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ERIE '79
PHYSICAL EXPERIMENT
PRELIMINARY SCIENTIFIC REPORT

by
F.M. Boyce
National Water Research Institute
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INTRODUCTION

The analysis phase of ERIE '79 is well underway and enough is known about the quality of the data returned to begin an assessment of the successes and failures of the experiment. This report attempts to compare realized performance with the goals of the experiment as set out in the final version of the proposal. Such a comparison, at this stage must be considered as very preliminary since the scientific analysis must be completed before the real value of the work is known.

I have divided the total experiment into a number of sub-experiments, much as the proposal has done. I have left aside any considerations as to how well the U.S. data, when it becomes available, will assist in attaining the goals. Nor have I considered the large-scale circulation experiment which has been the main thrust of our U.S. counterparts and to which our measurements will ultimately contribute. Within each sub-experiment I have based the assessment mainly on the completeness of the data collection adding where I am able, an interpretation of the data itself. The causes of instrument failure are discussed in a separate report.

I should like to acknowledge at the outset the willing and enthusiastic support we received from Engineering Service, Technical Operations, the officers and crew of CSS LIMNOS and CSL ADVENT, and Water Quality Branch. Quite apart from the serious scientific endeavour, but perhaps contributing to it in important ways, was the fact that participating in this experiment was both exciting and fun.

EXPERIMENT 1

Goal: To obtain "climatological" data on the coastal flow regimes in three locations.

1.1 Northern Shore of the Eastern Basin, the Nanticoke Area

For the past decade, various agencies of the Ontario Government have been concerned with the environmental impact of the large industrial concentration now coming into being on the north shore of Long Point Bay. Nearshore currents and temperatures have been collected for a number of years but little is known about how these local flows connect or are influenced by the large scale circulation of the Eastern Basin itself. The present experiment, designed in consultation with the Ontario Ministry of the Environment, supplements nearshore measurements made at the Nanticoke site itself with measurements of current and temperature both along shore and offshore (Fig. 1). At the back of the mind of everyone concerned with the effects of shoreline activity on the lake is the question as to how fast or how far contaminants will be carried or dispersed into the main body of the lake. These questions can only be answered to the extent that the flow regimes, their potential for mixing or transport, are documented.

The array of instruments placed in the Nanticoke area must be regarded as a modest effort designed to explore the main features of the nearshore flow (Fig. 1). The nearshore data collected by Ontario Ministry of the Environment was supplemented by two bottom mounted CATS systems at the sites designated C2 and C1. These systems are designed specifically for nearshore locations and employ electromagnetic current meters so as to be able to filter out the substantial wave induced orbital velocities. As figure 2 shows, the return from the CATS systems was incomplete but nearshore data to the eastward of the Nanticoke site was collected throughout the experiment. There appear to be some differences in the two CATS sites which may influence results; the eastern system CATS 1 is reported to have rested in a patch of boulders and current data shows weaker currents at the CATS 1 site than at the CATS 2 site to the west. The turbidity sensors on CATS 2 alone seem to have produced useable data.

The Ontario Ministry of the Environment reports that their data collection at the Nanticoke site will provide a record of current at a depth of 11 m from May through October.

Offshore at sites C4, C5, and C7 the data is complete during the A period (mid May to the beginning of August). The FTP data at site C6 is complete throughout. The current meters at site C6 appear to have been entangled in the gas-drilling activities. The pinger attached to the anchor has now been located some four miles off station but attempts to locate the equipment have been frustrated by weather. Some hope remains that the instruments and data may be recovered.

During the B period, with the exception of site C6 which returned a complete data set, we may have to face the loss of data from sites C4, C5 and C7 at the 10 m level. RCM-12 current meters were used in these positions in the expectation that they had been cured of their earlier faults. Unfortunately they have not proven to be more reliable than they were in the beginning. A question mark hangs over this data until we can spend enough time on it to determine what can be salvaged.

Meteorological data collected at site C6 appears to be complete.

Data collected during the A period seem to be complete enough to attempt a "coastal boundary layer analysis" (Murthy and Dunbar, 1977). The doubts about 10 m data at sites C4, C5, and C7 during B period make this possibility remote during the second half of the experiment. Some current meter data was collected by CCIW in the Long Point Bay area in 1968 and in 1971. This should be excamined together with the 1979 data in order to produce a more complete current climatology of the region.

1.2 South Shore of Central Basin near Cleveland

Cleveland represents the largest urban/industrial concentration in the Central Basin and is presumably the source of a substantial fraction of the nutrients and contaminants entering the basin, ranking next to the inputs from the Western Basin. The impact of a particular contaminant on the basin as a whole depends on the lifetime of the substance in the water column and the rate at which the material is transported/diffused out of the coastal zone. Profiting from the lakewide coverage provided by the U.S. experiment, now was the appropriate time to collect physical data from which we can estimate diffusivities and coastal residence times. (Fischer, 1980). (Figure 3).

With the exception of data from 10 m depth at C21 (RCM-12), the array functioned 100% during the A period (10 May to 1 August) (Fig. 4). During the B period there is no 10 m data at either C19 or C21, and only 60% return from C20. Thus, as at Nanticoke, only the A period offers complete enough data for a boundary layer analysis. The combined data set, A and B periods, appear adequate to establish a climatology of major flow events (reversals, stagnations, preferred directions) during the May to October period.

1.3 North Shore of the Central Basin - Upwelling Experiment

Blanton and Winklhofer (1972) indicate a mean northwest drift of hypolimnion water during the summer of 1970. It was not established where this water moved once it reached the northern shore but one possibility is upwelling of bottom water along this shore. B and W could not offer concrete evidence of such a phenomenon but alluded to certain surface features which might be indicative of it. The current meter array on the north shore of the basin was established to learn more about the hypolimnion currents near the north shore and to support a series of launch cruises which collected temperature and dissolved oxygen data in the nearshore zone (Fig. 5).

The return of current meter data from this array is disappointing (Fig. 6). Once again, we did better in the A period with the records below 17 m being relatively complete. The surface (10 m) data in the B period is compromised because most of the instruments used were of the RCM-12 type.

The launch cruises proved to be most interesting. They revealed a curious distribution of temperature nearshore (Fig. 7) tantamount to a thickening of the thermocline as one moved shorewards; the isotherms associated with the top of the thermocline intersected the bottom. This configuration can be interpreted as the signature of an active mixing process occuring at the lake bottom nearshore with bottom water moving shorewards and a mixed water moving offshore in the thermocline (Hansen and Rattray, 1972). The significance of this phenomenon is not yet understood, nor do we yet know the source of energy for the bottom mixing. With luck the marriage of the current meter data with the launch cruise data will make things clearer.

EXPERIMENT 2

2. Dynamic Balance in Mid Central Basin

The array in mid basin (Fig. 5) is designed to serve two purposes.

1. To determine the temporal and spatial variability of horizontal motion in the main body of the basin at scales which could not be resolved by the lakewide array. In terms of spatial separations, the lakewide array has an aperture length scale of perhaps 20 km. The mid basin array has a minimum separation of about 5 km interspaced between elements of the lakewide array. We shall be able to form correlations between stations which are 5,

10, 15, and 20 km apart. This kind of information, which is missing in the 1972 IFYGL experiments will provide valuable physical insight into the "meso-scales" - inertial type motions for example and ultimately be a practical benefit in the parameterizing of sub grid scale horizontal diffusion for numerical hydrodynamical models.

2. Going one step further in the analysis of the data, we made the assumption that the energetic portion of the horizontal motions in mid basins would have scales greater than 5 km and therefore we designed our array with the intentions of decomposing the balance of forces which create and destroy these motions. We may write the balance of forces in words

Local accelerations = (1) advection of momentum by horizontal currents + (2) coriolis forces

+ (3) surface pressure gradient forces + (4) internal pressure gradient forces + (5) wind stress

+ (6) horizontal diffusion of momentun + (7) vertical diffusion of momentum

The temperature profile in the Central Basin over much of the summer closely approximates a two layered system. As a first approximation, we assume that a single measurement of horizontal velocity in the centre of each layer will represent the mean velocity of that layer.

Taking the balance of forces term by term on the righthand side of the equation

1) <u>Advection of momentum</u>. Assuming that the array spacing is smaller than the energy carrying modes of motion, this term requires estimates of the horizontal derivatives of current $\frac{\partial u}{\partial x}, \frac{\partial u}{\partial y}, \frac{\partial v}{\partial x}, \frac{\partial v}{\partial y}$. A minimum of three closely spaced current meter stations are required.

2) <u>Coriolis force</u>, can be estimated directly from a knowledge of mean current.

3) <u>Surface pressure gradient forces</u>. Requires a knowledge of the slope of the water surface $\frac{\partial h_s}{\partial x}$, $\frac{\partial h_s}{\partial y}$. where h_s is the height of the surface above a fixed reference level. Requires a minimum of three tide gauges in a two dimensional array about the central point.

The surface pressure gradient term, the surface expression of the barotropic component of motion, may in fact be better determined by a numerical model (storm surge model) Such a model would yield the barotropic or vertically averaged component of flow. By appropriate differencing between the upper and lower layer equations, we obtain the balance of forces of the baroclinic flow component and perhaps this is a more direct path to the desired vertical momentum flux component. Water level measurements in mid lake are of course invaluable in setting up the barotropic model. This approach may relax somewhat the very stringent instrumentation requirements necessary to a direct measurement of water surface slope.

4) Internal pressure gradient. In a two layered system, this force acts on the lower layer only and can be estimated from a knowledge of the density difference between the two layers and the slope of the thermocline $\frac{\partial h_i}{\partial x}$, $\frac{\partial h_i}{\partial y}$ where h_i is the height of the thermocline (defined as the height of a representative isothermal surface above a fixed reference level). This slope can be estimated with a minimum of three thermistor arrays spaced about the central point.

5) Wind stress. Based on measurement of local wind speed and direction plus estimate of the drag coefficient. The latter is known to depend on atmospheric stability at the water surface and sea state.

6) Horizontal diffusion of momentum. Assuming that the scale of motions which carry this flux have approiximately uniform velocities over each of the mixed layers, these terms can be calculated from and estimate of the Reynolds stress divergence over a control volume centred on the point of interest. Correlation of the form $\overline{u'v'}$, $\overline{u'u'}$, $\overline{v'v'}$ are developed at each of the instrument sites (elements of the Reynold's stress tensor) where the primes and bars indicate that these are averages of fluctuations about mean quantities.

7) <u>Vertical diffusion of momentum</u>. Since we cannot measure vertical velocities at the required scales, we are unable to estimate the Reynolds stress terms associated with the vertical fluxes of momentum. This term must be estimated as a residual, once the other terms are known.

Knowledge of terms 1, 3, 4, 5, and 6 in the momentum balance recipe is very useful in its own right, however, the real action insofar as the direct contribution of this experiment to the assessment of the oxygen and nutrient budgets of the Central Basin's hypolimnion lies in our ability to extract useful estimates of term 7. How well did we do this time?

Terms 1 and 6 (advection, horizontal diffusion) will depend on the completeness of the current meter data and on the efficiency of the array. With regard to the former, the performance summary is presented (Fig. 8) in a form which highlights the spatial completeness of the data. For the "A" period (Fig. 8), mid June to mid July, the data is complete at the two lower depths (19.5 m and 21 m) and complete enough at the two upper depths 10 and 15 m to form estimates of first derivatives. For the "B" period, mid July to mid August (Fig. 8b), there has been loss of data at all levels, minor at 15, 19.5, and 21.2 m, but serious at 10 m where only three out of seven instrumented sites returned data. The "C" period, mid August to mid October, (Fig. 8c) returned a full set of 10 m data, six out of seven meters operated at 15 m, while five out of seven produced data in the two lower depths.

With the exception of the "B" period 10 m data, the returns appear good enough to establish correlation at several space scales and possibly to estimate the horizontal advection and diffusion terms.

The surface pressure gradient experiment was not successful. Two out of the three gauges failed, and only the gauge at station C23 returned a complete record. Although this series will be helpful in establishing spectra and cospectra with the shore stations in the Basin, we will have to use indirect methods to obtain the surface pressure gradient for the dynamic decomposition.

With the internal pressure gradient as determined by FTP measurements, we face the same problems as for the currents. There is first the adequacy of the array with regard to the energy-carrying scales of motion, and second, the completeness of the records. The FTP array is in the form of an equilateral triangle with one array at the centre (C11). The spatial separations are 10 and 18 km. I have the suspicion, from time series temperature data collected during the anchor stations (see below) that displacement of the thermocline at the longer time scales one would associate with these separations are quite small. I doubt that the absolute depths of the sensors in each of the four arrays are exactly known due to small variations in water depth, and possibly due to variations in the amount each anchor may have sunk into the mud. Given an accurate calibration of thermistors, we can attempt a leveling among the array elements by assuming that the mean slope of the isothermal surfaces over long periods of time is very small or zero. This may be problematic if there should turn out to be persistent currents in the lower layers; in which case the leveling process would eliminate the internal pressure gradients associated with these movements. Temperature data collected by the current meters could also be used to help map the topography of isothermal surfaces at times when the current meter was located in the thermocline zone.

With regard to the data returns we report a progressive degradation of data from "A" period to "C" period due to the failure of the two 20 m cables at C24 and C11. The failures were ones of steady degeneration of data as the number of "good" channels decreased. Returns from the "A" and "B" period (Fig. 8) appear adequate and the return from the "C" period is marginal.

The data returns from the meteorological buoys have not yet been determined, but known failures appear to have been few; it seems safe to assume that the wind speed and direction will be adequately determined at the experiment site.

To summarize the results of the mid-lake array experiment, we may say that the data is complete enough to give good information about the scales of motion present and to permit the direct estimate of some of the terms in the momentum balance during some of the measurement periods. Prospects for the "dynamic decomposition" are brighter for the "A" period. The loss of the water level gauge data is unfortunate and serves to remind us that greater efforts will be required to increase the chances of successful returnsin the future. Although this report intends to discuss only the data which was actually collected, we record here our disappointment that the vertical profiling current and temperature system (GVAPS) was not operational in time for the Erie '79 experiments. Success with this system would have elevated the experiment from the commonplace to the unique.

EXPERIMENT 3: ANCHOR STATION EXPERIMENTS

The anchor station work has been reported earlier (Boyce, 1979) but will be summarized here for the sake of completeness. With the extensive background information provided by the array of moored instruments at the C11 site a number of smaller scale (both time and space) experiments seemed profitable. The research vessel LIMNOS was used as a platform for the experiments during three periods.

A. July 9-22 (nominal)

B. August 12-22. For most of this period the ship anchored at C11. It moved to another Central Basin site for 36 hours and then returned for a final 24 hours to the C11 site.

C. September 4-14.

During each episode the following measurements were conducted:

3.1 Short time and space scale variability in thermal structure.

3.2 Structure of near bottom flow.

3.3 Lagrangian measurements of currents using drogues.

3.4 Surface wave measurements.

3.5 Time series measurements of dissolved oxygen, nutrients, optical properties.

Each of these will be discussed in turn.

3.1 Short time and space scale variability in the thermal structure

From a heat budget study of the Central Basin hypolimnion, Burns and Ross (1972) conclude that thermocline water is at times entrained into the hypolimnion and that this mechanism constitutes an episodic resupply of dissolved oxygen to the lower layer. In the same volume, Blanton and Winklhofer (1972), reporting on the physical measurements, suggest that this reverse entrainment process follows a period of relative calm during which the thermocline region appears to become thicker (reduction of the temperature gradients). They further indicate that the spacing of wind events in time is critical to the onset of the "reverse entrainment" observed by Burns and Ross.

Although we can imagine a variety of plausible mechanisms for both the reverse entrainment and the preliminary relaxation of the temperature/density gradients, we have no firm data indicative of what is actually happening. Moreover, the data which we do possess is largely derived from a sequence of basin-wide ship surveys and is thus integrated in space and blurred in time. The shipboard experiments were intended to document changes in the midbasin temperature profile should we be lucky enough to be at anchor during an episode of either thermocline thickening or reverse entrainment and also to explore one of the mechanisms which might provide a substantial portion of the vertical mixing energy, the growth and breaking of small scale internal waves.

In order to surmount the problem of adequate resolution in the vertical as well as in time, a two-pronged sampling was employed. EBT casts were made at 20 minute intervals and an array of thermistors was hung from the ship. All sensors, the two EBT channels, the 12 thermistors, and a pressure sensor at the bottom of the array, were sampled and recorded at two second (nominal) intervals. The thermistors were separated vertically by a nominal distance of 1 m and the array was adjusted from time to time to ensure that one or more thermistors were placed in the thermocline zone. Often the thermocline was so sharp that the entire region encompassed less than 1 m vertical distance. The nominal EBT vertical speed (descending) was about 0.5 m/s; the vertical resolution of each profile is thus about 0.2 m, half that of the thermistor array, but obtained only three times per hour.

The system operated faithfully during the three anchor station periods; the quality of the data returned is thus affected only by the design of the apparatus and the conditions of deployment. It is certain that the data is degraded somewhat by the motion of the ship at anchor, as she pitched to the seas and as she yawed about her anchor. The former motions were coupled strongly into the recorded temperature signals as the thermistors were oscillated at the surface wave periods through regions of strong gradients. The pressure sensor will have responded to a combination of the imposed vertical motion and the subsurface pressure field imposed by the waves themselves. The latter (unknown) will be attenuated significantly at the sensor depth so that there is some hope for elimination of a good portion of this error. The yawing motions, having a period of several minutes, can be expected to cause some Doppler shifting of internal wave periods in the short term which will be eliminated in the spectral analysis of suitably long portions of the record. The danger is that the yawing period may coincide with a dominant wave period and thus contaminate the spectra.

From a reading of the stripchart records of selected thermistor channels made in parallel to the main digital records, we learned that short period internal waves are almost always present in the main thermocline. Typical periods are of the order of one to six minutes. Amplitude and frequency both respond quickly to changes in wind forcing; the amplitudes grow from a background level of 10 cm or so to 100 cm and the periods lengthen as the wind increases above 15 knots. The time of response to changes in wind is about one half hour. This last result itself may be useful in gauging the length of time needed for the wind stress to produce sheared currents at the thermocline level.

The shipboard system will yield fairly complete one-dimensional spectra of the short period internal waves which may then be related to wind speed and currents. The next step in the study of these waves is to determine their phase speeds and directions of propagation. This was attempted during periods B and C of the anchor station experiments modifying the original M-CATS system (see below) to include outrigger thermistors (Fig. 9). The idea was to create an array of three thermistors located vertically in the thermocline and forming an equilateral triangle in the horizontal. The array spacing was chosen to be 30 m, based on observed wave periods and theoretical estimates of phase speed. This setup is the minimum required to give a rough estimate of the speed and direction of propagation of the internal wave trains.

Two experimental difficulties were encountered. The first was the positioning of the outrigger thermistors into the proper horizontal configuration and determining the orientation of the triangle. From LIMNOS we were able to lower the M-CATS frame to the bottom and to deploy the outriggers in such a way as to avoid tangles. Later on, at the first opportunity, we dragged the outriggers into position with respect to each other and the main frame as best we could with the Boston Whaler. A hand-held compass was used to take bearings of the array arms. This was not easy to do and we must accept the possibility of an error ±15° in array orientation.

The second problem concerned the placing of the thermistors in the thermocline. We could position them at equal heights above the bottom (±20 cm) readily enough but were limited to a distance of four metres by the maximum height of the M-CATS mast. During all of the B period, the thermocline was more than 4 m above the bottom, and consequently the temperature variations measured by the array are very small. During the C period the thermocline was deep enough to intersect with the array and we have some records worthy of analysis. This experience has led to a redesign of the system to allow greater flexibility in the positioning of the thermistors. As with the shipboard array, the data return is 100%; the limitations are imposed by experimental design.

3.2 Structure of near bottom flow

The exchange of materials across the sediment water interface is an important component of the overall nutrient or dissolved oxygen balance. Such exchanges are more active when the flow over the bottom is rapid and turbulent, and more active again when there is sufficient energy in the near bottom flows to resuspend the recent sediments. The proper framework of study for such matters is that provided by boundary layer theory. A velocity profile synthesized from at least three levels of measurement above the bottom can be used to infer bottom stress and roughness length, and to construct eddy viscosities as a function of distance above the bottom. The M-CATS system referred to at various places in this report is designed to collect velocity and temperature measurements close to the bottom. The system comprises three current meters at 1, 2, and 3 m above the bottom and an array of thermistors spaced over a four metre vertical distance above the bottom. The instruments are mounted on a guyed aluminum mast which is stepped in a bottom "platform". The platform carries batteries and data logger. The sampling interval is 16 seconds; endurance at this rate is 11 days. Conventional impeller driven current meters are not acceptable because of their high threshold values. We have used two electromagnetic current meters at the 2.0 and 3.0 metre levels, and an acoustic current meter at the 1.0 m level. These instruments are able to measure flow speeds as small as 1 cm/s.

Such high sensitivities are paid for with a loss of stability of the instruments. Both the electromagnetic and the acoustic current meter are subject to drifts of zero offset and gain. The weakness of the system then will be in the ability to detect and confirm small velocity differences between the various levels. Interference from the eddies created by flow around the structure is also a source of potential contamination of the data.

During the A and B anchor station experiments, the entire system lay within the lower layer; the measurements then can be interpreted as boundary layer profiles. During the C period the upper instrument was in the thermocline, a region which can support strong velocity gradients as well as temperature gradients. The data return seems complete.

3.3 Drogue tracking

The measurements which are most useful for estimating turbulent mixing are those in which the paths of marker water particles can be traced (Lagrangian description of the flow field) water particles may be tagged in a continuous fashion with a soluble tracer (often a dye) or in a discrete fashion using clusters of drifting objects such as drogues. Such experiments are difficult and costly to perform. On the other hand, an Eulerian description of the flow in terms of measurements of the currents at fixed points in space, such as is provided by an array of current meters is more easily produced. To use Eulerian measurements to characterise diffusion processes is not straightforward because of the separations of the instruments is almost always greater than some of the eddy scales involved in the mixing. Appropriate statistical treatment of Eulerian-type data can help to bridge the gap and a number of techniques have been proposed. The number of experiment sets where both Lagrangian and Eulerian measurements have been made simultaneously are few and therefore valuable.

The drogue measurements made while the ship lay at anchor during the three periods are described fully in the earlier cruise reports (Boyce, 1979). We experienced difficulty in tracking the drogues by radar in rough seas, as might be expected, and therefore some of the records are gappy in time. The present drogue design is light, cheap, and easy to deploy but perhaps not sufficiently robust for the demands we make of it.

We anticipate nevertheless that the drogue data combined with the current meter data will yield some valuable insights into the problem of deducing mixing properties from current meter data alone.

3.4 Surface wave measurements

The wind stress acting on the water surface activates the surface wave field as well as drives the currents and vertical mixing. The input to the last two processes must be viewed therefore as a function of the surface wave field, particularly under rapidly changing wind conditions (Donelan, 1979). The wave field, in its own right, is of more than passing interest to navigators and coastal engineers. There has been a flurry of recent efforts to produce wind wave prediction models which treat the variable Great Lake situations (e.g. Donelan, 1978). Measurements of offshore sea state, particularly when there is a supporting network of meteorological observations, are valuable test data for wave prediction models.

At the beginning of each anchor period, a wave rider buoy was installed as the C11 site. The buoy was recovered immediately before leaving the station at the end of the anchor period. The wave rider receiver, data logger and programmable timer were mounted aboard LIMNOS. The programmer turned on the receiver and recorder once every three hours for an interval of 40 minutes. Visual observations of wave heights and directions were recorded each hour in the meteorological log.

The wave rider system worked statisfactorily through the A and C periods. During the early part of the B period some data was lost. The buoy was launched without the antenna so as to lessen the risk of damage. It was intended, once the LIMNOS was settled at anchor, to install the antenna from the Boston Whaler. Unfortunately, the winds freshened and the antenna could not be installed until they abated some 48 hours later. During all three cruises, the winds were variable; there were periods of calm followed by periods of strong winds and substantial seas. The "before-and-after" wave rider measurements are promising as model verification data.

Following the C anchor period, the wave rider was redeployed at the C9 site to the north in support of a prototype wave buoy undergoing testing and evaluation.

3.5 Time series measurements and dissolved oxygen, nutrients and optical properties

Since the major scientific goal of the entire experiment is to understand how the water movements affect the fluxes of nutrients and dissolved oxygen within the Basin it makes sense to sample some of the chemical parameters. Acting on the advice of N.N. Burns, we drew samples for a variety of parameters. Water Quality Branch provided sample bottles and performed many of the analyses. The accompanying table lists the data, both physical and bio-chemical which were collected aboard LIMNOS as a total bio-chemical package. BIMS has undertaken to organize a data report in which all the relevant data will be presented in both graphical and tabular form. Some of the dissolved oxygen data and light transmission data are presented in the preliminary cruise reports (Boyce, 1979).

As a general comment, the extreme vertical gradients of dissolved oxygen, for example, make it difficult to construct reliable vertical profiles with so clumsy a sampling device as the Rosette sampler. To meet the sampling requirements of this demanding environment, a continuous profiling method is clearly needed.

CONCLUSIONS

We have viewed the joint U.S./Canadian Lake Erie physics experiment as a one-shot effort, much like the 1972 International Field Year. This has prompted us to take deliberate risks and to attempt a wider variety of experiments in order to capitalize on the presence of the U.S. network. We have sacrificed a comfortable redundancy in order to extend our areas of coverage.

The results, therefore, are uneven. We seem to have had very good luck in the A mooring period, rather less good luck during the B and C periods. In each of the subexperiments, with the exception of one, we have collected useful data which will contribute to an overall progress. So far, so good.

However, in viewing the program as one installment of a continuing sequence, then we must judge our success more in terms of how far it got us toward the avowed goals, and whether additional effort will be fruitful or wasted.

In this context, I think that we can accept the results of the two coastal experiments, one off Nanticoke, and one off Cleveland. Both have produced valuable "engineering" data in return for a modest level of field effort.

My view is that we should press home the attack on the open lake meso- and micro-scales of motion which we began with the mid basin (C-11) experiments. The data which we collected in 1979, while valuable scientifically in its own right, can also be used as a means of refining our experiment.

1) It may be possible to improve the spatial array of current meters, FTP's, etc., from a "scale-of-motion" analysis of the 1979 data.
2) All evidence points to the desirability of obtaining good vertical resolution of currents, temperature, and bio-chemical parameters. We were not successful in 1979 with the G-VAPS and related experiments; we should make every effort to close this gap.
3) More effort is needed to produce useful measurements of the surface pressure gradients. We gambled and lost in 1979 with a ~~maximum~~ minimum outlay.
4) The MCATS system and its associated experiments can be improved by replacing the acoustic current meter with an EM meter of the

same type as the other instruments so as to facilitate intercomparisons, and also by improving/extending the vertical resolution of the three dimensional thermistor array.

5) The curious upwelling phenomenon observed on the north shore of the basin, with the strong evidence that bottom friction plays an important role, is worthy of a closer look. We should extend our current measurements further inshore - an ideal CATS application.

6) The relationship between Eulerian and Lagrangian descriptions of turbulence is a crucial and unresolved issue. More and better drogue experiments are highly desirable.

7) The biochemical portion of the program can be strengthened by more careful attention to underwater light properties and to sampling which respects the natural variability.

There are some strong reasons for continuing the 1979 thrust into 1980. Instead of an experiment spread out over the summer months, I am proposing a single intense effort concentrated in the month of August. A detailed experiment plan is in preparation.

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CAPTIONS TO FIGURES

Figure 1: Sketch map of Nanticoke Array.

Figure 2: Performance diagram for Nanticoke Array.

Figure 3: Sketch map of Cleveland (South shore, C.B.) Array.

Figure 4: Performance diagram for Cleveland Array.

Figure 5: Sketch map of North Shore Array, showing sampling grid for launch cruises and mid basin array centred on station C11.

Figure 6: Performance diagram for North Shore Array.

Figure 7: Temperature sections along provile 3 (seee Fig. 5) lakewards from Port Crewe A) 28 August 1979
B) 25 September 1979

Figure 8: Performance diagram for Mid Basin Array.
a) "A" period mid June to mid July
b) "B" period mid July to mid August
c "C" period mid August to mid October

Figure 9: Sketch of MCATS system.

Parameter	Method	Interval
Wind Speed & Direction	Manual recording ships instruments	1 hour 3 hour
Air temperatures, wet and dry	Manual recording	1 hour 3 hour
Barometric pressure	Manual recording barograph	1 hour 3 hour continuous
Water Currents epi hypo	Recording current meters	10 min. 30 min.
Surface waves	Eyeball estimates manually recorded	3 hour
Water temp. sfc	Bucket thermometers	1 hour 3 hour
Water temp.	Ship's EBT	1 hour 3 hour
Water temp.	Rosette Sampler	6 hour
Radiation Incoming total solar	Shipboard sensors strip chart and integrator	Continous
Subsurface irradiance	Quantum meter	3 hours

Parameter	Method	Interval
Transmission coefficient	Martek 25 cm transmissometer	3 hour
	J. Jerome special	
DO_2	Rosette Sampler Winkler titration	3 hour
Total P SRP	Rosette Sampler Lab analysis	6 hour
POC Chl a corrected	Rosette Sampler Lab analysis	6 hour
NH_3		
NO_3/NO_2		
S_iO_2	Rosette Samples	6 hour
TFP	Lab Analyses	
NTP		
FTACK		
CAV		

TABLE 1

DATA COLLECTED IN SUPPORT OF BIOCHEMICAL PROGRAM

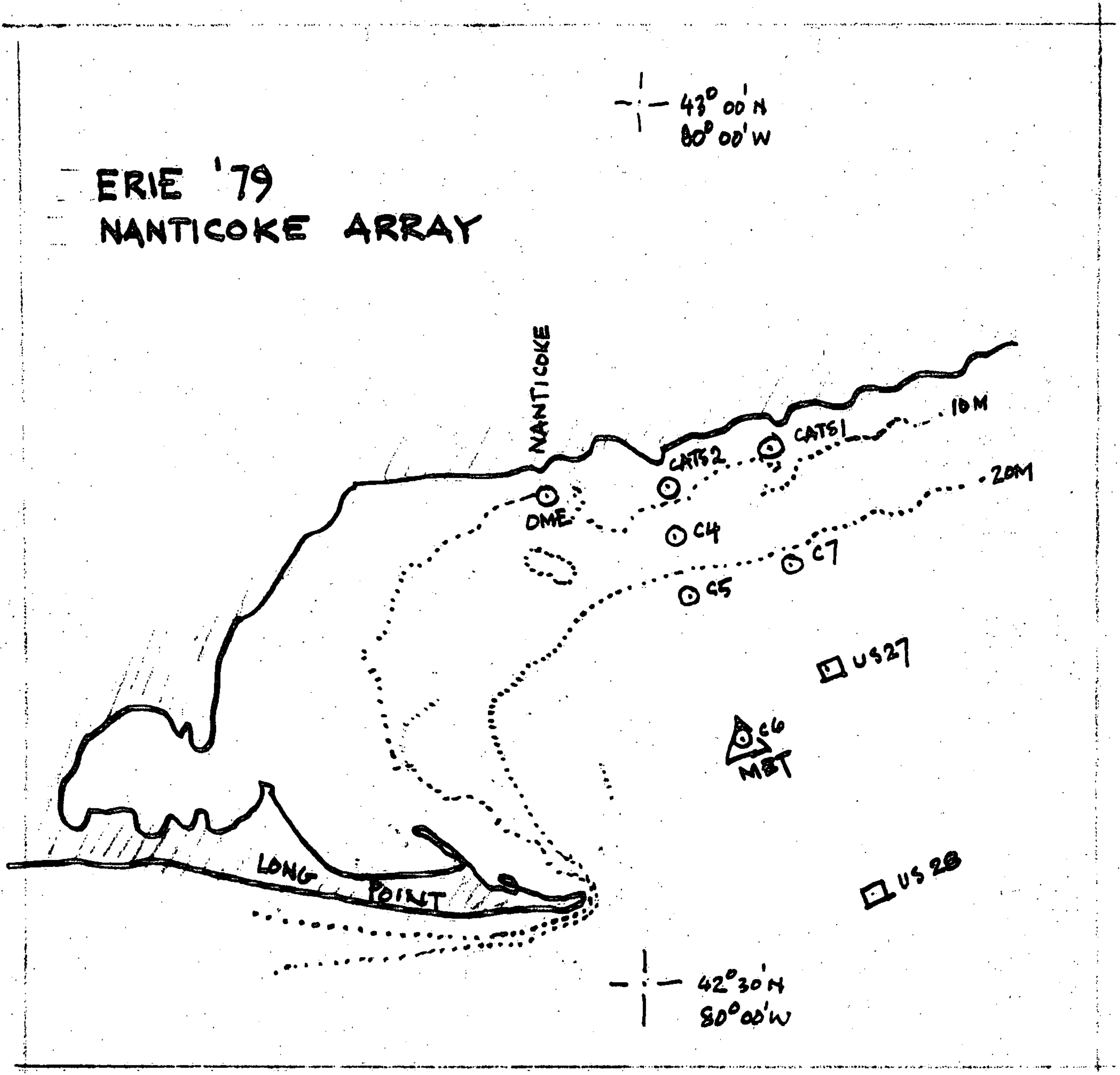

43° 00' N
80° 00' W
ERIE '79
NANTICOKE ARRAY
NANTICOKE
CATS 2
CATS 1
10M
20M
DME
C4
C7
C5
US27
C6
MET
LONG POINT
US28
42° 30' N
80° 00' W

Figure 1

NANTICOKE ARRAY

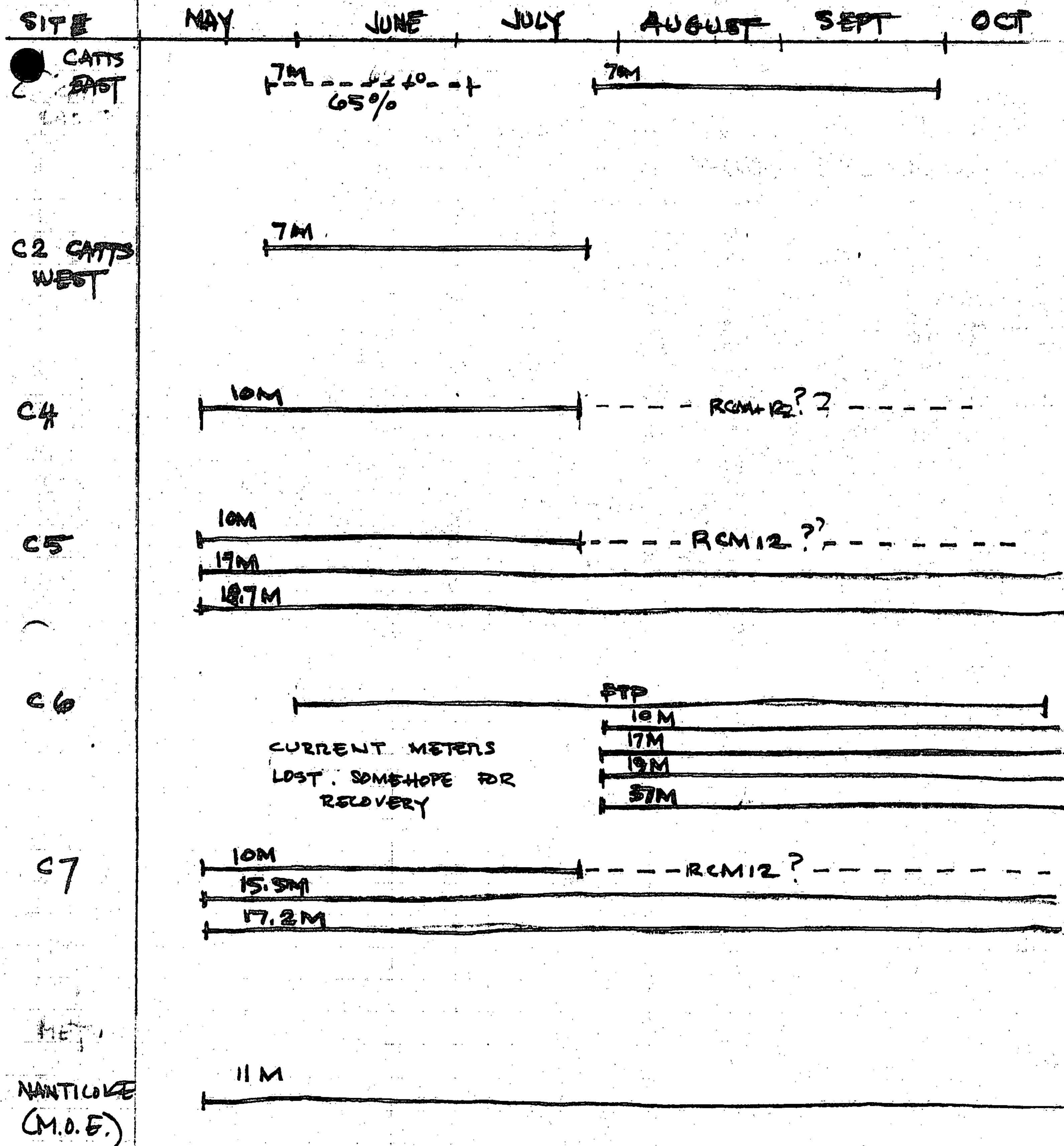


FIGURE 2

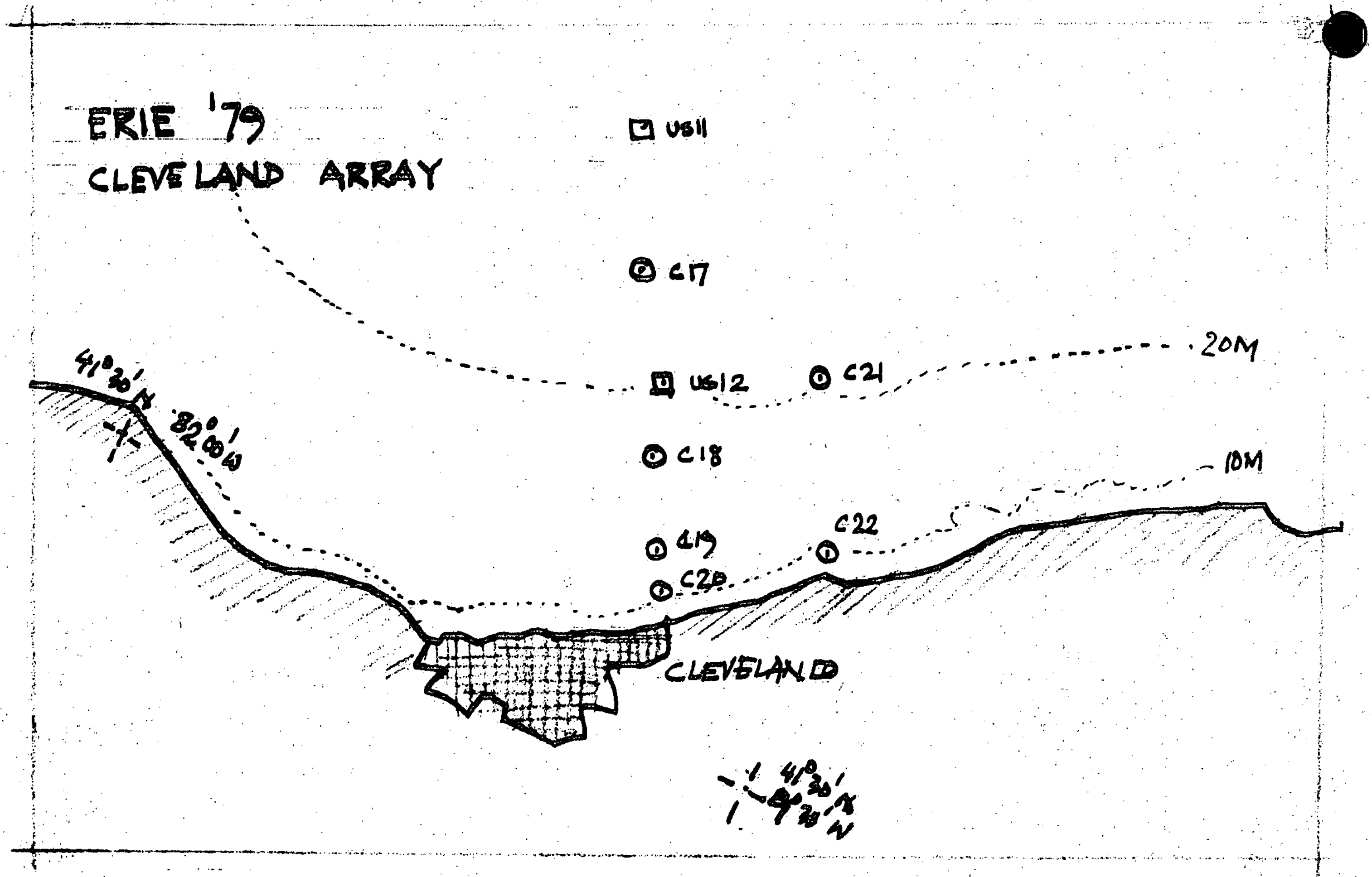

ERIE '79
CLEVELAND ARRAY
US11
C17
US12
C21
20M
41°30'N
82°00'W
C18
10M
C19
C22
C20
CLEVELAND
41°30'N
81°30'W

Figure 3

CLEVELAND ARRAY
SOUTH SHORE CENTRAL BASIN

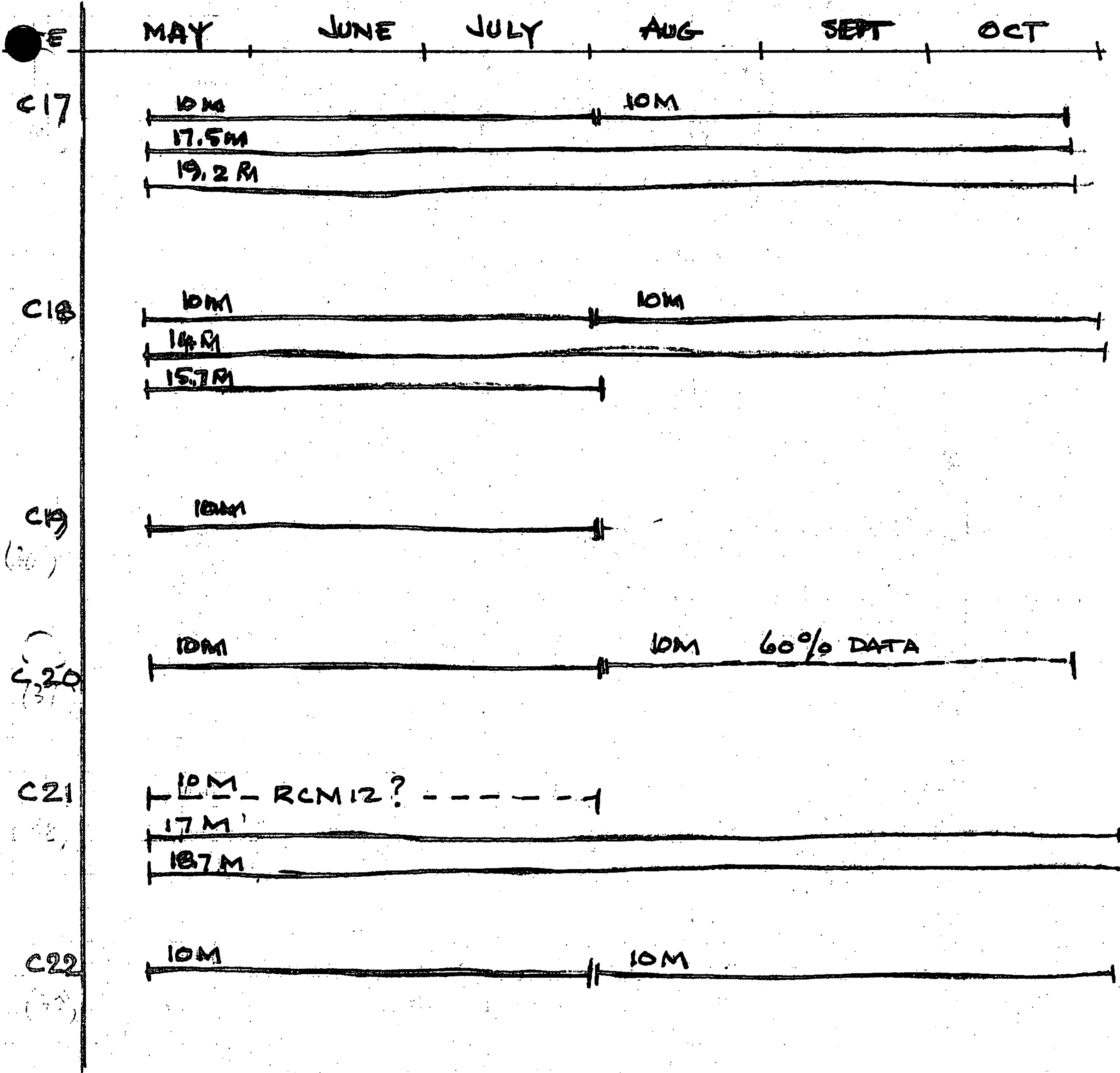
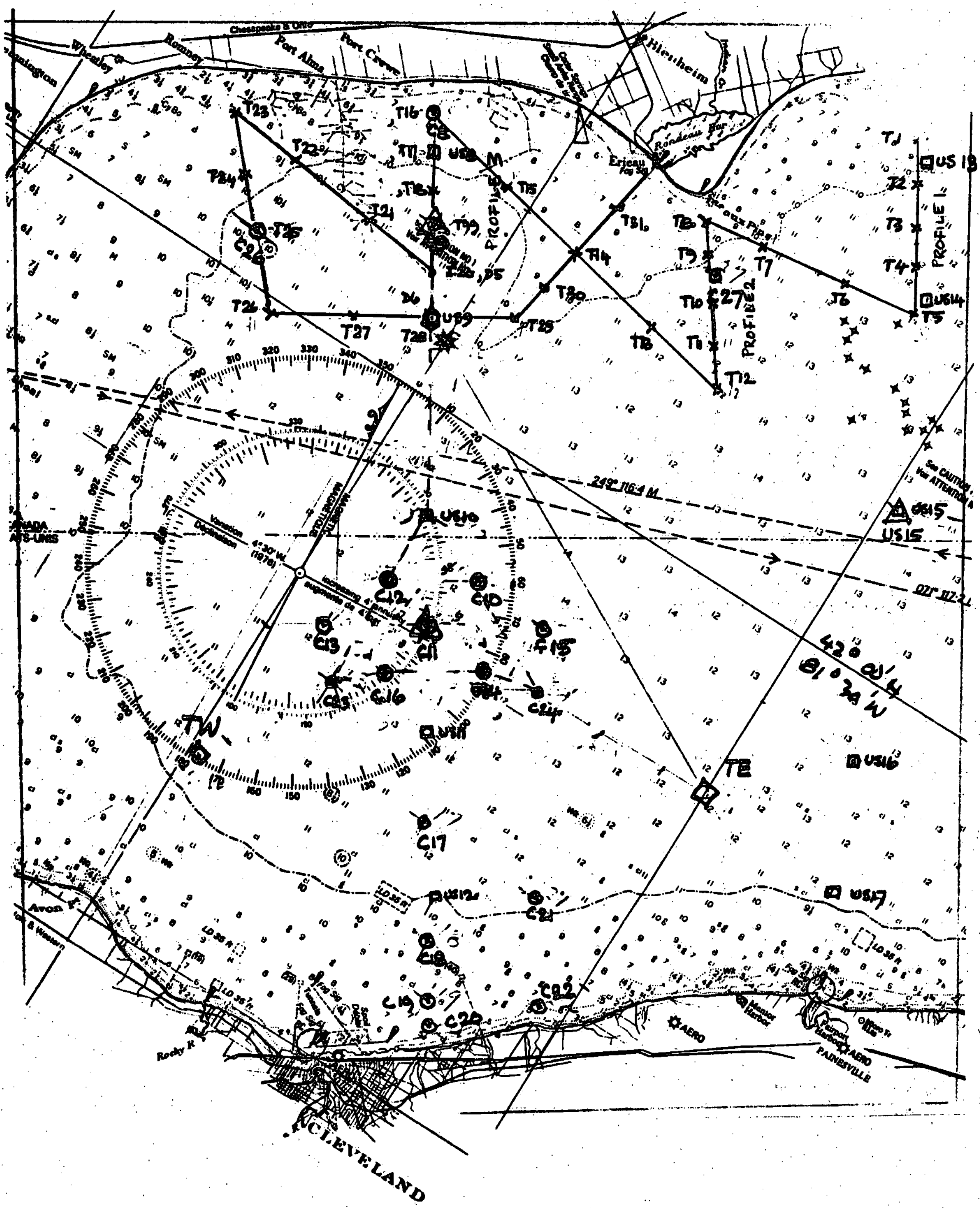


FIGURE 4



ERIE '79   CENTRAL BASIN ARRAY

Figure 5

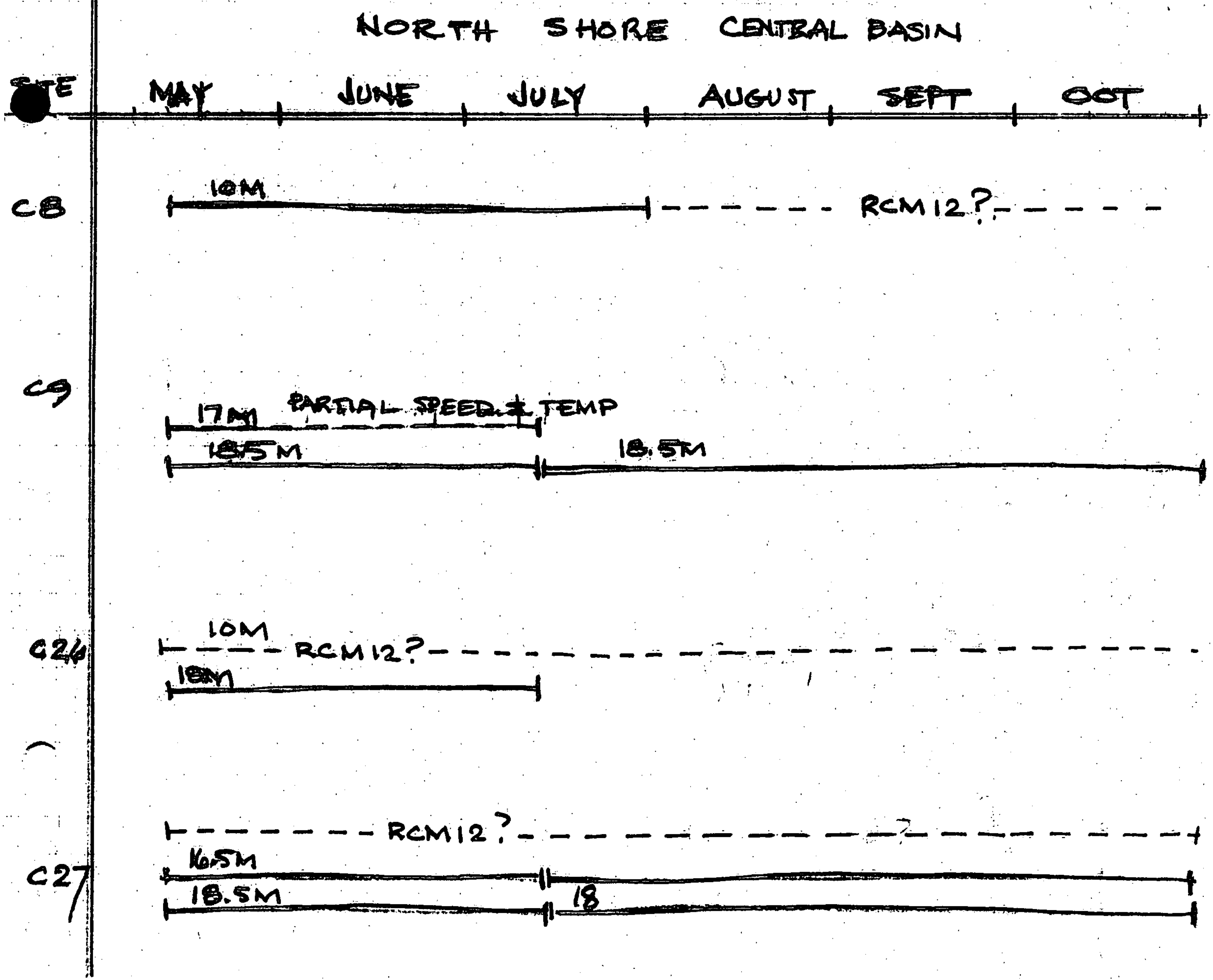

NORTH SHORE CENTRAL BASIN
SITE
MAY
JUNE
JULY
AUGUST
SEPT
OCT
C8
10M
RCM12?
C9
17M
PARTIAL SPEED & TEMP
18.5M
18.5M
C26
10M
RCM12?
18M
C27
RCM12?
16.5M
18.5M
18

FIGURE 6

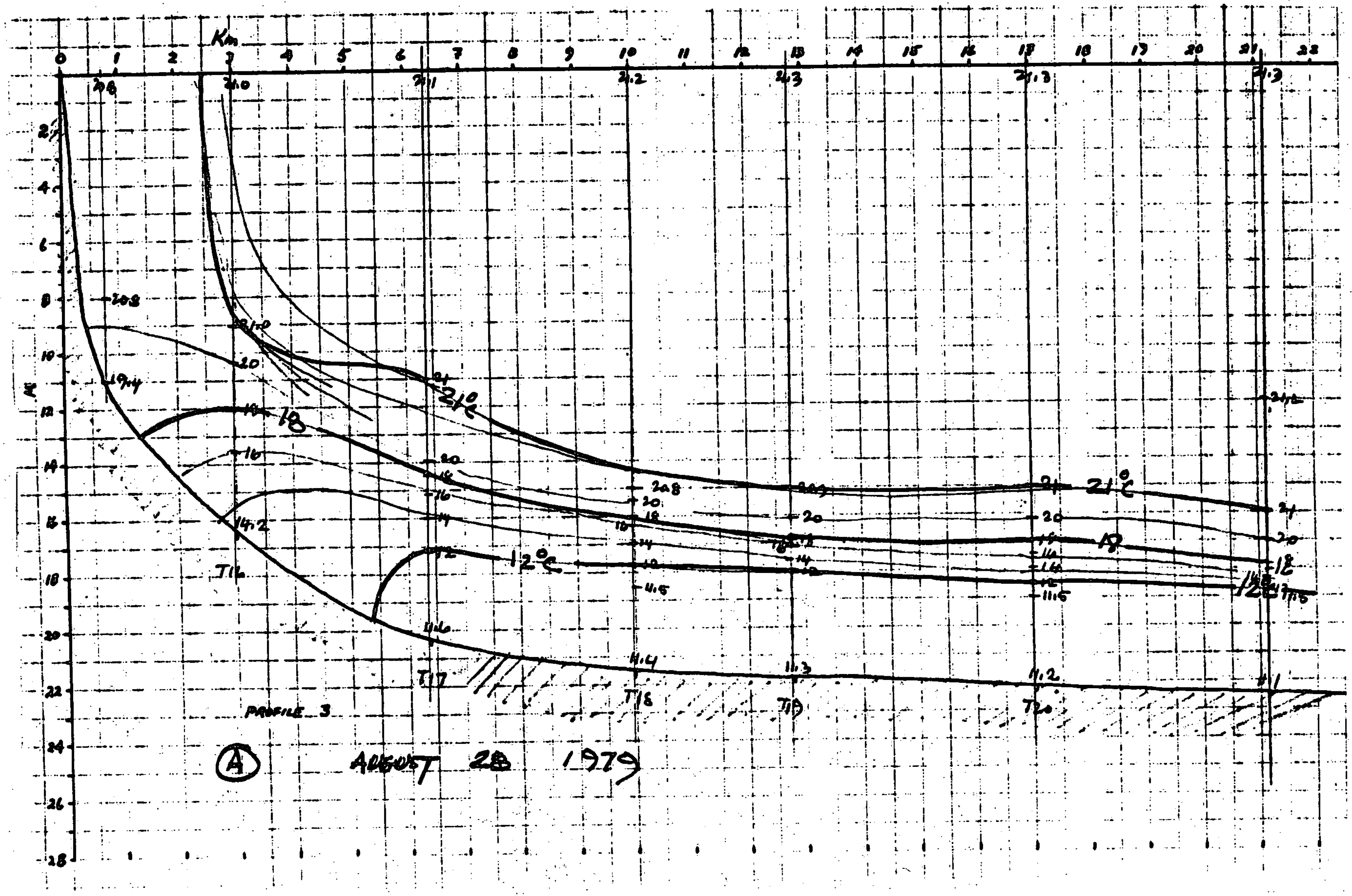

Km
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
M
2
4
6
8
10
12
14
16
18
20
22
24
26
28
20.8
21.0
21.1
21.2
21.3
21.3
21.3
21°C
18
12°C
21°C
18
12°C
T16
T17
T18
T19
T20
PROFILE 3
Ⓐ AUGUST 28 1979

Figure 7 (A)

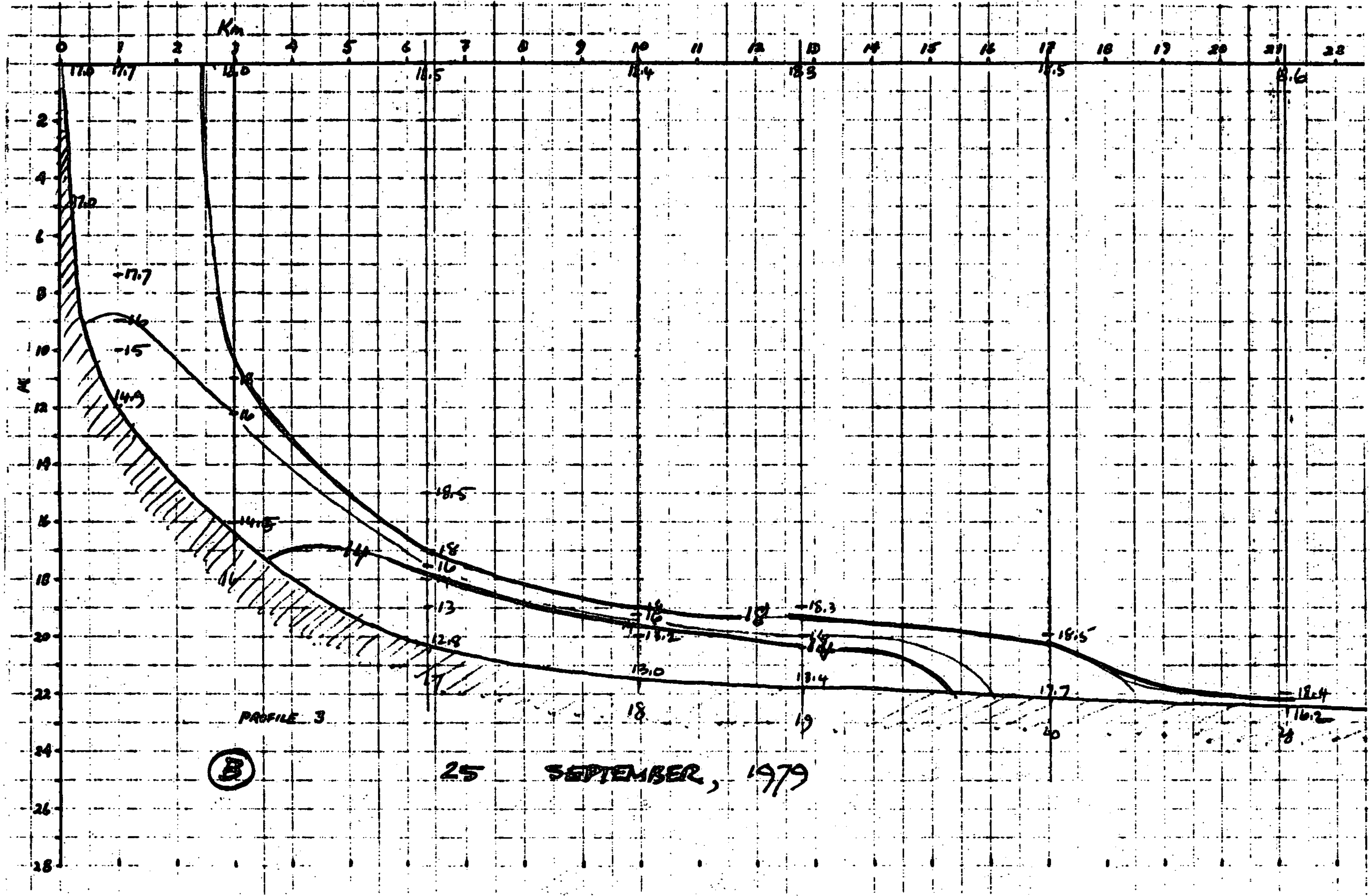
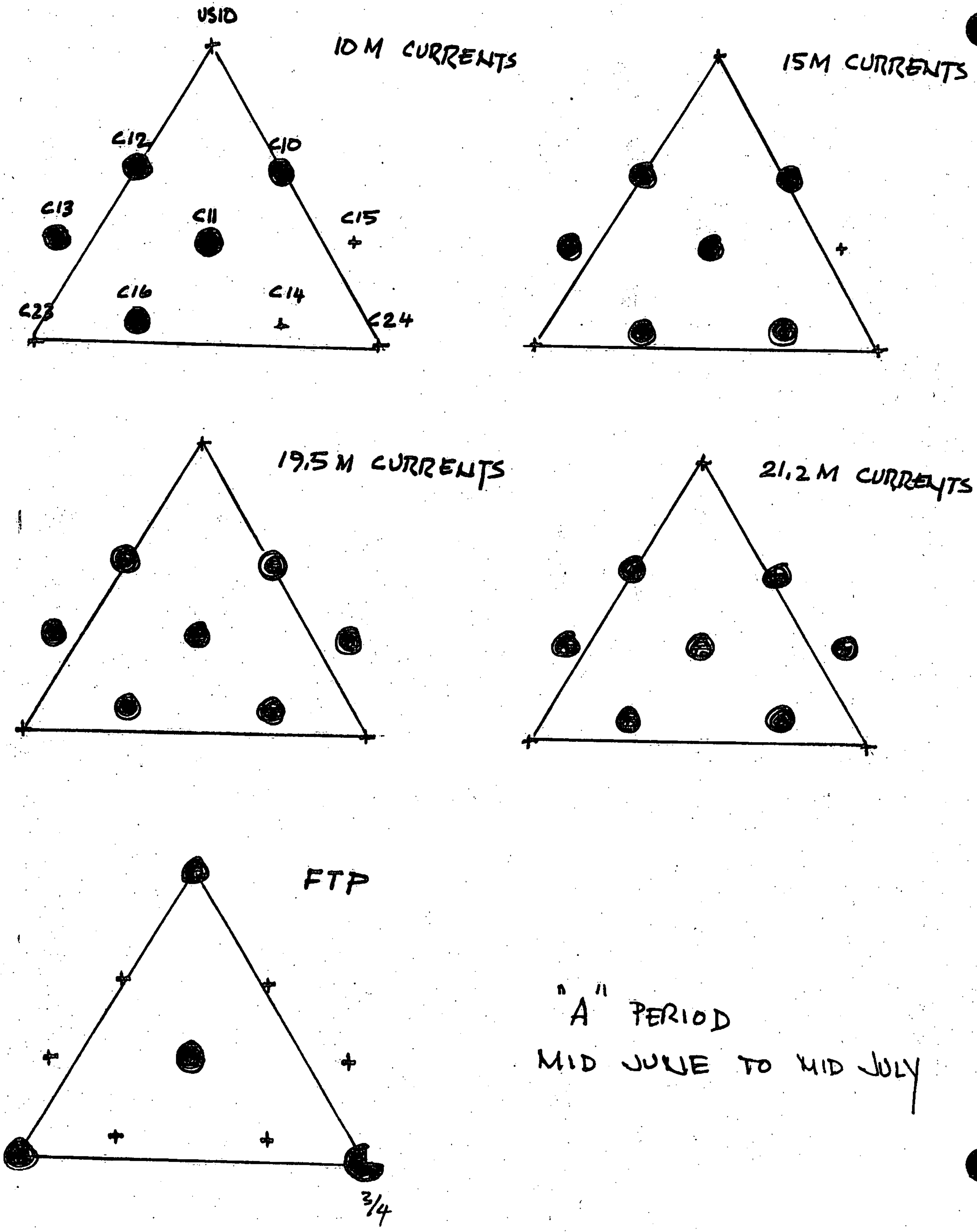

Km
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
M
2
4
6
8
10
12
14
16
18
20
22
24
26
28
17.0
17.7
18.0
18.5
18.4
18.3
18.5
18.6
17.7
16
15
14.9
16
18
14.5
14
18.5
18
16
13
12.8
16
18
13.2
13.0
13.4
18.3
18.5
17.7
18.4
16.2
PROFILE 3
B
25 SEPTEMBER, 1979

Figure 7 (B)


10 M CURRENTS

15M CURRENTS

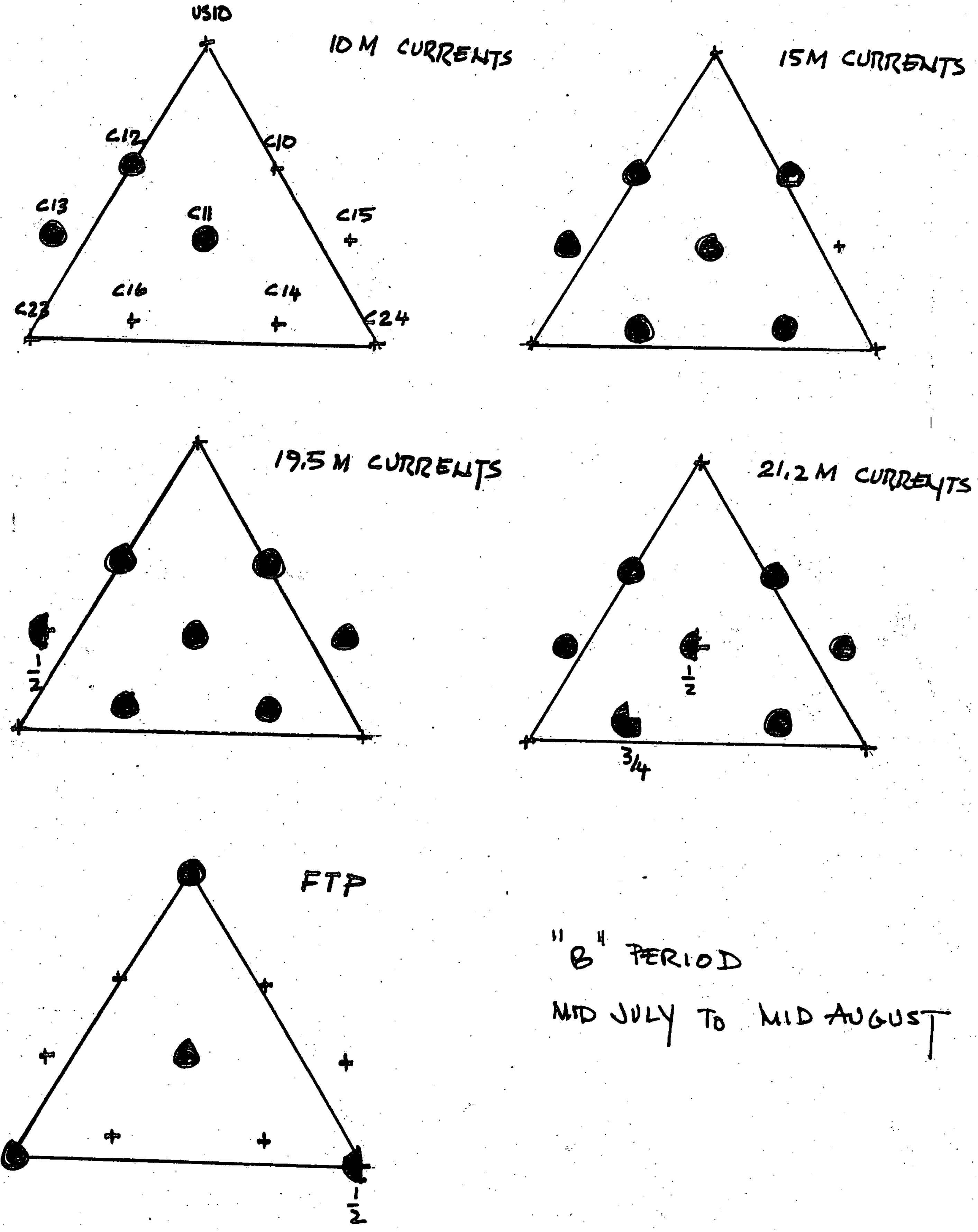
19.5 M CURRENTS

21.2 M CURRENTS

FTP

"A" PERIOD
MID JUNE TO MID JULY

Figure 8 (A)



10 M CURRENTS

15M CURRENTS

19.5 M CURRENTS

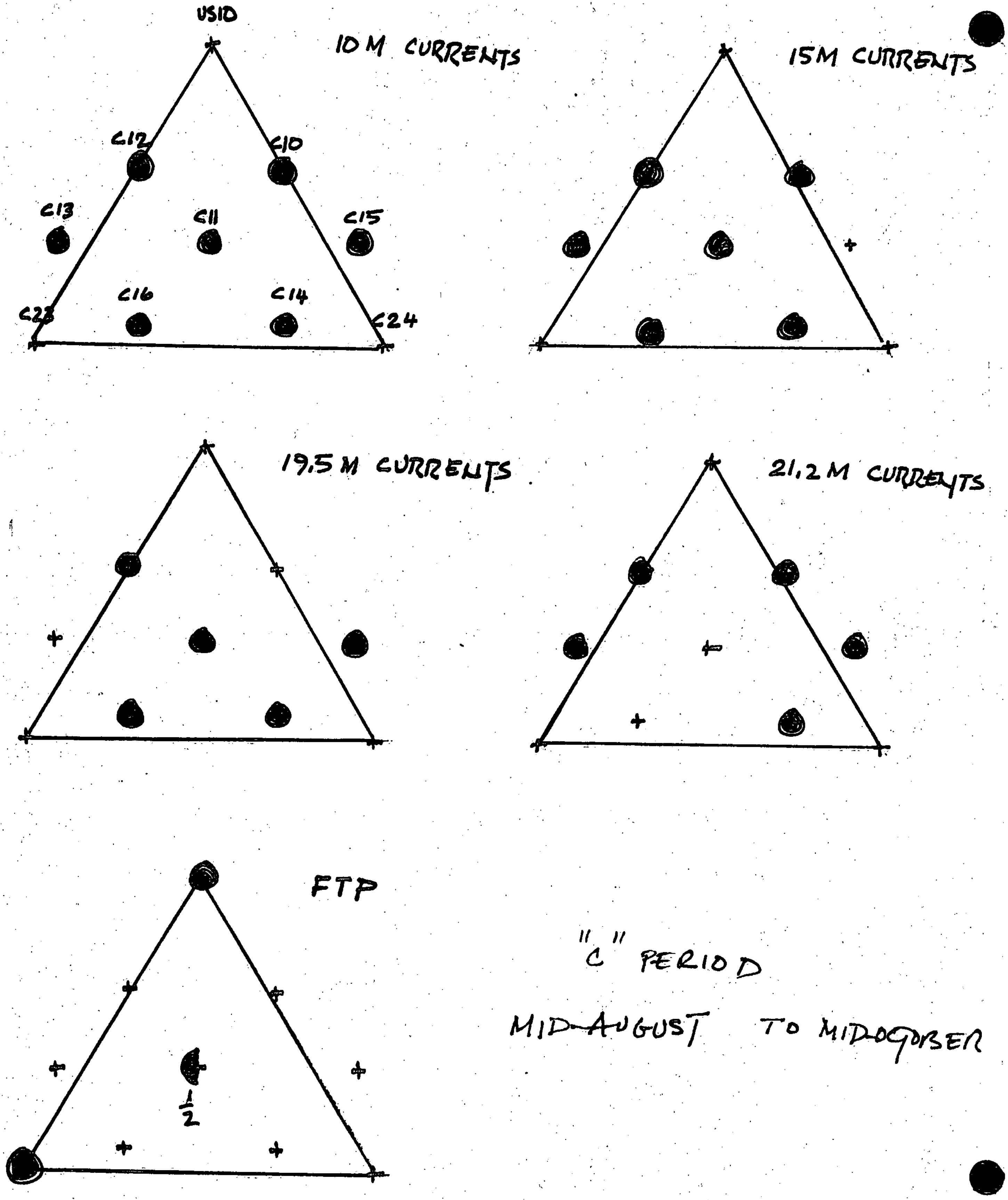
21.2 M CURRENTS

FTP

"B" PERIOD

MID JULY TO MID AUGUST

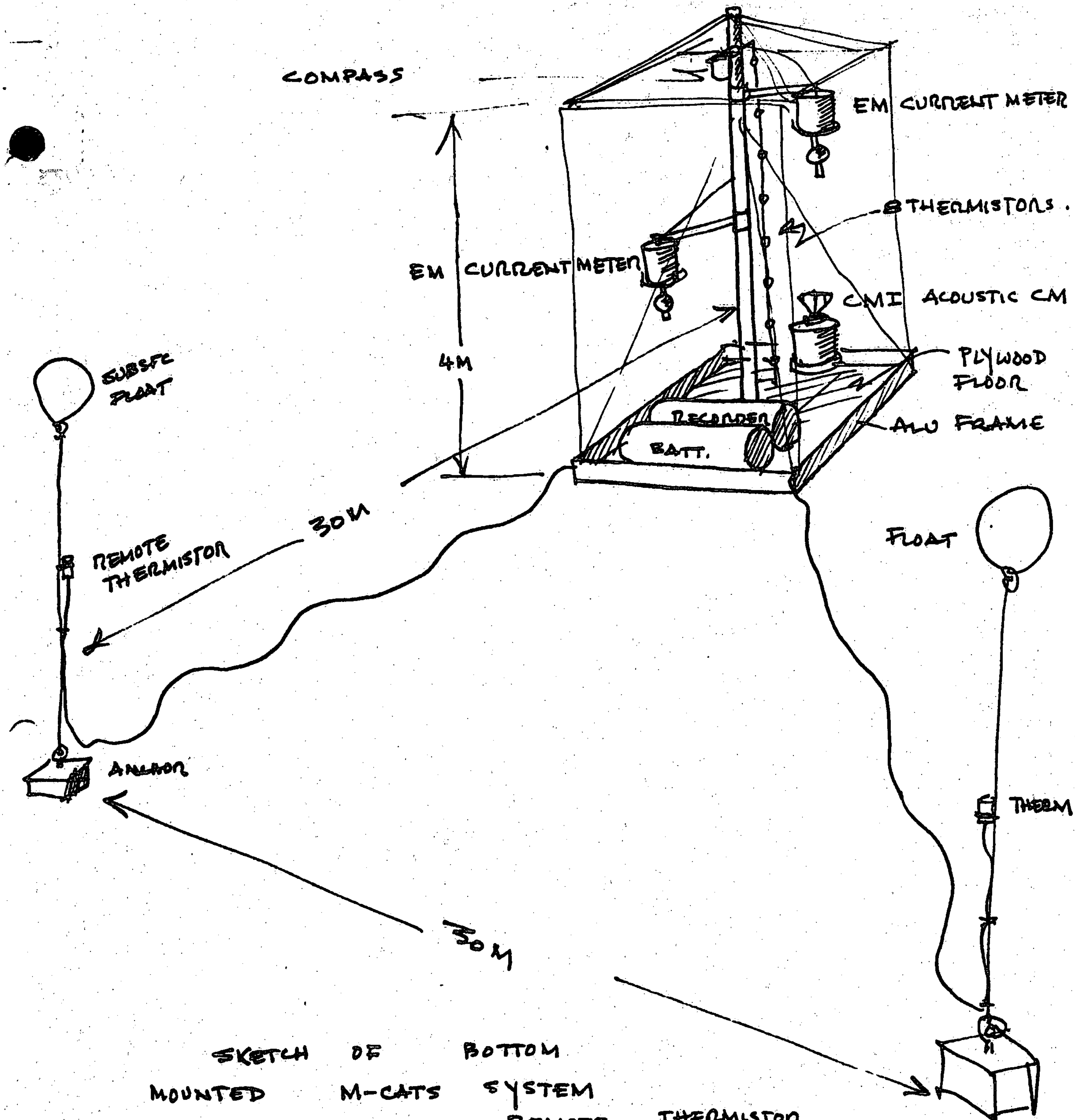
Figure 8(B)



"C" PERIOD

MID-AUGUST TO MIDOCTOBER

Figure 8(c)



SKETCH OF BOTTOM MOUNTED M-CATS SYSTEM SHOWING REMOTE THERMISTOR ARRAY.

FIGURE 9