THE THERMAL STRUCTURE OF THE SURFACE WATERS OFF WESTERN PHILIPPINES BASED ON BT OBSERVATIONS

By TEODORO G. MEGIA and ALFONSO R. SEBASTIAN
Of the Bureau of Fisheries, Manila, Philippines

EIGHT TEXT FIGURES

Within the lighted portion of the water column in Philippine waters there are two distinct layers easily distinguishable by their thermal structure. Superimposed upon the discontinuity layer or the main thermocline is the mixed or isothermal layer of uniformly high temperature. Owing to phytoplankton activity, the isothermal layer is generally deficient in the chemical nutrients known to regulate and limit plant growth. The thermocline below militates against the vertical movements of the richer waters beneath it, as a consequence of which there is no active replenishment of the impoverished waters within the isothermal layer.

While it is highly desirable to study the thermal structure of both layers in order to acquire a more thorough understanding of the mechanisms controlling nutrient exchange, the BT (bathythermograph) tows did not penetrate deep enough to reach the lower boundary of the main thermocline. The maximum BT penetration never exceeded 150 meters. Below this depth there were still evident significant temperature gradients as shown by the vertical temperature distribution curves based on the hydrographic data.

To conform with the standard units adopted by the Indo-Pacific Fisheries Council with which the Philippines is affiliated, the BT measurements of temperature and depth are expressed in the metric system. The conversion facilitated the scaling of values corresponding to the standard depths adopted in the reduction of the hydrographic data, thus permitting comparison between the two types of data.

Except for a few stations occupied during the first part of the survey, the BT observations were made at points approximately midway between pairs of successive stations.

The data used in this study were collected by the *Spencer F. Baird* of the United States Fish and Wildlife Service in July and August, 1949 at the height of the southwest monsoon period. The survey was completed in a single cruise of 24 days.

Though the data at hand are not by any means complete as to provide a closer coverage of the area under study and comprehensive enough as to present fully the average condition of temperature during the southwest monsoon period, the results yield valuable information that permits the drawing of general conclusions.

SOURCES OF ERROR

Two bathythermographs were used, the first having been lost overboard at BT–861 when rough seas were encountered during the first leg of the survey. The performance of the two instruments was satisfactory throughout except in one instance at BT–836 where the lost BT showed an apparent shift in its "zero point". While a shift in the zero point does not affect the shape of any given trace, wide deviations from the reversing thermometer temperature reading should amply warn of the necessity for adjustment or repair of the instrument. Owing to the fact that a different calibration grid was used in scaling values from the traces recorded by one of the two bathythermographs, there may be a systematic error in the absolute values of the temperature data. Since, however, all the BT temperatures were referred to the hydrographic data, such error can be expected to be of little significance. Due to the limitations in the accuracy of the instrument and the conversion of values from one unit to another, the temperature values may deviate as much as 0.2° C. and the depths not greater than five meters from their true values. These errors, however, are within the accuracy required.

REDUCTION PROCEDURE

The conversion of depth in feet into the metric unit was effected by using a transparent sheet upon which the lateral grid lines were etched to correspond to depths expressed in meters. Temperature values scaled to the nearest 0.1° F. were converted to ° C. and later corrected for the difference between the BT reading and the mean of the two reversing thermometer surface readings taken from the nearest pair of consecutive hydrographic stations. If both types of observations were made in the same station, the correction was based on only one reading. In either case this correction was applied to all the BT readings corresponding to the other standard depths. The converted values appear under each station in Table 1.

TABLE 1.—*Corrected temperatures in °C corresponding to standard depths expressed in meters*

Depth	BT–820	–822	–824	–826	–829	–833	–836	–843	–846
0	29.4	29.4	29.3	29.3	29.5	30.0	29.1	29.4	29.1
25	29.2	29.3	29.3	29.2	29.5	29.9	29.1	29.6	29.1
50	27.8	28.7	29.3	28.9	29.1	29.2	28.8	28.5	27.0
75	24.0	22.2	23.8	21.6	25.4	22.9	------	24.5	24.0
100	24.0	19.5	------	19.5	21.1	20.5	------	21.3	------
125	------	16.6	------	------	------	------	------	------	------

Depth	–848	–850	–855	–861	–863	–865	–867	–869	–871
0	29.1	28.8	28.5	29.3	29.7	29.5	29.1	29.4	29.6
25	29.1	28.8	28.5	29.2	29.6	28.3	28.7	29.1	29.3
50	28.6	28.7	28.1	29.0	29.5	28.3	28.5	28.9	27.0
75	23.9	------	26.7	26.9	26.9	26.9	25.4	22.9	23.6
100	------	------	24.6	25.0	23.6	24.5	23.2	20.4	------
125	------	------	20.7	20.9	------	21.2	------	------	------

Depth	–873	–876	–878	–880	–833	–885	–890	–892	–894
0	29.4	29.4	29.5	29.3	29.3	29.3	29.1	29.5	29.7
25	29.1	29.2	29.3	29.0	29.1	28.8	28.5	28.7	29.4
50	25.4	28.4	29.2	28.0	27.5	28.2	27.1	28.4	29.2
75	------	23.8	------	25.6	24.3	25.7	24.7	25.8	24.8
100	------	20.6	------	------	22.7	23.5	22.5	22.3	22.3
125	------	------	------	------	------	------	------	20.9	20.7

Depth	–896	–899	–901	–903	–906	–908	–910	–913	–915
0	29.3	29.1	28.9	28.9	28.8	28.7	29.9	29.2	29.1
25	29.2	28.0	28.6	27.8	26.6	28.9	28.9	28.2	29.0
50	26.6	25.1	24.2	25.8	25.9	27.3	26.4	27.4	27.3
75	23.5	21.6	21.9	20.9	23.6	24.7	23.0	25.9	25.3
100	21.0	19.8	19.5	18.6	19.6	20.1	21.0	24.6	22.5
125	19.3	------	------	------	17.8	------	19.4	------	------

Depth	–917	–920	–922	–924	–927	–929
0	28.9	29.1	29.5	29.7	29.7	29.9
25	28.0	28.8	27.9	28.6	29.4	29.3
50	27.4	27.9	27.3	27.2	28.3	28.9
75	25.7	26.9	25.8	25.6	25.0	27.2
100	23.4	25.4	22.4	22.4	22.4	24.1
125	21.4	------	19.8	------	------	22.4

Where sharp inflections in the curve occurred above the first significant temperature gradient, they were disregarded if it was apparent that they were due not to a special feature of the water but to the unavoidable jagging of the instrument caused by the uneven tension of the BT wire at any one time.

Owing to the gradual transition between the isothermal layer and the thermocline as indicated by a number of the traces, the difficulty of ascertaining the depth of the isothermal layer necessitated the establishment of an arbitrary measure of temperature gradient. Thus for our purpose a gradient less than

1° F./25 feet (about 1° C./15 meters) did not constitute a thermocline. On this basis the total temperature drop within the isothermal layer did not exceed 2° C. in all cases. That depth below which the first significant gradient occurred was accepted as the depth of the isothermal layer. Layer depth values are entered in Table 2.

TABLE 2.—*Layer depth temperature*

Station No.	Layer depth		Station No.	Layer depth	
	C.	*meters*		*C.*	*meters*
BT—820	29.0	36	—880	29.0	40
—822	28.9	49	—883	29.0	46
—824	29.2	52	—885	28.8	43
—826	29.0	49	—890	28.5	40
—829	29.4	49	—892	28.3	52
—833	29.9	47	—894	29.1	53
—836	29.6	55	—986	28.9	43
—843	29.3	38	—899	28.4	37
—846	29.0	34	—901	28.7	21
—848	29.4	45	—903	28.9	15
—850	29.0	47	—906	28.6	31
—855	28.9	38	—908	27.6	46
—861	29.8	43	—910	28.1	30
—863	29.5	51	—913	29.2	13
—865	29.3	52	—915	29.0	27
—867	27.7	55	—917	26.8	50
—869	28.8	54	—920	------	------
—871	29.2	40	—922	26.7	64
—873	28.5	34	—924	29.0	57
—876	28.8	44	—927	28.5	55
—878	29.4	54	—929	28.6	57

STATION PLAN

Fig. 1 shows a layout of the carefully spaced network of BT and hydrographic stations occupied during the survey. Numerals represent station numbers. Where no BT station is shown between any two adjacent hydrographic stations occupied in succession, BT observations were taken when the boat stopped to make hydrographic measurements.

TEMPERATURES

The spacing of isotherms in the distribution chart for temperature at the surface was made at an interval of 0.2° C. as against 0.5° C. at 50 meters. This is to bring out by comparison the interesting feature shown by the strong horizontal temperature gradients at 50 meters over Stewart Bank located approximately in the western center of the 5° quadrangle west of northern Luzon.

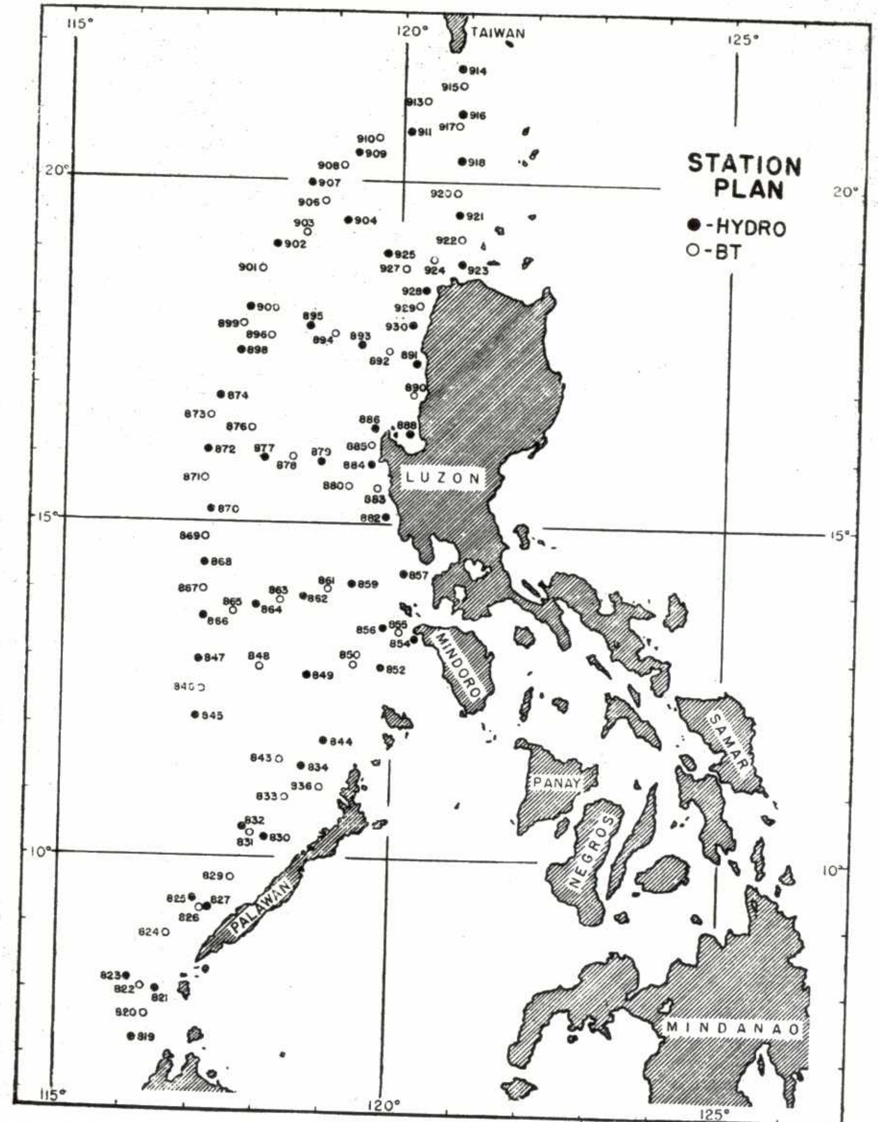


FIG. 1. Lay-out of stations occupied during the cruise of the *S. F. Baird*, July-August, 1949

Figs. 2 and 3 present the horizontal distributions of temperature at the surface and at a depth of 50 meters.

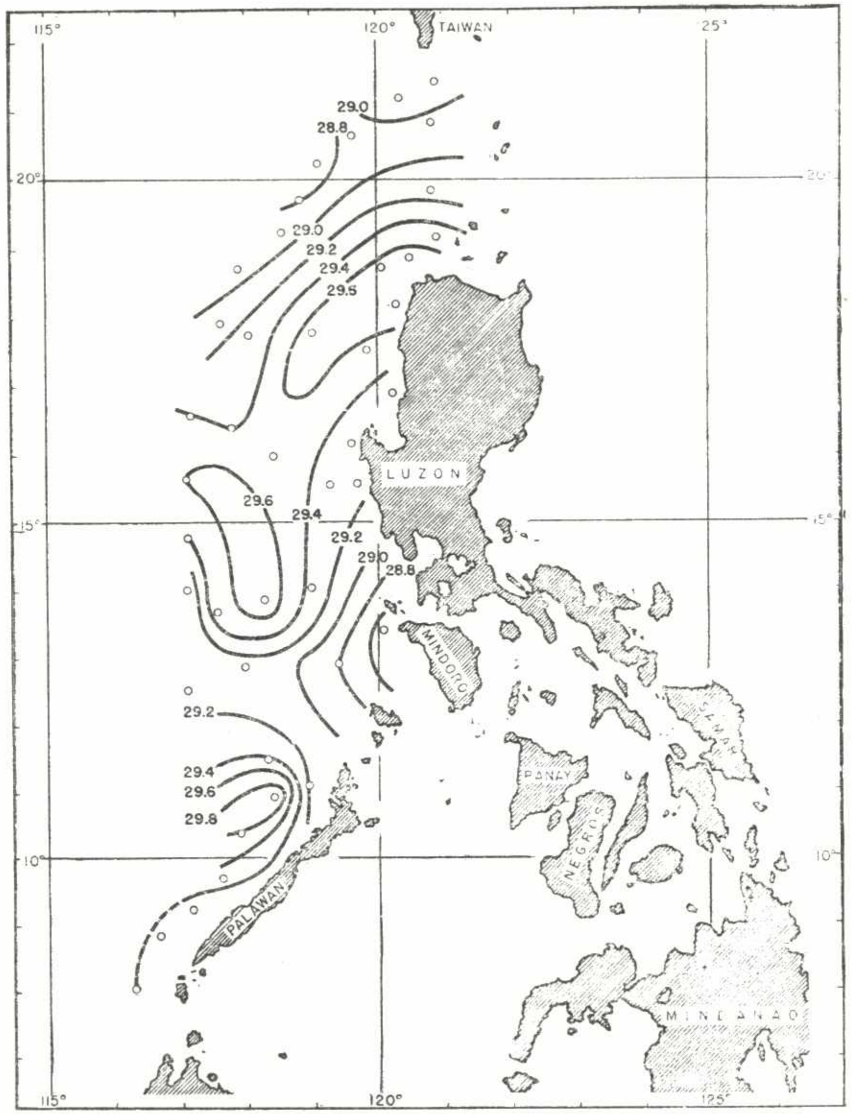


Fig. 2. Temperature distribution at the surface.

Surface.—Temperatures are generally lower in the northern than in the southern part of the area, the difference between the maximum and minimum values exceeding 1.0° C. In the southern part close to the shore the temperature increases from east to west but shows a reverse trend in the area to the north off northwestern Luzon.

Two patches of water having a temperature higher than 29.6° C. make up the warm region which appears west of

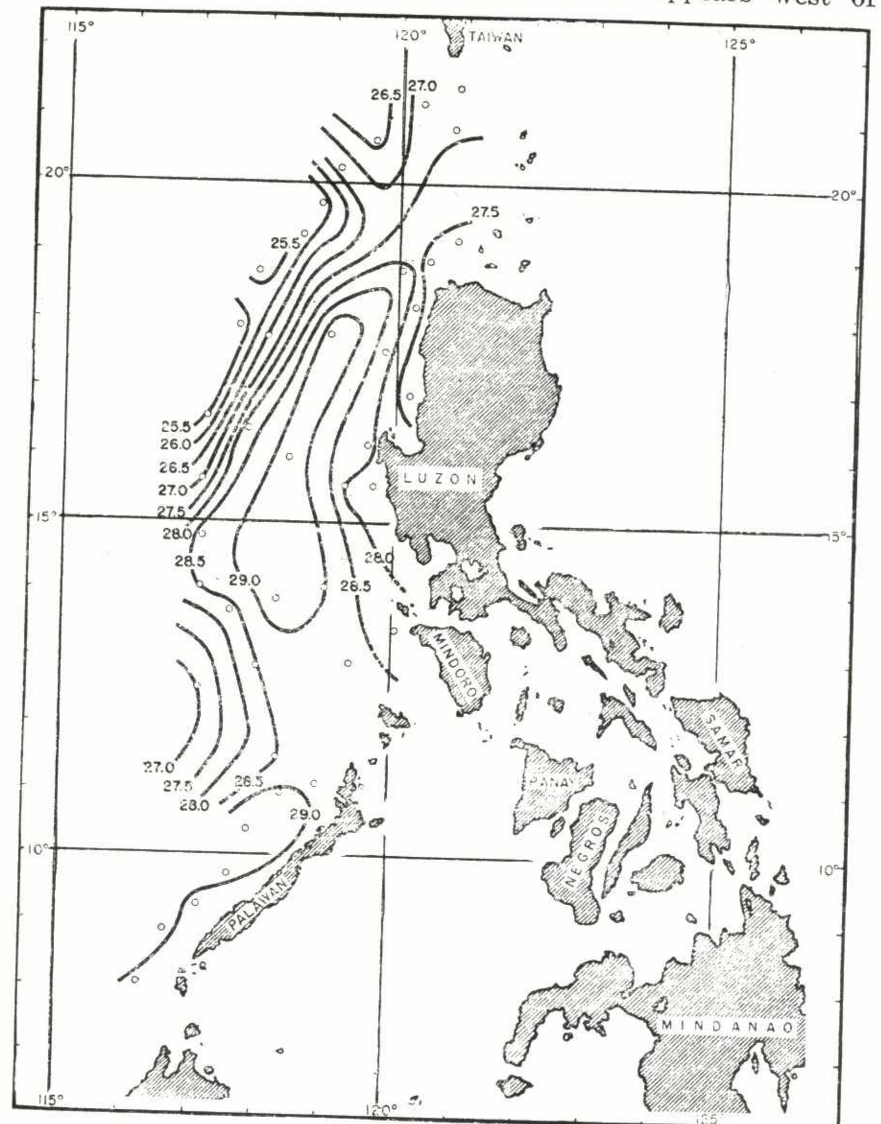


Fig. 3. Temperature distribution at 50 meters.

Luzon. This warm water has been found by Leipper and Wood (1947) to migrate from north to south during the northeast and in the opposite direction during the southwest monsoon period. Due to its large extent and its apparent displacement further south than when found by these investigators it seems likely that this warm water must have reached the limit of its southern migration at time of survey.

Another region of warm water much less in extent but of higher temperature appears off northwestern Palawan. Presumably this is a part of the South China Sea water that has broken away from the parent stream and found its way through the narrow trough separating Palawan from the extensive shallow reefs to the west. Upon hitting the shallow area at the northern tip of Palawan, the water departs from its normal course to form what appears to be a tight eddy. This pattern of flow based on the tonguelike distribution of temperature may not be confirmed by the actual streamlines owing to the wider fluctuations in salinity as shown by the hydrographic data.

Fifty meters.—At this depth the two warm patches found at the surface close to each other have coalesced to form a band of water tapering off to the northeast. Its broad base extends as far south as 13° 30′ N. latitude. The other end is seen to extend as far north as 18° N. latitude.

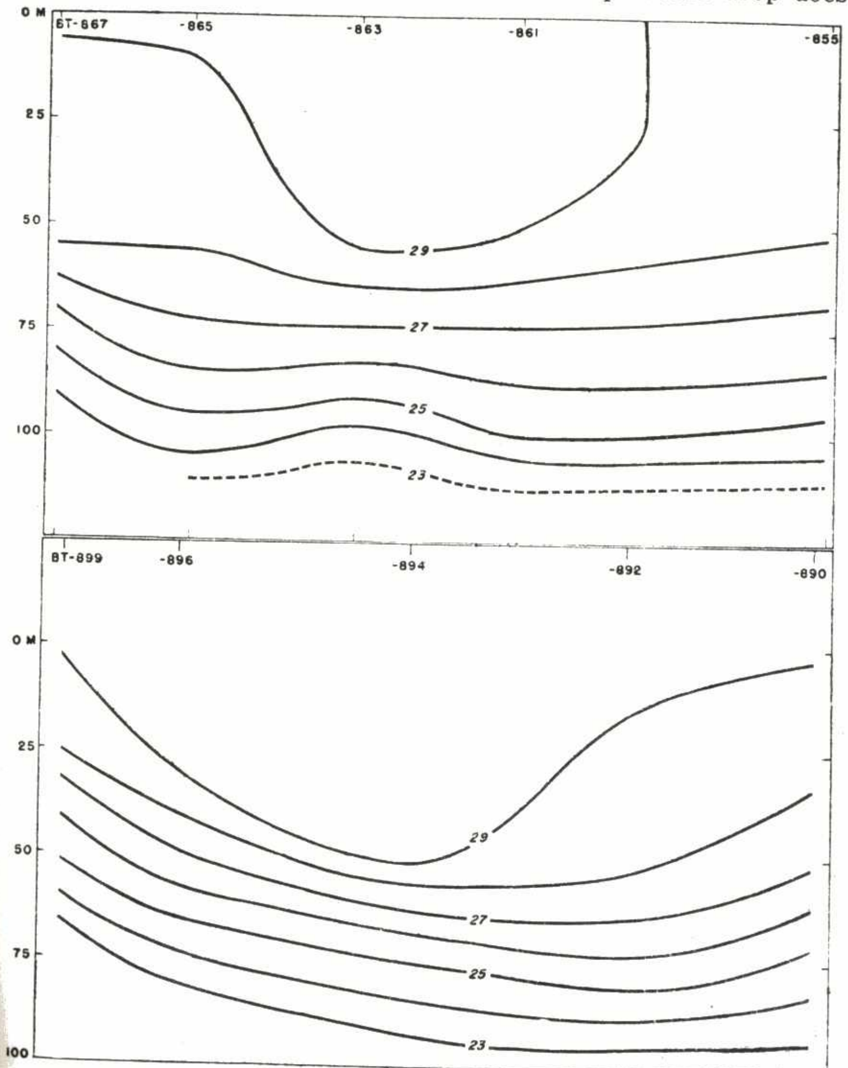
A special feature of the temperature distribution at this depth is the packing of the isotherms over and in the vicinity of Stewart Bank referred to previously. These marked horizontal temperature gradients reveal the possible presence of processes taking place that may account for the highly productive fisheries reported by fishermen in that area. That the presence of the cold water there is not a temporary feature is corroborated by the Japanese data collected during the same period in 1937.

Another noteworthy feature of the temperature distribution at this depth is the appearance of a tongue of warm water extending northeastward from the region of warm water.

ISOTHERMAL LAYER

Figs. 4, 5, and 6 are profiles presenting the extent of the isothermal layer. The first profile runs along the line of stations from BT–855 to BT–867 cutting across the base of the band of warm water enclosed by the 29°-isotherm shown in fig. 3. The second profile starts from BT–890 directly north of Lingayen Gulf and extends northwestward in the direction of Stewart Bank. The position of the profile in fig. 6 was chosen to conform with the apparent axial position of the 50-meter isobath, which is shown in fig. 7 to run from BT–822 west of Balabac Strait to BT–917 in the Bashi Channel south of Formosa.

These profiles show the 29°-isotherm to define the lateral and vertical boundaries of the isothermal layer everywhere except as shown in fig. 4. On either side of the isothermal layer shown in this figure, there is another layer of water of greater thickness within which the total temperature drop does



FIGS. 4 and 5. Profiles of isotherms in the southern and northern parts of the isothermal layer.

not deviate more than 1° from 28° C. This profile further shows lower temperatures at all depths than in the southern section of the central core of warm water. This may be due to solar heat being rapidly dispersed downward by more active vertical circulation. The same process probably also explains the disappearance of the 29°-isotherm in the landward part of the section. That the mixing resulting from such circulation does not penetrate deeper than 50 meters is shown by the position of the 28°-isotherm which is only slightly displaced horizontally. The obliquity of the isotherms on both sides of the isothermal layer in the northern section indicates that the horizontally unstable water mass depicted in fig. 3 extends to greater depths.

The crowding of the isotherms on the southern part as shown in fig. 6 indicates the intensity of the thermal stratification

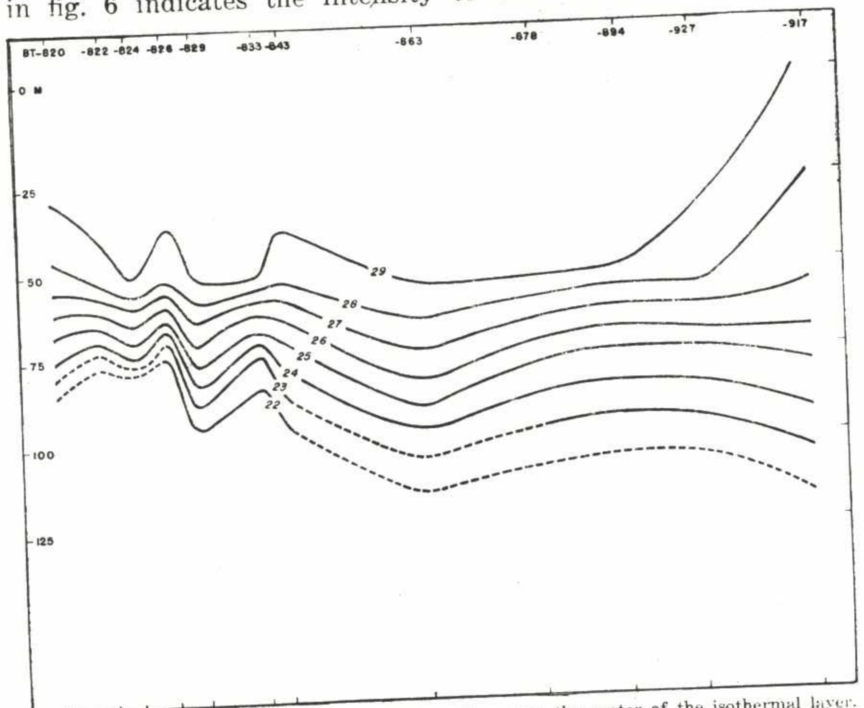


FIG. 6. Profile of isotherms in a longitudinal position near the center of the isothermal layer.

below the shallow isothermal layer there, while their sharp slopes probably represent the combined effects of the tight eddy referred to previously and the unusually rough seas encountered during the first days of the survey. The distortion of scale in representing horizontal and vertical distances in the profile exaggerates the slopes which will appear more gentle under actual sea conditions. Beyond the northern periphery of the small eddy the isotherms rise slowly at first and then slope

rapidly upward as the water reaches the passages north of Luzon.

The series of BT traces presented in fig. 8 show roughly the direction of movement of the isothermal layer and the rate of its transport. Degradation of the gradients follows the

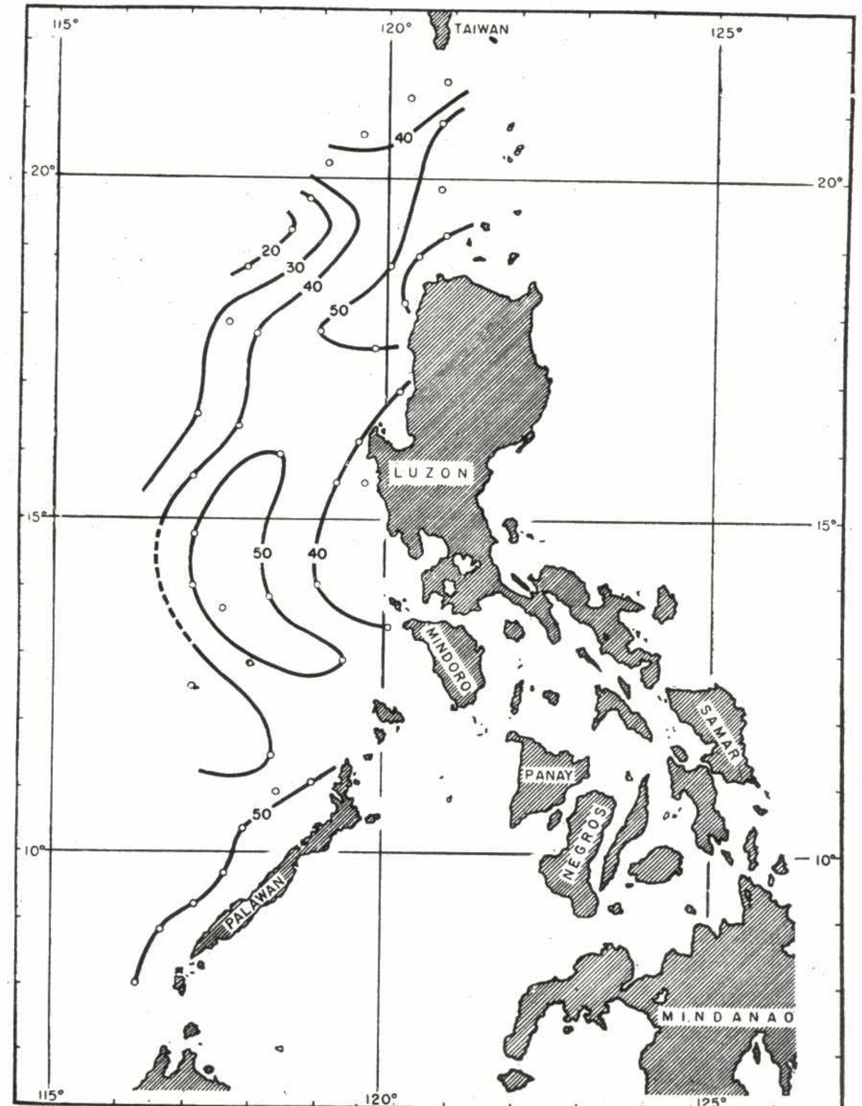


FIG. 7. Layer depth chart.

assumed line of flow. Based on the concept of maximum flow in the direction of maximum degradation, the rate of motion should be greatest toward the north in the direction of the axis of the isothermal layer.

CONCLUSIONS

The full understanding of the mechanism responsible for the transport of water deduced from the degradation of the traces in fig. 8 must await specialized studies. Whatever the mechanism, such transport probably will be destructive to the fishing grounds on the narrow insular shelf to the extent that the freely floating plant and animal life may be carried away from the coastal waters where they maintain the fisheries.

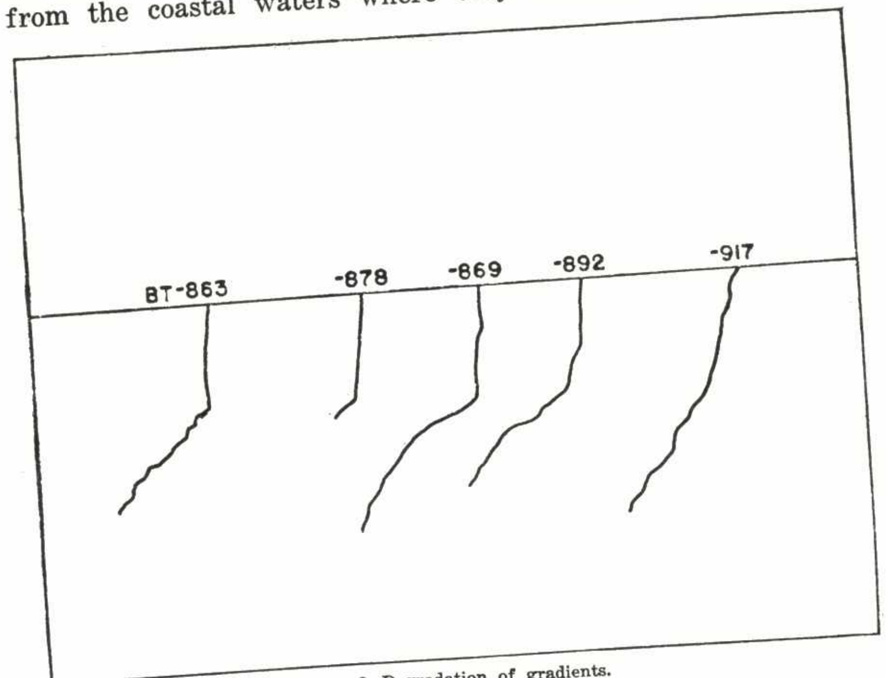


FIG. 8. Degradation of gradients.

The importance of this mechanism seems to have been recognized by the Japanese who investigated the other side of the isothermal layer near Stewart Bank. The promiscuity of distribution of the stations they occupied in that area apparently shows an attempt to analyze the agency responsible for the maintenance of the horizontally unstable water mass shown in figs. 2 and 3.

The banking of cold water against the edge of the isothermal layer near Stewart Bank and the presence of the tongue of warm water off northwestern Luzon (fig. 4) are special features of the temperature distribution that should be of value to tuna long-line operators. Japanese investigations show that such thermal features are indicative of routes of migration of the

What effects this thermal structure of the isothermal layer and the thermocline have on the biological processes can probably be deduced from a study of the distribution of the chemical and biological data also collected during the cruise. Such aspect was outside the scope of this report and, therefore, no attempt was made to analyze them. However, a few statements may be worthwhile to make at this time. If the temperature gradients within the thermocline are strong, lateral diffusion can be expected to be correspondingly great and if the isotherms sweep upward in a particular region, the return of the plant nutrients removed from the layer of plant activity can easily take place. Due to the persistence of the thermocline throughout the year in Philippine waters especially in offshore areas, the isopycnic transport of nutrients, which has been appreciated for some time, appears to be the only effective mechanism that brings up plant nutrients from below. For the purpose then of assessing the fertility of Philippine waters, stress should be given on the investigation of the large-scale horizontal circulation of our waters, the forces that maintain it, and the biological processes with which it is associated.

Admittedly, the thermal structure of the water presented in this report may represent only one stage in the cycle of oceanographic events. However, its investigation such as was attempted herein may provide a starting point in analyzing the secular changes in its character.

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ILLUSTRATIONS

TEXT FIGURES