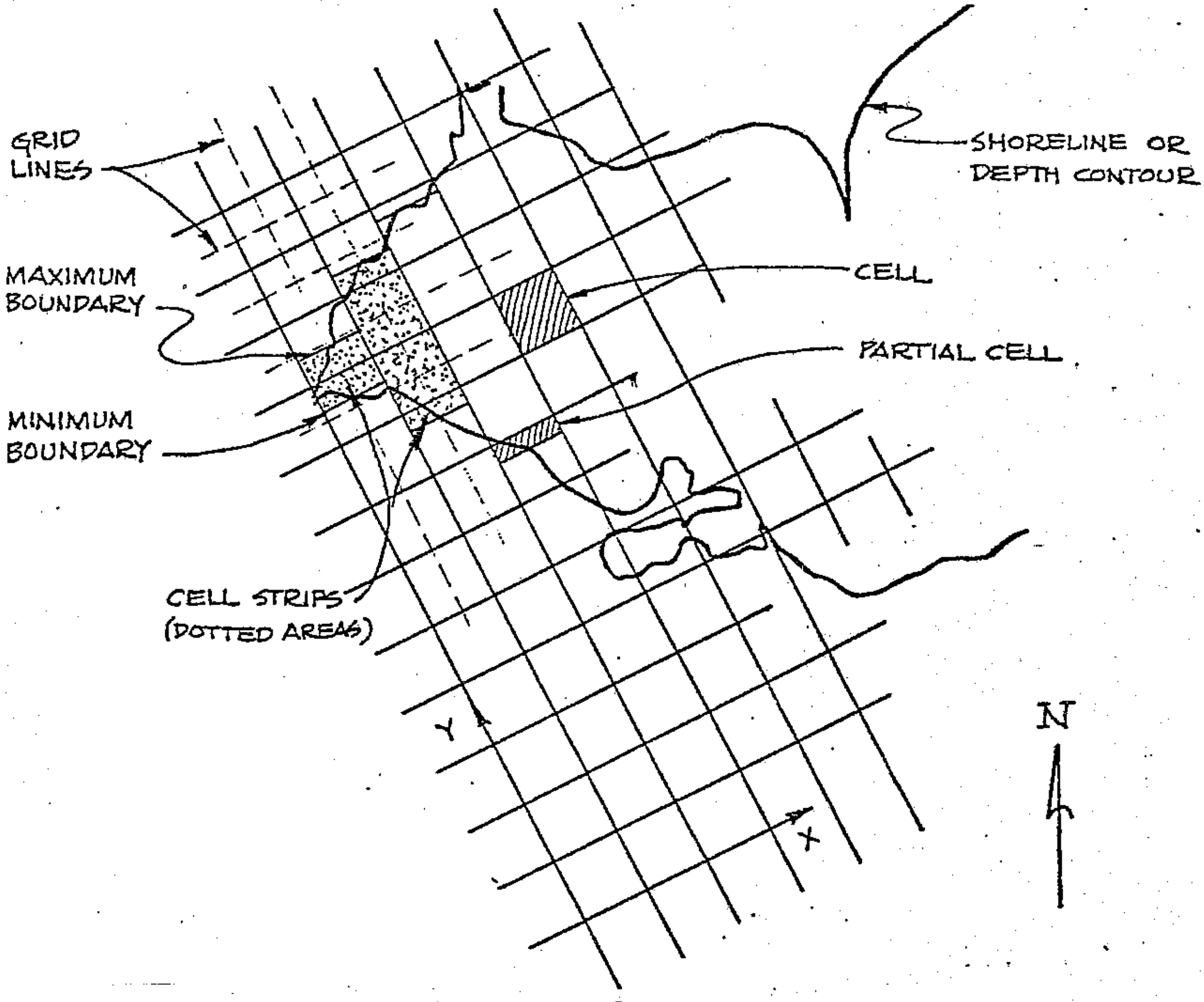


FIGURE 7. Grid Nomenclature

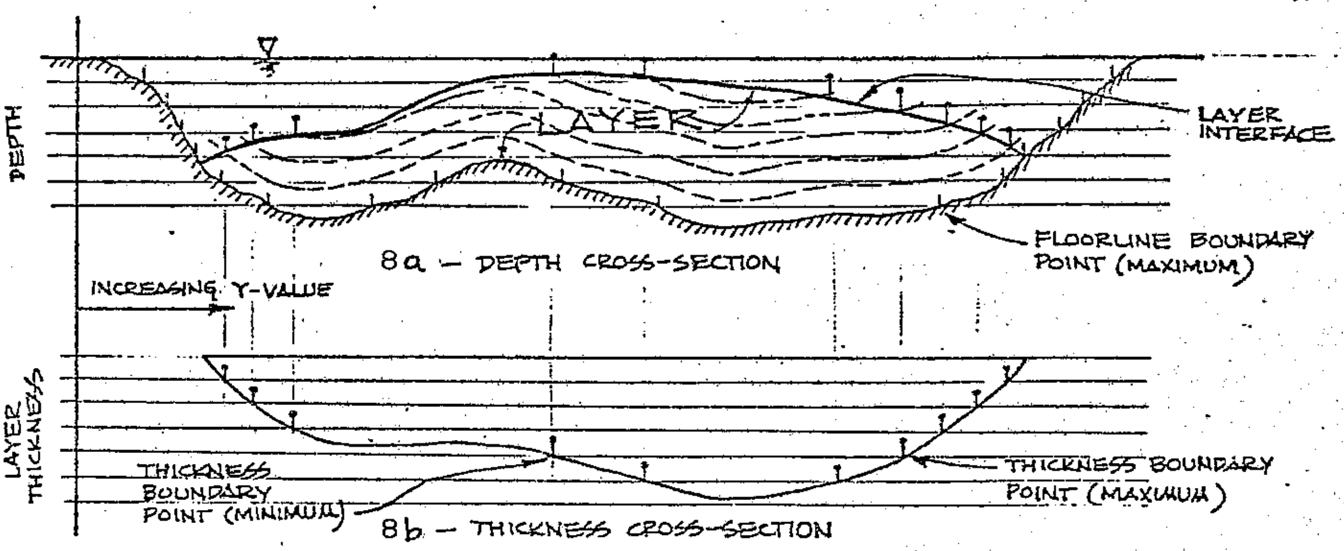


FIGURE 8. A crossection of a cell strip comparing depth strip boundaries with thickness strip boundaries.

for an irregular surface such as the floor this program required the input of the depths to the irregular surface measured from a horizontal plane. Therefore, strip boundaries for a layer between two irregular surfaces such as the upper hypolimnion and lake floor were calculated by inputting the layer thickness. As shown in Figure 8b these boundary values were just as suitable for computing volume as the boundary values calculated for the two irregular surfaces defined by depths below the lake surface. When all grid points had been processed, the strip boundary values were outputted on cards in groups according to depth. Figure 9 is a sample of this output in printed form and Figure 10 shows a block diagram of the program logic.

Development of Program II - Grid Value Program

Computation of Grid Values. The second major program, the grid value program, was developed as a modification of the boundary program. Since the Snowden contouring program required a grid containing rows with equal numbers of points, the raw lake data which was scattered over irregularly distributed stations had to be interpolated to the grid points. The sequence of steps to find the three stations nearest to each grid point was duplicated for Program II, but, the sampling stations were not broken into zones since there were only fifty stations. To keep storage requirements at a minimum, these grid point parameter values (hereafter referred to as grid values) were only stored long enough to accumulate sufficient values to fill an 80 column card, whereupon they were punched on card output. Figure 11 is a printout of a typical set of grid values.

Computation of Cells. In addition to this interpolation routine, a section was developed to calculate areas, volumes, and volume weighted averages. As the computer processed each grid point in a strip, it compared the grid point coordinates to those of the minimum and maximum strip boundaries read in from the boundary data cards. Partial and complete cells inside the boundaries were counted toward the total area and volume, and each cell was multiplied by its assigned value and added to the previous sum of these products. The total number of cells in a layer divided by the layer thickness produced the area, and the total number of cells in all layers divided by the unit cell volume produced the volume. Also, the sum of the cell-value products divided by the number of cells yielded the volume weighted average (VWA) value. Thus, the computation of area and volume depended solely on the boundary values calculated by the boundary program, whereas the VWA values depended on the boundary values as well as grid values. The final output produced by this program consisted of cards containing all the grid values at each depth considered for contouring.

INTERFACE BOUNDARY VALUES
5.0 KM GRID

INTERFACES – UPPER HYPOLIMNION AND LAKE FLOOR
CRUISE 2 JULY 17 – AUGUST 2, 1973
CORRECTION: 0.89 METRES ADDED TO MAP DEPTHS

LEVEL #, SETS OF X,YMIN,YMAX IN GRID UNIT COORDINATES MAXIMUM # OF BOUNDARY VALUES AT ANY DEPTH = 69

DEPTH = 0.50 METRES

1	8.	12.00	11.00	9.	12.00	11.00	10.	12.00	11.00	11.	12.00	11.00
1	12.	12.00	11.00	13.	12.00	11.00	14.	12.00	11.00	15.	12.00	11.00
1	16.	12.00	11.00	17.	12.00	11.00	18.	12.00	11.00	19.	12.00	11.00
1	20.	12.00	11.00	21.	12.00	11.00	22.	12.00	11.00	23.	12.00	11.00
1	24.	12.00	11.00	25.	12.00	11.00	26.	14.66	17.14	27.	15.55	16.94
1	28.	14.27	18.82	29.	7.76	8.06	29.	10.18	19.11	30.	6.52	19.26
1	31.	5.87	19.36	32.	4.97	19.34	33.	4.54	19.99	34.	3.96	20.04
1	35.	3.98	19.80	36.	4.71	19.09	37.	4.80	18.89	38.	5.11	18.33
1	39.	5.62	18.43	40.	5.91	19.55	41.	5.88	20.06	42.	6.55	20.34
1	43.	6.43	20.48	44.	6.30	21.11	45.	6.36	21.27	46.	6.45	21.73
1	47.	6.58	21.84	48.	6.69	22.34	49.	6.49	22.20	50.	6.57	22.11
1	51.	6.12	22.18	52.	6.21	21.47	53.	6.22	21.18	54.	6.64	20.47
1	55.	6.55	19.74	56.	6.26	19.28	57.	6.64	10.97	57.	11.06	18.25
1	58.	6.69	17.29	59.	7.04	17.07	60.	7.33	9.98	60.	10.25	13.94
1	61.	7.05	9.93	62.	6.88	11.56	63.	6.99	13.39			

DEPTH = 1.50 METRES

2	8.	12.00	11.00	9.	12.00	11.00	10.	12.00	11.00	11.	12.00	11.00
2	12.	12.00	11.00	13.	12.00	11.00	14.	12.00	11.00	15.	12.00	11.00
2	16.	12.00	11.00	17.	12.00	11.00	18.	12.00	11.00	19.	12.00	11.00
2	20.	12.00	11.00	21.	12.00	11.00	22.	12.00	11.00	23.	12.00	11.00
2	24.	12.00	11.00	25.	12.00	11.00	26.	16.84	17.06	27.	15.91	16.19
2	28.	14.96	18.42	29.	10.86	19.02	30.	6.72	8.38	30.	10.21	19.10
2	31.	6.27	19.25	32.	6.19	17.17	33.	5.16	19.85	34.	4.12	19.96
2	35.	4.17	19.61	36.	4.79	18.82	37.	4.97	18.58	38.	5.34	18.24
2	39.	5.73	18.31	40.	5.99	19.44	41.	5.93	19.65	42.	6.72	20.11
2	43.	6.54	20.20	44.	6.41	20.99	45.	6.52	21.09	46.	6.61	21.48
2	47.	6.76	21.46	48.	6.87	21.15	49.	6.66	22.08	50.	6.79	21.45
2	51.	6.61	21.96	52.	6.43	21.23	53.	6.41	20.77	54.	6.88	20.14
2	55.	6.86	19.08	56.	6.66	10.54	56.	12.17	19.66	57.	6.82	10.08
2	57.	12.96	17.52	58.	6.88	9.95	59.	7.42	13.13	60.	7.95	8.16
2	61.	12.00	11.00	62.	7.00	9.95	62.	10.09	11.19	63.	7.23	13.17
2												

DEPTH = 2.50 METRES

3	8.	12.00	11.00	9.	12.00	11.00	10.	12.00	11.00	11.	12.00	11.00
3	12.	12.00	11.00	13.	12.00	11.00	14.	12.00	11.00	15.	12.00	11.00
3	16.	12.00	11.00	17.	12.00	11.00	18.	12.00	11.00	19.	12.00	11.00
3	20.	12.00	11.00	21.	12.00	11.00	22.	12.00	11.00	23.	12.00	11.00
3	24.	12.00	11.00	25.	12.00	11.00	26.	12.00	11.00	27.	12.00	11.00
3	28.	15.62	18.02	29.	13.45	18.68	30.	6.93	7.46	30.	10.89	18.88
3	31.	6.69	19.14	32.	6.87	19.01	33.	6.03	19.71	34.	4.62	19.75
3	35.	4.45	19.42	36.	4.88	19.45	37.	4.94	18.27	38.	5.57	18.15

FIGURE 9. Printed Output of Boundary Values.

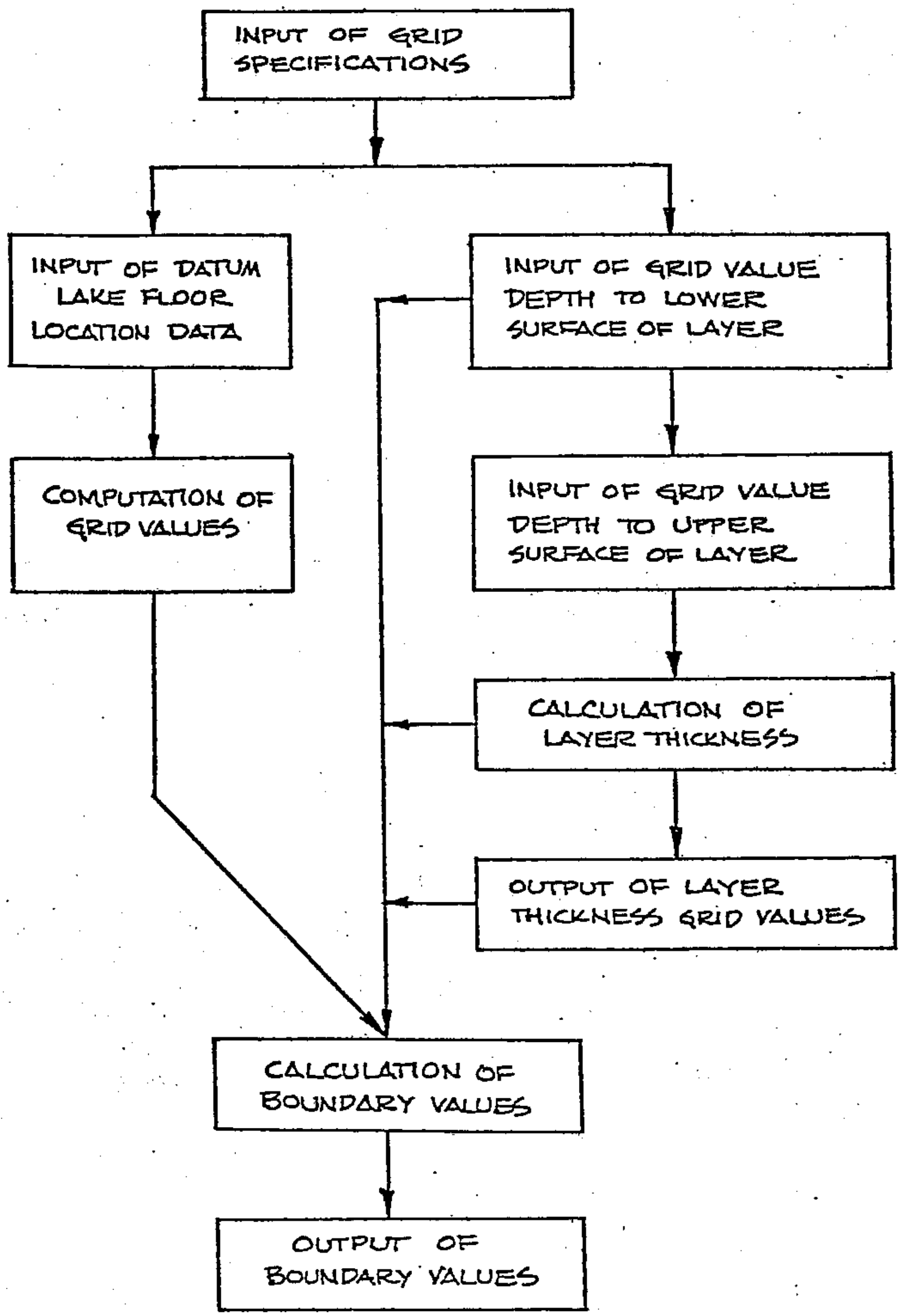


FIGURE 10. Block Diagram of Boundary Program.

GRID VALUES AND GRID UNIT COORDINATES
5.6 KM GRID

LAYER THICKNESS (METRES)
UPPER HYPOLIMNION AND LAKE FLOOR
CRUISE 2 JULY 17 – AUGUST 2, 1973

													GRID COORD. OF LAST VALUE IN ROW
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	8.,15.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	9., 4.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	9.,17.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	10., 6.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-11.29	10.,19.
-12.36	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	11., 8.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-12.87	-9.99	-9.70	-10.32	11.,21.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	12.,10.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-11.80	-8.54	-6.66	-6.30	-8.18	-13.21	-99.00	12.,23.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	13.,12.
-99.00	-99.00	-99.00	-10.68	-7.19	-6.96	-5.09	-5.42	-6.40	-11.66	-11.96	-99.00	-99.00	13.,25.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	14.,14.
-11.40	-8.24	-6.72	-5.95	-5.74	-5.66	-5.85	-6.74	-15.02	-99.00	-99.00	-99.00	-99.00	15., 3.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-13.53	-8.74	-9.15	-9.59	-7.20	15.,16.
-6.12	-6.32	-6.07	-5.18	-6.44	-5.26	-11.79	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	16., 5.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-7.89	-5.93	-6.50	-8.04	-5.74	-5.98	-5.60	16.,18.
-5.83	-5.80	-5.87	-7.01	-11.17	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	17., 7.
-99.00	-99.00	-99.00	-99.00	-11.60	-5.61	-5.73	-5.55	-5.32	-5.76	-5.66	-5.75	-5.65	17.,20.
-6.10	-7.44	-11.27	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	18., 9.
-99.00	-15.82	-8.12	-4.38	-9.75	-5.23	-5.04	-5.24	-5.07	-5.56	-5.49	-5.95	-7.45	18.,22.
-12.12	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-12.78	-12.65	-1.39	19.,11.
-8.75	-6.11	-11.27	-13.83	-5.07	-4.89	-5.02	-5.20	-5.36	-6.03	-9.78	-19.00	-99.00	19.,24.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-13.98	-6.72	-4.26	-3.59	-6.09	-10.34	-1.81	20.,13.
-2.19	-3.61	-6.76	-4.71	-4.83	-5.06	-6.84	-14.15	-99.00	-99.00	-99.00	-99.00	-99.00	20.,26.
-99.00	-99.00	-99.00	-12.75	-5.04	-3.73	-3.87	-2.56	-4.29	-7.15	-3.97	-12.12	-9.22	21.,15.
-5.15	-3.94	-4.10	-5.00	-5.43	-22.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	22., 4.
-99.00	-15.28	-4.39	-2.67	-1.75	-2.06	-3.20	-4.85	-3.93	-8.50	-15.19	-14.79	-3.67	22.,17.
-3.66	-5.09	-6.02	-23.67	-48.82	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-13.79	23., 6.
-3.26	-0.65	-0.17	-1.98	-3.43	-4.79	-6.45	-6.50	-7.57	-9.99	-6.20	-5.40	-5.38	23.,19.
-5.17	-22.99	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-12.21	-2.62	-0.23	24., 8.
-0.22	-2.29	-3.75	-5.00	-4.97	-6.69	-7.36	-6.15	-6.80	-4.56	-4.45	-5.90	-99.00	24.,21.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-23.68	-7.44	-1.87	-2.71	-1.83	-3.17	25.,10.
-2.65	-3.71	-4.03	-4.61	-8.09	-7.99	-5.27	-7.67	-7.79	-16.22	-99.00	-99.00	-99.00	25.,23.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-9.65	-0.22	0.13	-1.24	-3.58	-2.47	-3.32	26.,12.
-3.62	-2.93	-7.66	-3.19	2.37	-11.43	-9.79	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	26.,25.
-99.00	-99.00	-99.00	-99.00	-7.43	0.44	-1.60	-1.46	-2.47	-2.25	-1.52	-1.84	-3.43	27.,14.
-1.04	1.76	0.42	-4.84	-11.83	-9.87	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	28., 3.
-99.00	-99.00	-4.78	-0.12	0.03	-1.32	-1.04	-0.31	-0.25	0.06	0.11	1.56	3.08	28.,16.
3.82	2.56	0.05	-7.82	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-22.39	29., 5.
-4.20	0.28	0.57	-0.66	0.23	1.70	1.58	2.00	3.12	2.90	3.25	3.77	4.12	29.,18.
1.74	-9.27	-12.70	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-17.54	-2.10	2.87	30., 7.
2.06	0.60	1.19	2.67	2.98	3.22	3.62	4.84	4.55	5.52	4.95	2.16	-4.30	30.,20.
-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-99.00	-15.57	-1.89	0.96	3.22	3.05	3.54	31., 9.
3.23	3.19	3.50	4.23	4.69	5.91	5.85	6.28	7.61	3.77	-5.41	-12.26	-99.00	31.,22.
-99.00	-99.00	-99.00	-99.00	-99.00	-8.09	0.75	1.21	2.70	4.18	1.72	3.90	4.11	32.,11.
4.53	5.23	6.22	6.01	6.47	7.40	8.04	2.55	-3.52	-21.17	-99.00	-99.00	-99.00	32.,24.
-99.00	-99.00	-15.93	-0.49	1.33	2.42	4.80	5.72	6.46	5.15	5.17	5.82	6.48	33.,13.
7.28	7.54	7.24	7.49	7.84	7.63	0.44	-24.23	-99.00	-99.00	-99.00	-99.00	-99.00	33.,26.

FIGURE 11. Printed Output of Grid Values.

Establishment of Horizons. Further studies of the objectives of the project indicated that the grid value program needed more flexibility in the selection of contourable surfaces called horizons, for which grid values could be calculated. Contours at a uniform depth below the lake surface were not sufficient since contours on typically irregular lower epilimnion and upper hypolimnion surfaces were desired. This flexibility was added by incorporating a section which would accept the input of a specified depth at each sampling station. These specified depths were the depths to an irregular surface such as the lower epilimnion or the upper hypolimnion and designated which parameter value at each station was to be used in grid value calculations. See Figure 12 for a block diagram of Program II.

Development of Program III - Contouring Program

Once the systems to compute cell strip boundaries and grid values were developed, the Snowden contouring program was modified to suit the needs of this project. The contour program in its raw form calculated contours to the extreme edge of the grid system without regard to any intermediate boundary limitations. The boundary cards were added to the program data and used to blank out contours that fell outside the boundaries specified. The application of these boundary cards was similar in concept to the employment of picture matting over a picture to blank out unwanted portions when it is framed. Before this idea was conceived, the possibility of using a real matting frame to screen out unwanted contours was actually considered. The computer screening was accomplished by following the trace of each contour as it was computed. The Snowden program in its natural form computed all trace points for a contour sequentially for each individual contour line. To take advantage of this characteristic, a point location routine was written as a subprogram to this program. As the trace progressed, the location of each successive point was compared to the minimum and maximum strip boundary segments formed by the two nearest strip boundaries. When the trace crossed either of these segments, the plotting pen position indicator was reversed (from write to no-write or vice-versa). In addition to this routine, a section was written to receive and store the input of grid values and to call the Snowden program (a subprogram also) at the appropriate time.

Development of Accessory Programs

Since the contouring program only computed the plotter commands for the contours, a separate program was written to compute plotter instructions for the drawing of the lake shoreline, meridian lines, and a graphic scale. This set of plotter cards was used over again for

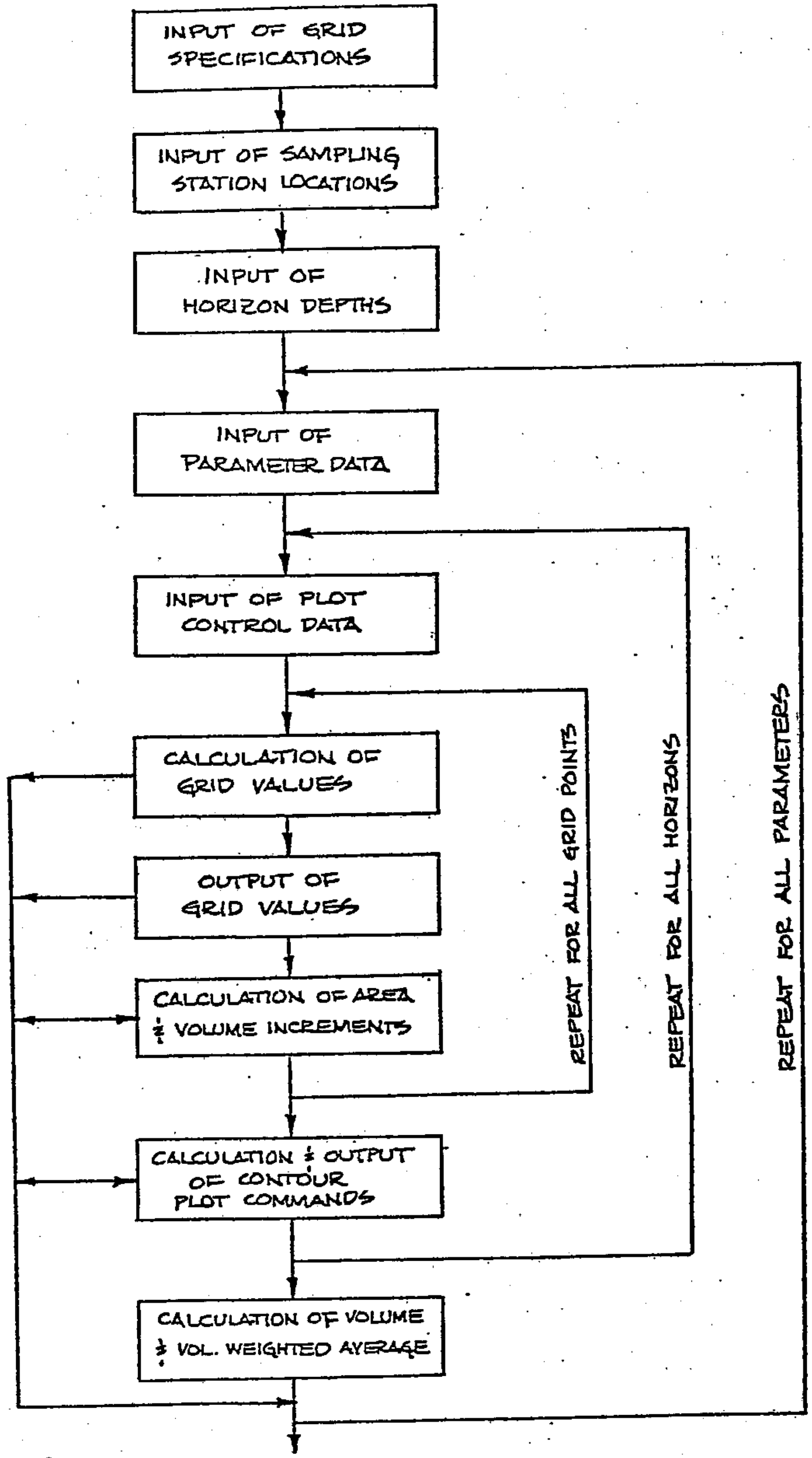


FIGURE 12. Block Diagram of Grid Value Program.

each plot since the information did not change. A completed contour plot was produced by superimposing the contour lines on the shoreline plot.

PROGRAM IMPROVEMENT

Initial Debugging

Once the first versions of the programs were completed, a cruise of data on dissolved oxygen concentrations was selected as test data. Language errors and major logic were debugged in approximately one and one half months. Most of the problems were encountered while correcting and adjusting the logic in the point location subroutine used in the contouring program. The first routine written became too complicated to debug as additions were made to correct exceptions in logic. The same happened with the second attempt, but the third routine was fast and accurate.

Streamlining of Production

An immediate goal of the project was to produce 200 plots of the most critical parameters from the major cruises. Eventually 400 to 500 were to be required, so the programs had to be studied and improved to handle a large volume of plots. In the course of producing one plot, Program II produced 103 cards containing grid values to be used in Program III. Program III, in turn, produced an additional 75 to 150 cards depending on the complexity of the contours. Thus, production of the 200 urgent plots would have generated from 36,000 to 50,000 cards. The logistics of handling this volume of cards, as well as the cost, would have overshadowed the benefits of the computer solution. To overcome this problem, Programs II and III were tied together as one program. Instead of being outputted on cards, the grid values went directly to the array used by the contouring subprogram for storage.

A second major area of streamlining plot production was on the plotting machine itself. Each new plot required the operator to shift the pen manually to a new origin location, mark that location, and start the second plot. Before the second stage of the plotting could begin the pen had to be returned manually to the same origin in order for the plots to superimpose correctly. This was very time consuming, so additions were made to the contouring program to automatically shift the plots as each successive plot was calculated. This was accomplished by adding an offset value to the plotting coordinates that depended on the number of the plot being calculated. This reduced the manual shifting of pen position to two operations no matter how many plots were being constructed. This shift was added to the shoreline program as well. Initially the operator wet the pen and marked the origin, then as many shoreline frames as required were generated. The pen was then returned to the origin and the contours added, in succession, to each plot.

Elimination of False Contour Gradients

Description of Problem and Likely Causes. After the first plot was produced, the contours were compared to the station values contoured. The contour plot had more contour fluctuations and sharper contour gradients appeared to fall along the shoreline areas, although there were also some of these areas in the middle of the lake (see Figure 13).

A closer inspection revealed that all of these questionable areas fell in large open areas between stations. The grid value program always used the three stations nearest to a grid point to calculate a parameter value for that grid point. This was reasonably accurate whenever the grid point was surrounded by the three station values, so that the grid value was calculated by interpolation. However, when the three closest stations fell to one side of the grid point, the parameter value was calculated by extrapolation. In some cases, this grid point was located two to three times as far away from the nearest station as the average distance between the three stations. This condition caused extremely high or low values to be extrapolated from minor variations in parameter station values. As calculations progressed down a strip of grid points the same 3 stations would be used until a new one became closer. If values were extrapolated over a large distance the new station sometimes drastically changed the grid parameter value compared to the value at the previous grid point.

Solutions. To correct this problem, the weighting of the stations used to calculate the grid values was altered to give more weight to the closest station's parameter value. When this new procedure was employed, the sharp gradients were reduced, but the ghost fluctuations were still present (see Figure 14). If the computer solutions were to be comparable to earlier hand solutions by other scientists, the computer plots had to produce interpretations that were reasonable and fairly consistent with interpretations produced by hand. Thus, it was important to eliminate as much as possible the logic errors causing the ghosts. For all practical purposes, the problem was eliminated by changing the algorithm to a "trap" routine to find the three closest stations which straddle or trap the grid point. This was accomplished by first finding the eight closest stations. The six furthest stations of

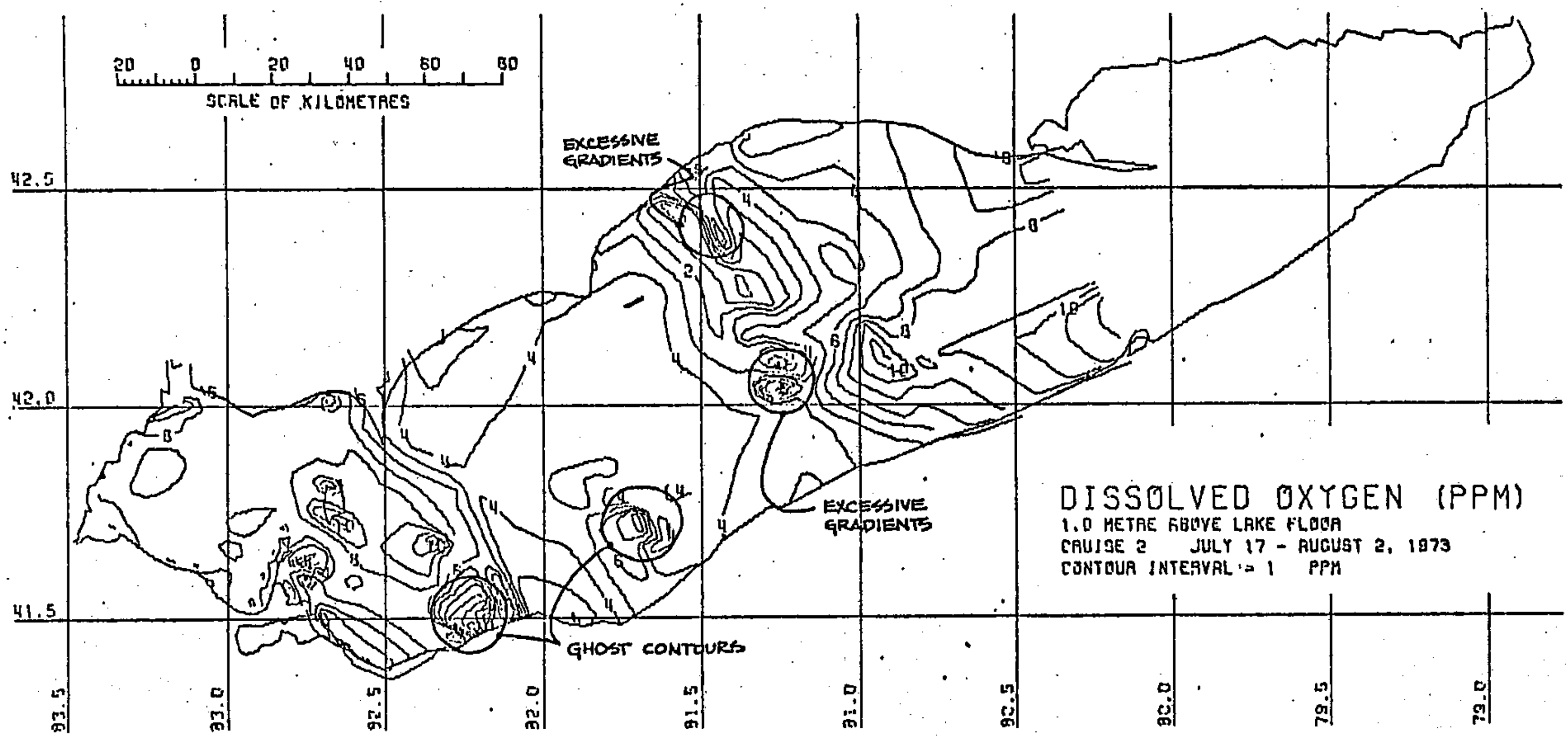


FIGURE 13. Contouring Without Extrapolation Adjustment.

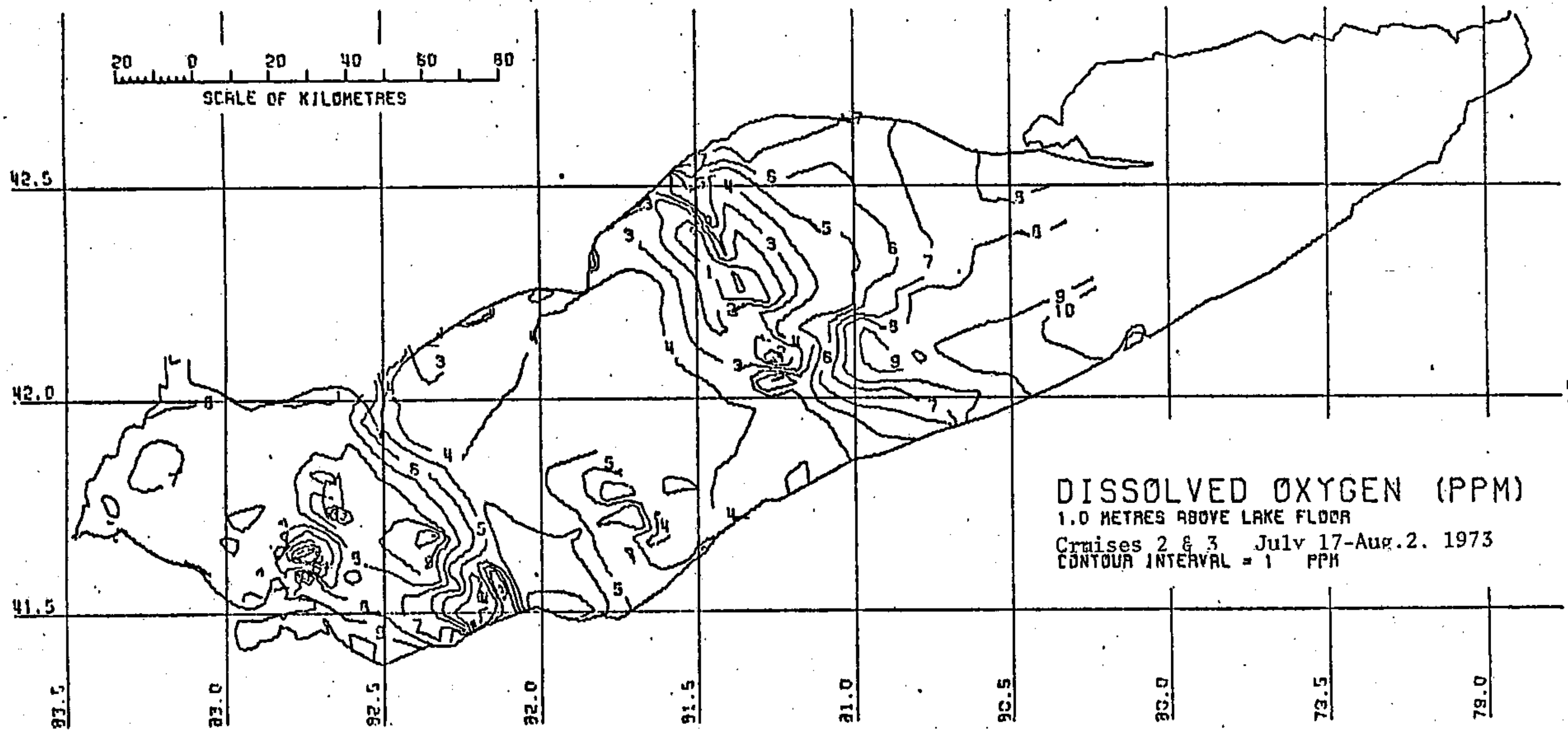


FIGURE 14. Contouring with Weighted Value Adjustment.

the eight were then surveyed to find the closest additional station which enclosed the grid point. If none of the six trapped the grid point, the grid point parameter value was calculated as an arithmetic average of the eight values. This procedure was highly effective and gave very reasonable interpretations of the data (compare Figure 15 to the two previous figures).

Reduction of Data Requirements

In its original format Program II required considerable data aside from the strip boundaries and station parameter values. The preparation and assembly of this data was complicated and required some extensive pre-calculations. To meet the objective of simplicity, some of the pre-calculations and data were eliminated by reducing the program flexibility in areas where it was not greatly beneficial. For example, initially the input required a specification of contour interval, contour label spacing, number of label digits, and minimum allowable contour value. Experimentation yielded the best label spacing as well as contour interval. The spacing was incorporated as a constant, and the contour interval was program calculated to produce an average range of six contours per plot. When labels were plotted with three digits and a decimal point the plot became very cluttered, so labels were plotted only as integers and the appropriate label magnification factor listed in the title block. A minimum allowable contour value of zero was incorporated into the program to prevent the plotting of negative parameter levels which resulted from extrapolation errors. In actuality, this guard became unnecessary when the trap routine was added.

Reduction of Looping Problems

Occasionally the computer would get caught in a closed loop because incorrect data was submitted or correct data was submitted in an incorrect fashion. In these situations the computer would repeat calculations until allotted time expired or an erroneous condition such as overflow was created. To reduce this hazard, special error statements coupled with stop commands were added at areas of likely trouble.

Compression of Storage

Some of the program job costs were based on the storage required for compilation and execution of the program. The storage was allotted in 126,000 byte blocks and with cost based on the number of blocks required. For this reason it was advantageous to keep the storage at or just below a multiple of 126,000 bytes. The original

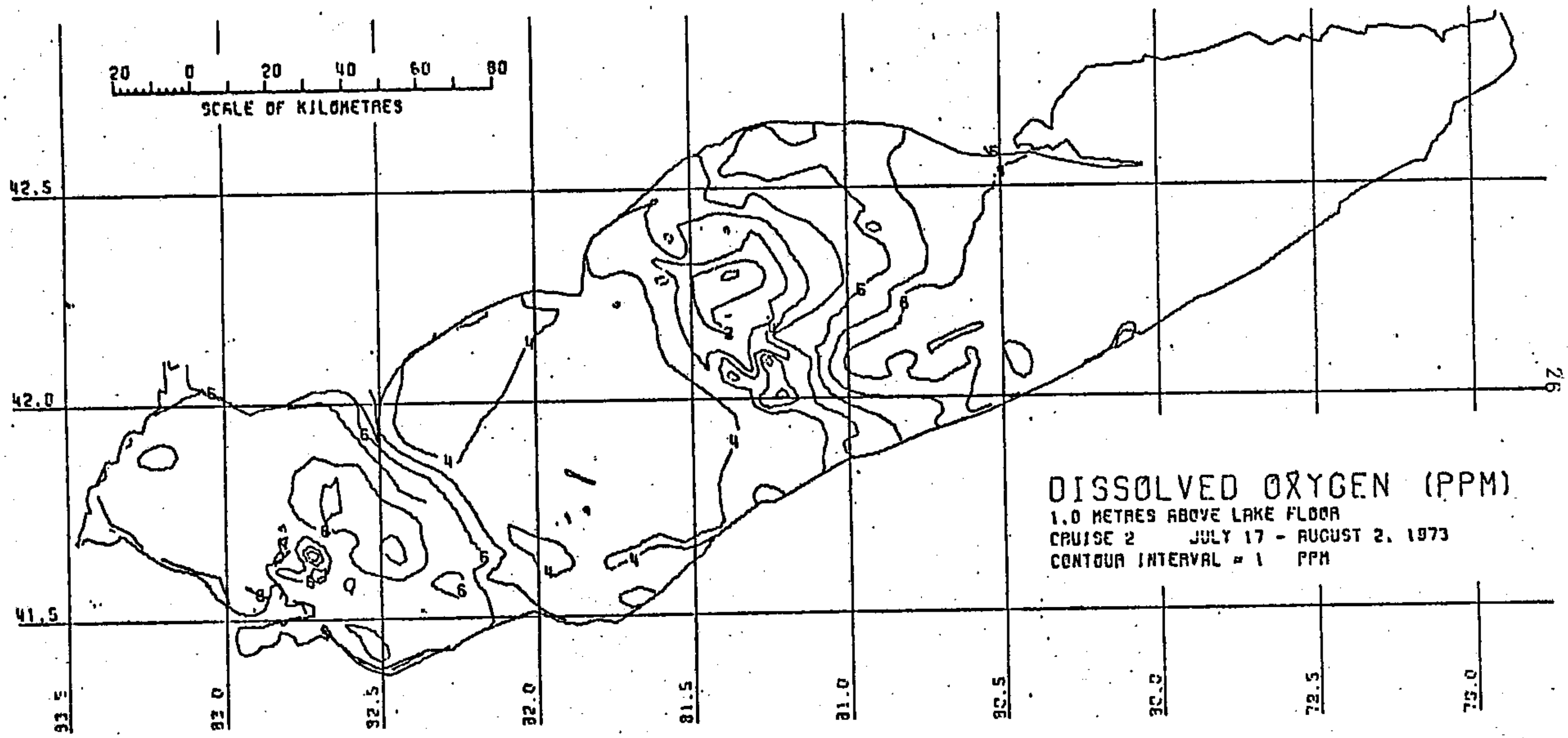


FIGURE 15. Contouring with Trap Routine

design of the programs required less than 126,000 bytes, so when programs were combined or expanded, as much storage as possible was shared by different segments of the program to keep storage to less than one block.

Packaging of Common Data

Finally, because of the great similarity in the program data required for each of the 200 plots, a subroutine was added to the grid value-contouring program. The subroutine included four different packages of values for the common variables which varied with the nature of the lake stratification. By specifying one certain package number, the program automatically selected the appropriate values for grid limits, contouring option, volume option, chart factor for plot size, other miscellaneous plot factors, options to print or punch grid values, as well as the number of plots.

As the programs were run, more improvements were added to yield the final product shown in Figure 16. As written, the programs worked quite well and produced the contours desired, provided the correct data was submitted.

PROGRAM EVALUATION

Advantages

The final two programs accomplished nearly all objectives set forth initially and provided some extra flexibility. The plots that were produced were detailed, accurate, neat, and of good reproducible quality. The time to produce the plots was less than expected which made the cost lower. The programs produced contours for the two major types of horizons - a flat plane at a uniform depth below the lake surface and a warped surface at varying depths below the lake surface. Input was fairly simple, especially when the package values were used, and the original data from the data sheets was transferred to computer cards in an easy, logical, and compact manner without the need for alterations or conversions. The contour plots could be produced at any scale greater than fifteen kilometres per inch, but only the scales for three sizes of paper, 8 1/2" x 11", 16" x 11", and 24" x 11", had the multiple plot capability incorporated by an automatic shift of the plotting pen on the plotting machine. In addition, the grid value program computed volumes and areas as accurately as could be checked.

Beyond the original objective, some additional features were incorporated. Major analytical groups, such as contouring, package

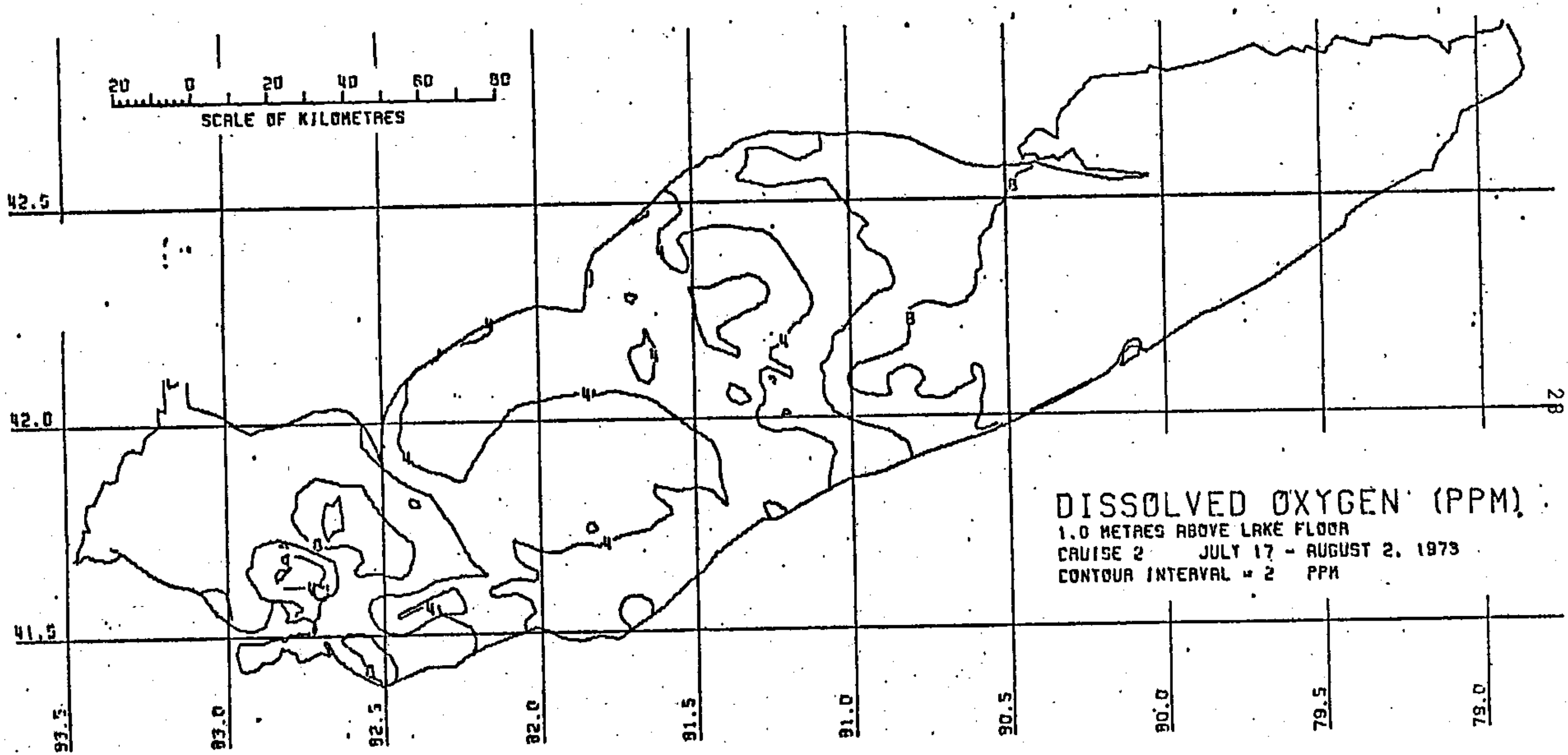


FIGURE 16. Final Contour Plot.

values, grid value calculations, and others were constructed as separate subprograms or main programs to facilitate additions or changes. The program could printout the grid values used in the contour calculations to produce likely parameter values in small areas of the lake not having a sampling station. Provisions in the strip boundary program produced boundary values which could designate contours to be plotted in only one basin or area of the lake if so desired. Changes in the volume of water in the lake were handled. With a few modifications the contouring program could produce contour plots of cross-sections of the lake.

Disadvantages

The results of the project were not without shortcomings, however. The major point of inconvenience was a data requirement for Program II. As a result of efforts to keep computer storage at a minimum every plot required the input of its own strip boundary deck. Even if several parameters were contoured within the same set of boundaries, the boundary deck had to be duplicated and read in for each plot. Additionally, the program generated 75 to 100 cards of plotter instructions for each plot. If the plotter instructions were kept for future recall, the large number of boxes of cards became a storage problem. On the plots themselves, only a few problems could not be resolved. One of them was the inaccurate plotting of contours around islands and peninsulas whose widths were less than the grid spacing. A second problem was the occasional overlap of contour labels onto nearby contour lines. Only a larger scale seemed to help this.

Other problems and limitations were minor compared to the ones above, and, on the whole, it was felt the final design met and exceeded the project objectives satisfactorily.

PROGRAM INPUT AND OUTPUT

Boundary Program

Required Input Data.

1. Length of a grid unit
2. Grid coordinate limits in X-direction
3. Special grid limits for basin (if desired)
4. Take floor depth below chart datum lake level (locations of data points and depths)
5. Designation of depth data stations included in each zone
6. Option designations for output desired

7. Sampling station locations
8. Minimum and maximum depths for which boundaries are desired
9. Boundary area name and date
10. Measured lake floor depths at stations (if option requires)
11. Grid values of depth to lower and upper surfaces of a layer (if option requires)

Possible Output Data.

1. Strip boundary values (printed and/or punched)
2. Floor depth grid values (printed and/or punched)
3. Layer thickness grid values (printed and/or punched)
4. At each sampling station, difference between measured floor depth and chart datum floor depth.

Grid Value and Contouring Program

Required Input.

1. Length of grid unit
2. Number of warped surfaces on which to be contoured
3. Number of parameters to be contoured
4. Sampling station locations (longitude and latitude)
5. Depths to warped surfaces at stations
6. Plot title information:
   parameter name
   contoured surface name
   date
   contour units
7. Number of stations of parameter data
8. Maximum number of data values at any station
9. Sampling frequency (every metre of depth or just at selected interfaces)
10. Magnification factor for plotted contour labels
11. Strip boundary values
12. Option designations for output desired

Possible Output.

1. Contour plots of parameter values
2. Area within specified boundaries
3. Volume within specified boundaries
4. Volume weighted average parameter values
5. Parameter grid values or warped surface depth grid values (printed and/or punched)

CONCLUSIONS

Applications

As a result of the large amount of flexibility built into the programs, this system could easily be expanded to handle all three basins of Lake Erie. For that matter it is also applicable to data from any other lake or general volume where there were enough sampling points to construct contour plots. The grid layout and the lake floor or physical boundary location data are the only major items that change from one situation to another.

The major benefit of this system to any lake is the vast amount of data that can be illustrated in detail in a short period of time. Once the grid is set up and lake floor location data prepared, a dozen plots or more can be constructed in the same amount of time conventional hand methods produce one plot, and at less cost. With this great time advantage, more aspects of the data can be examined than under other methods.

In addition to the plots, this system can also generate other information of value in lake water quality analyses. The volume of the hypolimnion can be calculated as well as the area of the anoxic region within this area. With the volume weighted average option, the average dissolved oxygen content in the hypolimnion or the heat content can be calculated to determine changes over a season or a number of years.

With some minor changes, the programs could also be used to produce cross-sectional contours or to determine optimum sampling point locations based on contour gradients.

Areas of Improvement

Aside from the wide range of applications, there are some areas where the programs could be improved. A great deal of the duplication of data could be eliminated if strip boundary information that is used more than once could be stored in Program II, at the expense of storage. Handling of the program and final output could be eased by placing these items on magnetic tape. The operation of the programs could also be simplified if the two programs could be combined or run together and if some of the input requirements could be incorporated as constants in the programs. However, the final system more than adequately met the goal and objectives of the project and the applications and improvements are almost unlimited in the field of water quality.

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APPENDIX

A. Lake Erie Temperature Plots

B. Lake Erie Dissolved Oxygen Plots

C. Lake Erie Conductivity Plots

D. Lake Erie Alkalinity Plots

E. Lake Erie Nitrate-Nitrite Plots

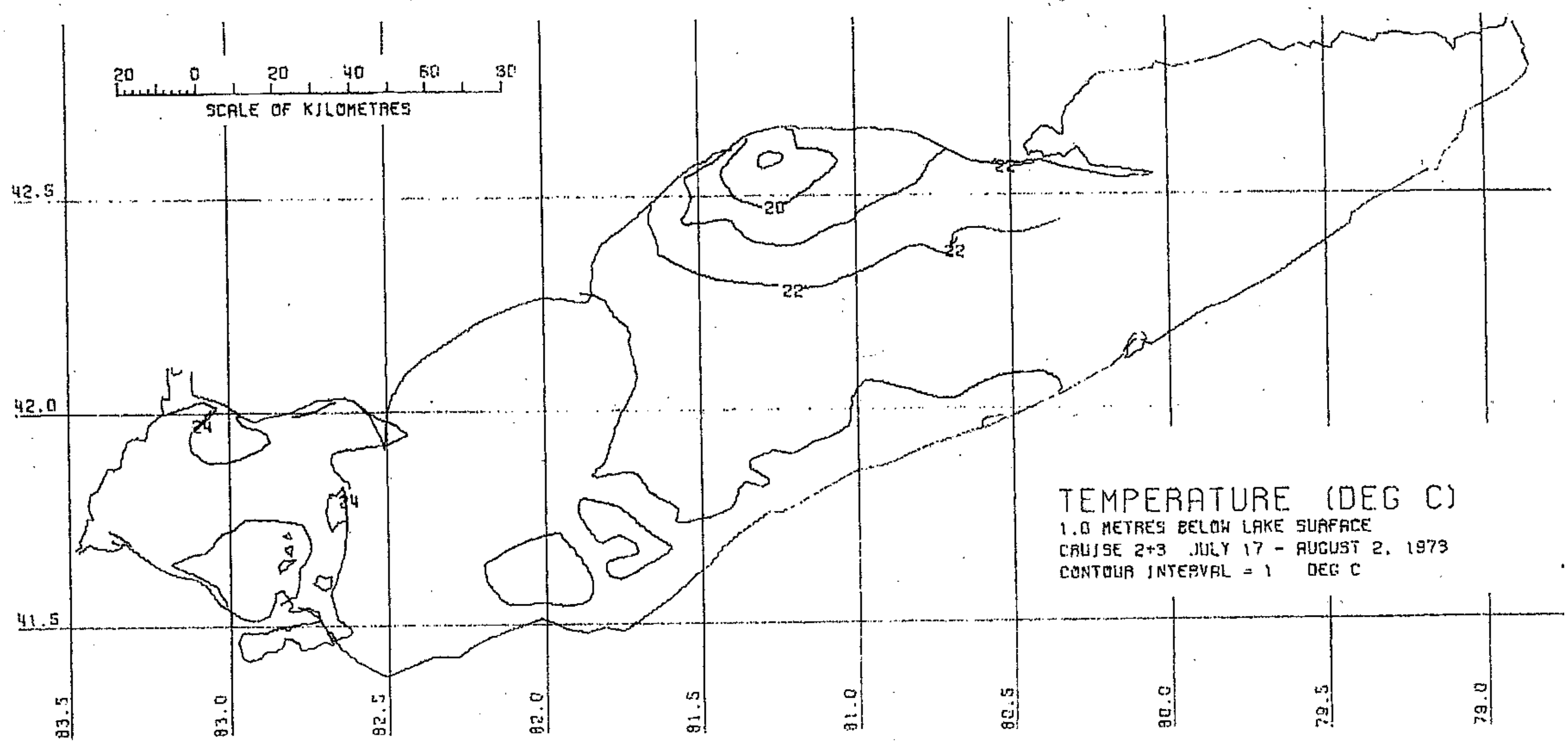
F. Lake Erie Total Inorganic Nitrogen Plots

G. Lake Erie Total Phosphorus Plots

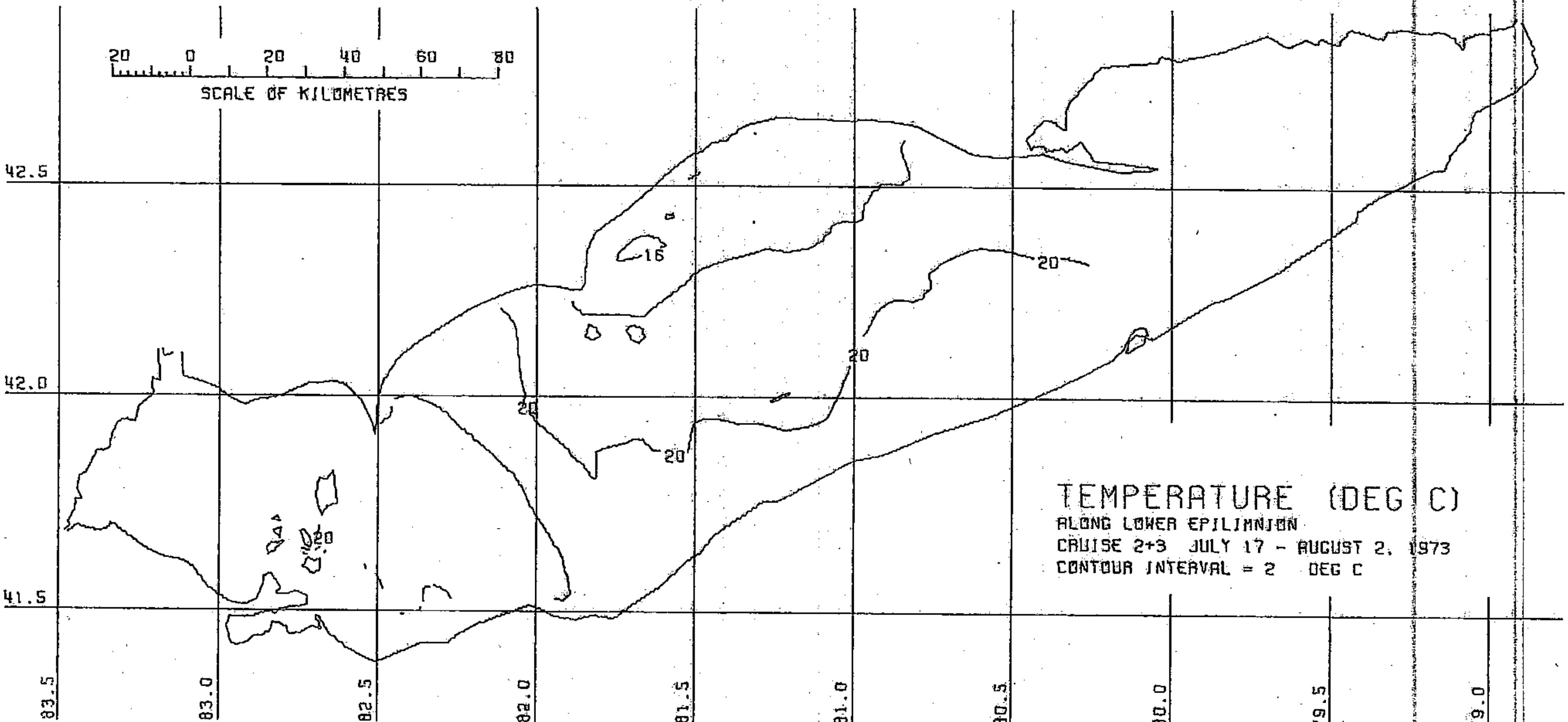
H. Lake Erie Chlorophyll Plots

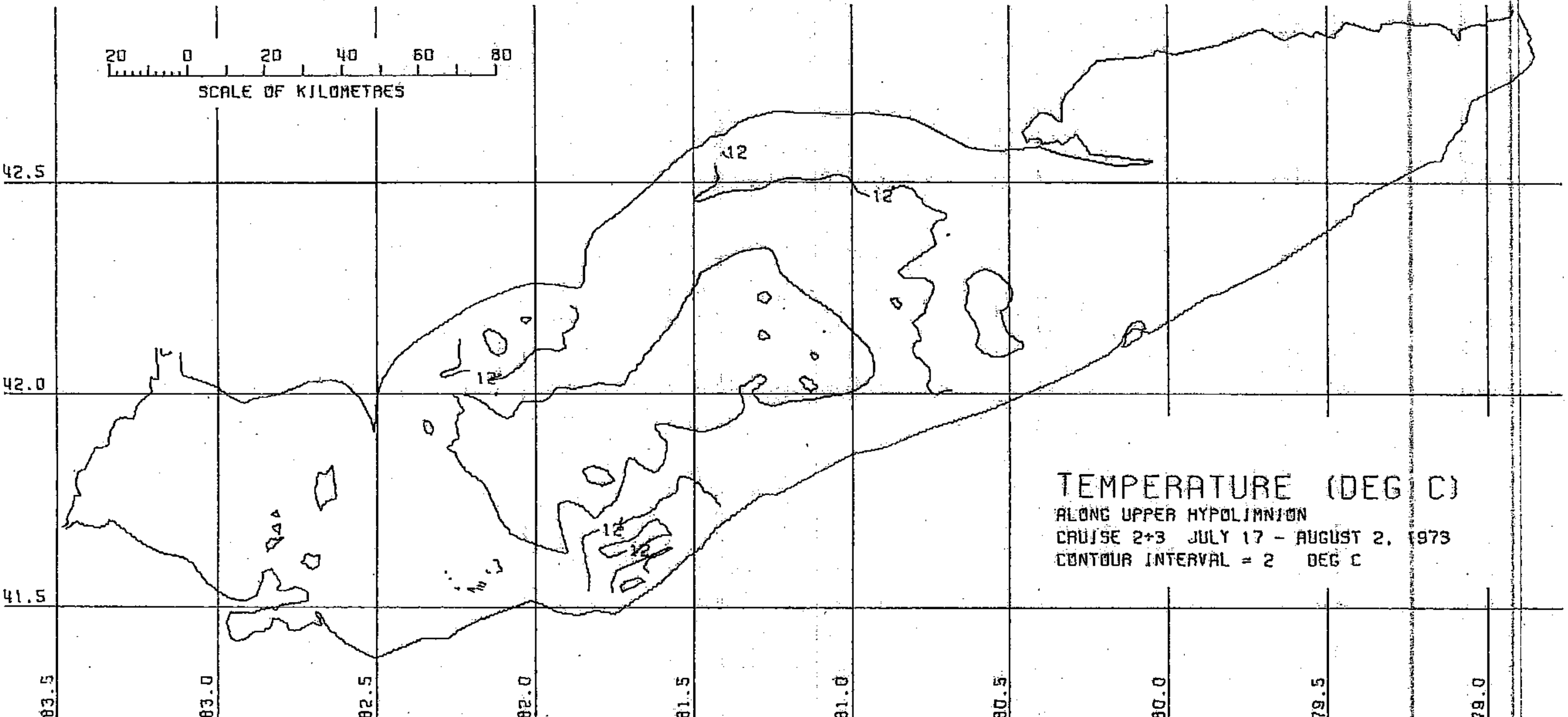
APPENDIX A

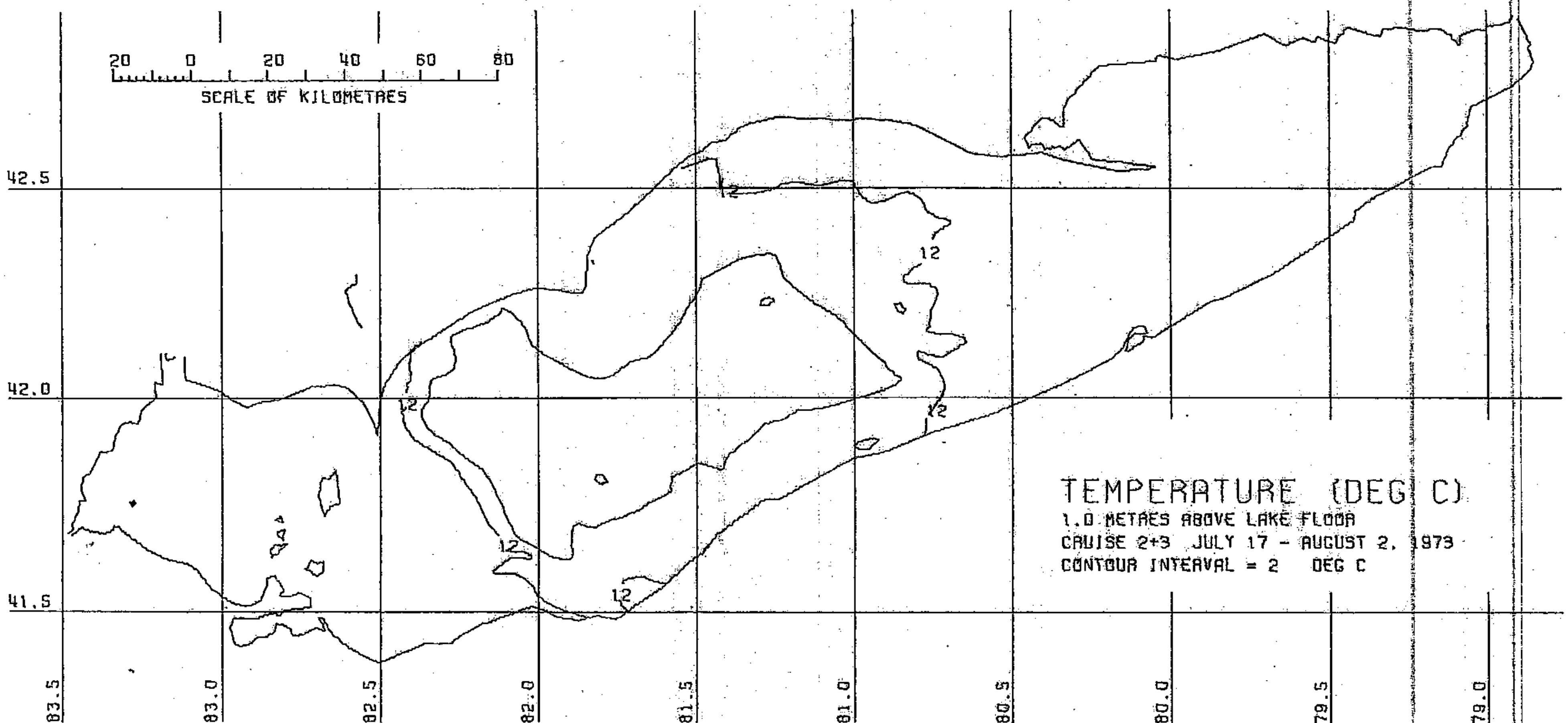
LAKE ERIE TEMPERATURE PLOTS



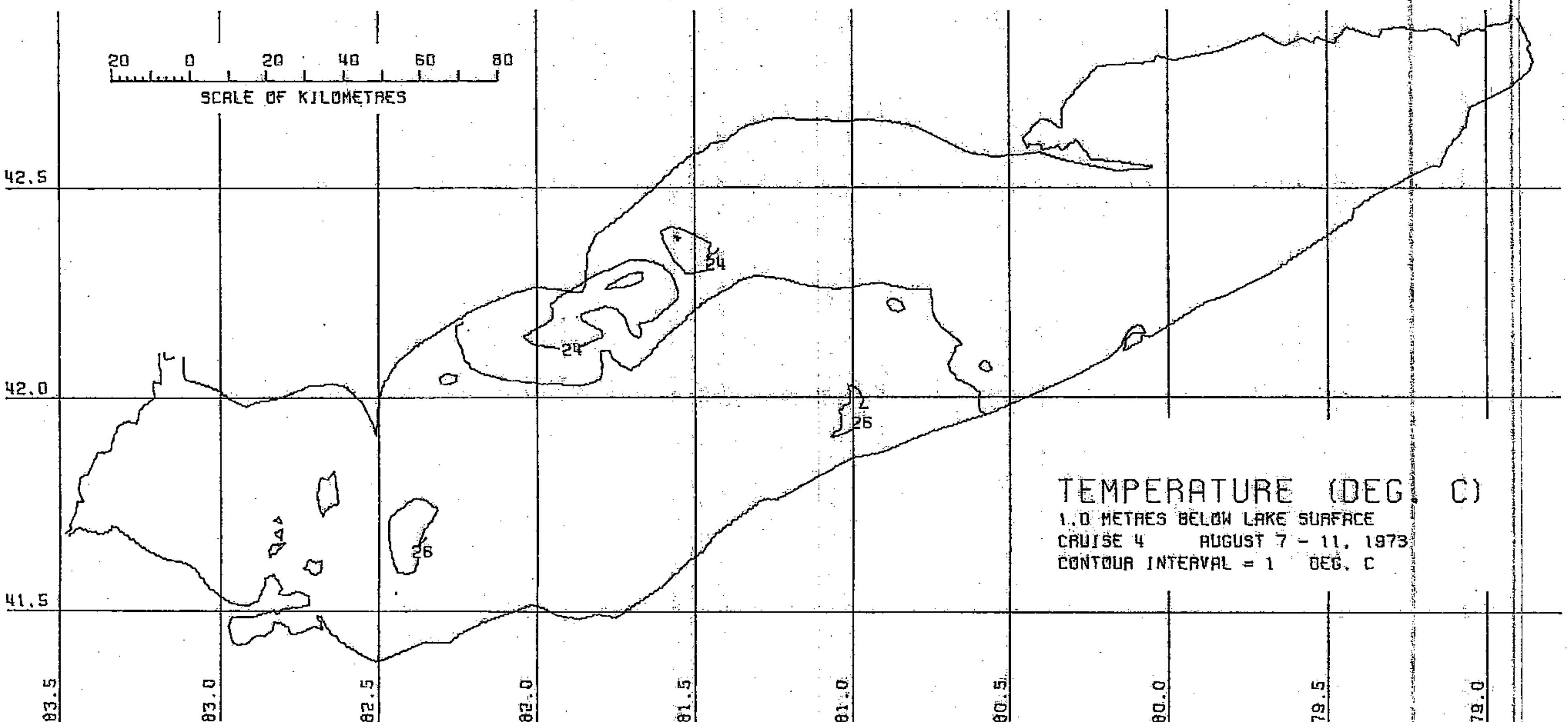
TEMPERATURE (DEG C)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 DEG C
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
20
22
22
22
24
24

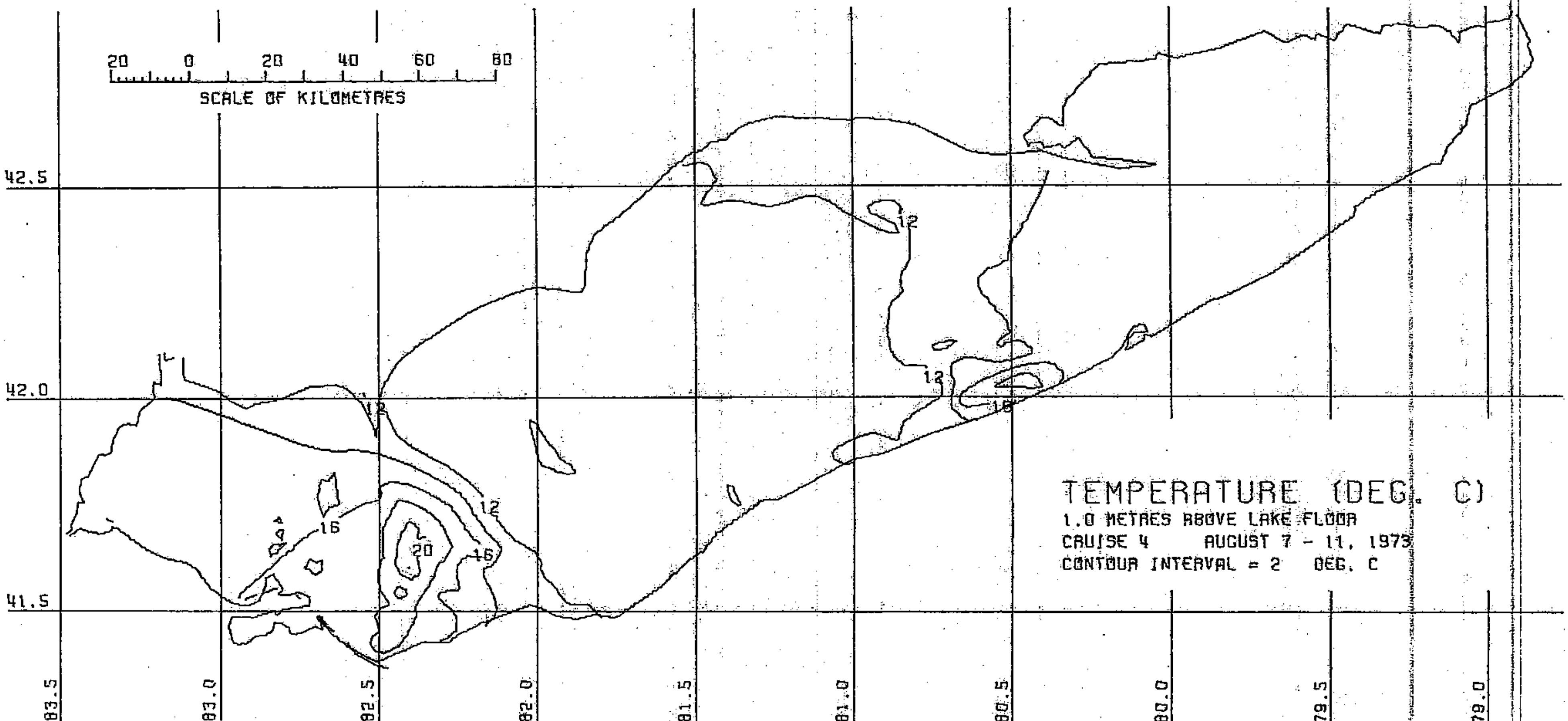

TEMPERATURE (DEG C)
ALONG LOWER EPILIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 DEG C
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
20
16

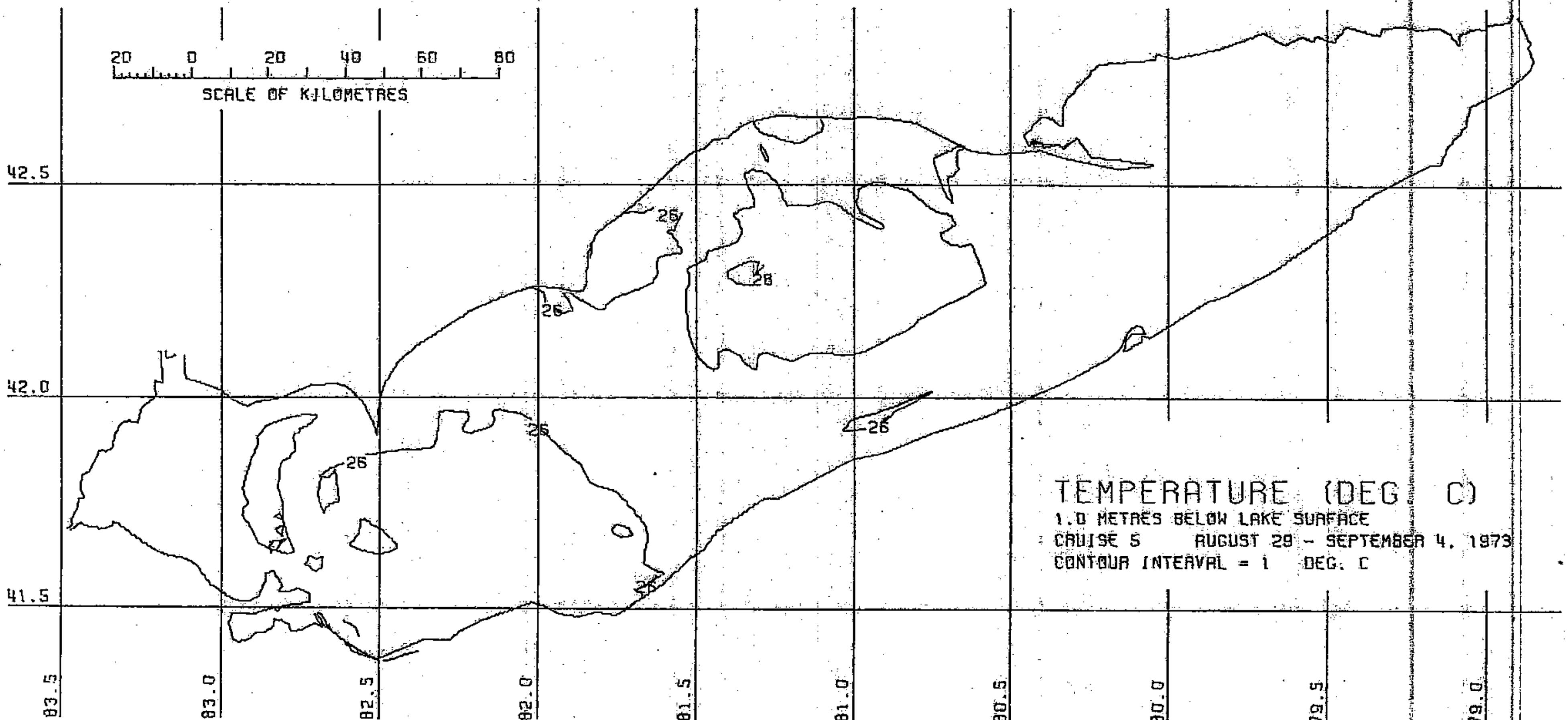

TEMPERATURE (DEG C)
ALONG UPPER HYPOLIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 DEG C
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
12
12
12
12

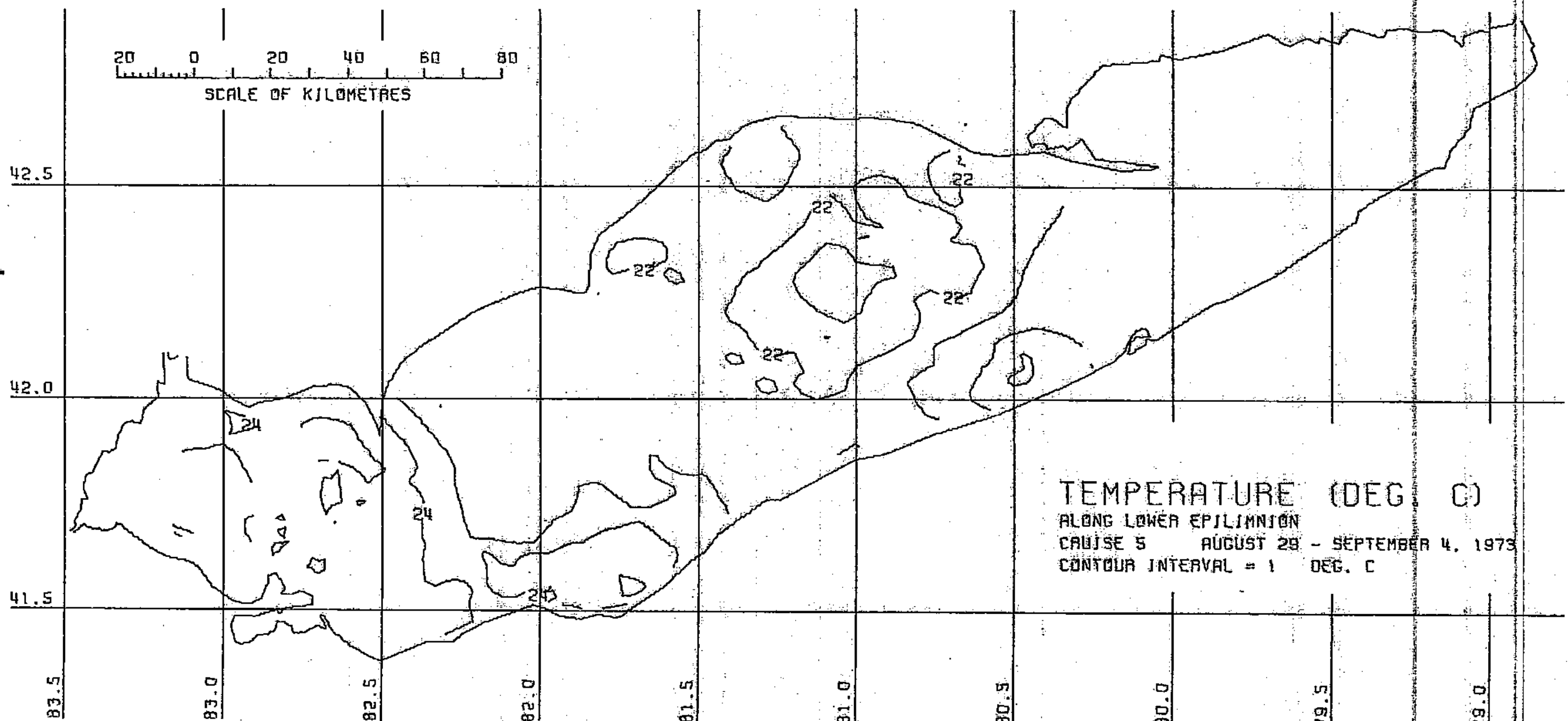


TEMPERATURE (DEG C)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 DEG C
SCALE OF KILOMETRES
20 0 20 40 60 80
12
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


TEMPERATURE (DEG. C)
1.0 METRES BELOW LAKE SURFACE
CRUISE 4 AUGUST 7 - 11, 1973
CONTOUR INTERVAL = 1 DEG. C
20 0 20 40 60 80
SCALE OF KILOMETRES
24
24
26
26
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


TEMPERATURE (DEG. C)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 4 AUGUST 7 - 11, 1973
CONTOUR INTERVAL = 2 DEG. C
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
16
20


TEMPERATURE (DEG C)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 DEG. C
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
26
26
26
26
26
26
26


TEMPERATURE (DEG C)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 DEG. C
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
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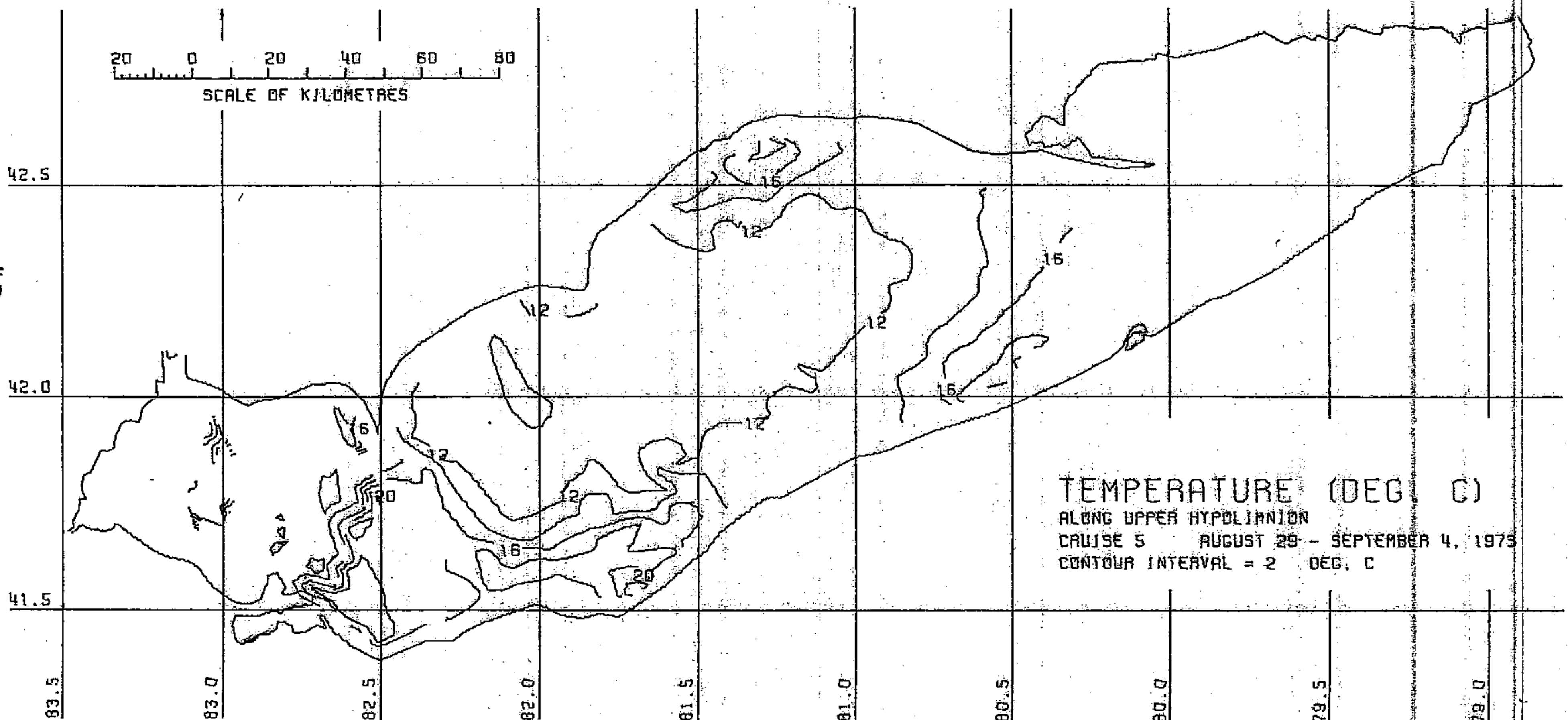
79.5
79.0
22
24


TEMPERATURE (DEG C)
ALONG UPPER HYPOLIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 2 DEG. C
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
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82.5
82.0
81.5
81.0
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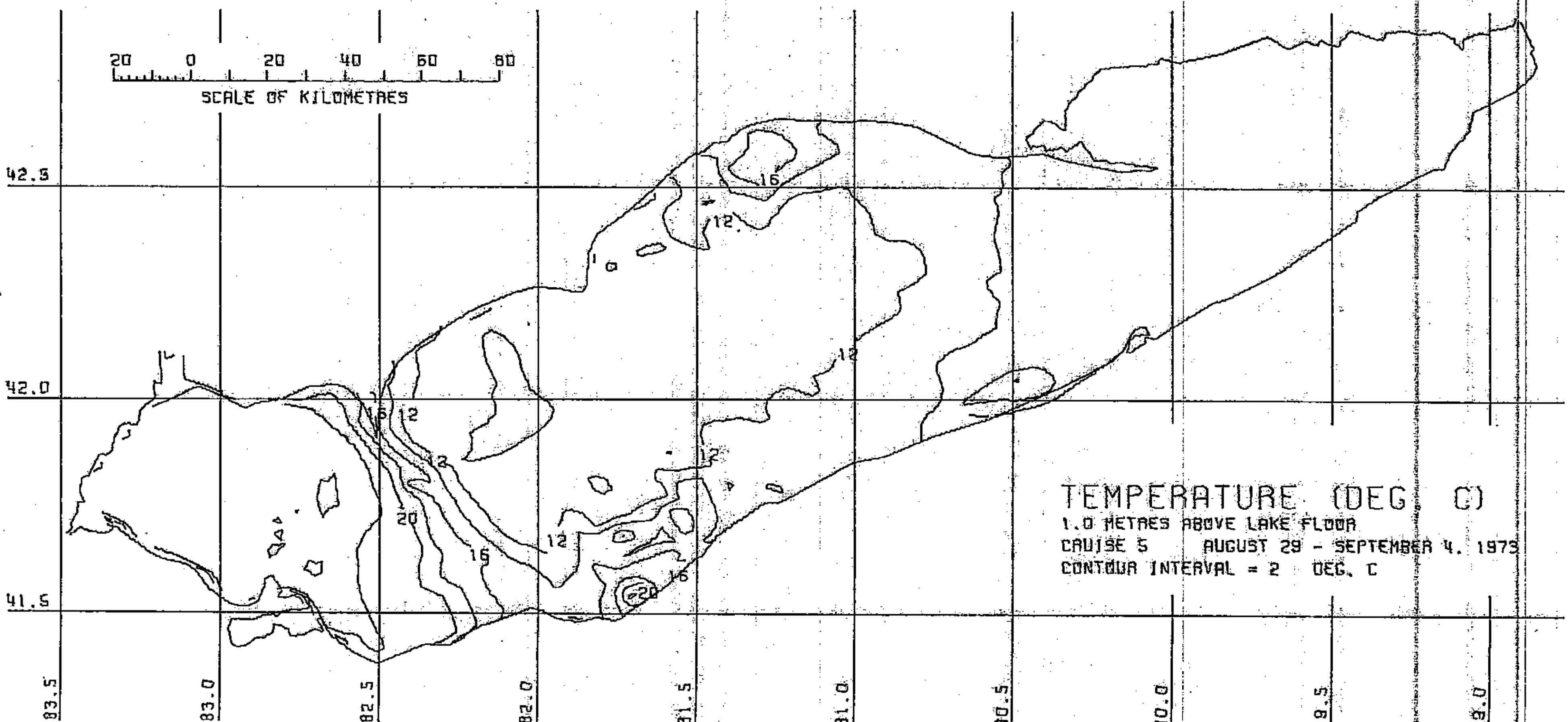
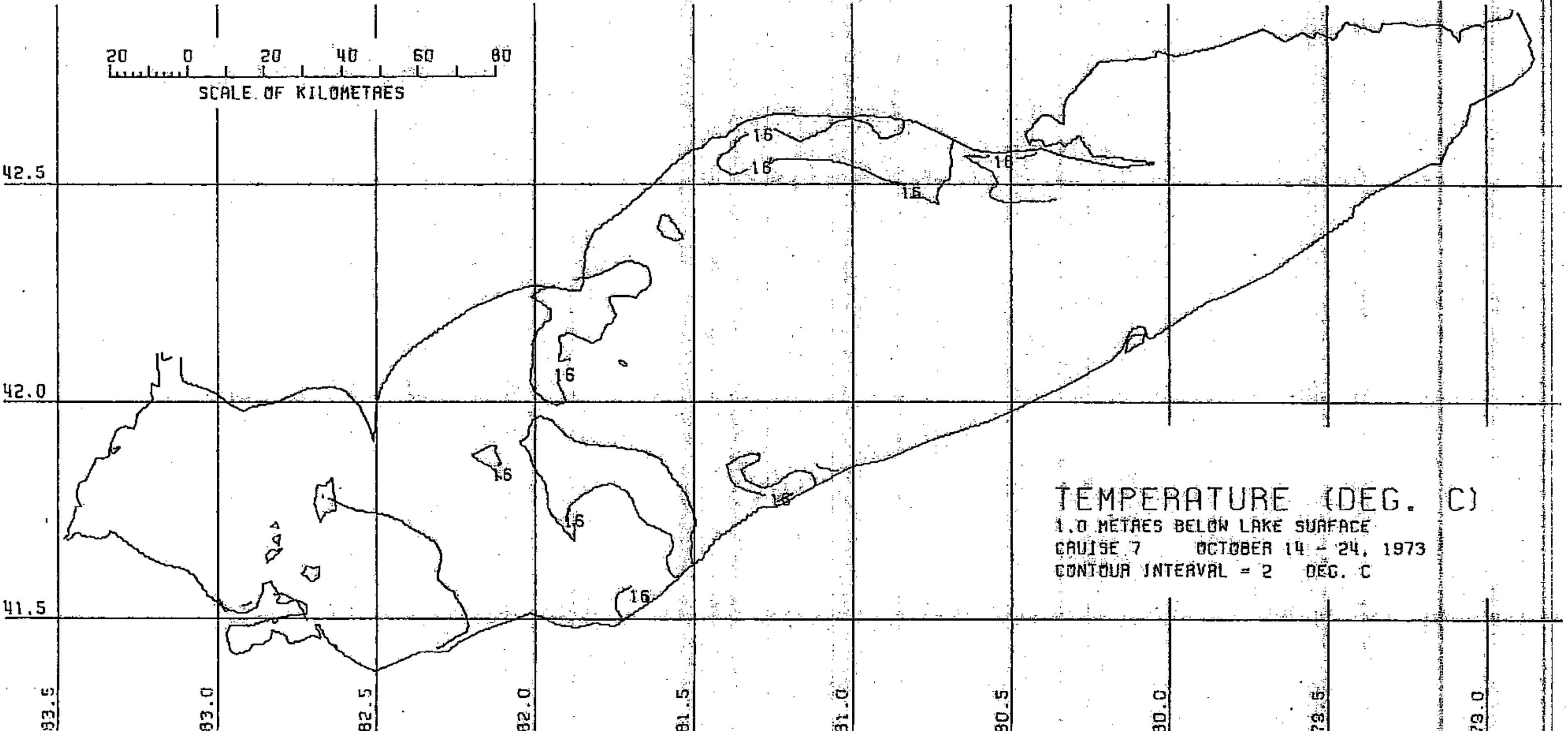
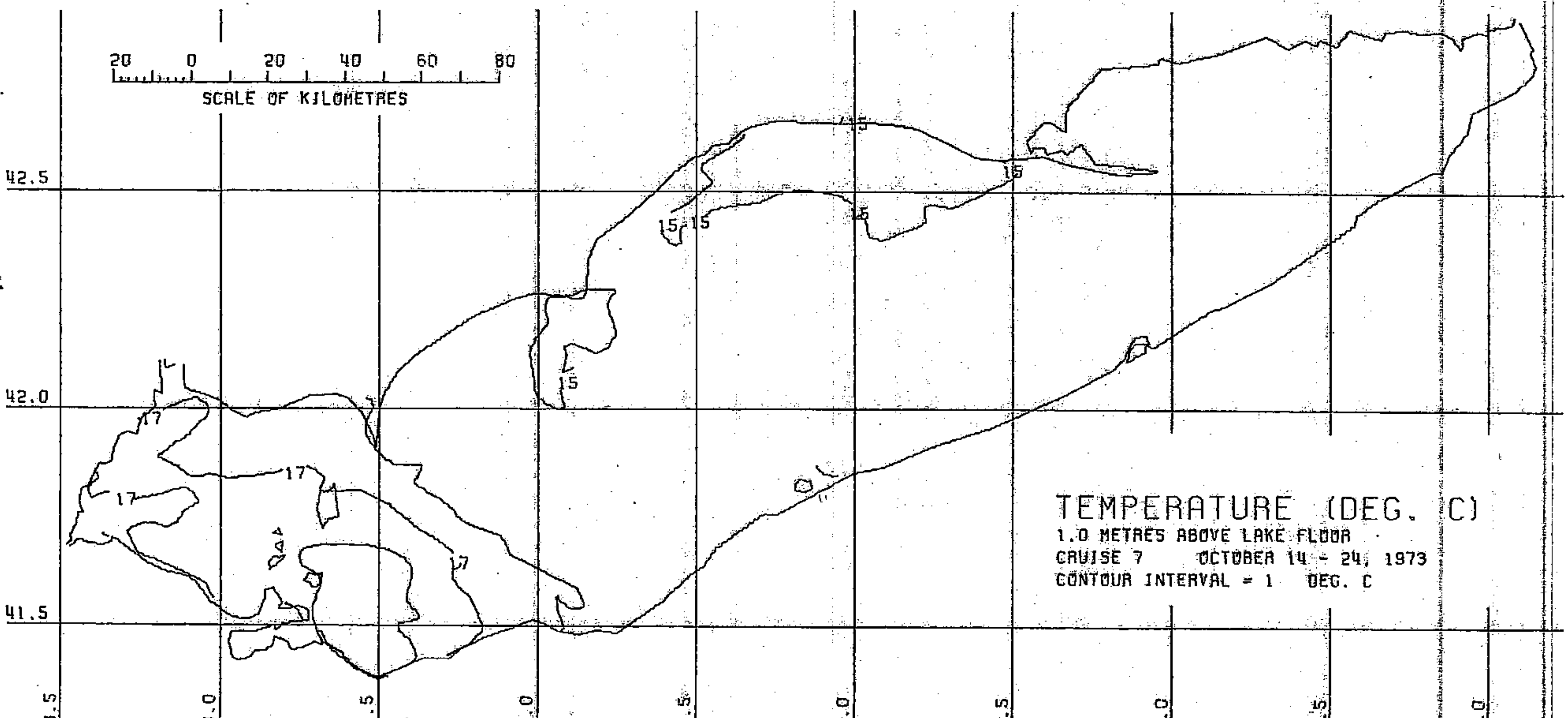
80.0
79.5
79.0
12
16
20


TEMPERATURE (DEG C)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 2 DEG. C
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
16
20

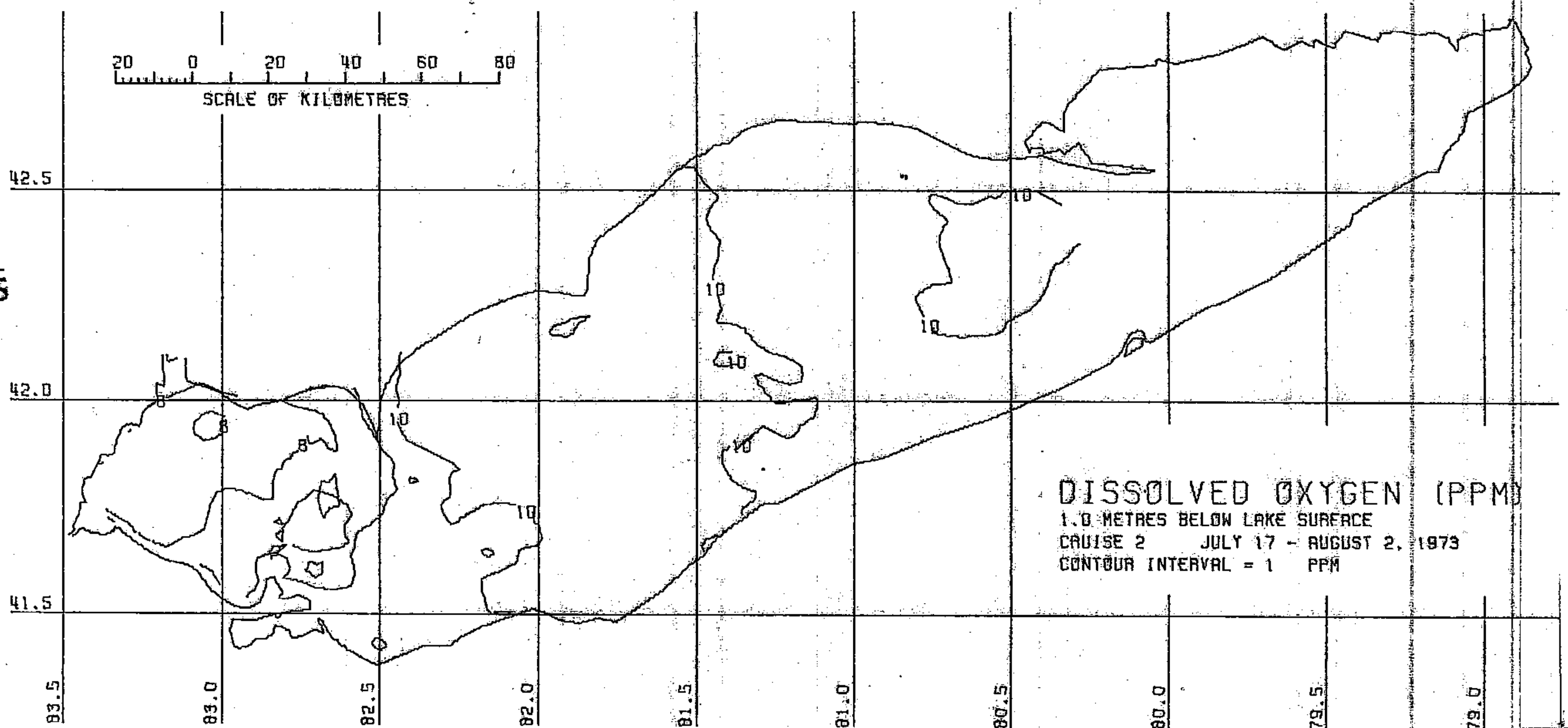


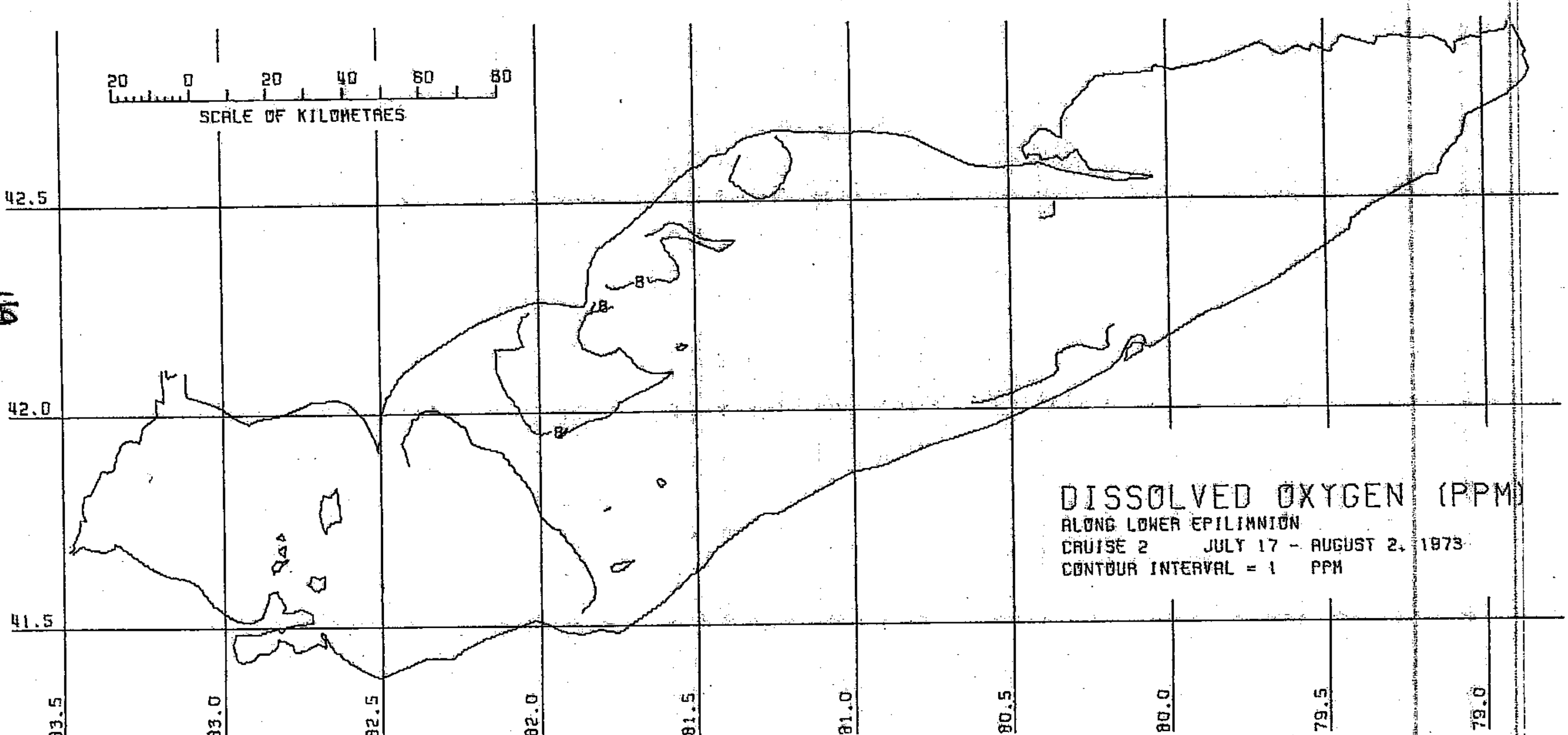
TEMPERATURE (DEG. C)
1.0 METRES BELOW LAKE SURFACE
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 2 DEG. C
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
16


TEMPERATURE (DEG. C)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 1 DEG. C
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
15
17

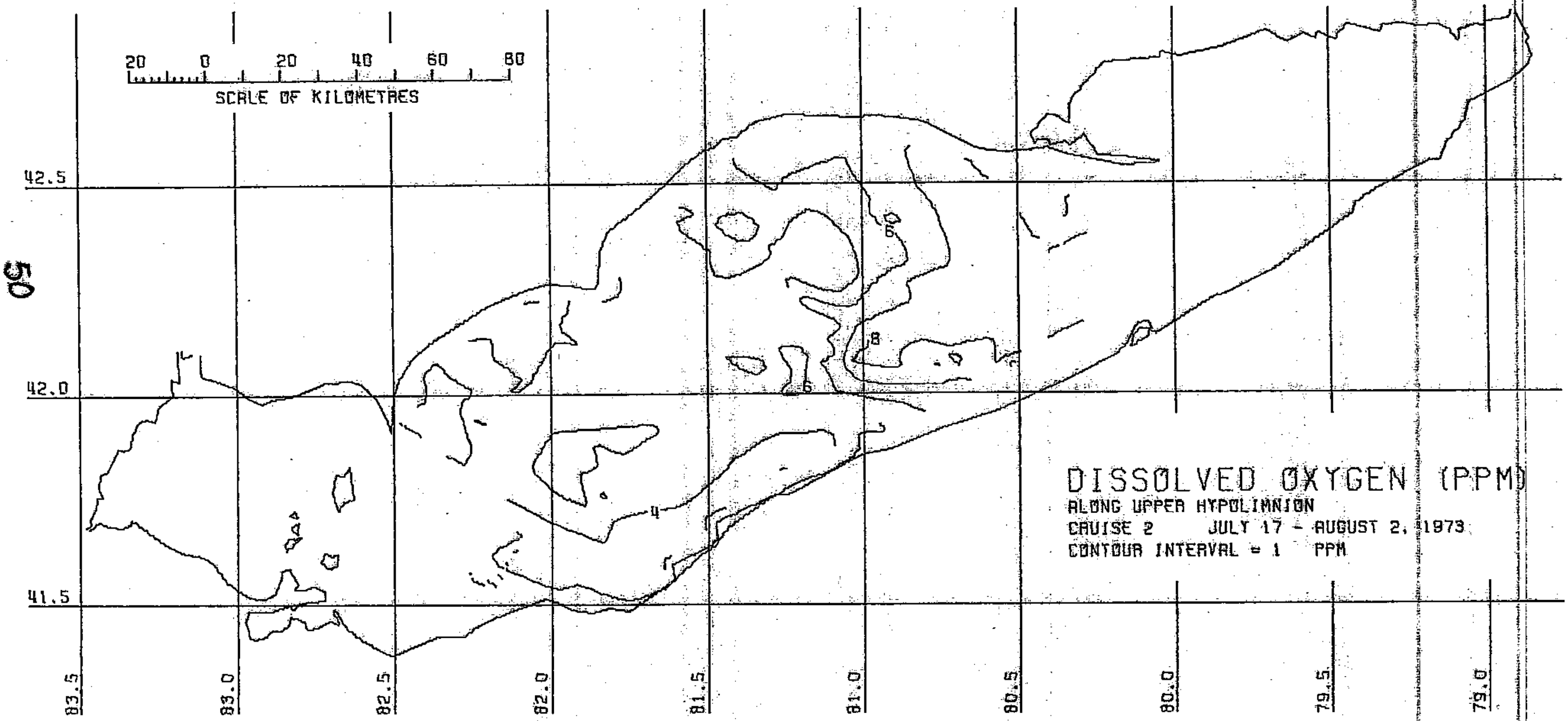
APPENDIX B

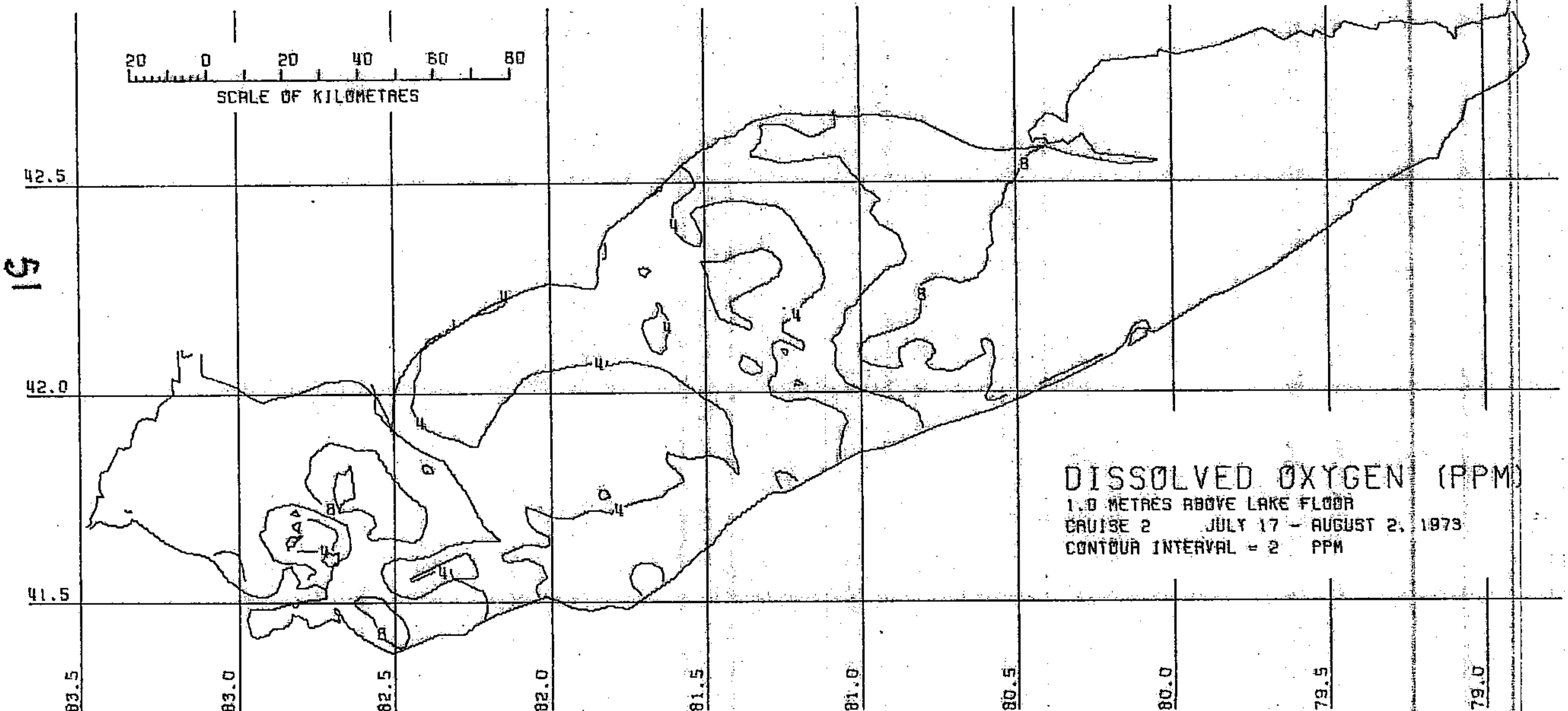
LAKE ERIE DISSOLVED OXYGEN PLOTS

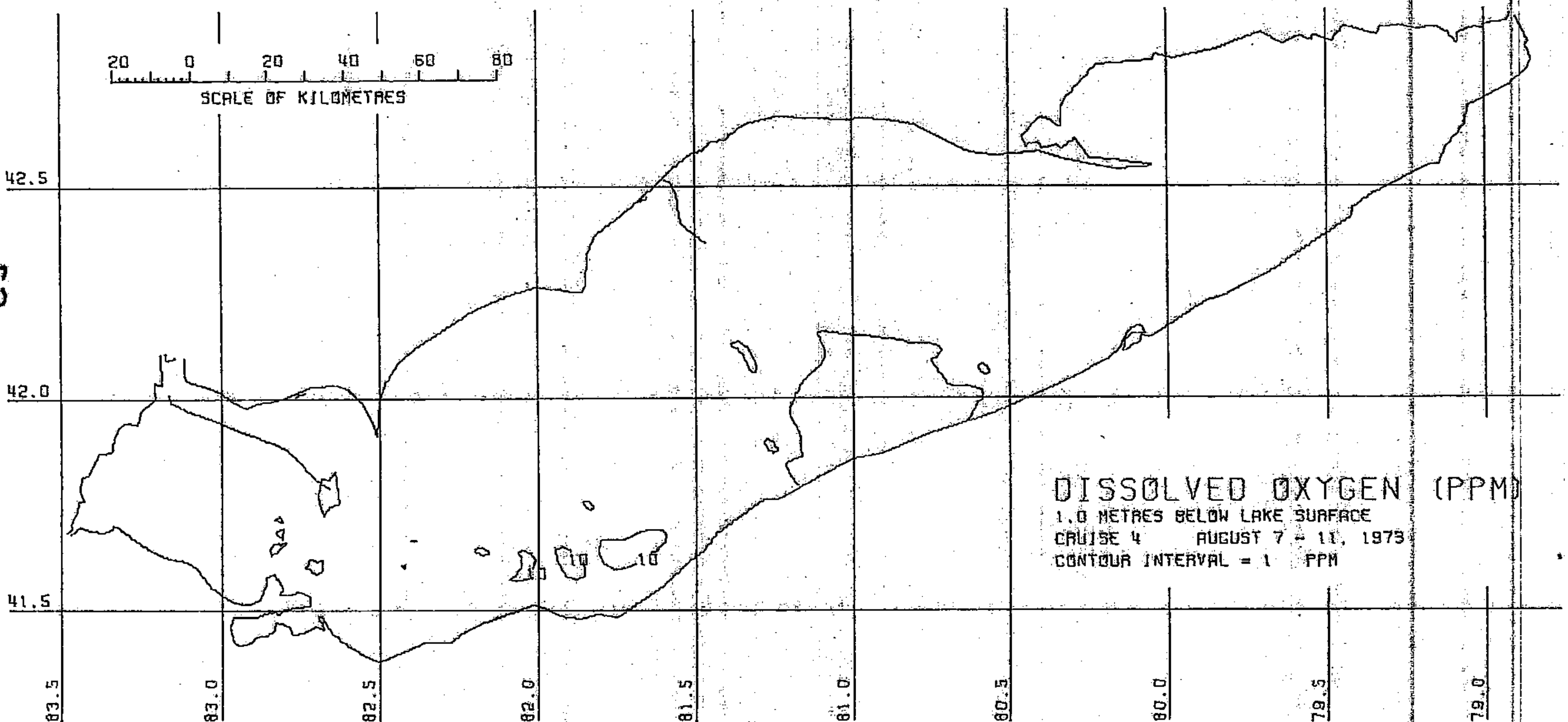

DISSOLVED OXYGEN (PPM)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 PPM
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
10
8

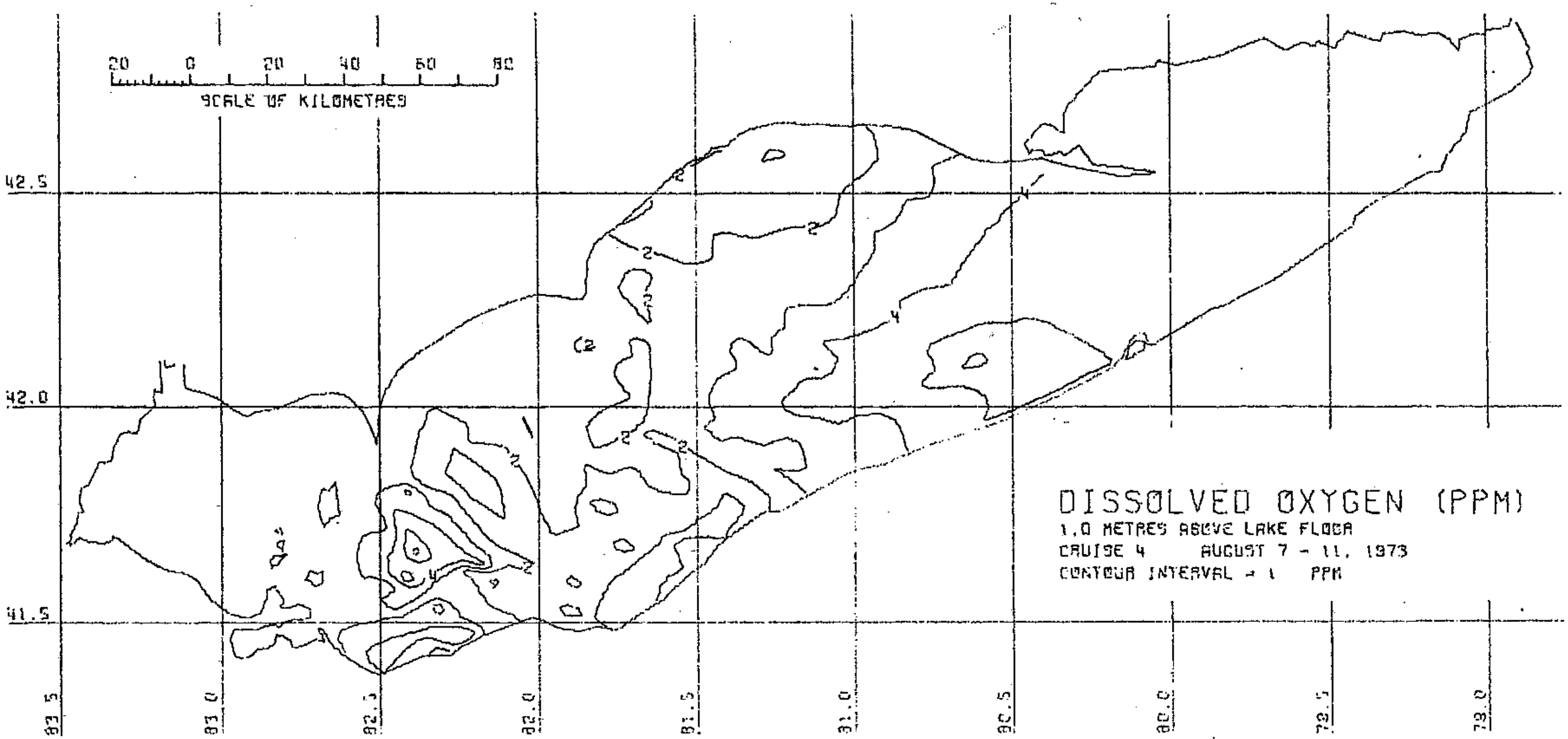


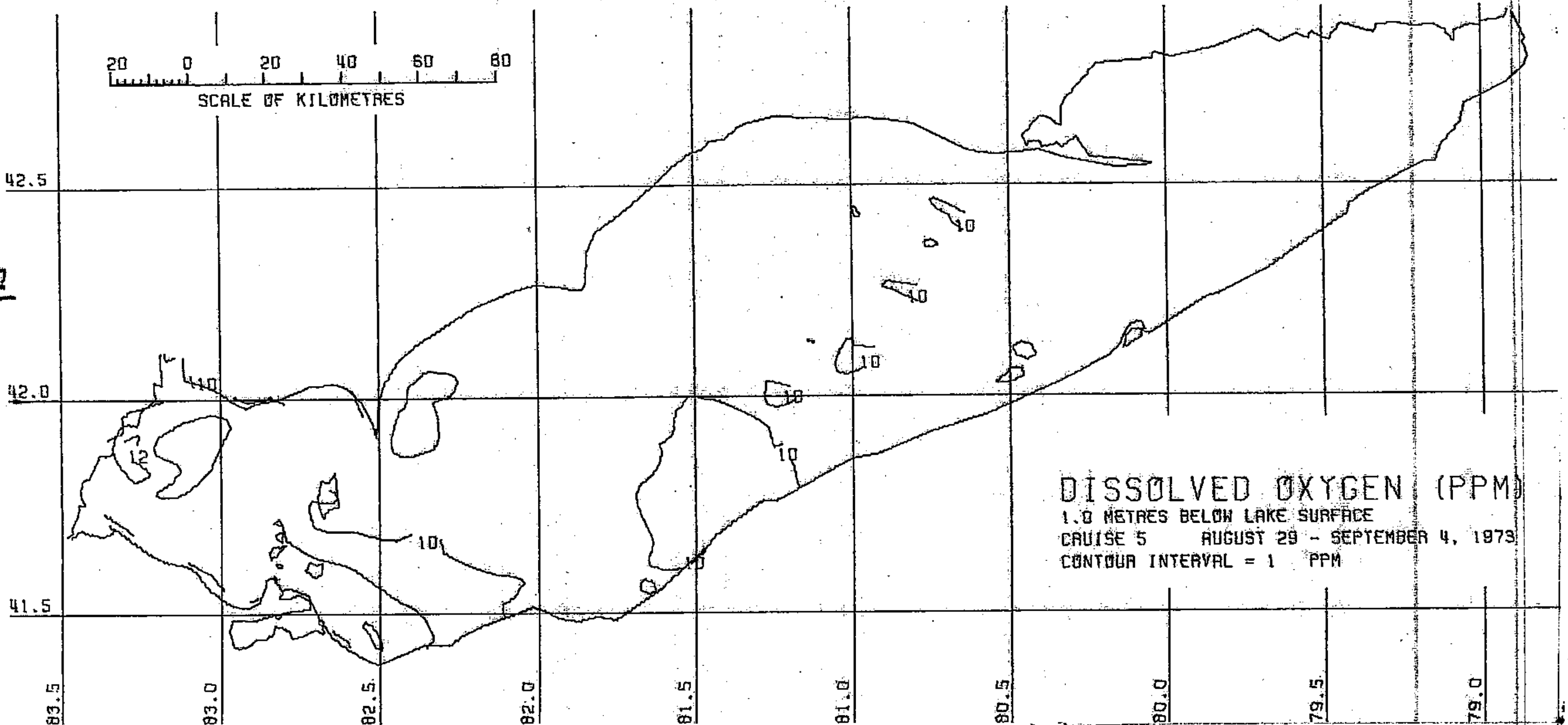
DISSOLVED OXYGEN (PPM)
ALONG LOWER EPILIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 PPM

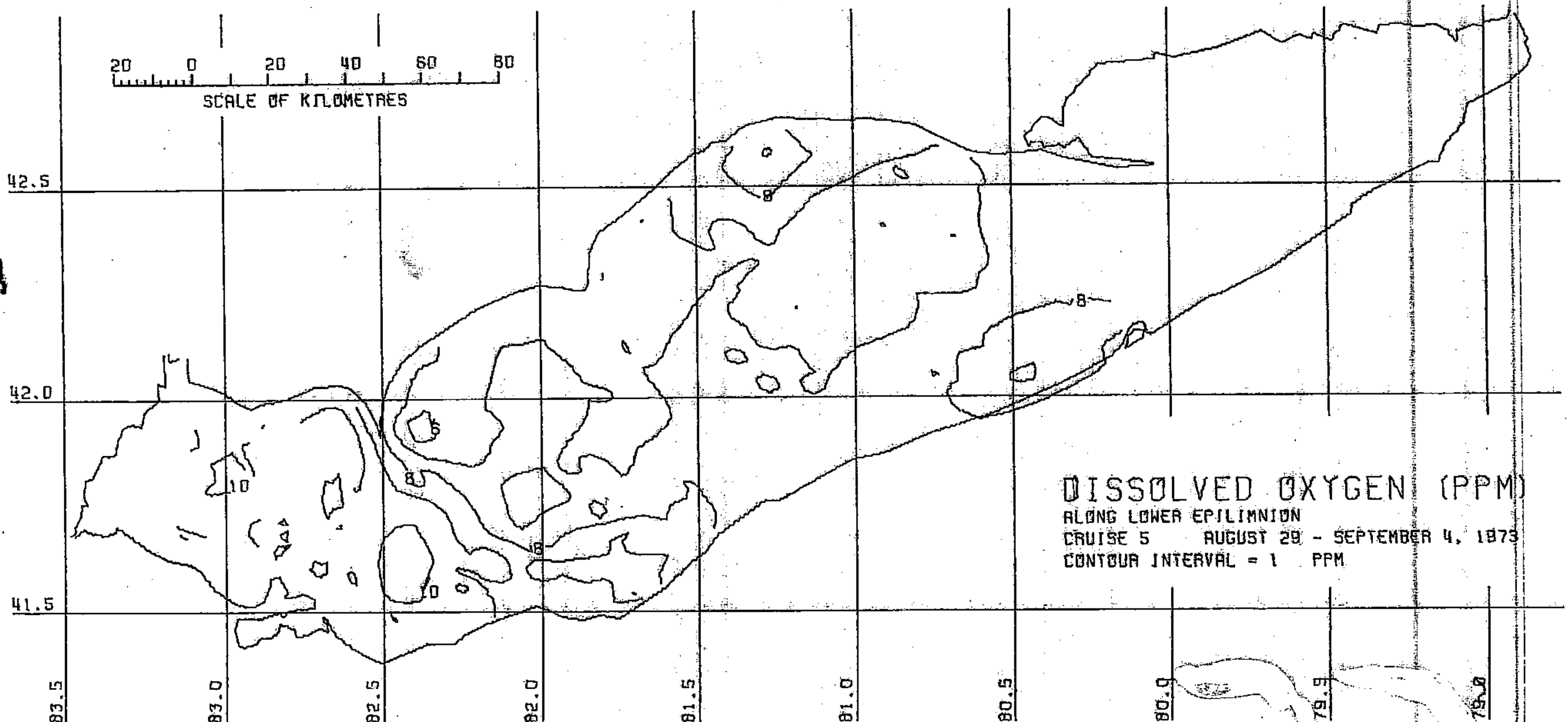

DISSOLVED OXYGEN (PPM)
ALONG UPPER HYPOLIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
4
6
8
9

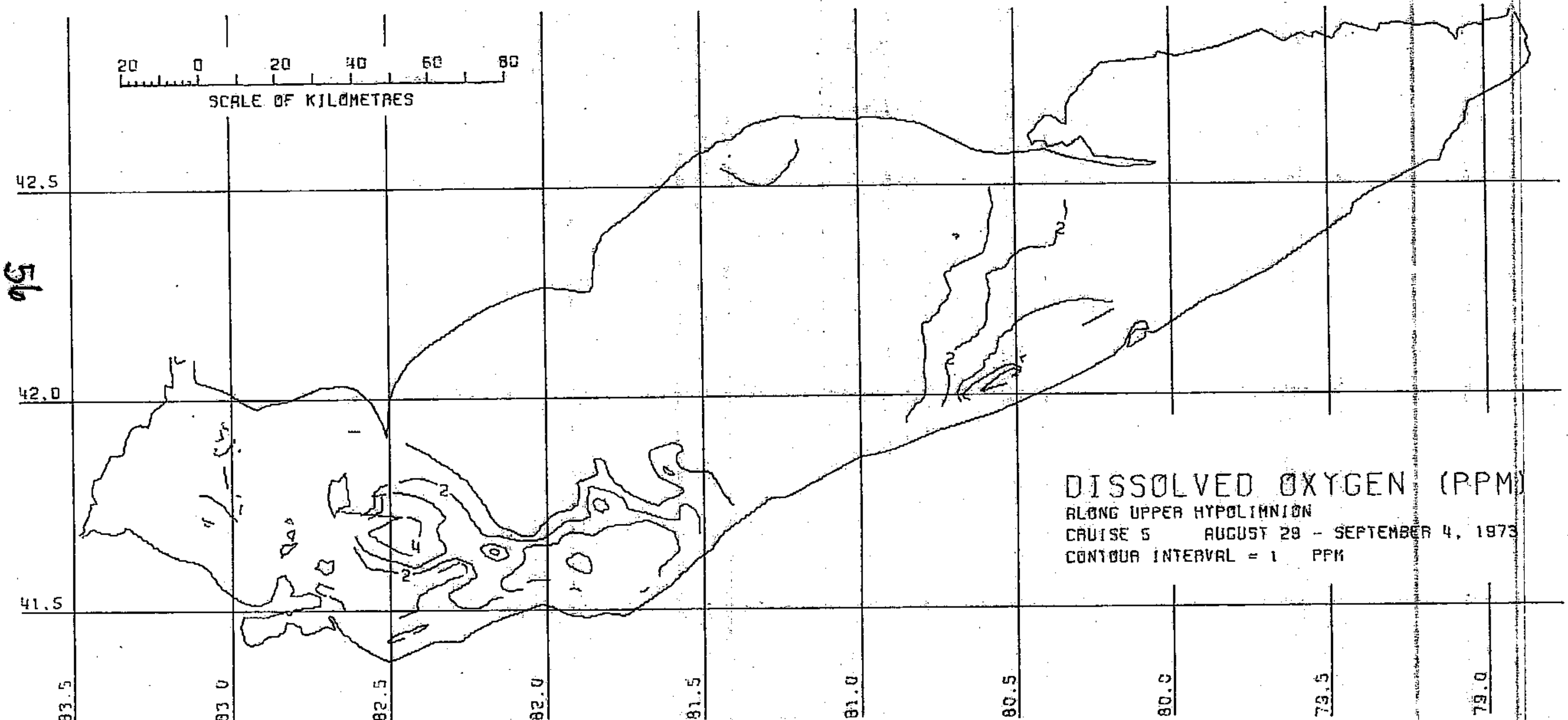

DISSOLVED OXYGEN (PPM)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 PPM
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
4
8

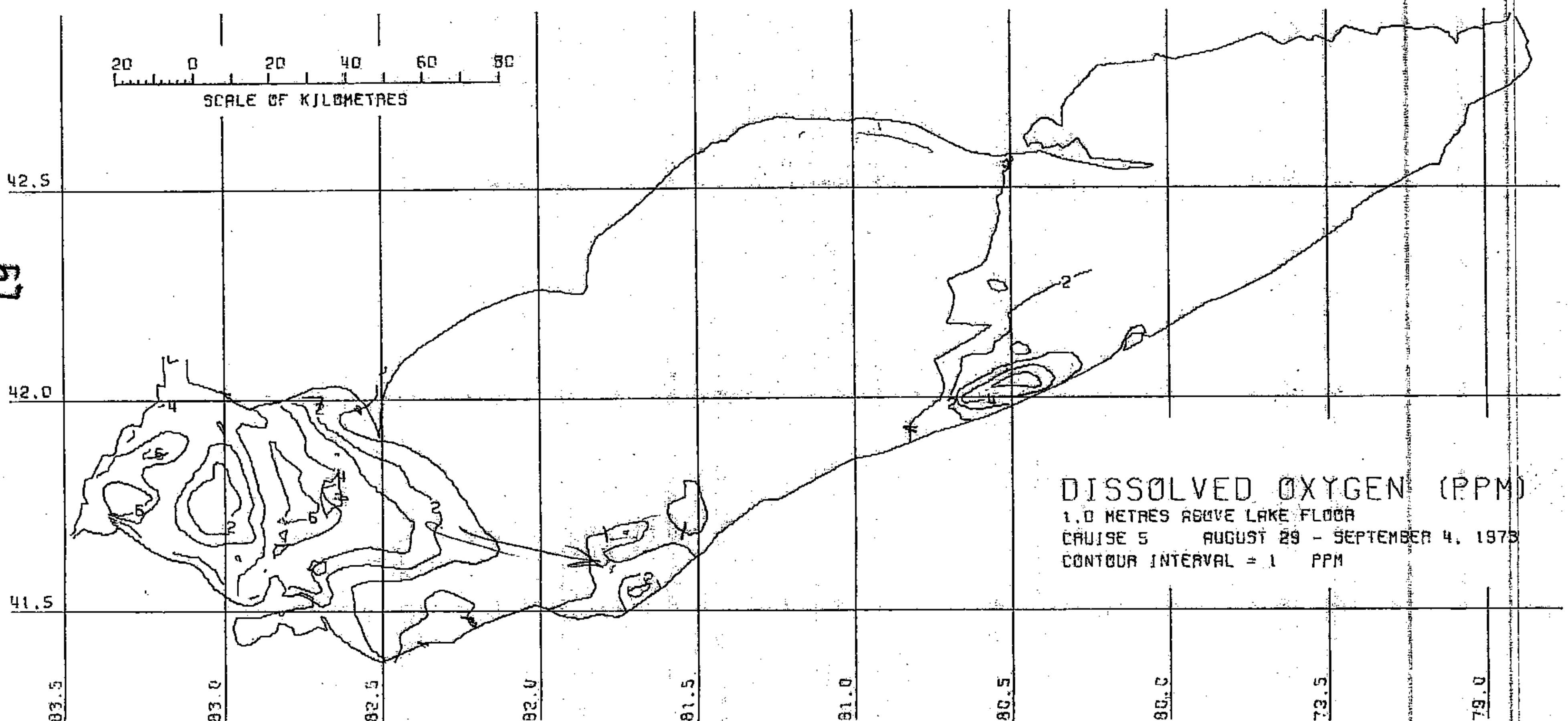

DISSOLVED OXYGEN (PPM)
1.0 METRES BELOW LAKE SURFACE
CRUISE 4 AUGUST 7 - 11, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
10
10
10
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

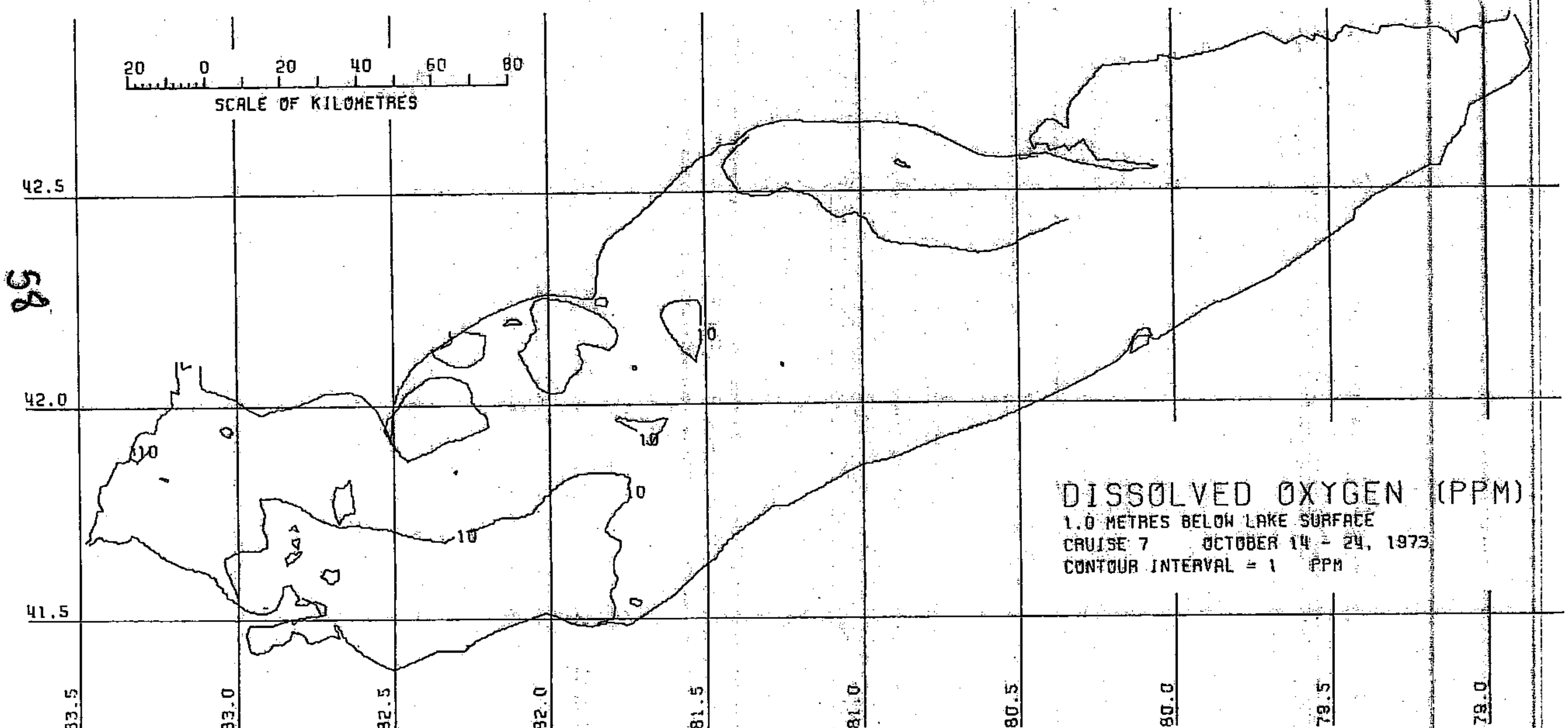

DISSOLVED OXYGEN (PPM)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 4 AUGUST 7 - 11, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

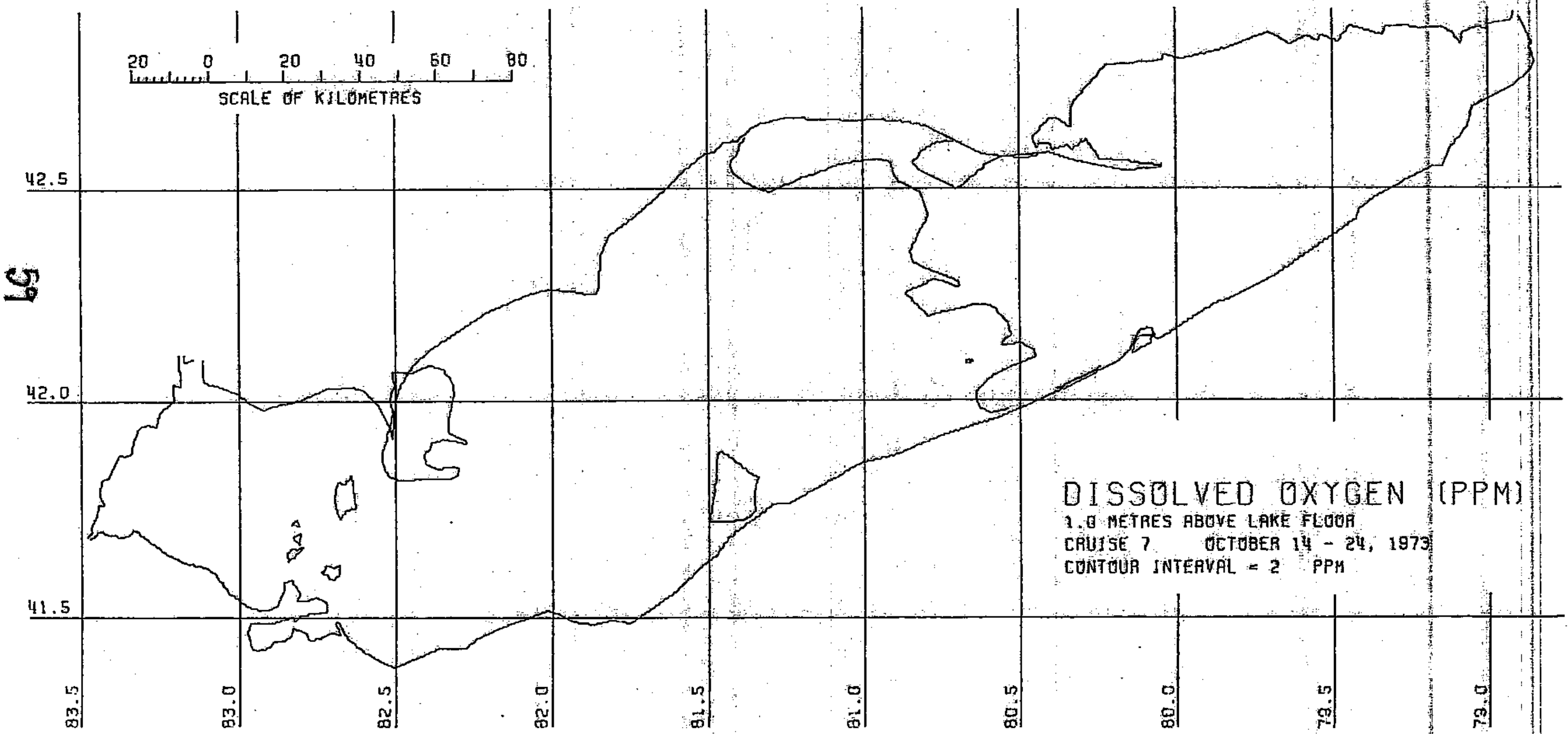

DISSOLVED OXYGEN (PPM)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 PPM
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
10
12


DISSOLVED OXYGEN (PPM)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
8
10
6


DISSOLVED OXYGEN (PPM)
ALONG UPPER HYPOLIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20
0
20
40
60
80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
2
4

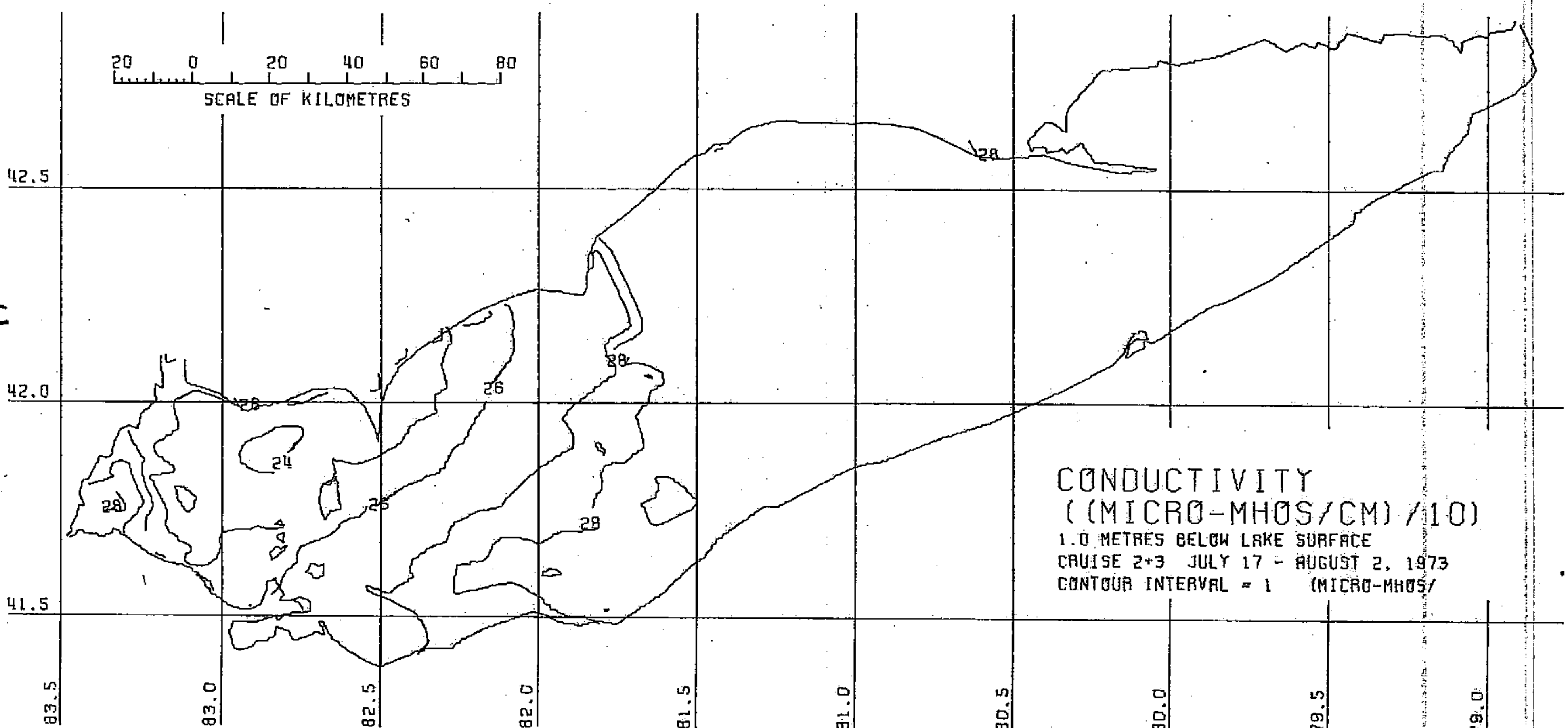

DISSOLVED OXYGEN (PPM)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

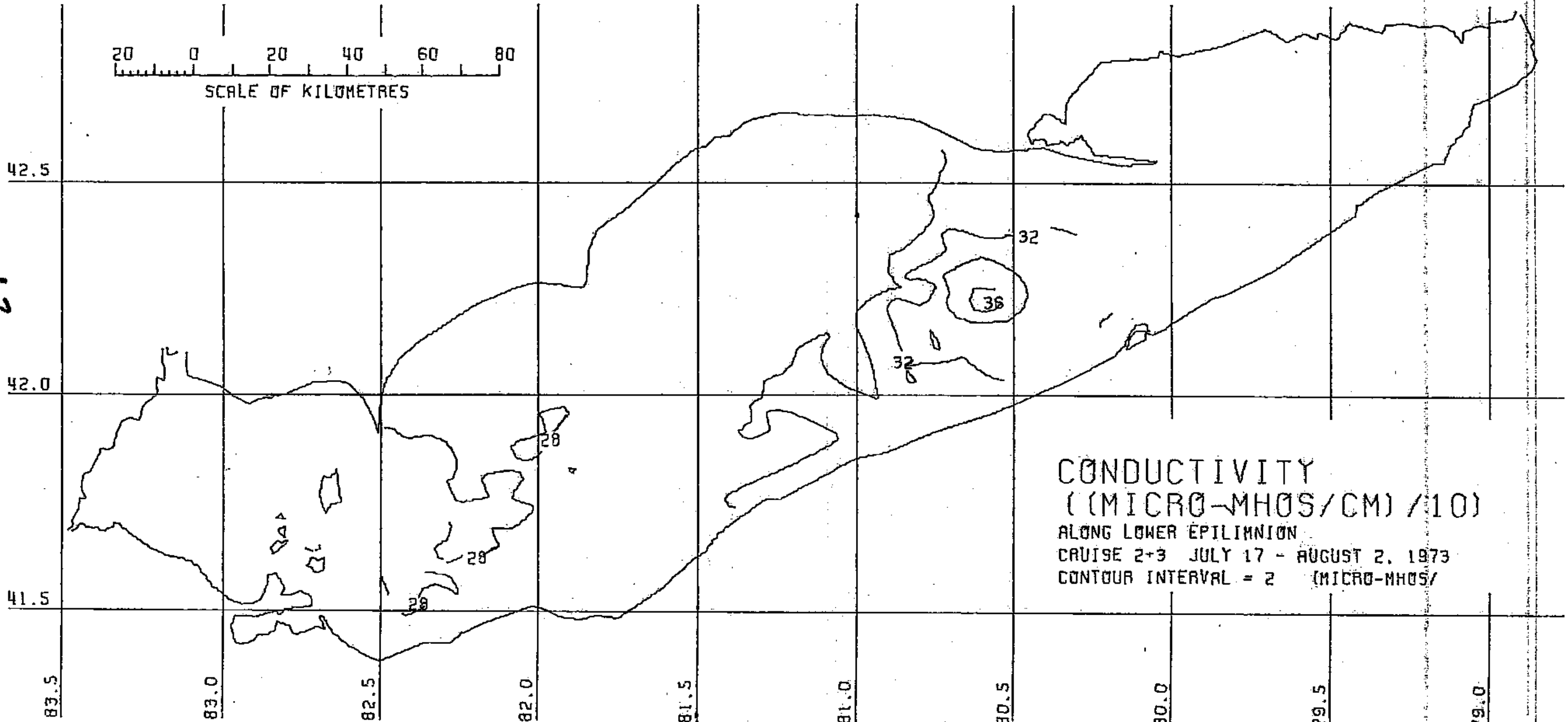

DISSOLVED OXYGEN (PPM)
1.0 METRES BELOW LAKE SURFACE
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 1 PPM
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
10
10
10
10
10

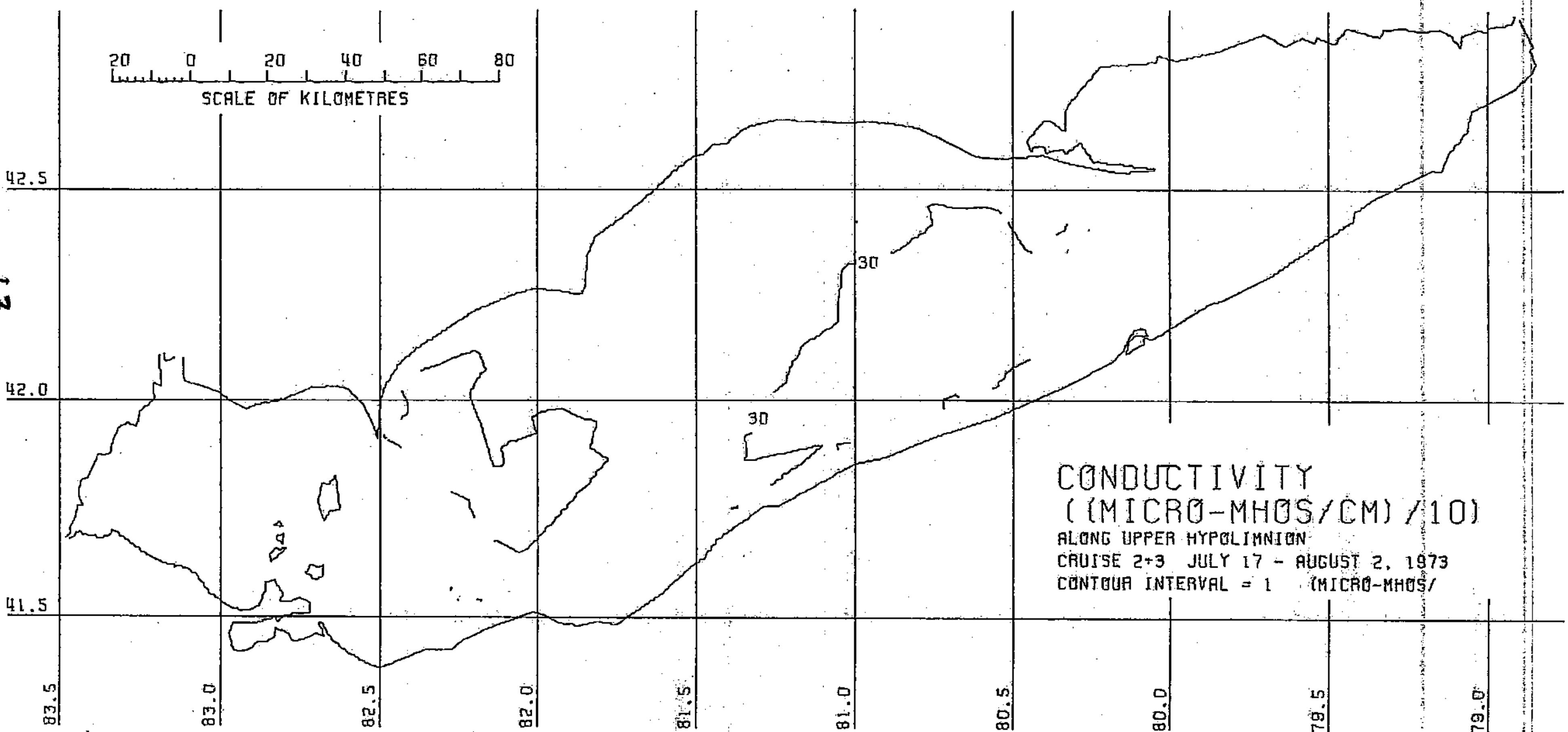

DISSOLVED OXYGEN (PPM)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 2 PPM
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

APPENDIX C

LAKE ERIE CONDUCTIVITY PLOTS


CONDUCTIVITY
((MICRO-MHOS/CM) /10)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 (MICRO-MHOS/
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
28
26
24
25
28
28
28
28


CONDUCTIVITY
((MICRO-MHOS/CM) /10)
ALONG LOWER EPILIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 (MICRO-MHOS/
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
32
36
32
28
28
28


CONDUCTIVITY
((MICRO-MHOS/CM)/10)
ALONG UPPER HYPOLIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 (MICRO-MHOS/
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
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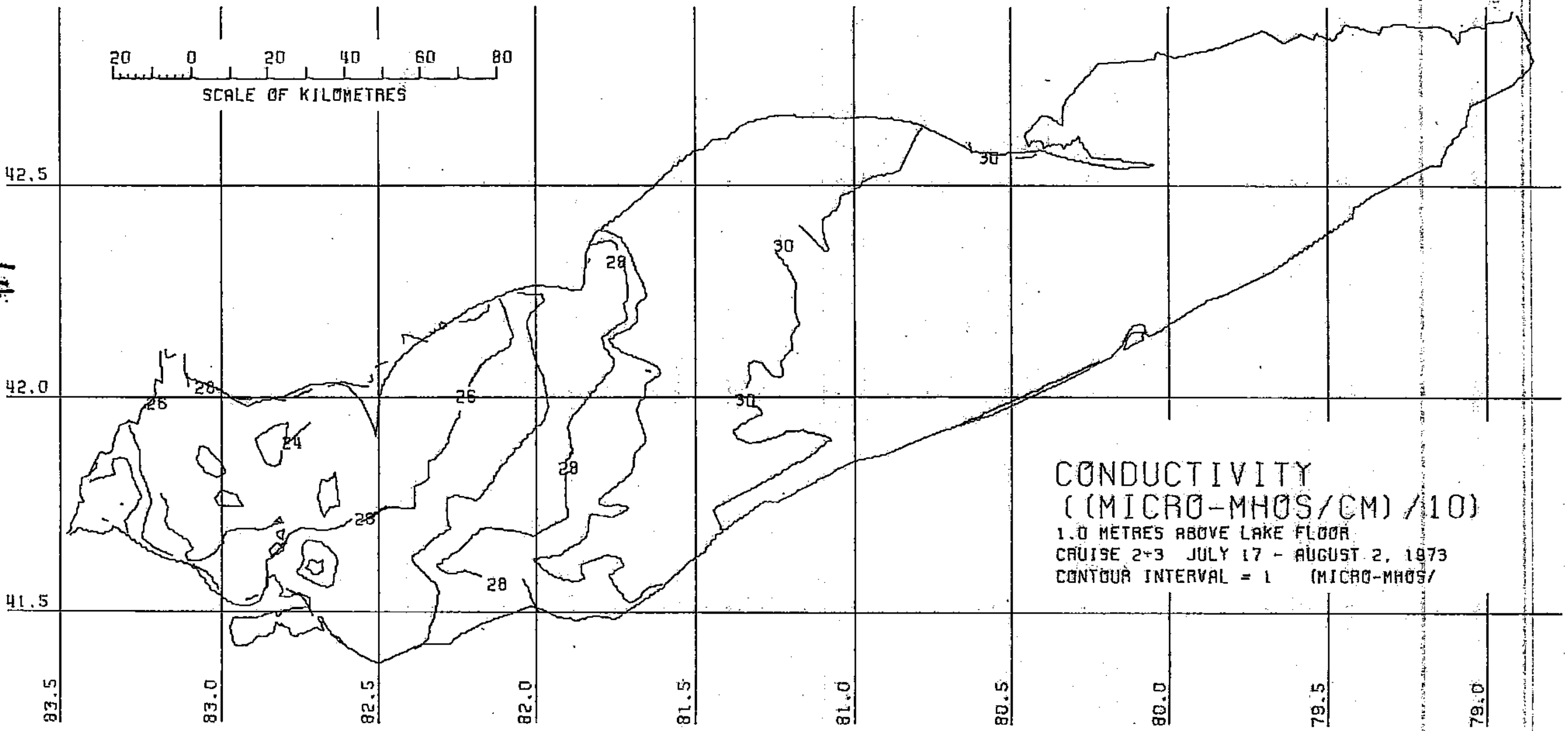
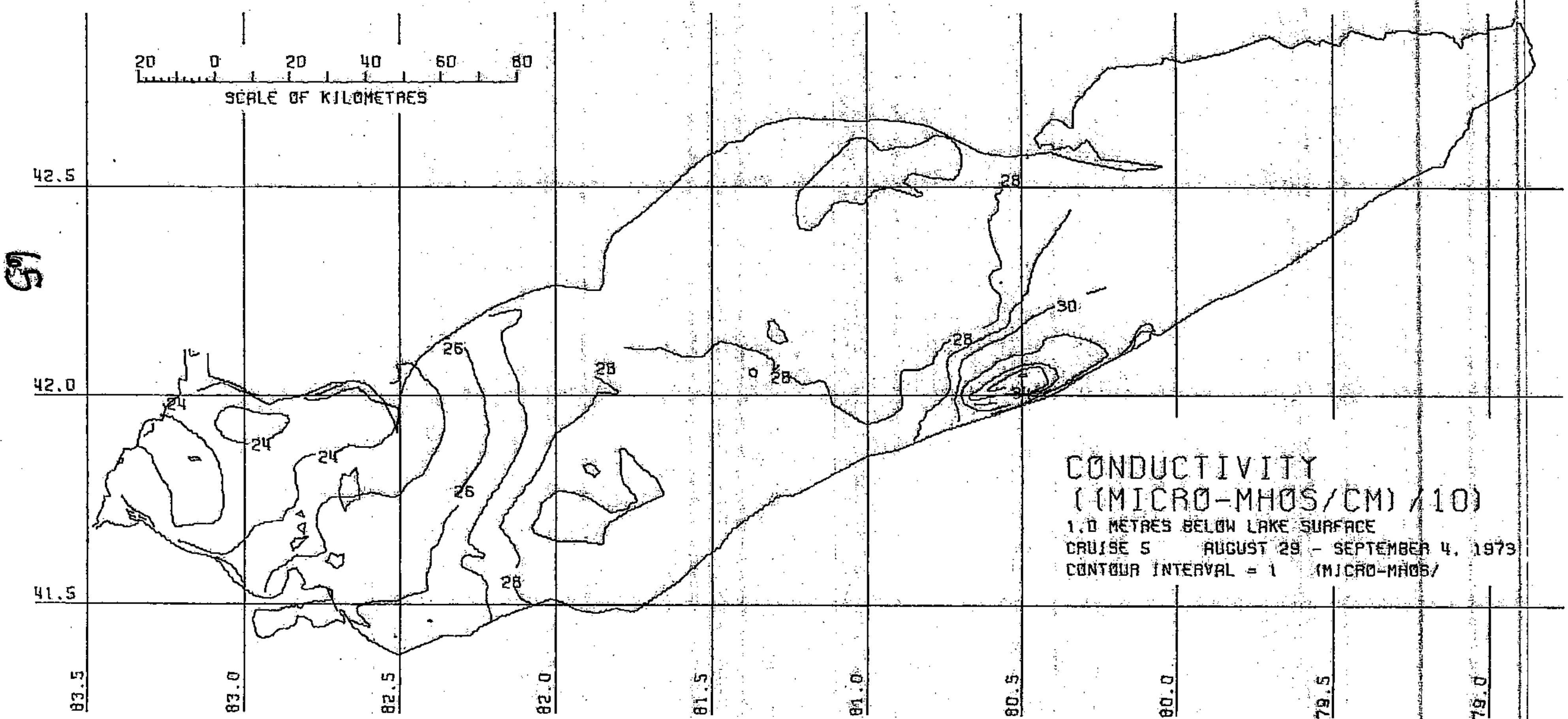
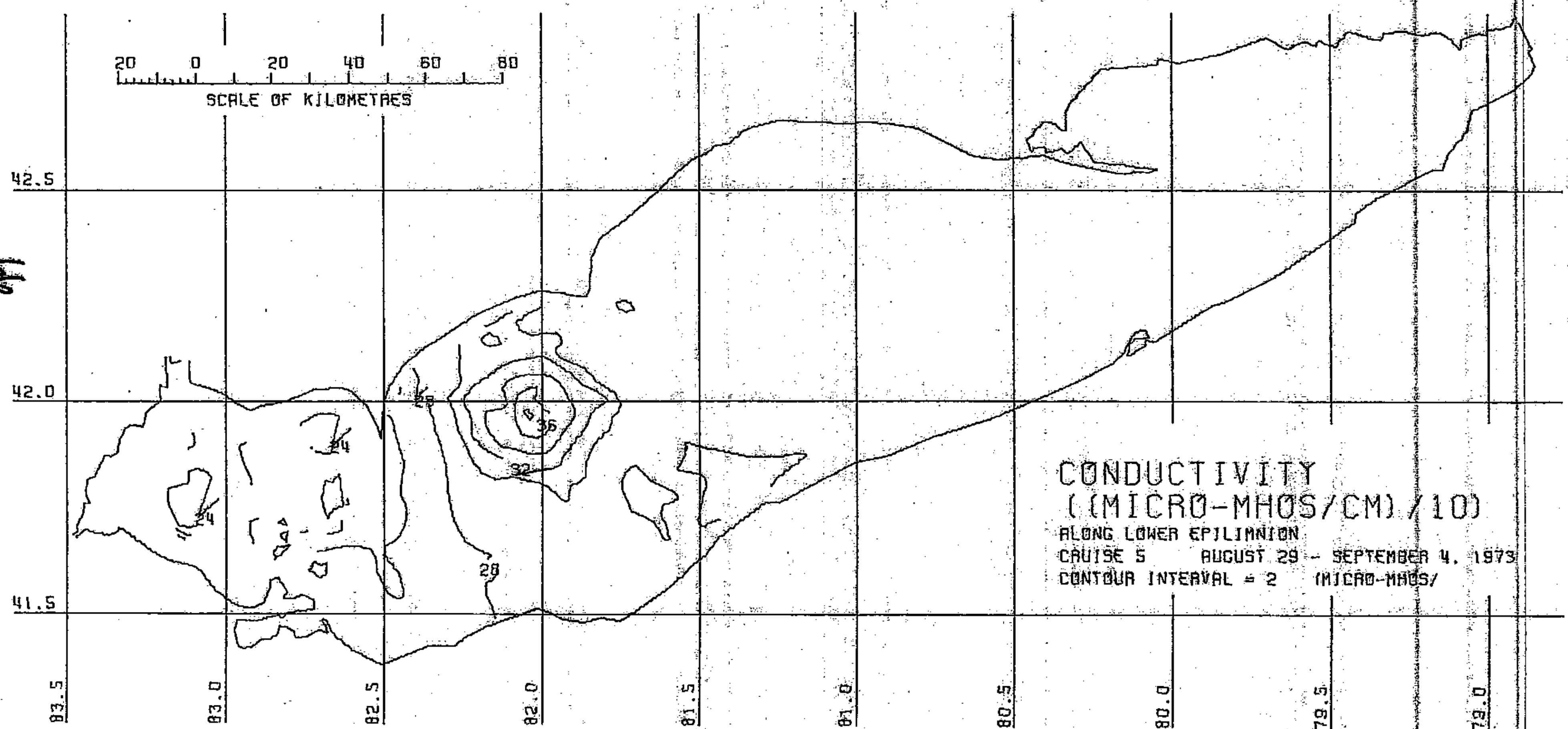
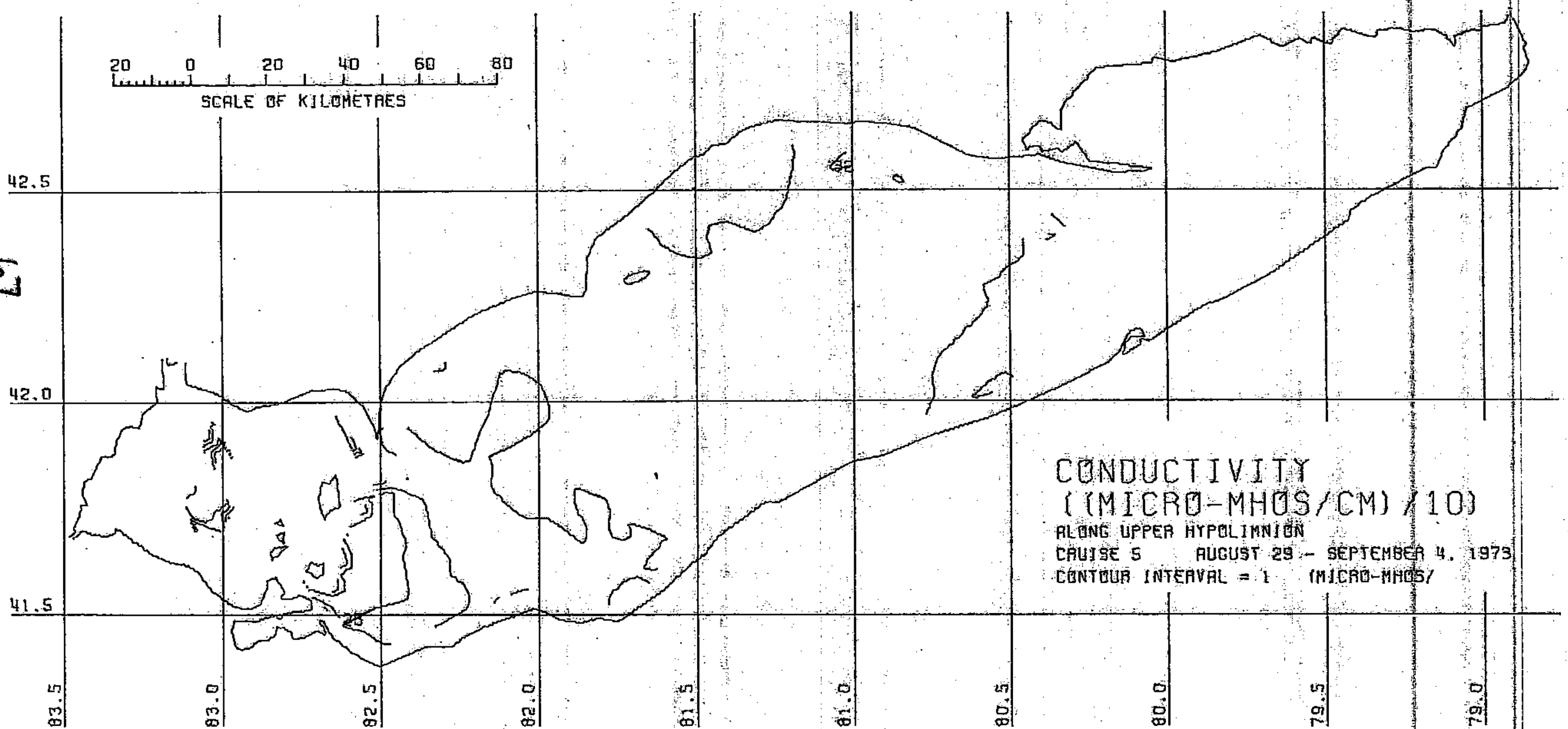
79.5
79.0
30
30

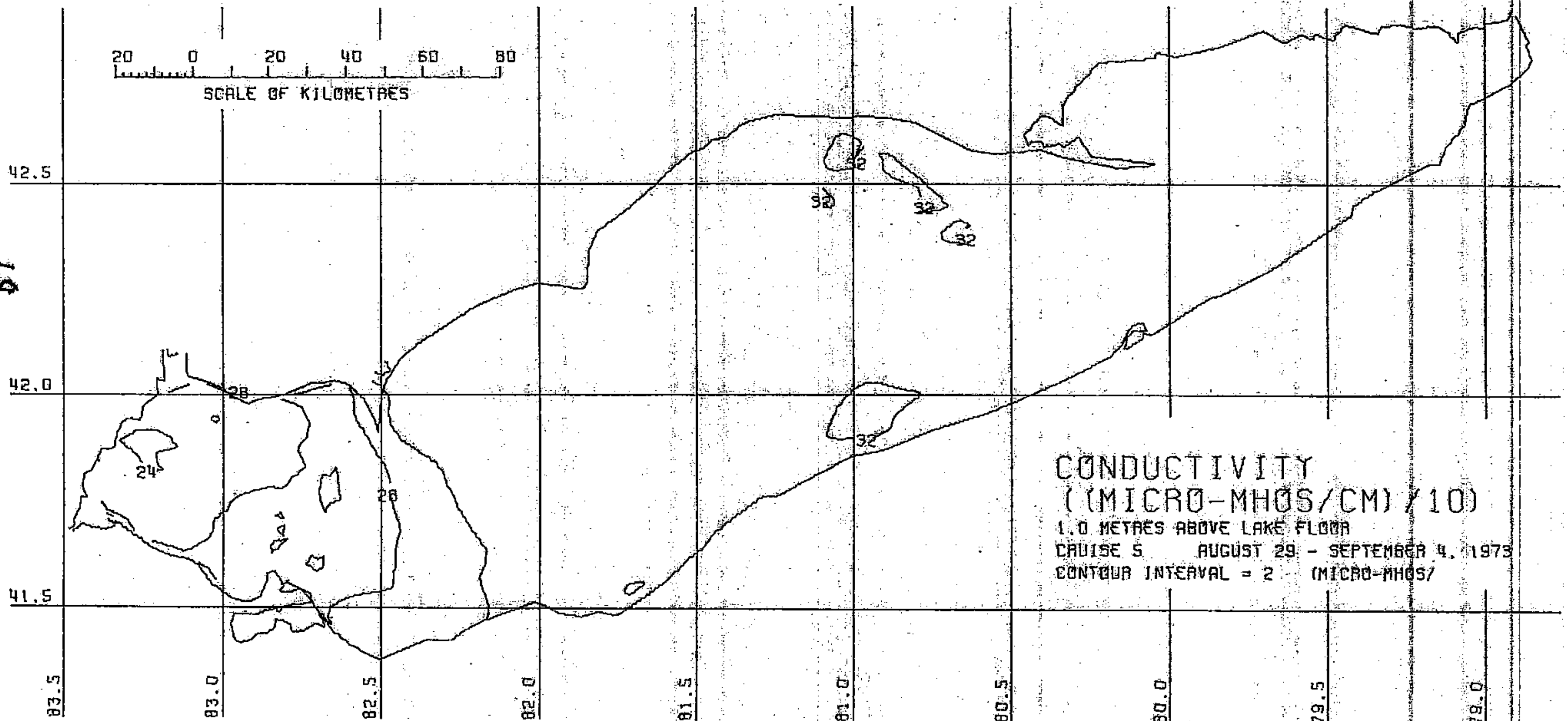

CONDUCTIVITY
((MICRO-MHOS/CM)/10)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 (MICRO-MHOS/
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
30
28
26
24


CONDUCTIVITY
((MICRO-MHOS/CM)/10)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 (MICRO-MHOS/
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
24
26
28
30



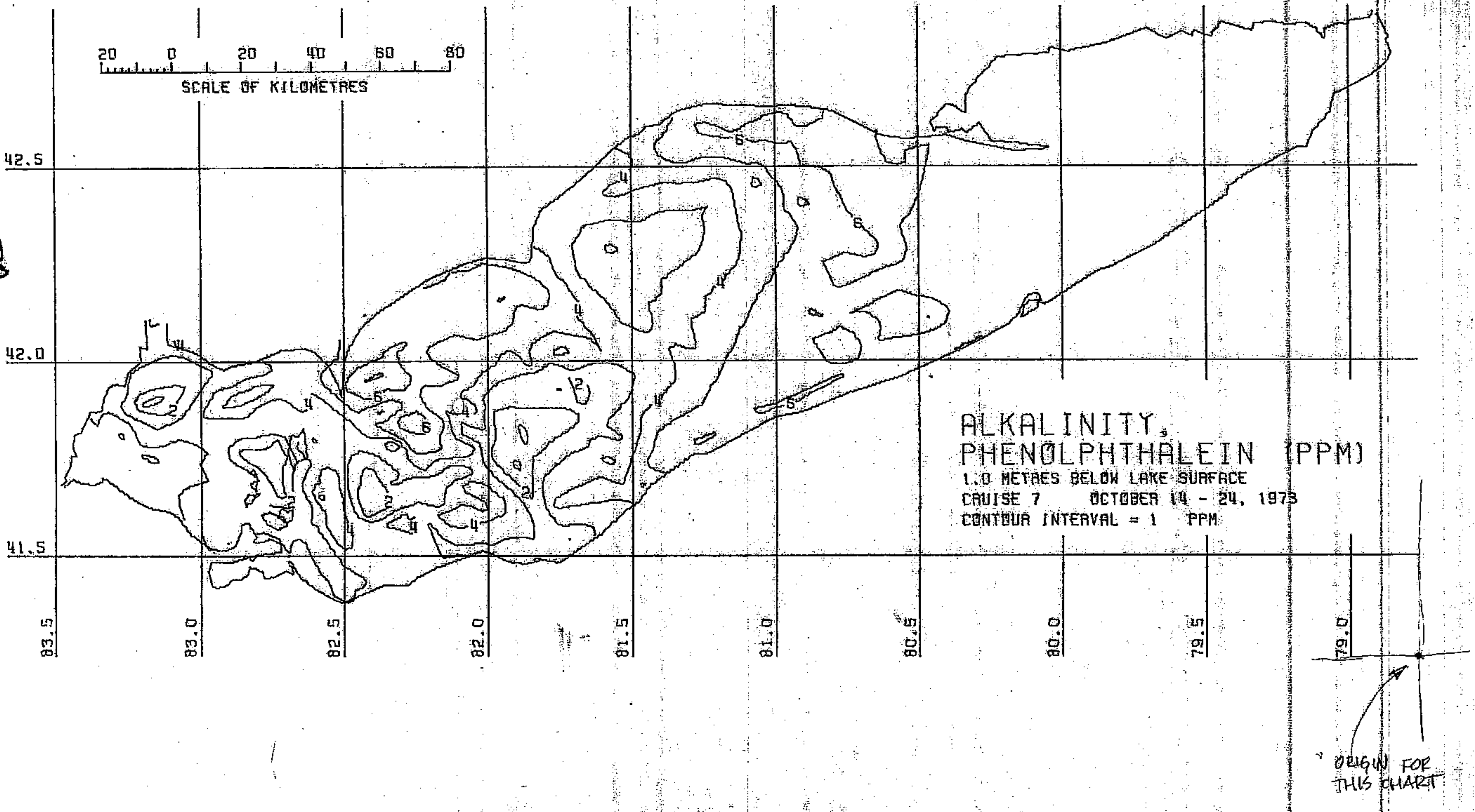
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
36
32
28
28
24
24
CONDUCTIVITY
((MICRO-MHOS/CM)/10)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 2 (MICRO-MHOS/


CONDUCTIVITY
((MICRO-MHOS/CM) /10)
ALONG UPPER HYPOLIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 1 (MICRO-MHOS/
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


CONDUCTIVITY
((MICRO-MHOS/CM)/10)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 2 (MICRO-MHOS/
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
24
28
28
32
32
32
32
32

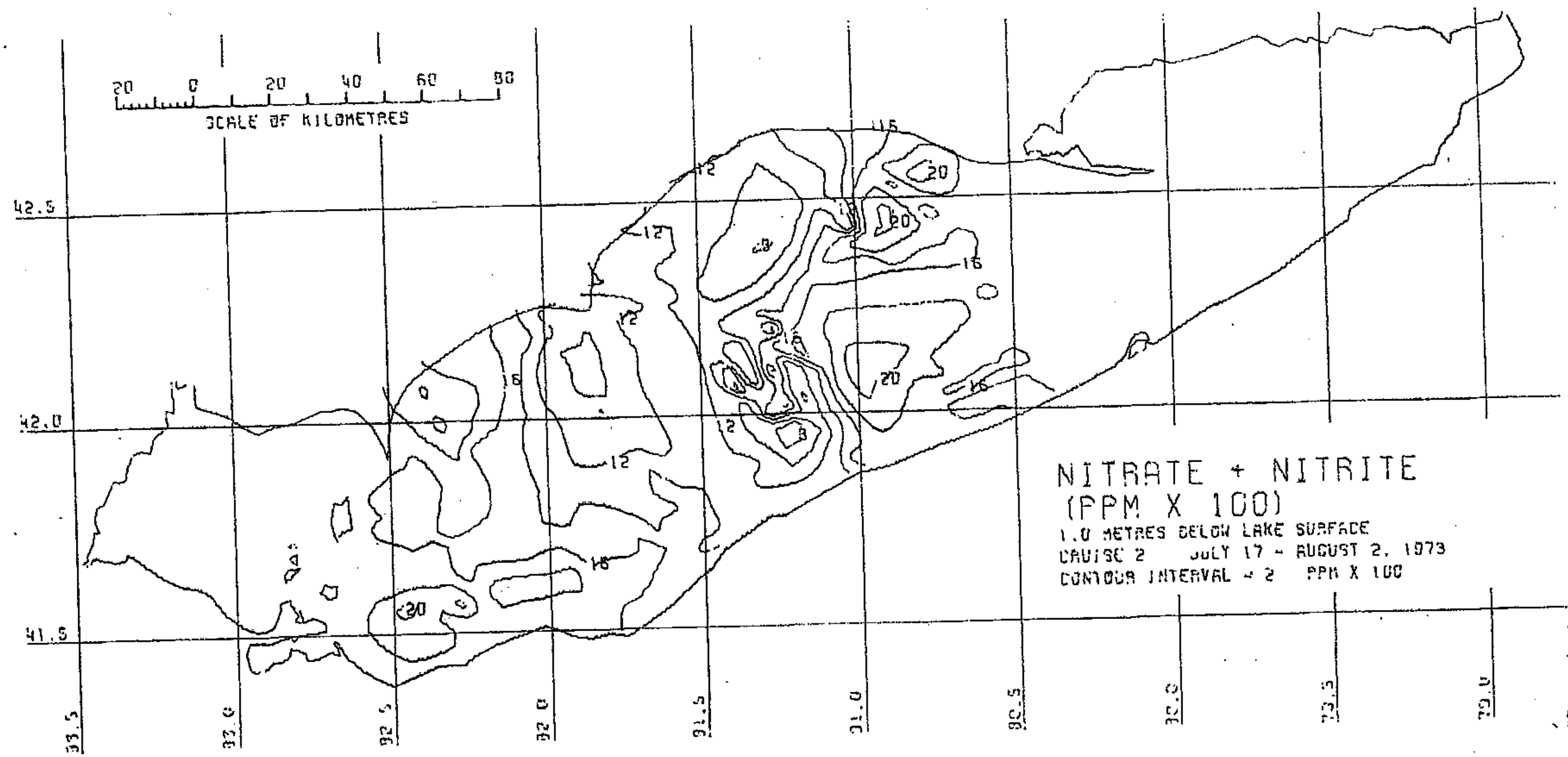
APPENDIX D

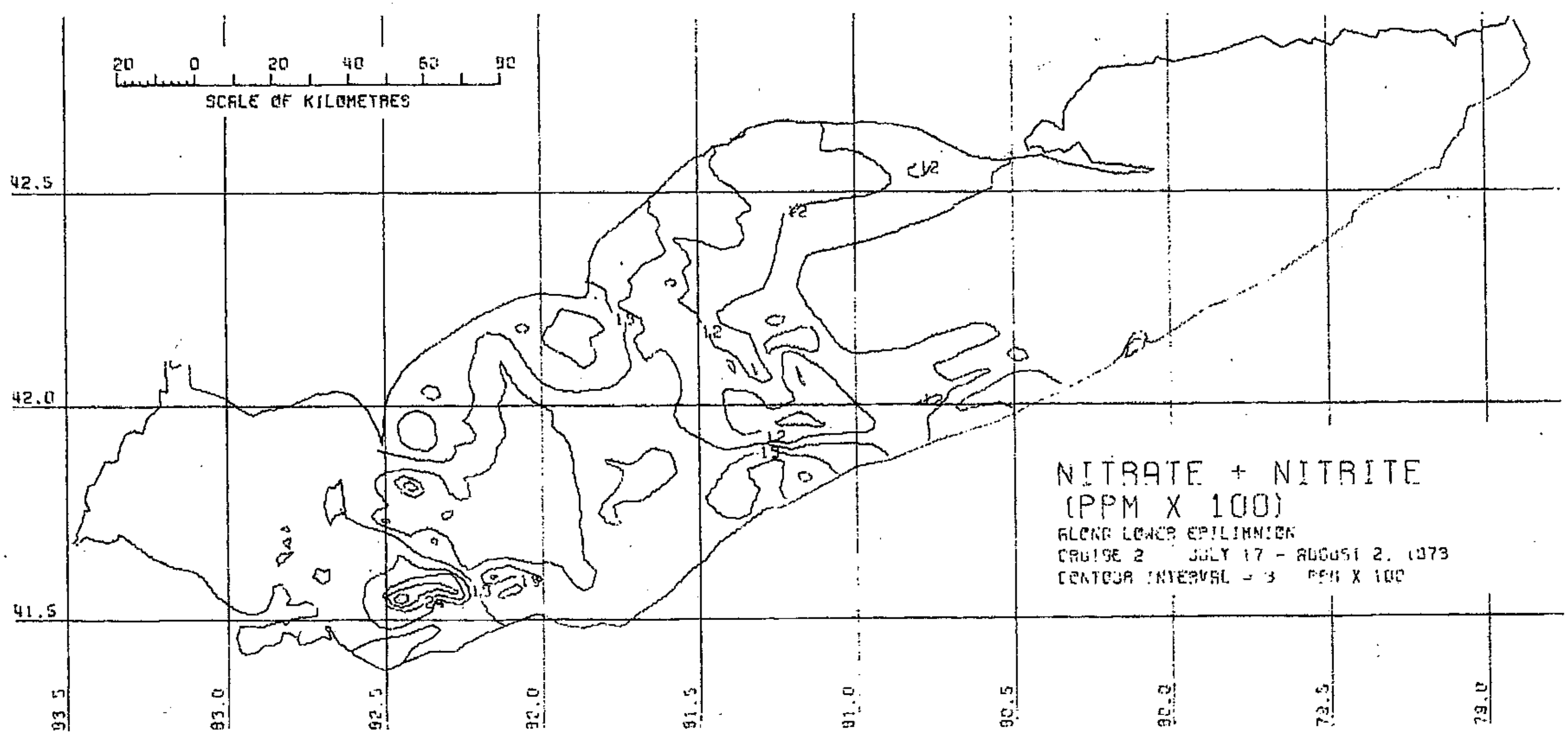
LAKE ERIE ALKALINITY PLOTS

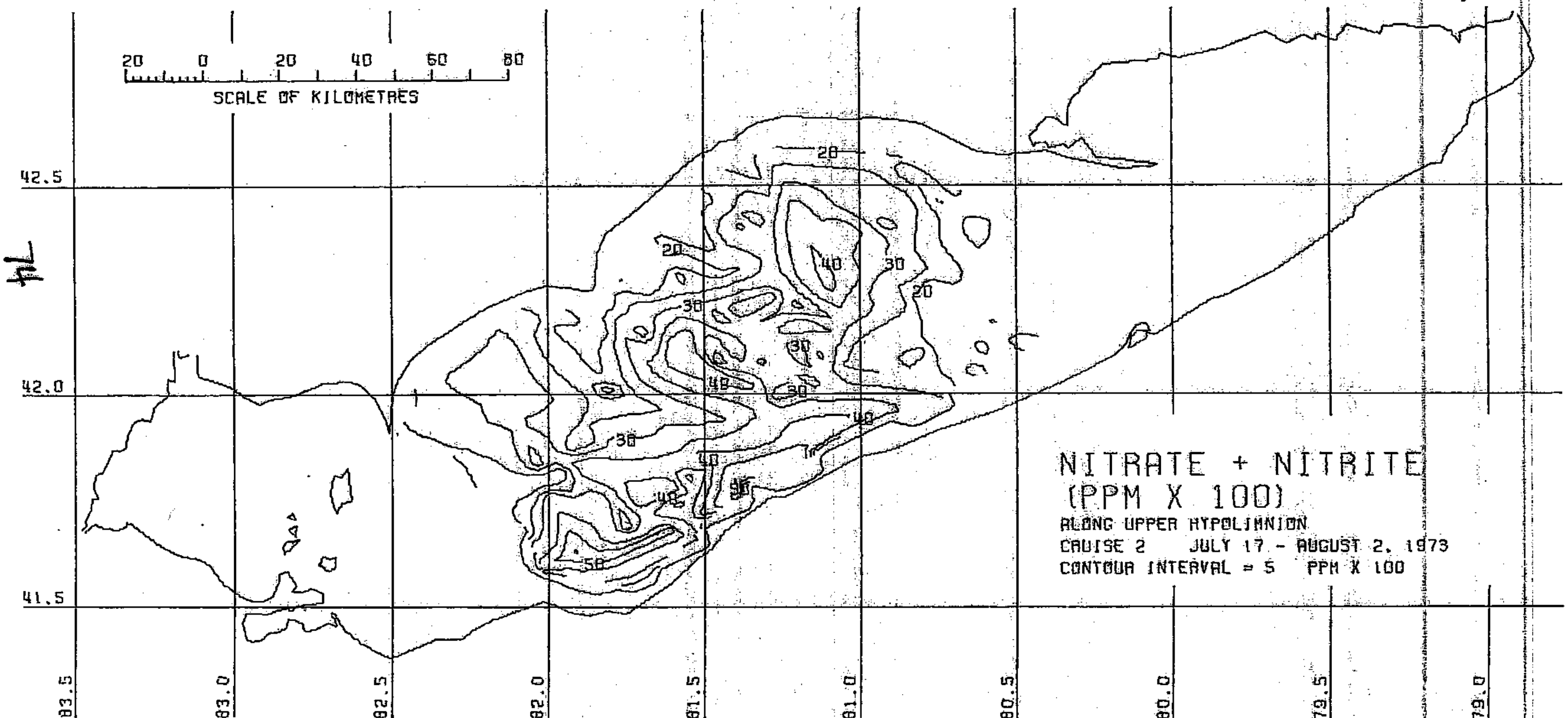

ALKALINITY,
PHENOLPHTHALEIN (PPM)
1.0 METRES BELOW LAKE SURFACE
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 1 PPM
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
ORIGIN FOR THIS CHART

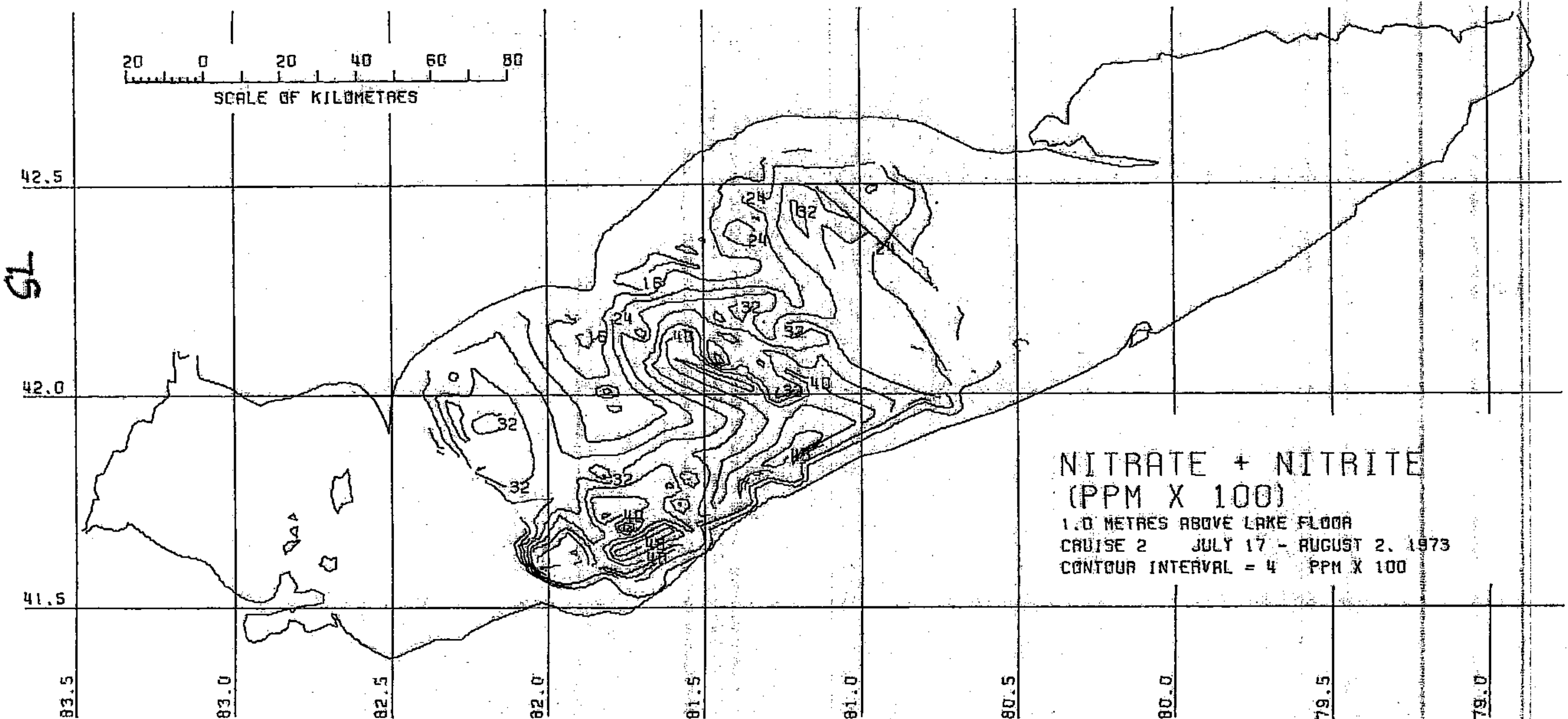
APPENDIX E

LAKE ERIE NITRATE-NITRITE PLOTS


NITRATE + NITRITE
(PPM X 100)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 PPM X 100
SCALE OF KILOMETRES
20
0
20
40
60
80
42.5
42.0
41.5

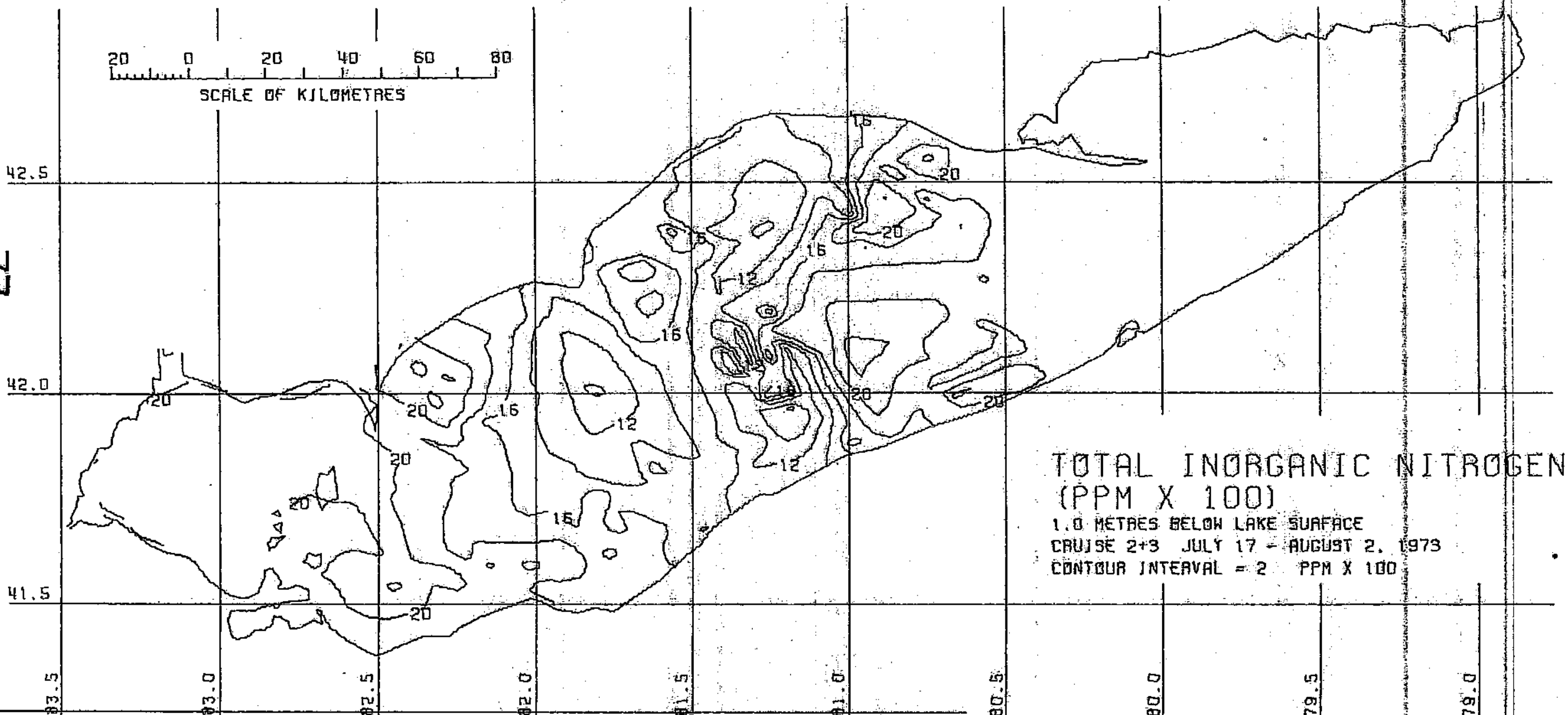

NITRATE + NITRITE
(PPM X 100)
ALONG LOWER EPILIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 3 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5

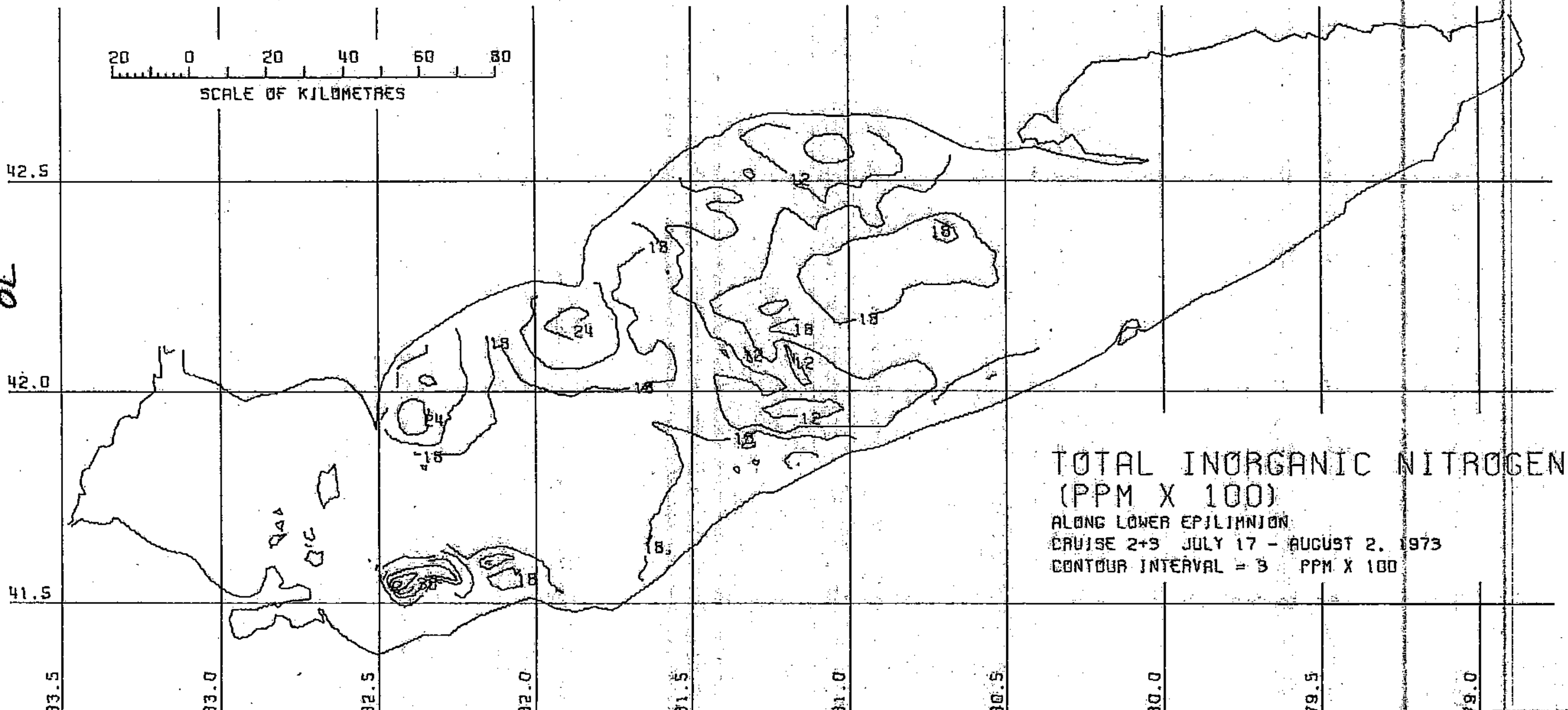

NITRATE + NITRITE
(PPM X 100)
ALONG UPPER HYPOLIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 5 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
20
30
40
50


NITRATE + NITRITE
(PPM X 100)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 4 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

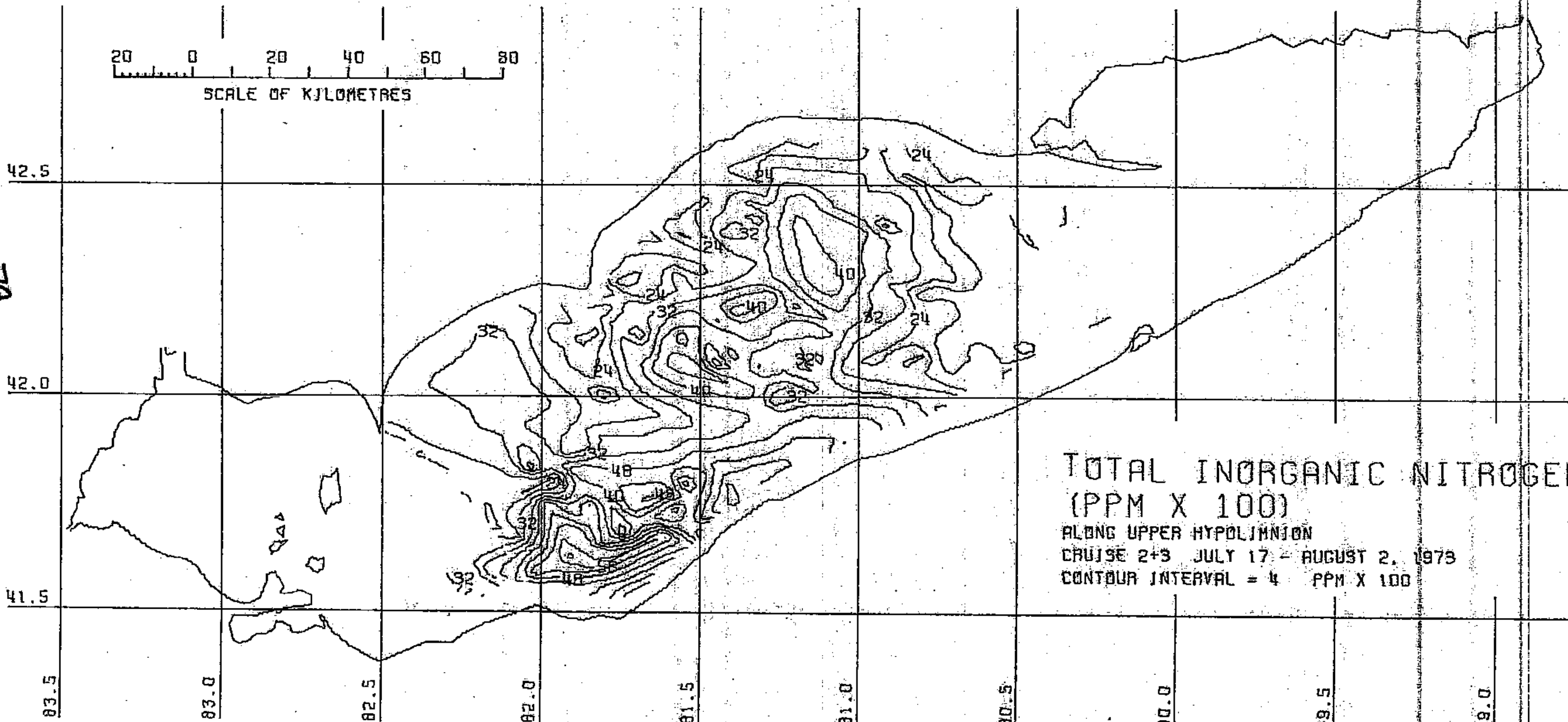
APPENDIX F

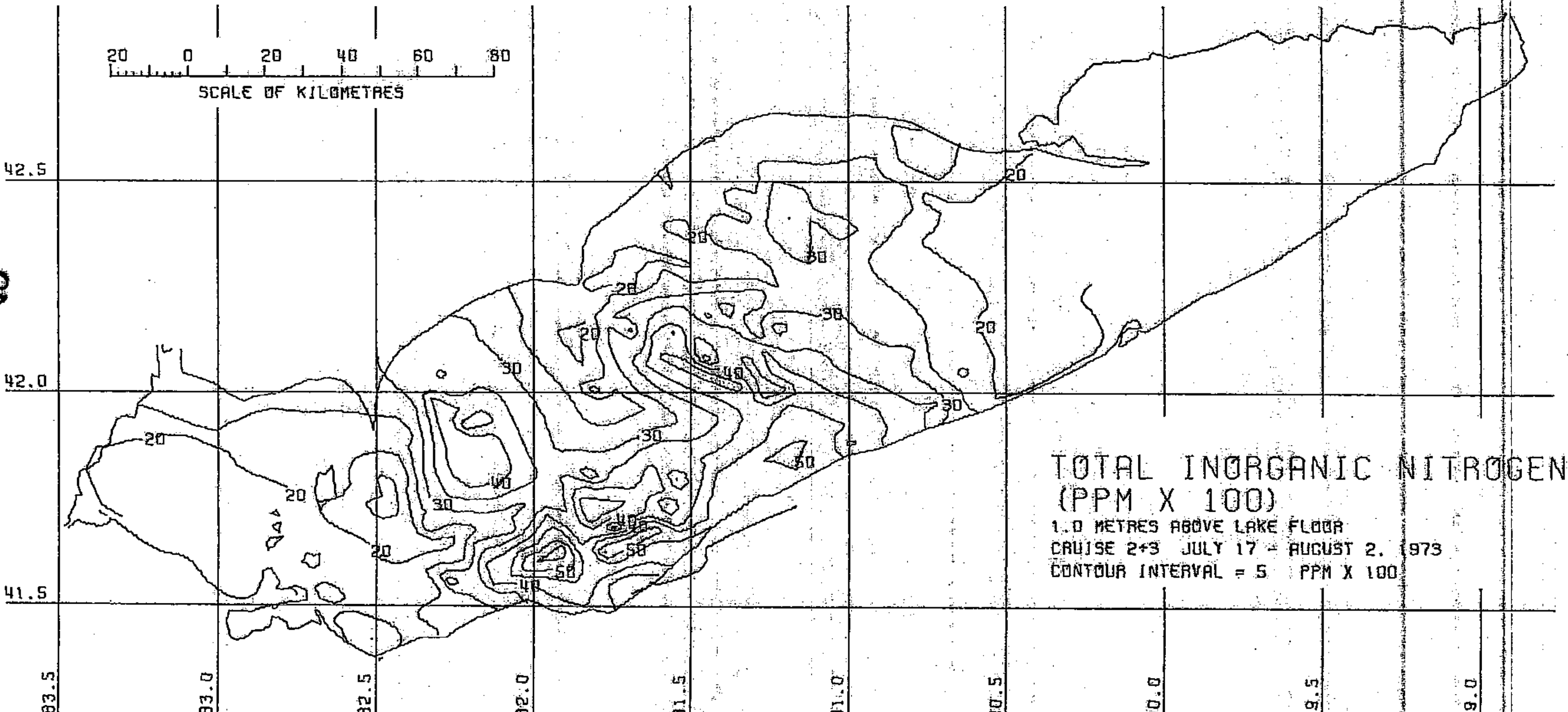
LAKE ERIE TOTAL INORGANIC NITROGEN PLOTS

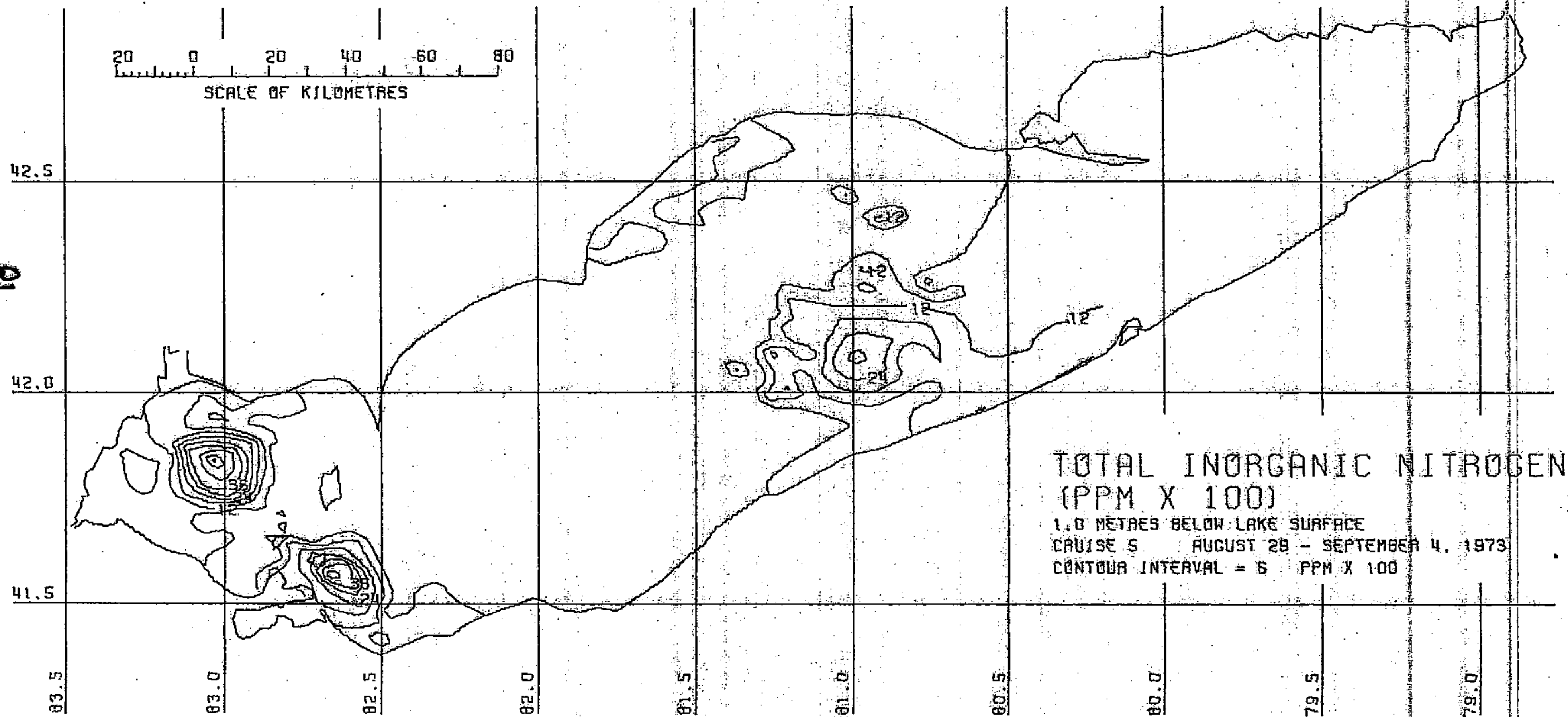

TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 2 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

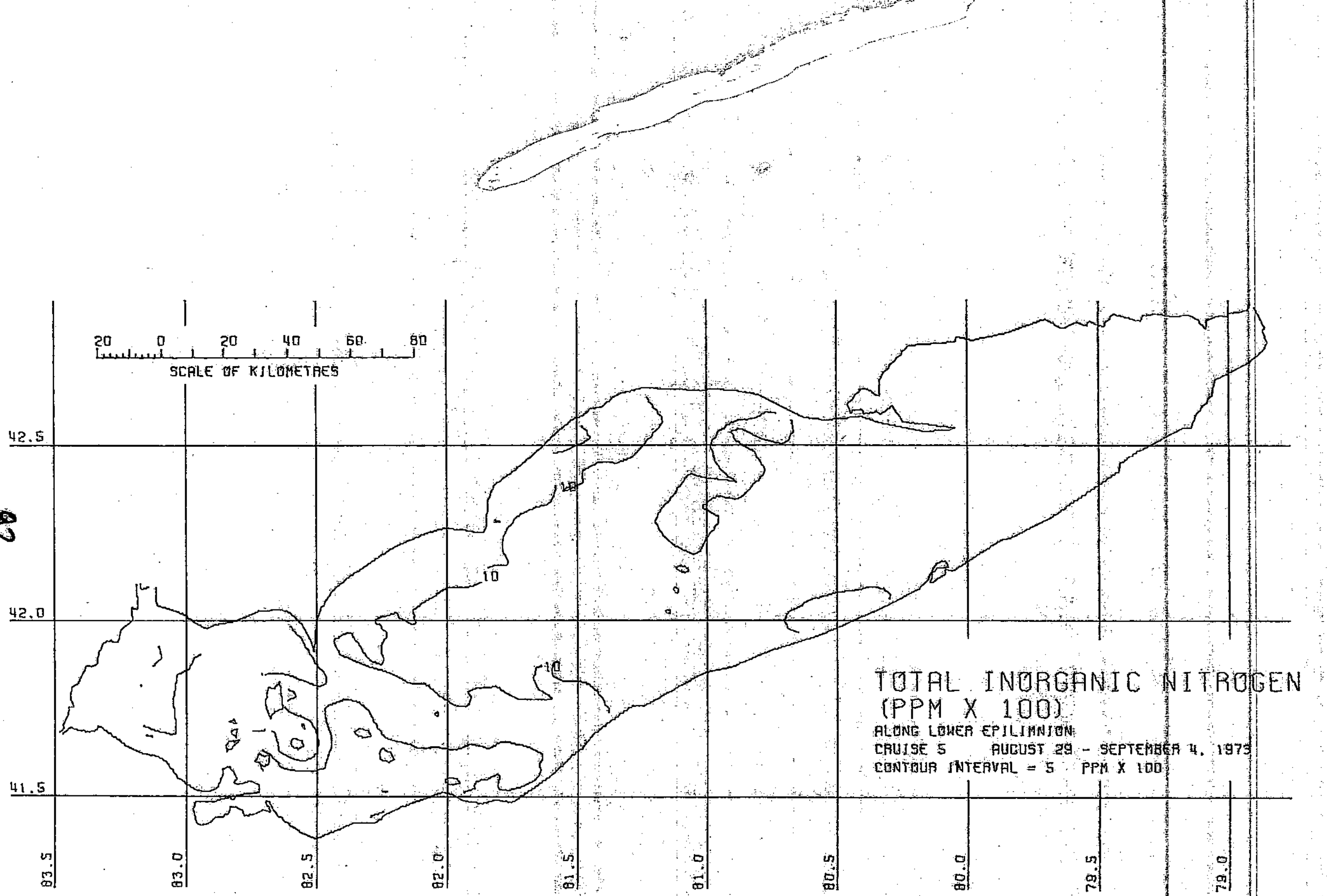


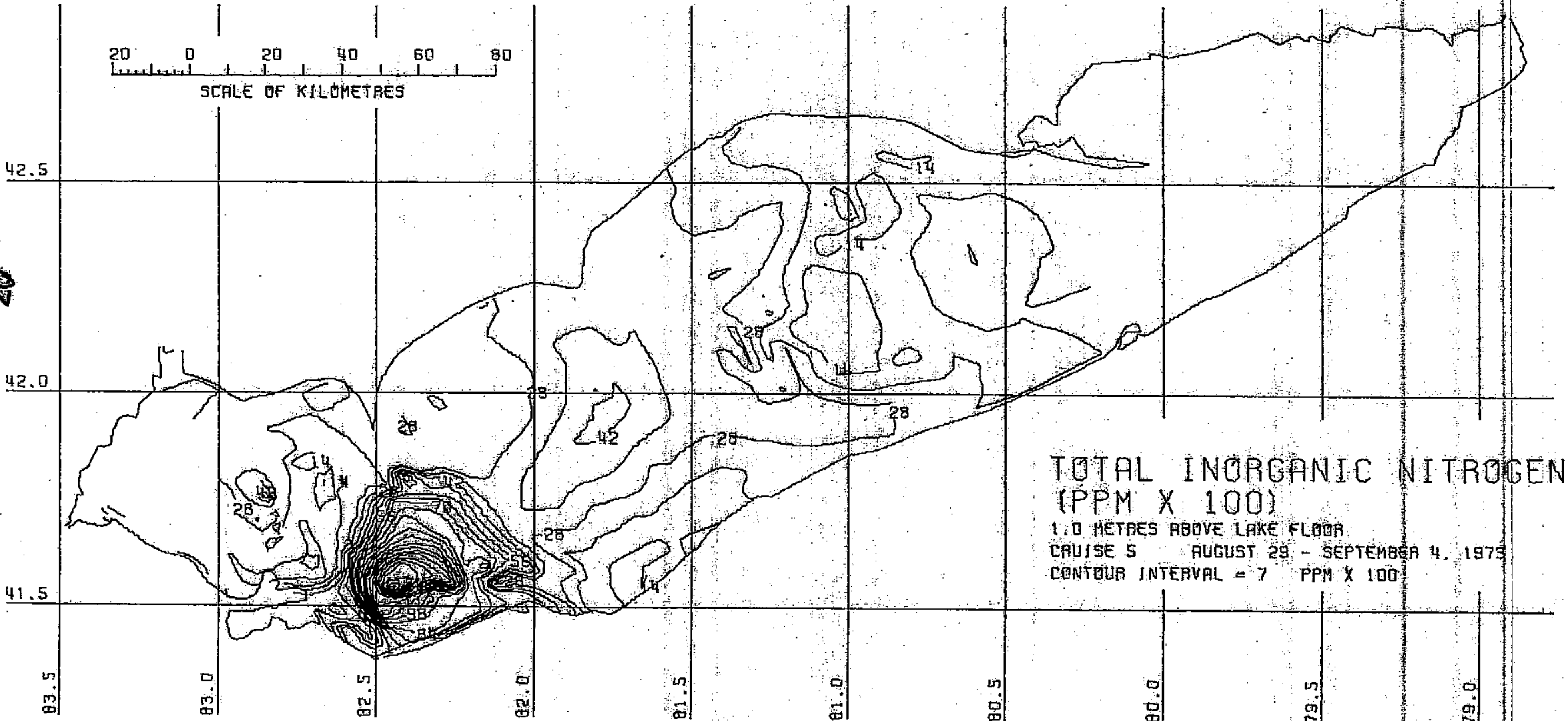
TOTAL INORGANIC NITROGEN
(PPM X 100)
ALONG LOWER EPILIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 3 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
18
24
30

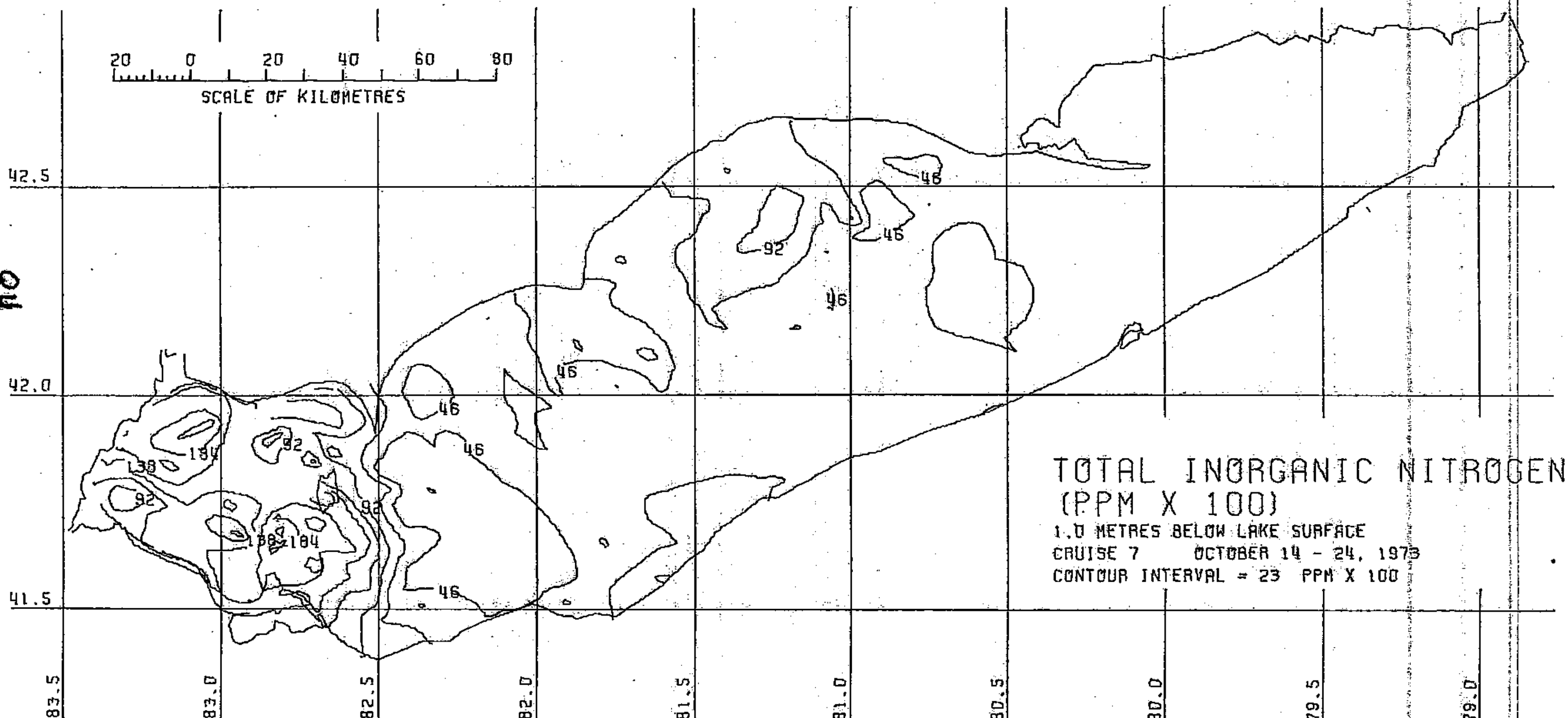

TOTAL INORGANIC NITROGEN
(PPM X 100)
ALONG UPPER HYPOLIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 4 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
24
32
40
48

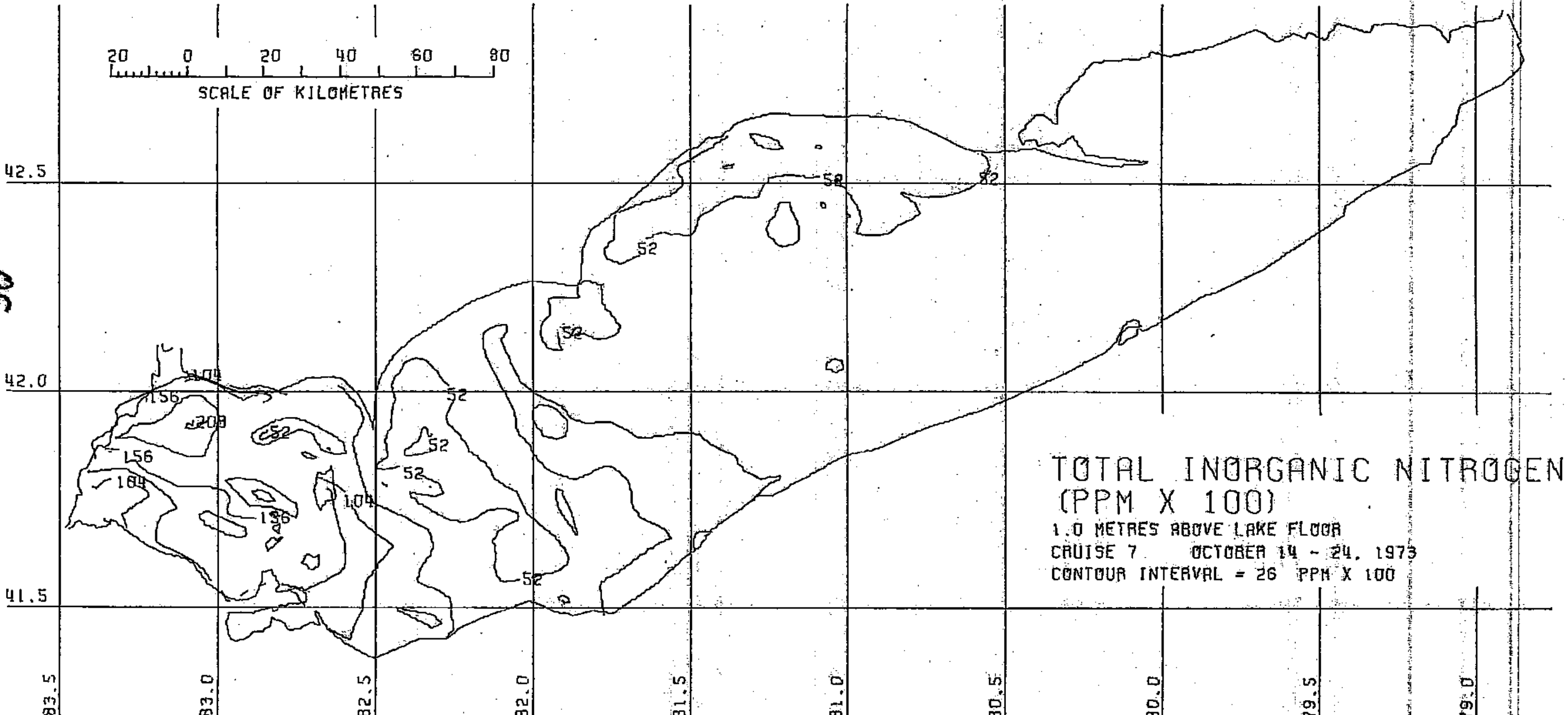

TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 5 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
20
30
40
50


TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 6 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
24
42
36


20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
10
10
10
TOTAL INORGANIC NITROGEN
(PPM X 100)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1975
CONTOUR INTERVAL = 5 PPM X 100

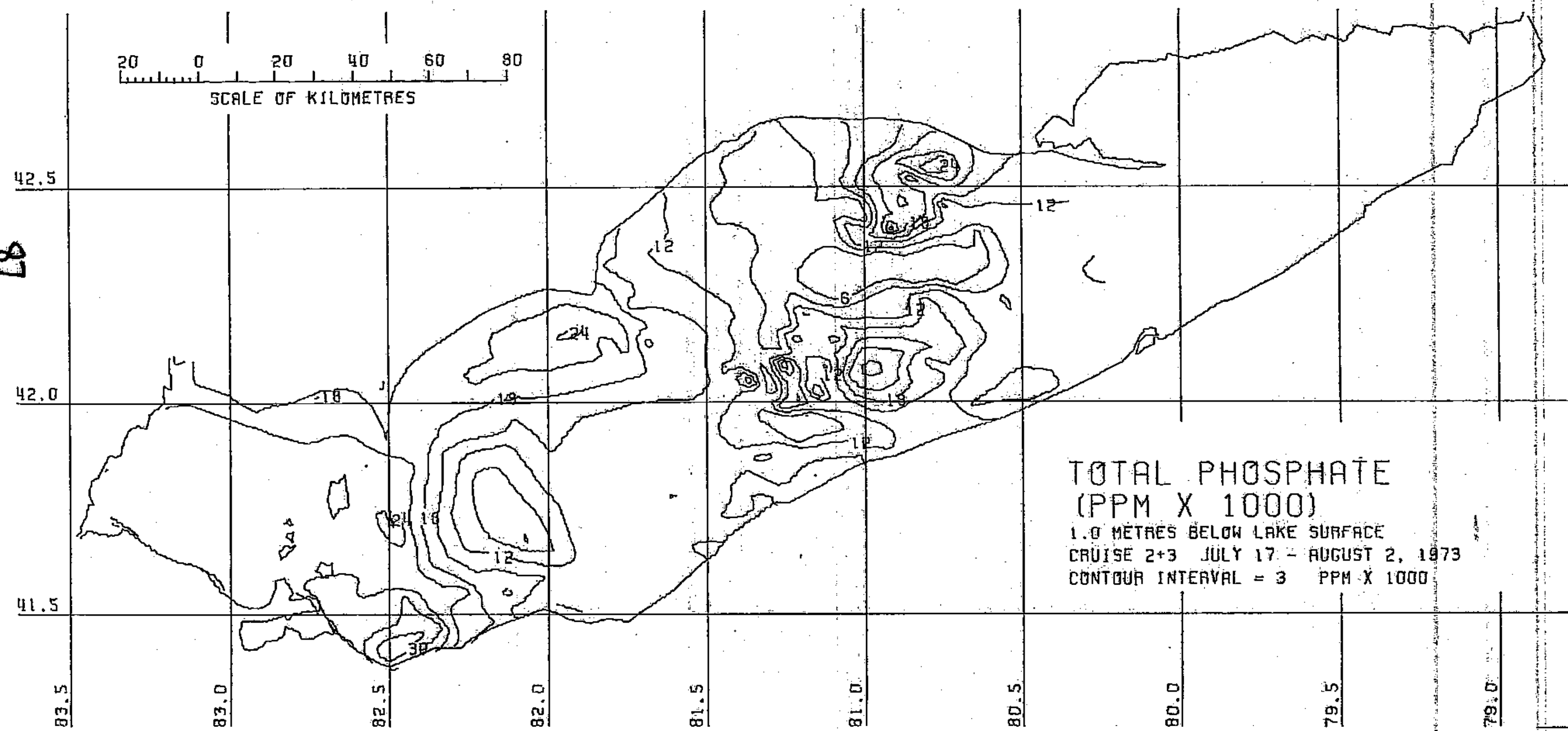

TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 7 PPM X 100
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
14
28
42
56
98
84

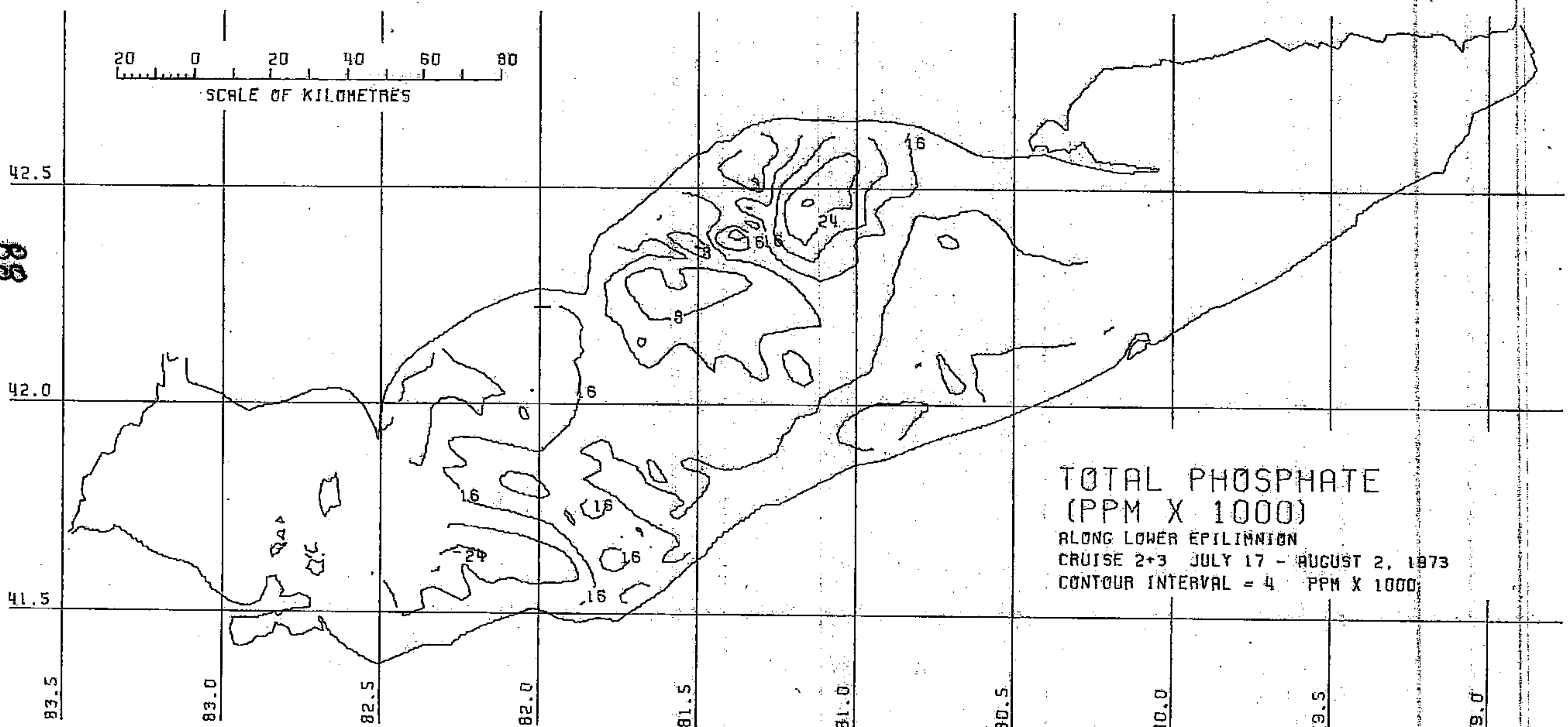

TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES BELOW LAKE SURFACE
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 23 PPM X 100
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
46
92
138
184


TOTAL INORGANIC NITROGEN
(PPM X 100)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 7 OCTOBER 14 - 24, 1973
CONTOUR INTERVAL = 26 PPM X 100
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
52
104
136
156
164
208

APPENDIX G

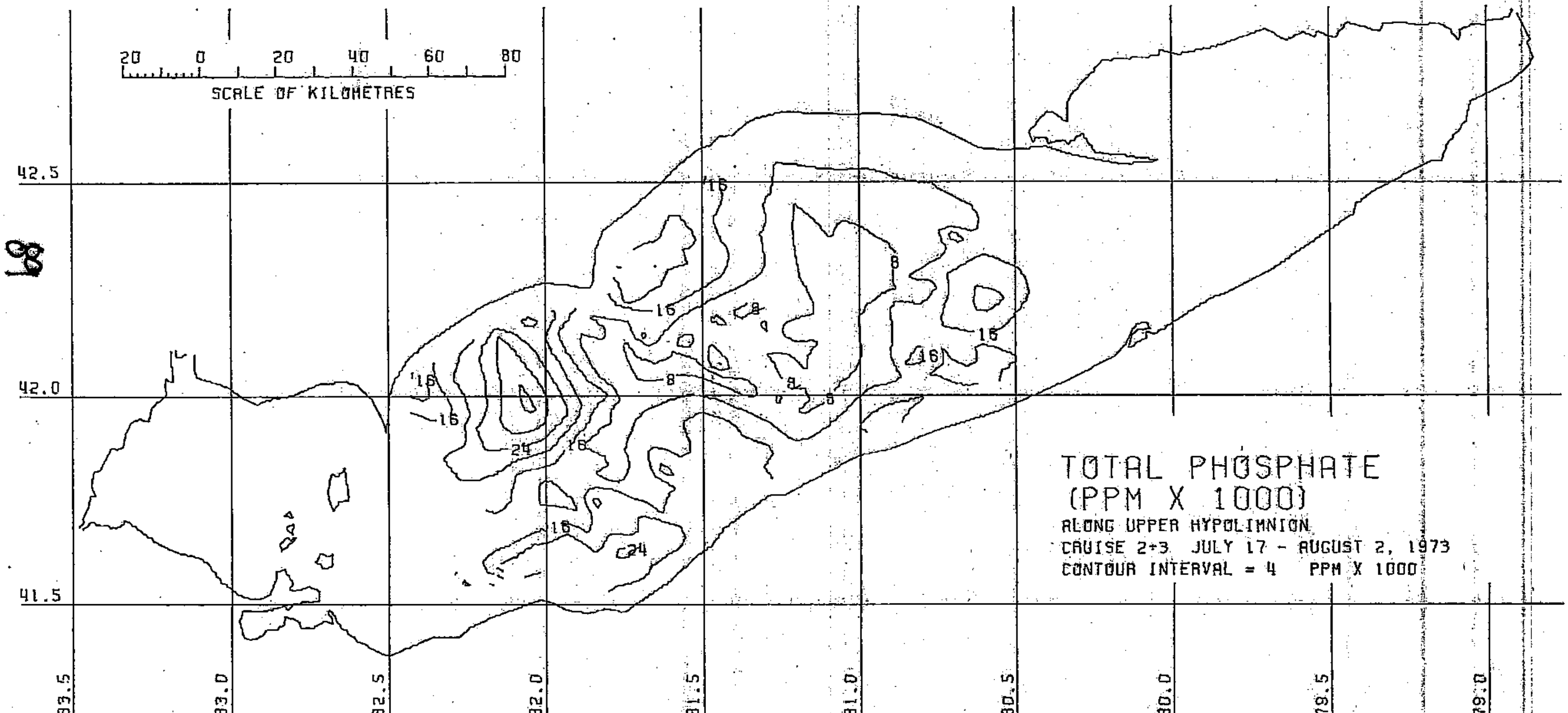
LAKE ERIE TOTAL PHOSPHORUS PLOTS


TOTAL PHOSPHATE
(PPM X 1000)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 3 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
6
18
24
30

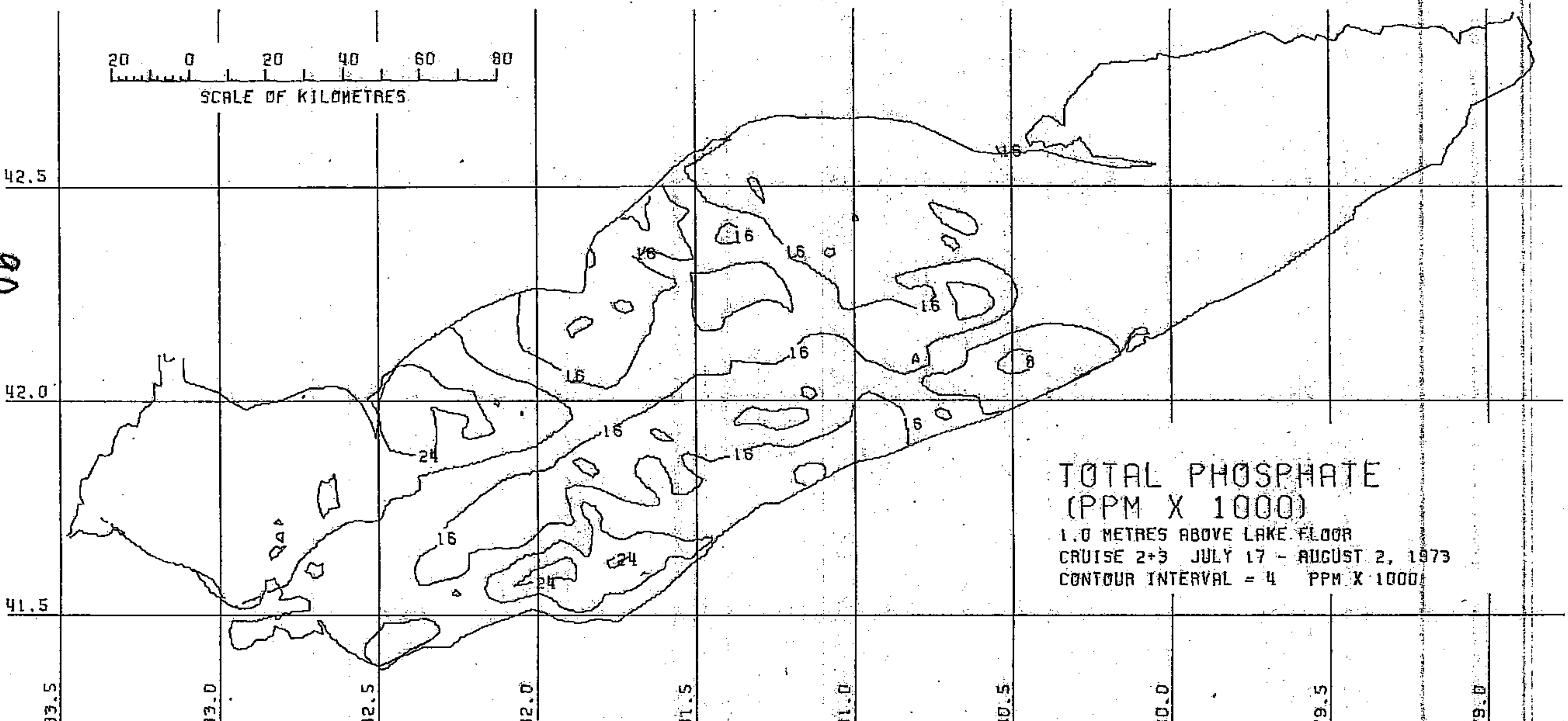


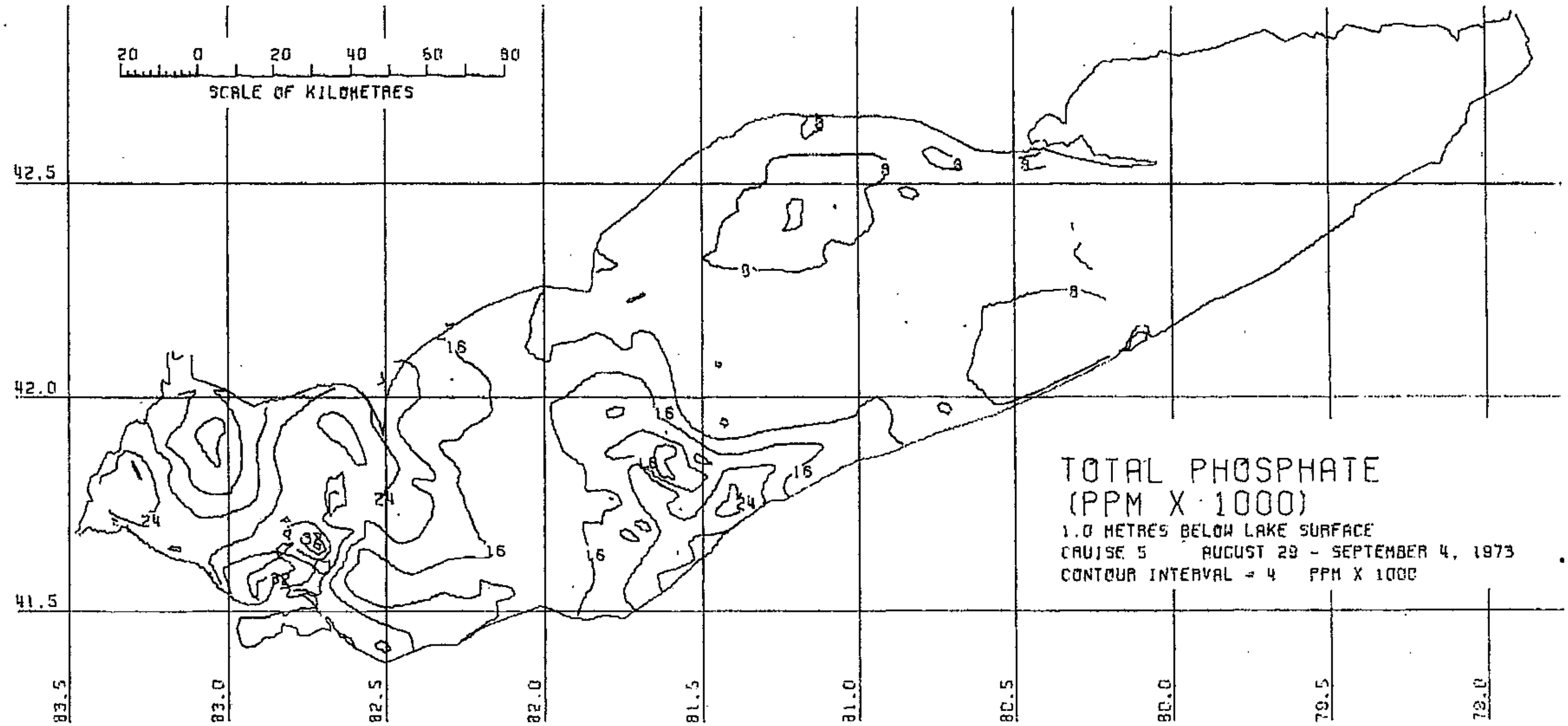
TOTAL PHOSPHATE
(PPM X 1000)
ALONG LOWER EPILIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 4 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
16
24
8

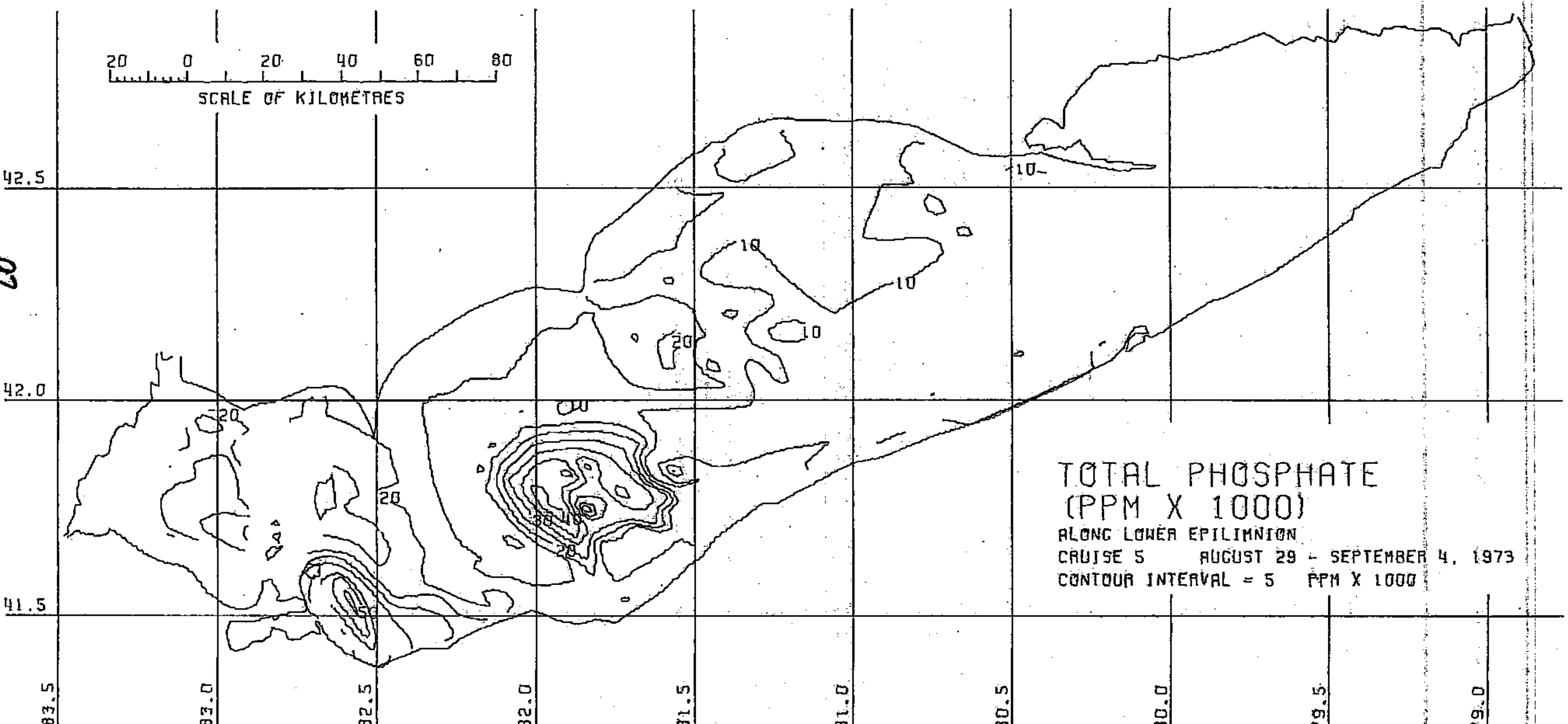
88

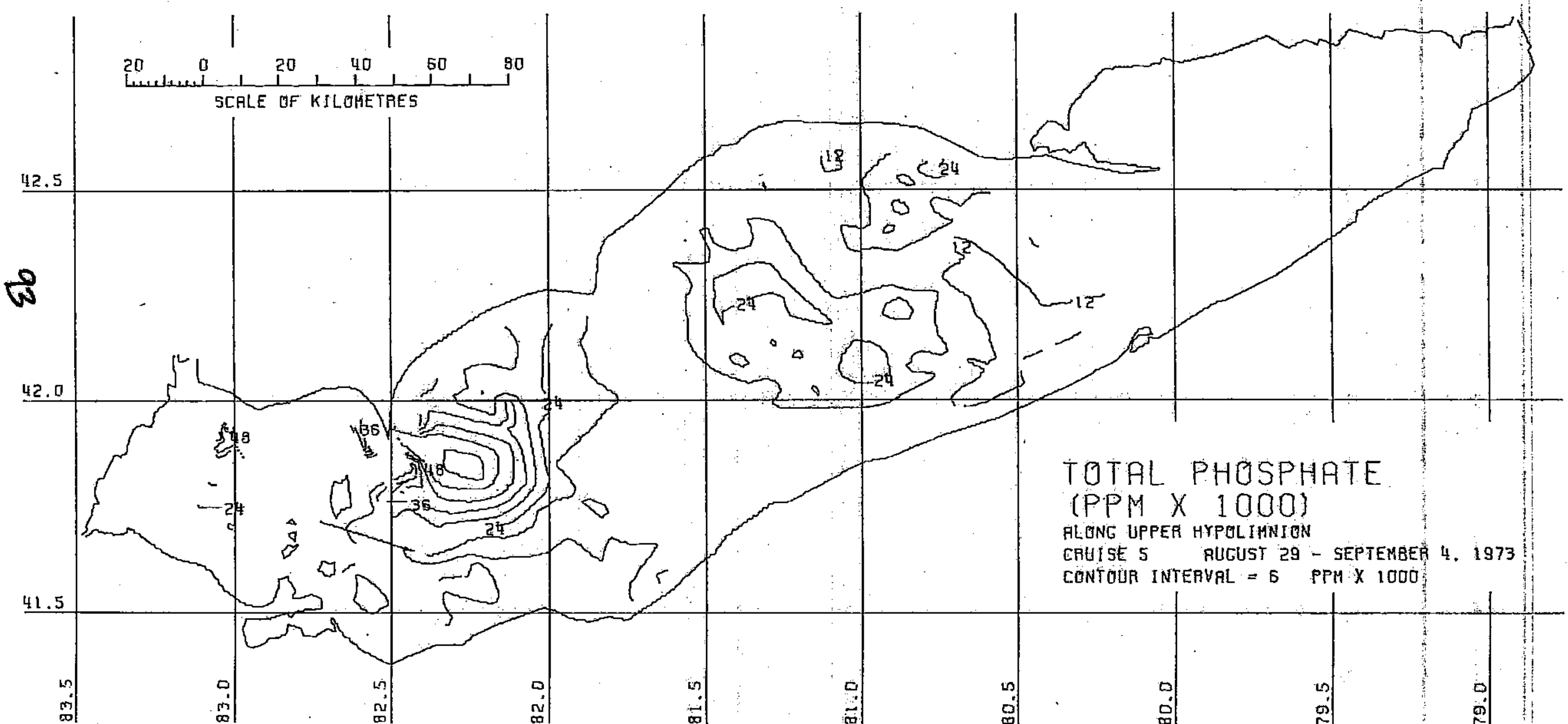


20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
16
8
24
TOTAL PHOSPHATE
(PPM X 1000)
ALONG UPPER HYPOLIMNION
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 4 PPM X 1000

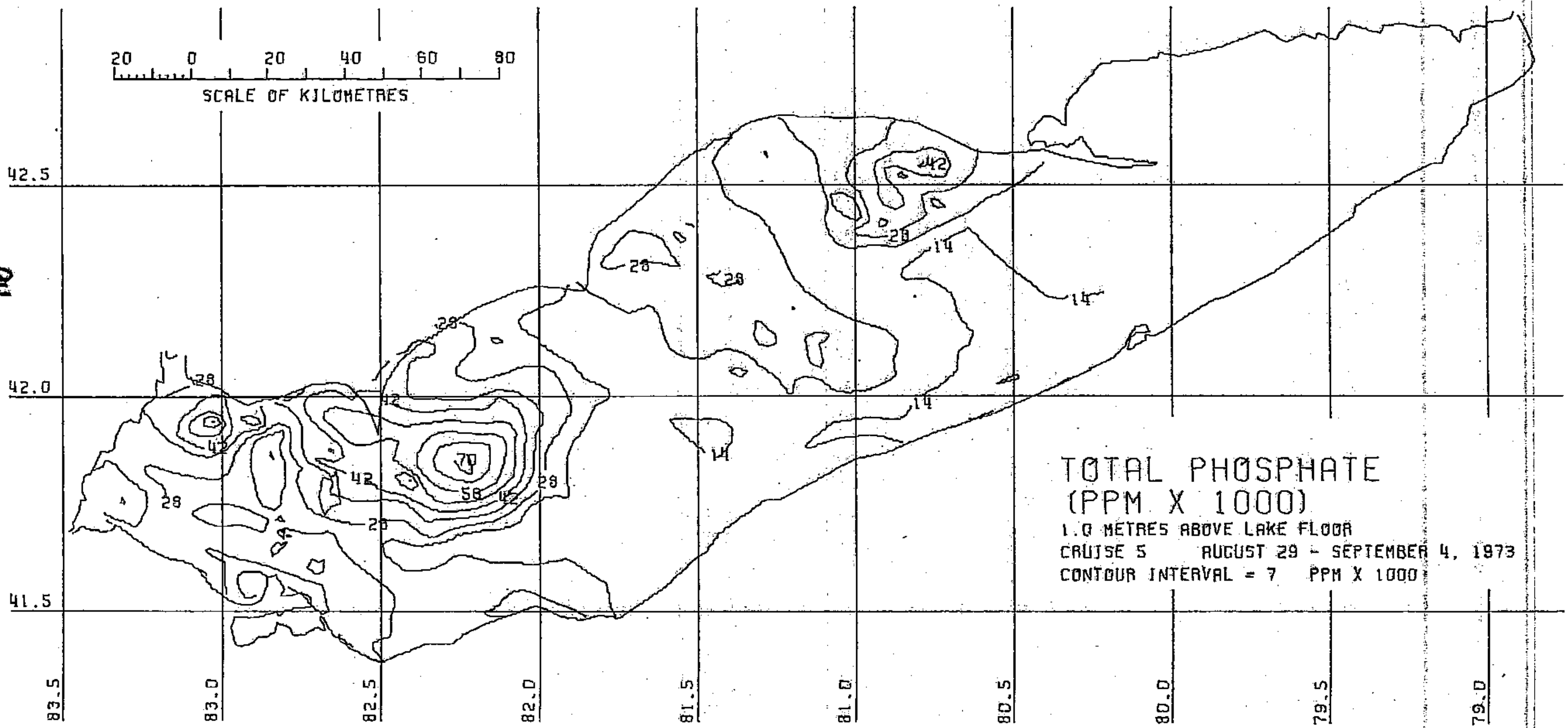

TOTAL PHOSPHATE
(PPM X 1000)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 2+3 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 4 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
16
24
8
4

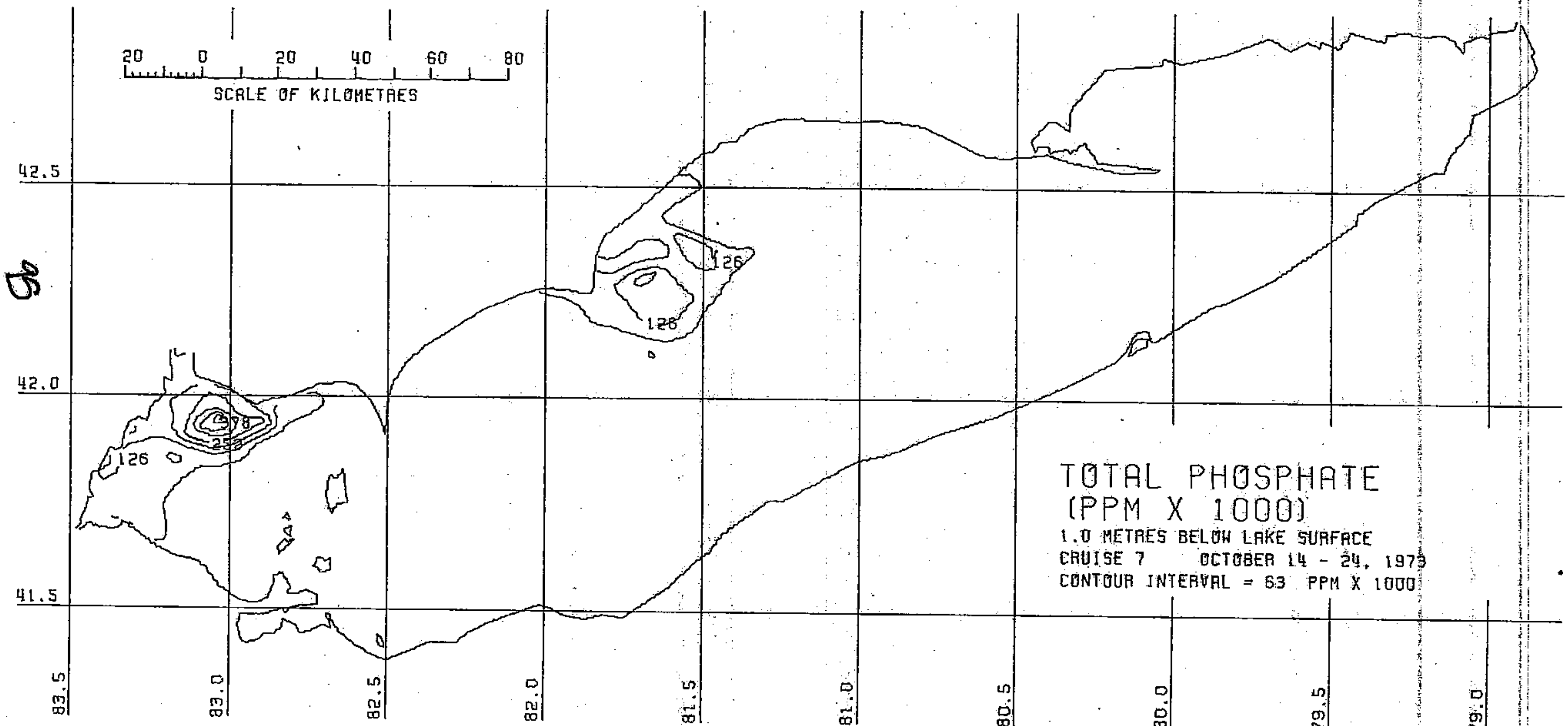

TOTAL PHOSPHATE
(PPM X 1000)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 4 PPM X 1000
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
8
16
24
32
36


TOTAL PHOSPHATE
(PPM X 1000)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 5 PPM X 1000
SCALE OF KILOMETRES
20
0
20
40
60
80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
10
20
30
40
50



TOTAL PHOSPHATE
(PPM X 1000)
ALONG UPPER HYPOLIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 6 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12
24
36
48

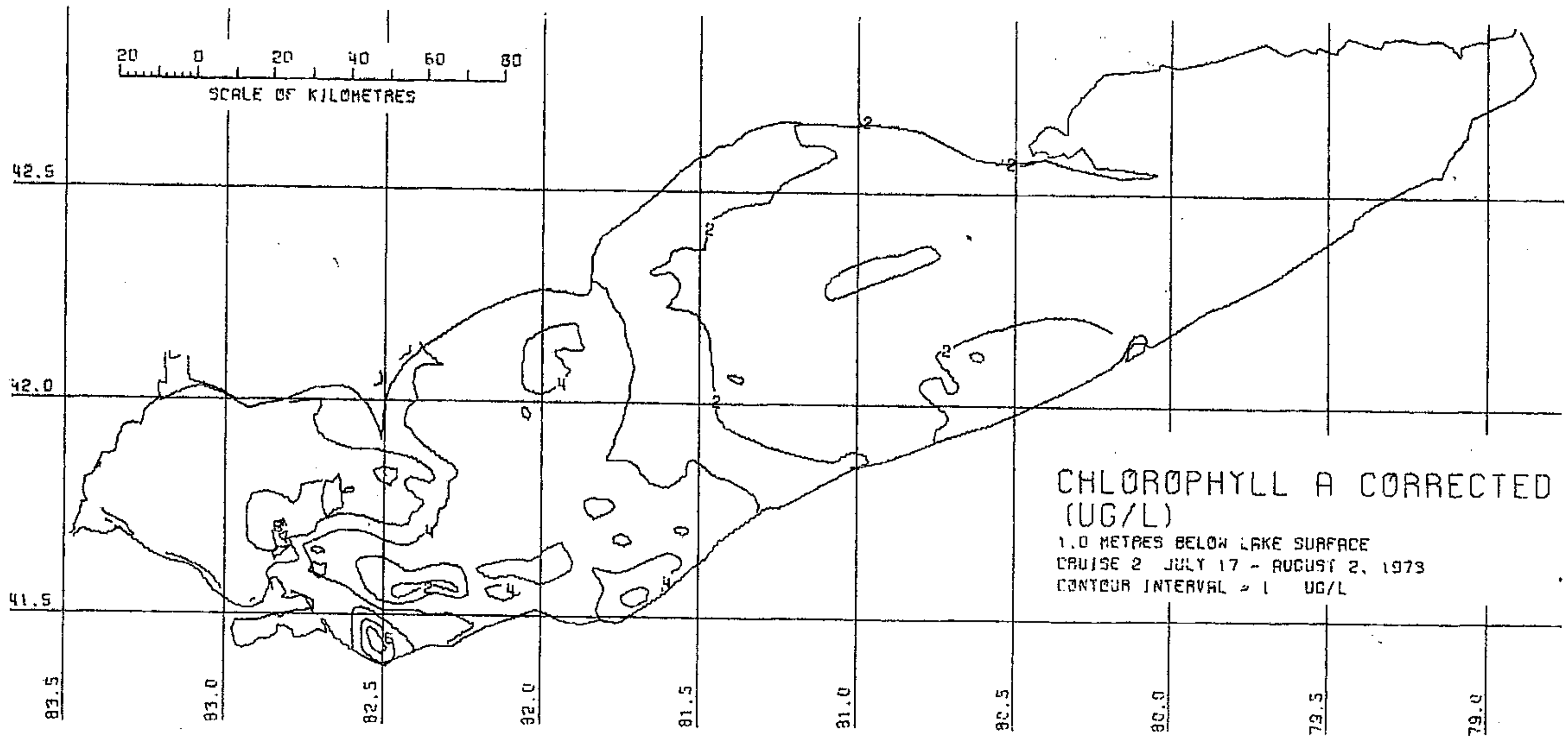

TOTAL PHOSPHATE
(PPM X 1000)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 7 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
14
28
42
56
70

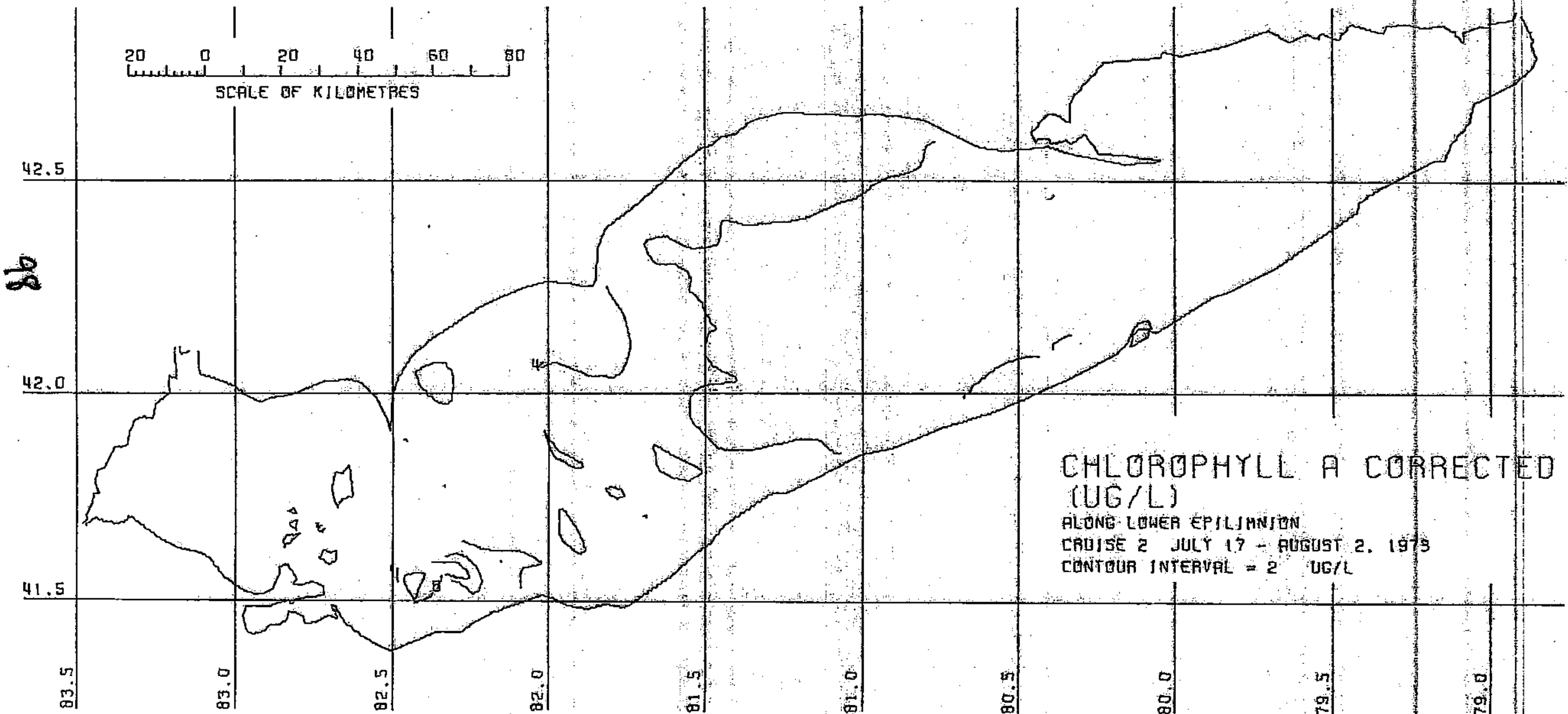


TOTAL PHOSPHATE
(PPM X 1000)
1.0 METRES BELOW LAKE SURFACE
CRUISE 7 OCTOBER 14 - 24, 1979
CONTOUR INTERVAL = 63 PPM X 1000
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
126
126
126
252
378

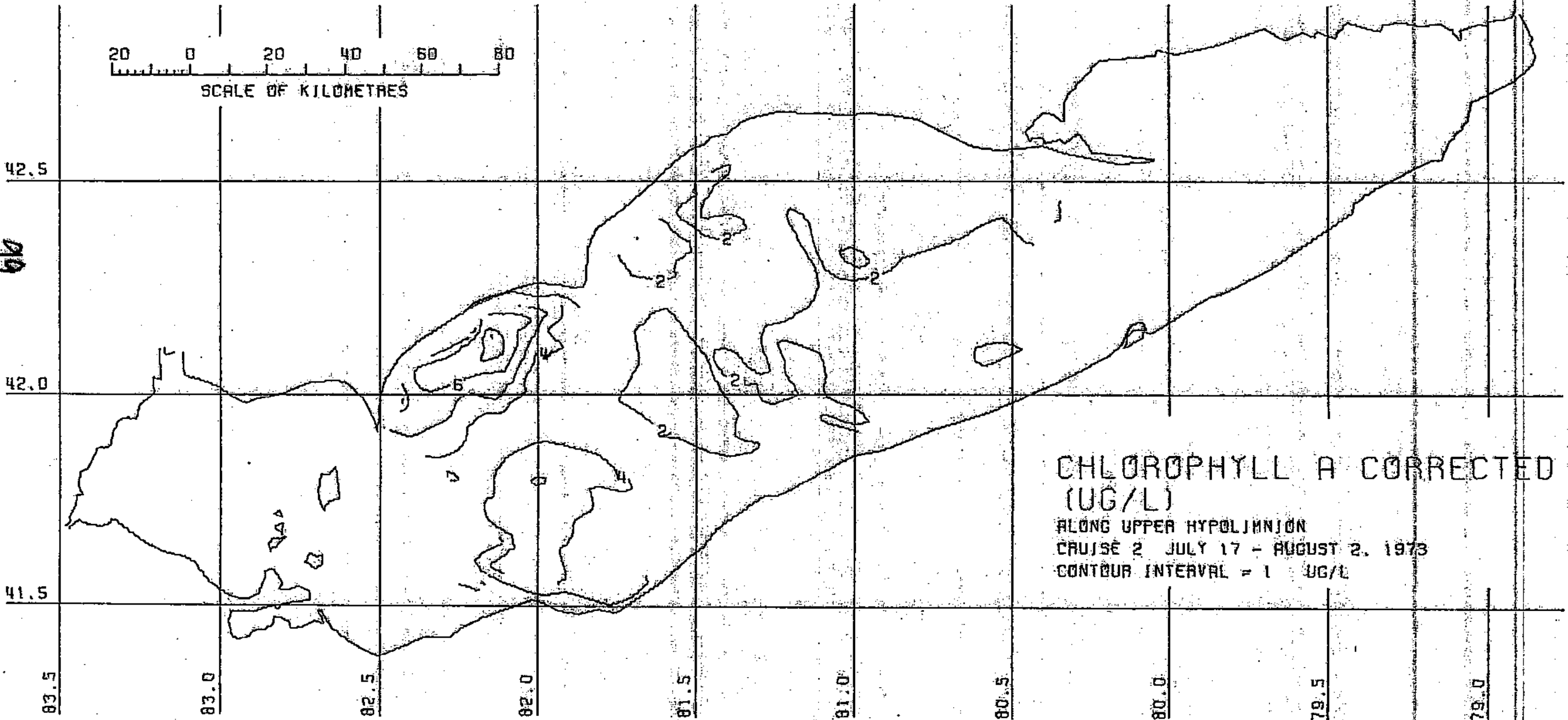
APPENDIX H

LAKE ERIE CHLOROPHYLL PLOTS

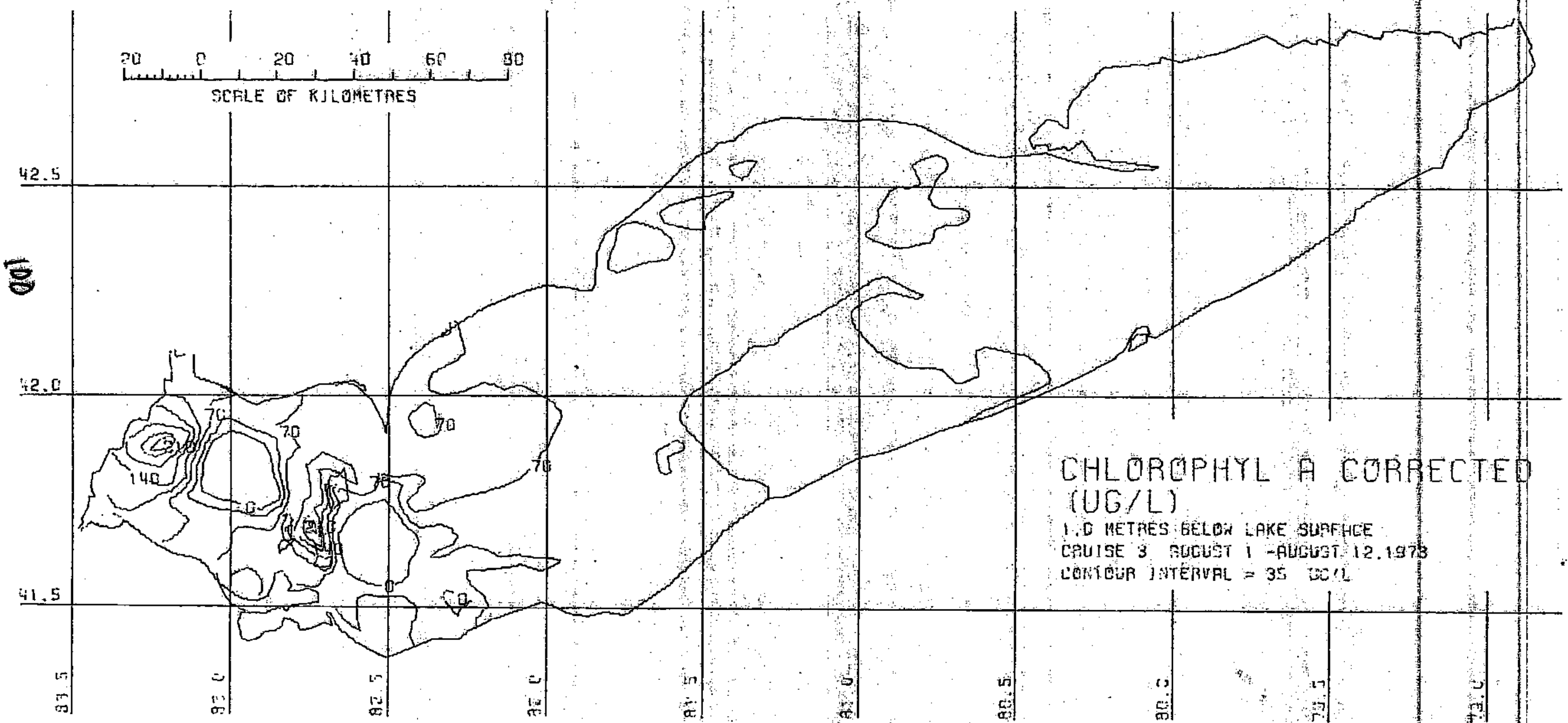

CHLOROPHYLL A CORRECTED (UG/L)
1.0 METRES BELOW LAKE SURFACE
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 UG/L
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

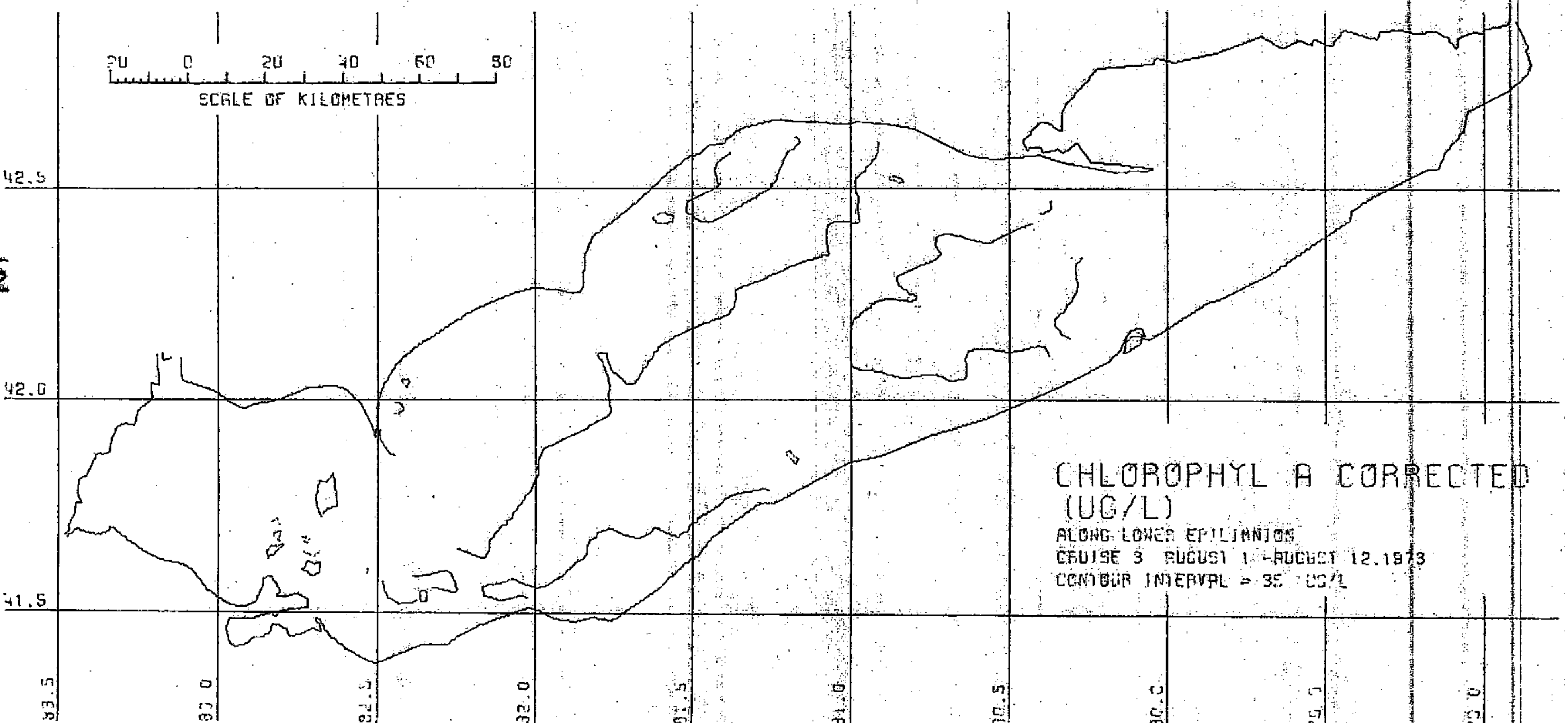


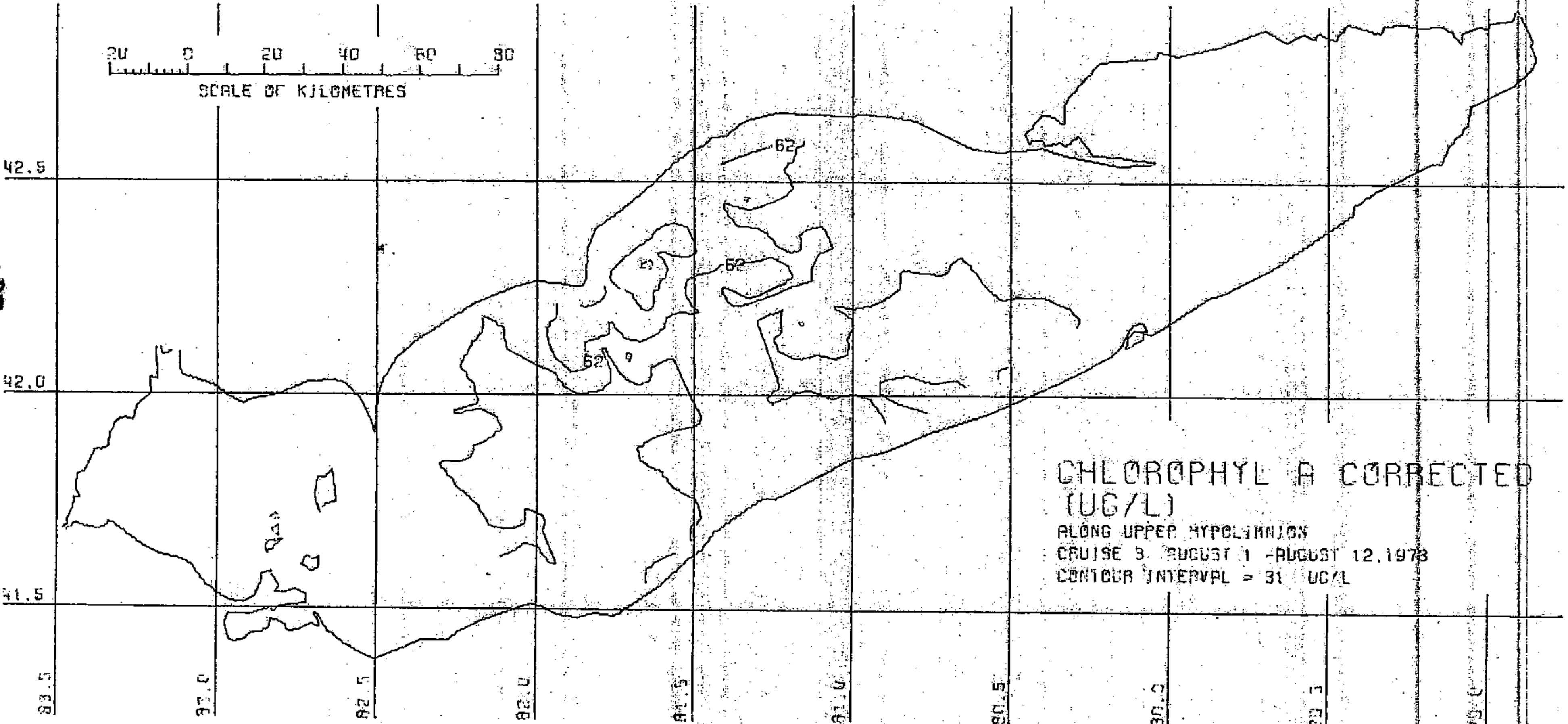
CHLOROPHYLL A CORRECTED
(UG/L)
ALONG LOWER EPILIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1978
CONTOUR INTERVAL = 2 UG/L
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0

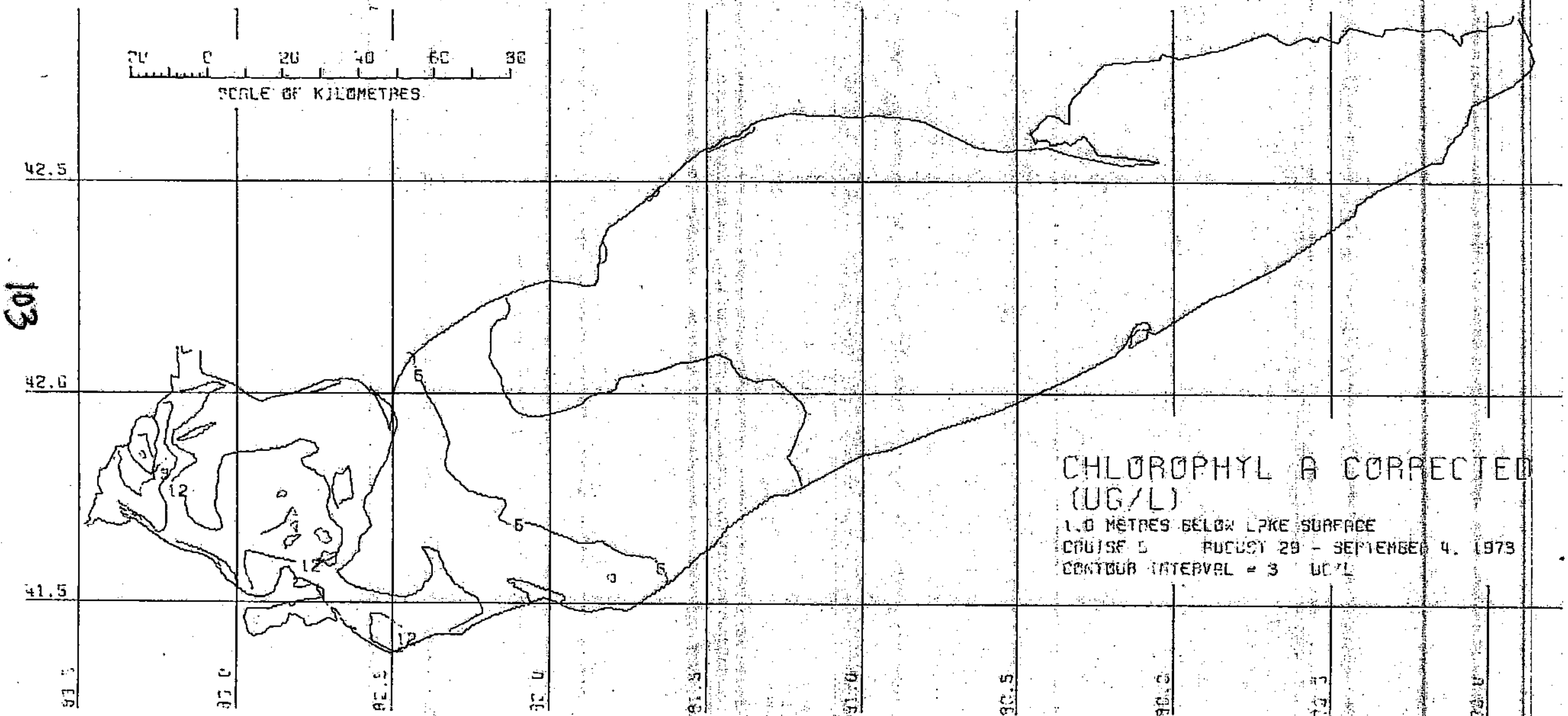


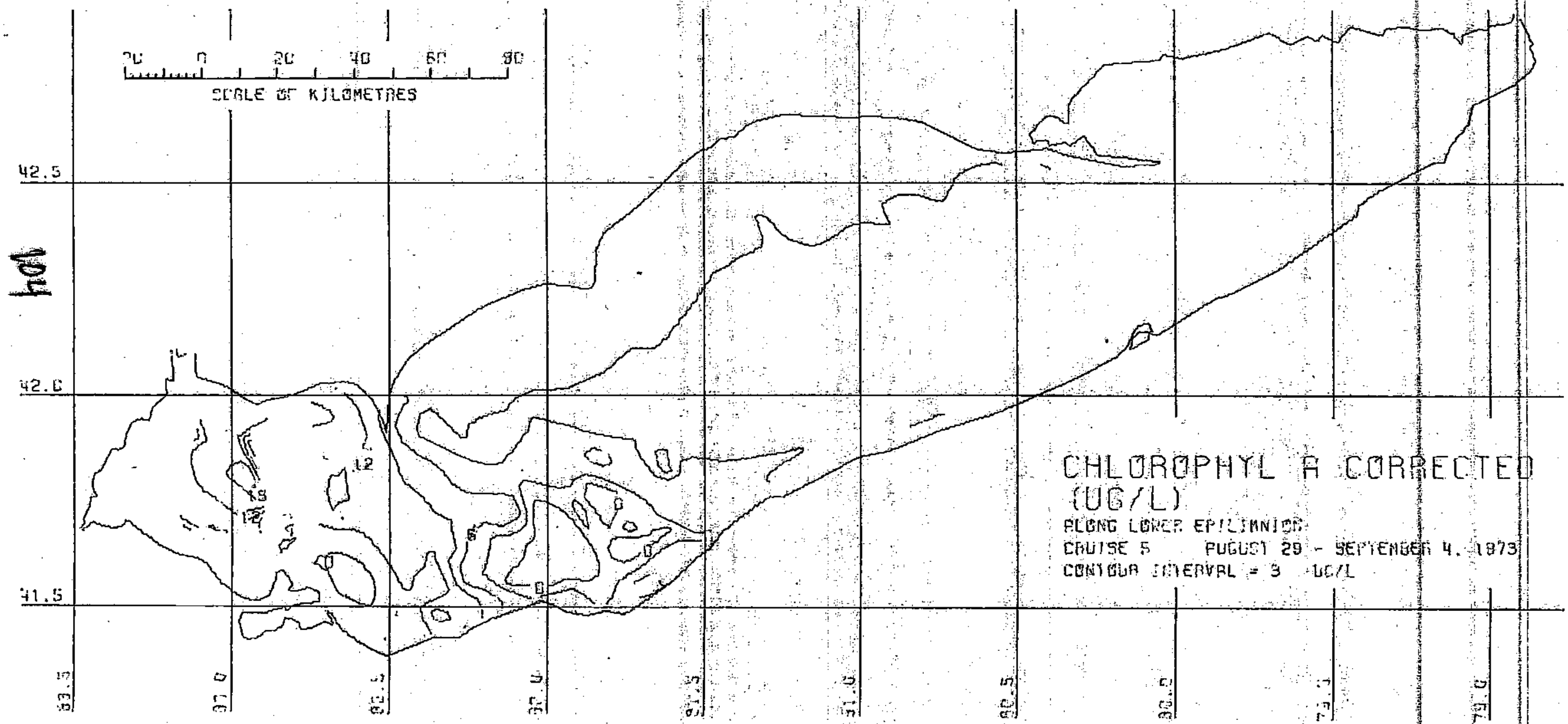
CHLOROPHYLL A CORRECTED (UG/L)
ALONG UPPER HYPOLIMNION
CRUISE 2 JULY 17 - AUGUST 2, 1973
CONTOUR INTERVAL = 1 UG/L

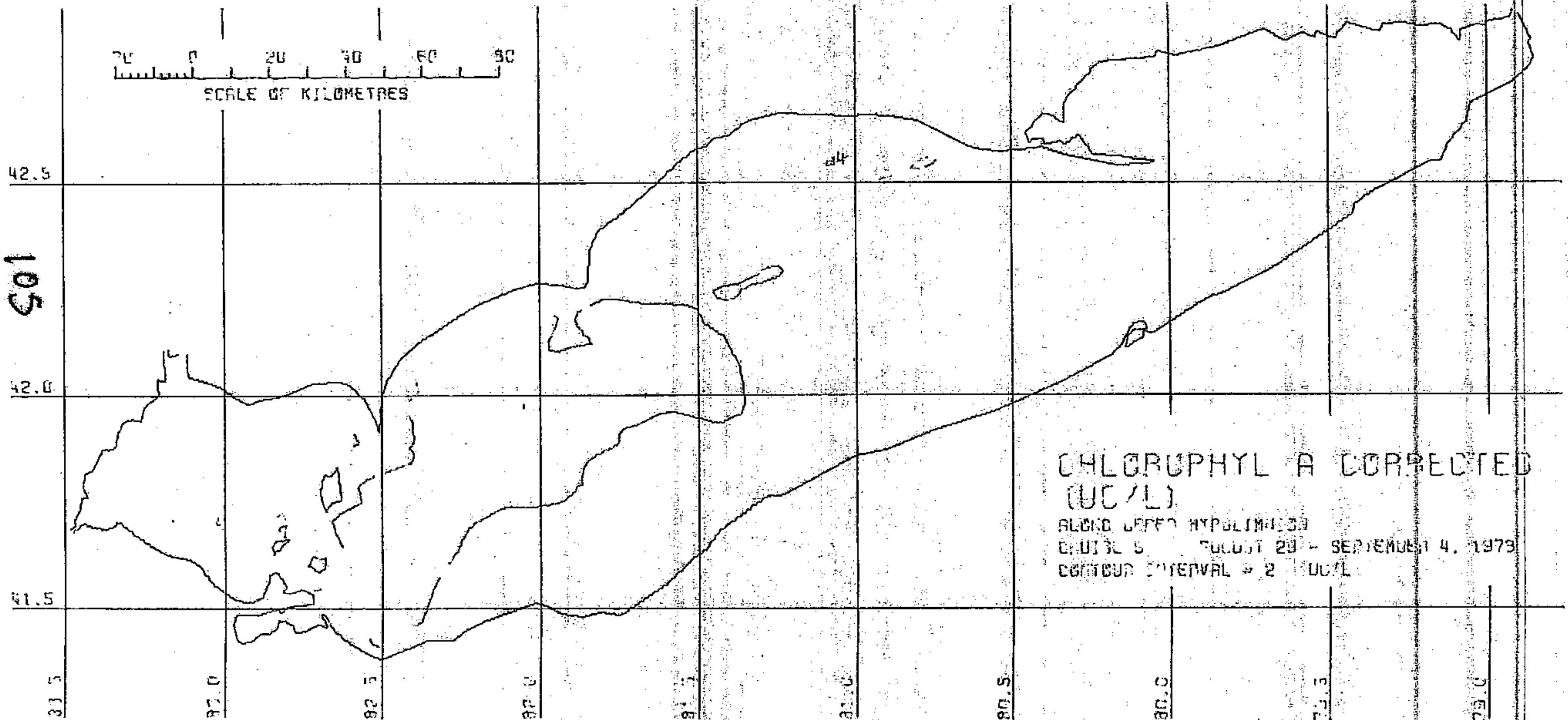

CHLOROPHYL A CORRECTED
(UG/L)
1.0 METRES BELOW LAKE SURFACE
CRUISE 3 AUGUST 1 -AUGUST 12,1978
CONTOUR INTERVAL = 35 UG/L
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
70
140
0

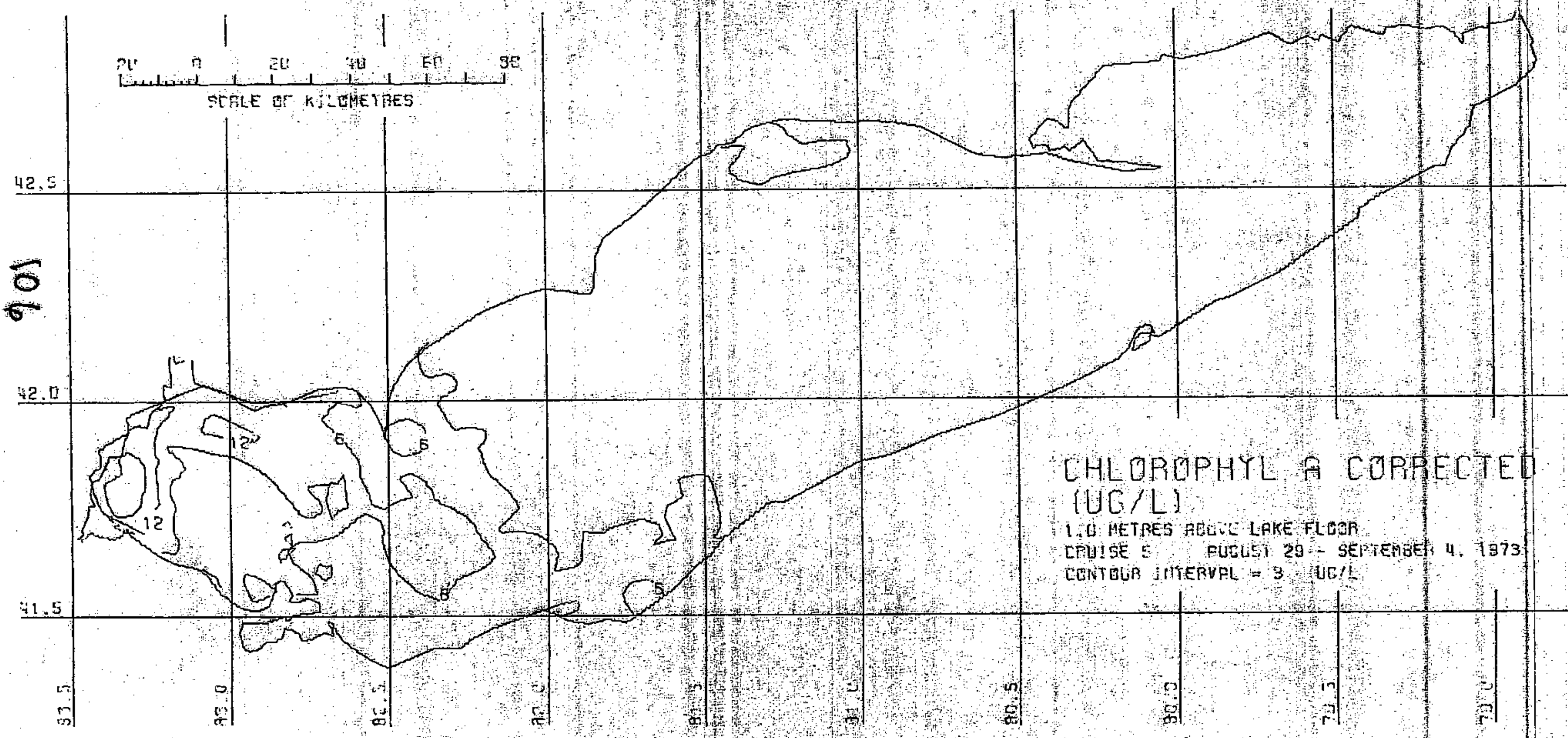

CHLOROPHYL A CORRECTED
(UG/L)
ALONG LOWER EPILIMNION
CRUISE 3 AUGUST 1 - AUGUST 12,1973
CONTOUR INTERVAL = 35 UG/L
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


CHLOROPHYL A CORRECTED
(UG/L)
ALONG UPPER HYPOLIMNION
CRUISE 3 AUGUST 1 -AUGUST 12,1978
CONTOUR INTERVAL = 31 UG/L
SCALE OF KILOMETRES
20
0
20
40
60
80
62
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


SCALE OF KILOMETRES
CHLOROPHYL A CORRECTED
(UG/L)
1.0 METRES BELOW LAKE SURFACE
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 3 UG/L


CHLOROPHYL A CORRECTED
(UG/L)
ALONG LOWER EPILIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 3 UG/L
20 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0
12


CHLOROPHYL A CORRECTED
(UG/L)
ALONG UPPER HYPOLIMNION
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 2 UG/L
10 0 20 40 60 80
SCALE OF KILOMETRES
42.5
42.0
41.5
83.5
83.0
82.5
82.0
81.5
81.0
80.5
80.0
79.5
79.0


CHLOROPHYL A CORRECTED
(UG/L)
1.0 METRES ABOVE LAKE FLOOR
CRUISE 5 AUGUST 29 - SEPTEMBER 4, 1973
CONTOUR INTERVAL = 3 UG/L
SCALE OF KILOMETRES
20 0 20 40 60 80
42.5
42.0
41.5
12
12
6
6
6
6