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STUDIES
ON
THERMOCLINE FORMATION
AND VARIATION

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To Charles C. Hill and Earl N. Bryant, whose ingenuity made the bathythermograph's construction possible.

Contents

Introduction

The science of limnology has reached that point in its growth where the observation and recording of additional data, without attempting a correlation of the involved factors, would be of questionable value. For instance, there are virtually no available data in the English language on the correlation between meterological phenomena and thermocline variation. This study was undertaken to determine some of the fundamental factors in thermocline formation and the variation due to the effect of various meterological conditions. The securing of data was facilitated by the employment of modified oceanographic instruments and techniques to the field of limnology with considerable success.

Acknowledgements

The problem has been carried out under the general direction of Dr. Frank E. Eggleton, to whom I am gratefully indebted for numerous suggestions and constructive criticisms. Thanks are due Dr. F.F. Hooper and Mr. Allan Tucker for assistance in field work and making certain temperature data available.

Many individuals have assisted in various capacities

during the construction and development of the bathythermograph, and such service is gratefully acknowledged. Messers Charles C. Hill and Earl N. Bryant's many ingenius contributions during the construction of the instrument, largely made this study possible. The W.M. Chace Company of Detroit provided certain test components of the bathythermograph. Finally, my wife has always been a constant source of encouragement from the inception of the bathythermograph, and has provided material assistance in both field and laboratory work.

Region under Discussion

Studies on the thermocline were limited to intensive investigation on Douglas Lake and periodic observation on Lancaster Lake. The location of these waters in the Northern part of the Lower Peninsula of Michigan is shown by Map 1. Various aspects of the limnology of these lakes may found in papers by Eggleton (1931,1935), Welch (1928, 1945), and Welch and Eggleton (1932, 1935)

Lancaster Lake's protected position and regularly shaped basin provided a source of data that perhaps may be compared to a control, in that effects of certain features as the wind, irregularity of the basin, etc. were largely eliminated. South Fishtail Bay of Douglas Lake presented a varity of possible conditions with varying meterological conditions. Intensive observations were carried out on this body of water, including over 500 surface to bottom temperature series with a bathythermograph.

Thermocline Variation

Previous Studies

Early work showing correlation between meteorological conditions and thermocline variation are few. Most of these mention such items merely in addition to other data. One of the earliest writers on this subject was Wedderburn (1907a, 1907b, 1908) who attempted to correlate the temperature variation in Loch Ness with seiche action. Later Birge (----) contested his data and offered another explanation. Birge continued to contribute to the field of physical limnology. Two of his works, though not actually on thermocline variation, were basic to all considerations of water movement (Birge 1910, 1916). That he understood the need for variational studies was obvious, as may be noted from the following statement in the discussion of the (Birge 1916: 345) work of the wind in mixing. "Our knowledge of the process is very small...certainly [it] varies enormously from stratum to stratum of depth and from place to place of area, and from hour to hour". In Germany at about the same time Schmidt (1915) formulated his theories on the relation of the work of mixing to wind and included some data on the effect of thermocline position.

To my knowledge, the period 1917-1926 yielded very little data on thermocline variation. In Whiple's famous "The Microscopy of Drinking Water" the correlation between wind and the deflection of isotherms was noted. A considerable general discussion of the actual variation and seasonal history of the thermocline may be found in Welch (1935). The most recent quantitative work on the correlation of the thermocline position to wind is that of Tucker (M.S.), who by means of vector analysis, plotted the strength of the wind along the long axis of the lake to the position of the thermocline. By this means he correlated the depression of the thermocline with increased wind force.

Thus from a survey of literature, it can be readily seen that very little qualitative or quantitative data exist on the relation of meteorlogical conditions to the variation and position of the thermocline. With these facts in mind the problem was undertaken to determine the possible relationships between thermocline and the following meteorlogical conditions.

A. Sun - (heating)
B. Rain - (cooling)
C. Wind - (mixing)

Methods

From the onset of the problem it was evident that standard limnological techniques were inadequate for this study, and as a subsequent result I had to turn to the field of oceanography for suitable methods.

For obtaining temperature series from surface to the bottom the oceanic bathythermograph was modified and employed to advantage. The limits of accuracy of the instrument were one meter depth and one degree centigrade. For detailed study of surface waters a Negretti and Zambra reversing thermometer was employed. The study of currents was facilitated by a rather crude drift-current meter and various dyes. Ropes and cables suitably graduated and standardized at each use were used throughout. When desirous, chemical analysis, as prescribed in Standard Methods of Water Analysis, were run to corroborate other data.

Descriptions of Instruments

Fresh Water Bathythermograph

The oceanic bathythermograph is a relatively new instrument. Essentially, it records vertical distribution of temperature against depth. First mention of it was made by Rossby and Montgomery (1935) who referred to the test model as an "oceanograph". No description of the instrument was given at this time, and it was not until 1938 that a detailed description of the instrument was published by Spilhaus (1938). At that time he reported on certain studies made in the Atlantic Ocean which attested to the potentialities of the instrument. The same author later published (Spilhaus 1940) another description of a second instrument showing marked improvement over the earlier model. The bathythermograph has been so successful that it is now employed by a number of oceanographic laboratories. Adams (1942) reports it as standard equipment of the U.S. Coast and Geodetic Survey. Sverdup et. al. (1942) points out the instrument's great value in oceanographic research. I have been told* that it is in extensive use on the west coast, and is also employed by the Australian government. The oceanographic instrument may be purchased from Wallace and Tiernan Products at a cost of about $395.00.

The bathythermograph was first employed (unmodified) in fresh water by Church during his temperature cycle studies of Lake Michigan (Church 1942). The present modification of the bathythermograph is shown by Plates I and II.

The essentials of the instrument are a compressible bellows (B) which carries a smoked glass slide in a carrier (C). The bellows contain a tungsten steel spring, and both of these contract with pressure.(which is prop-

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* Personal communication with Dr. Carl L. Hubbs

ortional to depth) thus moving the slide at right angles to the motion of the tracer arm (P) of the bimetal coil (T) (whose position depends upon temperature). The record on the slide is very similar to a depth-temperature curve. Actual values may be determined by projecting the slide upon a calibration chart by means of a properly adjusted 2" x 2" projector.

Figure 1 is a reproduction of a slide from the bathythermograph. Figure 2 shows this same record projected upon the calibration chart. The limitation of the instrument is 1° C. and 1 m. depth. The cost of construction minus labor was just over $100.00.

The outstanding advantages of the instrument are as follows:

1. Rapid operation
2. Continuous temperature records from surface to bottom
3. Simplicity of operation
4. Low cost

Drift-Current Meter

This instrument was used to determine the weak underwater currents that affected the thermocline. Plate III shows its construction. It consists of a glass container with fins, which houses batteries, and a timing mechanism. A cable leads to the surface light. The instrument is

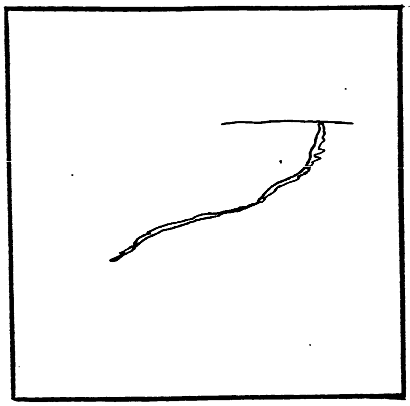


Figure 1. Bathythermograph trace on smoked glass slide.

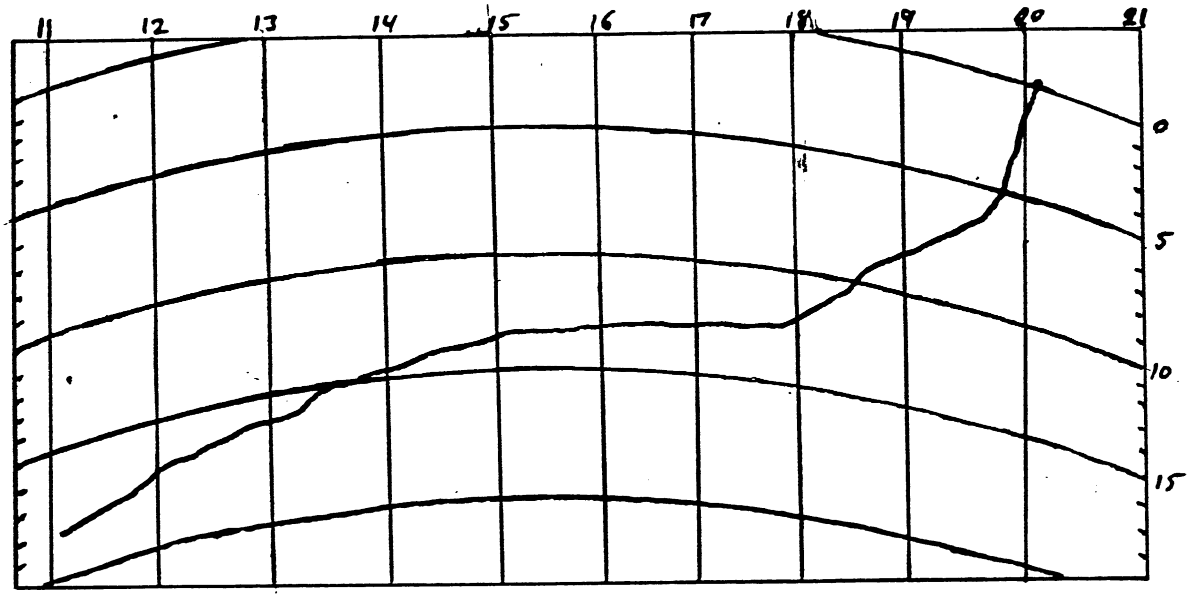


Figure 2. A projection of the slide illustrated in figure 1 upon a calibration chart for obtaining temperatures at given depths. Bathythermograph data are preserved and filed in this manner.

adjusted to float at the required depth with weights and its movement is traced by a blinking light.

Dyes

The following dyes were employed in tracing water movements.

Aniline violet for use over a light colored (sand, etc.) bottom

"Life jacket dye" for use in deep or dark colored water

The latter dye is very florescent and dilutes with a remarkably large volume without losing effectiveness.

Effects of Meteorlogical Conditions

Heating

The following effects of the suns heating on the formation of the thermocline were noted.

A. Intense heating in a period of calm usually resulted in less demarkation of the upper limit of the thermocline

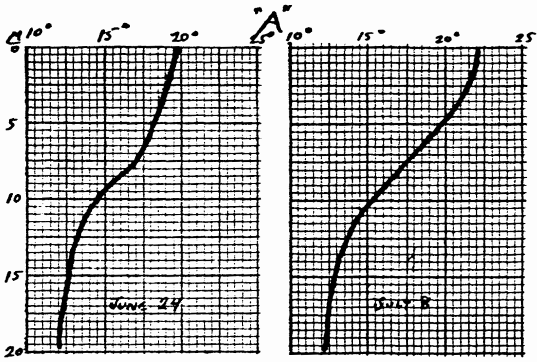
B. Intense heating in a period of strong wind usually resulted in lowering the upper limit of the thermocline and causing a stronger demarkation of the upper surface of the thermocline.

C. Intense heating during a period of intermittent low wind usually resulted in the formation of a secondary thermocline.

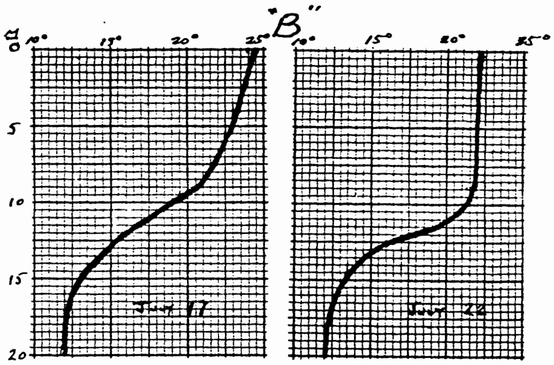
D. The effect of heating on thermocline variation is dependent upon its duration and wind action.

Selected Data for the Above Cases

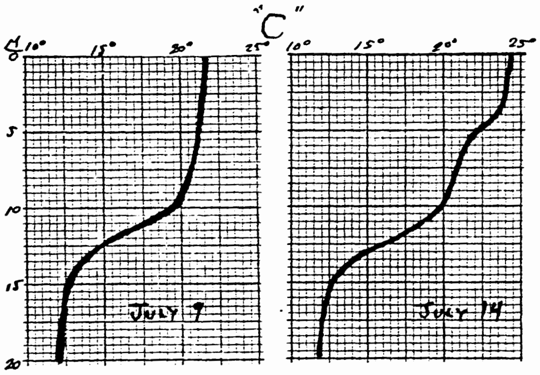
"A"



"B"



"C"



Cooling

The following effects of cooling by rain* on the variation of the thermocline were noted.

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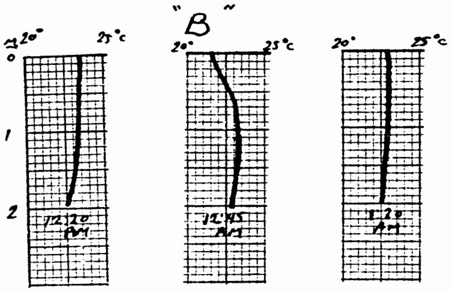
* Cooling due to wind will be discussed with wind mixing as the latter is the more effective

A. Results from data obtained during the three heaviest rain storms this summer yielded no conclusive data on thermocline variation.

B. Cold rain can lower the temperature of the first 1/3 meter of water considerably in a short period of time (1/2 hour) but eddy and density currents soon form and cause the upper meter stratum to become virtually homothermous.

C. The effect of rain on thermocline variation is apparently nil.

Selected Data for the Above Cases



June 30

Mixing

The following effects of mixing by wind on the variation of the thermocline were noted.

A. Slight mixing with warm surface waters usually resulted in less demarkation of the upper limit of the thermocline.

B. Slight mixing with cool surface waters usually resulted in increasing the homothermous condition of the epilimnion and lessening dedemarkation of the upper limit of the thermocline.

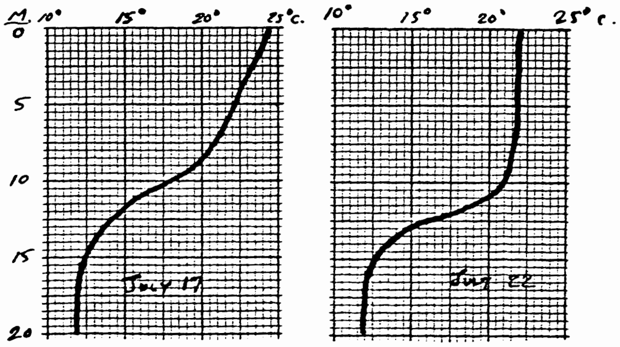
C. Much mixing with warm surface waters resulted in the strongest demarkation of the upper limit of the thermocline and in lowering the same point in depth.

D. Much mixing with cool surface waters, followed by a period of little mixing, usually resulted in raising the upper surface of the thermocline and less demarkation of that point from the epilimnion.

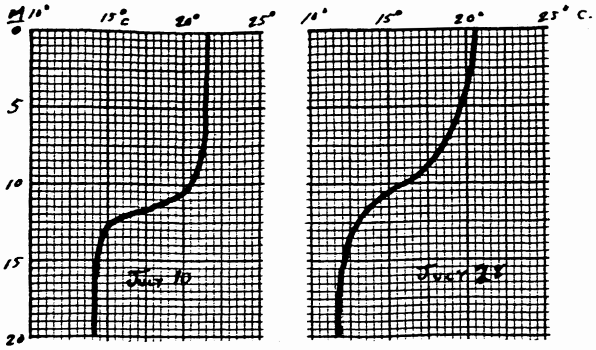
E. Mixing due to wind is the most important factor in thermocline variation.

Selected Data for the Above Cases.

"C"



"D"



Miscellaneous Effects

Diurnal Cooling

Results of a series of bathythermograph readings made every half hour for 24 hours indicates a cycle of warming and cooling of the epilimnion. The effect is more marked at the surface and is virtually undiscernible at the surface of the thermocline.

Seiches

Temperature seiches were found existant on three separate dates; July 12, July 15, and July 30. Strong wind action was always associated with this phenomenon. On July 12 the temperature seiche was found to be "rocking" about a point, rather than in a single plane. A possible explanation for this action is the counter clockwise current found to be present in South Fishtail Bay.

Currents

The counter-clockwise current in South Fishtail Bay was checked by the drift-current meter and by various dyes. Plate IV shows how water movement of various forces affected the dyes. Such current motion can be easily distinguished from wave washed dye concentrations. Other evidences for the counter clockwise current were the motion of plankton and wave front intersection in spite of wind and waves in the opposite direction with a force sufficient to build sand spits. See Figures 3-5. The total effect of horizontal currents on thermocline variation were undetermined.

Shoals

Though considerable data is available on warming of surface water over shoal areas, in no case was I able to correlate this warming effect (magnitude of 0.5° C. average) to thermocline variation.

Conclusions

Due to the limited period of investigation, no quantitative correlation can be formulated at this time.

Figure 3. Sand spit caused by N.E. prevailing wind.

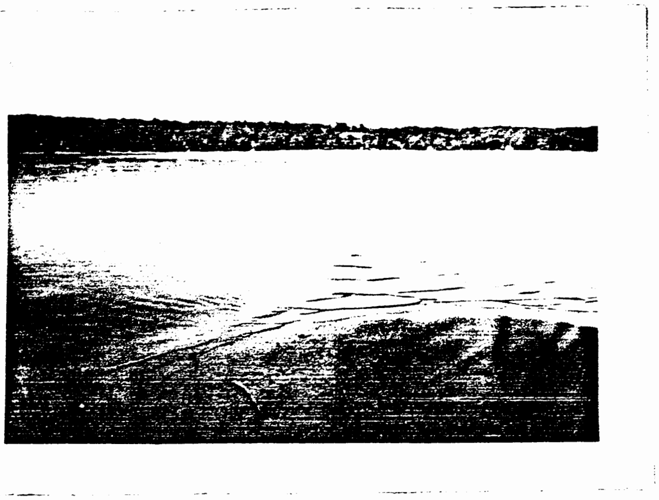


Figure 4. Intersecting wave fronts of current and prevailing waves.

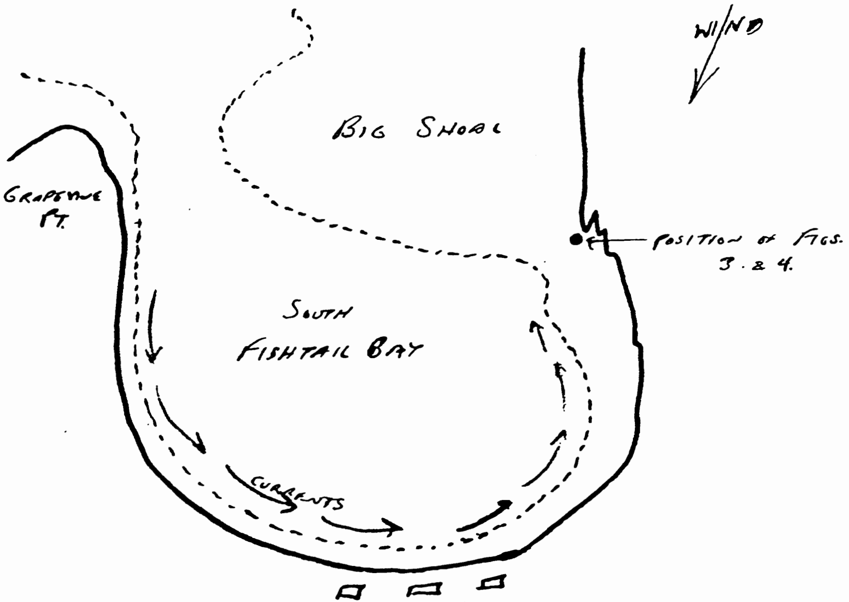


Figure 5. Path of counter clockwise current in Douglas Lake.

Qualitatively however, it can be seen that there is a positive correlation between heating (sun) and mixing (wind) to thermocline variation and formation. The present work indicates no correlation of cooling by rain to thermocline variation. The effects of currents on the thermocline are no doubt considerable but data are lacking.

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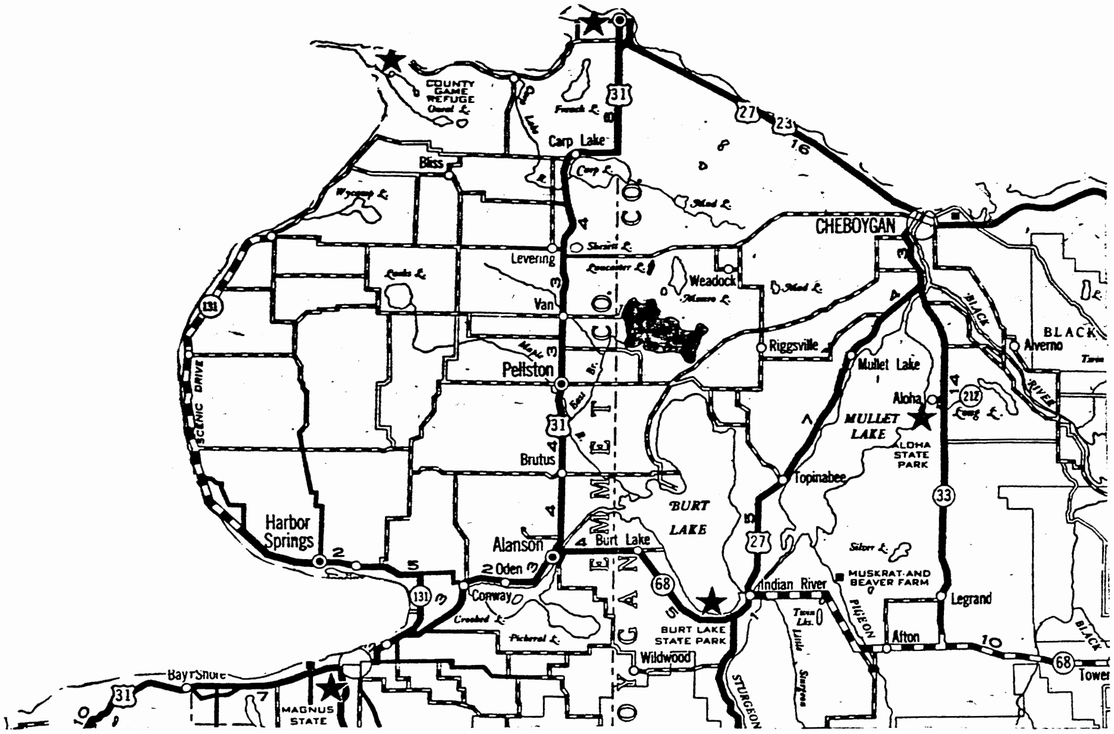

Map 1

Northern half of Lower Peninsula of Michigan showing location of lakes studied.

Explanation of Plate I

BB	Upper bellows bolt
C	Slide carrier
LC	Lowering cable
N	Lock nut
O	Opening to replace slide
OT	Outer tube and cylinder
P	Pointer on tracer arm
R	Lowering ring
SC	Safety chain
SS	Smoked glass slide
TB	Bimetal lock bolt

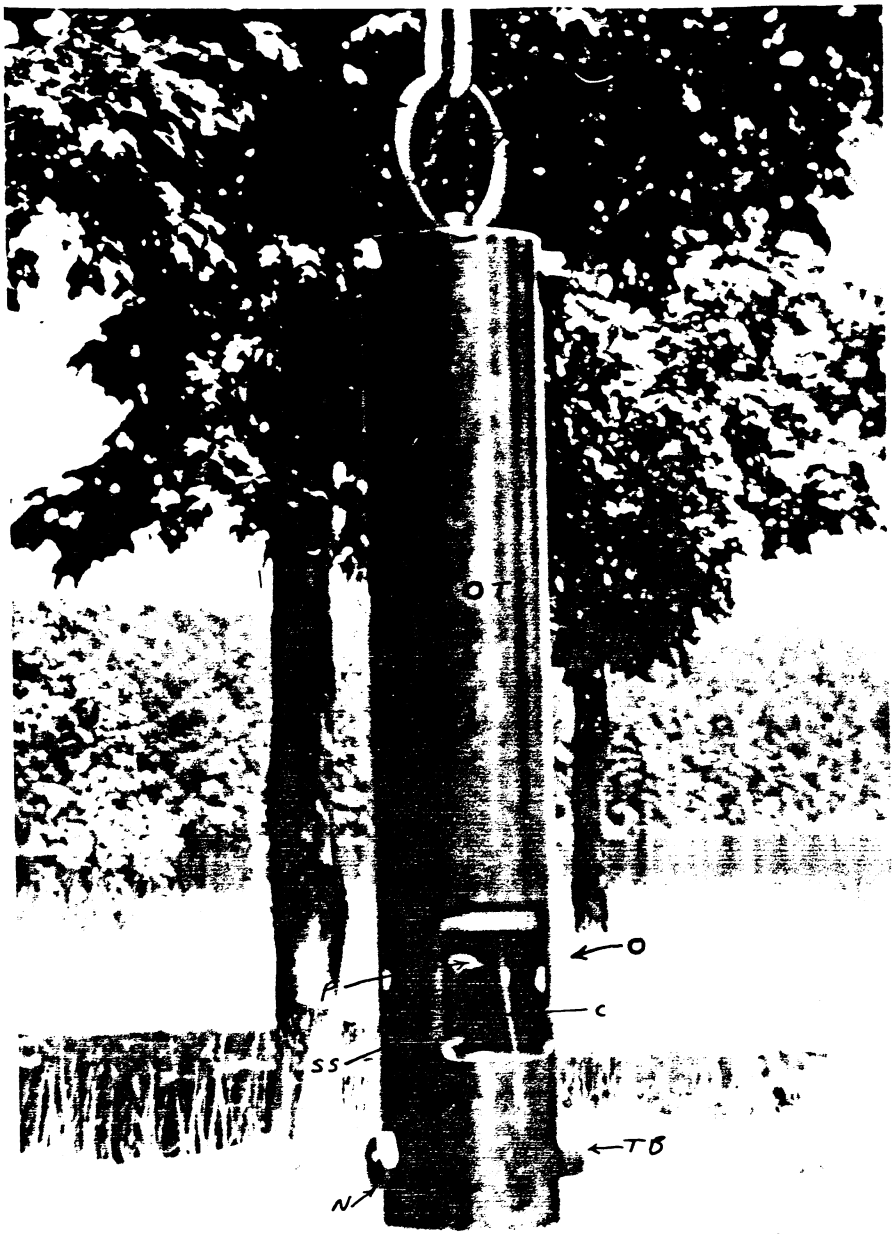

Plate I

Bathythermograph

Explanation of Plate II

BB	Upper bellows bolt
C	Slide carrier
GP	Piston
L	Loops to lock chain to upper bolt
N	Lock nut
O	Opening to replace slide
OT	Outer tube and cylinder
P	Pointer tracer arm
R	Lowering ring
S	Upper assembly lock bolt
SC	Safety chain
T	Bimetal coil
TB	Bimetal lock bolt

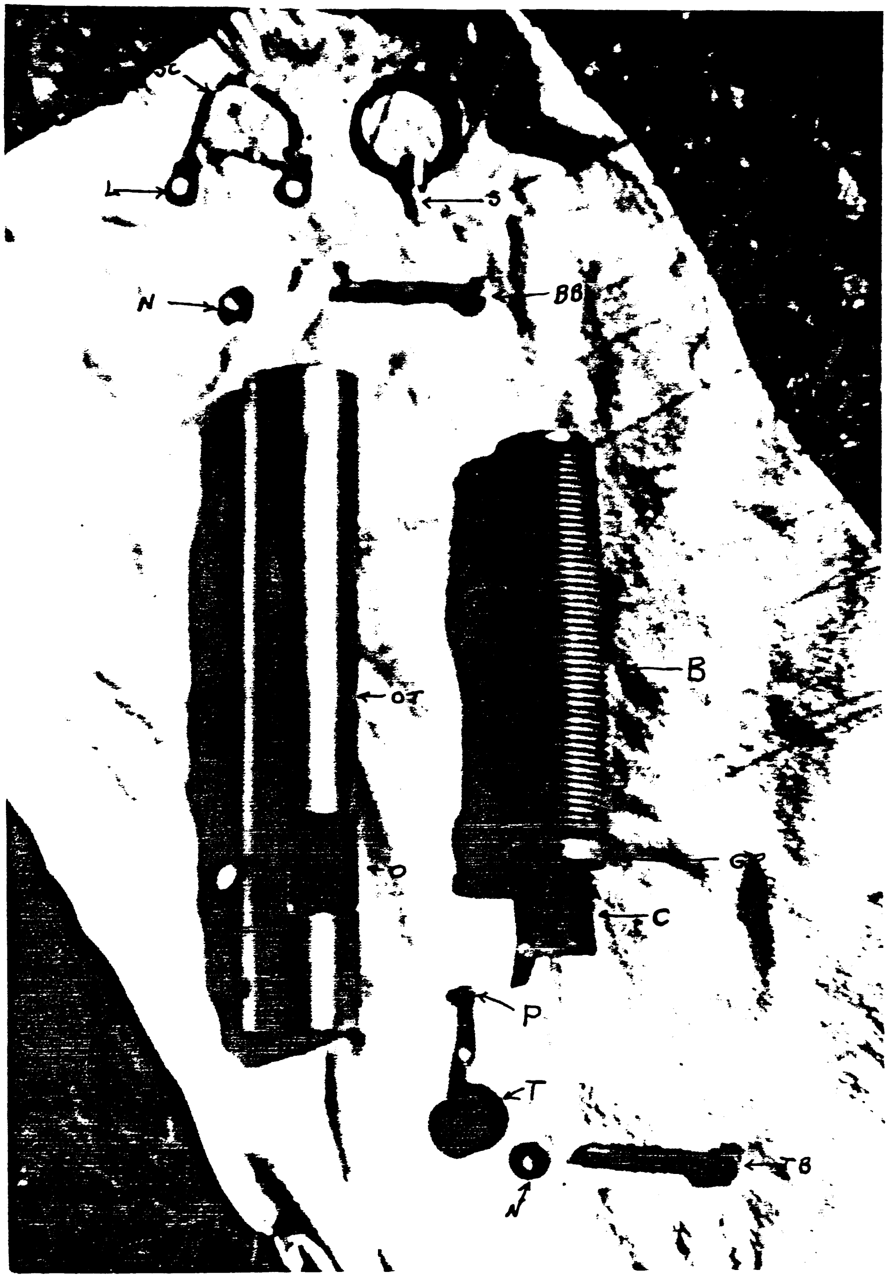

Plate II

Bathythermograph disassembled

Explanation of Plate III

B	Bands for securing fins
C	Container for batteries and mechanism
CF	Lateral fins
CW	Connecting wires
F	Surface float
L	Blinker light
R	Depth rope
TF	Tail fin
TFS	Tail fin supports
W	Weight

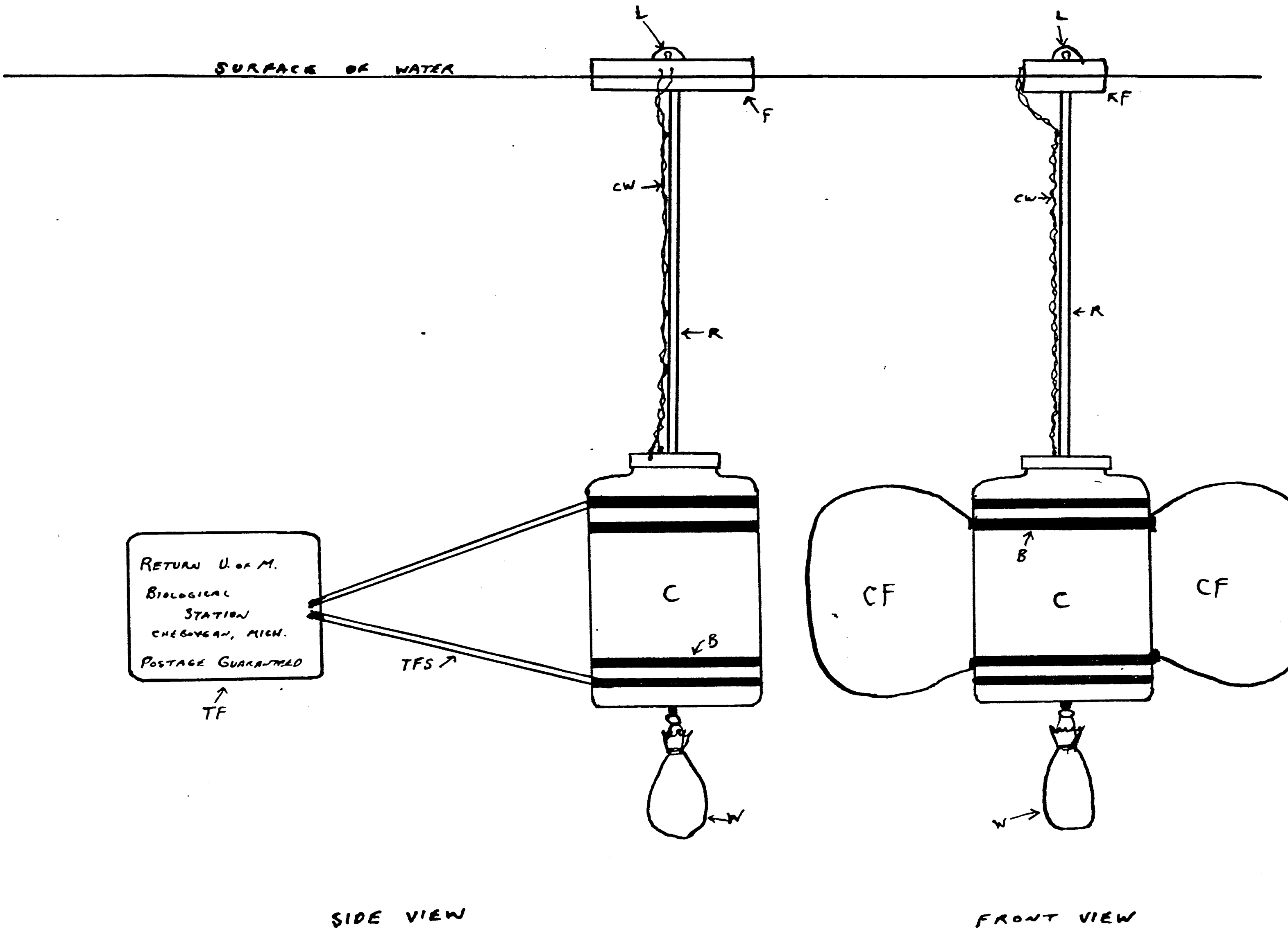

Plate III

Drift-Current Meter

Explanation of Plate IV

Arrows indicate wind direction (toward nearest shore in all cases). Inset map shows stations and route of current in South Fishtail Bay. All sketches were made after twenty minutes of the placement of dye.

A. No noticeable current

B. Slight current, "fingers" of dye move to North (left)

C. Considerable current, "fingers" of dye long and slender

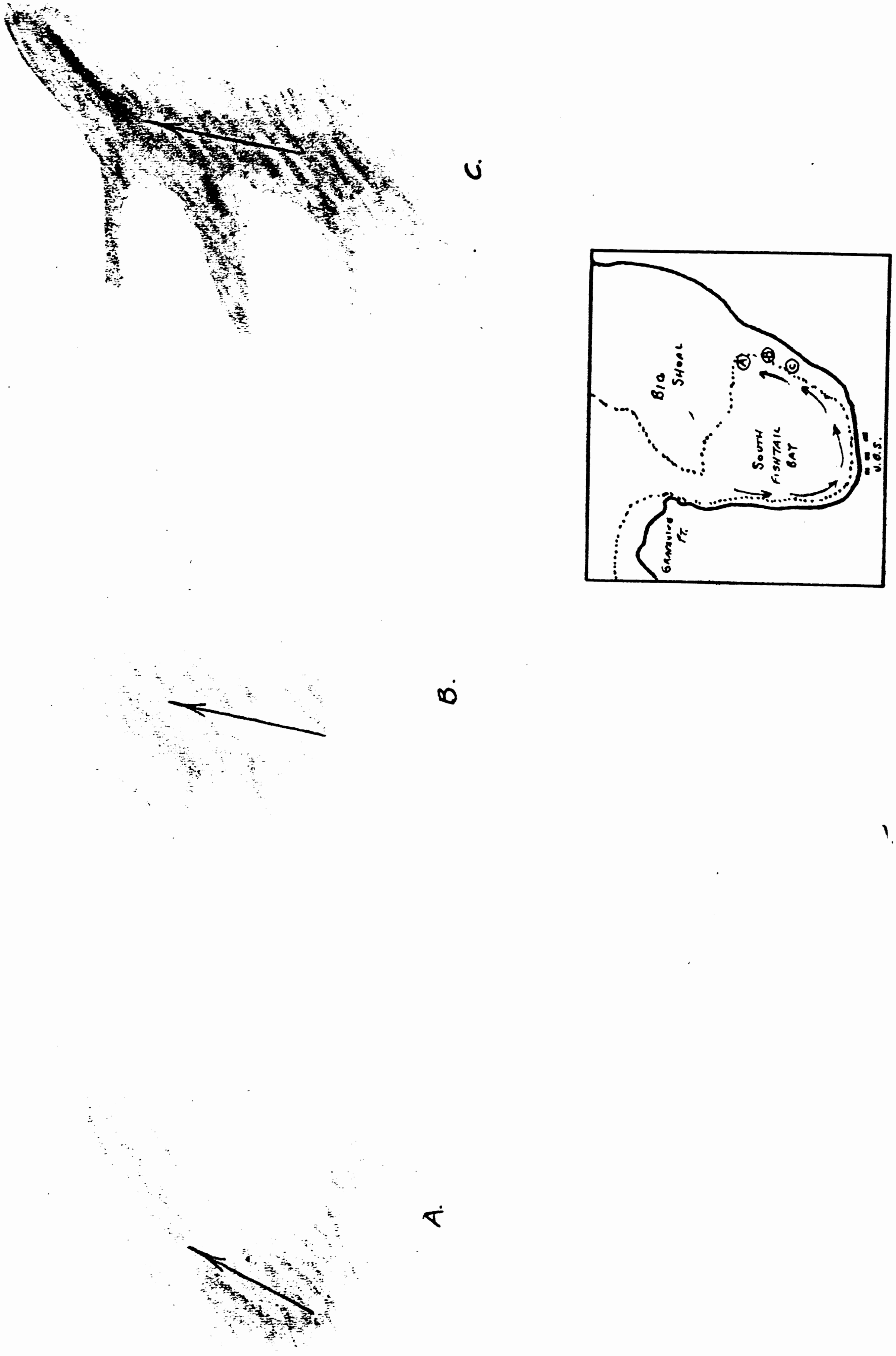

Plate IV

Effect of Currents on Dye Concentrations