THE WATER MASSES OF SEBASTIAN VIZCAINO BAY

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INTRODUCTION

This report is a descriptive analysis of the water masses and certain processes, which combine to produce the major changes in the physical environment observed throughout the year in Sebastian Vizcaino Bay. No effort is made to explain the forces involved or mechanics of the changes described. A discussion of the currents of the bay has been avoided since it is felt sufficient measurements for such a discussion have not yet been obtained.

GENERAL AREAL DESCRIPTION

Sebastian Vizcaino Bay is located 350 miles (all distances are expressed in nautical miles) south-southwest of San Diego on the Pacific Coast of Baja California (Fig. 1). The bay has the shape of a fish-hook completely exposed to the sea toward the northwest. The distance from the northern end of Cedros Is. due north to Punta Canoas on the mainland measures 63 miles; the distance from Punta Canoas to the southernmost shore of the bay is about 115 miles. The narrowest dimension of the bay measures 48 miles from the northern end of Cedros Is. to Punta Maria. The inset in Figure 1 shows Monterey Bay of central California for a size comparison. Two channels, separated by Natividad Is., open to the sea in the southwestern portion of the bay: they are Kellett Channel, which is 8 miles wide and 40 to 45 meters deep, and Dewey Channel, which is 4 miles wide and 25 to 30 meters deep. Three very shallow lagoons are found along the southeastern boundary: Scammon, Black Warrior and Manuela. The San Benitos Islands lie approximately 15 miles west of Cedros Is. Ranger Bank, about 100 meters deep, lies 15 miles northwest of Cedros Is. There is little rainfall in this area and no rivers empty into the bay.

DESCRIPTION OF WATER MASSES[2]

For purposes of identification, seven water-mass sources are defined. The term "water-mass source" is a misnomer in some cases since some of the areas mentioned as source regions are not sources of water having definite reproducible characteristics, but rather areas where more or less permanent processes occur which result in water types which differ strikingly from neighboring water.

The seven water sources (Fig. 2) are:

1. California Current water, which is a water mass with very characteristic physical parameters. It is the source of low-salinity water for the bay. It is relatively cool, but not the coldest water in the bay; it has a high oxygen and PO_4-P content. It is present in large quantities and often dominates the bay waters.

2. Upwelled water from the Punta Canoas region. Water of definite physical characteristics cannot be assigned to this region since upwelling is a process which brings to the surface layer whatever type of water happens to be present below the surface at a particular time. Usually the upwelling process, coastal

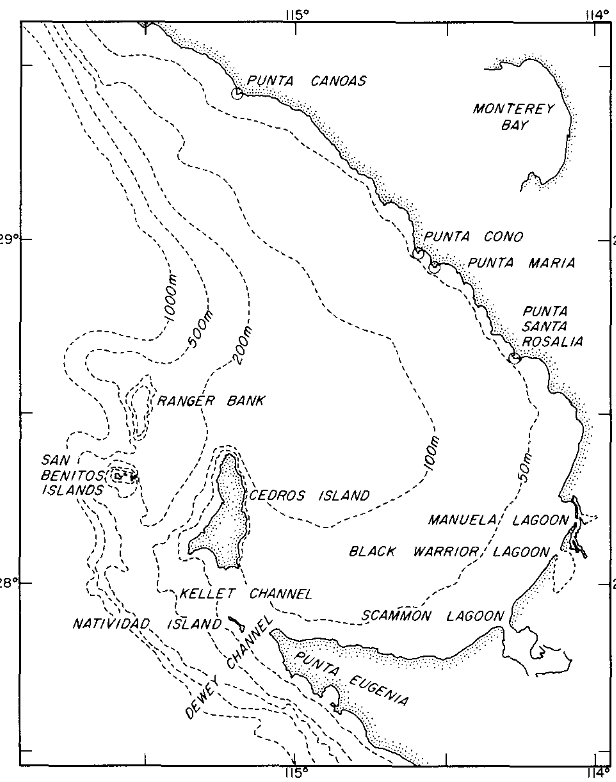

FIGURE 1. Geography of Sebastian Vizcaino Bay.

[1] Contribution from the Scripps Institution of Oceanography.

[2] The water masses described in this report should not be confused with the major water masses as defined by Sverdrup in "The Oceans". They are used for convenience only in identifying and separating the local conditions found within, and in the immediate vicinity, of the Bay.

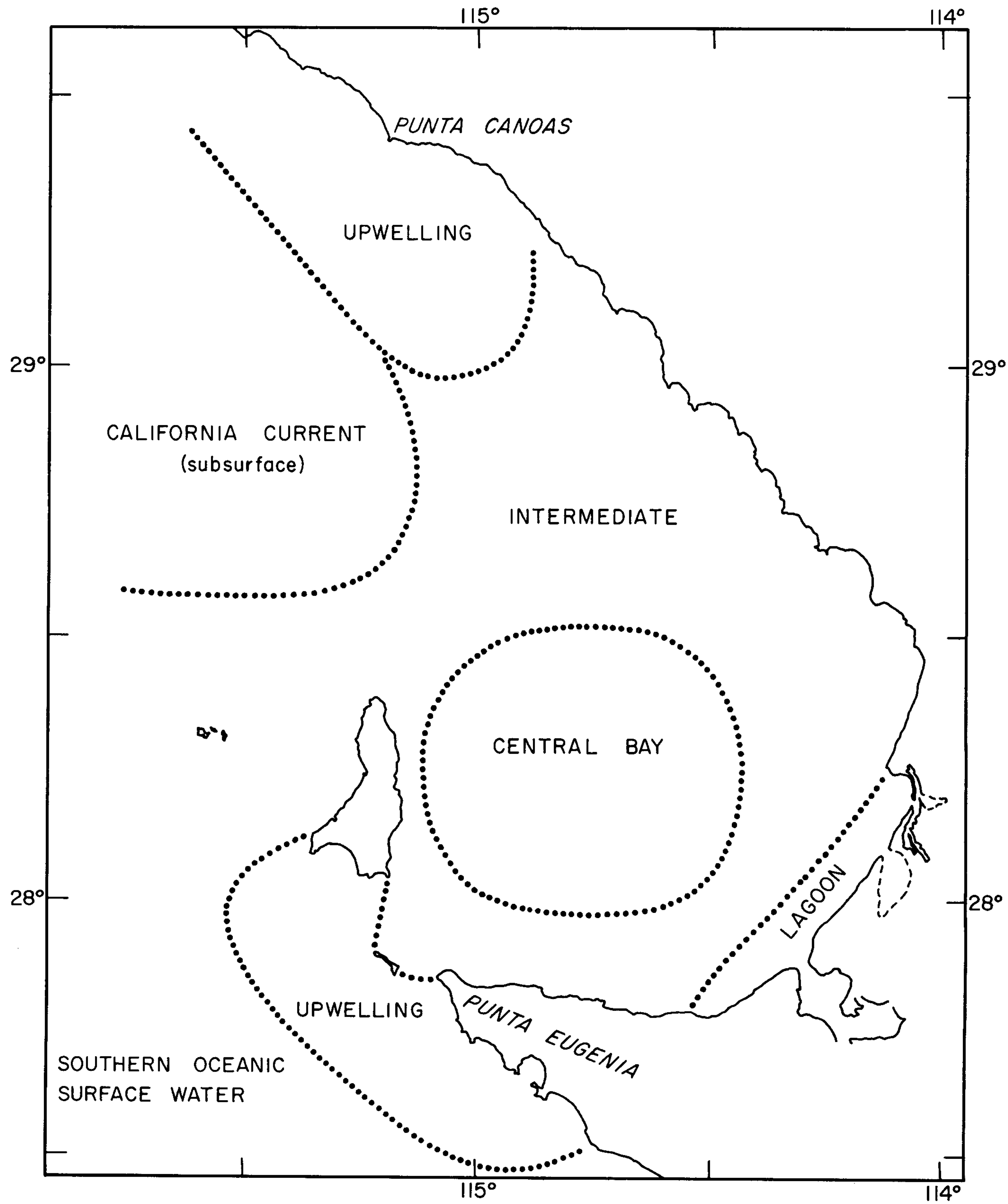

FIGURE 2. Water masses of Sebastian Vizcaino Bay.

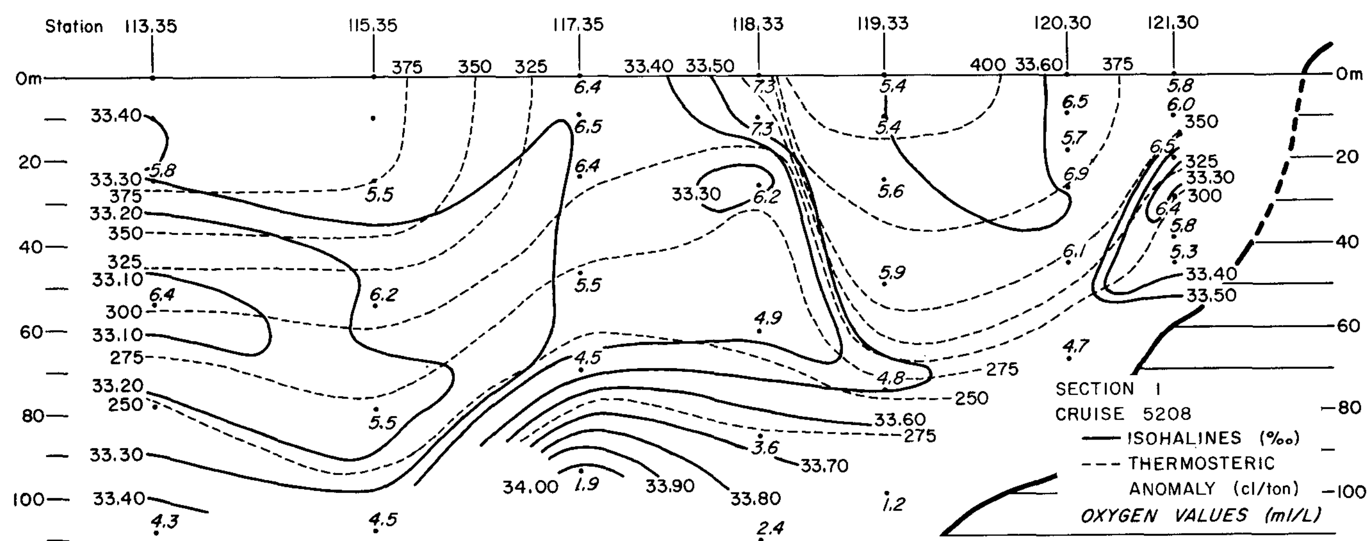

FIGURE 3. Section 1, Cruise 5208. Vertical section from the surface to 110 meters showing distribution of salinity (isohaline lines), thermosteric anomaly (lines of equal Δ′ or δT) with oxygen values (ml/L) entered.

in this region, results in the coldest water because the vertical temperature gradient is normally negative. Whether or not this water will have a high or low salinity value depends upon what water is being upwelled. In the Punta Canoas area higher-salinity water is most frequently upwelled.

3. Central Bay water is also the result of a local condition and cannot be described as having definite characteristic values. There appears to be a permanent or semi-permanent clockwise rotating eddy in the bay. Its position and size vary considerably. It is definable because it is characteristically delineated from the

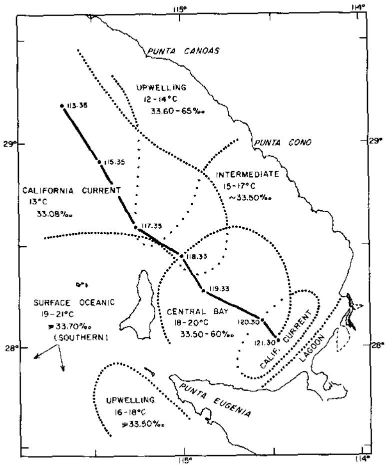

FIGURE 4. Cruise 5208. Block Diagram showing general characteristics and locations of water masses in August 1952 (5208).

surrounding water by a very sharp thermocline and oftentimes by "fronts" (Cromwell and Reid 1956). This pocket of water is usually found to be well mixed and relatively warm. It is usually warmer than the surrounding water indicating it is probably held for a longer time in the surface layers.

4. Lagoon water appears to be of minor importance in the regime of the bay, but it often has extremely different characteristic values. High temperatures and salinities are found. This water is probably mixed into the bay water somewhere along its southern periphery. It can be called a true source region since water of definite characteristics forms there.

5. Upwelled water from the Punta Eugenia area can be described in the same manner as the water from the Punta Canoas region. The main difference is in the importance of the two areas in relation to the bay. Punta Eugenia water is probably the least important of any of the water-mass sources described. Some of this water may enter through the southwestern channels and affect some of the southern coast of the bay, as evidenced by certain cold water algae found there (Dawson 1952).

6. Southern oceanic surface water is characterized by high temperatures and salinity. This water is found along the coast to the south of Punta Eugenia and influences the bay mainly during the late summer and fall months.

7. Water from the deep coastal salinity maximum is a subsurface mass (usually found at 200-300 meter depth) which is characterized by relatively high temperatures and salinities, a very low oxygen content and a relatively high phosphate content. It is actually an extension of Equatorial Pacific water northward along the coast. It enters the bay circulation from below by moving up over the continental slope and shelf.

In addition to the types of water just described other water is sometimes found which does not fit any of these classifications. This is, of course, to be expected when two or more of the above water types mix. We will call this intermediate water.

A general descriptive analysis of certain special cruises into the bay will be made in terms of the above-mentioned water-mass source regions.

SPECIAL CRUISE, AUGUST, 1952 (CR 5208)

In August, 1952, the first special CalCOFI cruise was made into Sebastian Vizcaino Bay. At this time low salinity California Current water was found within the upper 100 meters. (Fig. 3 and Fig. 4). This appears as a tongue of water to the west and northwest of the bay entrance, north of Cedros Island. Salinities as low as 33.08 ‰ and temperatures of about 13°C were observed in the core of the tongue at a depth of 50 to 55 meters immediately west of the bay entrance (Fig. 3). A patch of similar water is found along the southern shore at a depth of 20 meters or more. It may be a continuation of the present invasion or the remnants of an earlier invasion.

Punta Canoas upwelled water has a temperature range of 12 to 14°C and a salinity range from 33.60 to 33.65 ‰ in the surface layers. It is found as a crescent shaped ridge opening to the west, extending south from Punta Canoas, reaching to within 10 miles of Cedros Is. (Fig. 4 and 5). This water is found at the surface in the northern one-third of this distance only. It apparently upwells from depths of less than 100 meters. A relatively strong "front" is found between the California Current water and this upwelled water. The entrance of upwelled water into the bay circulation probably accounts for the depression of the bay temperatures as compared to the neighboring surface oceanic waters (Fig. 4).

Central bay water is restricted to a prominent clockwise rotating eddy occupying the main part of the bay east of Cedros Island (See the isobaths and isothermes of the $\Delta' = 300$ surface on Figure 6). The $\Delta' = 300$ surface has been chosen as a reference surface because it coincides closely with the core of the low salinity California current water in this region and usually delineates the bottom of the central bay eddy. A sharp thermocline separates this water from the colder less saline water below. The central bay

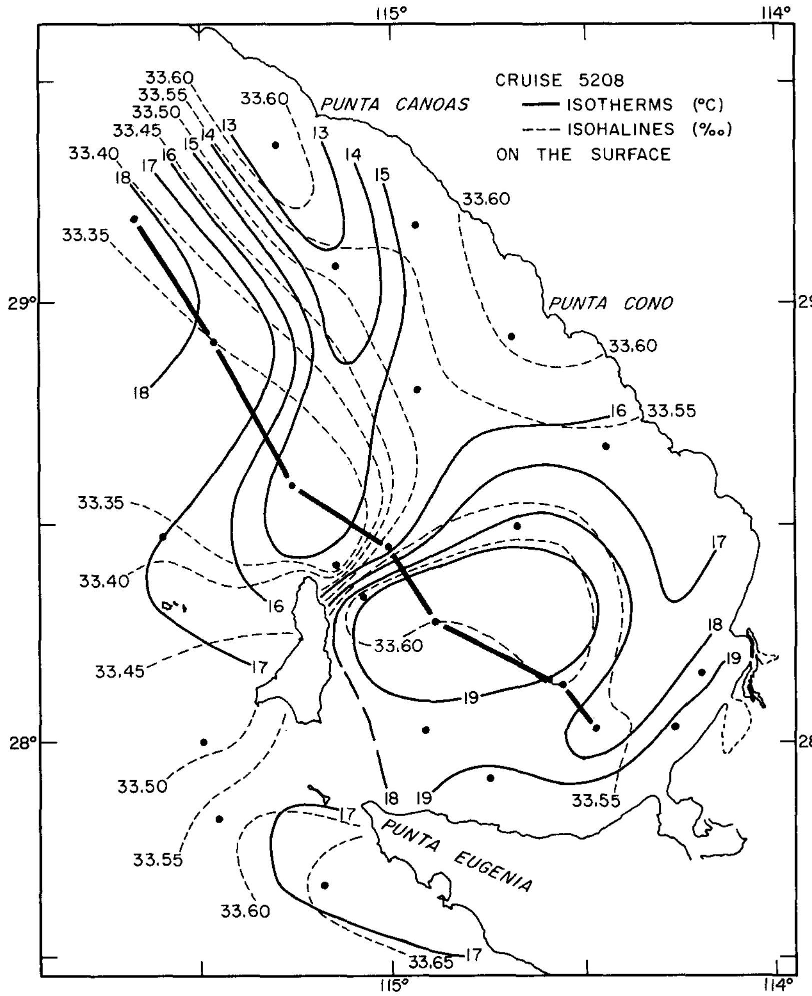

FIGURE 5. Cruise 5208. Surface temperature and salinity distribution (Isotherms in °C, isohalines in ‰).

water is well mixed from the surface to the thermocline, which has a maximum depth of 60 to 70 meters. The surface temperatures range from 18 to 20°C and the salinities from 33.50 to 33.60 ‰. A strong "front" is found along the northwestern boundary of the eddy. The southern end of the cold Punta Canoas upwelled water is found adjacent to the central water and helps to intensify the "front" (Fig. 5). Another weaker "front" can be traced between the central bay and the intermediate water found to the east and northeast. Along the southeastern edge of the eddy the intermediate and central water becomes homogeneous and the "front" disappears.

Lagoon water is found immediately offshore of the lagoons along the southeastern edge of the bay. We have little data but we do know the water is very warm and saline.

Upwelled water from the Punta Eugenia area had surface temperatures from 16 to 18°C and salinities of 33.50 ‰ or greater (Fig. 4). Apparently some of this water is carried into the bay on the incoming tide and gives evidence of being found along the northern shore of Punta Eugenia (Dawson, 1952).

Southern surface oceanic water is found southwest of the bay beyond the Punta Eugenia upwelled water with temperatures, at the surface, from 19 to 21°C or greater (Fig. 4). None of this water seems to have been in the bay at this time.

Intermediate water was found as a very shallow layer (less than 20 meters thick) immediately west of Punto Cono (Fig. 4 and 5). It extends along the eastern and southeastern shoreline of the bay where it blends with the central water. Temperatures range from 15 to 17°C and salinities are near 33.50 ‰. This water appears to be a mixture of California Current, Punta Canoas upwelled and central bay waters. The thermocline separating it from the cooler water below comes to the surface just southeast of Punta Canoas forming another front. This front between the upwelled and intermediate water becomes diffuse to the south.

Underlying most of the water in the bay is water from the deep coastal salinity maximum. This water may slide up the continental shelf south and west of Kellett and Dewey Channels and continue over the sill between Cedros Island and the San Benitos Is-

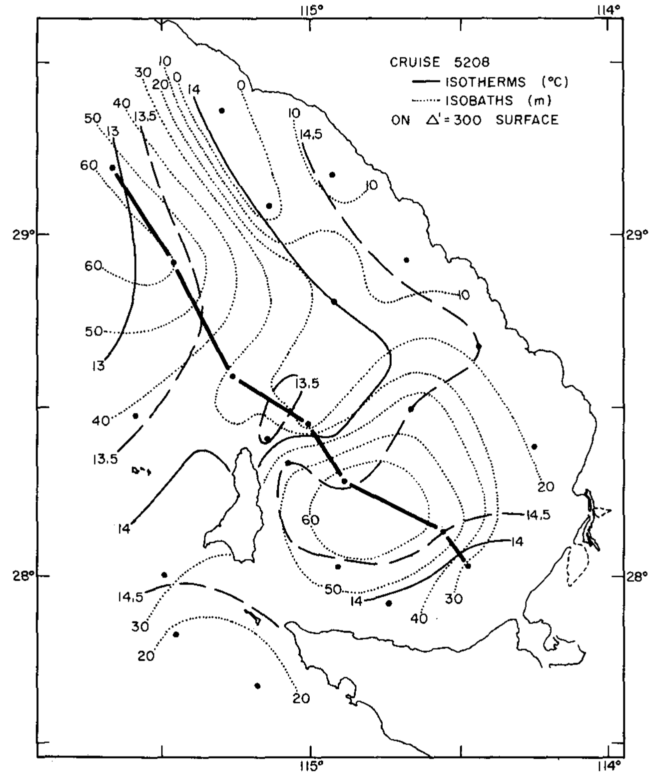

FIGURE 6. Cruise 5208. The depth of, and temperature distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isotherms in °C.)

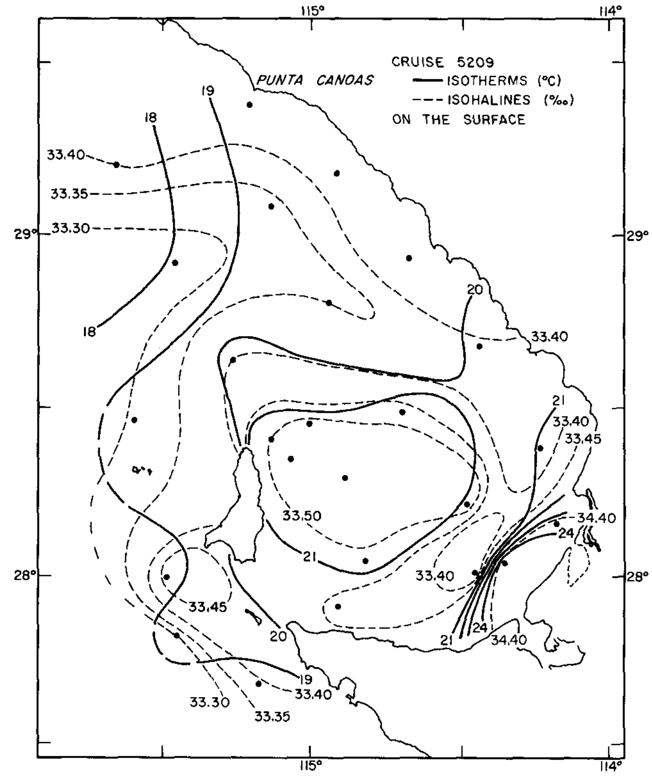

FIGURE 7. Cruise 5209. Surface temperature and salinity distribution. (Isotherms in °C, isohalines in ‰.)

lands and then around the northern end of Cedros Island into the bay (Fig. 1). The presence of this water is clearly seen at station 117.35 in Sect. 1. Evidently water of this type is often upwelled into the surface layers.

The weather situation at the time of this cruise should have resulted in a moderately strong flow of air from the northwest. This fits in well with the observed conditions, since evidence of coastal upwelling certainly was found.

COMPARISON WITH OTHER CRUISES

The special cruise made in August, 1952, (CR 5208) was followed by a second special cruise, the next month, September, 1952, (CR 5209) which is of interest since it gives some idea as to how conditions can change at least within four or five weeks.

A list of the most obvious changes are given below:

1. No upwelling was in evidence at either Punta Canoas or Punta Eugenia.

2. California Current water had invaded most of the bay as well as the area immediately outside the bay.

3. The central bay eddy shifted northward.

4. No strong fronts were found.

5. There was marked warming of the entire bay.

In general, these changes brought about more homogeneous conditions between the water masses in the bay. (Fig. 7) California Current water dominated the scene. The core of this relatively cool, low salinity water enters the bay midway between Punta Canoas and Cedros Island spreads to the east and southeast along the coast, then underruns and mixes with the central bay water along the southern and southeastern coast.

The central bay water has been diluted with California Current water. The average salinities dropped from 33.50 to 33.60 ‰ to 33.40 to 33.45 ‰, except at the very surface with salinities continuing at about 33.50 ‰. On the average the temperatures are about 2°C higher in the mixed layer than in August. With the cessation of upwelling off Punta Canoas and the spread of the central bay water northward, the surface fronts along the northern edge of the eddy appear to have been eliminated. (Compare Figures 5 and 7.)

Lagoon water is evident along the southern shore. It is very warm (23 to 24°C) and saline (34.20 to 34.40 ‰). This water apparently remains along the southern coastline.

Surface oceanic water outside the bay in the upper few meters is a degree or two warmer than in August, but it is otherwise not much changed.

The intermediate water of the August cruise is difficult to find. The region where it was found during August now has water with salinities from 0.20 to 0.35 ‰ lower and temperatures from 19 to 21° C, an average of 3 to 4° higher.

Deep coastal salinity maximum water is found at Stations 117.35 and 118.35. In figures 8 and 9 this is

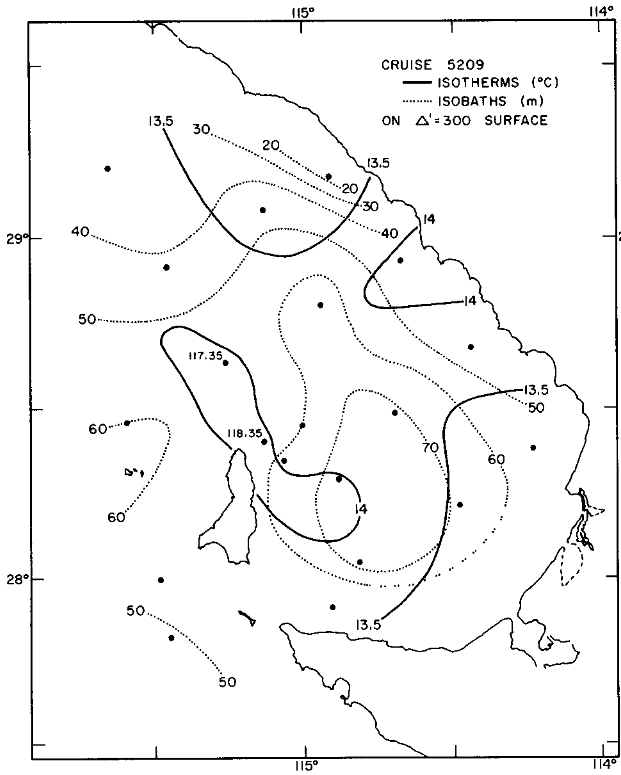

FIGURE 8. Cruise 5309. The depth of, and temperature distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isotherms in °C.)

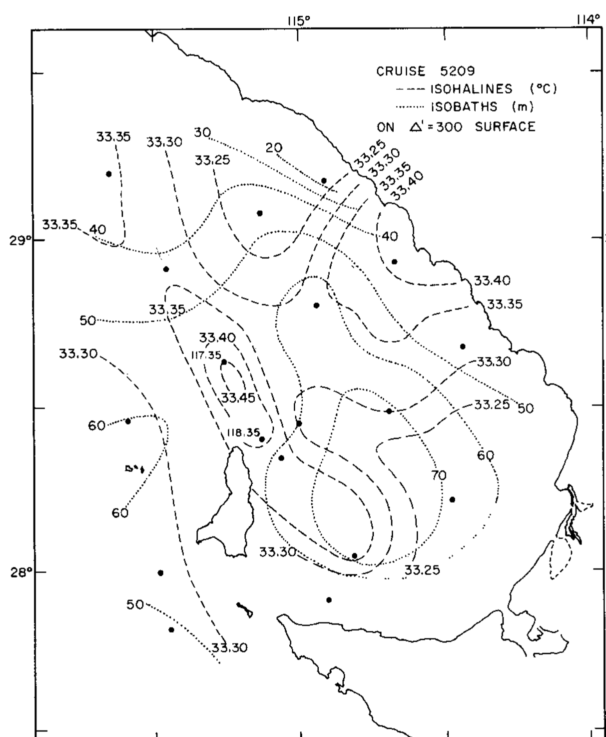

FIGURE 9. Cruise 5309. The depth of, and salinity distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isotherms in °C.)

clearly seen as a warmer, more saline zone on the $\Delta' = 300$ surface. This water is about 1°C warmer than during August.

The general meteorological conditions over the Pacific should have resulted in a relatively weak flow of air from the northwest. This could account for the absence of coastal upwelling at this time.

Reference has been made to surface oceanic water originating to the south and southwest as playing a part in the water-mass sequence in the bay. Neither cruise in 1952 offered any definite evidence of this. We were fortunate, however, in obtaining direct evidence during a special bay cruise in September, 1953,

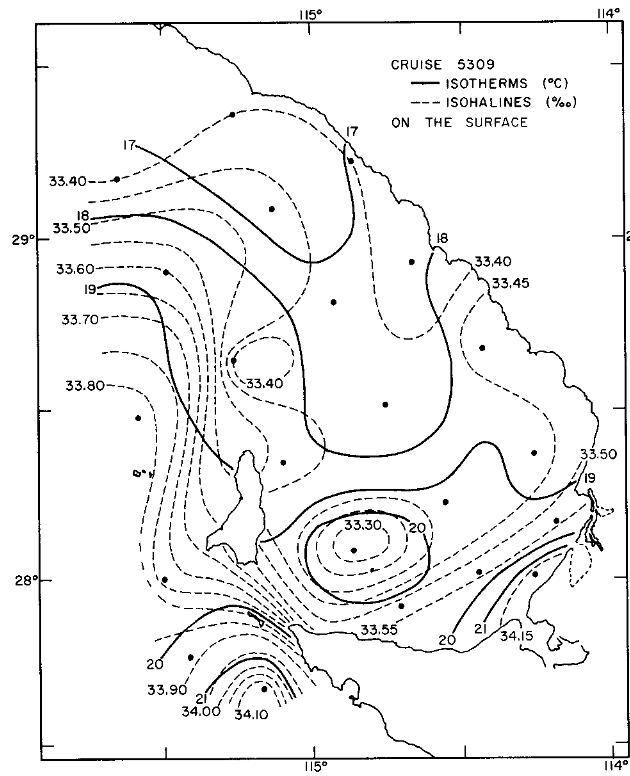

FIGURE 10. Cruise 5309. Surface temperature and salinity distribution. (Isotherms in °C, isohalines in ‰.)

(CR 5309, see Fig. 10). At this time conditions were found to be similar to those in September, 1952, (CR 5209). No upwelling was in evidence at either Punta Canoas or Punta Eugenia. California Current water dominated the scene, being found along the entire northeastern shore of the bay to a depth of 50 meters. It was also found beneath the central bay water as a layer 10 meters or more thick. It could be traced as a subsurface layer 20 to 30 meters thick seaward from the northern half of the bay and as a thin sheet to the northern end of Cedros Island.

The central bay water was diluted with California Current water. It had uniform salinity values of 33.35 to 33.40 ‰, and surface temperatures near 20°C. The eddy was displaced to the southern portion of the bay (Figure 10) as contrasted to September, 1952, when it was found to the north (Figure 7). A weak front can be found along its northern edge.

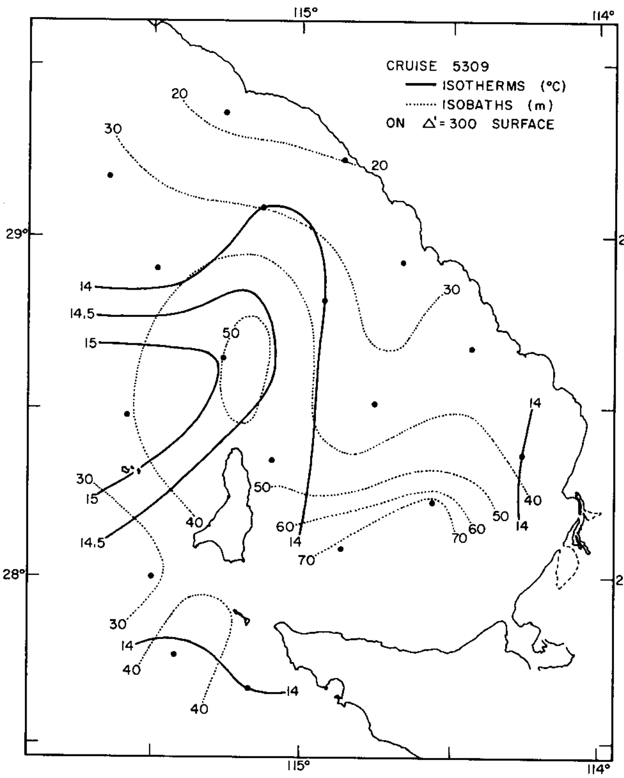

FIGURE 11. Cruise 5309. The depth of, and temperature distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isotherms in °C.)

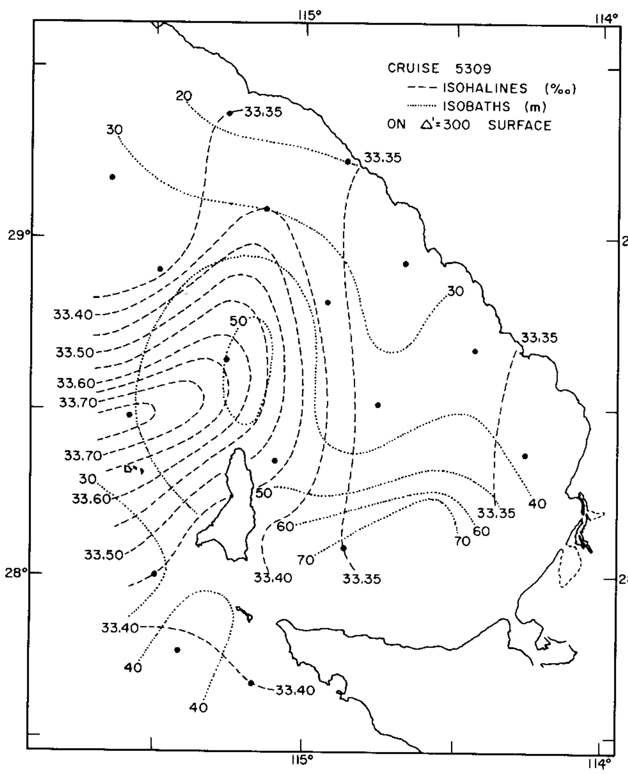

FIGURE 12. Cruise 5309. The depth of, and salinity distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isohalines in ‰.)

As in the 1952 cruises, lagoon water was found along the southern shore line. Temperatures of at least 22°C and salinities greater than 34.00 ‰ are found.

The most interesting feature, however, is the southern surface oceanic water found immediately west of the channels and Cedros Island in the upper 30 to 50 meters. As can be clearly seen on Figures 11 and 12, this warm saline water extends into the bay around the northern end of Cedros Island. Invasion of the bay by water of this type and in this amount could certainly account for any sudden increase in the temperature and salinity values, especially in the surface layers.

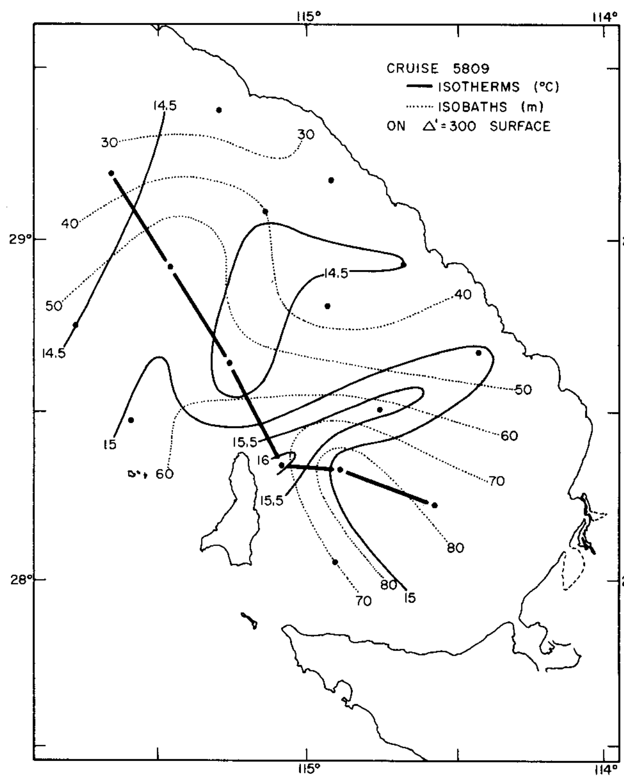

FIGURE 13. Cruise 5809. The depth of, and temperature distribution on, the thermosteric anomaly surface $\Delta' = 300$. (Isobaths in meters, isotherms in °C.)

In September, 1958, (CR 5809), a good example of the influx of deep coastal salinity maximum water into the bay circulation is found (Figures 13, 14 and 15). This is of special interest since it shows this deeper water being injected into the upper (shallow) levels of the bay water and therefore being made available for rapid inclusion in the surface circulation. As is evident from the figures, this water is relatively warm and saline with an exceptionally low oxygen content.

Other special cruises have been made into the bay but the above mentioned cruises give examples and support the hypothesis that the sequence of events of the physical environment, both seasonally and year to year changes can, in part, be explained and described in terms of these water masses and processes.

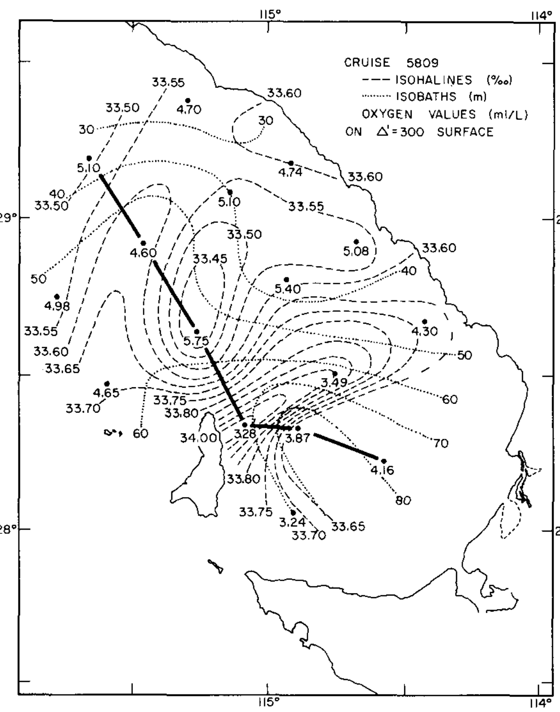

FIGURE 14. Cruise 5809. The depth of, salinity distribution and oxygen values on the thermosteric anomaly surface Δ' = 300. (Isobaths in meters, isohalines in ‰, oxygen values in ml/L.)

SEASONAL VARIATION

In discussing seasonal patterns at any particular point, we wish to delineate between variations which are easily predictable, such as the effect of incoming radiation from the sun and sky, and those which are not. The less predictable events which cause variations throughout the year are the replacement of one water mass by another, plus all the degrees of mixing which attend these changes. The changes we observe are a result of a combination of all these phenomena.

In the upper layers each water mass undergoes its own seasonal changes which can vary to some extent from year to year. These year by year variations can change the characteristics of a water mass, but these changes are not usually so great that the water mass loses its identity. Therefore, even though water mass characteristics may vary, they can still be distinguished from other water masses.

An examination of a monthly plot of surface temperatures for Station 120.30 in the bay, shows the coldest months to be March and April and the warmest, September and October (Fig. 16). This follows closely the 10 year averages for neighboring inshore oceanic stations not in the bay. These stations also show March-April as the coldest period and September-October, the warmest. The bay tends to be 1° or 2°C cooler than the oceanic water outside the bay most of the year. This is probably due to its proximity

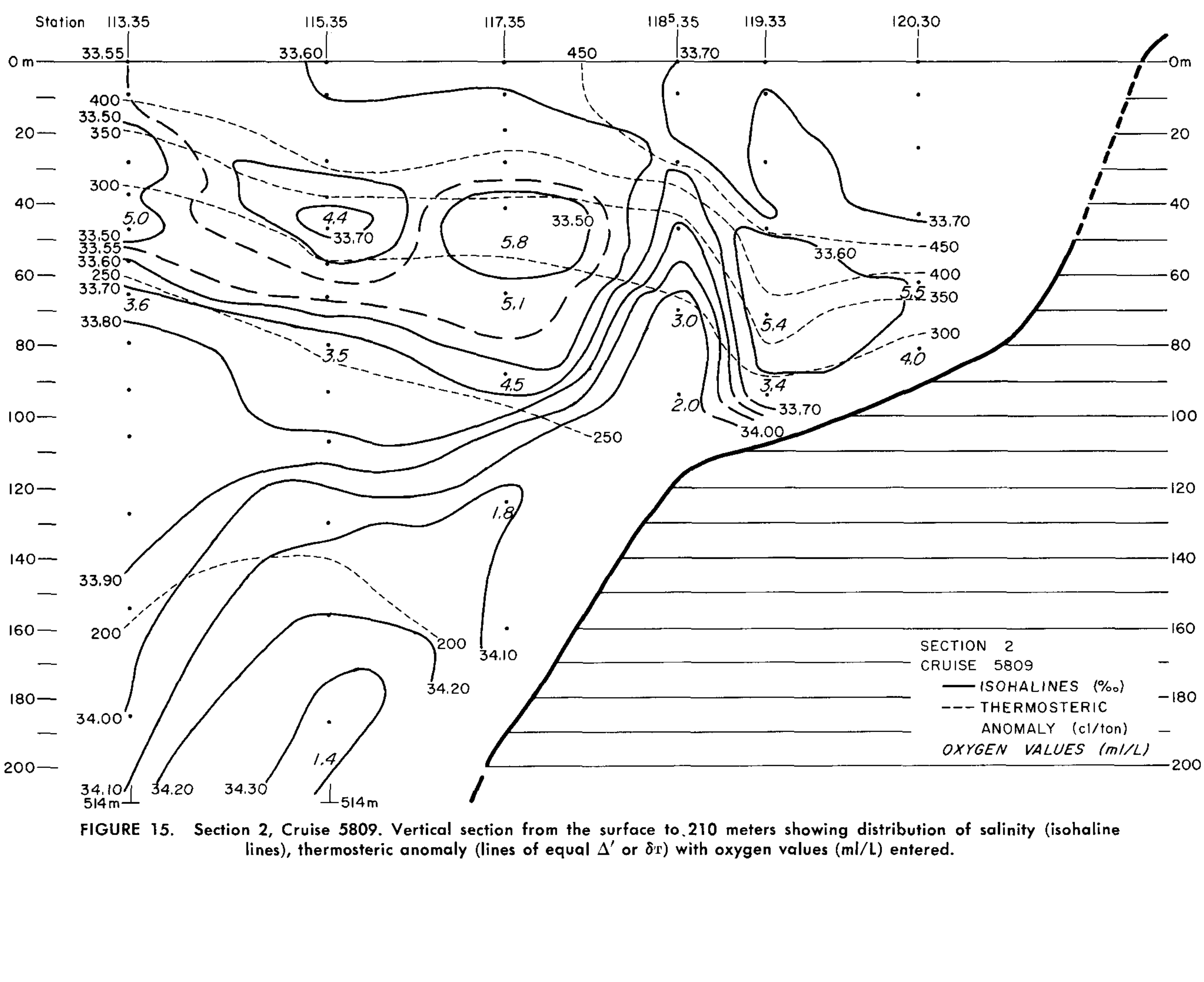

FIGURE 15. Section 2, Cruise 5809. Vertical section from the surface to 210 meters showing distribution of salinity (isohaline lines), thermosteric anomaly (lines of equal Δ' or δ_T) with oxygen values (ml/L) entered.

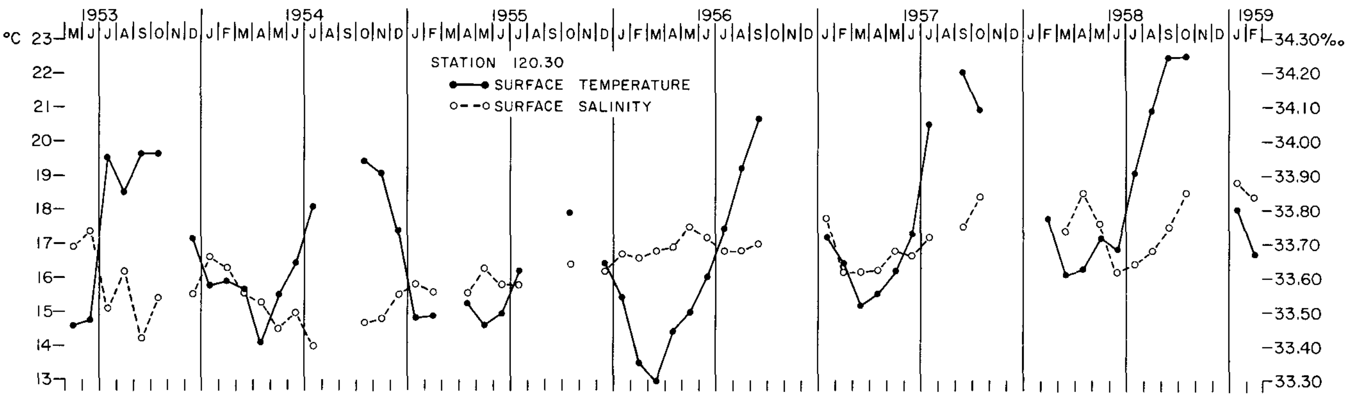

FIGURE 16. Plot of surface temperature and salinity values for each month observed from May 1953 to February 1959 for station 120.30.

to the coastal upwelling area near Punta Canoas. The annual temperature range for the surface layers in the bay is normally 5° to 7°C.

A plot of the salinities for each month does not show any such simple pattern on the average (Fig. 16). If we keep in mind the relative temperature and salinity conditions at any particular location and within a period of time of a few months, at most, so as to eliminate from the discussion longer trends, the presence of a more or less predictable cycle is found.

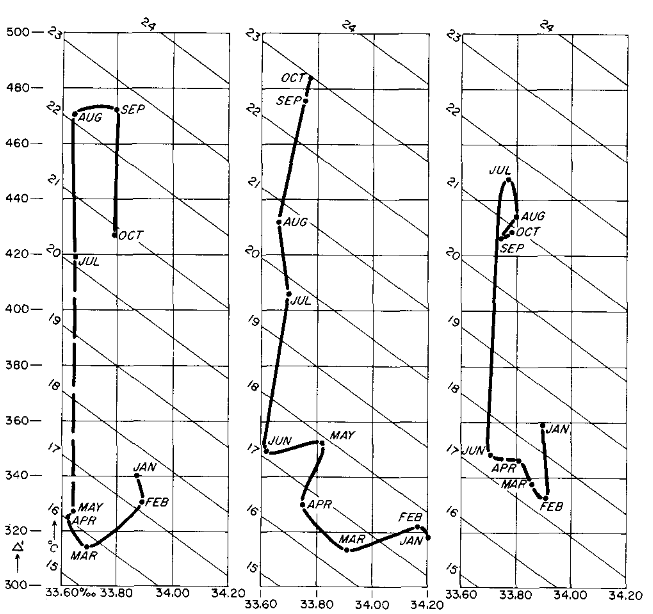

FIGURE 17. Monthly values of the surface temperature and salinity at station 119.33 plotted on a special chart used in the processing of hydrographic data (Klein, MS).

Figure 17 gives some examples of the surface temperature and salinity values plotted on a special chart developed by Klein (Klein, MS). Each point represents the observed value at station 119.33 for a given month. This station was chosen for the illustration since it is centrally located and is usually under the influence of the central bay eddy which in turn seems to reflect the characteristics of the water masses which are dominating the bay at any particular time. Considering the lower points on this graph to be relatively cold, the upper points relatively warm, the points farthest left as having relatively low salinity and the ones to the right relatively high salinity, we can regroup the data into a table showing the relative values, as defined above, from month to month (Fig. 18). This table also includes results from station 120.30. A pattern emerges which can be explained in terms of the water masses and processes defined as available for the bay.

In general, the bay waters are relatively cool from January through June. At the same time the salinity can be either high or low. The water is cold at this time because of two factors. The first is the predictable normal temperature pattern for all waters of similar latitude due to the incoming radiation. The second factor is the presence of coastal upwelling which tends to keep the water cold. Upwelling can and does occur at any time of the year but seems to be most persistent during this period. The salinity variation can be explained by the presence or absence of upwelling or California Current water, or both. With upwelling in progress, a source of higher salinity water is available. Although all upwelled water is not necessarily of high salinity, it usually appears to be in this area. With California Current water present, a readily available source of low-salinity water is found. Therefore these are the dominating factors controlling conditions in the bay from January through June.

The months of July and August tend to be somewhat warmer with low-salinity values continuing. Detailed weather data throughout the year would clarify the picture, but it is proposed that the upwelling process usually weakens at this time, owing to lighter winds. This, in addition to the normal increasing solar radiation, would allow more rapid warming of the mixed layer. The main source of water available to the bay would most likely be low-salinity California Current water. This would account for the relatively warm low-salinity water usually found at this time.

During the months of September through December the bay waters tend to be warmest and most saline, although the warm water is normally in the process of cooling later during this period, especially during December. The higher salinities are most likely the result of advection of water from the coastal regions

Relatively	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
LOW SALINITY	○	○	○	○	○	○	○	○	○				○	○	○	○	○	○	○	○	○			
HIGH SALINITY	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●			●	●	●	●
LOW TEMPERATURE	△	△	△	△	△	△							△	△	△	△	△	△						
HIGH TEMPERATURE							▲	▲	▲	▲	▲	▲							▲	▲	▲	▲	▲	▲

FIGURE 18. Tabulation showing the relative seasonal values obtained from Fig. 17. The data are repeated through a two-year period to show the pattern more clearly.

south of the bay. An example of this type of invasion was described earlier in this report (September 1953, CR 5309).

The cycle begins again with the onset of more wind and consequent upwelling in late December or early January along with normally cooler weather. This sequence is probably oversimplified and may be interrupted but the available data indicate the presence of a basic pattern. If this is the case, a combination of monitoring certain water masses and a good coverage of wind and weather for the bay may be sufficient to follow satisfactorily the changes in the physical environment.

ACKNOWLEDGMENT

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