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RECONNAISSANCE OF THE WATERS AND PLANKTON OF MONTEREY BAY, JULY, 1928

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I. Introduction

The study of the physical and chemical character of the water, and of the plankton of Monterey Bay, described in the following pages, was carried out jointly by members of the Hopkins Marine Station of Stanford University, the Museum of Comparative Zoölogy, the Scripps Institution of Oceanography; and by the California Division of Fish and Game, which made the field work possible by placing at our disposal their patrol boats "Steelhead" and "Albacore."

In this presentation of the general results, our thanks are due to Prof. W. E. Allen for counts and specific determinations of diatoms; Dr. Albert Mann, specific determinations of diatoms; Dr. Tage Skogsberg, determinations of peridinians; to the Scripps Institution for allowing the use of much unpublished data on physics and chemistry of California waters; to Miss Alice Beale, Miss Mary Sears and Mr. C. V. MacCoy for identification of plankton (p. 541). Acknowledgments are also due to the U. S. Bureau of Fisheries, and to the

Scripps Institution for the loan of apparatus. We wish also to express our gratitude to Mr. E. C. Scofield of the Division of Fish and Game for his constant supervision of, and assistance in the boat work; also to Capt. Walter Engelke, and to the crew of the "Albacore," without whose friendly coöperation nothing could have been done.

The equipment consisted of a handwinch, with steel wire, suitable for work to 600 meters, the usual water bottles, deep sea thermometers, and open tow nets.

Determinations of salinity, phosphates, silicates and nitrates were carried out (by Leslie) in the laboratory of the Hopkins Station. The chemical methods are described below.

Counts of diatoms were made at the Scripps Institution.

Thirty-one stations were occupied in various parts of the bay and in its offing, between June 30 and July 24, the results of which are tabulated below (p. 567).

II. Methods and Standards of Accuracy

The observational error for temperature (with the instruments employed) is about $\pm 0.15°$ for the surface, $0.1°$ for the subsurface readings.

Salinities were determined by the titration method developed by the Conseil Permanent International pour l'Exploration de la Mer. The method is now in general use and is accurate to ± 0.03 ‰.

Dissolved oxygen was determined by the Winkler method as described by Jacobsen (1921) and the percentage saturation was computed from the table given by him.[1] By means of a tube attached to the stopcock of the Ekman bottle, the water for the oxygen determination was drawn directly into the sample bottle. The latter was allowed to fill and overflow until it had been thoroughly rinsed of air-contaminated water. Reagents were added immediately and the samples kept in the dark until they were titrated the following day. The experimental error is 0.05 cc. per liter.

Silicate was determined by the Diénert and Wandenbulcke (1923) method as modified by Atkins (1923a). No correction for salt error was made. King and Lucas (1928) have recently pointed out that the concentration recommended by Atkins for the picric acid solution (used as an artificial standard in the silica test) was too great. Com-

[1] The values for 100% saturation given in this table are slightly lower than those found in Harvey (1928) and American Public Health Association (1917) but Jacobsen's table is based on the Winkler method and hence should be used here. See also Jacobsen (1905).

parison of our standards with corresponding ones prepared according to King and Lucas gives a factor of 1.33 by which our values should be multiplied to make them strictly correct. For comparison with the work which has already been done by others on the basis of the old standards we leave our data as originally determined. According to Atkins the figures in the second decimal place are of uncertain significance.

Estimation of phosphate was carried out by the method of Denigès (1920, 1921) as described by Atkins (1923). As Atkins and Wilson (1927) have pointed out, this method is also sensitive to arsenates so that these values represent any arsenate present as well as phosphate. Atkins claims an accuracy of ± 0.001 milligram per liter.

The water samples for phosphate and silicate determinations were analyzed the afternoon of the day they were collected, except one series which was analyzed the following day.

Exceptionally high values of phosphate and silicate were found at stations 25 and 26. Investigation revealed that ordinary plankton bottles with cork stoppers had been used as containers for these two series of samples. Tests with distilled water confirmed our suspicion that phosphate and silicate were dissolved from either the cork or the glass, so the chemical data from these two stations were rejected. The citrate of magnesia bottles used as containers for the samples at all other stations were well seasoned and we have no reason to doubt the reliability of these results.

The method developed by Harvey (1926, 1928a) with the changes described by Moberg (1929) was used for nitrate. A great deal of difficulty was experienced in preparing a suitable reagent and only a limited quantity was finally available. Most of the samples stood from two days to three weeks before being determined. This and the fact that some difficulty was experienced with the colorimeter leave the nitrate values open to some question. However since they give a general idea of the state prevailing at that time, we include them.[1]

[1] For an excellent discussion of methods for the determination of phosphates and nitrogenous compounds in sea water, and for some technical improvements, see Rapports et Procès-Verbaux des Reunions, Cons. Internat. Explor. Mer., **53**, 1929.

III. Topography

Since the oceanographic character of any coastal sector is largely determined by its submarine topography and by the trend of the coast line, we may point out that Monterey Bay is a shallow bight, some twenty miles across its mouth from headland to headland, by about eleven miles deep (Fig. 1). Off the southern headland (the Monterey

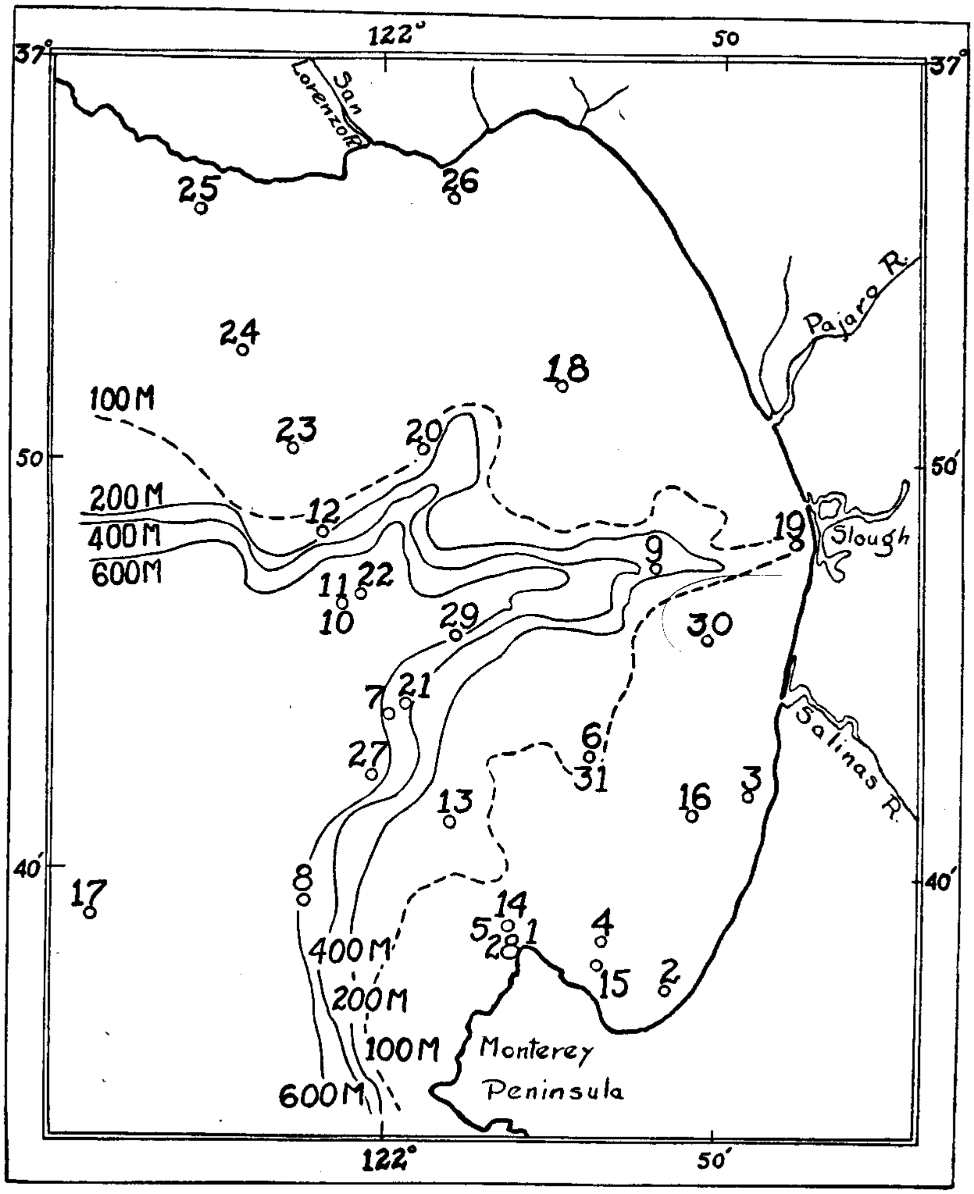

Fig. 1.— Chart of Monterey Bay, showing locations of stations, and bottom contours for depths of 100, 200, 400 and 600 meters.

peninsula), the 200 meter contour — generally taken as marking the edge of the continent — is within $1\frac{1}{2}$ miles of the shore at the nearest point, but lies some $8\frac{1}{2}$ miles out, abreast the northern boundary of the bay. Here, as along the coast of California in general, the slope is steep down to great depths, with 3,000 meters only some 35–45 miles out. The submarine topography of the bay itself is characterized by the existence of a deep, open, submerged valley, extending inward across the bay, a valley often spoken of as the submerged valley of the Salinas River [we express no view as to the geologic implication] because, so far as the general topography of the region is concerned, it seems a submarine continuation of that general drainage system.

At the mouth of the bay this trough is about 1,000 meters deep and about 5 miles broad between the 200 meter contours, narrowing to less than a mile in breadth and shoaling to about 200 meters, at a point about two miles off shore. Its slopes, as indicated on the contour chart (Fig. 1), are much steeper than the slope of the shoaler bottom, either to the north of it, or to the south. Thus any profile of the bay running north and south crosses this deep trough about midway.

IV. Physical Oceanography

A. Temperature

It is now so thoroughly established that the low temperatures of the surface waters along the coast of southern and central California are due to upwelling of colder water from below that no defense of this thesis is required.

In a region of this sort the thermal state prevailing at any given season is instructive chiefly (a) as it affects the environmental character of the region from the biological standpoint and (b) as an expression of the activity with which upwelling has been taking place for some time previous, and of its regional localization.

The first of these requirements demands statement of the prevailing state, especially of the absolute values as well as of the amplitude of variation, at different localities, seasons and depths, as defining the conditions under which the animals and plants of the region actually live, and the fluctuations that they must either endure or in some way be able to escape, as by emigration.

The physical problem involves analysis of the regional variations as associated with other physical and chemical features of the water, also with the topography of the bottom. In the following account these two lines of approach are followed successively.

1. *Midsummer state as illustrated by July, 1928*

Surface

During July, 1928 the extreme recorded range of surface temperature for Monterey Bay (Fig. 2) was from 12.4° to 15.8°, the water

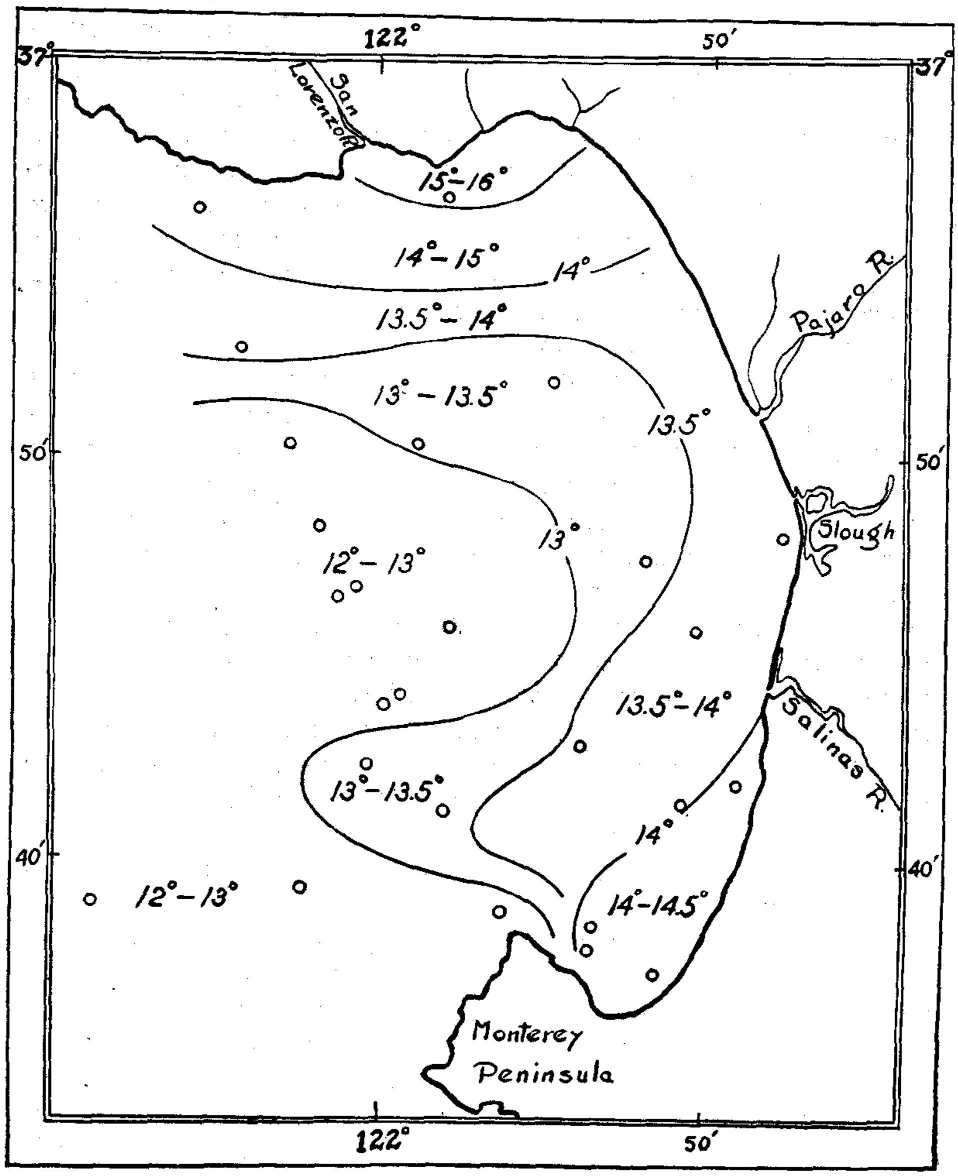

FIG. 2.— Surface temperature, July 1–24, 1928.

averaging coolest (12.4°–13.1°) over the mouth of the deep submarine cañon that gives the bay its distinctive character. Relatively low readings were also recorded close to the shore of Point Pinos at the southern portal to the bay, where local upwellings or turbulence maintained values close to 13° throughout the month as illustrated by the following succession: June 30 (Sta. 1), 13.3°; July 5 (Sta. 5), 12.1°; July 16 (Sta. 14), 12.8°; July 23 (Sta. 28), 12.4°. The warmest surface water (warmer than 14°) was localized (and by local report usually is localized in summer) in the two bights in the southeastern and northeastern parts of the bay, where protection from wave action, combined with shoalness of the water, not only favors heating of the surface by solar radiation *in situ*, but allows the warm surface stratum to accumulate as it is driven inshore by the sea breeze that develops by day along this sector of the coast at this time of year. In fact, local topography would have suggested as much.

It is not unlikely that somewhat higher values than those actually recorded would have been found had we paid more attention to these localities, particularly if we had taken more readings close in to the mouth of the San Lorenzo River. But it seems established, by our own records as well as by local report, that it is only in these sheltered parts of the bay that the surface may be expected to warm above 14° before August. Apparently these warm pools did not connect with each other along the eastern shore at the time.

Fractional differences recorded from day to day at given localities, resulting from disturbances of the water, combined with the general progress of seasonal warming, make it difficult precisely to locate the surface isotherms, from data extending over a period as short as was that covered by our investigations. At the mouth of the bay, for instance, the surface was 13.1° at Station 10 on July 13, but only 12.5° at the same location on the 21st (Sta. 22). The chart of surface temperatures (Fig. 2) is, therefore, only a generalization of the prevalent state for the month.

The mean surface temperature of the bay for July, 1928 was close to 13.4°; the maximum deviation from this mean was 2.4°, or only about 1° if the three warmest stations (temperatures of 15.8°, 14.9°, and 14.9°) be omitted from the calculation. And when it is recalled that these readings extend over a period of three weeks, that they cover an area of about two hundred square miles, and that they were taken at various stages of the tide, sometimes on a rough day, sometimes a smooth, some in fog, others in bright sunlight, and at different times of day, great regional uniformity is evidently characteristic of

Monterey Bay. This, in fact, applies to the whole Californian coast sector, as contrasted with the wide regional variations that prevail along the Atlantic coast of North America at corresponding latitudes.

Subsurface

At the season of our investigation Monterey waters cool comparatively slowly from the surface downward, as might have been expected. This vertical cooling, illustrated by curves for representative stations (Figs. 3 and 4), was, as a rule, most abrupt in the upper 25 meters. At some stations the rate of vertical change was nearly uniform throughout this depth-stratum, at others most rapid between 10 or 15 meters and 25; at others, again, the uppermost stratum (5–10 meters) was more nearly homogeneous as to temperature, while at still other stations a homogeneous layer was recorded at 5–15 meters depth. Station to station differences such as these, in the uppermost 15 meters, no doubt reflect the temporary or local effects of tidal movements, or of the stirring by the waves. But our studies were not sufficiently detailed for analysis of the factors that controlled in any one instance.

On the average the decrease in temperature, with depth from the surface downward to the 25 meter level, amounted in July, 1928 to about 3.3°, the mean temperature at the 25 meter level being 10.1°, the extreme values at that depth 9.1°–11.7°, or omitting the one warmest station (located at the head of the trough close to land) 9.1°–10.9°.

Projection of the 25 meter temperature (Fig. 5) shows a reversal as compared with the surface in the relative locations of the warmest and coldest water at the time, the former being concentrated over the submarine trough at the 25 meter level, instead of over the shoal parts of the bay; especially notable is the accumulation of warm water right up to the head of the trough. This phenomenon, discussed below (page 471), is more clearly demonstrated by a profile (Fig. 6) running out from the coastline at Moss Landing along the axis of the trough, which shows all the successive isotherms as dipping sharply toward the land at all depths from 10 meters down to about 50.

On the average, cooling with depth was considerably less rapid from the 25 meter level downward than above that level, but continued at a nearly uniform rate down to the greatest depth from which we obtained data. Thus an increase in depth from 25 meters to 50 meters corresponded during the period to an average chilling by about 0.7°, the average value at 50 meters (19 stations) being 9.4°. It is also worth noting that the temperature was more nearly uniform regionally (considering the area included) at about 50 meters than at any other level down to considerably greater depths, with an extreme range of only from 9.1° to 10.1°.

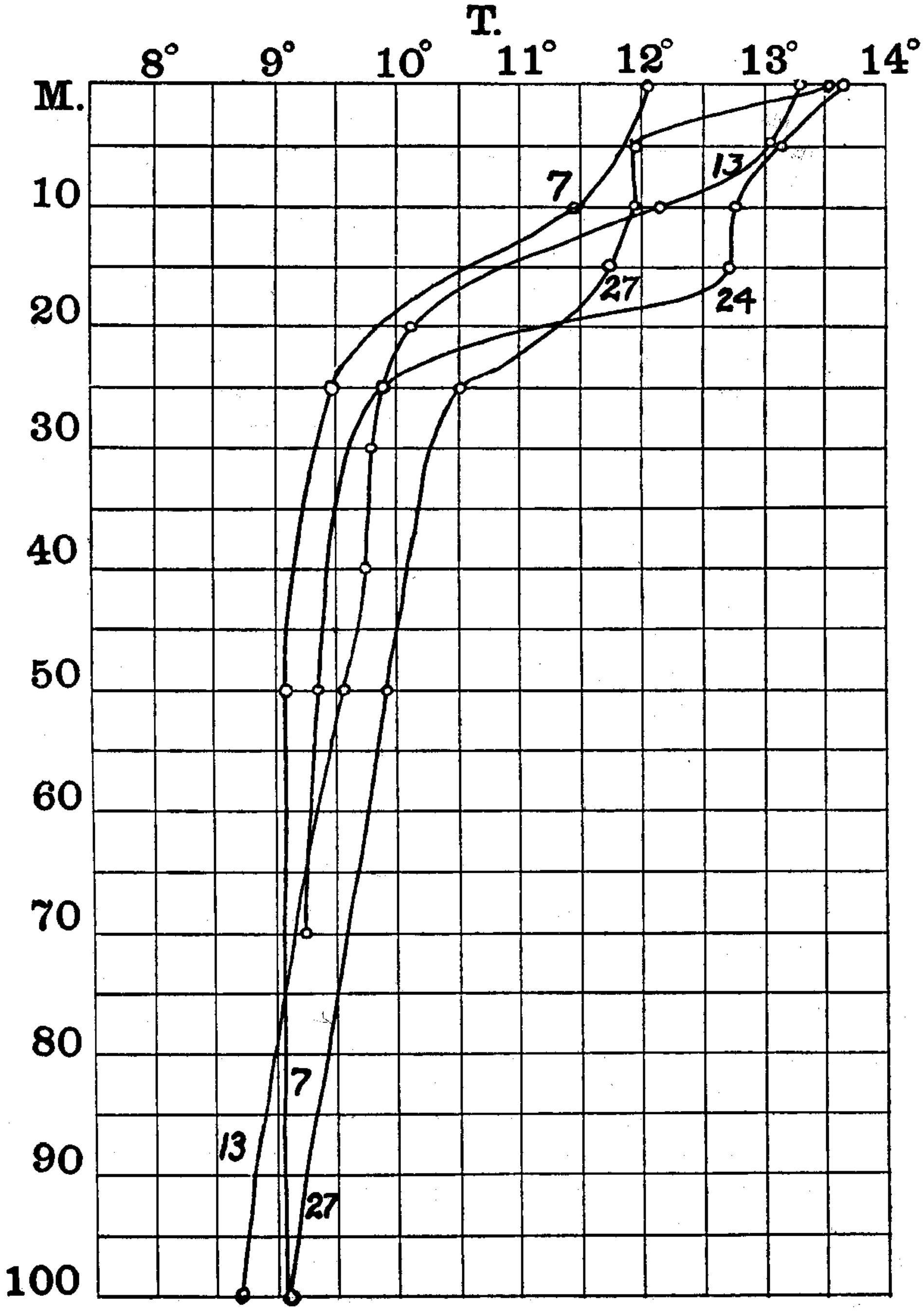

Fig. 3.— Vertical distribution of temperature at representative stations 7, 13, 24, 27) in the upper 100 meters.

Owing to this regional uniformity, projection of the values at the 50 meter level would of itself throw little light on the loci of most active upwelling, for although the isotherm for 9.5° divided the area, into a cooler northern and offshore part and a warmer belt around the

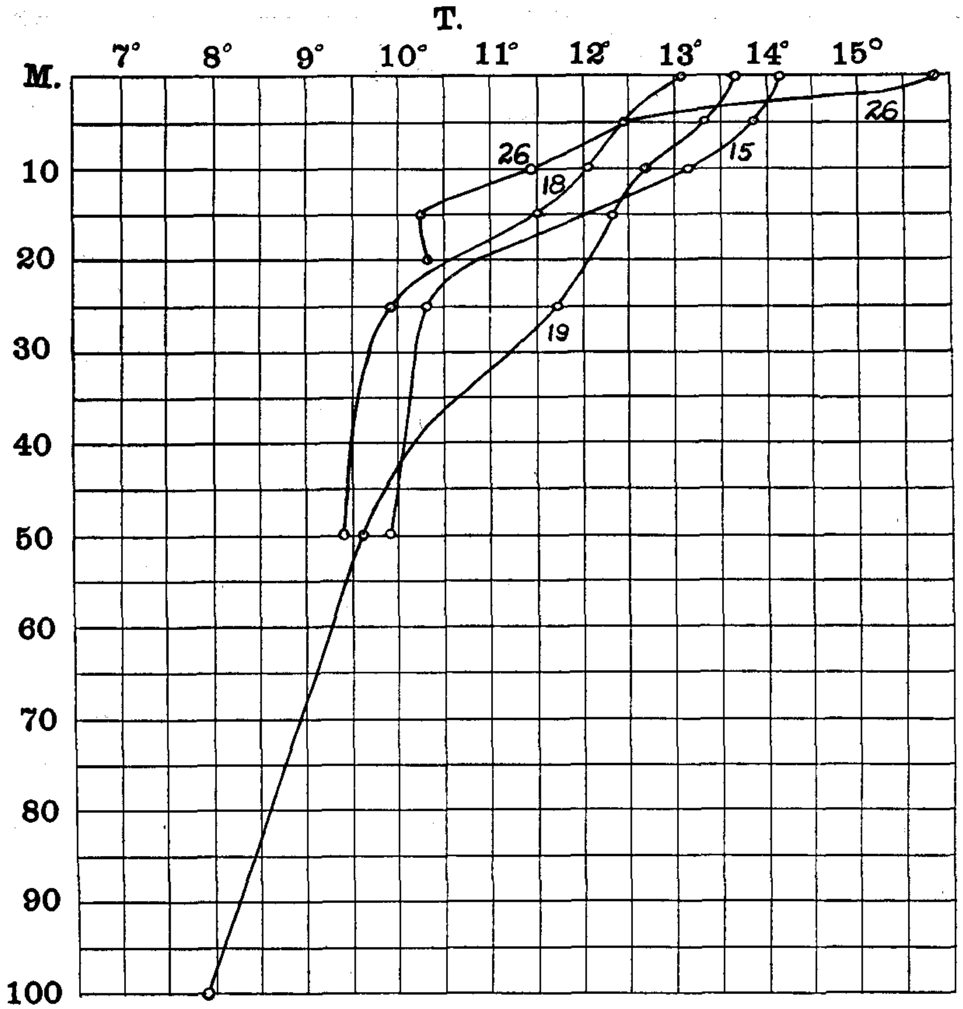

Fig. 4.— Vertical distribution of temperature at successive stations around the shore of the bay (15, 18, 19, 26).

western and southern margin at this level, the difference in the recorded values was so small from station to station, and the observations extended over so long a period of time that they do not give a just idea of the spacial distribution of temperature at this general level. In this case other types of projection are needed. Thus a profile crossing the mouth of the bay from north to south (Fig. 7), for the period July 13–23, shows that within the stratum between the 50 meter and 100 meter levels the successive isotherms for 9° and 9.5°, running

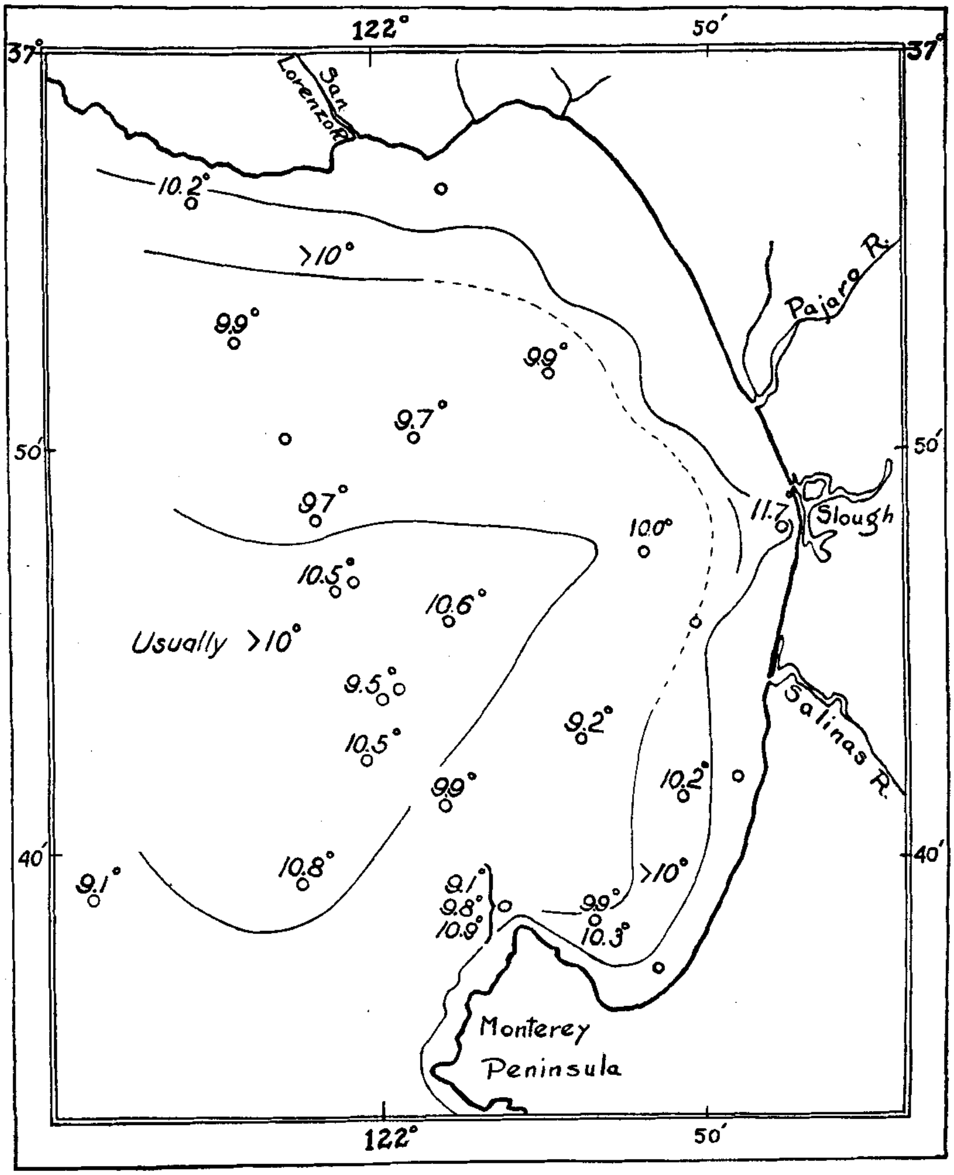

FIG. 5.— Temperature at a depth of 25 meters, July 1–24, 1928.

level across the northern half of the bay, dipped abruptly into the axis of the trough. Had the profile been run a week earlier, when upwelling was more active, as shown by the closer approach of cold

(<9.5°) water to the surface in the trough (Sta. 7), the distribution would have been essentially the same, with the successive isotherms rising closer to the surface over the southern slope (Sta. 7) than in the deep axis (Sta. 10).

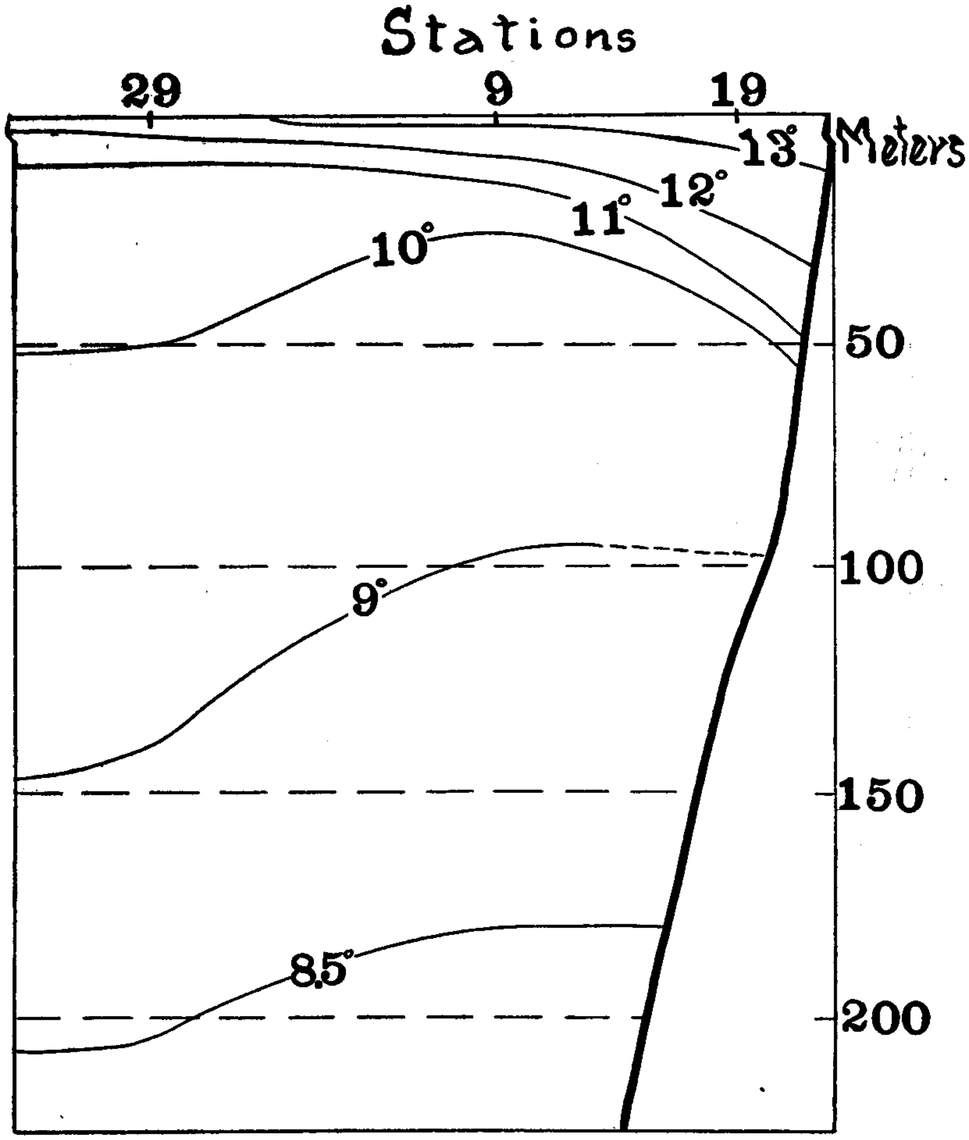

FIG. 6.— Temperature profile, running offshore from Moss Landing, July 12–24.

The average thermal difference between the 50 meter level and the 100 meter level (about 0.6°) was only about one seventh as great as the difference recorded in the equally thick stratum of water from the

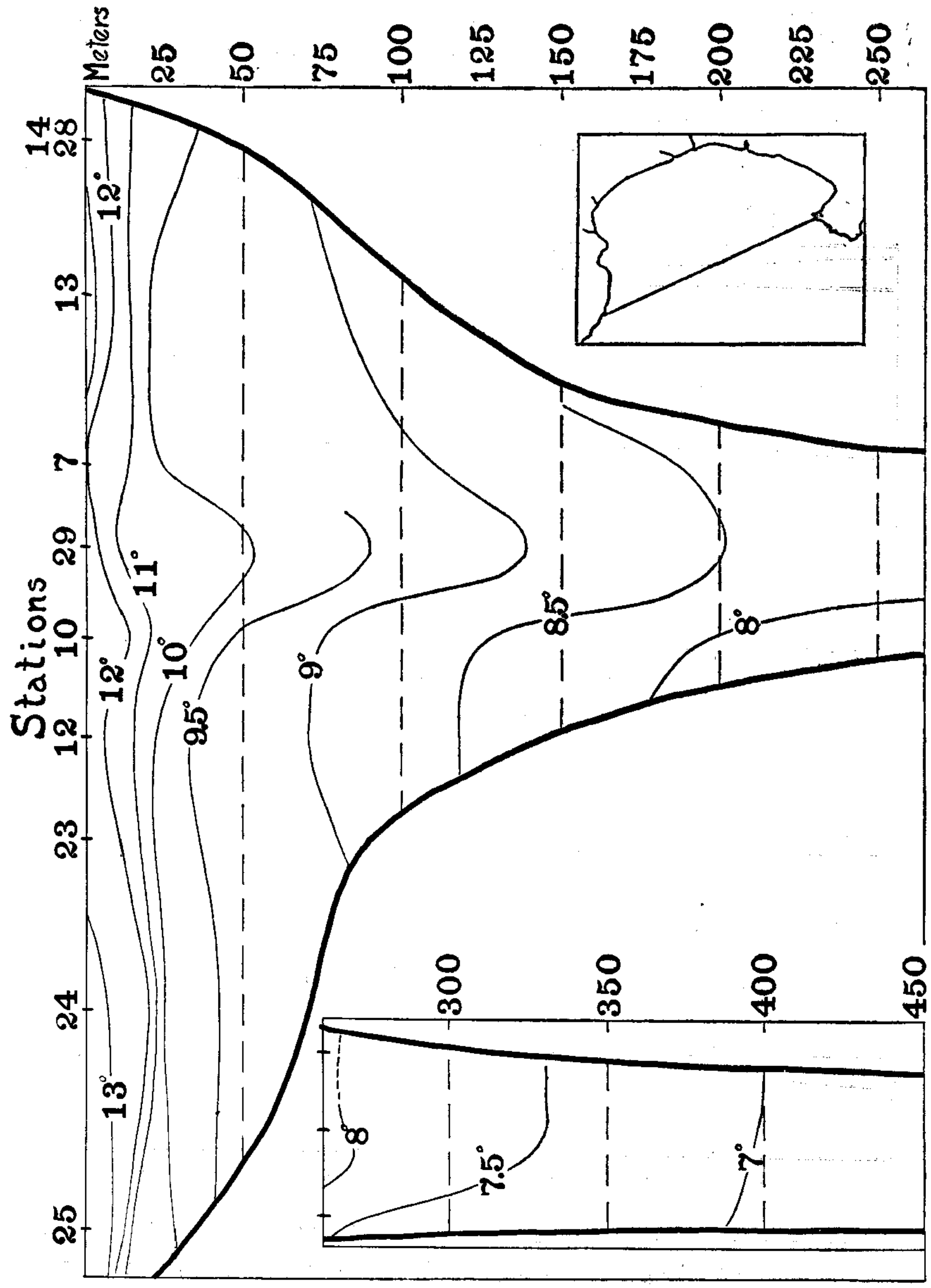

FIG. 7.— Temperature profile crossing the mouth of the bay, July 10–24.

surface downward to 50 meters (4°). The mean value (nine stations) at 100 meters was about 8.8°. But in spite of the contraction of the area at increasing depths, caused by the converging slopes of the submarine

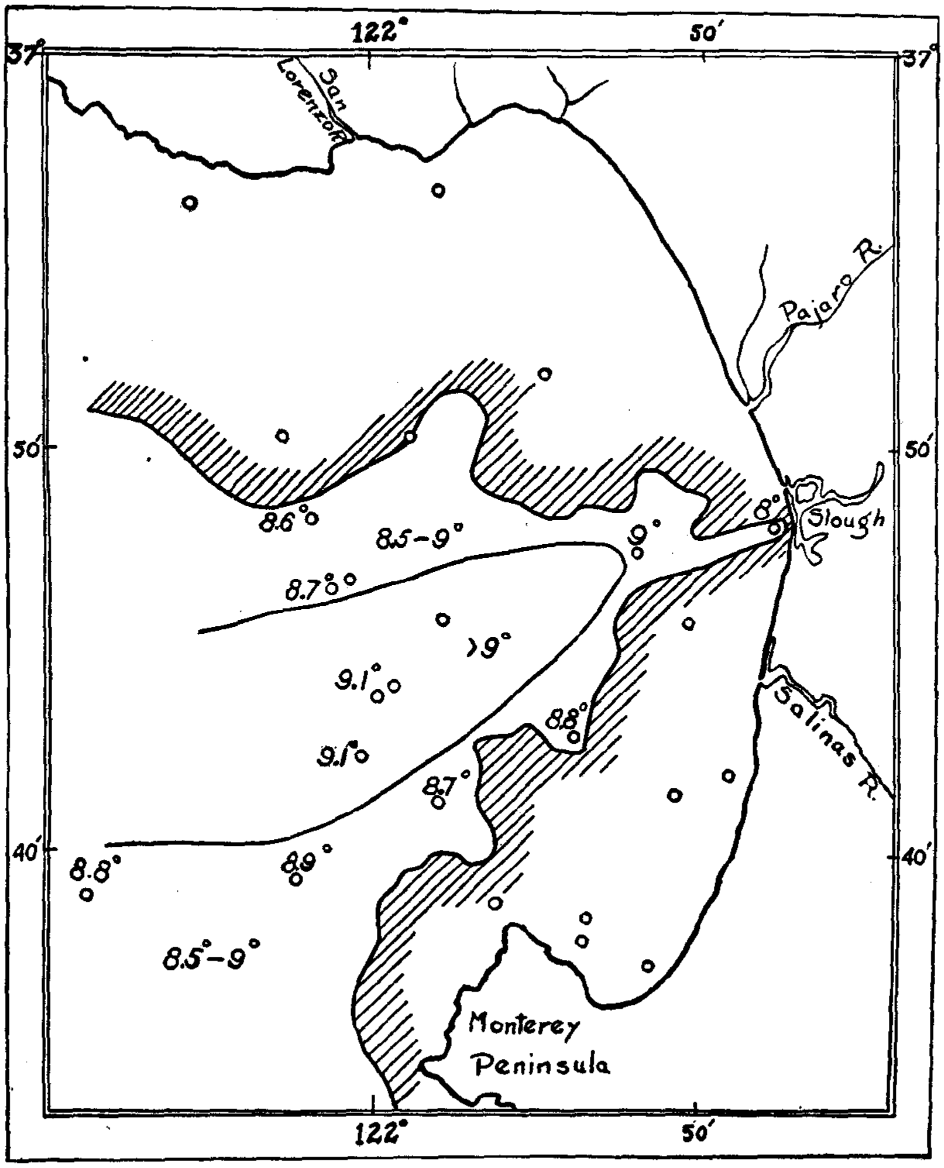

FIG. 8.— Temperature at a depth of 100 meters.

valley, the extreme recorded temperatures were farther apart at 100 meters (7.9°–9.4°) than at 50 meters. Furthermore, horizontal projection of the 100 meter isotherms (Fig. 8) including all the stations, irrespective of date, shows definite localization of the warmest water (>9°) over the axis of the trough, and of colder (<9°) water over its slopes, as already noted for the profile (Fig. 7). The isotherms for 9° and 9.5° also show localization of the updraft of cold water chiefly on the northern side.

Our records for temperature at depths greater than 100 meters are confined to the trough, and to the continental slope off the Monterey peninsula to the south. Within the former, our stations show a banking up of the coldest water against the northern slope (Fig. 7) down to at least 150 meters as illustrated by the isotherm for 8°. But the extreme thermal range recorded at 200 meters (7 stations) was only about 0.4° (8.2°–8.6°), while at 400 meters 3 stations in the trough (10, 27, 29) gave almost precisely the same value (6.9°–7°) as did two stations off the open slope (8 and 17, 6.85° and 6.95°) although the observations covered an interval of twelve days. And regional uniformity in temperature is apparently characteristic of this part of the slope, for it prevailed down to 600 meters (our deepest observations), where readings at two stations in the trough, as well as at one off Point Pinos, were respectively 5.4°, 5.6° and 5.5°, with the curves of vertical distribution for two other stations (8 and 29) suggesting about this same value at that depth (Fig. 9).

It is, of course, desirable to establish whether an average temperature close to 5.5° is typical of the 600 meter level across the Monterey front, not only in other seasons, but from summer to summer, or whether the state prevailing in July, 1928 represents any considerable departure from the normal one way or the other. Unfortunately no recent serial observations as deep as this are available for comparison for considerable distances to the north, to the south, or offshore from Monterey Bay. Neither did the "Albatross" take bottom readings at the 600 meter depth during her dredging campaigns in the bay in 1890, 1891, or 1897 (Townsend, 1901). But graphs constructed from her bottom readings in shoaler and deeper water suggest a mean 600 meter value close 5.6° C.; which corresponds almost exactly with the "Albacore" values of 1928.

In 1873 the "Tuscarora" made several serial determinations of temperatures off the Monterey peninsula which suggest a temperature about 1° lower (mean, 4.8°C.) than either the "Albatross" or "Albacore" values. But for instrumental reasons (page 466) it is not possible to judge how closely comparable these early observations are with the more recent ones.

2. *Seasonal variation*

It is not possible to reconstruct the normal seasonal variation of temperature below the surface of Monterey Bay from the few scattered bottom readings taken prior to the "Albacore" investigation.

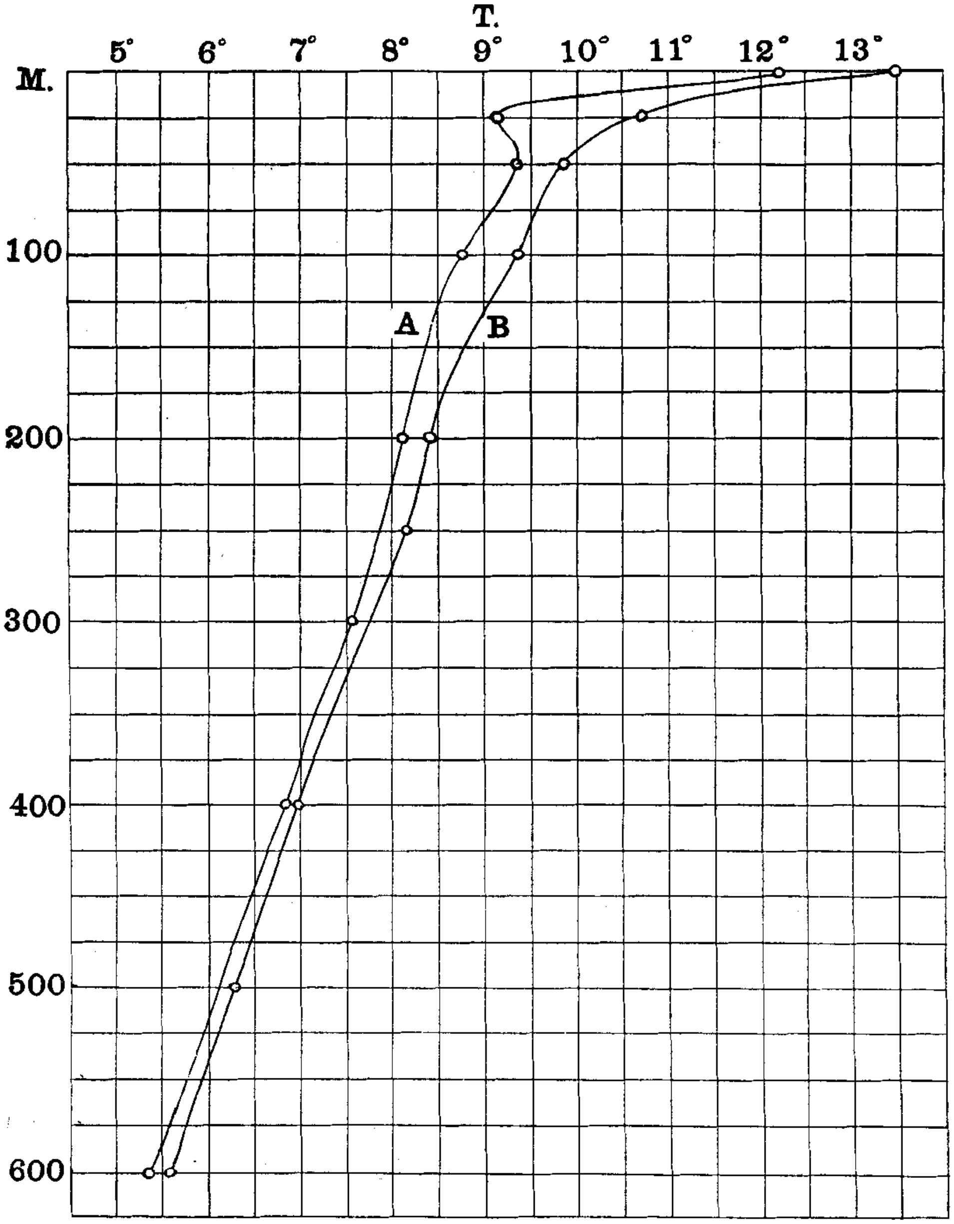

FIG. 9.— Maximum (B) and minimum (A) temperatures, surface to 600 meters, at Stations 8, 10, 17, 27 and 29.

But daily readings (Fig. 10) taken at the Hopkins Marine Station at Pacific Grove, on the south shore of the bay, during the years 1919–27 (Dorman, 1927a; Hubbs and Schultz, 1929), afford a good picture of the seasonal range of surface temperature at this inshore location [1] with some indication of the annual fluctuations that have taken place there, within that period.

It is, of course, a matter of deduction how closely readings for this locality, subject to all the disturbing effects of the coastline, can be accepted as typical of the bay as a whole. In July, 1928 the weekly averages there were 13.5°, 12.6°, 12.7° and 12.4°; contrasting with our readings of 14.2° and 14.9° about a mile offshore on the 3d (Sta. 4) and 17th (Sta. 15), and with a general average of 13–14° for that side of the bay for the month. This suggests that fractionally lower readings may be expected close to the tide line than out in the bay, in summer, as was to be expected from the stirring effect of the tide. But the difference is not great enough to rob the laboratory data of their illustrative value for the bay as a whole, with the important proviso that these inshore temperatures may show day to day and week to week fluctuations that do not parallel the surface temperature variations out over deeper water. Such a difference is, of course, to be expected, as is the case along almost any coastline where in- and offshore movements of the warmest surface stratum, caused by wind or tide, alternately bring relatively high temperatures close into the beach, or cause somewhat cooler water to well up from below when the warm stratum shifts out from the tide line. Bathers are perfectly familiar with this phenomenon wherever the surface is appreciably warmer than the underlying water in summer.

In regions where the range of temperature from winter to summer is wide, as it is around the coastline of the northern North Atlantic, day to day fluctuations of this sort usually are narrow, as compared with the seasonal progression, as illustrated, for instance, by the temperature graphs that have been published for Woods Hole (Sumner, Osburn, and Cole, 1913; Fish, 1925). But in regions such as Monterey Bay, where the seasonal swing is small, it is not surprising to find the week to week variations, caused by local events, exceeding the mean seasonal deviation for the year. In the year 1927, for example, the temperature at the Hopkins laboratory rose by about 3.5° during the month of October (fortieth to forty-fifth week); then fell again by about 2.5° within the next four weeks; while in 1919 an equally abrupt decline

[1] These readings were taken in a sheltered cove within a few yards of the shore, in water less than three feet deep.

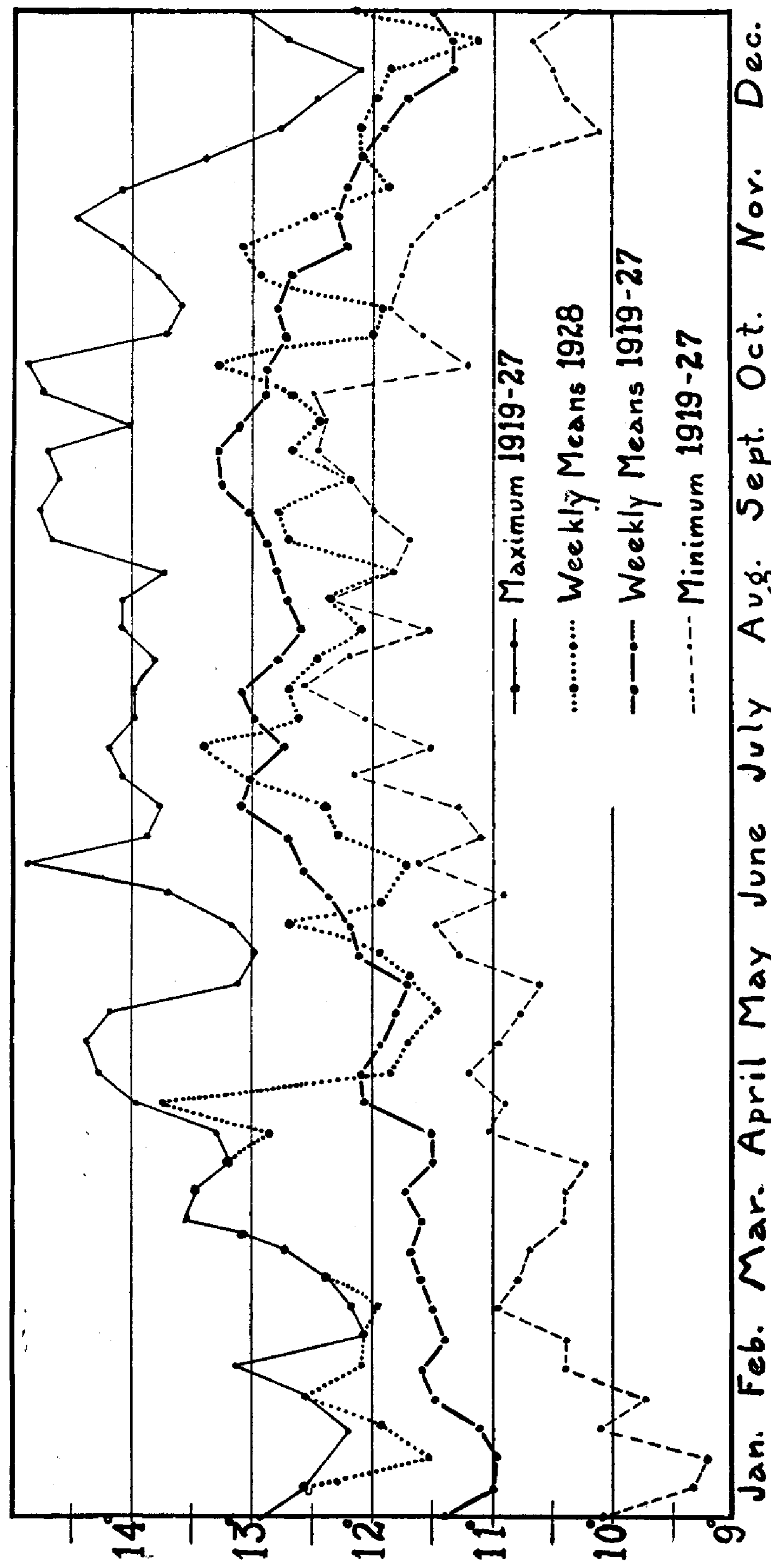

FIG. 10.—Seasonal progression of surface temperature at Hopkins Marine Station; light curve, maximum weekly means 1919–1927; broken curve, minimum weekly means; heavy curve, average weekly means for the period; dotted curve, weekly means for the year 1928.

of 1.8° was reported from the fortieth to the forty-sixth week, followed by almost as abrupt a recovery, although the mean annual range for the whole nine year series is only about 2.5°. The year 1928 again showed a sudden cooling by about 2° during April (Fig. 10), from the fifteenth week to the seventeenth, although gradual warming is the normal event at that season. Furthermore, there is no apparent consistency from year to year in the ups and downs, the curves for the several years crossing and recrossing one another as is better shown on the graph (Fig. 10) than verbally. Dorman (1927a, p. 85, Fig. 3) has already illustrated these sudden shifts of temperature for the 1923 series at Pacific Grove, and similar events are no less characteristic for the vicinity of La Jolla,[1] hence they are evidently characteristic for the coastline of southern and central California as a whole.

But in spite of the abrupt peaks and valleys that would characterize temperature graphs for the individual years, and in spite of the relatively considerable differences from year to year, in the values for given weeks, the trends for all but one of the years are roughly parallel (Fig. 10). And since this series covers nine consecutive years, the average thermal succession illustrated, namely coldest (averaging close to or slightly above 11° in late December and in January, warming progressively to an average maximum of about 13.5° in August and early September, to cool again at about the same rate throughout the autumn, may be accepted as characteristic.

The normal annual range for Monterey Bay is thus only about 2.5°, the extreme range that appears in the seven year series of weekly averages was about 5.6° (Fig. 10). The maximum deviation recorded in any one week of the series is 3.9°. Although deviations of 2° or more, within a single week, may be expected at any season of the year, having been recorded in every month except March, they have occurred most frequently in April, May, June, and July, when a total of twenty-seven such events has been recorded, contrasted with fourteen instances for other times of year. They are thus most frequent during the season of vernal warming, and when the temperature of the surface water is at its maximum, i.e., when the vertical gradient of temperature is steepest, as was to be expected if our explanation of their origin as due to local updrafts or churnings be correct.

At La Jolla, about 3° 45′ of latitude to the south, records taken by the Scripps Institution at their pier show the surface averaging coldest somewhat later in the winter (January and February), warmest some-

[1] See, for example, Allen, 1927, p. 35.

what earlier (July and August), and with a wider annual range (about 10°).

With respect to the annual range of surface temperature, the Monterey sector (like other similar areas in mid- or high latitudes where mass upwelling prevails) is the antithesis of waters at corresponding latitudes off coasts where the continental shelf is wide, and where the geographic situation is such that the interplay between local solar warming and winter chilling chiefly controls the thermal complex. Compare the seasonal curve for Pacific Grove with parts of the Gulf of Maine, for example, or with the southern side of the Gulf of St. Lawrence where the average range of surface temperature is close to 20°.

3. *Year to year variations*

The graph (Fig. 10) shows that the deviation in surface temperature from the mean over a term of years at Pacific Grove averages about 1° in each direction. During the period of record the greatest weekly deviation, above and below the mean, has been about 2°. And since no extraordinarily cold or extraordinarily warm years fell within the nine year period, even for the surface waters, it is evident that such events very seldom chance in this locality, if ever.

Hubbs and Schultz (1929) have already pointed out that 1926 was an abnormally warm year from January to May, but slightly colder than normal from June to November. The year 1928 was of this same type (Fig. 10), the weekly means averaging about 0.5° above normal during January, February and March. From mid-April until about mid-July, 1928, can be described as a normal year, with some of the weekly means falling above, others below the average curve. During August and September the means for 1928 averaged about 0.5° low, but these again rose fractionally above normal during the late autumn. Deviations of this sort, and at these particular times of year, make 1928 notable, among the years of record, by a seasonal trend more nearly horizontal than usual, for the spread between the maximum and minimum weekly means for that year (about 2.6°) is considerably less than in several of the other years of record (about 4° in 1920), with the highest and lowest points of a smoothed curve for the year 1928 only about 1° apart, contrasting with the usual range of 2.5°. Furthermore the regular seasonal progression exhibited by the records for all the other years (p. 448) was hardly apparent for 1928, when the mean temperature for winter and early spring was about as high as the midsummer mean, instead of something like 2° lower as is the usual case, and with the water coldest in late spring when in most years vernal warming takes place.

4. *Comparison with southern California waters*

The contrast between the seasonal trend of surface temperature at Monterey, and in the offing of La Jolla, has already been referred to (p. 448). In summer McEwen's graphs (1916, pl. 34, 36) show the water in the vicinity of the Coronado Islands averaging about 7° warmer than Monterey Bay at the surface. If the subsurface temperature for July, 1928, can be taken as representative, the more southern locality is 2°–3° warmer at 50 meters, about 1.5° warmer at 100 meters, 1° warmer at 200 meters, fractionally warmer at 400 meters and at 600 meters. But temperatures recorded by the U. S. S. "Albatross" [1] at stations off Lower California, and off Santa Barbara in October, 1916 at 600 meters (5.7°, 5.75° and 5.6°), agree almost exactly with the 600 meter readings off Monterey Bay in July, 1928. No comparison is yet possible for other times of year, lacking subsurface data for Monterey Bay for any month except July, or for any other year.

B. Salinity

1. *Surface*

Midsummer, 1928

The surface waters of Monterey Bay were characterized in July, 1928, by remarkable uniformity in salinity, regionally considered, the maximum range recorded at that level being only .11 ‰ as shown in the following table of maximum, minimum, and mean values for different levels.

Depth Meters	Maximum	Minimum	Mean	Spread	No. of Stations	No. of Stations falling within ±.02[2] of the mean value	Mean Increase with depth
Surf	33.91	33.80	33.87	.11	26	19	
25	33.98	33.73	33.88	.25	20	11	.01
50	34.11	33.89	33.95	.22	18	11	.07
100	34.04	33.96	34.00	.08	10	3	.05
200	34.11	34.04	34.07	.07	5	4[3]	.07
400	34.22[3]	34.18	34.20	.04	4	3	.13
600	34.29	34.29	34.29	0	3	3	.09

[1] From data compiled by S. W. Chambers, 1929.

[2] This deviation is chosen because corresponding to the probable error of chlorine titration.

[3] Two stations by direct observations; two by interpolation.

The station to station differences are so small (when the experimental error of ±.02 is taken into account) that no definite subdivision of the surface into salter and fresher regions could be definitely established at the time, the recorded values being slightly higher at some stations, slightly lower at others near by, as would naturally be expected to result from wave action, tidal movements, etc. As further illustration of this regional uniformity, we need only point out that a profile from the southern headland of the bay to the northern (Fig. 15) shows no definite succession at the surface, most of the recorded values being almost precisely identical, while on lines from Monterey Harbor out to the continental slope the surface readings at six stations (2, 4, 8, 15, 17, 28) were precisely alike (allowing for the probable error), i.e., 33.86–33.89‰, though covering an interval of twenty-three days.

Even within a mile or so of the coastline, the surface water was not measurably fresher than in the central parts of the bay, while water samples taken daily at the landing of the Hopkins Marine Station show that this generalization can be extended right in to the tide line at this time of year, at least for this side of the bay. Thus at the time of our offshore investigations, the weekly means at the Hopkins Marine Station were 34‰, 33.93‰, 33.93‰, 33.86‰, giving an average for the month of about 33.92‰, corresponding closely with the average (33.87‰) just stated for the bay as a whole. The slightly higher mean for the first week of the period (34‰) probably reflected some local and temporary updraft over this sloping beach.

But the weekly averages at the Hopkins station, computed from readings taken there since 1919, show that much more violent fluctuations in the state of the water take place there within periods of a few days, than we encountered anywhere in the open bay during the whole month of July, 1928. The weekly variations for the month of July are as follows:

Year	Range	Year	Range	Year	Range
1919	.08‰	1922	.18‰	1925	.10‰
1920	.19‰	1923	.17‰	1926	.06‰
1921	.11‰	1924	.11‰	1927	.12‰

This considerable range of variability in the inshore waters for the month of July does not, however, reflect any prevailing increase or decrease throughout the month, the trend being practically horizontal at this time of the year as described below (p. 452).

Sporadic alterations of this sort are to be expected in the salinity of the water close to the coastline, in any region where the column is characterized farther offshore by an increase or by a decrease in salinity, with depth. They are evidence of movements of the surface water in- and offshore, with corresponding updrafts from below, just as are the corresponding short-time alterations in surface temperature (p. 446). In the summer season it should be easier to correlate these local alterations with their causes (winds, tides, etc.) in regions like Monterey Bay where land drainage and rainfall are both negligible for a considerable portion of the year, than it is along coastlines where rivers discharge at all seasons, and where rainfall is more evenly distributed. In the former case vertical displacements chiefly need be taken into account; in the latter horizontal as well.

Seasonal variation at the surface

The uniformity that characterized the surface salinity, not only over the bay as a whole but also at the Hopkins Station, throughout July, 1928, together with other evidence shortly to be mentioned, shows that this is a season when the trend of surface salinity is practically horizontal; hence the "Albacore" observations throw no light on seasonal variation. For this we must turn to the daily readings that have been taken at the Hopkins Marine Station since 1919, just mentioned. And although the day to day, and week to week fluctuations are considerable there for salinity just as they are for temperature (p. 446), the fact that the mean value for the four weeks of July, 1928 (33.92‰) was almost precisely the same there as at our stations farther out justifies acceptance of the general seasonal trend of salinity at the Hopkins Station as representative of the bay as a whole.

Weekly averages at the station show a regular seasonal progression, with the surface averaging least saline from mid-February to mid-April (about 33.2–33.3‰), increasing comparatively abruptly in salinity through May and early June to a maximum (average about 33.7‰) which, in most years, was reached about the middle of that month. Little change then takes place through July and August, after which the salinity decreases slowly and at a comparatively constant rate throughout the autumn and early winter (Fig. 11).

On the whole, this seasonal progression corresponds to the seasonal distribution of the discharge from the Salinas River, most of which is condensed in the months of November, December, January, and February, according to the following measurements taken near its

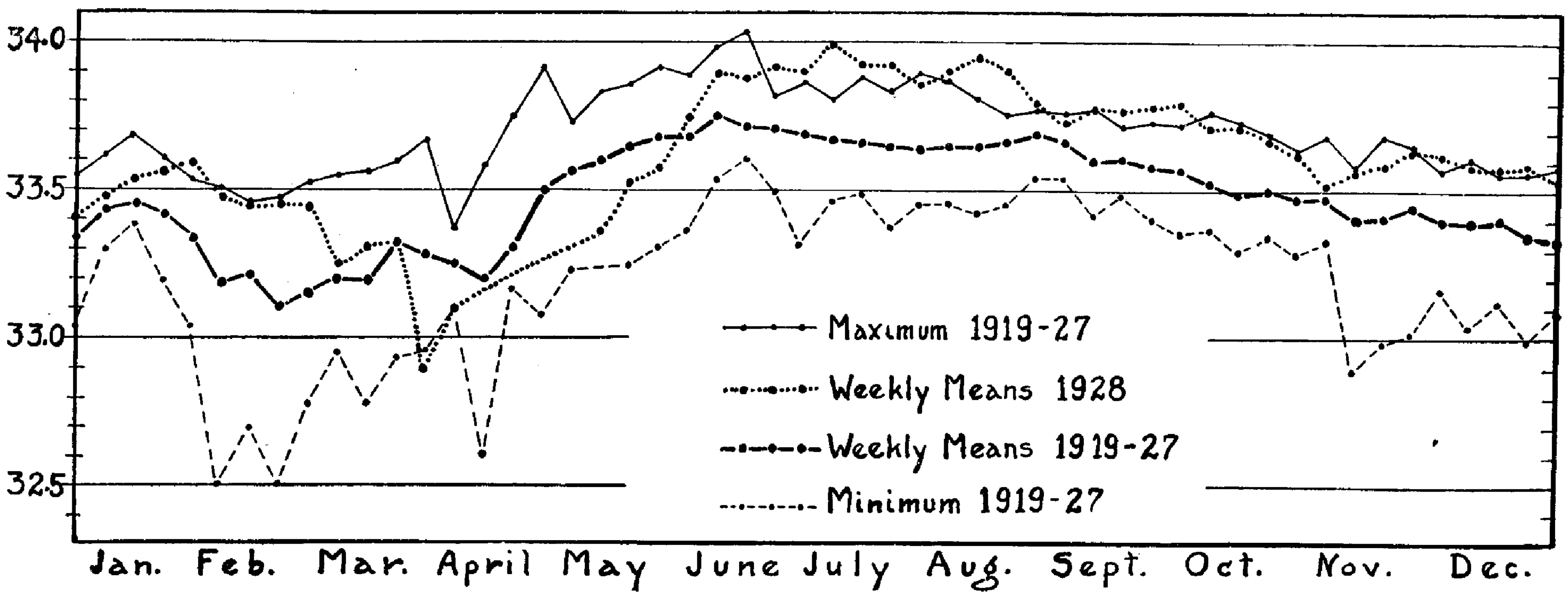

FIG. 11.— Seasonal progression of salinity at the Hopkins Marine Station; light curve, maximum weekly means, 1919–1927; broken curve, minimum weekly means; heavy curve, average weekly means; dotted curve, weekly means for the year 1928.

mouth by the U. S. Geological Survey in 1900 (Hamlin, 1904, Van Winkle and Eaton, 1910).[1]

Month	Mean discharge
January	848 ft. per second
February	105
March	73
April	22
May	17
June	16
July	8
August	7
September	6
October	2
November	2,413
December	295

The decrease that takes place in the salinity of the bay during the autumn and early winter probably reflects this local source. An increase, which seems a normal event because something of the sort took place in seven of the nine years of record, is shown from the first to the third week of January. Active upwelling at the time, interrupting the progressive incorporation of land water, would effect an alteration of this sort. And comparison with the corresponding weekly averages of temperature suggests this as its cause, because in six of the seven years it was accompanied by a fall in temperature, such as would result from an updraft in a region where the surface does not normally chill to the temperature of the underlying water even at the coldest season.

One other feature of the seasonal progression of salinity remains to be mentioned, namely, much greater variability from week to week during the half of the year when salinity is near its minimum than during the period of maximum salinity (Fig. 11). No doubt when the surface is flooded with land water the vertical gradient of salinity is considerably steeper than it is in summer. In this case that any displacement of the water in and out from the shore, or any churning by storm winds, would be much more clearly reflected along the shore by an alteration in the salinity than is the case when the whole column of water so affected is more nearly homogeneous vertically. The ups and downs that would be recorded on the curve for any one individual

[1] No data as to the volume of flow are available for the other rivers tributary to Monterey Bay, but as this reflects the seasonal distribution of rainfall in the mountains, probably it agrees with that of the Salinas River.

year (Fig. 11) may thus be interpreted as reflecting, in a sense, the incorporation into the general mass of the land water and of rainfall. The more completely has this incorporation taken place, the more nearly uniform from day to day may we expect to find the salinity of the water as it flows in and out over the beach.

2. *Subsurface, July, 1928*

When the vertical distribution of salinity is plotted for our stations it is at once apparent that while in every case the water was considerably more saline at 50 meters or deeper than at the surface the distribution in the uppermost stratum was of two different types. At most of the stations either the uppermost 25 meters was close to homogeneous as to salinity, or a slight increase of salinity was recorded from the surface downward. But four stations in the central part of the bay showed an unmistakable minimum-layer, at depths of 5 to 25 meters, where the salinity was lower than at the surface. At one of these (10) this layer was recorded at 10 meters (0.06‰ less saline than the surface), below which salinity increased. At another station (12) there were two such strata of low salinity, one at 5 meters (0.13‰ fresher than the surface), a second (0.18‰ fresher than the surface) at 25 meters. At the third station of this group (18) the upper 5 meters of water were homogeneous, with water 0.07‰ less saline at 25 meters; while at the fourth station (9), the upper 10 meters were homogeneous, the 25 meter level somewhat fresher, with a comparatively abrupt increase in salinity from that level down to 50 meters (Fig. 12).

When plotted horizontally, whether for the 5 meter, or for the 25 meter level, it appears that these stations showing a minimum layer fell into two separate and discontinuous regional groups. It is not clear whether Stations 10 and 12 represented a circumscribed pool, or whether they reflected the inshore edge of a more extensive area characterized by this type of vertical distribution. But it seems certain that Stations 9 and 18, closer to the land, did fall within such a pool, with a rather definite minimum layer centering at about 25 meters.

With only one month's data, it is of course an open question whether such a minimum stratum is characteristic of the locality and season, or whether it represented an unusual state. However, there is nothing novel in the discovery of layers or pools of low salinity of this sort, at small depths below the surface off the coast of California, for a minimum layer, centering at about 30 meters depth, is characteristic of the offing of southern California in general, in summer, as described by McEwen (1916) and by Moberg (1928).

McEwen (1916) has discussed in detail the balance of forces, namely upwelling from below, evaporation from the surface, solar heat,

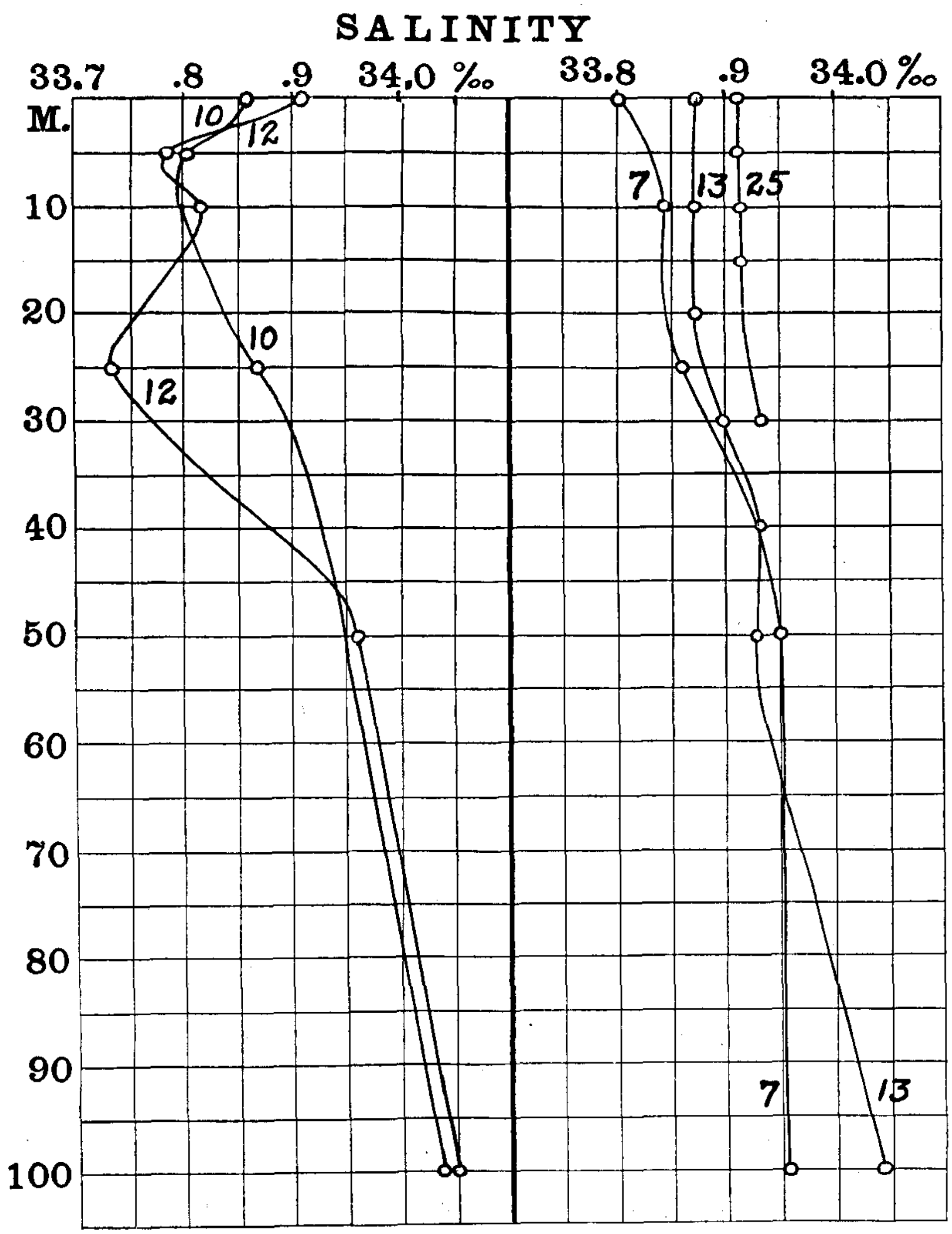

Fig. 12.— Vertical distribution of salinity in the upper 100 meters at representative stations (10, 12; and 7, 13, 25).

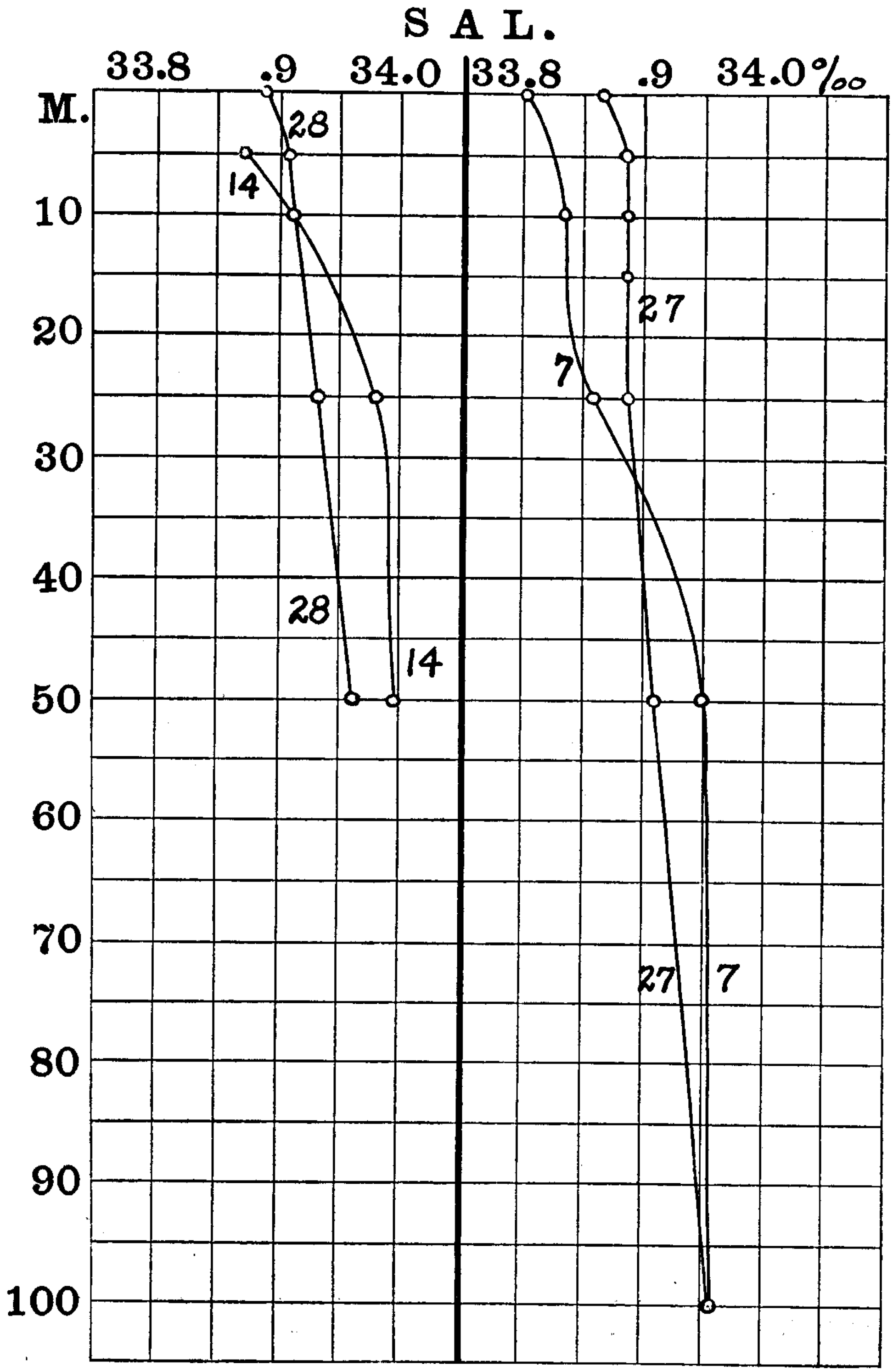

FIG. 13.—Vertical distribution of salinity in the upper 100 meters at pairs of stations off Point Pinos, July 16 and 23 (14, 28); also at the mouth of the bay, July 10 and 23 (7, 27).

convection, and salt diffusion between strata differing in osmotic pressure, by which such a layer might, theoretically, be maintained, once it had in some way been established, but so far as we have been able to learn, no explanation has been offered for its origin.

On this the profile recently run by the Carnegie expedition from San Francisco to Hawaii may be expected to throw light. One possible source is a subsurface drift of low salinity from the north. Local events may also tend to produce the phenomenon in question, in this particular situation, for the general situation with regard to the seasonal increment of fresh water is so similar all along the California coast as to make it justifiable to argue from analogy with the state prevailing at La Jolla where the winter freshening involves the whole upper stratum down to a depth of 100–150 meters and where, as McEwen (1916) shows, the upper 50 meters are nearly homogeneous as to salinity from November through February, though with some slight indication of the 30 meter minimum even at this season.

Evaporation proceeding at the surface during the spring months, after the contribution of fresh water diminishes practically to *nil*, must then increase the salinity of the surface water, and so directly tend to produce the type of vertical distribution now under discussion, stability being maintained by the thermal gradient. Thus the presence of a minimum layer, some few meters down, may be relict of the state that the whole uppermost stratum possessed a few weeks earlier, just as the persistence into the summer of a cold mid-layer in the Gulf of Maine (Bigelow, 1927), and in the Gulf of St. Lawrence (Bjérkan, 1919) reflects the previous winter's cooling there. Further progressive salting from above, by evaporation, during late summer and autumn, would then tend to obliterate this minimum layer, as the salter water so formed is carried down by turbulence; at the same time upwelling would tend to obliterate it by bringing up water of higher salinity from below. How fast such obliteration would take place would obviously depend on the activity of vertical circulation, as well as on the other factors that McEwen (1916) has discussed. The fact that traces of such a layer were found at only four stations in Monterey Bay, apparently in isolated pools, suggests that if our investigation had been postponed until a few weeks later in the season the upper 25 meters would everywhere have shown the homogeneity, or the slight salting with depth, that was characteristic of the majority of our stations in July.

Apart from the minimum pools, just mentioned, no definite regional segregation as to salinity was apparent at the 25 meter level.

At the 50 meter level (averaging about 33.95‰, and 0.08‰ more saline than the surface), the temporal alterations recorded at Point Pinos (from 33.96‰ on July 5 to 34.00‰ on July 16) and close to Monterey (from 34‰ on July 3 to 33.91‰ on July 17) were almost as wide as the total range of variation recorded for the whole bay at that level during the month. However, the station data at this level suggest a regional gradation of a sort not demonstrable at shoaler levels, from slightly higher values (>33.95‰) in the deep central part of the bay, off shore, and next the Monterey peninsula, to slightly lower (<33.95‰) over the shoal northern slope of the bay and in its southeastern bight. This distribution does not correspond to that of temperature at this level (it being accepted that high salinities and low temperatures both draw from the same deep source), for while relatively low values of temperature (about 9.3°) were recorded at some stations where salinity was relatively high (33.96–34.1‰), at one station with salinity of this value the temperature was relatively high (10.1°), while at another where the salinity was relatively low (33.91‰), temperature was also low (9.2°). But at the 100 meter level (Fig. 14) not only was a much more definite gradation in salinity evident, and a considerably wider range (33.96–34.05‰), but the distribution corresponded very closely to that of temperature (cf. Fig. 14 with Fig. 8), the least saline (corresponding to the warmest) water being localized along the trough, with the most saline (corresponding to the coldest) over its northern and southern slopes, and offshore to the southward. The implication of a distribution of this sort, in relation to upwelling, is discussed on page 467.

Although the absolute variation from station to station in salinity proved to be nearly as wide at 200 meters as at 100, the increase in depth was accompanied by decided regional equalization, the station to station range, within the narrow confines to which the rising slopes of the submarine cañon confine this depth zone within Monterey Bay, being only about 0.05‰ (34.04–34.09‰), with no definite regional gradation, i.e., only slightly greater than the observational error. And with increasing depth, station-to-station differences decreased, as illustrated by the table (p. 567) and graph (Fig. 16) until at 600 meters the water off Monterey proved as uniform in salinity (34.29‰) as it was in temperature (p. 444).

3. *Year to year variations in salinity*

The mean surface values at the Hopkins Station, for the nine years 1919 to 1927, suggest that the normal maximum for surface salinity

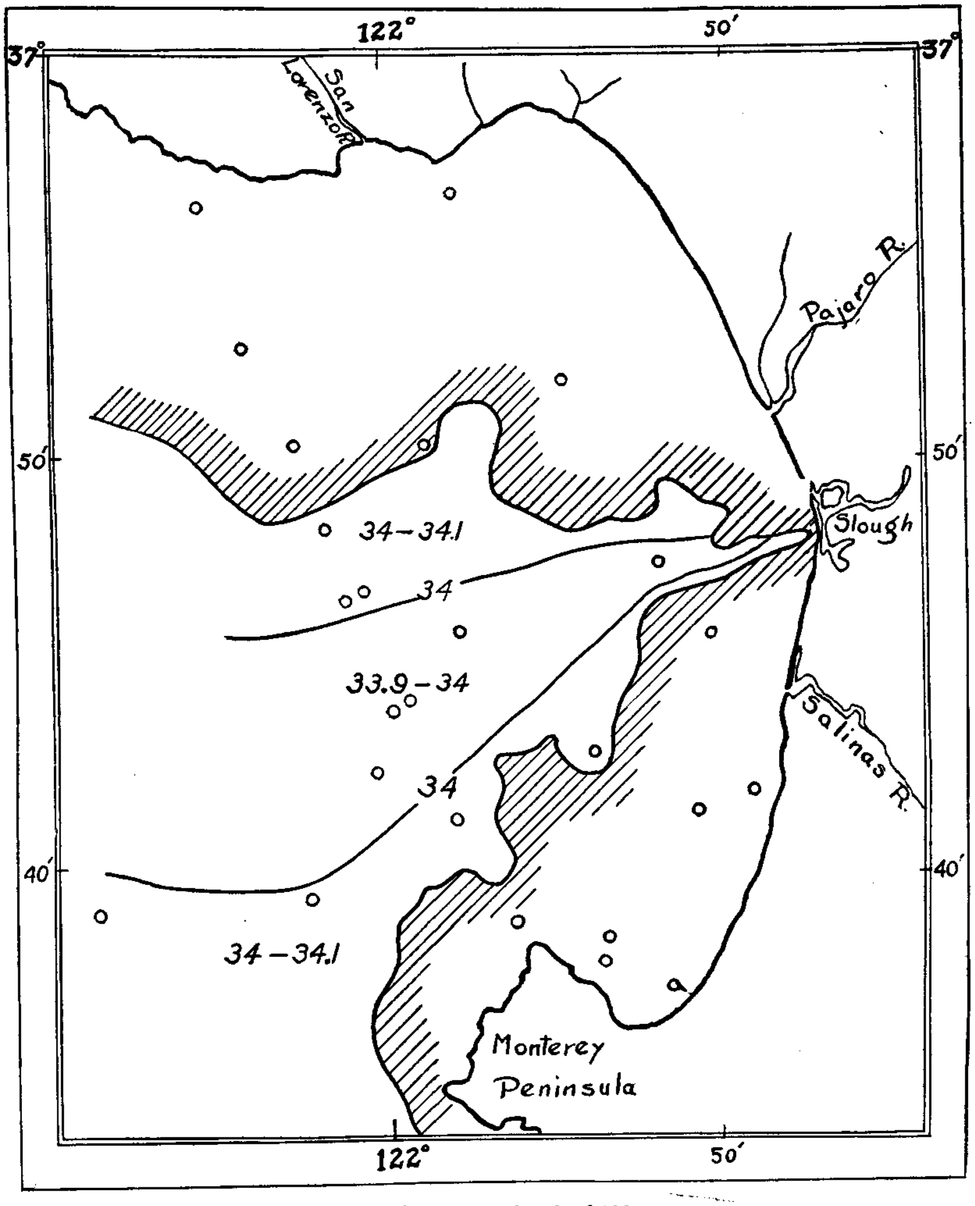

FIG. 14.— Salinity at a depth of 100 meters.

in this side of the Bay is close to 33.7‰; and that the period during which the salinity remains practically stationary usually lasts from May to August. On the whole, 1928 can be named a year of high

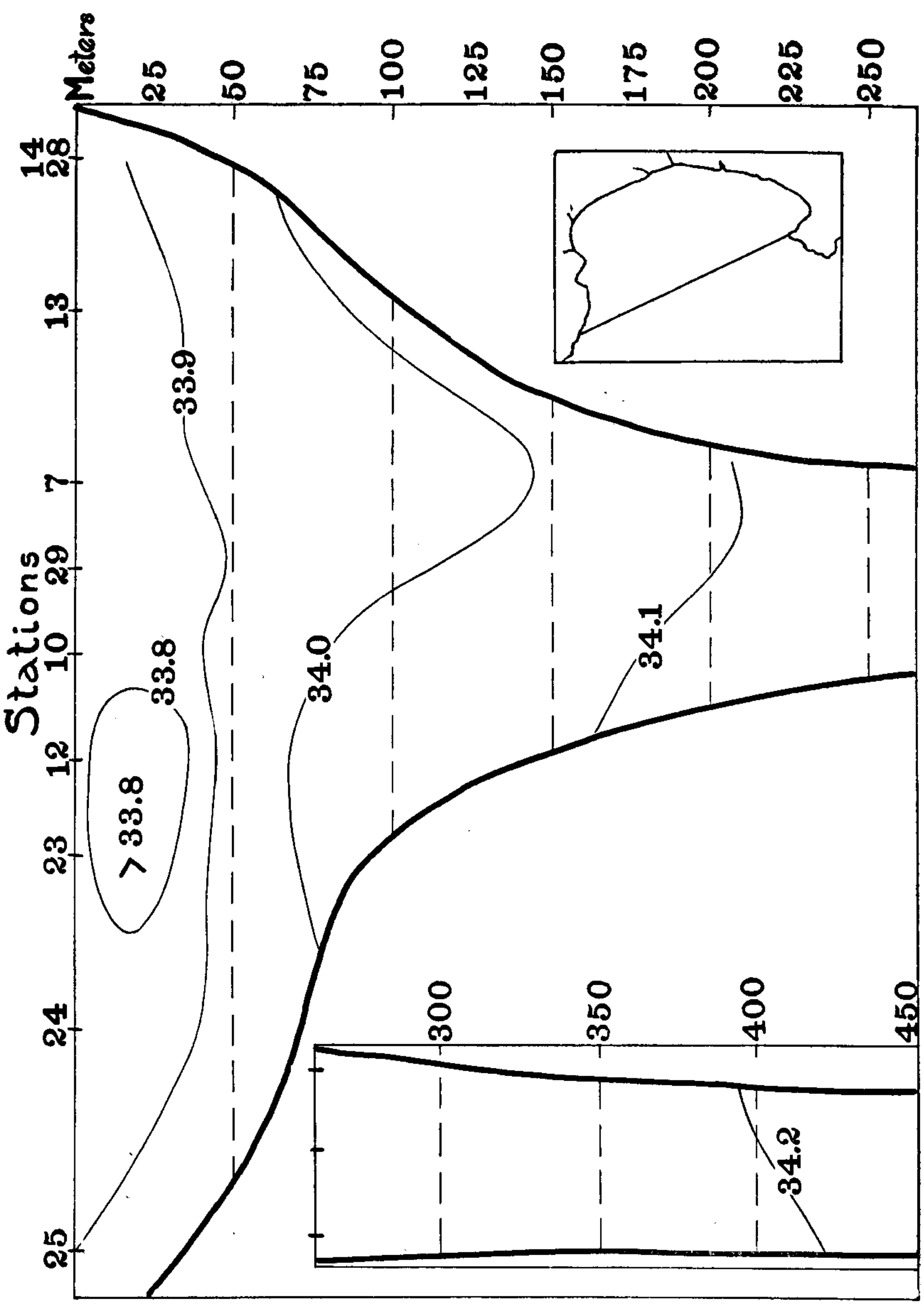

FIG. 15.— Profile of salinity, crossing the mouth of the bay, July 10–24.

salinity (Fig. 11), for the values averaged 0.1–0.2‰ higher than the nine-year mean in January–February, and again from May throughout the summer and autumn; in fact the highest values for that time of year were recorded in 1928. And with salinities averaging slightly lower than the mean in March and in May (presumably in April also), the seasonal range of salinity was also somewhat wider in that year than is usual at this station. The maximum and minimum weekly values (Fig. 11) show, however, that it is certainly an unusual event for the weekly (still more so for the monthly) means to vary from normal by more than about 0.3‰, in either direction. And the data for individual weeks show that when variations as wide as 0.3‰ do occur, they do not long persist.

Unfortunately no data are yet available as to annual variations below the surface of Monterey Bay. But the facts that the surface values have continued so constant from year to year, and that they have shown so regularly recurrent a seasonal variation in a region where the whole oceanographic complex is given its distinctive character by upwelling water, suggest that the deeper down in the water, the smaller are the variations in salinity from year to year.

4. *Salinity of Monterey Bay compared with Southern California*

If the salinity records for Monterey for July 1928, be compared with the data and graphs for the offing of La Jolla, given by Michael and McEwen (1916), by McEwen (1916), and more recently by Moberg (1928), a close agreement appears in the salinity of the surface waters of the two regions at that season. Thus surface values averaging close to 33.9‰ along shore in Monterey Bay in that July, and seldom rising above 33.95‰ there at the time, even in "salt" years, correspond closely with midsummer values of about 33.6‰ to 33.8‰ along shore at La Jolla. Except for the characteristic presence at La Jolla of a layer of minimum salinity centering at about 30 meters depth, of which only traces were found at Monterey, the vertical distribution also proved in general parallel down to 600 meters. At a depth of 100 meters, the Monterey values for 1928 average slightly higher than the mean of about 33.85‰ given by McEwen (1916, pl. 37) for the vicinity of the Coronado Islands; but, as just noted, 1928 was a year of high salinity in the upper strata of Monterey Bay. With increasing depth the relationship is reversed, the 200 meter level averaging about 34.2‰ at the Coronados in August, 34.1‰ at Monterey in July; the 400 meter level 34.3‰ at Coronado, 34.2‰ at Monterey; and the 600 meter level about 34.4‰ and 34.3‰

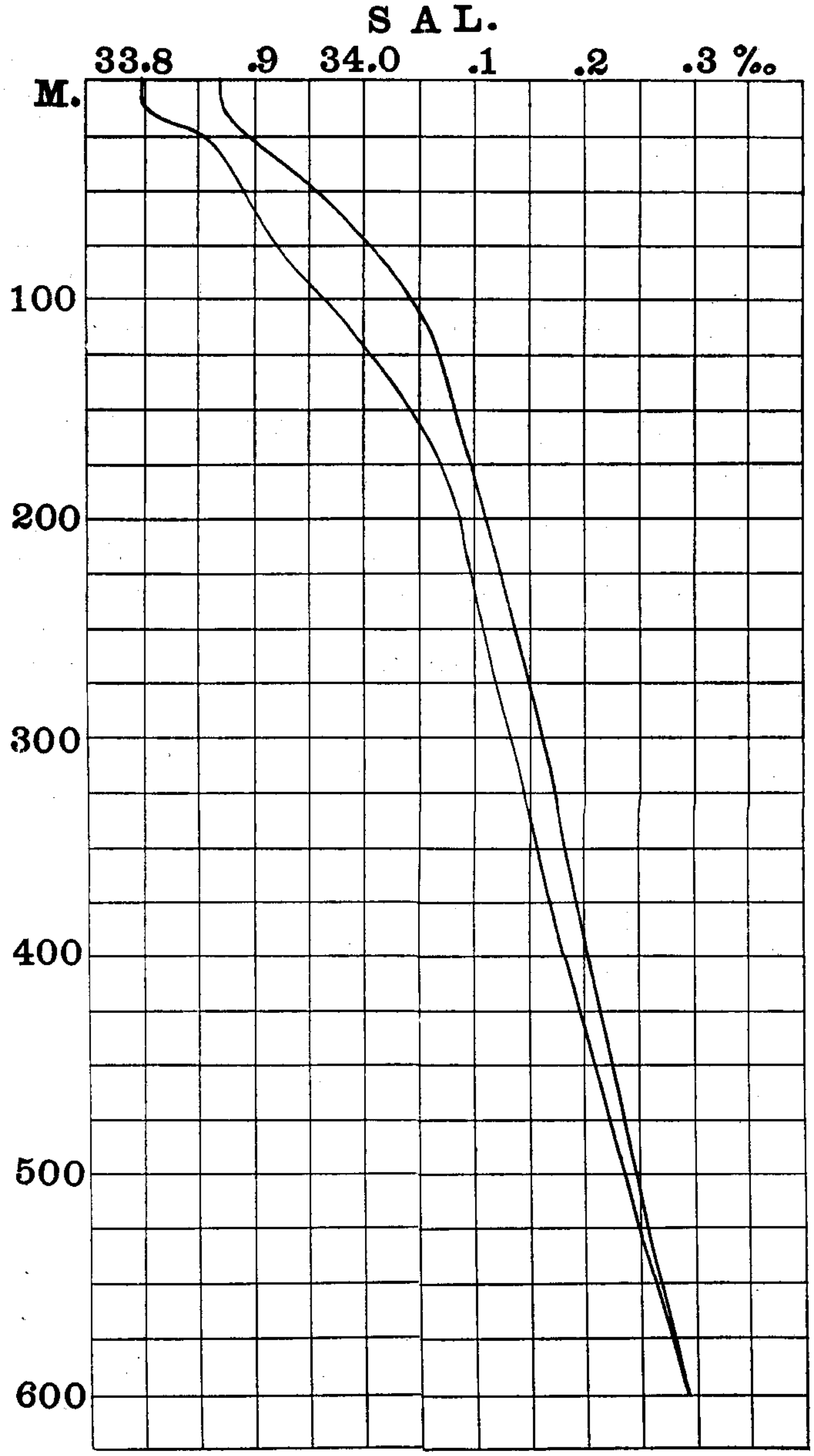

FIG. 16.— Maximum and minimum values of salinity, surface to 600 meters, Stations 8, 10, 17, 27, 29.

respectively. But the difference is so small (remembering that subsurface data are available for only one summer at Monterey) that it is the uniformity between localities so far apart, and between different years, that is striking, rather than the small divergence.

Turning, now, to the seasonal progression of salinity at the surface, we find the maximum and minimum values falling at about the same seasons off northern as off southern California, i.e., midsummer maximum, late winter minimum. The mean maximum values also agree closely. But the mean minimum values are considerably the

	Monterey	Off Coronado[1] Beach	Near Coronado[1] Island
Mean maximum	33.7‰±	33.8‰	33.7‰
Mean minimum	33.1‰±	33.55‰	33.5‰

lower at Monterey, as might be expected from the vicinity of the Salinas River, and from the greater rainfall. It is also interesting to find the type of seasonal progression that available data indicate as characteristic of Monterey (with a comparatively sudden increase in surface salinity during the late spring, and a comparatively slow decrease during autumn and early winter) more nearly reproduced offshore near the Coronado Islands, than inshore, near Coronado Beach. From the biological standpoint, however, the whole south central sector of the Californian coast line may (judging from these two localities) be regarded as a unit from the standpoint of salinity, regional differences of the magnitudes just stated being insignificant (when annual variations are weighed against them) as compared to the variations that exist along many coast lines.

Off Coronado (McEwen, 1916, pl. **26**, Fig. 46), considerable seasonal variation in salinity was detected down to at least 400 meters, with the deep water least saline during the autumn. How deep, into Monterey Bay, the autumnal and winter freshening extends, is an interesting problem for the future.

C. Upwelling

1. *Foci as indicated by temperature and by salinity*

Control of the thermal state of Monterey Bay by mass upwelling being sufficiently established, regional variations there in temperature and in salinity at any given time have especial interest as evidence of the regions where updrafts are most active at the time,

[1] From McEwen, 1916, Plate 25.

or have been most active shortly previous, and of the depth-strata within which they have recently caused the greatest thermal displacement. Similarly, the periodic variations at localities where temperatures and salinities have been determined on successive dates throw some light on the periodic pulses, even within the short time covered by the "Albacore" investigations, if the effects of local solar warming, and of wind currents within the bay be properly allowed for, this last proviso being of special importance in this particular locality.

In Monterey Bay, at the season of our survey, when the vertical range of temperature covered about seventy-five measurable units, that of salinity only about fourteen measurable units,[1] temperature is, of the two, the more useful index to upwelling. Salinity, however, has proved more instructive in this respect than the narrow range of variation might have suggested, because at the time there were no disturbing factors of local origin to confuse the picture, no rain having fallen for some time previous, while the little land drainage entering the bay in summer is negligible (p. 452).

Whereas upwelling is a process proceeding from below, it is the effects on the upper strata that are most interesting, so the rational approach to this problem is from the deeps, upward. Along the Monterey front the 600 meter level may be taken as the base plane for discussion because of the uniformity of temperature and of salinity prevailing at that depth (p. 444, 459). And as the mean values for two readings at 600 meters depth off Santa Barbara in August, 1928,[2] were likewise close to 5.5° and to 34.3‰, this would appear to be applicable all along the eastern slope of the Pacific at latitude 34° to 37° N. But as the two determinations from which this Santa Barbara mean is derived (one taken in a bowl-like depression) differed by more than a degree (4.82° and 5.98°) it is evident that the topography of the bottom, as affecting upwelling, may cause considerable local differences.

Whether profiles running farther off shore would have shown the isotherms and isohalines dipping seaward at depths greater than this, off Monterey (as might be expected if true abyssal water was then flooding up the continental slope, or had done so shortly previous) was not determined, for our outermost station lay only ten miles out from the land.

[1] Vertical range of temperature, surface to 600 meters, in July, about 7.5°; probable error of determination 0.1°; vertical range of salinity about 0.43 ‰; probable error of determination 0.03‰.

[2] Data contributed by the Scripps Institution.

Temperatures at two stations on a profile that the "Tuscarora" ran out from Pt. Carmel in 1873 suggest a thermal slope in the upper strata just opposite to what upwelling would produce, i.e., with the coldest water rising nearest to the surface at the outermost station (Belknap, 1874, p. 38, casts numbers 1 and 11). But there is some question as to the instrumental error of these early observations taken before the introduction of the reversing deep-sea thermometer. In this connection it is interesting to find the U. S. Coast and Geodetic Steamer "Guide"[1] reporting almost precisely the same temperatures at 600–650 meters (5.7° to 5.8°) off the Hawaiian Islands August, 1928, as prevailed at 600 meters off Monterey Bay the month previous.

If the spacial distribution of temperature and salinity as prevailing from July 10–24, 1928, be followed upward, from the 600 meter base level at the mouth of the bay, and inward along the trough of its submarine cañon, warping of the isotherms and of the isohalines (evidence of upwelling) first unmistakably appears at about the 250 meter level, as illustrated on the profiles crossing from headland to headland (Figs. 7, 15). But profiles do not afford a satisfactory picture of relationships from this point of view because confined to a single vertical plane, whereas it is the regional distribution that is the most instructive. The latter is made clearer by projections of temperature and of salinity at the 100 meter level (Figs. 8, 14), which, together, show that the piling up of the coldest and most saline water against the slopes of the trough was not confined to the mouth of the latter, but extended up it. At shoaler levels, however, horizontal projections of this sort do not afford satisfactory pictures of circulatory activity at the time, because the horizontal variations, whether of temperature or of salinity, were so small. It was therefore necessary to have recourse to reconstruction of the contours of successive layers of equal temperature, and of equal salinity (technically known as isothermobaths and isohalobaths), measured by the depths below the surface at which these lay. Submarine reconstruction of this sort is less familiar than the ordinary horizontal projections of temperature or of salinity; but it is not novel, having been used effectively *inter alia* by Schott (1902) in his presentation of thermal distribution in the Atlantic and Indian Oceans, based on the results of the "Valdivia" expedition.

The isothermobaths for 6° and 7°, centering respectively at about 500 and at about 380 meters depth, proved practically horizontal throughout the zone where our stations extended deep enough to reach temperatures that low, corroborating the profile (Fig. 7) to the effect that upwelling was producing no regional distortion at depths

[1] Data compiled by S. W. Chambers, 1929.

deeper than about 250 meters, at the time. But the isothermobath for 8° already suggested a definite though small warping, lying lowest along the axis of the submarine cañon, highest along the northern and inner slopes of the latter, and abreast of the Monterey Peninsula, with an extreme variation of about 40 meters between its highest and its lowest points. If this isothermobath stood alone no definite interpretation could be given it, both because only four stations were involved, because the station-to-station differences in temperature at given levels through its general depth zone were so small that the observational error of $\pm .1°$ might largely negative them, and because they covered a period of 13 days. But this distribution so clearly foreshadows that of temperature at 100 meters, just commented on (Fig. 8), and is so consistent with the isothermobaths for higher values, next to be described, that it may be accepted as an indication of the deepest thermal distortion that upwelling was then causing. Thus the indication is that the updraft tended to follow up the slopes of the trough, and towards the head of the latter, from the deepest level to which the water was involved.

This control (at least temporarily) of the underlying circulation by the contour of the bottom, resulting in its alteration into an updraft on striking the slopes, is made more evident by the isothermobath for 9° (Fig. 17) which at the time showed a slope of some 65 meters, with a much more definite valley overlying the entrance to the submarine cañon, and rising thence over the northern and southern slopes of the latter, as well as shoreward along its axis, to flatten out over the more gentle submarine slopes above. In order to avoid as far as possible the disturbing factor of temporal alteration, but at the same time to include stations generally enough dispersed, the projection (Fig. 17) covers only the period July 11–24. If station 7, occupied on July 10, were included, the relation between low and high would remain the same, but the individual contour-lines would be considerably altered, over the southern slope of the trough. Interpreted in terms of upwelling, a contour of this sort points unmistakably to an intensification of the updraft on all sides of the trough contrasted with its axis, as the surface is approached and with expansion of the area included within the picture. The isohalobath of 34‰, centering at about the same depth (Fig. 18) shows a similar contour, similarly to be interpreted, with its distortion not only corresponding regionally to that of the isothermobath for 9° but showing about the same steepness of slope. Water of this salinity also occupied approximately the same proportion of the area of the bay as did 9° temperature, overflowed the slope to within about the same distance of the shore, and was at about the same depth below the surface at any given loca-

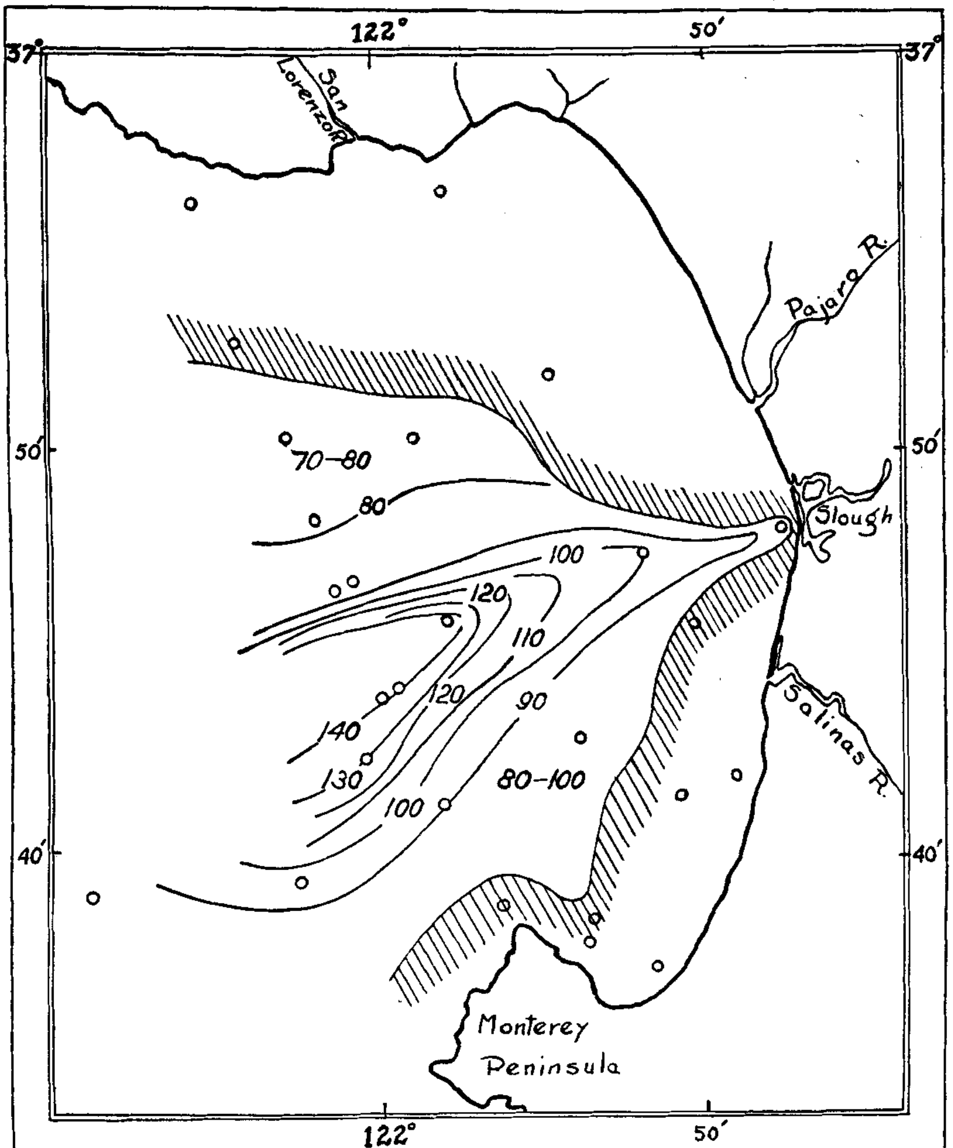

Fig. 17.— Depth in meters below the surface of the isothermobath for 9°, July 11–24.

tion in the bay. Since the precise values are stated on the charts (Figs. 17, 18) we need only add further that a closer correspondence seldom appears between any two constants of sea water.

The fact that the contour of the isothermobaths for 9.5° and 10° (Fig. 19) had the same general conformation as that for 9° shows that

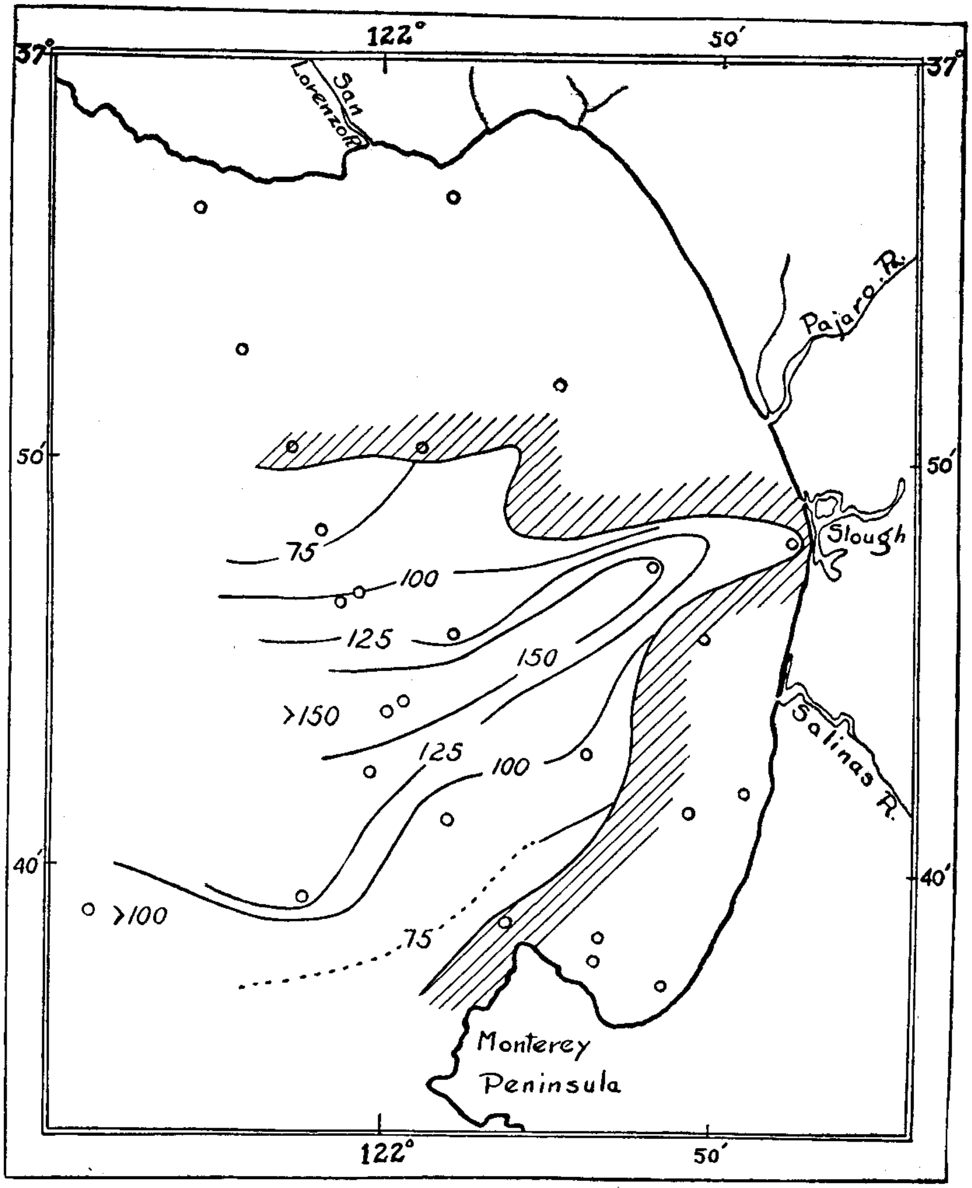

FIG. 18.— Depth in meters below the surface of the isohalobath for 34‰.

in July, 1928, this draft up the slopes, with tendency to spread in all directions shoreward over the more gradually shoaling bottom above the 100 meter depth-line, was active enough to effect considerable thermal distortion upward to within 30–40 meters of the surface, over a large proportion of the shoaler parts of the bay. But the facts

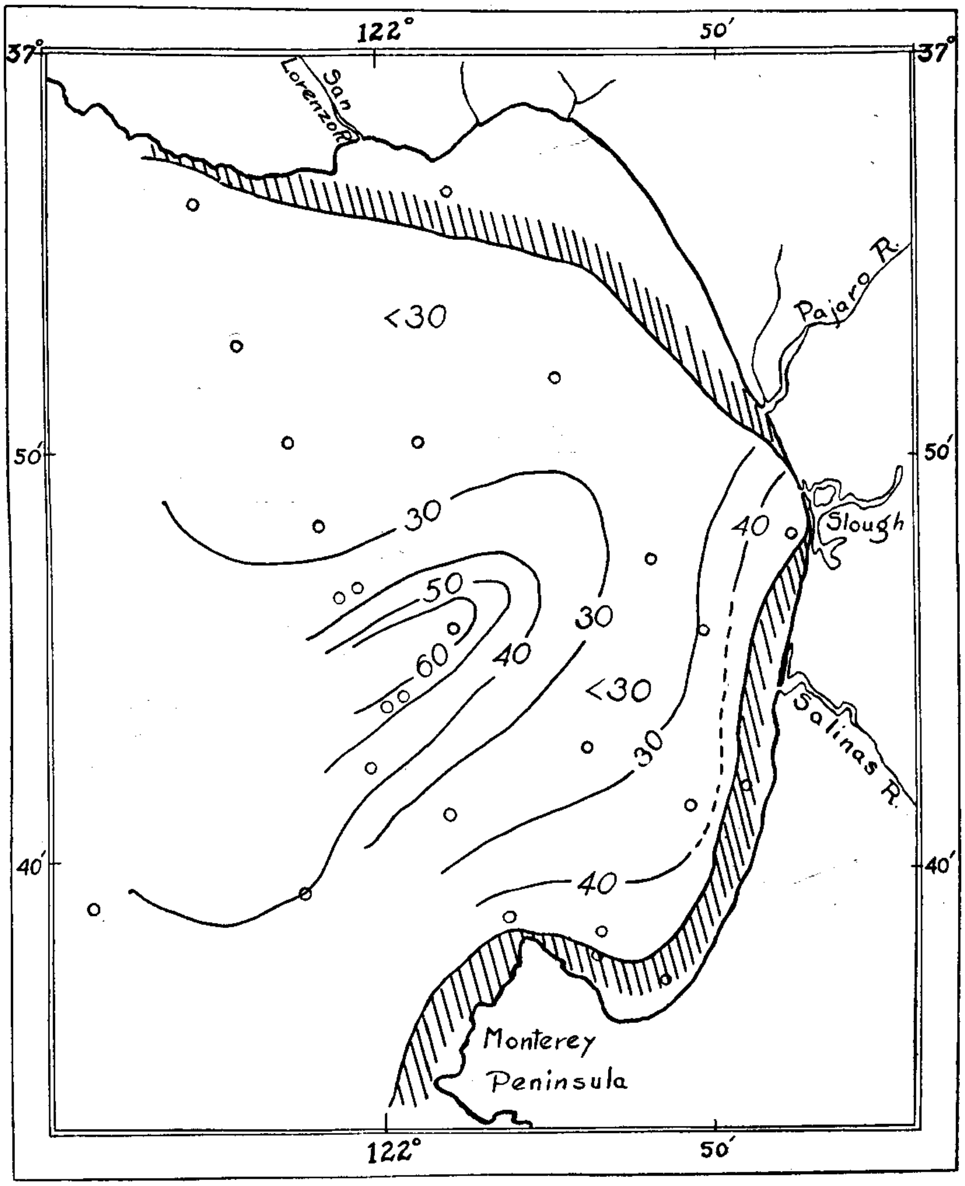

FIG. 19.— Depth in meters below thc surfaee of the isothermobath for 10°, July 11–24.

that the slopes of successive isothermobaths decreased in steepness as the surface was neared (the difference in level between the highest and lowest points is about 65 meters for the isothermobath for 9°;

about 55 meters for 9.5°; only about 40 meters for 10°), combined with flattening of the isothermobaths over the shoaler parts of the bay, points to a slackening of the updraft in the superficial stratum, coupled with a general dispersal radial from the steepest slopes of the bottom.

When the surface was approached so closely that successive isothermobaths (e.g. for 10.5° and 11°, Fig. 20) were underlain by water columns of considerable length over most of the bay, their highest points extended as nearly level planes right across the bay from north to south, evidence that near the surface the bottom contour does not so directly control the course of the updrafts. As a result the isothermobath for 10.5° (centering at about 20–25 meters), varied by only about 23 meters in level over the entire bay during the period July 12–24, nor would introduction of the stations taken earlier in the month make any appreciable difference in this contour, while that for 11° (centering at about 15–20 meters), sloped about as much, from a depression at the mouth of the bay to an elevation around the inner parts of the latter.

The asymmetry of the bottom of the bay, with the angle of slope changing from more steep to less steep near the 100 meter depth line in the northern side, but about 100 meters deeper than this in the southern (Fig. 1), offers a reasonable explanation for the fact that the coldest and most saline water approached closest to the coastline in the southern side, as is illustrated by the isothermobath for 9° (Fig. 17) and by the isohalobath for 34‰ (Fig. 18).

Coincident with the circulatory transition from the deeper layers, where opposing submarine slopes were localizing the updraft, to shoaler levels, where freedom from such interference allowed the upwelling water to spread, depression of the successive isothermobaths corroborates the profiles in showing a reciprocal concentration of the warmest water along the southwestern shore-slope of the bay. At the time this involved chiefly the stratum enclosed between the 30 and 60 meter levels. The isothermobaths for 10° and for 11° (Figs. 19, 20) illustrate this phenomenon the most clearly.

This piling up of warm water next the land was no doubt caused by the local wind. It is now generally agreed that the cause of mass upwelling along the California coast is that the winds, a few miles out at sea, usually blow parallel to the coast and from the northerly quadrant, so that the current thereby set in motion (as deflected to the right by the earth's rotation), trends offshore, with consequent upwelling next the coast slope. The correctness of this explanation of the California upwelling, based on the Ekman theory of wind currents, first suggested by Thorade (1909), was demonstrated mathematically by McEwen (1912, and subsequent papers). If the long

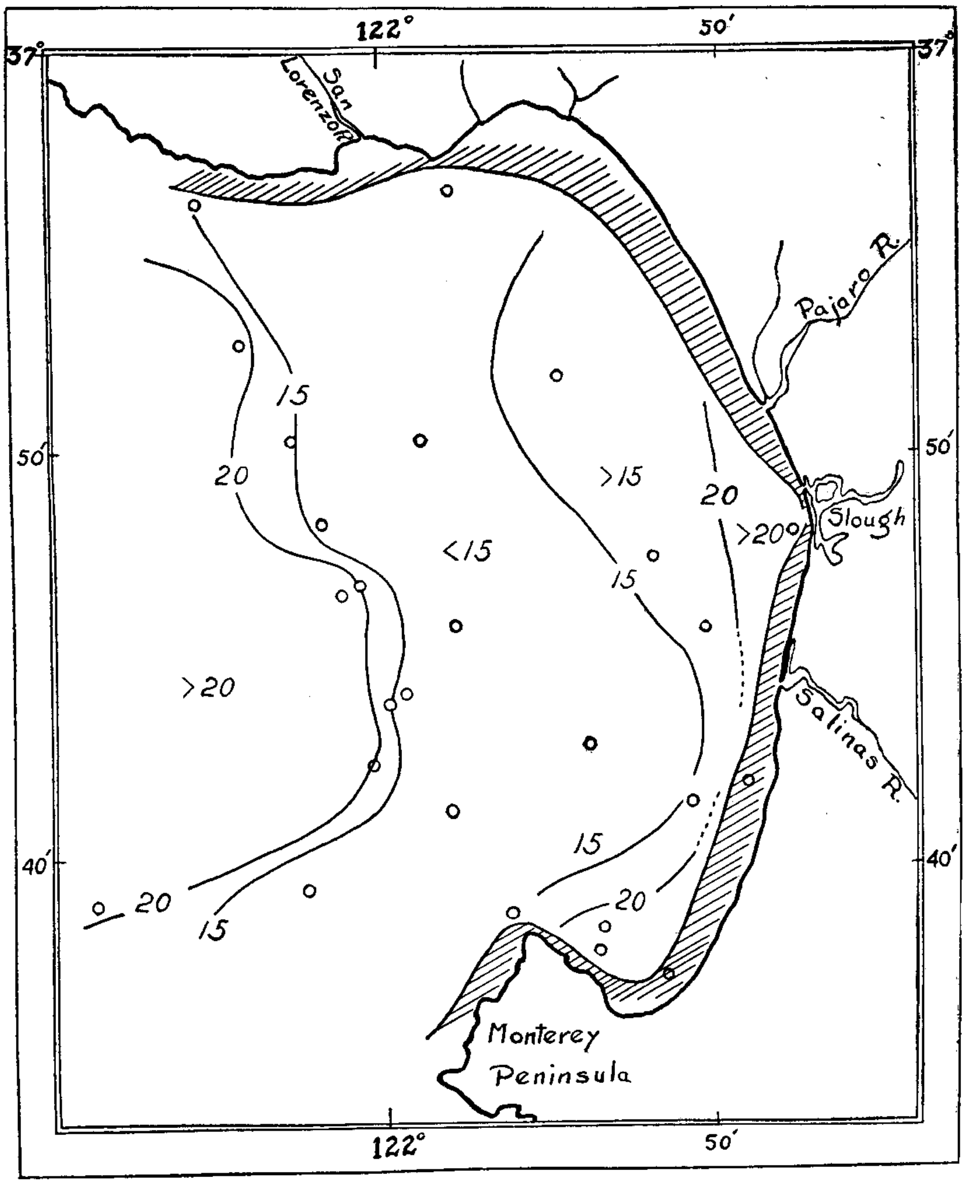

FIG. 20.— Depth in meters below the surface of the isothermobath for 11°, July 11–24.

shore wind governed right in to the coastline of Monterey Bay, the surface water of the whole bay would, on the whole, drift off shore in the same way, causing updrafts to follow the bottom slope right in to the shore line. In that case the successive isothermobaths would slope upward, right in to the shore, with the temperature decreasing, at any given level, approaching the coast line.

Narrow coastal belts in which temperature averages low, produced by local upwellings resulting from winds driving the surface water offshore, are, in fact, familiar phenomena in many parts of the world. McEwen's (1916) analysis of temperatures and salinities along the southern Californian coast show this to be the prevailing state there. In Monterey Bay, however, the situation with regard to the wind is different. True, the wind blows almost constantly from the northwest a few miles out at sea off this sector of the coast. Thus the windrose for the appropriate 5° square on the U. S. Hydrographic Office Pilot chart of the North Pacific Ocean, for July, shows the reported winds as blowing between north and northwest 85% of the time, with none noted from other directions. This averages parallel to the general trend of the coastline, and is therefore of the type to produce upwelling in this situation. But in summer the diurnal heating of the valleys inland from Monterey Bay causes almost daily development, over the whole area of the bay, of a local sea breeze that springs up with great regularity in the morning, strengthens during the day, to die out in the evening, while the nights are as a rule windless. It is common local knowledge that this sea breeze usually blows much more strongly across the southern half of the bay (to draw up the superheated Salinas valley), than across the northern half, which is somewhat sheltered by the jutting coastline. Any drift of warm surface water set up by such a wind (as deflected by the earth's rotation) is necessarily directed toward the southeastern bight of the bay.

It is an interesting question whether resultant accumulation of a superficial stratum of warm water there, such as observed in July, 1928, ever causes the development of sinking currents, either next this part of the coastline, or at the head of the gully. The low degree of vertical stability prevailing in a water-mass as nearly homogeneous in physical characters as is that under discussion, would offer comparatively little opposition to circulation of that sort.

However that may be, it is no doubt because of this division of the winds that upwelling water was made most evident by low surface temperature well out in the bay. On the other hand the steepest thermocline [1] developed in the part of the bay (northeast bight) that is the most sheltered from the wind (Fig. 21), where solar warming of the surface can proceed most nearly at the rate normal to such a

[1] Vertical range of 5.5° in a depth of 15 meters at Station 26.

locality at the latitude in question. And this is probably the characteristic summer state.

The transition in the relative activity of vertical circulation from the state prevailing at the time in the deeper strata of the bay to that being caused in the uppermost stratum by the division in winds, combined with station to station differences in the vertical distribution of temperature caused by waves, tides, etc., makes difficult any more precise interpretation of the regional thermal differences recorded in

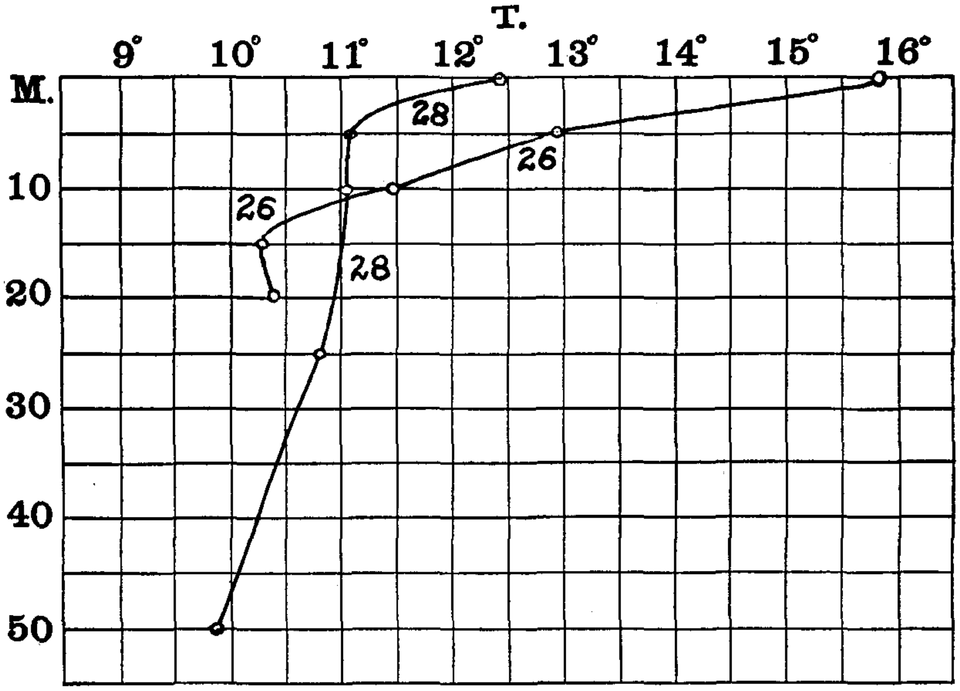

FIG. 21. Vertical distribution of temperature in the northern and southern bights of the bay (Stations 26, 28).

the upper 10 meters. In the upper 25 meters small regional variations in salinity are equally difficult to interpret in midsummer, without knowing the state that prevailed shortly previous. This is because of the strong probability that the pools of low salinity below the surface (page 455) are relicts of a minimum layer that had involved the whole bay some weeks earlier, which, in its turn, was a relict of low salinity characterizing the whole superficial stratum during the winter. If this interpretation be correct, upwelling during the early summer might either lessen or increase the salinity of the surface, depending not only on the extent to which this minimum layer still persisted, but also on the activity of the updraft, and on the depth zone involved. Furthermore, with a minimum layer existing some 20 to 30 meters down, any sort of local stirring would freshen the surface. But in the parts of the bay where the minimum layer had already been obliterated, upwelling would increase the surface salinity.

2. *Periodicity as indicated by temperature and salinity*

It is generally recognized that upwelling, along the Californian coast is an intermittent process. To gain any reliable picture of active and inactive periods, and to determine the regularity, or reverse, of its seasonal schedule would obviously require frequent periodic record of the temperature of the central parts of the bay, as well as of its margin.

Our work in 1928 was not continued long enough to throw much light on this subject in general, except that a warming of the upper 50 meters by about 1°, at a pair of stations at the mouth of the bay, between July 10 (7) and 23 (27), suggests that the updraft over this part of the slope was more active during the first week of the month than thereafter. In line with this conclusion is the fact that near Point Pinos, surface temperature dropped by about 1° between June 30 (1) and July 5 (5); that the whole column then warmed considerably, to the 16th; with the vertical range of temperature and of salinity then decreasing (cf. Stations 14 and 28, Figs. 13 and 22) as would naturally result from stirring by tidal currents running over the broken bottom. It is interesting in this connection that the tow there, at the surface, yielded a considerable amount of algal debris at Station 28, as well as a number of species of bottom-living diatoms (p. 537) that had not been found there three weeks previously (Sta. 5).

3. *Comparison with other points on Pacific coast*

In the preceding lines we have interpreted so far as seems warranted the variations in the physical state of the water from place to place existing within Monterey Bay in July, 1928, as rough indices of vertical circulation. The data so far gathered do not justify any discussion of the actual rate of upwelling at the time.[1] But the depression of

[1] McEwen (1929) has pointed out that any such calculation must include, as elements in the equation, the periodic variation in several constants for which no data are yet available for Monterey Bay, i.e. the rate of evaporation of the surface, turbulence, solar radiation, as well as alteration in temperature, or depression of the latter below the value normal to the latitude and season.

surface temperature in Monterey Bay, at the warmest season, below the value normal for that month for the Pacific Ocean as a whole at the corresponding latitude, compared with the corresponding depression at La Jolla, gives a rough measure of the relative activity of upwelling at these two locations, and of the relative degree to which this process

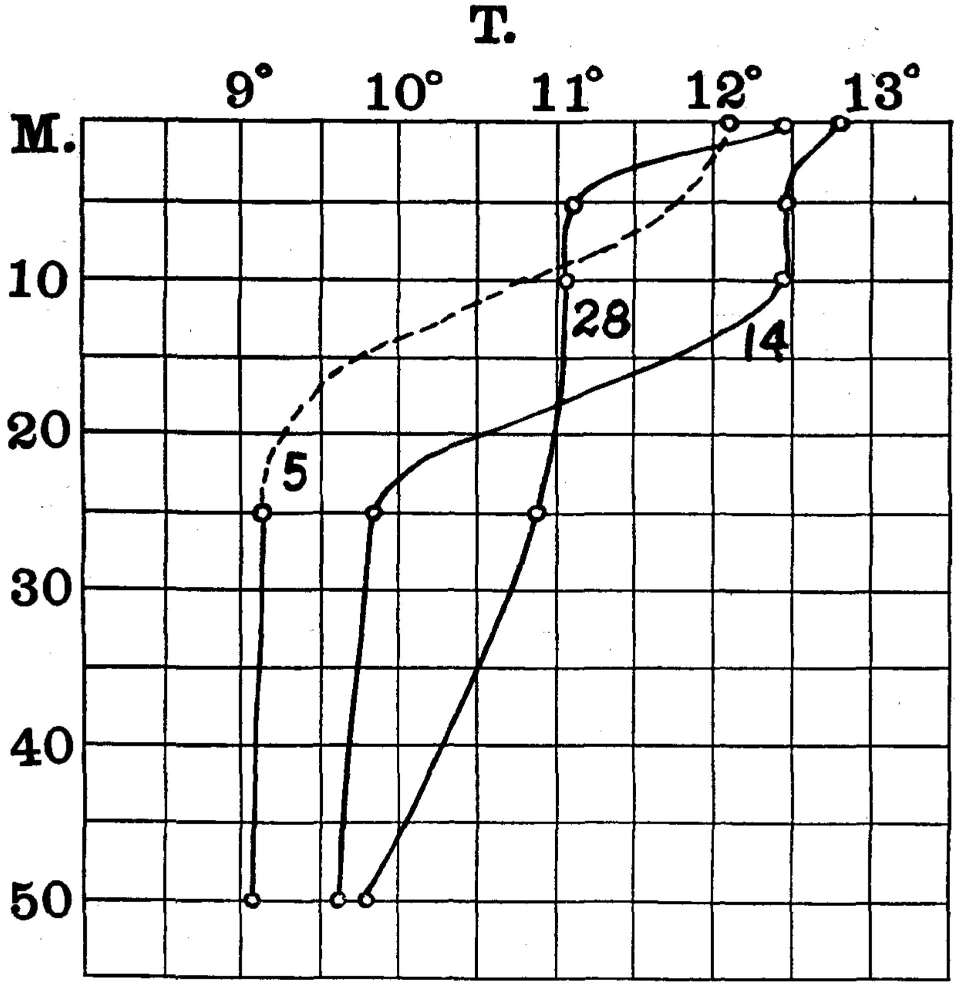

Fig. 22.— Seasonal progression of salinity near Point Pinos, July 5 (Sta. 5); July 16 (Sta. 14); and July 23 (Sta. 28).

controls the oceanographic complex off the mid Californian and the southern Californian coasts. At Pacific Grove the mean summer maximum (years 1919 to 1928) is nearly 8° lower than is normal for the latitude.[1] And while the introduction of abnormally cold or ab-

[1] Normal temperatures from calculations contributed by Dr. McEwen.

normally warm summers into the calculation would slightly alter this difference, the series has continued long enough to show the orders of magnitude involved. There is no season when the coastal belt off Monterey Bay is not colder than the normal for the latitude; at the coldest season it averages about 1.7° colder than normal, proof that

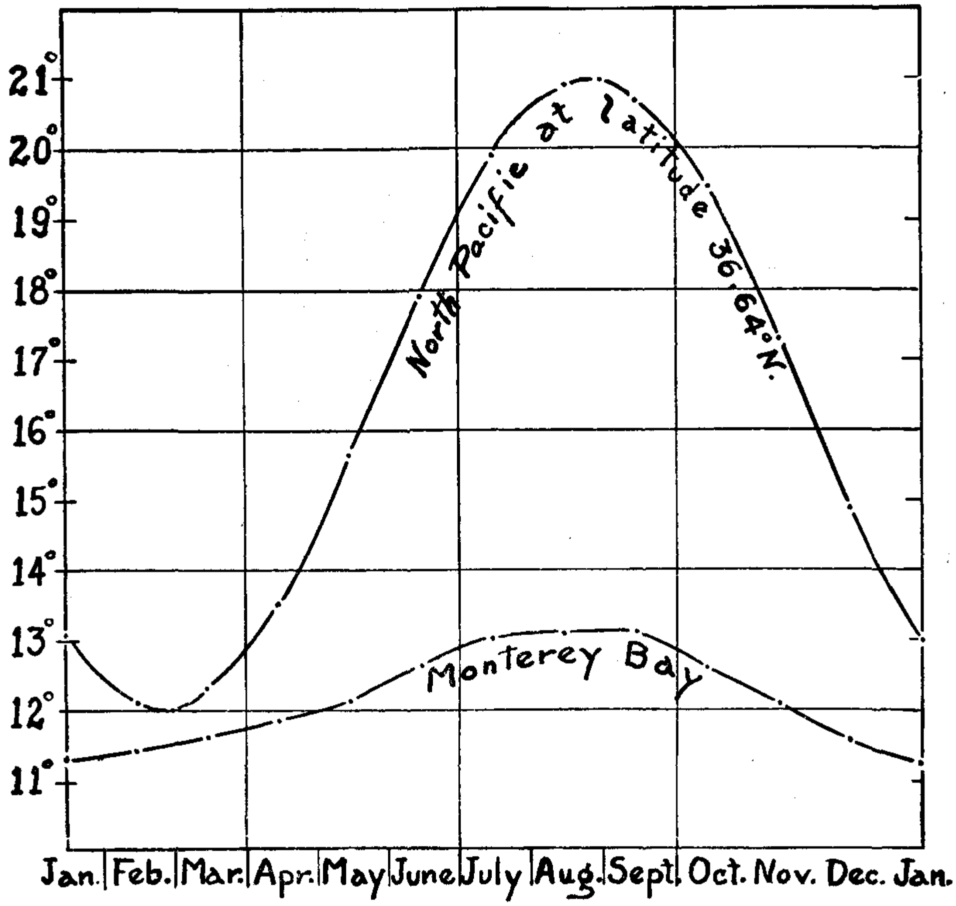

FIG. 23.— Average surface temperature of Monterey Bay, for the year, based on records for 1919–1928 (lower curve), and normal surface temperature for the North Pacific as a whole at the corresponding latitude from calculations by G. F. McEwen (upper curve).

upwelling takes place throughout the year. The fact that Monterey surface waters chill to their minimum temperature about six weeks earlier than the expectation, i.e. in January instead of early in March (Fig. 23), with no apparent explanation from local conditions, suggests that on the whole upwelling reaches its greatest volume there during the autumn.

In the region of La Jolla the maximum (about 20°) is depressed only about 3° [1] below the value normal for the latitude. In the vicinity of Cape Mendocino, lat. 40° N, where the lowest surface temperatures for the whole Californian-Oregon coastline are usually encountered in summer, McEwen's (1912, p. 268) calculations show the maximum midsummer temperature depressed about 7°–8° below normal. And observations at Blunt's reef, near the Cape, showed about this same depression in summer, for the years 1922–1928.[2] In midwinter the water off the Cape is about normal in temperature by the earlier data, but about 1° warmer than normal according to these more recent records.

Without entering further into the theoretic aspects of the question, it is evident that upwelling much more effectively controls the physical character of the water in Monterey Bay than in the vicinity of La Jolla. The small regional range of surface temperature at Monterey, the fact that the difference of about 7° between the seasonal maxima for these two localities is much greater than could be explained on the basis of a difference of latitude alone, and the greater prevalence of fog at Monterey in summer than at La Jolla, would indeed have suggested as much.

Such evidence as is now available suggests that upwelling is about as active off Monterey as it is in the coast sector just north of San Francisco, or at least that it is about as effective in chilling the surface water.

D. Horizontal Circulation

In the preceding pages we have emphasized the vertical circulation of the bay, both because this gives the bay — and the California coast sector as a whole — its peculiar oceanographic character, and because our observations were of a sort to throw some light on the loci of upwelling at the time.

It is obvious, however, that wherever this type of circulation brings cold, highly saline — and consequently heavy water up to the surface, in juxtaposition to lighter water, it must at the same time cause a dynamic tendency toward horizontal motion, following the gravitational force that tends to bring the water back into a state of horizontal equilibrium. Certainly this dynamic tendency toward current

[1] Normal temperatures from calculations contributed by Dr. McEwen. McEwen's (1912, page 265; 1916, Plate 25, fig. 42) earlier calculations, based on less extensive data, showed slightly lower maxima and higher minima.

[2] Information contributed by Dr. G. F. McEwen.

development varies regionally, and periodically, with the activity of upwelling, as well as with the time of year, thus complicating the problem of tracing the horizontal drift that is set in motion locally by the prevailing wind.

In general, according to ship reports, the dominant movement of the surface waters abreast this part of the coast is toward the south, as represented on the pilot charts — the "California current." But so far as we have been able to learn, no analysis of horizontal movements has been attempted for Monterey Bay.[1]

1. *Tides*

The tidal currents setting in and out of the bay are strong. According to the U. S. Coast and Geodetic Survey (1929) the velocity of the flood, at its strength, is about 1.1 knot past Point Pinos on the one side of the bay, about one knot past the Santa Cruz shore on the other, the inward and outward currents running, in each case, parallel with the coast line.[2]

Small tide rips and choppy seas also give evidence of strong tidal currents over the slopes of the submarine trough of the bay, near its mouth. But local reports as to the direction of the dominant set (if any) within the bay are conflicting.

Our own observations do not afford any direct evidence on this question. But knowledge of the direction of the dominant drift is so important for understanding the distribution and especially the migrations of the local fauna, that it seems worth while to outline the dynamic state prevailing at the time of our survey.

2. *Dynamic state*

Off a straight coast line and slope, a band of continuous upwelling, along shore, would tend to maintain a continuous band of high specific gravity next the coast. But where, as in Monterey Bay in July, 1928, upwelling is localized and directed by the slopes of a submarine trough running roughly at right angles to the general trend of the coast line, a much more complex situation is to be expected. Furthermore, the dynamic gradients may be expected to alter rapidly, according as upwelling becomes more or less active.

[1] Drift bottles, and other floats, have been put out in the bay, in connection with surveys for a proposed breakwater, but the results have not been made available as yet.

[2] The flood is described as averaging about N 35° E past Point Pinos, S 80°E past Santa Cruz light.

During the last half of July, 1928, both the temperatures and the salinities of the upper 50 meters of Monterey were so uniform from station to station, and consequently the superficial layer was so stable, horizontally, that the maximum dynamic gradient for the stratum included between the surface and the 50 decibar level was only about 1.3 dynamic centimeters between the offing of the bay (Sta. 17) and the head of the gully (Sta. 19), 0.5 dyn. cm. across the mouth of the bay. It is necessary, however, to take the whole column of water into account, not the superficial stratum alone, because temperatures and salinities showed more dislocation in the mid-depths than at the surface.

In one respect Monterey Bay, in summer, offers a decidedly favorable field for studies of this sort, because the water proved so nearly uniform as to specific gravity at 500 meters and deeper, both within the trough and in the offing, as to suggest that this level can usually be taken as a stationary base for the dynamic calculations.

The differences in depth from station to station, resulting from the steepness of the bottom slope, are, however, greater than can properly be allowed for by any empiric method of calculation yet proposed. Consequently, while the direction of the dynamic slope represented on the accompanying chart (Fig. 24) seems sufficiently established for the time of observation, its precise steepness, and the velocities calculable therefrom, can only be taken as rough indices to the orders of magnitude that actually were indicated during our survey.[1]

Even without the construction of such a chart, the evidence of temperature, showing relatively cold water banked up against the slopes of the trough, and spreading shoreward over the shoaler bottoms to north and south, as described above (p. 467) suggests that when upwelling is active, the updrafts of heavy water over the slopes, contrasted with the comparatively quiescent state along the axis of the trough, tend to establish an anticyclonic system of circulation at the mouth of the bay. And this is corroborated by the dynamic projection, which shows that the surface then stood dynamically highest over the mouth of the trough and up the axis of the latter, dynamically lower over the shallows within the bay, to the north and south. Corresponding to the distribution of bottom temperature (p. 467), the

[1] The dynamic contour chart (Fig 24), calculated by the Bjerkenes theorem, is of the sort now widely employed. For a recent description of the method of calculation, see Smith, (1925). Differences in depth, between adjacent stations, have been allowed for by the empiric correction introduced by Jacobsen and Jensen (1926). This method was chosen, rather than the simpler alternative recently developed by Harvey (1929), because of the necessity for taking the contour of the bottom into account.

surface was then dynamically lowest in the whole northern half of the bay, and practically uniform there regionally. Our survey did not

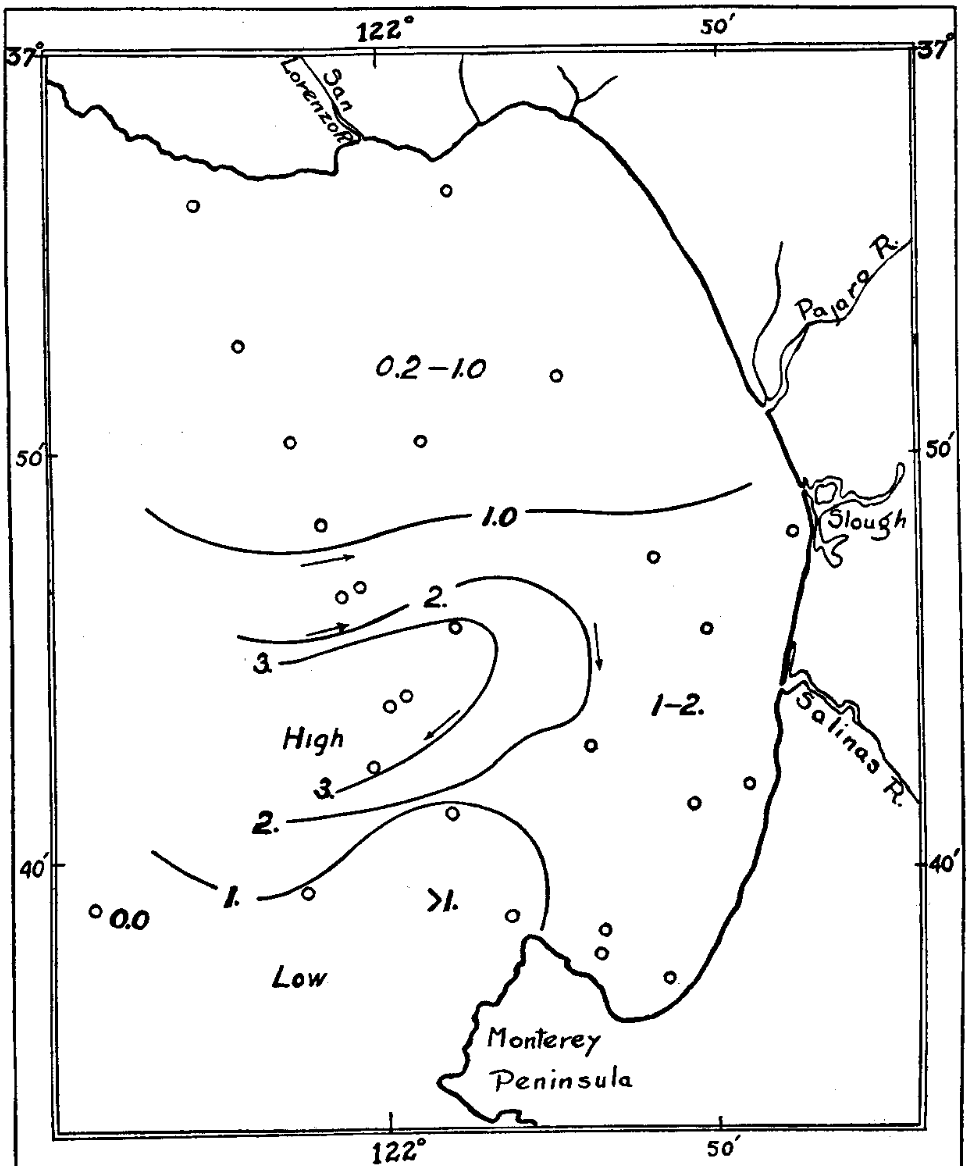

FIG. 24.— Dynamic gradient and indicated drift, at the surface, July 10–24, referred to the offing of Point Pinos (Sta. 17) as base station. The dynamic heights are given for every one dynamic centimeter.

extend far enough offshore to show whether the dynamically high centre (representing low specific gravities), was a circumscribed pool, as is suggested by the fact that the surface was dynamically lowest (i.e., the mean specific gravity of the whole column of water greatest) at our outermost station (17), or whether it represented an extension inward along the trough of a state generally prevailing farther offshore at the time.

The circulatory implication of a dynamic distribution of this sort, at the situation in question, is clearly the development of a clockwise eddy (relative to the chosen base level), around the centre of low specific gravity, either closed, or forming a sector of the general north-south drift, according to whether the high centre did or did not represent an isolated pool. And since evidence is strong that the base plane (500 meter level) was practically stationary at the time, the actual surface drift probably was of the sort that the dynamic calculation calls for.

By contrast, the whole northern part of the bay was dynamically "dead" at the time.

In general this distribution suggests dynamic tendency for an indraft to enter the bay along the northern side of the trough, an outdraft to leave it around its southern side, as indicated on the chart (Fig. 24) by the arrows. But in the inner parts of the bay the dynamic gradients were so small, the tidal and wind currents so strong, and the directing effect of an almost straight coast line so immediate, that some more direct line of evidence is needed to show how closely the prevailing drift around the coast line of the bay did actually correspond to the dynamic calculation.

For the reason just stated, calculated velocities are not of much value in this case: may, in fact, be more misleading than instructive. Therefore, we need only remark that in the central part of the bay, where the dynamic gradient was then steepest, the calculated velocity around the southern side of the clockwise eddy (Sta. 13–27) was about 0.9 cemtimeter per second (0.18 knot), or at the rate of about 4.3 miles per day; only about one third as great at the northern edge of the eddy.

There is no warrant for assuming that the dynamic contour existing during the last half of July, 1928 represented a long continuing state, or that it is regularly representative of the summer season. On the contrary, every fresh updraft from below necessarily alters the tendency toward horizontal circulation by distorting the existing distribution of dynamic contours by introducing heavy water into or one another part of the picture in the upper levels. And whenever upwelling slackens, the gravitational tendency toward regional equalization reduces the existing gradients.

The decrease that took place in the specific gravity of the water at the situation of Stations 7 and 27, between July 10 and 23, in the upper 50 meters of water (table, p. 567), illustrates the rapidity with which such alterations may occur in the dynamic state of Monterey Bay. Nevertheless, theoretic probability so closely agrees with actual observation, that upwelling in Monterey Bay brings heavy water near the surface chiefly over the slopes of the submarine trough, as to make it likely that the existence of some such clockwise dynamic centre, over the axis of the latter, is characteristic of midsummer. One other disturbing factor besides wind currents (p. 473) must, however, be taken into account, namely, the progressive motion, around the bay that the deflective effect of the earth's rotation should, theoretically, give to the horizontal tidal oscillations (Huntsman, 1924; Bigelow, 1927). Theoretically this calls for a circulation of the reverse order, i.e. anti-clockwise, or from south to north around the shores of the bay, a discrepancy pointing the complexity of the circulatory problem that still remains to be solved there.

V. Chemical Oceanography

A. Dissolved Nutrients

1. *State prevailing in July, 1928*

Between July 10 and 24 the concentrations of dissolved phosphates and silicates were determined for vertical series at eighteen stations, three of them extending down to depths of 600 meters, one to 500 meters and one to 400, while surface measurements were made at three more stations. Nitrates were also determined at eight serial stations and at four others at the surface. For discussion of the methods, see p. 431. These data are valuable for comparison with the amounts of phytoplankton present at the time (p. 512), and for the light that the regional and vertical distribution of these chemical substances may throw, both on the efficiency of upwelling as an agency for the renewal of fertility in the upper strata of water, and as indications of the places where organic substances are most rapidly going into solution on the bottom.

Phosphate and Silicate

The distribution, regional and vertical, of phosphates and silicates was so nearly alike that these two solutes can be treated as a unit.

At the surface both of them showed considerable variation, phosphates ranging from about 0.009 to about 0.069 milligrams per liter,

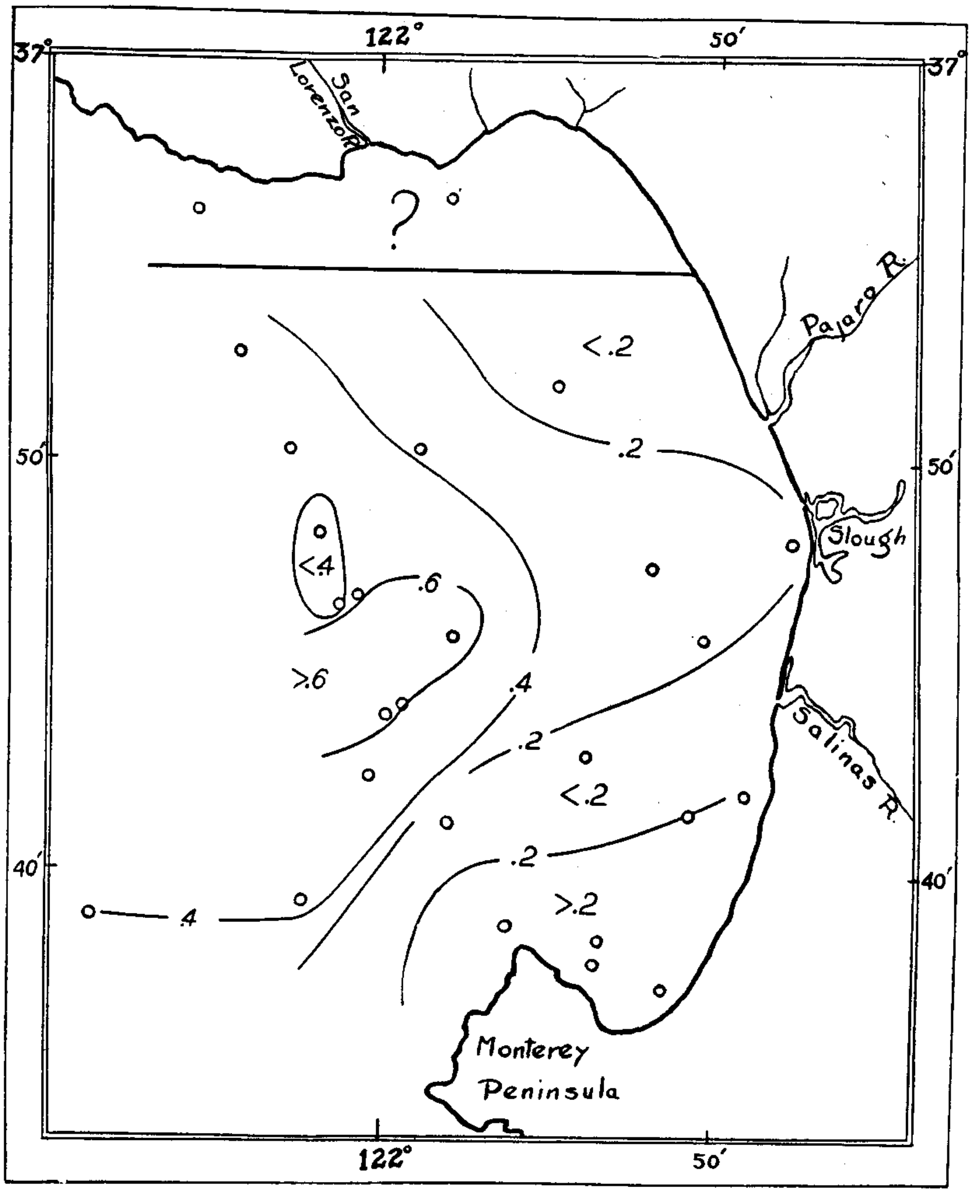

FIG. 25.— Distribution of silicates (as milligrams per liter of SiO_2), at the surface.

silicates from 0.143 to 0.78. To find so wide a range at the surface within so small an area is unusual. It is difficult to measure less than 0.05 milligrams per liter of silicate or 0.005 milligrams per liter of phosphate with any speed and accuracy. The minima in both cases were only slightly greater than these amounts, while the maxima were close

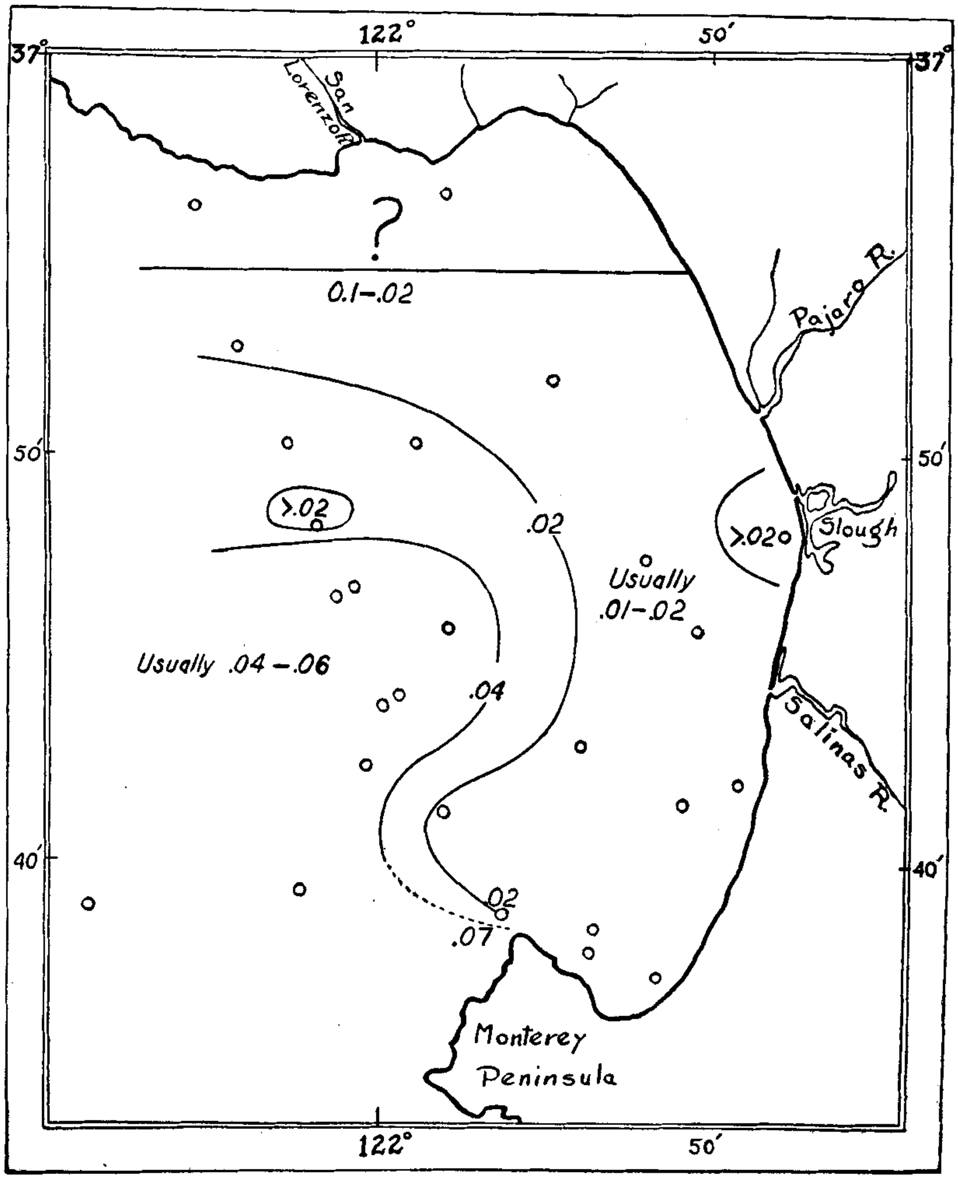

FIG. 26.— Distribution of phosphates (as milligrams per liter of P_2O_5), at the surface.

to the average values that characterized the 25–30 meter level at the time. The regional distribution for both (Figs. 25, 26) was characterized by relatively high values over the mouth of the submarine cañon, lower over the inner parts of the bay generally, and the regional gradation was about equally abrupt for the one substance as for the other, except in the vicinity of Point Pinos, where relatively high values as well as low were recorded. Both charts (Figs. 25, 26) furthermore, show the rich offshore water interrupted, midway across the bay, by barren pools.

The mean surface value for phosphate at the time was about 0.036 mg. per liter; for silicate about 0.4, the orders of magnitude involved being about ten times as great for silicates as for phosphates. This is the ratio that usually obtains at La Jolla also. We may point out in passing that arithmetical averages of the station records can only give a rough indication of the mean values for the bay as a whole, because the localities of record were not distributed regularly enough over the area.

In the upper 10–15 meters various irregularities and small reversals were recorded from the surface downward, as illustrated by the graphs for individual stations (Fig. 27). But the vertical distribution of silicates and of phosphates was similar from 15 to 250 meters at most of the stations (Fig. 28), both of these substances showing an uninterrupted increase in richness downward, either to the bottom or to the greatest depth reached, at every station but one (as has usually proved true elsewhere). In spite of the irregularities just noted for the superficial stratum, and in spite of the fact that the mean value at 10 meters was, in neither case, appreciably higher than at the surface, most of the stations showed considerably greater increase in both silicates and phosphates between the surface and a depth of 50 meters than in any stratum of corresponding thickness at greater depths, a fact reflected by a dislocation in the curves at the 50 meter level for most of the stations. From that depth downward the rate of increase was not only slower in most cases, but continued nearly uniform down to the deepest level reached; usually close to the bottom.

In fact the curves for silicates and phosphates were in most cases so nearly parallel from the surface down to the 200 meter level (if drawn to appropriate scale) that if superimposed they would be close to coincident. But at depths greater than 200 meters the two classes of curves diverge, enrichment being slightly more rapid, with depth, for silicates than for phosphates. This difference is illustrated by the graphs for the mean values for silicates and phosphates (Fig. 28): also by the mean increase for intervals of 50 meters tabulated below (p. 488). Its significance is discussed on p. 504. At the one station (9) which by showing a considerably lower value at 200 meters than at 100, formed an exception to the rule that phosphates increased regularly with depth, the vertical distribution of silicates was of the more usual type. And at one other station (17) where the water was homogeneous as to phosphates from a depth of 50 meters down to 200 meters, silicates showed the usual increase.

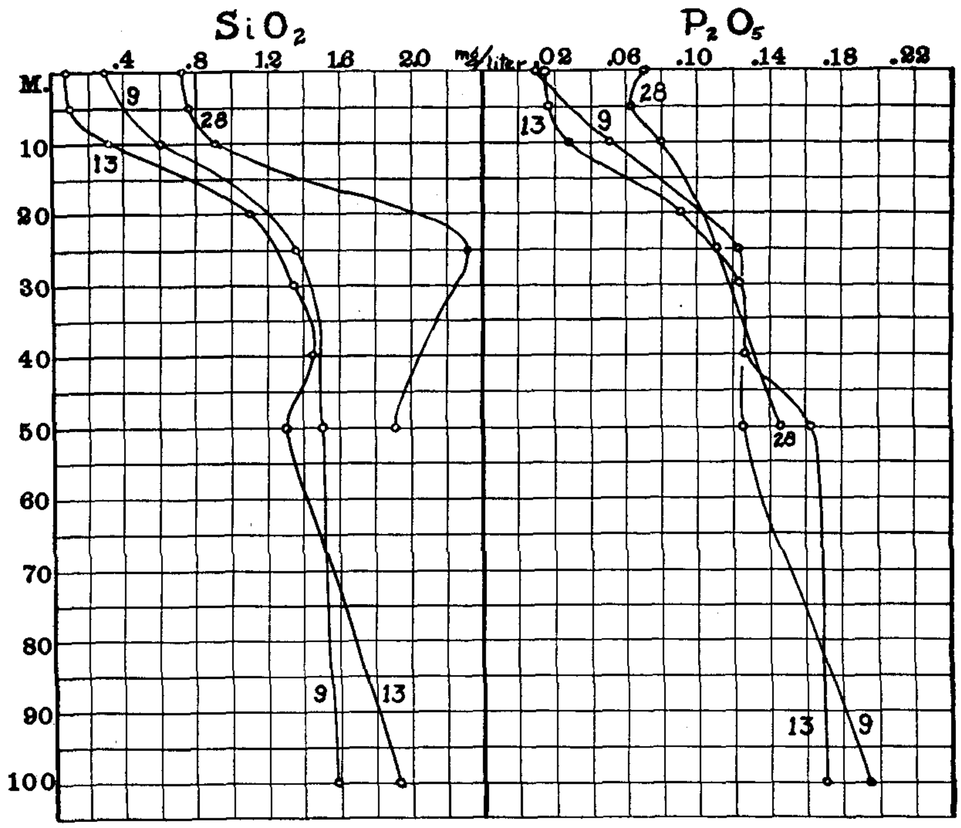

FIG. 27.— Vertical distribution in the upper 100 meters, of silicates (as SiO_2) and of phosphate (as P_2O_5) in milligrams per liter, at representative stations (9, 13, 28).

We refer the reader to the following table (p. 488) for the maximal, minimal, and mean values for silicates and phosphates at different depths, pointing out that the water was about six times as rich in silicates and five times as rich in phosphates at 600 meters as it averaged at the surface, although only about 1.001 times as rich in total salts.

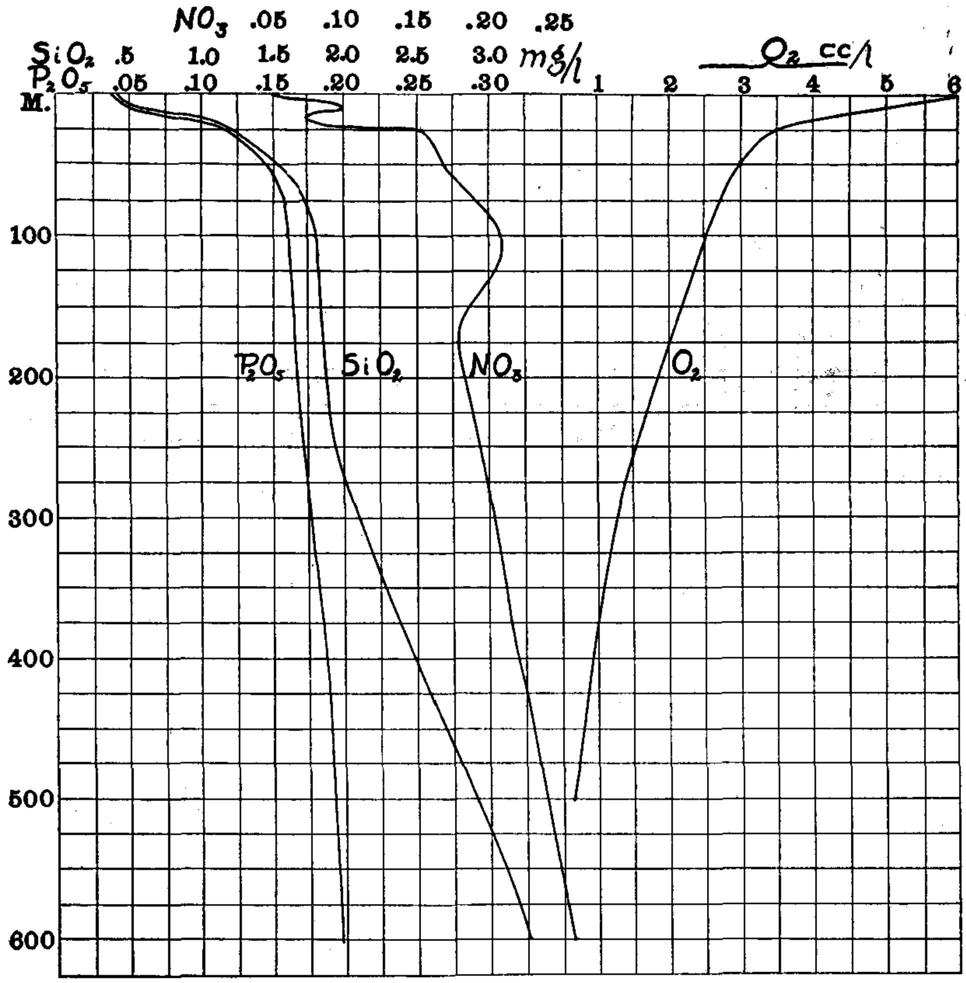

FIG. 28.— Mean value, for all stations of record, of phosphates (as P_2O_5), of silicates (as SiO_2), and of nitrogen in the form of nitrate, in milligrams per liter, and of dissolved oxygen in cubic centimeters per liter reduced to pressure of 760 mm. of mercury and temperature of 0° C.

Maximum, minimum and mean values for silicates (as SiO_2) *and phosphates* (as P_2O_5) *in milligrams per liter*

Depth meters	Silicates Max.	Silicates Min.	Silicates Mean	Phosphates Max.	Phosphates Min.	Phosphates Mean	Mean Increase per 50 meters Silicates	Mean Increase per 50 meters Phosphates
0	.78	1.43	.40	.069	.009	.036		
							1.11	.106
50	1.90	1.13	1.51	.163	.118	.142		
							.26	.016
100	2.41	1.38	1.77	.196	.134	.158		
							.05	.004
200	2.41	1.61	1.87	.196	.142	.166		
							.15	.005
400	2.91	2.39	2.49	.200	.175	.186		
							.19	.005
600	3.57	3.06	3.27	.217	.196	.207		

Irregularity of the station to station differences from the surface down to 50 meters added to the comparatively wide limits of variation at the surface, but uniformity at the deeper level, points to an unstable state, and to the probability that if observations had been taken shortly earlier, or shortly later in the season, or if they had been compressed into a shorter period, a different regional picture would have resulted in the superficial stratum of water. Close to Point Pinos, for instance, silicates increased from 1.456 mg/li on July 16 to 2.308 on July 23, but the value for phosphates was almost precisely the same on the later date as on the earlier (0.115 and 0.114 mg/li, respectively).

These complexities, however, smoothed out at depths greater than those to which the depleting influences of the plankton, and the disturbing effects of waves, etc., extend. Thus horizontal projections for the 50 meter level show that no definite separation into rich or poor areas was possible for phosphates at the time, slightly higher values appearing as more or less isolated pools at some stations, slightly lower values at others. A corresponding chart for silicates would be similarly uniform, as compared with the surface; the contrast between high surface values off the mouth of the cañon and lower at the western side of the bay, is but slightly indicated at 50 meters, the existence of the rich surface pool, next the Monterey Peninsula, but faintly reflected by values slightly higher there (1.56 and 1.88 mg/li) than in the adjacent band of water offshore.

This regional equalization of the chemical state of the water from the surface downward to 50 meters parallels that of temperature (p. 438). With increasing depth, below the 50 meter level, silicates, like temperature (p. 443) and salinity (p. 459) again showed progressive localization of relatively high and low values and of the same sort, namely, concentration of the highest values along the margins of the submarine valley, to a maximum right up at the head of the latter, with values lowest along the axis of the trough, and out at sea. This regional correspondence between silicates and temperatures in the mid-depths is best illustrated by the charts for the 100 meter level (Figs. 8, 29). But the agreement is not complete because the values for silicates were considerably lower at our outermost station in the deeper strata than they were closer in to this part of the slope.

Lack of data for one of the critical stations (29), makes it unsafe to reconstruct the distribution of phosphates at the 100 meter level. If the phosphate value was relatively low at that station, as the silicate value certainly was, essentially the same picture would result for phosphates as for silicates in the inner part of the bay, as might be expected from the generally close agreement between the two. The regional gradation for phosphates off the Monterey Peninsula at the

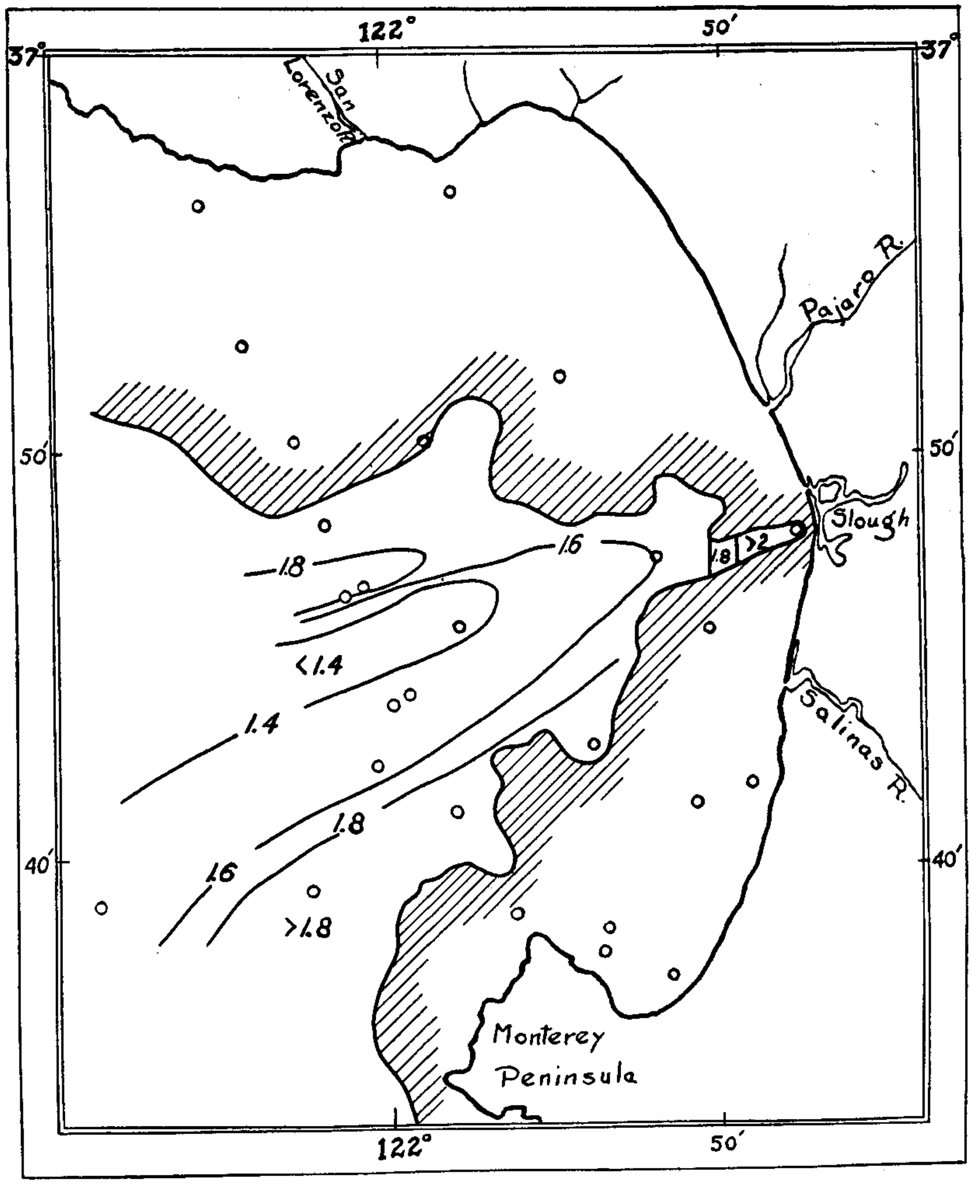

FIG. 29.— Distribution of silicates (in milligrams per liter of SiO_2) at a depth of 100 meters.

100 meter level, was essentially like that for silicates, with a decrease in richness from coast slope seaward. Furthermore, the 100 meter water was richest in phosphates at the head of the trough (0.168 mg/li

at Station 19) just as it was for silicates; least so at the outermost station (Sta. 17, 0.143 mg/li), while the profile for phosphates (Fig. 31) like that for silicates (Fig. 30) shows an unmistakable piling up of the richest water on the north and south slopes of the trough in the stratum between 50 and 150 meters, though not to as great a degree.

At depths greater than 100 meters the regional range of variation decreased both for phosphates and for silicates with increasing depth, corresponding to the contraction of the area involved. But even as deep as 600 meters the station to station variation for phosphates was seven times the experimental error, the variation for silicates 25 times the experimental error.[1]

In the case of silicates, horizontal projections, like the profile (Fig. 30) show that the concentration of the richest water around the slopes of the trough involved the whole mass of water down to a depth of 400 meters. Thus the distribution of silicates was essentially the same at the 200 meter level as at 100 meters (Fig. 29), except that the absolute maximum was recorded off the Monterey peninsula at the deeper level instead of at the head of the trough. And even at 400 meters the values of silicates were appreciably higher at our two stations over the northern and southern slopes than at the three other stations in the deep trough. But with increasing depth this distributional type gave place to a regular gradation from low values offshore, and over the southern slope of the trough (3.06–3.19 mg/li), to high (3.57 mg/li) over the northern slope of the latter. The significance of so great a difference in silicates, at the deepest level of observation, between locations only 10 miles apart, contrasted with the uniformity of temperature and of salinity, is discussed on page 504.

At depths greater than 100 meters an equally striking difference appears between the regional distribution of silicates and that of phosphates, for at 200 meters the latter (Fig. 32) were lowest at the head of the trough (Sta. 9), where silicates were high, and highest at the station at the mouth of the trough (Sta. 17) where silicates were lowest (Fig. 33). At the 600 meter level maximum values for phosphates (0.127 mg/li) at the outermost station, minimum (0.196 mg/li) over the northern slope of the trough, again reverse the silicate distribution.

[1] With the values prevailing at this depth, the experimental error is about 0.004 mg/li for phosphates, 0.04 mg/li for silicates.

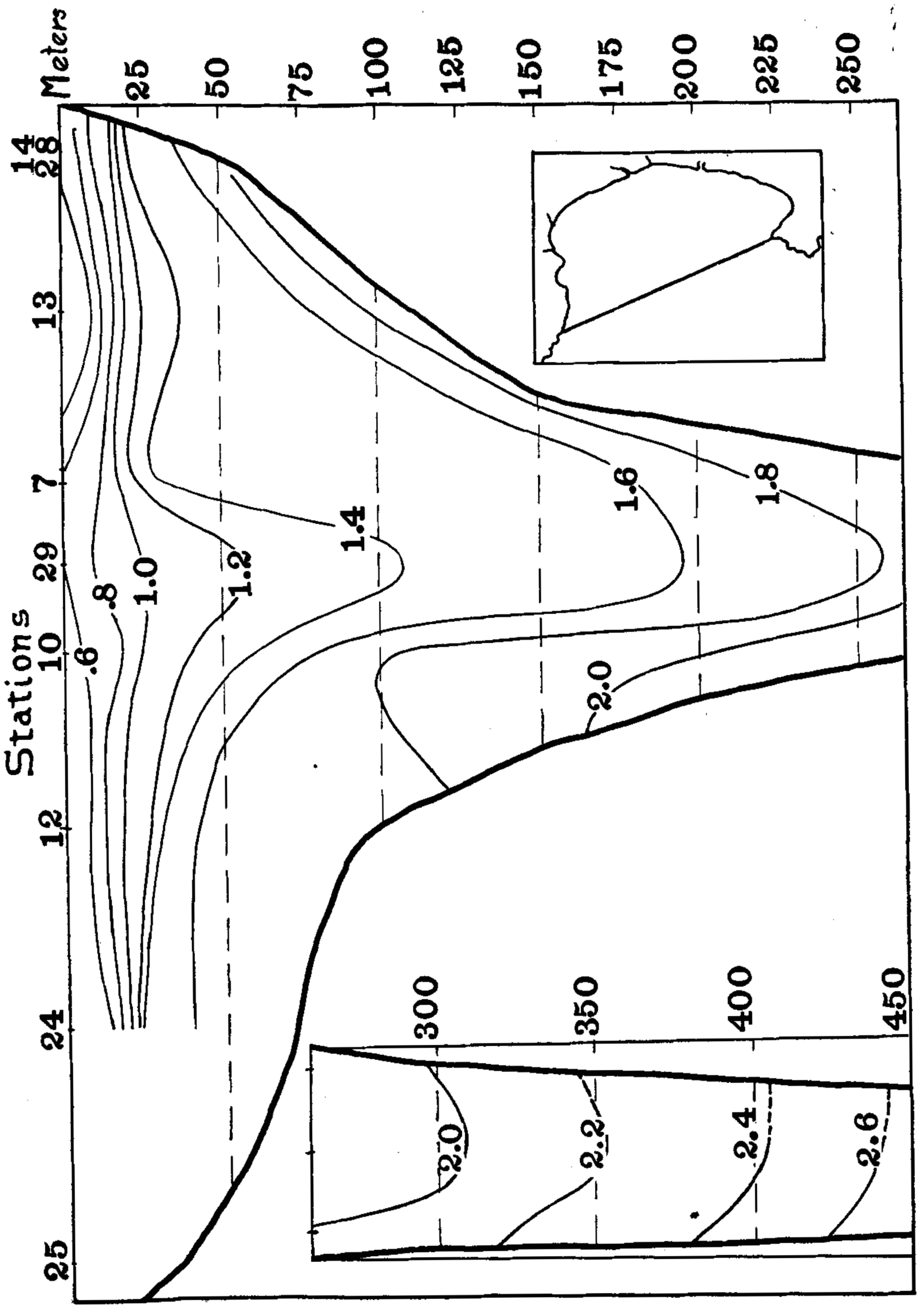

FIG. 30.— Profile across the mouth of the bay for silicates (in milligrams per liter of SiO_2).

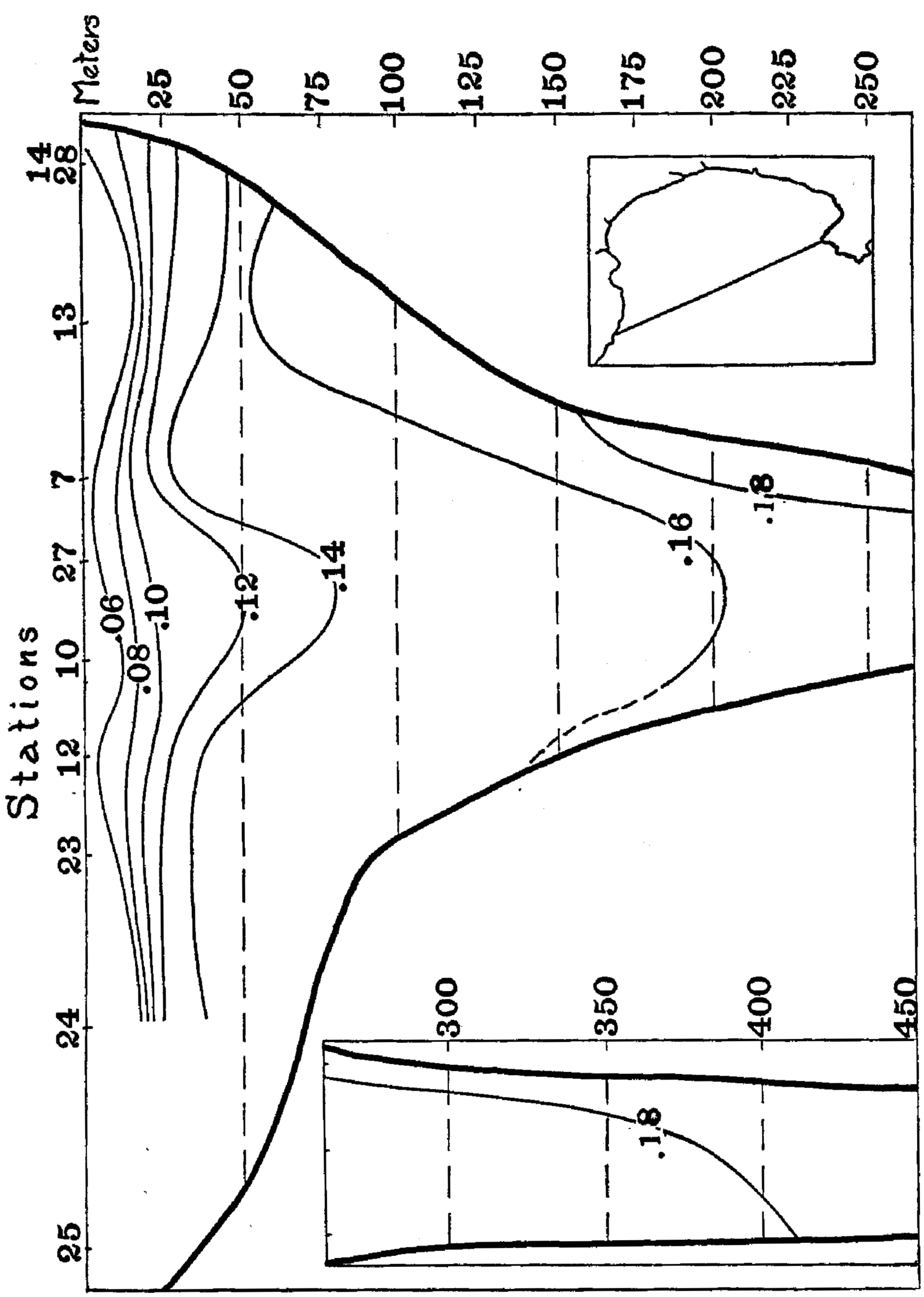

FIG. 31.— Profile across the mouth of the bay for phosphates (in milligrams per liter of P_2O_5).

Nitrate

For technical reasons, explained on page 432, the determinations for nitrates were not only less numerous than those for silicates and

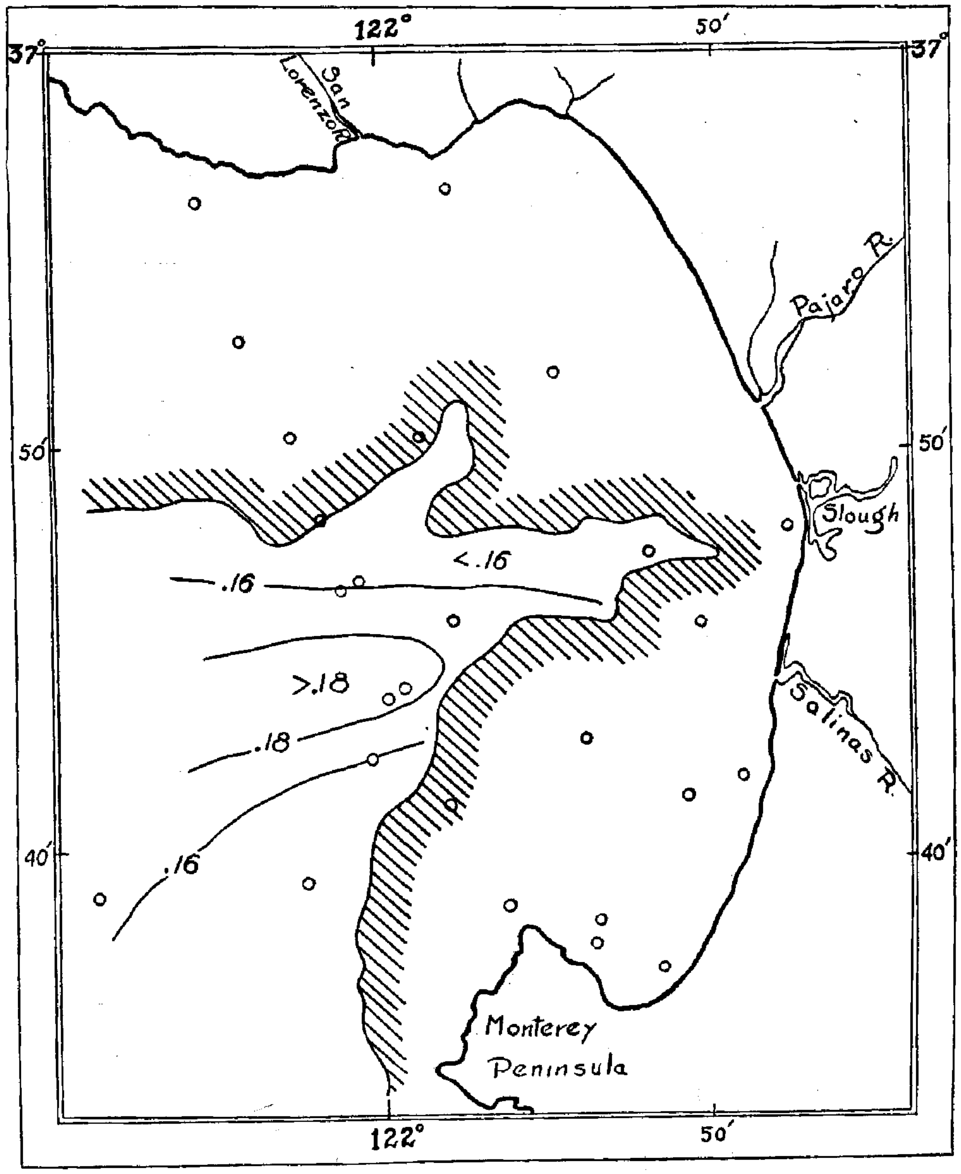

FIG. 32.— Distribution of phosphates (in milligrams per liter of P_2O_5) at a depth of 200 meters.

phosphates, but less satisfactory. Consequently it is not wise to draw conclusions from station to station differences, unless these show regional consistency, are consistent with other chemical features of the water, or are consistent with the regional abundance of diatoms or of peridinians.

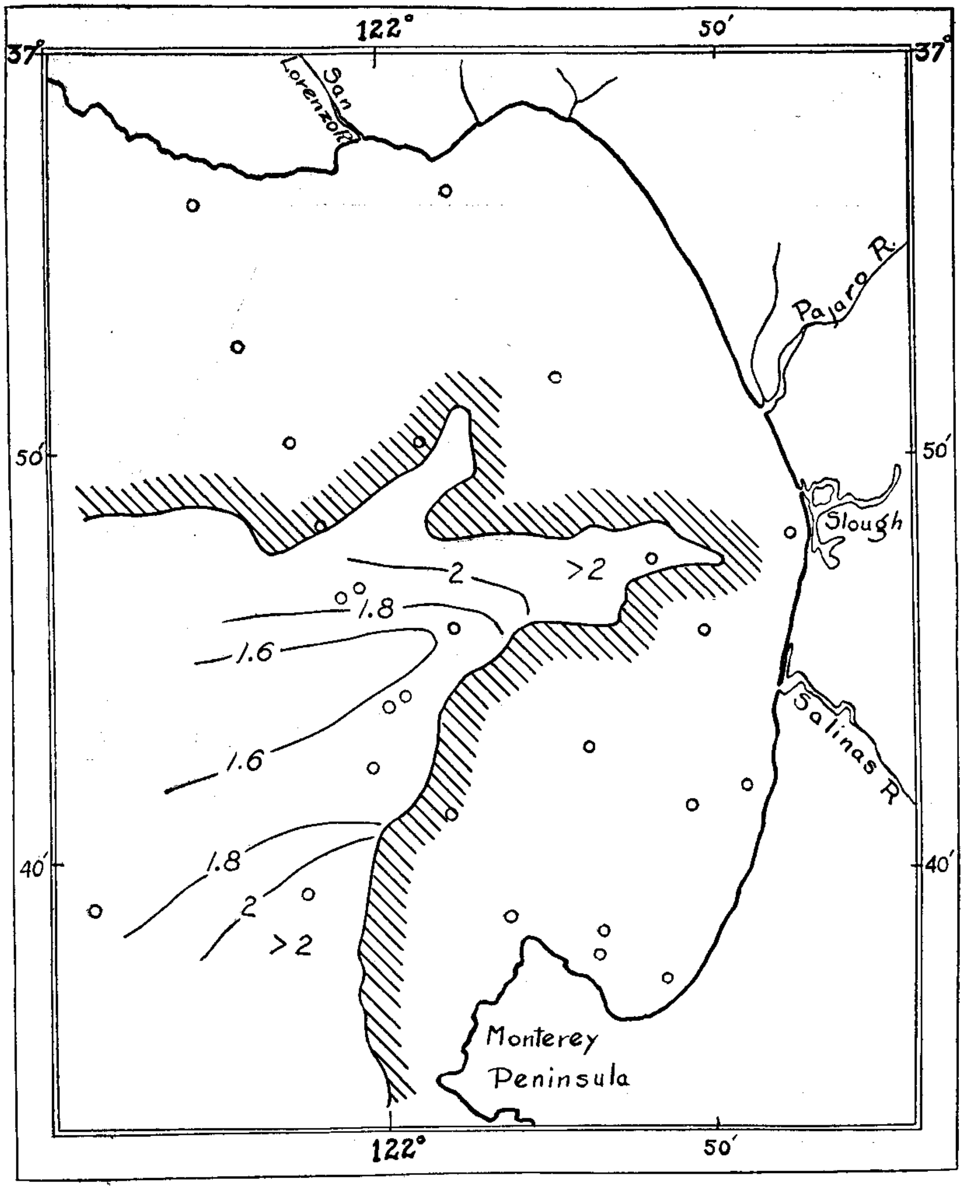

FIG. 33.— Distribution of silicates (in milligrams per liter of SiO_2) at a depth of 200 meters.

The most interesting aspect of the nitrates at the surface is that at three stations we found the surface water wholly nitrate-free (Stations 21, 22, 23, Fig. 34), whereas measurable amounts of silicates and of phosphates were detected at every station. But as no sub-

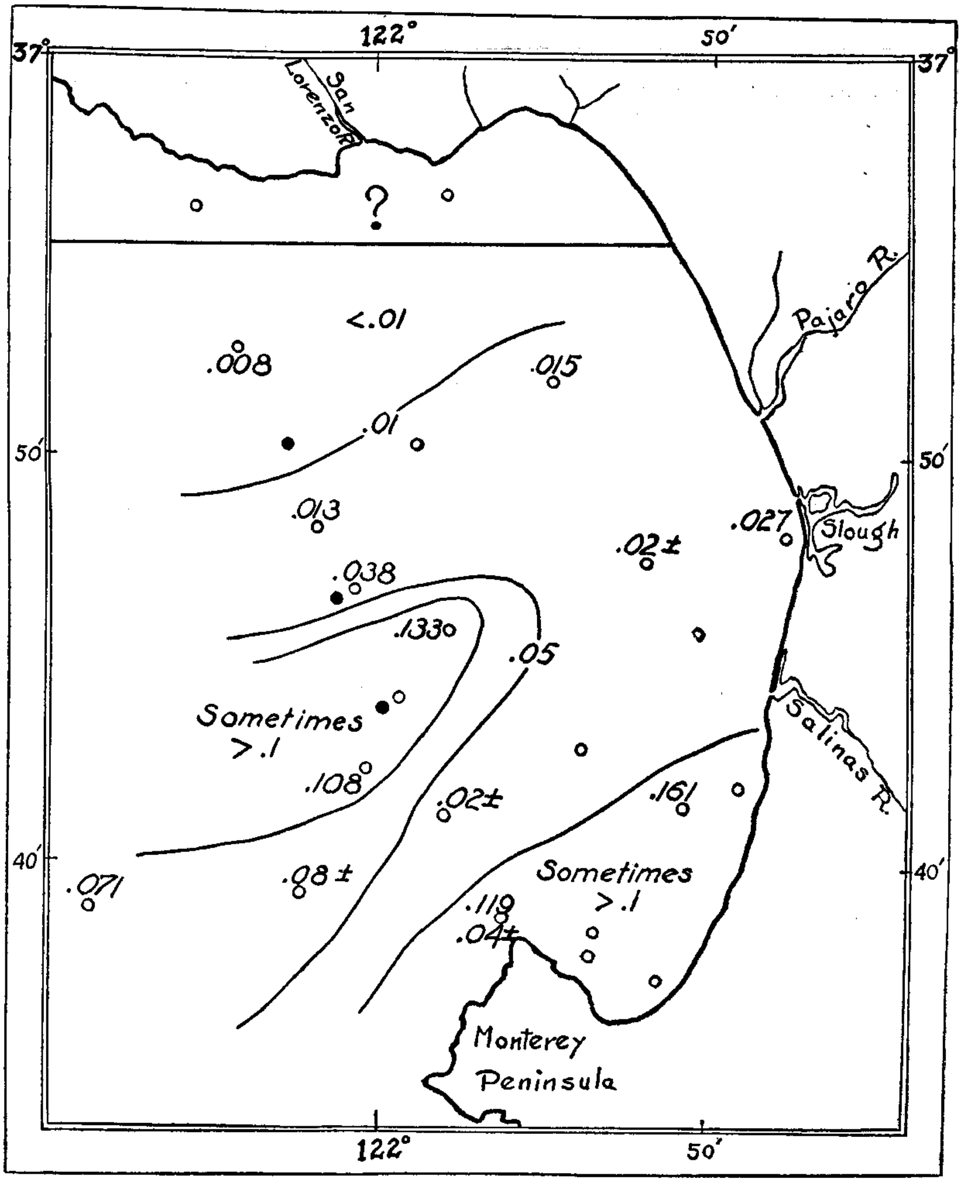

FIG. 34.— Distribution of nitrates (in milligrams per liter of NO_3) at the surface. Heavy dots, nitrate-free.

surface data for nitrates are available for these particular stations, we cannot state how thick the nitrate-free stratum may have been. The vertical distribution of nitrates, at the few localities where serial observations were made, showed considerable variation from station to station in the upper 25 meters. Thus two stations (12, 17) showed a continuous increase downward to that level, whereas at three others,

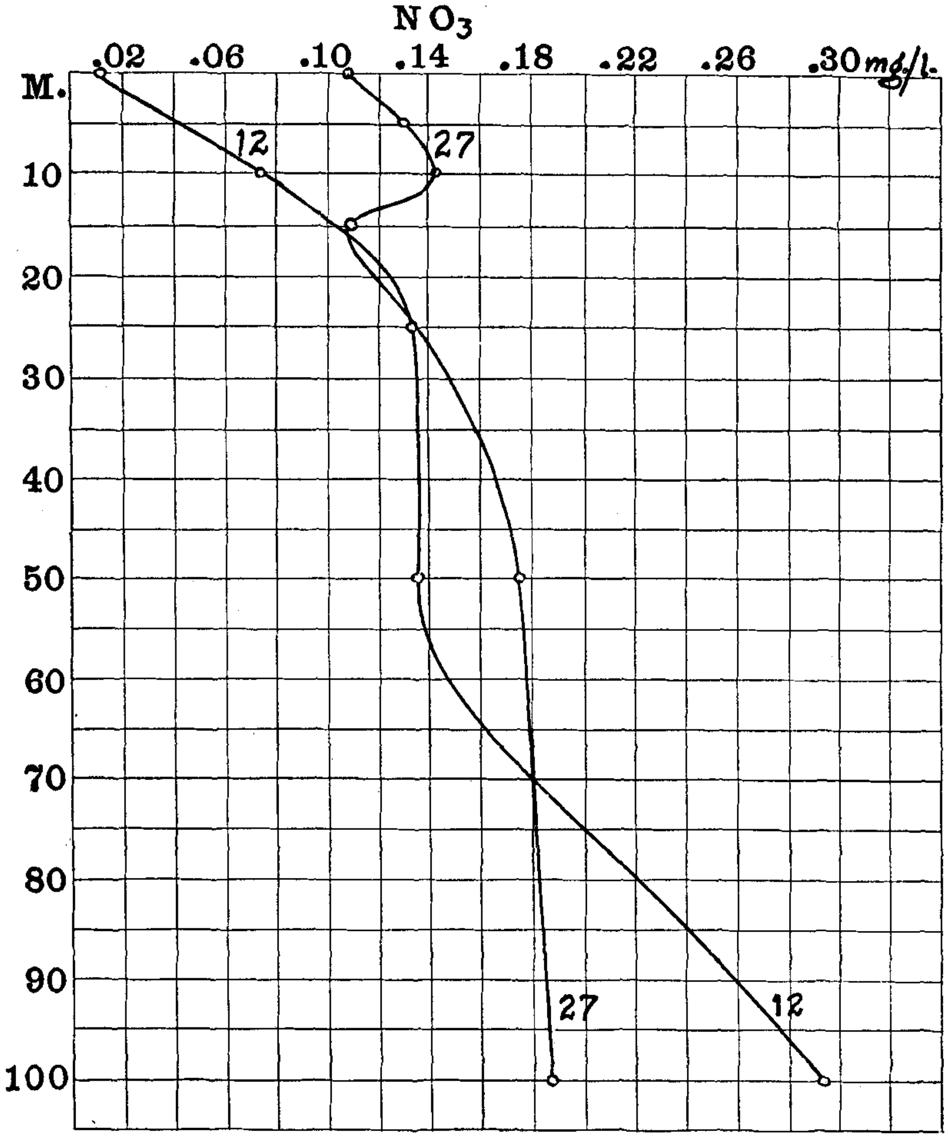

FIG. 35.—Vertical distribution of nitrates (in milligrams per liter of NO_3) at Stations 12 and 27.

one deep and two shoal (24, 27, 28), a comparatively rich stratum at 5–10 meters was sandwiched in between poorer waters, both at the surface and deeper (Fig. 35). This alternation was so pronounced in these instances that it appears also for the average values for the levels in question, as tabulated below. And while it characterized only three of the stations, with no definite regional segregation, it deserves attention because it was not paralleled either by silicates or by phosphates.

NO_3 Nitrate, mg. per liter

Depth meters	No. of samples	Maximum	Minimum	Mean
surface	9	.161	.00	.047
5	3	.161	.013	.101
10	4	.141	.038	.097
15	3	.108	.021	.074
25	5	.174	.136	.152
50	7	.178	.136	.169
100	4	.292	.174	.209
200	2	.197	.158	.178
600	3	.266	.251	2.60

In general, and for the area as a whole, the concentration of nitrates may be described as increasing with depth, at the time, from the 25 meter level downward to the deepest level reached (600 meters); and in every case the 50 to 100 meter stratum proved considerably richer in nitrates than did the superficial 10 meters of water. Two stations (24 and 27), it is true, offered apparent exceptions to this progressive enrichment with depth, the recorded values suggesting slightly less nitrate at 70 meters than at 150 in the one case, slightly less at 200 meters than at 100 in the other. But in both these instances the apparent reversals were hardly greater than might result if the experimental error chanced to be cumulative, hence they need not be discussed further.

We must point out, however, that while the 600 meter level showed a considerably higher value of nitrate than any shoaler level at each of the deep stations (17, 24), the absolute maximum for the whole area (0.292 mg/li) was recorded at a depth of only 100 meters, at a station (12) where the progressive enrichment from the surface downward with increasing depth was so orderly that there was no probability of any considerable error in the determinations. As this value is not only considerably higher than any other recorded in Monterey Bay at an equal depth, but considerably higher even than the values encountered 500 meters deeper, the most rational explanation is some local source of enrichment (p. 507). However this may be, one exceptional value does not interfere with the generalization that at every station deeper than 100 meters the bottom water averaged at least five times richer than the surface in nitrates. Thus for nitrates, as for phosphates and silicates, the water of the deeps off the mouth of the bay, and in the trough of the latter, contained a store which, if it seems small by absolute standards, was extremely high by comparison with the poverty of the surface.

2. *Comparison with near-by regions*

Moberg's (1928, p. 512) graphs for summer averages in the upper 150 meters at La Jolla show phosphate values somewhat lower at the surface there (averaging about 0.01 mg/li) than we found in Monterey Bay at the same season (about 0.04). But this difference decreases with depth until at 150 meters the average summer values so far recorded for the two localities are almost precisely alike (0.16 to 0.17 mg/li). In the case of silicates, however, the Monterey values average considerably the higher throughout the entire depth column, the surface mean being only about 0.32 mg/li at La Jolla (0.5 for Monterey Bay); the 50 meter mean 0.64 mg. per liter as against 1.51; the 100 meter mean 0.91 as against 1.77; the 150 mean 1.17 as against 1.8. Furthermore, the La Jolla graph for silicates shows much more irregularity in the upper 30 meters, even for averages, than does the corresponding graph for Monterey Bay (Fig. 28). In spite of these differences, the vertical distribution of silicates was essentially of the one type at these two localities, the water averaging 3.6 to 3.7 times as rich at 150 meters as at the surface in each case. And with only one month's data for Monterey Bay, it is doubtful whether the recorded difference represents a normal divergence between the two regions.

No data for phosphates or silicates have yet been published for southern Californian waters for depths greater than 150 meters. But the following values, from unpublished data contributed by the Scripps Institution for two stations about one hundred miles north of La Jolla, August, 1926, show that phosphates continued in about the same amount as off Monterey in July, 1928, but silicates lower, down to 600 meters:

Depth	Phosphates P_2O_5 Mg. per liter	Silicates SiO_2 Mg. per liter
200	.175	1.76
400	.200	2.23
600	.221	2.68
1000	.264	3.80

The discharge from the Fraser River results in much greater richness in silicates in the partially enclosed waters of the Straits of Georgia, Hutchinson (1929) having recorded values as great as one to four parts (as SiO_2) *per thousand*, contrasting with a maximum of only about 2.41 parts *per million* at Monterey for the same depth zone.

The concentration of phosphates, however, is about the same in the Straits of Georgia as we found it in Monterey Bay, Hutchinson's (1928) graphs showing phosphates varying from 0 to 0.06 milligrams per liter at the surface and from about 0.075 to 0.135 milligrams per liter at 15 meters depth, at selected stations.

The fact that the waters off California show increasing richness in phosphates and silicates, with increasing depth, downward to depths of 500–1000 meters (now amply established) proves that the northeastern Pacific agrees in this respect with the north and south Atlantic (Atkins and Harvey, 1925; Atkins, 1923–1926; Harvey, 1928; Wattenberg, 1927). This, therefore, may be accepted as the state prevailing throughout all the ocean basins. The actual values reported for the 500–1000 meter stratum, by recent methods, have also been of about the same general orders of magnitude, wherever measured.

The summer values recorded by Moberg (1928) for La Jolla, compared with our data, suggest that in summer Monterey Bay waters are considerably the richer in nitrates in the superficial strata, for he found the water off La Jolla practically nitrate-free in the upper 15 meters, and as deep as 30 meters carrying only about 0.05 milligram per liter of nitrates, whereas the surface water at Monterey was only occasionally nitrate-free, and at 30 meters the average concentration was between 0.15 and 0.16 mg/li. But at 50 meters the nitrate values averaged slightly the higher at La Jolla (about 0.18), with the differential in this direction increasing with increasing depth until at 150 meters the La Jolla average (about 0.33) was about 0.14 mg/li the higher. Even if the maximum Monterey values be taken for the comparison, La Jolla water at this depth showed a surplus of about 0.085 mg/li. The vertical gradient, as graphed by Moberg (1928, p. 512) suggests still more difference between the two localities at greater depths. In short such data as are yet at hand point to a much richer store of nitrates in the deeps off La Jolla than off Monterey Bay. The relative states are not so clear for the surface waters, for while the recorded differences may seem considerable, we might have found a more consistent depletion of the surface stratum with regard to nitrates if we had studied the bay a few weeks earlier or a few weeks later, or in another summer.

It is interesting that the nitrate values of Monterey Bay at 100–600 meters, differed little from those recorded for that depth zone off Ireland, by Harvey (1928a).

3. *Maintenance of chemical fertility in Monterey Bay waters*

Successive determinations of the amounts of nutritive chemicals (using this term in a broad sense) in solution in sea water have shown so general a correspondence between their changes in richness, and the fluctuating abundance of planktonic plants, that depletion of one or another nutrient substance, or group of substances, seems, on the whole, the factor that most effectively limits plant production in the sea.[1] Opportunities to examine the means by which the drafts upon such substances as phosphates, silicates and nitrates are made good are therefore welcome, especially any opportunity to determine the relative importance, for given regions, of the overturn of matter within the sea itself, as compared with the materials contributed by rivers and land-wash in general.

Upwelling as the chief agent

Monterey Bay offers an exceptional opportunity for studies in this field, both because the governing type of circulation there brings water up from below, and because the contribution of salts made by tributary rivers is concentrated within so short a part of the year that its direct effect, at other seasons, can be looked on as negligible (p. 510). It also offers an opportunity to compare the state prevailing in a sector typically oceanic, controlled by upwellings from the deeps, with the conditions existing in enclosed waters in the same general region, where river waters play a leading part — Puget Sound, for example (Hutchinson, 1928), and San Francisco Bay (Miller, Ramage and Lazier, 1928); as well as with the North Sea and English Channel, made classic in this respect by the pioneer studies of Brandt, Raben, Atkins, and others.

Since consumption of these nutrient salts by plants, in their photosynthesis, is necessarily confined to the superficial stratum, where sunlight penetrates with intensity sufficient to afford the requisite energy, and since animals (so far as yet established) cannot, as a group, make use of these simple chemicals directly (we make no critique here of Pütter's theory), oceanographers have come to regard

[1] For a recent quantitative presentation of this thesis, see Atkins, 1926a.

the upper 40 meters or so as the zone of chief consumption in the sea. On the other hand the deep waters of the English Channel, of the north and south Atlantic (Atkins, 1923, 1925, 1926b, Wattenburg, 1927), and latterly of the Pacific (Moberg, 1928) have been found so generally rich in phosphates, etc., as to show that everywhere, over the open oceans, and even in shoaler regions, the bottom waters are a reservoir for plant nutrients, needing only some mechanism to bring the latter up to the photosynthetic zone. Recent studies have thus substantiated Nathanssohn's (1906) early realization of the rôle played by upwelling currents in maintaining oceanic fertility.

A glance at the graphs for the average amounts of silicates, phosphates and nitrates at different depths (Figs. 28, 35) is enough to show that in July, 1928, Monterey Bay and its offing formed no exception to this rule, but that the deep water held in solution an abundance of all these substances. Neither is there any reason to suppose that the abyssal water off the Californian coast is less rich at any other time of year, or that the years 1926 (for La Jolla)and 1928 (for Monterey) were exceptional years in this respect.

The fact that upwelling proceeds constantly enough, rapidly enough, and in sufficient volume in the Monterey sector, to depress the midsummer temperature of the surface water some 8° below the value to which solar warming would otherwise bring it (p. 476), were it not frequently replaced by colder water from below, gives some picture of the parallel efficiency of this same updraft in bringing up water that (as has been found) is richly stocked with the substances in question. In brief, present indications are that Monterey Bay is an especially favored location so far as replenishment of the surface water is concerned — hence potentially an exceptionally rich region for the production of planktonic plants. It is only because of events taking place in the uppermost stratum, namely absorption of solar heat and consumption of chemicals by plants, that upwelling fails to keep the whole column of water off Monterey Bay homogeneous from top to bottom.

The prevalence of a type of circulation best fitted to bring up rich water from below is, however, but one side of the fertility-picture: another involves the sources from which the deep water becomes stocked with nitrates, silicates and phosphates and other solutes; likewise the localities where replenishment of this sort proceeds the most rapidly. Up to date, detailed information, as to this general question, has been scanty for any particular region, though it is evident that such restocking of the bottom water, as contrasted with the surface, results from the decomposition of carcasses, and by the solution of their shells, possibly also from nitrogen fixation by bacteria.[1]

In interpreting the differences that we found in the deeps off Monterey between the regional distribution of temperature, and that of the few chemicals for which the local waters have yet been tested, it is necessary to bear in mind that the two classes of phenomena are governed by different factors, though in many respects parallel. The low temperature of the abyssal water is directly reminiscent of the sinking from the surface of cold water at some far distant station, subarctic or subantarctic. But wherever animals or plants, sinking down, rot in the deeps or on the bottom, enrichment of the water with compounds of phosphorus and nitrogen results—with compounds of silicia also if their shells or skeletons are siliceous.

Thus while the floor of the sea, however deep, is not a cooling agent *per se,* it is a most effective agent for the chemical enrichment of the water. A certain amount of enrichment of the bottom water must take place everywhere on the sea floor, unless both the latter, and the overlying waters as well, be barren of life, though in shoal waters consumption from above may outstrip this enrichment from below, bringing progressive depletion as the end result. Thus as bottom water, in depths below the zone of photosynthesis, drifts along over the floor of the sea, the tendency is for it to gather a greater and greater load of solutes, the rapidity with which this happens depending upon the amount of organic decomposition that takes place, quite independent of the depth. Movement over the sea floor, or temporary isolation in the deeps, have, on the contrary, very little effect on the temperature of the water if the depths be so great (or the situation such) that vertical stirrings are negligible.

It is possible that the richness of the deep waters off California, in silicates, phosphates and nitrates chiefly reflects substances taken into solution at lesser depths in the sub-Antarctic, or sub-Arctic, plus the added load picked up, en route in its oblique drift across the Pacific; or it may result chiefly from organic decomposition taking place over the Pacific slope of North America. However this may be, the comparative uniformity of the 600 meter level with respect to phosphates and nitrates along the Monterey front, is an indication that there was no one specially rich focus of local enrichment at the time of our investigations, at what was then apparently the base-

[1] The restocking of the superficial stratum that takes place, direct, from land drainage, and by absorption of ammonia from the atmosphere is another question.

level for active upwelling. The case seems to have been different for silicates, because it is hard to explain the banking of silica-rich water against the northern slope of the trough, at 500–600 meters except on the assumption that some process of enrichment was locally at work there for silicates, that was not effective for phosphates or for nitrates. The fact that in the deep strata, from 200 meters downward, enrichment in silicates averaged more rapid, with increasing depth, than for phosphates, though the curves for these two substances were parallel in lesser depths (p. 486), points in this same direction.

Our profiles for silicates and phosphates (Figs. 30, 31), and the isobathic projections for the higher values of each (Figs. 36–38), so closely parallel the corresponding projections for temperature, especially in revealing a banking up of the higher values around the slopes of the trough, as to show that upwelling was in fact bringing rich water upward there at the time. in the mid depths. But in the superficial stratum the water richest in phosphates and silicates (Figs. 39, 40) like the coldest (p. 435, Fig. 2) then rose nearest the surface over the mouth of the trough, as might have been expected from the distribution of temperature and salinity.

When the shoaler strata are examined in detail, suggestive differences appear between the chemical factors and the temperature, for the angle of obliquity was steeper for silicates in the zone between the 70 meter and 200 meter levels, than for the isothermobaths (Figs. 17, 19, 20). For example, water of a temperature (8.2°–8.5°) that prevailed at 200 meters in the axis of the trough near its mouth was at the time flooding the slope up to the 120–100 meter level. But silicates of the value prevailing at that same depth in the trough (1.6 mg/li) also bathed the bottom over most of the shoal parts of the bay, to the north of the deep trough as well as to the south (Fig. 37). While the distribution of phosphates agreed more nearly with temperature in this respect in the northern side, the banking up of phosphate-rich water more nearly paralleled that of silicates in the southern (cf. Figs. 30 and 31 with Fig. 7, curves for 8.5° and 9° temperature, 0.16 mg. per liter P_2O_5, and 1.6 mg. per liter SiO_2). Interpretation of the state of the superficial waters is obscured by the danger of confusing periodic variations with regional differences. But the contrast between silicates and temperature is so wide in this respect that it remains to be accounted for, after all reasonable allowance has been made for the time factor, and for possible errors in the determinations.

If temperatures and salinities can be taken as safe indices to the loci of most active upwelling, as seems justifiable, the most reasonable explanation for differences of this sort between the physical and chemical states of the water of the bay is that while the only source

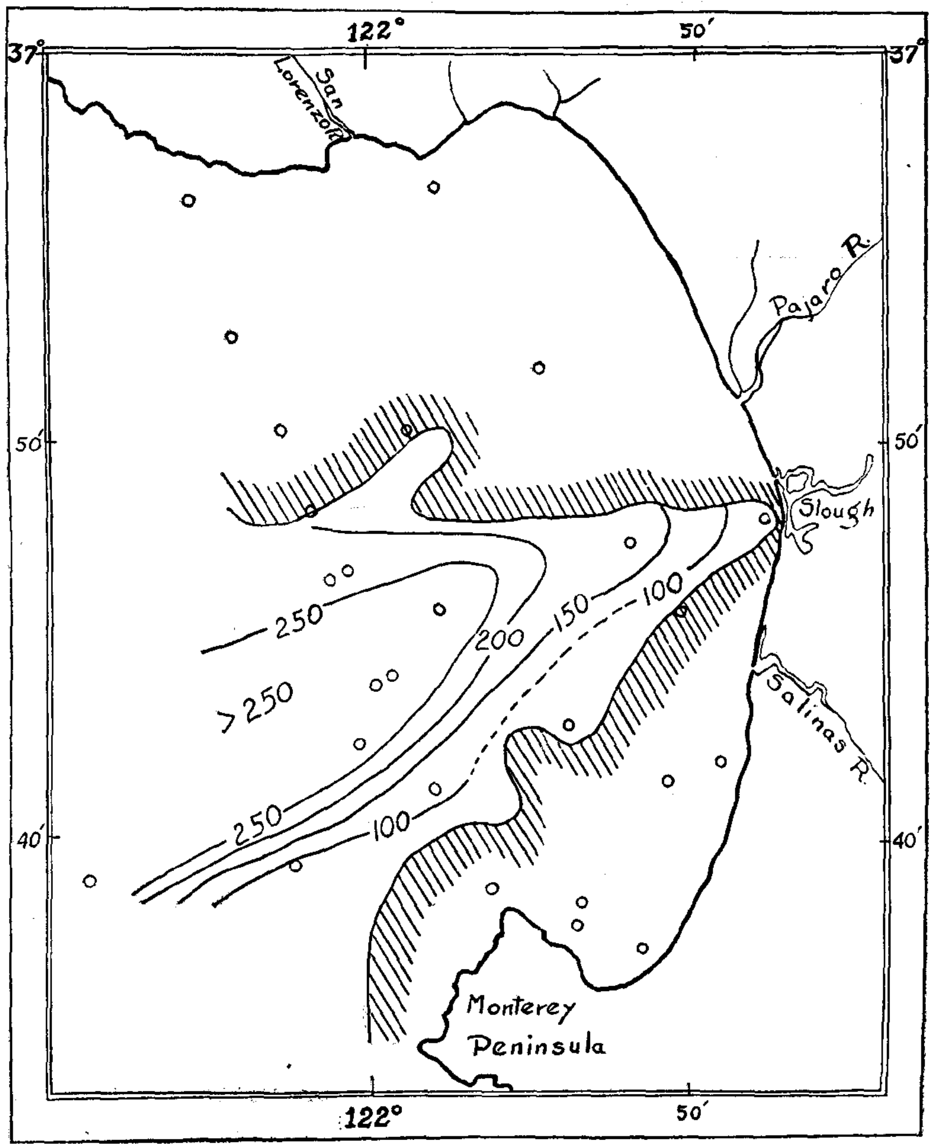

FIG. 36.— Depth below the surface of the layer of 2 milligrams of SiO_2 per liter.

for low temperature, at the place and season, was the underlying deeps, the upwelling water was further enriched as to silicates and phosphates as it spread over the upper slopes of the bay. Such a thesis needs no special defence, for this is what is to be expected. What is interesting, in the present case, is the strong indication that local

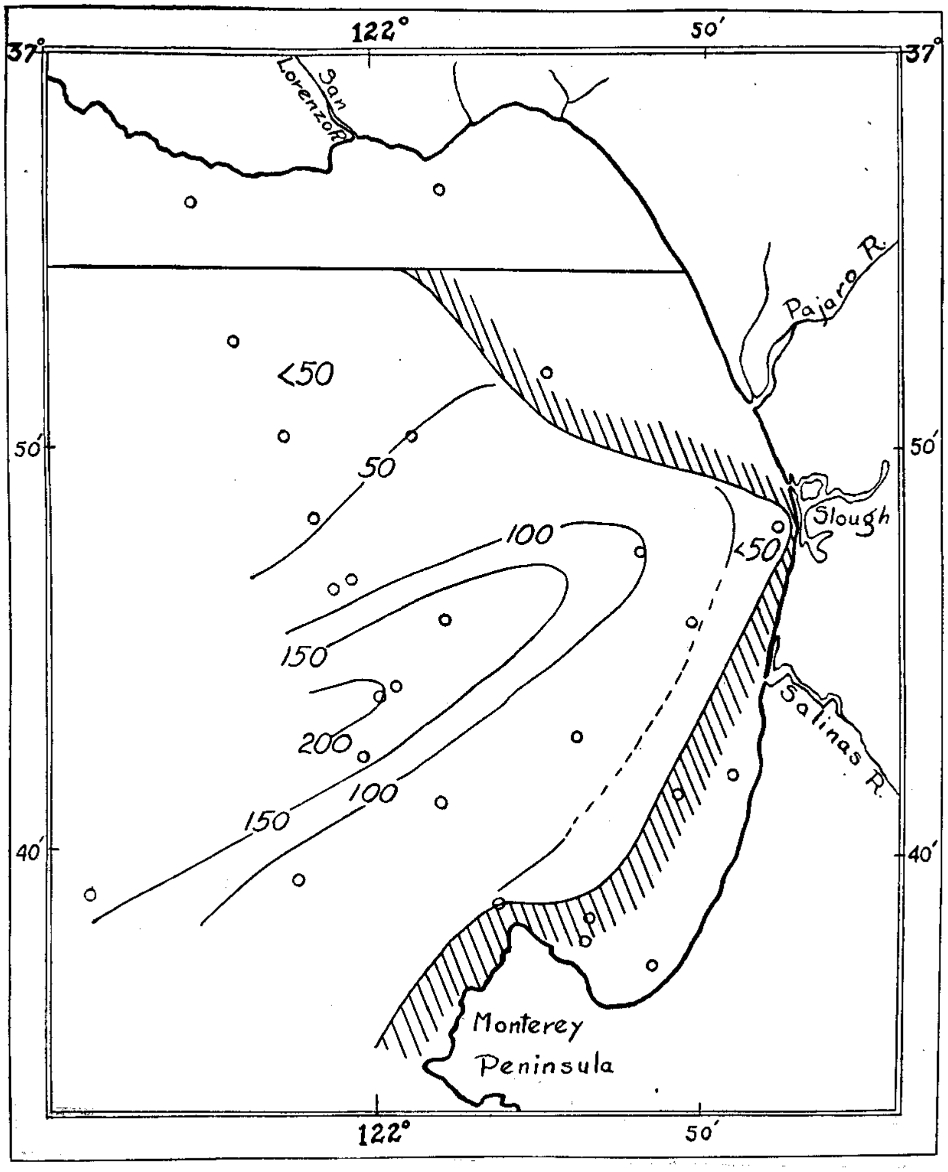

FIG. 37.— Depth below the surface of the layer of 1.6 milligrams of SiO_2 per liter.

solution of the chemicals in question, in depths less than 200 meters, may vie in importance with the deep reservoirs as a source of replenishment for the photosynthetic zone in this particular location. Consequently, in interpreting events at the surface of the bay, it is necessary to take into account not only the mass upwellings, but equally any

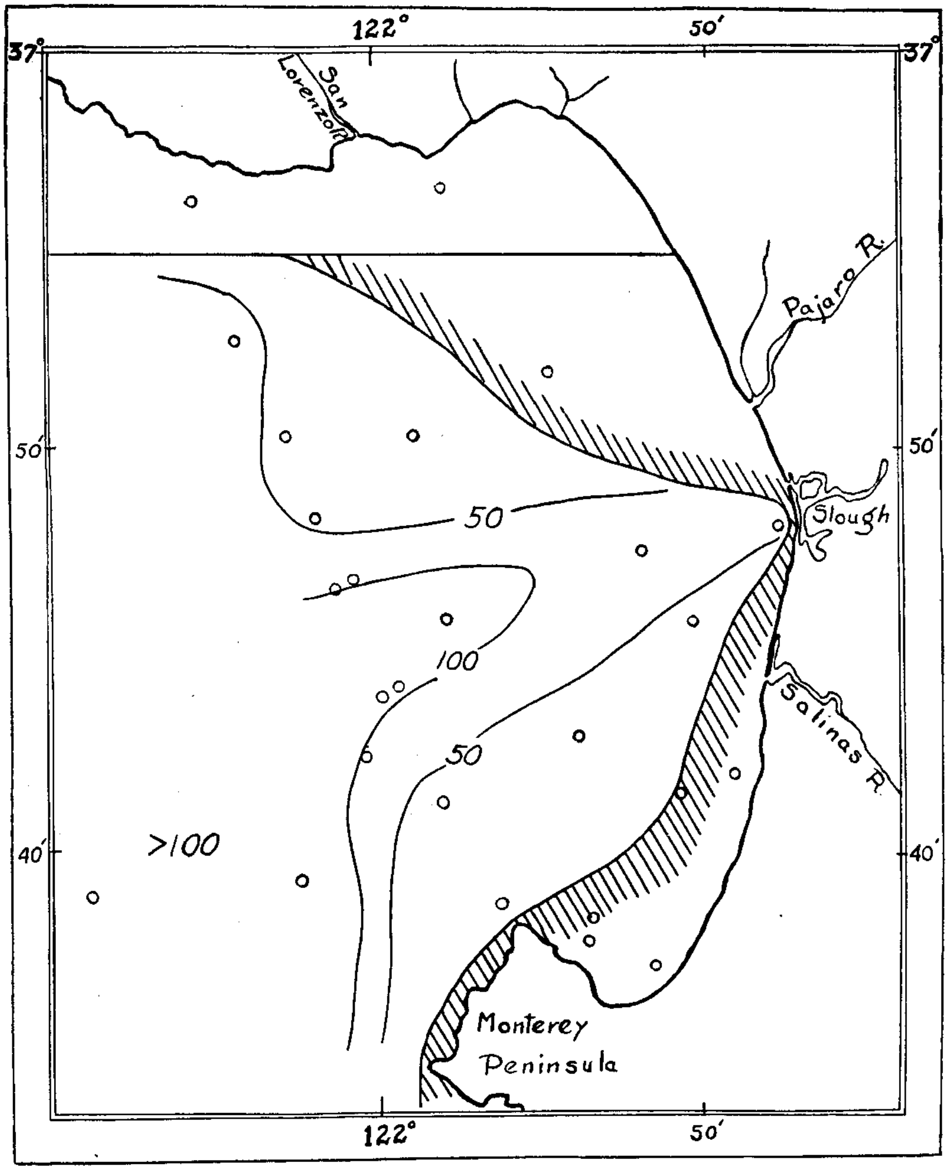

FIG. 38.— Depth below the surface of the layer of .15 milligram P_2O_5 per liter.

vertical movements that might bring water up from depths of 100–200 meters. Shoal bottom may therefore be an important factor in the maintenance of chemical fertility in Monterey Bay, though not to the extent that it is in regions (e.g., north Atlantic) where the continental shelf is wide.

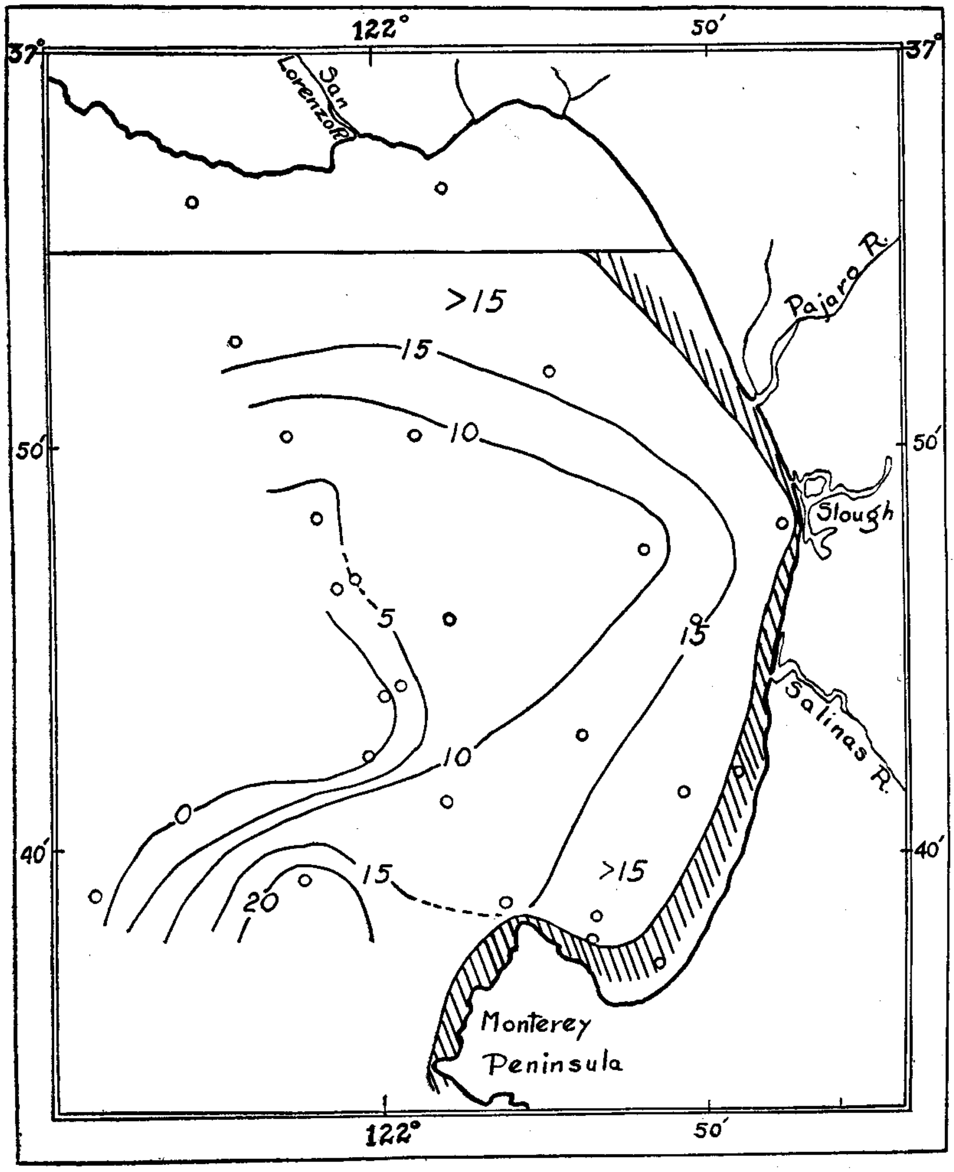

FIG. 39.— Depth below the surface of the layer of .05 milligram P_2O_5 per liter.

As already stated (p. 452), the amount of river water that enters the bay at the season of our survey, or for the five months previous, is negligible. But the discharge from the Salinas River, as well as from the other tributary streams, is so large during the months from November to February (p. 452; Van Winkle and Eaton, 1910) that this

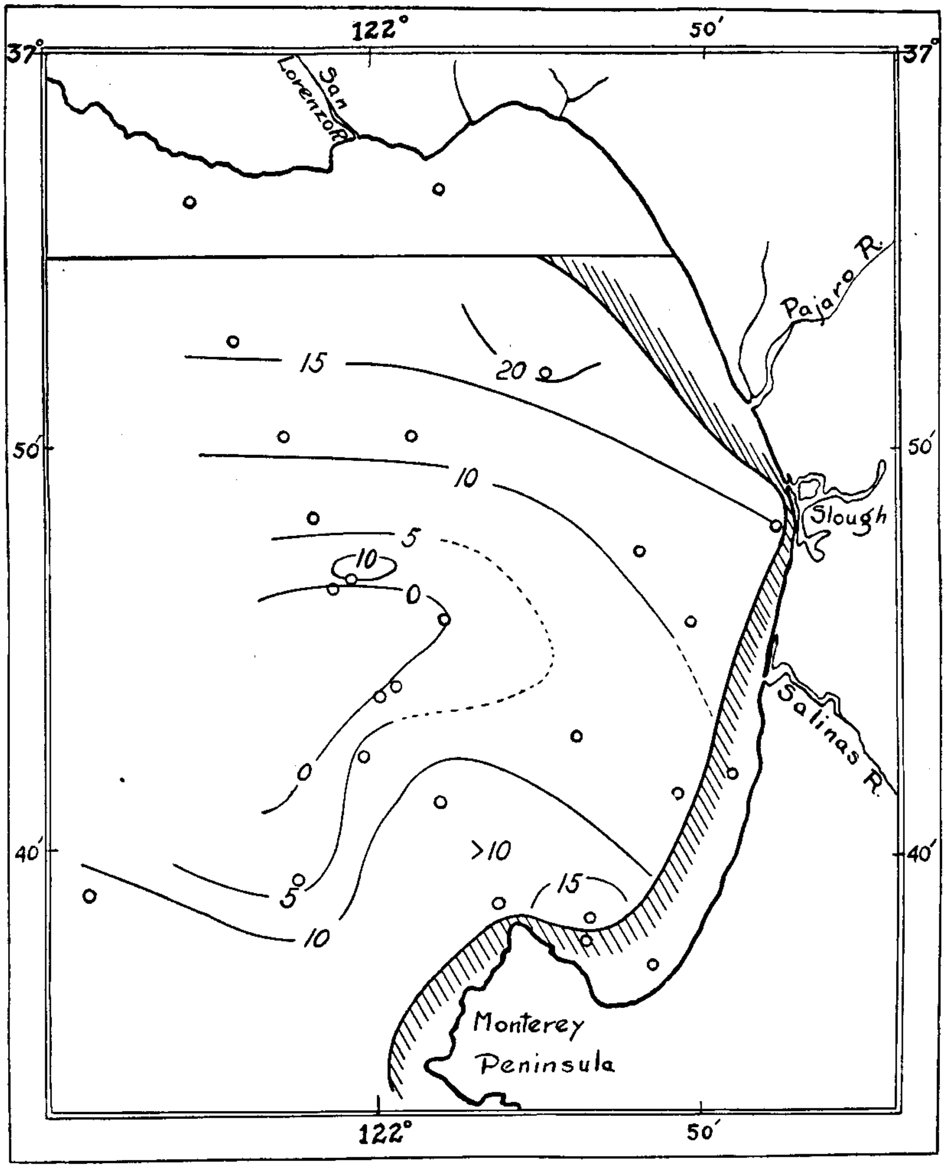

FIG. 40.— Depth below the surface of the layer of .6 milligram of SiO_2 per liter.

source of supply must also be taken into account in any year-round study of the bay. A sample taken just within the mouth of the Salinas on July 24, 1928, showed 12.82 mg. of silicates (SiO_2) per liter, while

Van Winkle and Eaton (1910) report 25 mg. per liter in August, 28 mg. per liter [1] in April, at a point a few miles upstream, with values of the same general order of magnitude for the San Lorenzo and the Pajaro, two smaller streams tributary to the bay, (19–33 mg. per li., and 15–32, respectively). Thus the river water that discharges into the bay is about twenty times as rich in silicates as we found the upper stratum of the latter to be in summer. But most of this contribution enters the bay so early in the year that by midsummer we could detect no regional evidence of it.

Replenishment as to silicates also takes place constantly, wherever diatom cells are dying and their shells dissolving. And the fragility of most of the latter, their lightness, and the relatively high solubility of this particular form of silica, probably results in more rapid solution within the photosynthetic zone than is generally appreciated.

Moberg (1928) has already emphasized the efficacy of this process, suggesting that the regular increase in silicates that he found with depth, at La Jolla, may be maintained by the solution of shells of dead diatoms as they sink. It is even possible that after a mass production of diatoms, the upper stratum of water may dissolve silicates from their dead shells rapidly enough to more than renew the store there, without accessions from the deeper waters.

This, in fact, seems the most reasonable explanation for the enrichment of the water by silicates that took place locally, near Point Pinos, from July 16th (0.337 mg/li of SiO_2 at the surface) to the 23d (0.71 mg/li) for the numbers of diatoms present at the surface there decreased meanwhile from 390,000 cells per liter to about 9,000, while temperatures and salinities (p. 475) show that this was a period of comparative quiescence, so far as upwelling was concerned.

No determinations have been made of the phosphates in the waters emptying into the bay at the season when their discharge is large. (We found 0.34 mg/li of P_2O_5 just within the mouth of the Salinas on July 24, 1928.)

According to the determinations reported by Van Winkle and Eaton, the Salinas River, both in April and in August is about ten times as rich in nitrates (1–1.3 parts per million of NO_3) as we found the water of the bay. Whether this appreciably enriches the latter during the season of discharge, or whether it is largely consumed within the mouth of the river or close by, as happens in summer in some localities (Harvey, 1928) is a problem for the future.

[1] Reported as parts per million.

Depletion of the upper strata

It is certain that in different regions, or at different times of year in the same region, different chemical solutes may be the limiting factors for plant production. This is reflected in the fact that students working in various localities, by various methods, have decided first that one, then that another substance is responsible. Thus, to quote only two instances,[1] Atkins (1926b) found the surface of the English Channel entirely depleted of phosphates at the time of mass production of diatoms. But in southern California coast waters Moberg (1928) found the surface stratum entirely denuded of nitrates, though containing measurable amounts of phosphates.

It is equally proven — both by observation at sea and by cultural experiments — that different groups of planktonic plants, and even different species within a given group, may differ widely in their cultural requirements.

Analogy with other parts of the sea indicates that in July, 1928, phosphates were present in sufficient amount at every station in Monterey Bay, and at all depths, to support an abundant planktonic flora, except locally, right at the surface. Thus means of about 0.04 milligram of phosphates per liter at the surface, 0.06 at 10 meters, and 0.14 at 50 meters, correspond closely with values of 0.025 to 0.039 mg. per liter between the surface and 70 meters, reported by Atkins (1928) for the English Channel, off Plymouth, in late winter and early spring. Similarly, Marshall and Orr (1927) report maximum values of about 0.05 mg. of phosphates per liter at the surface and at 20 meters in the Clyde sea area, in winter; while at La Jolla, Moberg (1928) found diatoms most abundant in water equally rich in phosphates. Hence, a concentration of about this order satisfies the phosphate requirements of planktonic diatoms as a group, although much higher values have been found in certain enclosed waters.

It also seems certain that the waters off Monterey were sufficiently stocked with silicates at all depths in July, 1928, to support an abundant stock of diatoms. Thus the mean surface value (0.4 mg. per liter) was somewhat higher than the annual maximum for the English Channel (between 0.2 and 0.3 mg. per liter), and almost equaled the yearly maximum for Plymouth Sound (Atkins, 1926, 1928), regions which, later in the year, support diatoms in abundance. Moberg (1928) also found diatoms most abundant in water of about this same silica content.

[1] The literature in this field is rapidly growing to formidable dimensions: for a recent résumé, see Harvey, (1928).

Much higher values have been reported in the Baltic (Brandt, 1920), in the Gulf of Maine (Bigelow, 1926; Wells 1922); and recently in the Straits of Georgia (Hutchinson, 1928). But, so far as diatom requirements are concerned, present indications are that silicates richer than 0.4–0.5 mg. per liter are in excess, unless all other required nutrients are also present in much greater richness than is normally the case in the open sea.

It is obvious that at the stations in Monterey Bay where the surface was nitrate-free, it could not be fertile for plants of any sort. Unfortunately no plankton counts were made for these particular stations. However, at the surface stations where nitrate was found, the mean value (0.05 mg. per liter) was about that found by Moberg (1928) at the depth (30 to 35 meters) supporting the greatest number of diatoms off La Jolla, while the mean for Monterey Bay at 5 meters (0.1 mg. per liter) about equals the yearly maximum reported by Harvey (1928, 1928a) for the English Channel.[1]

The preceding leads to the general conclusion that in July, 1928, the upper 10 meters of the bay were amply stocked with the three nutrients (phosphates, silicates and nitrates) to support active growth of diatoms, except locally, right at the surface, where depletion of nitrates had taken place.

Periodic surveys alone can show how uniformly upwelling maintains this relatively high degree of fertility from season to season, against the constant depletion by plants. But with the underlying water so well stocked with the three nutrients whose scarcity seems (by present knowledge) to be most apt to limit plant production, and with the mechanism for renewal from below working so actively (p. 475), Monterey waters are probably rich the year round.

From the standpoint of organic production, irregularities in the richness of the surface water in nitrates, phosphates and silicates are especially suggestive, in a region where upwelling brings renewals at least frequently from below, for a relatively low value for any of these, at a given locality, overlying much richer water, is explicable only on the basis of consumption by plants, unless land water, barren of these chemicals, be diluting the surface stratum at the time.

When the number of diatoms present per liter of water in the bay in July, 1928, is plotted against the values for silicates, phosphates and nitrates, it is evident, not only that the vertical distribution of the two sets of curves shows an inverse relationship (cf. Figs. 28 and

[1] He had considerably higher values in Plymouth Sound.

41), but that whenever diatoms were present in large numbers, the surface water was relatively poor in silicates and phosphates (Fig. 41).

In some cases the converse was true, i.e., rich water where diatoms were scarce — but not always. And at stations where only small numbers of diatoms were found in water poor in nutritive salts, it is

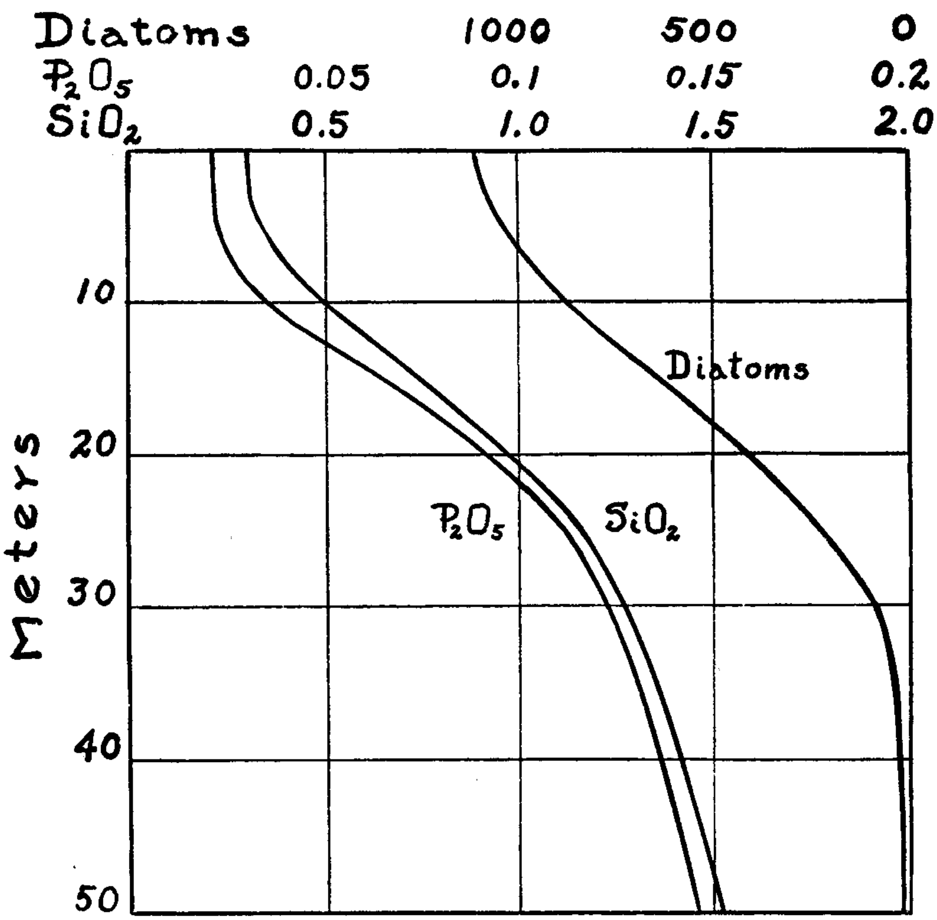

FIG. 41.— Vertical distribution of mean values for phosphates (P_2O_5) and silicates (SiO_2), in milligrams per liter, and of average number of diatom cells in thousands per liter, in the upper 50 meters, at Stations 7, 10, 12, 13,15, 16, 18, 19, and 24.

probable that the data were obtained so soon after the termination of abundant production, that enough time had not yet elapsed for upwelling to have again enriched the devastated area.

B. Oxygen

Investigation of the dissolved oxygen was not undertaken until the last few days of the survey, consequently it is impossible to follow some of the interesting problems suggested by the determined values; such, for example, as the boundaries of oxygen-poor water within the bay; the reason for the poverty of the midstratum in oxygen; the extent and degree of supersaturation in the surface stratum of the bay, and the efficiency of surf and of turbulence as local agencies of aeration.

1. *Monterey Bay in July, 1928*

The observations consisted of two vertical series, one in deep, the other in shoal water, and of a number of surface samples in various parts of the bay. These last were numerous enough and distributed generally enough to show that the surface water contained from 5.20 cc. to 7.33 cc. of oxygen per liter, which, at the temperatures of the individual stations *in situ* is from 85.9% to 124.5% saturated.

A series of samples taken at three-mile intervals, along a line running from headland to headland, on July 20, showed a definite gradation, both as to absolute amounts of oxygen, and as to the percentage of saturation, from a minimum over the mouth of the submarine valley in the central parts of the bay, to maxima next the northern and southern shores (Fig. 42). The two samples that yielded the minimum value of 5.20 cc. per liter over the trough (Station 29), and the maximum of 7.33 cc. per liter over shoal water (Station 31) were in agreement with the rest of the picture, although collected four days later.

To find so wide and definite a regional variation within so small an area was unexpected, for when in equilibrium with the atmosphere the surface of the sea is close to saturation with oxygen (95–105% saturated, allowing for the lag in adjusting to changes in temperature).

The quantities of oxygen in the surface water of Monterey Bay exceeded these normal limits so widely in both directions as to make the cause for this difference a matter of some interest.

Upwelling offers a ready explanation for a poverty of oxygen at the surface there, as it does for so many other oceanographic phenomena along the California coast, because the two vertical series revealed a rapid decrease in the oxygen content of the water with increasing depth, as follows:

	Station 20		Station 29		Mean	
	cc/li	% sat.	cc/li	% sat.	cc/li	% sat.
Surf	6.66	111.5	5.20	85.7	5.93	99
25 M.	2.99	45	4.00	64	3.49	55
50 M.	2.57	39	3.5	55	3.02	47
100 M.			2.46	38	2.49	38
250 M.			1.49	22	1.49	22
500 M.			0.63	9	0.63	9

Furthermore, the table shows that a considerable regional difference existed at the time in the rate of depletion of oxygen with depth, subsurface values being considerably lower at the station where the water was only about 90 meters deep, than over the trough, although the relationship was the reverse at the surface. In fact, the oxygen content at the shoal station was nearly as low at the 25 meter level as at 100 meters at the deep station.

The ways in which ocean waters are either enriched with oxygen, or denuded, and the levels in the sea at which these opposing processes chiefly work are so well understood that no discussion of them is needed here.[1]

The fact that the thickness of the oxygen-rich stratum off Monterey closely parallels the vertical abundance of diatoms is evidence that photosynthesis was the most effective local agent of oxygen replenishment there at the time, as indeed might have been surmised from the type of vertical circulation prevailing. More direct evidence to this effect is the fact that the highest oxygen values were recorded when diatom counts also averaged high (>800,000 per liter, compare Fig. 42 with Fig. 43). But no closer parallel can be drawn, because some of the individual stations where oxygen values were low yielded many diatoms, and vice versa.

A cursory observation of the active mixture of air with water that is caused around the rocky coast line of the Monterey peninsula by the heavy surf makes it an interesting question how effective this local agency for aeration is for the bay in general. But our observations were not sufficiently intensive to throw light on this point.

Wattenberg (1929) has already called attention to the fact that the lower boundary of the surface stratum rich in oxygen in the tropical Atlantic corresponds to the transition zone of density, as evidence of the depth to which turbulence carries oxygen down from the surface.

[1] See, especially, Wattenberg's (1929) discussion of the aëration of the Atlantic; and for an excellent bibliography of oxygen in sea water, Gaarder (1915.)

A similar parallelism obtains between these two classes of phenomena off Monterey, in this case rapid decrease in oxygen with depth ac-

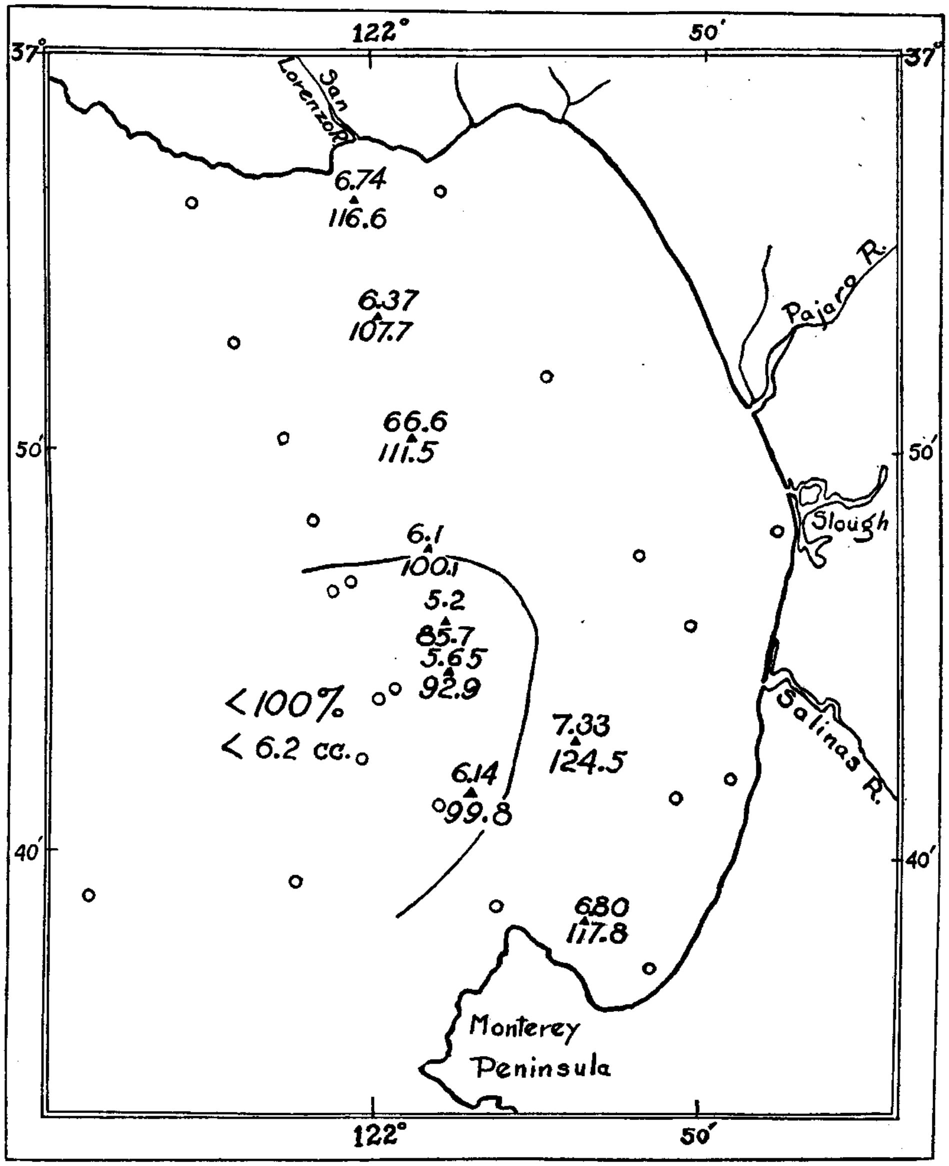

FIG. 42.— Oxygen at the surface, in cubic centimeters per liter (upper figures) and in per cent of saturation (lower figures).

companying the vertical stability indicated by a vertical increase in the specific gravity of the water.

This is further evidence that the presence of water poor in oxygen so near the surface off California is one of the striking manifestations

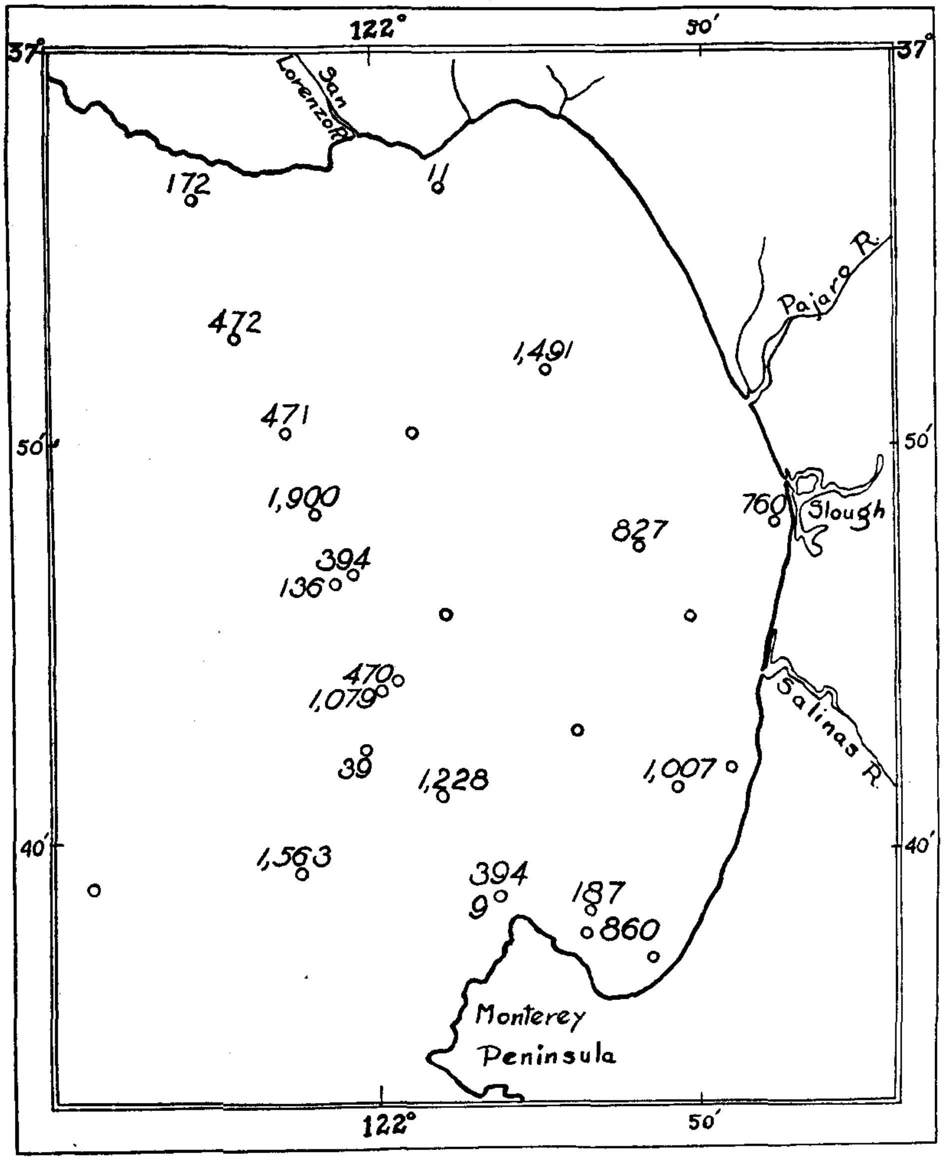

Fig. 43.— Numbers of diatom cells (good and bad condition combined) at the surface, in thousands per liter.

of the upwelling circulation active there. Apparently this circulatory agency prevents the processes of enrichment by absorption of air at the surface, and by photosynthetic action of plants from saturating or even supersaturating the water there to the considerable depths to which this often happens in other seas, for there is no reason to suppose that the values we found, in July, 1928, represented any unusual condition. Thus, off Monterey, the average percentage of saturation at 25 meters was only 64, while off La Jolla (Leslie and Moberg, 1930), where upwelling is not so active, the upper 40 meters carried nearly a full load of oxygen.

By this reasoning, the oxygen-rich surface stratum should not only be thinnest where upwelling water is in greatest amount, but the actual surface values smallest there. Our observations satisfy the second of these criteria, witness the regional correspondence between temperatures and oxygen at the surface (Figs. 2, 42). And satisfaction of the first-named criterion is indicated by the fact that the station where vertical cooling, with depth, was the more rapid (Station 20), also showed the more rapid decrease in oxygen from the surface downward.

Conceivably, upwelling might take place so rapidly, and in such volume, off California, and so greatly outstrip the regenerative processes there, as to bring to the surface water practically free from oxygen. But the abundance and variety of the littoral fish fauna, and especially the abundance of the local species of clupeids and engraulids makes it unlikely that this ever happens on a broad scale, though the possibility of ecologic disaster of this sort is ever-present where the vertical distribution of oxygen, and the prevailing vertical circulation are of the type characteristic of the ocean waters along the California coast.

2. *Comparison with other parts of the Pacific*

The Monterey data just stated are especially welcome because few determinations of dissolved oxygen have yet been recorded for other parts of the Pacific.

A few scattered determinations by the "Challenger" (Dittmar, 1884); four vertical series by the "Planet" from the surface down to 1000 meters between latitudes 2° S and 15° N, longitudes 145° E and 129 ° E (Brennecke, 1909); one serial in the Gulf of Panama (Schmidt, 1925); and several serials taken by the Scripps Institution off southern California complete the available list for the open basin of this ocean.[1]

More intensive information has been gathered for enclosed waters, along the Pacific coast of America. Berkeley (1922), Powers (1920),

[1] Collection of water samples for gas analysis is also stated to be included in current oceanographic work in Japan, but so far as we are aware, no data as to the oxygen have yet been published.

and Johnson and Thompson (1929), for example, have made many oxygen determinations in Puget Sound; Miller, Ramage and Lazier (1928) in San Francisco Bay. But such situations as these are not comparable to open ocean waters for obvious reasons.

The serials in the open Pacific have all shown a decided decrease in oxygen, from the surface downward, but with wide regional variation. Values of 0.4–0.6 cc. per liter at 500 meters off Monterey and southern California, but "practically no oxygen at all" at that depth in the Gulf of Panama (Schmidt, 1925, p. 593) indicate that the mid-depths in the eastern side of the North Pacific are poorer in oxygen in the tropics than in higher latitudes, as is the case in the eastern Atlantic (p. 520).

Whether a similar latitudinal gradation also exists in the western side of the Pacific is not yet known. But the fact that the lowest value found there by the "Planet" was 1.62 cc. per liter (or 24% saturated), in latitude 11°36′ N, longitude 128°29′ E, at 400 meters, suggests greater poverty of oxygen in this stratum for the eastern side of the Pacific than for the western.

Neither the Monterey nor the La Jolla serials extended deep enough to show the state of the abyssal water in this respect. However, Schmidt (1925) found oxygen increasing, in the Gulf of Panama, from 500 meters downward to 1000 meters, while the "Challenger" values averaged higher at 3000–5000 meters than at 700–800, indicating the general presence of more oxygen in the bottom water of the central and eastern parts of the North Pacific Basin than in the mid-depths. But the barren mid-stratum certainly extends deeper off California than in the tropics, for the La Jolla determinations showed no increase down to a depth of 1000 meters.

Apparently the vertical distribution of oxygen in the deeper strata is less uniform in type in the western side of the north equatorial Pacific, for three of the seven "Planet" serials deep enough to throw light on this question showed a minimum layer at 200–400 meters, with higher values at greater depths, whereas three others showed a decrease down to 1,000–2,100 meters.

3. *Comparison with the Atlantic*

So far as the oxygen poverty of the midstratum (with higher values near the bottom) is concerned, the eastern North Pacific agrees with the Atlantic — north and south — where recent observations at many localities have shown this to be the general state in low and mid-latitudes (Brennecke, 1909, 1921; Helland-Hansen, 1914; Gaarder, 1927; Wattenberg, 1927a). Greater impoverishment in the eastern side of the Pacific, than in the western, in the subtropical belt, also parallels the Atlantic state, for while the "Meteor" found less than 1 cc. per liter at about 500 meters on the African side, the minimum value on the South American was 4–5 cc. (Wattenberg, 1927a), while Schmidt (1925) reports the water of the Caribbean Sea as 40–50% saturated, at that depth.

Farther north in the Atlantic, however, the east-west distribution seems to be of the reverse order, for the mean values, at 800–900 meters, at 19 "Dana" stations off the southeastern United States out to longitude *ca.* 55° N (lat. 20°–35° N) were close to 3.5 cc. per liter,[1] whereas the "Armauer Hansen" found 4–4.5 cc. per liter (or 62–67% saturation) in the minimum layer at approximately the same depth between Spain, Morocco and the Azores (Gaarder, 1927).

Bilateral comparison, in this respect, can not be extended to higher latitudes in the Atlantic basin, because (so far as we can learn), no serial determinations have yet been made anywhere in the northwestern part of that ocean to the north of latitude 40° N and to the west of longitude 40° W, except in the arctic waters of Baffin Bay (Hjort and Ruud, 1929).

The minimum values in the 200–1000 meter stratum, off Panama, and off California, are decidedly lower than for corresponding latitudes in the Atlantic.

Thus Gaarder (1927) reports no values lower than 4.2 cc. per liter (500–1000 meters) between Spain and the Azores, an amount roughly seven times as great as the minimum we found off Monterey, at about the same latitude. Similarly, the least oxygen found by the "Meteor" in the eastern side of the tropical Atlantic was 0.36 cc. per liter (lat. 15° 24′ S; Wattenberg, 1927a) but the minimum layer in the Gulf of Panama is practically oxygen-free (Schmidt, 1925). Furthermore, such data as are at hand suggest that the midstratum of the eastern side of the North Pacific contains but little more oxygen 35°–40° north of the equator than in the tropics, whereas in the eastern Atlantic the minimum values increase from <1 cc. per liter near the equator, to 4–4.5 cc. at latitude 35°–40°N, and to 5–5.6 cc. at latitude 55°–60°N as shown on Brennecke's (1909, 1921) and Gaarder's (1927) profiles.

Details of the various serials also show that the stratum poorest in oxygen not only reaches deeper down into the Pacific, but that in mid-latitudes low oxygen values are closer to the surface there than

[1] Values calculated from the percentage of saturation and from the temperatures tabulated by Jacobsen (1929, p. 80, table 22).

in the Atlantic. Thus only in the equatorial belt, in the Atlantic, has anything been recorded comparable to the very sharp decline in oxygen values that we found between the surface and the 75 meter level off Monterey, 36°–37° degrees of latitude north of the equator.

The thesis that the poverty in oxygen of the midwater of the oceans is the result of the drafts that have been made thereon by living animals, and by the oxidization of carcasses, since its original aëration near the surface, needs no supporting argument. Wattenberg (1929) credits the greater poverty of the layer of minimum oxygen values in the eastern equatorial Atlantic than in the western to the greater abundance of plankton found by the "Meteor" in that side (Hentschel, 1928). But in estimating the relative regional effect of animal respiration, and of organic decomposition, the larger species of animals, in size from copepods upward, are probably more important than the small species of animals and plants that seem alone to have been included in Hentschel's (1928) estimates. Thus Schmidt (1925) found bathypelagic animals much more abundant in the Gulf of Panama, at the depth where the water was practically oxygen-free, than in the higher oxygen values in the Caribbean. And as nothing whatever is yet known about the proportionate abundance of plankton — animal or plant — in the two sides of the Pacific, or between different zones of latitude in either side, we need not speculate on that point here.

The cause of the greater poverty, as to oxygen, of the mid-strata of the western side of the North Pacific than of the North Atlantic calls, however, for a further word, for this is one of the greatest ecologic differences between the two oceans.

At bottom, as Schmidt (1925) has remarked, this indicates greater staleness of the water, i.e., a longer isolation in the deeps, for we have no warrant for assuming greater consumption of oxygen per unit area in the Pacific than in the Atlantic, whether widespread, or in the particular localities where the amounts of oxygen have been measured.

This greater staleness certainly results from differences in subsurface circulation, the most reasonable explanation being that it reflects a difference in the relative importance, as aerating centres, of the mass sinkings in the subarctic and in the subantarctic zones, whence the ocean deeps are replenished.

In this connection we have to consider chiefly the mid-water currents, comparatively low in salinity (34–34.4 ‰), that meridional profiles of the Pacific (Wüst, 1929), as well as of the Atlantic, show as sinking from the surface in latitudes 50°–60° north and south, to spread thence equatorward, at depths of 800–1500 meters.

It seems established by recent studies of oxygen distribution and of subsurface circulation, as Wattenburg (1929) maintains, that the midstratum of the North Atlantic receives its oxygen chiefly from sinkings in the subarctic, via meridional expansion of the deep horizontal currents, that is, from a source comparatively near at hand.

The oxygen poverty of the mid-depths off California points to a much longer journey after the water in question sinks from the surface. This, with the probability that subarctic sinkings in the North Pacific are relatively small in volume and confined to the western side, suggests that the subantarctic, not the subarctic, is the chief source of aeration for the deep strata throughout the South Pacific, and for the eastern side of the North Pacific as well, at least to latitude 40° N.

Wüst (1929) on the other hand concludes that the mid-drift of northern origin spreads equatorward as far as the tropical belt in the North Pacific. But his reconstruction is based on meridional profiles of temperature and salinity for the centre and western margin of the Pacific alone. Hence the discrepancy may be only apparent, for in the northern hemisphere water of northern origin, drifting equatorward (as deflected by the earth's rotation) must be concentrated in the western side, while water from the south would tend to cross, obliquely, to the eastern.

VI. Phytoplankton

It is obvious that a collection of phytoplankton confined to a period of one month gives no basis for reconstructing the seasonal cycle for other times of year. The absolute abundance of diatoms and peridinians in Monterey Bay, at the time of our work there, is, however, of interest as bearing on the conditions of organic production in other parts of the sea where upwelling circulation governs, while the list of species, by Dr. Mann (p. 532) helps to establish the general composition of the summer diatom flora of the region.

Gran (1929), from anaylsis of the voluminous literature on conditions prevailing around the northern coasts of the Atlantic, has recently emphasized the importance of the rôle played by nutrients washed down from the land in maintaining the fertility of coastal waters in temperate latitudes. He also proposes a classification of the "three principal types for the yearly development of the plankton" (1929, p. 60), based on the interrelationship between the abundance and periodicity of the supply of foodstuffs from this source, and the seasonal and regional variations in the activity of vertical circulation.

The coasts of middle and southern California offer, by contrast, the best available opportunity to study the association between plant production and mass upwelling. And the activity of upwelling in the immediate offing of Monterey makes this an especially interesting locality from this viewpoint.

During our work in July, 1928, phytoplankton was collected at the surface at most of the stations, with ordinary tow nets of No. 20 bolting silk. Seventy quantitative measurements of the plankton were also made by the simple but sufficiently accurate method (now standard at the Scripps Institution of Oceanography, Allen, 1929) of filtering measured volumes of water (usually 5 or 8 liters) through fine bolting silk with mesh openings averaging about .05 mm. These quantitatives include surface samples at twenty stations, with subsurface samples at eleven, mostly at intervals of 10 meters, downward to 40–50 meters (table p. 525). The counting of diatoms and of peridinians was done by Prof. W. E. Allen, of the Scripps Institution, who has also contributed much of the substance of the following discussion.

Technically this filtration method is satisfactory for cells as large as most of the planktonic diatoms and the thecate peridinians. And if samples enough could be taken simultaneously throughout the general area, the resultant picture would correctly represent the regional variations existing at the time, for these groups. But when counts are made several miles apart, it is obvious that if diatoms are streaky in occurrence, as is often the case, station to station differences in counts of the numbers of cells in given volumes of water might give an erroneous idea of the general state. And if the samples are taken over as long an interval as were ours, a rapid multiplication, or a high death rate, may further obscure the regional picture.

It was in the hope of guarding, in some degree, against the error (of unknown magnitude) that might result from streaky occurrence of the micro-plankton, that the tows were made. Unfortunately, however, inability to maintain an even rate of speed while towing, and heavy surging caused by the rough sea, made the net catches even less reliable as indices to quantitative distribution than is usually the case.

We hesitate, therefore, to draw any definite inferences from the fact that while the volumes of these catches roughly parallel the numbers of cells per liter over the bay as a whole for the stations occupied during the period July 17–July 23 (Stations 16 to 28), there is no correspondence at the stations occupied July 5–16. As the technical procedure was the same during the two periods, the implication is that diatoms were more evenly distributed through the water during the later period.

In most of the catches, whether quantitative, or by tow net, diatoms greatly outnumbered peridinians. At only one station (26) were peridinians more numerous than diatoms, though at one other (25) peridinians (about one-third as numerous as diatoms) were the larger in volume. Both of these stations were situated in the northern side of the bay, near the Santa Cruz shore. And since collections were made elsewhere in the bay on that same day and a day or two before, a regional rather than a seasonal segregation appears, with peridinians dominating in the Santa Cruz side, diatoms throughout the remainder of the bay.

A. Diatoms

The numbers of diatoms and their condition, whether good or bad (moribund or dead), are given in the table on page 525, contributed by Prof. Allen.

1. *Numerical abundance*

It is, of course, impossible (on the basis of one month's work) to state whether conditions as existing in July, 1928, were typical for that season of the year; it may have been a rich summer for diatoms, or a poor. But certainly in that particular month the planktonic diatom flora of Monterey Bay ranked among the richer concentrations of diatoms that have yet been described for the open ocean, and even approached the tremendous production that occurs in some enclosed waters. Thus the maximum number of diatom cells per liter, from our counts (nearly two million) compares with eight million Skeletonema cells recorded in the Baltic in June, 1906; with two million diatom cells per liter in Kiel Bay in April of that year (Lohmann, 1908); with a net catch reported there by Brandt (1902, p. 71) that indicated about six million per liter; and with a maximum of eight hundred thousand cells per liter at Storeggen, on the Norwegian coast (Gran, 1929).

And while still larger numbers have been recorded in enclosed coastal waters at the time of mass production — witness Marshall and Orr's (1927) record of 2,500,000 chains of Skeletonema per liter in the Clyde sea area, in April, which, by Gran's (1929) reckoning, indicates some twenty million cells per liter — the average at Monterey

NUMBERS OF DIATOMS CELLS PER LITER, AT DIFFERENT STATIONS AND LEVELS, COUNTED BY W. E. ALLEN

Sta.	Levels											
	Surface		10 meters		20 meters		30 meters		40 meters		50 meters	
	Condition Good	Condition Bad	Condition Good	Condition Bad	Condition Good	Condition Bad	Condition Good	Condition Bad	Condition Good	Condition Bad	Condition Good	Condition Bad
1	212200	180250										
2	29700	65150										
3	4600	2100										
4	150570	36500									87200	53400
5	330600	63400									22400	4160
7	970000	109300	547520	28400	193160	23160	12480		7680	8960	5760	2400
8	1321100	241400										
9	676750	150400										
10	360450	33800	70080	11040	170680	31640	5120	9760	8640	960	3200	1920
12	1736600	163500	49920	6560	13920	3680	5920	9280	8800	8480	16160	5120
13	1173050	54500	105120	37600	14400	12480	1600	320	2240	1280		
15	698160	161680	622080	136720	390040	139160	107520	66400	53760	39200	40000	38880
16	897000	109600	1020960	175120	261040	115680	41280	43520	3040	8160	1120	3040
18	1262600	228200			532080	260400	97080	64600	16480	14560	4480	5760
19	538880	221120	1242000	487200	442480	96960	220960	91360				
21	401840	67840										
22	95360	40720										
23	367200	103680										
24	299680	171840	1702080	351680	173040	97360	5120	11840	10560	8320	5120	35040
25	110640	61120										
26	6240	4320										
27	27680	10880										
28	2720	6080										
Av. good and bad	1,201,000		837,000		330,000		88,000		25,000		24,000	

Bay would be ranked as unusually high for any station in the open North Atlantic. Furthermore, the presence of a relatively large percentage of dead cells in our catches suggests that diatoms had been even more abundant in Monterey waters earlier in the season.

Comparison between the few Monterey counts and the extensive series that have been published for southern California waters is made more dependable than has usually been the case for different localities by the fact that the methods used were not only the same, but the counts made by the same individual. The average number at the richest level of Monterey Bay (about one million per liter) parallels roughly the richest weekly average recorded at La Jolla Pier for the years 1921–1924 (Allen, 1927, 1928a; Dorman, 1927a; Sleggs, 1927). And the maximum for Monterey Bay (two million) was more than four times the maximum recorded for the offing of La Jolla in the summers of 1924 or 1926 (Allen 1928, 1928b).

Thus present indications are that Monterey Bay is on the whole the more productive of the two localities in planktonic diatoms, unless 1928 was an unusually productive year. But much more extensive observations would be needed to definitely establish such a difference, because occasional waves of production, resulting for a time in large counts, are to be expected wherever these unicellular plants exist in any abundance. At the Pier at Point Hueneme, California, for example, Allen (1928a) reports one weekly average of two million per liter in 1924, although the averages for the richest weeks of the year there have usually approximated the July, 1928, average for Monterey.

Such counts of diatoms as have been made in the open Pacific off Oregon, to the north, have also been of about the same order of magnitude. Lewis (1927), for example, reports a maximum of about half a million per liter for the summer and autumn of 1924.

Unfortunately no comparison can yet be made between the abundance of diatoms in Monterey Bay, and in the coastal waters of British Columbia, because the estimates by Mounce (1922) and by Hutchinson (1928) of the amounts present in the Straits of Georgia were volumetric, not numerical, and the catches made by methods with which our towings are not comparable.

More specific examination of the Monterey catches is interesting from the standpoints of seasonal progression, as well as of regional and vertical distribution.

Successive counts at a pair of stations near Point Pinos, and at two pairs at the mouth of the bay, showed a decrease in the number of diatoms during the last half of the month, as follows:

Off Point Pinos:

Date	Sta.	Diatoms at surface, total per liter
June 30	1	392,450
July 5	5	394,000
July 23	28	8,800

Mouth of Bay, A:

Date	Sta.	Diatoms at surface, total per liter
July 10	7	1,079,300
July 21	21	469,680

Mouth of Bay, B:

Date	Sta.	Diatoms at surface, total per liter
July 13	10	394,250
July 21	22	136,080

This decrease cannot be laid to depletion of phosphates or silicates, for while at one offshore locality (Loc. A above) a slight decrease in the amounts of these solutes was registered for the surface water (table, p. 567), the reverse was the case at the other locality. And while no data as to phosphates or silicates are available for the earlier of the two stations off Point Pinos, both silicates and phosphates were present there in relatively large amounts at the latest station (28). At the offshore localities, the decrease in diatoms may have resulted from exhaustion of nitrates, for in each case (Loc. A and B), the surface water was nitrate-free at the later station, whereas at Loc. B, there had been 0.039 mg. per liter in the surface water at the earlier station. But at the Point Pinos locality, where the smallest diatom count was from water relatively rich in nitrates (Sta. 28, 0.119 mg. per liter), this explanation does not apply unless sudden regeneration of nitrates can be supposed to have taken place there, after diatoms had diminished.

It is the common experience to find the great majority of diatom cells in good condition while multiplication is proceeding actively, with the proportion of moribund and dead cells (shown by poor condition) increasing after the wave of production has passed. Prof. Allen, for example, contributes the information that off southern California, where diatoms are, as a rule, scarce in August, the catches made during that and the preceding month have been in poor condition.

Thus the relatively large percentage of the diatom cells that were either dead, or at least in bad condition, at most of the stations, with the fact that the ratio of cells in good to those in bad condition, was about the same at 50 meters as at the surface (table, p. 525), equally suggests that the last half of July, 1928, was in general a period of waning production. But the presence of many more diatoms at a station close to the Hopkins Marine Station on July 17 (15) than had been found there two weeks earlier (4) shows that active production was still taking place locally, as late as the middle of the month, though the upper 10 meters of water at the locality in question was then so poor in phosphates (14, 0.018–0.02 mg. per liter) as to make it likely that fewer diatoms would have been found there a week later.

In short, the available data suggest that fewer diatoms would have been found in Monterey Bay in August, 1928, than were actually found there in July, and that still larger numbers would have been found in June.

A seasonal succession of this order was, indeed, to be expected, for students in various parts of the world have found diatoms scarce in midsummer, in mid-latitudes, following periods of great abundance, except in estuarine situations, or in localities kept thoroughly churned by the tide, where active production may continue right through from spring to autumn.

Attempts to trace the ups and downs of the local production of diatoms off central and southern California are complicated by the possibility that the sudden appearance of a swarm may result from their transport thither, by longshore currents. This would result in an irregular succession of maxima and minima, of much the sort that has actually been recorded off La Jolla. But in spite of this disturbing factor Monterey Bay offers an exceptionally favorable opportunity to examine whether inherent reproductive periodicity of the diatoms themselves has any part in causing the summer minimum, for it seems certain that in this region, so richly stocked with nutrients at deeper levels, upwelling must soon refertilize the surface layers if the latter be temporarily denuded by an overproduction of vegetation.

In this connection, Prof. Allen points out, differences between different species in the ratio of living to dead cells are suggestive. Thus *Asteromphalus heptactis*,[1] which occurred with considerable frequency, in the quantitative samples at all levels down to 50 meters, was usually represented by dead cells only, except at Stations 10–13, where it appeared in good condition in the upper levels. *Ditylium brightwellii*[1]

[1] Identification by Prof. W. E. Allen.

(surface only) was also represented chiefly, if not entirely, by cells in bad condition. On the other hand *Asterionella japonica*,[1] and *Nitzschia seriata* [1] not only occurred frequently at all levels, in some numbers, but were for the most part in good condition. Differences of this sort corroborate the evidence of various sorts, brought out in other seas, both by observation and by cultural experiments, that different species differ so widely in their cultural requirements that some thrive in water that is barren for others.

2. *Regional distribution*

The most striking regional variation in the quantitative distribution of diatoms at the time of our studies was their scarcity in the northern side of the bay (Stations 25, 26). But diatoms change so rapidly in abundance that this may have been only a temporary phenomenon, presaging a progressive decrease from north to south across the bay. And, for this same reason, there is no warrant for crediting the distribution of richer and poorer catches (Fig. 43) with geographic significance, for it may have been briefly transitory. The parallelism between regional distribution of diatoms, and that of oxygen and of phosphates, has already been commented upon (pp. 515, 512).

Counts of samples taken close to the tide line, off the beach at the Hopkins Station, suggest that the water averages much less productive in diatoms immediately next the coast than it does a mile or more out in the bay, for the largest weekly average for 1923 was only about 6,000 cells per liter there (Dorman, 1927a), while in 1924 only three weekly averages exceeded 11,000 (Allen, 1928b). Therefore samples taken in a situation of that sort cannot be accepted as representative, in this particular region.

3. *Vertical distribution*

The diatom flora of Monterey Bay seems not only to average richer than that off La Jolla in summer, but in July, 1928, its vertical distribution was widely different, when quantitatively expressed.

At the more southerly locality, in the summer of 1926 (apparently a representative year), more than 75% of the total number of diatoms were concentrated in the stratum between the 25 meter and 40 meter levels (Allen, 1928; Moberg, 1928). This is in line with data obtained at La Jolla in earlier years (Allen, 1923; Dorman, 1927; Sleggs, 1927), which had already given strong indication that the normal production

[1] Identification by Prof. W. E. Allen.

off this part of the coast in summer is greatest 20–40 meters below the surface.

In Monterey Bay, on the contrary, our largest catch was made at the surface (table, p. 525), and the average number per liter was also greatest at the surface, slightly less at 10 meters, and decreasing with depth, as follows:

Depth meters	Surf.	10	20	30	40	50
Average Diatoms per liter	1,021,109	836,761	330,151	88,240	25,140	23,986

Two thirds of the diatoms of Monterey Bay were thus concentrated in the upper 15 meters of water at the time (fig. 41). Furthermore, Prof. Allen reports that the number of species represented in the quantitative samples was about twice as great at the surface (29) as at any level deeper than 20 meters, but only slightly greater than at 10 meters. All this unites to show that in July, 1928, the chief production in Monterey Bay took place between the 10 meter level and the surface. And maximum production seems to have been nearer to the surface than to 10 meters, because the surface catches were much greater than the 10 meter catches (living and dead cells combined) at four out of eight stations, the 10 meter catches considerably the larger at only two, with little difference between the two levels at the remaining two stations.

The difference between Monterey Bay and the offing of La Jolla, with respect to the vertical distribution of diatoms, so closely parallels the difference in the vertical distribution of phosphates and of nitrates (pp. 499, 500), that a causal connection may reasonably be assumed. The fact that the surface waters at La Jolla are kept practically denuded of nitrates, and decidedly poor in phosphates, is sufficient explanation for the barrenness of the superficial stratum there. Under such circumstances, and with upwelling so slow that the rich water from the deeps is denuded before reaching the surface, production is greatest at the greatest depth to which sunlight penetrates with intensity enough for active photosynthesis. In Monterey Bay, however, under the conditions existing at the time of our survey, upwelling is so much more active that the surface waters are kept more adequately stocked, or if locally depleted, seem to be replenished sooner, so that the supply of nutrients allows active multiplication of diatoms closer to the surface, where the intensity of light is most favorable. The fact that catches taken as close to the surface as was feasible averaged the largest, and that the percentage of dead cells was no greater there than at 10–20 meters, is good evidence that sunlight was not intensive enough to be generally lethal more than a few centimeters down at the time, if it ever is at this latitude. On the other hand, the decrease in the number of diatoms from the surface downward, in the face of increasing richness of nutrients, may be assumed chiefly to reflect the corresponding decrease in intensity of penetrant sunlight. And since the same species were prominent at different levels, it seems that those dominant at the time all required approximately the same intensity of light, for active photosynthesis. Upwelling currents may also have some effect in bringing diatoms up toward the surface.

The facts that the average number of diatoms at 40 meters was larger in Monterey Bay [1] in July, 1928 than off La Jolla during the summer of 1926; that at Monterey there were nearly as many diatoms at 50 meters as at 40 (table, p. 525); and that the percentage of dead cells was no greater at deep than at shallow levels; indicate that photosynthesis was proceeding at least down to 50 meters at the time. And as Allen (1928) records a rapid falling off in the number of diatoms below 40 meters, for La Jolla, it seems that the photosynthetic zone is about as thick at the more northern of the two localities, in spite of the difference in latitude and greater prevalence of fog.

The diatom fertility-cycle in a region of upwelling, such as Monterey Bay in summer, may then be reconstructed as follows. The clouds of diatoms existing in the upper stratum of water consume the nutrient salts in large amounts. With increasing depth decreasing light limits the activity of their photosynthesis and the rapidity of their multiplication, correspondingly limiting the drafts that they make on the fertility of the water. So long as upwelling supplies rich water to the surface stratum with sufficient rapidity, the combination of abundant nutrition with intense light makes this the zone of chief production, as was the case in July, 1928. But if the rate of upwelling were to decrease so much that the diatoms depleted the surface layer, the zone of maximum production would necessarily sink (as at La Jolla), as the diatoms previously living near the surface died off. There might even be some actual increase in production, temporarily, in the deeper strata, as the thinning out of those above allowed more sunlight to penetrate. But unless a new pulse of upwelling soon followed, the whole photic zone would either become depleted of food stuffs, and diatoms fall to a

[1] Monterey, about 25,000 per liter; La Jolla 7,000 to 15,000 at two stations (Allen, 1928, p. 206).

minimum, or a balance might be reached, allowing a moderate production to proceed near the lower boundary of the photic zone, as happens off La Jolla. Whether this latter state ever develops in Monterey Bay is an interesting question for the future.

It is much to be regretted that no data as to the concentrations of silicates, phosphates, or nitrates, were obtained at the stations in the northern side of the bay (25, 26), where, alone, peridinians were dominant.

The fact that the numbers of diatom cells in bad condition showed, on the average, about the same rate of decrease, from the surface downward as did those in good, runs counter to the expectation that where the chief production takes place near the surface, dead cells, as they sink, will be most prominent, relatively, in the deeper strata. And Prof. Allen contributes the like information that dead cells have not dominated the samples from 50 meters, or deeper, off southern California. This suggests that dead diatoms sink so slowly in the low temperatures (consequently high viscosities) and upwelling circulation prevailing off California that most of their shells disintegrate before reaching a depth of 50 meters, and so help to maintain the cycle of silica *in situ*. At any rate, writes Prof. Allen, "the small showing of dead specimens beneath a large representation of decadent specimens at several points in Monterey Bay is a phenomenon which needs explanation."

4. *Dominant species of diatoms*

Dr. Mann's examination of samples from the tow nettings (p. 430) shows a diatom flora decidedly varied, qualitatively, for he detected 107 species.

List of Diatoms, Identified by Dr. Albert Mann, from Random Samples from Eighteen of the Tow-net Hauls

Column A gives the percentage of the stations at which the species was found; column B gives the percentage of the stations at which the species was noted by Dr. Mann as "common"; column C, the percentage of the stations at which it was noted as "very common."

	A	B	C
Actinocyclus curvulatus Janisch	5	0	0
Ehrenbergii Ralfs	11	0	0
Ralfsii W. Smith	5	0	0
Actinoptychus alternans Mann	83	22	0
areolatus Mann	11	5	0
undulatus Bail.	44	5	0

	A	B	C
Amphora oblonga Greg.	5	0	0
Asterionella japonica Cleve	72	5	0
Asteromphalus heptactis Bréb.	100	61	22
Aulacodiscus	5	0	0
Biddulphia aurita Bréb.	39	0	0
extensa Mann	94	0	0
mobilensis Bail.	5	0	0
peruviana Gran	5	0	0
antideluviana Ehr.	5	0	0
Cerataulina Bergonii Perag.	22	0	0
Chaetoceras atlanticum Cleve	50	0	0
boreale Bail.	22	0	0
constrictum Gran	90	22	22
contortum Schutt	80	28	17
coronatum Grun.	11	0	0
crinitum Schutt	90	39	33
criophilum Castr.	50	0	5
debile Cleve	94	28	22
decipiens Cleve	100	44	50
densum Cleve	22	0	0
diadema Gran	44	0	0
difficile Cleve	22	0	5
didymum Ehr.	94	50	22
gracile Schutt	5	0	0
incurvum Bail.	17	0	0
ingolfianum Ost.	5	0	0
laciniosum Schutt	5	0	0
mitra Cleve	11	0	0
pelagicum Cleve	5	0	0
peruvianum Bright.	5	0	0
pseudocrinitum Ost.	11	0	0
scolopendra Cleve	100	50	11
Schuttei Cleve	33	0	0
teres Cleve	44	0	0
Weissflogii Schutt?	5	0	0
Willei Gran	22	0	0
Cocconeis costata Greg.	5	0	0
curvirotunda T. & Br.	5	0	0
disrupta Greg., var.	5	0	0
panniformis Br.	5	0	0
scutellum Ehr.	17	0	0

	A	B	C
Coscinodiscus asteromphalus Ehr.	11	0	0
concinnus W. Smith	50	5	0
curvulatus Gran	11	0	0
denarius A. Schmidt	5	0	0
excentricus Ehr.	44	0	0
Kutzingii A. Schmidt	5	0	0
lineatus Ehr.	37	0	0
Normanii Greg.	5	0	0
oculus-iridis Ehr.	11	0	0
pacificus Ratt.	11	0	0
praetextus Janisch	5	0	0
radiatus Ehr.	17	5	5
rex Wall.	5	0	0
subtilis Ehr.	61	0	0
symbolophorus Gran	5	0	0
Woodwardii Eul.	33	0	0
Coscinosira polychorda Gran	28	0	0
Corethron valdiviae Karst.	33	0	0
Cyclotella striata Kutz.	44	0	0
Ditylium Brightwellii West	83	0	0
Entopyla incurva Arn.	5	0	0
Eucampia groenlandica Cleve	33	0	0
zoodiacus Ehr.	100	39	11
Grammatophora marina Lyng.	5	0	0
Hyalodiscus subtilis Bail.	5	0	0
Isthmia nervosa Kutz.	5	0	0
Lauderia annulata Cleve	17	0	0
borealis Gran	33	0	0
delicatula Perag.	5	0	0
glacialis Gran	5	0	0
Leptocylindrus danicus Cleve	72	5	5
Licmophora californica Gran	5	0	0
Lyngbyei Kutz.	5	0	0
Lithodesmium undulatum Ehr.	50	0	0
Navicula directa W. Smith	11	0	0
formosa Greg.	5	0	0
Nitzschia gazellae Karst.	28	0	0
longissima var. closterioides Grun.	55	0	0
seriata Cleve	90	11	11
Pleurosigma acus Mann	5	0	0
delicatulum W. Smith	5	0	0

	A	B	C
Rhizosolenia alata var. obtusa Hens.	22	0	0
semispina Hens.	39	0	0
setigera Bright	28	11	0
Stolforthii Perag.	39	0	0
Sekletonema costatum Grev.	61	0	0
Stephanopyxis corona Ehr.	5	0	0
turris Grev.	11	0	0
Synedra nitzschioides Gran	83	11	0
Thalassiosira baltica Gran	5	0	0
decipiens Jorg.	50	0	0
gravida Cleve	78	5	0
hyalina Gran	5	0	0
Nordenskiöldii Cleve	5	0	5
subtilis Ost.	5	0	0
Thalassiothrix Frauenfeldii Gran	22	0	0
longissima Cleve	17	0	0
Trigonium arcticum Cleve	22	0	0
montereyi Bright.	5	0	0
Tropidoneis antarctica Gran	28	0	0
membranacea Cleve	22	0	0

In spite of the long list of species comparatively few were prominent in the collections, as is usually the case in short series of open-sea towings. Prof. Allen, from examination of the quantitative samples, records various species of Chaetoceras as forming the bulk of the catches. And Dr. Mann's lists equally emphasize the dominance of the phytoplankton by this genus, except in the northern side of the bay, where peridinians, not diatoms, predominated (p. 524).

A glance at column C in the preceding table will make this clear, for out of fourteen species appearing there nine belong to the genus Chaetoceras.

Among the twenty-six species of Chaetoceras detected by Dr. Mann, the following seven greatly predominated over the others, both in regularity of occurrence, and in abundance relative to other diatoms:—*C. constrictum*, *C. contortum*, *C. crinitum*, *C. debile*, *C. decipiens*, *C. didymum* and *C. scolopendra*. *C. decipiens* was on the whole the most important of these, at the time, for it occurred at all the eighteen stations from which samples were examined, and was recorded by Dr. Mann as "common" or "very common" at every station but one.

By the ranking in the table (p. 533), *C. didymum* and *C. crinitum* seem on the whole to have been numerically the predominant species at the time (after *decipiens*), and while *scolopendra* and *debile* both occurred somewhat more regularly in the lists, it is probable that sufficient search would have shown all the species of the group to have been universally distributed over the bay, at the time. All of these dominant species belong to the subgenus Hyalochaete, and all of them, except *decipiens*, are small forms.

No regional separation in the relative importance of these species of Chaetoceras appears for the inner parts of the bay. But the catch at our outermost station (17) is set apart by the fact that the species dominant there (*C. criophilum*, noted by Dr. Mann as "vc") is not only distinctly oceanic, but was of very minor importance inshore, for it was detected in only 50% of the other hauls, and invariably noted there as "few" or as "scarce."

All the other species of Chaetoceras were represented sparsely, in every case recorded as "few" or "scarce." Their relative regularity of occurrence was as follows:

50% of the hauls, *atlanticum*
44% of the hauls, *diadema, teres*
33% of the hauls, *Schuttei*
22% of the hauls, *boreale, densum, difficile, Willei*
17% of the hauls, *incurvum, pseudocrinitum*
11% of the hauls, *coronatum, mitra*
5% of the hauls, *gracile, ingolfianum, laciniosum, pelagicum, peruvianum, weissflogii*

Of diatoms other than Chaetoceras, *Asteromphalus heptactis* and *Eucampia zoodiacus* were universal (100% of the stations), *Biddulphia extensa* probably also (94%); while *Asterionella japonica, Leptocylindrus danicus, Thalassiosira gravida, Ditylium brightwellii, Actinoptychus alternans, Synedra nitschioides* and *Nitzschia seriata* were also detected at the great majority of stations (72–90%). For each of them the localities of record include stations close in shore, as well as in the mouth of the bay, proving that their distribution was general there at the time.

Among this group of regularly occurring species, *Asteromphalus heptactis* and *Eucampia zoodiacus* alone rivaled the dominant members of Chaetoceras in floral importance, the former being recorded as "common" or "very common" in all but one of the catches, the latter in nine out of the eighteen stations. *Actinoptychus alternans, Asterionella japonica, Coscinodiscus concinnus, C. radiatus, Leptocylindrus danicus, Nitzschia seriata, Rhizolenia setigera,* and *Thalassiosira gravida* were occasionally common; but within this group of species, numerical abundance did not in all cases correspond to regularity of occurrence. Thus while Leptocylindrus was recorded at thirteen stations, it was common only at two, Thalassiosira common at only one out of fourteen, Synedra at three out of fifteen, whereas *Rhizosolenia setigera* was common at two of the four stations where alone it was detected, *Actinoptychus areolatus* at one of two, *Coscinodiscus radiatus* at two out of its three stations of record.

The fact that the remaining eighty-five species, including several that occurred with considerable regularity [1] were invariably either "few" or "scarce" illustrates the qualitative monotony that may characterize the pelagic diatom-flora, even when actually composed of many species.

In fact no less than thirty-six of the species were found at only one station each, ten of them at only two stations; in most cases represented by scattered individuals only.

This group of rare species is, however, more interesting from the distributional standpoint than its numerical strength and the sporadic occurrence of its members might suggest, for it includes a considerable list of bottom forms. To find a scattering of this floral category in plankton gatherings taken near land is usual, as they are either swept up from the bottom by turbulent movements of the water, or carried out from the shore line with other flotsam. The surface water had received an unusually large contribution from this source off Point Pinos, at the close of the series (Station 28), the list for that haul including eleven species of this group, that were not detected in any of the other samples, as follows: — *Actinocyclus curvulatus*, Aulacodiscus, *Biddulphia antideluviana*, *Cocconeis costata*, *C. panniformis*, *Entopyla incurva*, *Grammatophora marina*, *Hyalodiscus subtilis*, *Isthmia nervosa*, *Licmophora Lynbyei* and *Trigonium montereyi*.

Apart from these bottom forms at Station 28, and except for the dominant species at the outermost station, analyses of the catches show no definite regional localization of different species, for such of them as occurred frequently enough for their recorded distribution to be significant were found both inshore, and out in the centre of the bay. Neither is any seasonal succession of species apparent.

It is for this reason that we have not included in the table the lists of species for individual stations.

Catches made close to the beach at the Hopkins Marine Station,[2] interesting for comparison with the waters of the bay farther out in

[1] *Biddulphia extensa, Ditylium Brightwellii, Coscinodiscus subtilis, Skeletonema costatum.*

[2] Data contributed by Prof. W. E. Allen.

July, 1928, showed dominance by the following species, at some time during June, July or August, 1923, 1924 and 1925.

In 1923, *Asterionella japonica*, *Chaetoceras compressum*, Chaetoceras sp.? Navicula sp.? and *Nitzschia seriata.*

In 1924, *Chaetoceras debile* and *Fragilaria islandica.*

In 1925, *Asterionella japonica*, *Chaetoceras longianum*, *Eucampia zoodiacus*, and *Leptocylindrus danicus.*

All these species, except the Navicula and Fragilaria, were recognized in the towings of July, 1928, or may have been represented then among the unidentified species of Chaetoceras.

It is interesting that *Fragilaria islandica* appears among this list of dominant species, at this locality in summer, for it is a diatom usually considered an arctic and subarctic indicator. But as it was prominent during only one week of the entire series (25th week of 1924) this was evidently an unusual event.

Unfortunately the samples for these years were so scattered in date that they do not show the seasonal succession for any one year, while to combine the records for the three years might confuse annual with seasonal variations.

The following tabulation of the ten species reported by Prof. Allen as most prominent during those months of spring when samples were obtained in two of the three years shows that annual differences are great.

	1923	1924	1925
March	*Skeletonema costatum*	*Asterionella japonica* *Chaetoceras scolopendra* Chaetoceras sp.? *Detonula schröderi* *Eucampia zoodiacus* Rhizosolenia sp.? Thalassiosira sp.?	*Chaetoceras curvisetum* *Skeletonema costatum*
April	no data	Chaetoceras sp.? Nitzschia sp.? *Skeletonema costatum*	*Chaetoceras sociale*
May	no data	*Chaetoceras difficile*	*Chaetoceras sociale* *Chaetoceras debile* *Chaetoceras compressa* Chaetoceras sp.?

In general these data for 1923–1925 suggest that Monterey Bay does not show the regular seasonal succession of different species and genera of diatoms that so generally characterizes coastal waters in regions where there is a wide seasonal variation in the physical, chemical and circulatory state of the water (the Gulf of Maine for instance, Bigelow, 1926), but that species that dominate at one season in one year, may do so at another season in another. And most of the species that often dominate, at any season of the year, are present in moderate numbers in midsummer. A similar seasonal irregularity, from year to year, in the succession of diatom species, evidently obtains off La Jolla, as shown by Allen's (1928) tables, but with a pronounced preponderance by the genus Chaetoceras. Allen's remark (1928, p. 365), that "there is no apparent indication that the abundance of any species gives ground for predicting that it will be followed or replaced by any certain other species" off southern California, applies equally to Monterey Bay, so far as can be judged from data yet available.

B. Peridinians

The three quantitative samples in which the number of dinoflagellates equaled 10,000 per liter (23, 25, 26), including the only one where they outnumbered the diatoms, were all taken in the northern side of the bay, and on one day, July 21. Stations 25 and 26, were also the only localities where the catches of the tow net can be characterized as "peridinian plankton." But tows on that same day, and two days later, also yielded a greater bulk (though a smaller number) of peridinians than of diatoms, at the mouth of the bay (22), and near Point Pinos (28) where diatoms had greatly predominated earlier in the series (10, 15). Thus a general replacement of diatoms by peridinians is indicated with the advance of the season, progressing from north to south across the bay, from a center of peridinian production near the Santa Cruz shore.

The fact that most of the peridinians at all of the stations were in good condition, as tabulated below, is further evidence that they were multiplying actively during the last part of July.

Peridinians, like diatoms (p. 530), averaged most abundant at the surface or close below it.

Although the numbers of peridinians per liter were insignificant, contrasted with the rich catches of diatoms, the average of about 7,000 per liter for the surface samples, for Monterey Bay as a whole, at the time, is approximately four times as great as the highest daily average for La Jolla, for the period 1920–1924, and more than seven times the July average there (Allen, 1928, p. 388). At Point Hueneme, near Santa Barbara, intermediate in location between La Jolla and Monterey Bay, the July average rose considerably above the Monterey average in three of these five years, but fell slightly below it in two, while the means for that month and for August for the five years at Point Hueneme (7,500–6,900) were close to the Monterey figure.

Counts of Dinoflagellates per Liter at Different Stations and Levels, by W. E. Allen

Sta.	Levels											
	Surface		10 meters		20 meters		30 meters		40 meters		50 meters	
	Condition Good	Bad	Condition Good	Bad	Condition Good	Bad	Condition Good	Bad	Condition Good	Bad	Condition Good	Bad
1	200											
2	1700	100										
3	2000	200										
4	1200	200									320	160
5	300											
7	800		480		320	160			160		320	
8	2200											
9	8300	200										
10	1700		160		320				160			
12	1800		320				1600			160	160	
13	500		320		640		480					
15	8960		6400		1720		640		640		480	
16	7800		1920	160	640						160	
18	3600	200			1820		160		320		320	160
19	8640		3200		6080		3360					
21	4000											
22	3680	160										
23	12800	320										
24	4320	800	5120		640	320	160		480			
25	62080											
26	23040	160										
27	640	480										
28	1120	160										

Av. good and bad at surface, 7146

These comparative counts indicate that the production of peridinians in midsummer is of about the same order of magnitude in Monterey Bay as in the vicinity of Santa Barbara; and correspondingly greater than at La Jolla, farther south.

Such data as are available suggest that the coast waters are also distinctly more productive of peridinians off middle California than along the sector next to the north, for the largest number per liter found by the U. S. S. "Guide" off Oregon in the summer and autumn of 1924 was only 160 (Lewis, 1927), while the maximum in samples taken by the U. S. S. "Pioneer" during that spring between the offings of San Diego and of Seattle was only 1,958.

Prof. Allen reports the presence of the following four species in about half the quantitative samples; *Ceratium furca* Ehr., *Dinophysis acuta* Ehr., *Peridinium divergens* Ehr., and *P. ovatum* Pouch. Among these, *C. furca* was not only the most regularly recurrent, but locally the most abundant. Probably it was universally distributed over the bay at the time, for at least a sprinkling of it was detected at fifteen stations[1] out of the twenty-one where tows were made. And it was almost entirely responsible for the large gatherings of peridinians in the northern side of the bay on July 21, just mentioned (p. 539, Stations 23, 25, 26).

Prof. Allen reports *Dinophysis acuta* as next in numerical strength in the quantitative samples, and it also was detected in most of the tows. About half of the tows also showed a scattering of another Ceratium, without developed antapical horns, provisionally identified as a form of *C. tripos*, as well as various unidentified species of Peridinium and of Dinophysis.

It is interesting, Prof. Allen points out, that *Prorocentrum micans* Ehr., the dinoflagellate that has most frequently been prominent in southern Californian waters of late years, was noted in only five of the quantitative samples, always in small numbers.

The dominance of the peridinian community by *Ceratium furca* in Monterey Bay, but by Prorocentrum off La Jolla, is a difference for which no reasonable explanation can yet be offered, unless the difference in latitude.

VII. Zoöplankton

Only a preliminary survey of the animal plankton has yet been made, consequently we can mention only the more prominent species:[2] discussion of many others — and of some whole groups — must be postponed to some future occasion. Fortunately, however, it proved that most of the dominant members of the different groups are species so well known in northern seas that their identification offers no special difficulty. We are, therefore, able to present the general facies of the planktonic communities that were living in different places and depths in the bay at the time, which after all, was the chief object of the biological part of our survey.

This is a matter of considerable interest, from its bearing on the natural economy of this part of the sea, for (so far as we are aware),

[1] Stations 6, 9, 12, 15–19, 21, 23–28.

[2] The following collaborators have made preliminary identifications, in different groups: — C. V. MacCoy, Copepods; Alice Beale, Chaetognaths, Radiolarians; Mary Sears, Crustacea other than Copepods, Annelids, Tunicates, Siphonophores.

this is the first attempt to analyze the zoöplankton of any part of the open North Pacific from the standpoint of the association of groups and of dominant species.

To some extent the picture is confused (just as it is for the phytoplankton) by the fact that the series extended over a period of twenty-four days. Multiplication is, however, a slower process for most groups of planktonic animals than it is for the dominant groups of planktonic plants — diatoms and peridinians — and the general character of the community as a rule changes more slowly, unless mass migrations occur, carried by sudden indrafts of water of distant origin. Consequently the time factor is not so important in this case.

On the other hand the qualitative complexity of the community is greater for the zoö- than for the phytoplankton, making qualitative characterization more difficult.

The hauls were made with ordinary open nets of three sizes, 0.5 meter, 0.75 meter, and 1 meter in diameter, towed horizontally at various depths, from the surface down to 550–0 meters.

A. Quantity of Plankton

Only a cursory glance at the catches, as brought on board, was needed to show that no great concentrations of animal plankton were encountered, compared with the rich catches that are sometimes made with similar nets in the coastal waters of the boreal Atlantic, at the time of year when zoöplankton is at its maximum there.

No exact quantitative statement is possible, because no vertical hauls were made. Volumetric analysis of the horizontal tows is made more than usually unreliable (as it is for the phytoplankton) by irregularity in the speed of towing. However, it was only at stations where the ctenophore *Pleurobrachia pileus* was abundant — an animal so large that it needs but few individuals to yield large volumes of it — that the yield of the tows was at the rate of one liter or more, when reduced to a standard of thirty minutes towing with one meter net, except at one station (23) where the half-meter net, towed at 10 meters, passed through a population of copepods dense enough to yield at about double that rate, an amount that is frequently surpassed in the Gulf of Maine in the summer season (Bigelow, 1926).

The average volume, calculated as just stated, for all the tows, at 10 meters or deeper, was, roughly, 500 cc. But the facts that our tows were made during a period when diatoms were diminishing, and that they yielded considerable numbers of juvenile copepods and euphausiids (p. 547) makes it likely that much larger amounts of zoöplankton would have been found a few weeks later in the season. No comparative data, as to the volumetric abundance of the zoöplanktonic communities as a whole, are available for Pacific coast stations either to the north or to the south of Monterey, though some statistical studies have been made of the numerical occurrence of individual groups of animals off La Jolla (see bibliography), and in the straits of Georgia (Campbell, 1929).

The topography of Monterey Bay and its dominant upwelling circulation, with its geographic situation relative to the continental slope and Pacific basin, combine to make this an interesting region, in the present connection.

B. Bathymetric Stratification

Analysis of the more prominent members of representative groups, by depths of capture, shows that (irrespective of systematic relationships) they fall into two rather sharply defined groups: (a) those that occurred with some regularity in the tows at 50 meters and shoaler; (b) a bathypelagic community that were taken chiefly in our few deep tows from 300 meters or deeper, and only occasionally nearer the surface. No sharp line can be drawn between these two bathymetric groups, for here, as is always the case, the transition is bridged by species which, while most plentiful at considerable depths occur also right up to the surface. As examples we may cite the common oceanic euphausiid-shrimp *Euphausia pacifica* Hansen; also the splendid siphonophore *Nectodroma reticulata* Bigelow, which, by its abundance, characterized the deep tows at Stations 8 and 27, and fragments of which were also taken in shoal tows (pp. 546, 560). On the other hand, when a species, occurring only occasionally, is found in a deep tow only, the possibility must always be recognized that it may have been picked up near the surface while the net was being let out, or hauled in. This probably happened with the one specimen of the Narcomedusa *Solmundella bitentaculata* (p. 560).

In spite of such connecting species the two chief bathymetric communities were sufficiently distinct to call for separate discussion, as, in fact, is usually the case when towing is done down to depths greater than 300 meters. The one community, dwelling chiefly shoaler than 100 meters, the more directly reflects local conditions in its composition; the other, living deeper, is part of the faunal association that is characteristic of the 200–500 meter stratum of the ocean basins, generally.

Fowler's term "epiplankton" is convenient for the former if understood as covering the community of the superficial stratum in general, not of any particular depth-zone therein. In the case of Monterey Bay the inclusive term "bathyplankton" appropriately names the inhabitants of the mid-levels. None of our tows were deep enough to touch abyssal waters.

C. Epiplankton

The catches made in the tows between the surface and a depth of 50 meters are the most characteristic of Monterey Bay itself, because only a small percentage of the area of the latter is deeper than 100 meters (Fig. 1). And it is these shoal catches that are the most interesting, faunistically, because little was previously known as to the associations prevailing within the bay at any season (anywhere along this general coast-sector, for that matter), or as to their seasonal successions, though the presence of a great variety of planktonic animals had been observed within the bay at one time or another. In fact, Monterey Bay was nearly as virgin a sea, in this respect, as was the Gulf of Maine when the Museum of Comparative Zoölogy and U. S. Bureau of Fisheries commenced their joint exploration of its plankton in 1912 (Bigelow, 1926).

1. *General Associations*

So far as the presence of the more prominent species is concerned, the shoal catches proved decidedly uniform from station to station throughout the series, though regional differences in the relative importance of copepods, ctenophores, appendicularians and siphonophores resulted in notable differences in the general facies of the population from station to station. (See table, pages 546, 547.)

In several cases one or another group so predominated as to result in a decidedly monotonous assemblage. Thus surface hauls at Stations 1, 2, 5 and 6; 10 meter hauls at Stations 2, 12, 13 and 23; and the 50–0 meter haul at Station 6 yielded little except copepods. The ctenophore *Pleurobrachia pileus* formed the bulk of the catch from 10–0 meters at Stations 4 and 5, from 50–0 meters at Station 12. Oikopleura was predominant at the surface at two stations (4 and 18), as was the siphonophore *Muggiaea atlantica* on six occasions, in hauls from 10–0, 25–0, and 50–0 meters (table, p. 546). In the other hauls no one species outranked the rest to this extent, though one or two groups in combination were much the most prominent in most cases, as noted in the accompanying table (p. 546). Such dominance of the inshore plankton by one species, or by a few in combination, is a familiar phenomenon in the upper 50 meters, in coastal waters of moderately low temperature.

In analyzing the regional differences in dominance by the different groups, vertical stratification must be taken into account even within the superficial 50 meters, when subsurface hauls are made at different depths, because the relative importance of different groups is different at the surface, at 10 meters, and at 50 meters. Pleurobrachia, for example, was predominant only in hauls from 10–0 meters or deeper, whereas it was only at the surface that an abundance of Oikopleura marked any of the catches. Copepods, however, and *Muggiaea atlantica*, either separately, or in combination with some other group, dominated some of the deeper as well as some of the surface hauls. This stratification is best illustrated by stations where hauls were made at two or more levels. Thus at Station 4 *Oikopleura dioica* and another member of the genus not yet identified formed the most prominent element at the surface, Pleurobrachia at 10–0 meters. Similarly, at Station 5, copepods dominated at the surface, Pleurobrachia at 10–0 meters. At Station 12 Muggiaea and the copepod *Calanus finmarchicus* characterized the catch at 10–0 meters, Pleurobrachia at 50 meters while at Station 18 the surface catch was chiefly copepods and Muggiaea, the 10–0 meter catch chiefly the latter. And more instances of the same sort might be cited (table, p. 546).

Radiolarians as a group were also represented more abundantly and by a greater variety of genera in hauls from 25–0 and 50–0 meters than closer to the surface; so, too, the Hyperiid amphipod *Hyperia galba*, which occurred widespread over the bay. Among copepods, *Eucalanus elongatus*, and Tortanus were abundant only in tows from 50–0 meters. On the other hand Acartia, Microcalanus, and other minute species formed a larger percentage of the copepods at or near the surface.

Certain species, furthermore, such as *Euphausia pacifica*, appeared only in subsurface tows as adults, though larvae probably referable to them were plentiful at or near the surface. In the case of *Calanus finmarchicus* the surface may be described as a nursery at the time, for several of the surface tows yielded a large proportion of its juveniles, with older stages predominating at deeper levels, as is the general rule wherever the biology of this economically important copepod has been studied.

The feeding habits of different species also affect their associations, for when large rapacious animals multiply they may soon denude the water of its smaller inhabitants. Thus while copepods were important,

Table of Occurrence of Representative Species in Hauls from 50 Meters and Shoaler

(Those marked D were dominant, those marked d dominant within the respective group)

Station	1	2	2	4	4	5	5	6	6	7	8	12	12	13	13	15	17	18	23	24
Depth	0	0	10–0	0	10–0	0	10–0	0	50–0	10–0	0	10–0	50–0	10–0	50–0	25–0	5-0	10–0	10–0	50–0
Radiolarians	....	....	....	....	....	....	....	....	....	....	....	....	D	....	....	....	....	....	....	....
Aulastrum	....	....	....	....	....	....	....	....	×	....	....	....	×	....	×	×	....	×	....	×
Aloscena	....	....	....	....	×	×	....	....	×	....	....	....	×	....	×	×	....	×	....	×
Aulosphaera	....	....	....	....	×	×	....	....	×	....	....	....	×	....	×	×	....	×	....	×
Castanella	....	....	....	....	....	....	....	....	×	....	....	....	....	....	×	....	....	....	....	....
Castanidium	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Castanissa	....	....	....	....	×	....	....	....	×	....	....	....	×	....	×	×	....	....	....	×
Coelodendrum	....	....	....	....	×	×	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Sagenoscena	....	....	....	....	×	×	....	....	×	....	....	×	×	....	×	×	....	×	....	×
Sagoscena	....	....	....	....	×	....	....	....	×	....	....	....	×	....	×	×	....	×	....	....
Siphonophores	....	....	....	....	....	....	....	....	....	D	....	D	....	....	D	D	....	D	....	D
Diphyes truncata	....	....	....	....	....	×	×	....	×	....	....	....	....	....	....	....	....	....	....	....
Muggiaea atlantica	×	....	×	×	d	d	d	×	d	D	d	D	×	×	D	D	d	D	....	D
Nectodroma reticulata	....	....	....	....	....	....	....	....	×	×	×	....	....	....	×	....	....	....	....	....
Sphaeronectes truncata	....	....	....	....	×	....	×	....	×	×	....	....	×	....	×	×	....	....	....	×
Ctenophores	....	....	....	....	D	....	D	....	....	....	....	....	D	....	D	....	....	....	....	....
Pleurobrachia pileus	×	....	×	....	D	×	D	....	×	×	....	×	D	×	D	×	×	×	×	....
Chaetognaths																				
Sagitta bipunctata [1]	×	....	×	×	×	×	×	....	....	×	....	×	×	×	×	×	d	....	×	....
Sagitta hexaptera	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Sagitta lyra	....	....	....	....	....	×	×	....	....	....	....	....	×	....	×	×	×	×	....	....
Sagitta serratodentata	....	....	....	....	×	....	....	....	....	....	....	....	×	....	....	×	....	....	....	....
Copepods	D	D	D	....	....	D	....	D	D	D	....	D	....	D	....	....	....	....	D	....
Acartia	....	d	....	d	....	×	×	D	....	×	×	....	....	×	....	....	×	×	D	D
Aetidius armatus	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....
Calanus finmarchicus	D	d	D	×	d	D	d	×	D	D	d	D	d	×	d	d	d	d	×	×

[1] See footnote, page 552.

Station	1	2	2	4	4	5	5	6	6	7	8	12	12	13	13	15	17	18	23	24
Depth	0	0	10–0	0	10–0	0	10–0	0	50–0	10–0	0	10–0	50–0	10–0	50–0	25–0	5–0	10–0	10–0	50–0
Eucalanus elongatus	....	....	....	....	×	×	....	×	×	×	....	....	d	....	....	×	×	....	×	....
Euchaeta juv.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Eucheirella pulchra	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....
Gaetanus juv.	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×
Metridia lucens	....	....	....	....	....	....	....	×	×	....	....	....	....	×	....	....	....	....	×	....
Microcalanus	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Oithona	....	×	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Pontella	....	....	....	....	....	....	×	....	....	×	d	....	....	....	....	×	×	....	×	....
Rhincalanus nasutus	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Tortanus	×	....	....	×	....	....	×	....	....	....	....	....	....	....	....	....	....	×	....	×
Other copepods	×	d	×	×	×	×	×	×	×	×	×	×	....	×	×	×	×	×	×	×
Many juveniles or Nauplii	×	×	....	×	....	×	....	×	....	....	×	×	....	×	....	....	×	....	×	....
Amphipods																				
Hyperia galba	....	....	....	....	....	×	×	....	×	×	×	×	....	×	....	×	....	....	....	×
Phronimopsis tenella	....	....	....	....	....	....	....	....	×	....	....	....	....	....	×	×	....	....	....	....
Streetsia challengeri	....	....	....	....	....	....	....	....	×	....	....	×	....	....	....	....	....	....	....	....
Tyro pacifica	....	....	....	....	....	....	....	....	×	....	....	....	×	....	....	....	×	....	....	....
Euphausiids																				
Euphausia pacifica	....	....	....	....	....	....	....	....	....	....	....	....	×	....	×	×	×	....	×	....
Thysanoessa spinifera	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....	....	....
Thysanoessa gregaria	....	....	....	....	....	....	....	....	....	....	....	....	×	....	....	....	....	....	....	....
Euphausiid larvae	×	D	×	×	D	×	×	....	D	×	×	×	×	×	....	×	×	....	×	×
Tunicates	....	....	....	D	....	....	....	....	....	....	....	....	....	D	....	....	....	....	....	....
Doliolum	....	....	....	....	....	....	×	....	....	×	....	×	....	....	....	×	....	×	....	....
Oikopleura dioica	×	....	×	D	....	....	....	×	....	×	....	×	....	D	....	×	d	×	....	....
Oikopleura labradorensis	....	....	×	....	×	....	×	....	×	×	×	....	×	....	×	×	....	×	....	×
Oikopleura intermedia?	....	....	×	D	....	....	....	....	....	....	....	....	....	×	....	....	×	....	....	....
Oikopleura juveniles	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	×	....
Decapods																				
Macruran larvae	....	....	....	....	×	×	×	....	×	×	×	×	....	×	×	×	....	×	×	×
Brachyuran larvae	....	....	....	....	×	×	×	....	×	×	×	×	×	×	×	....	×	....	×	×

at one station or another, in combination with small siphonophores (Muggiaea), with Euphausiid larvae, and in combination with Oikopleura, without exception they were relatively scarce wherever Pleurobrachia were notably plentiful. This scarcity no doubt results from the efficiency with which the Pleurobrachia fish with their trailing tentacles.

Our station data do not suggest any definite localization of dominance, by one or another group, in definite parts of the bay — none, in fact, was to be expected in so small an area, and in one the physical state of which is so constantly determined by upwelling. The most that can be said is that copepods and Pleurobrachia were relatively most prominent, at the time, in a rather definitely circumscribed area in the southern part of the bay, out to midway across its mouth, and offshore to the continental slope abreast Point Pinos, and that the three stations where *Oikopleura labradorensis* was prominent (4, 13, 18) were all either near the coast, or in shoal water.

The stations where siphonophores were prominent were so generally distributed that no grouping is possible.

The tows throw no light on the rapidity with which one group or species may replace another in the dominating rôle in Monterey Bay. We can only note that off the Hopkins Marine Station, where Pleurobrachia had dominated at 10–0 meters on July 3 (4), it was but sparsely represented on the seventeenth (15), having been replaced by *Muggiaea atlantica*. In the centre of the bay, however, the plankton at 10–0 meters was of the same general type on the twenty-first (21) as it had been on the tenth (7), Muggiaea dominating on both occasions.

And since the Pleurobrachia taken early in the series averaged in general small, those taken later large, it seems that one generation of this ctenophore grew nearly or quite to maturity in the bay during the first three weeks of July, 1928.

From the negative standpoint, the hauls were made interesting by the scarcity of buoyant fish eggs and of larval fishes, only a scattering of which were noted at any of the stations.

In a situation as open to the ocean as Monterey Bay, the relative importance of immigrants and of endemic inhabitants, in the planktonic community is a matter of interest. In July, 1928, the plankton seems to have been chiefly endemic. Calanus, for example, was multiplying locally (p. 554). Pleurobrachia may be expected to do the same, judging from its faunal status in general. Local reproduction is also established for Muggiaea (p. 551) though invasions on its part may also take place. It seems safe to assume local parentage for the Euphausiid larvae, hence for *Euphausia pacifica* (p. 557). *Oikopleura dioica* is so nearly universal that there is no warrant for assuming an exotic nursery for the local stock, while *Sagitta bipunctata* is also native to Californian coast waters in general (p. 553).

At the time of our survey we found no planktonic animals quantitatively prominent, for which a distant exotic origin could safely be assumed, for while the few genera of Hyperiid amphipods, other than Hyperia (p. 547), several of the chaetognaths, and the common siphonophores are oceanic, it is probable that their areas of regular production include the immediate offing of the bay, at the depths most favorable for them. Furthermore, no typically tropical species were found, though many of the forms listed — *Rhincalanus* for example — are at home only in moderately high temperatures. On the other hand, the tows showed no distinctively arctic element. *Oikopleura labradorensis* (p. 558), must, however, been regarded as a northern species, in the bay, for this seems near the southern boundary to its regular occurrence. But whether it finds its most southerly breeding station there, or to what degree maintenance of the local stock depends on immigrations from the north, is a question for the future.

The geographic status of the Radiolarians in the bay, as a group, is also to be learned. It is certain, however, that mass immigrations do take place into the bay from offshore at times. Thus, as Mr. E. F. Ricketts informs us, Velella was "cast upon local beaches this spring (1927) by the million." He adds "on an average of two or three times each year we get perfect hordes of medusae, ctenophores and siphonophores in belts of pelagic forms." But while events of this sort are so spectacular that their occurrence has long been recognized at the Hopkins Marine Station, nothing is yet known as to their periodicity, nor of the hydrographic conditions responsible, except that they may be expected to take place when upwelling is least active.

The thermal affinities (subtropical) of Velella, and of its companion visitors, is no indication to the direction from which such incursions come, beyond the evident fact that they are from offshore, because the surface waters out at sea to the northwest as well as to the west and southwest, are considerably warmer than is the immediate offing of Monterey. In fact Velella appears, not infrequently, on the coast as far north as Puget Sound (Bigelow, 1911), and has been reported in abundance to the westward of the Queen Charlotte Islands, in latitude about 52° N (Nichols, 1926).

The epiplankton of Monterey Bay in midsummer may be characterized as temperate boreal, corresponding to the prevailing temperature, with no important elements either of arctic or of tropical nature; as oceanic, with only small contributions from the coast line; as dominated by species that are at least widespread, if not cosmopolitan, in appropriate temperatures and depths; and as chiefly endemic.

It is not unlikely that animals not represented at all in these July tows may dominate at other seasons; at the times of invasion by offshore plankton this certainly happens. But it is probable that the particular species of copepods, siphonophores, ctenophores, and appendicularians that we found dominant in July constitute the normal basis for the plankton of summer and autumn, for mass production is characteristic of all of them, in other seas. Most of these dominant species play the same rôle in one locality or another in the north Atlantic, the only important exception being the Euphausiid shrimp, *Euphausia pacifica* (p. 557). This close parallel between the planktonic communities of the two oceans, in comparable latitudes and temperatures, contrasts with the littoral animals, and those living on bottom in shoal water.

2. *Notes on the More Prominent Groups*

Coelenterates

An interesting aspect of the zoöplanktonic associations in Monterey Bay at the time is the predominance of the small siphonophores, *Muggiaea atlantica* and *Sphaeronectes truncata*, Muggiaea being far the more plentiful of the pair, in the ratio of about fifteen to one for the stations where random samples were counted.

Muggiaea atlantica is a species of distribution so wide that it is probably cosmopolitan: it has been reported from localities as far apart as the English Channel, the southeastern tropical Pacific, and Japan.[1]

Up to the present, mass production of it had been reported only in the English Channel, near Plymouth, England, where it sometimes appears in great abundance (Cunningham, 1892; Gough, 1905). Apparently it enters the channel as an immigrant from the Bay of Biscay, appearing in waves, at different seasons in different years, from early spring to November, but never passing through the channel to the North Sea (Kramp, 1913). The only data at hand as to it in Monterey Bay, other than our own collections, are information contributed by Mr. E. F. Ricketts of the Pacific Biological Laboratories, Pacific Grove, that it occurs, sporadically, in the bay, in abundance with medusae, ctenophores, and other siphonophores, "on an average of two or three times each year." This would suggest that Muggiaea appears in the bay chiefly as an immigrant from offshore. This the open-

[1] For summary of its distribution, see Moser, 1925.

ness of the bay to the Pacific would favor. But the fact that our catches contained large numbers of sexual gonophores almost certainly belonging to this species, as well as its swimming bells of different sizes, points to active production within the bay at the time as responsible at least in part, for its periods of abundance there. Receipt of very large nectophores from Mr. Ricketts, taken in April (of 1924), with the abundance of detached gonophores in July, 1928 suggests that its period of reproduction extends throughout spring and summer, which is in line with Moser's (1925) account of it as breeding in late summer and early autumn in the English Channel.

Its companion-species *Sphaeronectes truncata* is so widespread in the oceans, North Pacific included, that there is nothing surprising in its presence in Monterey Bay. The discovery of *Nectodroma reticulata* in the bay (table, p. 546) deserves more attention because this is only the third notice of this large siphonophore. Previous records are from the eastern tropical Pacific (Bigelow, 1911), and from the northwestern Pacific between San Francisco and Unalaska (Bigelow, 1913). It was to be expected in Monterey Bay, however, because the collection of the Museum of Comparative Zoölogy contains fragments of it from Friday Harbor, Puget Sound. It is represented in our hauls chiefly by the very characteristic bracts, with portions of the stem. The representation of these shows that its chief centre of abundance in the bay was below 50 meters, as follows: —

Station 7, surface, fragments: 10–0 meters, 1 bract
50–0 meters, many bracts and segments of stem with appendages
Station 8, 270–0 meters, many bracts and segments of stem with appendages
Station 27, 550–0 meters, many bracts and segments of stem with appendages

The tows did not yield a single recognizable nectophore of Nectodroma: any that may have been taken had been mashed beyond recognition. But identification seems assured by the close correspondence between these bracts and those earlier described (Bigelow, 1911, 1913).

An occasional nectophore of some other Prayid, too fragmentary for naming, was also found. But the only other siphonophore definitely identified from the shoal tows is the well known *Diphyes truncata* (table, p. 546). Since this species is cosmopolitan, from subarctic to subantarctic, already recorded from widely separated localities in the Atlantic and in both sides of the North Pacific, including the coasts of British Columbia and Bering Sea, it is to be expected anywhere along the Pacific coast of North America.

Mr. Ricketts also reports long-stemmed siphonophores belonging to the physophorae as appearing in the bay at the times when incursions of other pelagic Coelenterates enter. Velella, specimens of which have been received from him, is also reported, as sometimes cast up on the beaches, in great abundance. And the general conformation of this part of the coast line, with the nearness of the continental edge, makes it likely that most of the holoplanktonic Coelenterates proper to moderate temperatures, in the upper waters of the North Pacific, would be found in the bay, were watch kept for them.

By common report, Monterey Bay also supports a varied list of hydromedusae, while at times the large scyphomedusa *Chrysaora gilberti* appears there in swarms. But apparently their periods of abundance do not fall in midsummer, for the only scyphomedusae seen, or taken, were odd examples of Chrysaora and of Phacellophora, while only a scattering of the smaller medusae (not yet examined) were taken in any of our tows.

Ctenophores

Local and temporary monopolization of the upper waters by *Pleurobrachia pileus* is so familiar an event, wherever, in northern marginal seas, this ctenophore occurs regularly, that its dominance in Monterey Bay calls for no special comment. Pleurobrachia may, in fact, be expected to swarm anywhere along the Californian coast, for Esterly (1914) found it in about 25% of his hauls at La Jolla, where it is the commonest ctenophore, most abundant in August, though he reports it as occurring less commonly there than do either the commonest chaetognath (*Sagitta bipunctata*) or the commonest offshore copepod (*Calanus finmarchicus*).

Chaetognaths

Dominance of the plankton by chaetognaths — a common occurrence in cool coastal waters in the North Atlantic — did not occur at any station in Monterey Bay in July, 1928. But the presence of *Sagitta bipunctata* [1] in all parts of the bay (table, p. 546), and in considerable numbers in most of the hauls, shows that a period of active reproduction for it alone was needed for it to monopolize the upper waters of the

[1] These specimens clearly belong to the species recorded by Michael (1911) under that name, as common off La Jolla. But it is unwise to hazard an opinion as to the relationship of this Pacific species to the Atlantic form to which von Ritter Zahony (1911, 1911a) concludes that this name rightly belongs, without comparison with Atlantic material of the latter.

bay as completely as does its relative *S. elegans* in corresponding situations in the Atlantic. The largest catches of *S. bipunctata* (>50 per haul) were in the southern side of the bay (Stations 1, 4, 5, 15), midway of its mouth (12), and in the offing of the Monterey Peninsula (8, 17). But this species did not occur regularly enough to allow any definite part of the region to be named a center of abundance for it at the time. The few hauls from 50 meters and deeper proved less productive of this Chaetognath than did hauls from 10–0 meters. Thus at Station 12, the haul from 10–0 meters yielded fifty, that from 50–0 meters only two or three. At Station 13, nine were seen in the 10 meter, only one or two in the 50 meter haul, although the latter was made with a net of four times the mouth area of that used for the former. At Station 17, one hundred and fifty were taken near the surface in a net one-half meter in diameter, only eight or nine in a haul from 550–0 meters with 75 cm. net. And at one station (5) it seems to have been more plentiful right at the surface than a few meters down. At another station, however, (8) the numbers from surface and deep (275–0) hauls are roughly equal, when the difference in the mouth areas of the nets is allowed for.

The status of *S. bipunctata* is thus the same in Monterey Bay as off La Jolla, where Michael's (1911) statistical study showed it typically epiplanktonic, most frequent and abundant shoaler than 40 meters. Other sagittae detected in the shoalest hauls (table, p. 546) were represented by occasional examples only. Thus one specimen of *S. serratodentata* was found in the 10–0 meter tow, Station 4; odd examples of *S. lyra* from that same depth-zone at Stations 5, 17 and 18. Both of these species were better represented in hauls from 50–0 meters, seven *serratodentata* being recorded from that depth at Station 12, about thirty *lyra* in that same haul, while both of them were much more plentiful in the deep hauls (p. 560). Their vertical distribution is thus essentially the same off Monterey as off La Jolla, where Michael (1911) found them chiefly bathyplanktonic, most abundant near 400 metres, and only occasionally at shallow levels.

Copepods

The following notes on the genera and species of copepods are based on examination by C. V. MacCoy, of random samples. Wherever copepods dominated the tows from 10–0 or 25–0 meters, *Calanus finmarchicus* and Acartia were usually chiefly responsible. Exact percentages have not yet been determined, but in most of the hauls from this depth zone these two together formed more than 50% of the numerical stock of the adult copepods. And wherever juveniles were numerous (table, p. 547), these same copepods were chiefly responsible, so far as the first cursory examination shows. Of the two, Calanus was the more regularly occurrent (in number sufficient for detection in the samples examined) and the more regularly prominent, as appears clearly from the tabulation (p. 547). Furthermore, while Calanus, in significant numbers, was regionally universal in the bay, in fact did not fail at any station, or in any haul so far examined, Acartia was dominant only at stations near land (2, 4) or, if farther out, in comparatively shoal parts of the bay (6, 13, 23, 24).

In this respect, our records, so far as they go, are in line with Esterly's (1912) observations at La Jolla, where *Calanus finmarchicus* is the most numerous copepod out from the land, though Acartia so greatly outnumbers it close to the shore there Calanus "plays no part whatever" in the general community (Esterly, 1928, p. 332). In view of the status of *Calanus finmarchicus* in southern California waters, and of its latitudinal distribution in the Atlantic, to find it occurring regularly in Monterey Bay was to be expected. Thompson (1898) also found it the most plentiful copepod in Puget Sound, to the north, while Campbell (1929a) had it at various localities between Vancouver Island and the mainland. And even in the estuarine waters of San Francisco Bay, Esterly (1924) found it the third, in frequency, among copepods. Off the west coast of Vancouver Island however, also in Bering Sea, and off the Arctic coast of Alaska and Canada, other copepods have been found usually to outnumber Calanus (McMurrich, 1916; Willey, 1920). Present information, therefore, points to the sector from southern California to Puget Sound as the region within which, off the Pacific coast of North America, *Calanus finmarchicus* is relatively the most important as a member of the copepod community. This contrasts with its geographic status in the North Atlantic, where it swarms not only in boreal waters, but in the icy Labrador current, in the northern part of the Norwegian Sea, and up into the polar basin (Sars, 1900).

We made no catch of Calanus in Monterey Bay that would be classed as "large" by the North Atlantic standard, nor did our nets in any case yield the rich and monotonous Calanus plankton that is so frequently encountered in the Gulf of Maine in the one side of the Atlantic, in north European waters in the other. But the abundance of juveniles in several of the hauls (table, p. 547) shows that this copepod —the most important of its group economically in the high seas—was multiplying actively in Monterey Bay at the time. Thus 50% or more of the copepods in the samples examined by Mr. MacCoy, from the following tows, were early juveniles: no. 1, surface; no. 2, surface; no. 5, surface; no. 8, 300–0 meters; no. 12, 10–0 meters; no. 13, 10–0 meters; no. 23, 10–0 meters. And while the percentage of Calanus among these early stages has not been determined, preliminary examination shows that in most cases it is at least 50%. Furthermore Nauplii, provisionally referred to Calanus, were reported by Mr. MacCoy in the surface tow at Station 2; at 10–0 meters, Station 23. Thus tows taken a few weeks later, when the juveniles of July had grown to subadult or adult size, might well have yielded much larger volumes of Calanus. And if our visit fell at the beginning of a period of multiplication, as the comparative scarcity of large adults suggests, it is probable that the numerical strength of the stock would also have been much greater, in August or early September.

This also applies to copepods as a whole, for other species, as well as *C. finmarchicus*, were strongly represented among the Nauplii and juveniles recorded by Mr. MacCoy. At Station 2 (surface tow), for example, Mr. MacCoy reports an abundance of other Nauplii. As Acartia was about as numerous as Calanus in this tow, they may have belonged to the former.

Therefore, it need not be surprising if Monterey Bay waters are at times as fully monopolized by copepods, or if they support a stock of those little crustaceans as large as do the regions in the North Atlantic where their quantitative occurrence has been studied.

In short, the copepod community, with *Calanus finmarchicus* as the key species and Acartia vying with it, or surpassing it in abundance near land and near the surface, may well play as important a rôle in the natural economy of Monterey Bay as food for the Californian sardine (*Sardina coerulea*) as it does for plankton-feeding fishes, generally, in the two sides of the North Atlantic. Various phases in the life history of Calanus in the bay, such as number of generations a year; numerical strength of the stock from season to season; bathymetric distribution of its different developmental stages, etc., may, therefore prove so important, economically, as to point the need of statistical study of it there, such as Ruud (1929) [1] has recently carried out, in Norway.

Esterly (1923), also describes copepods, as a group, as by far the predominant planktonic animals in surface tows taken daily at the Pier at La Jolla over a period of two years, and as most abundant in

[1] See Ruud (1929) for bibliography of the life history of *Calanus finmarchicus*.

late winter and early spring, though, as just noted, other genera were more numerous than Calanus at this particular location, as might be expected from the shoalness of the tows, and the close vicinity to the tide line.

Among the large adult or subadult macrocopepods, no other species approached *Calanus finmarchicus* and the genus Acartia in importance in the tows from the 10–25 meter depth zone, except at one station (23) where *Metridia lucens* about equaled Calanus in a very sparse population. One of the 50–0 meter tows (12) also gave a showing of the large slender adults of *Eucalanus elongatus* about equal to Calanus, and *Eucalanus* is evidently a characteristic inhabitant of the bay, for it was sparsely represented in most of the subsurface tows, if not in all. In the surface tows, which yielded very few adult Calanus or other large copepods of any sort, other smaller species were relatively numerous. In addition to Acartia, the surface tows yielded a scattering of *Microcalanus*, of Oithona and of other microcopepods still to be examined. In one of the surface tows (8) Pontella dominated, the only occasion when more than a scattering of this genus was taken.

Amphipods

Only one Hyperiid-amphipod, the well-known *Hyperia galba*, was found at more than two of our stations. This is a species of such wide distribution (North Atlantic, Mediterranean, North Pacific), and through so wide a range of depths, that it will probably prove cosmopolitan near land in the temperate and boreal belt of the northern hemisphere.

We may point out, in passing, that in July, 1928, the Hyperia of Monterey Bay were, for the most part, living independently; not sheltering under medusae as they so often do. Although found at most of the stations, the representation was sparse in each case, ca. 25 being the largest number counted in any one tow.

The other Hyperiids taken in the shoal hauls (table, p. 547) are oceanic species, represented by odd individuals only.

The Hyperiid element of the plankton was also made interesting, negatively, by the absence of the genus Euthemisto, which is so often well represented along the edge of the continent off the opposite coast of the United States and of Canada.

EUPHAUSIIDS

July was a period of reproduction for Euphausiids in Monterey Bay, as well as for copepods: witness the abundance of larvae at Stations 2, 4 and 6, which, while not specifically identified, probably belonged to *Euphausia pacifica,* as the only species, adults of which were then present in any numbers in any of our tows, shoal or deep. Although no adults of this species were taken at either of the stations that yielded many larvae (and only a sparse representation in the 50 meter hauls), the deep hauls made large catches of it (table, p. 560), showing that its centre of abundance in the bay was below the 50 meter level, when adult. *Euphausia pacifica* has already been taken in Monterey waters on several occasions (Hansen, 1913, 1915), and is abundant off La Jolla (Esterly, 1914). First described from the Formosan-Japanese-Corean region, where it is abundant (Hansen, 1911), it is now known to be cosmopolitan offshore in the temperate and boreal parts of the North Pacific, often occurring in shoals.[1] On the American side it has been reported from southern California northward to Alaskan waters, but has not yet been found in the tropical Pacific. Its abundance makes it a species of great economic importance, for, like all its tribe, it is eaten by plankton-feeding fishes — salmon, for instance (Hansen, 1913). The strength of its representation in our deep tows, and the general occurrence and local abundance of Euphausiid larvae in Monterey Bay at the time make it likely that the "shrimp" on which local fishermen report the Californian sardines as feeding at certain times belong largely to this species, as Lewis (1929) has found to be the case off La Jolla.

The only other Euphausiids identified from the shallow hauls (*Thysanoessa gregaria* and *Th. spinifera*) have also been taken off the west coast of North America both to the south of Monterey and to the north (Holmes, 1900; Esterly, 1914, Hansen, 1915). Their presence in Monterey Bay, therefore, needs no further comment.

DECAPODS

In the shallow tows decapods were represented only by larvae (both Macruran and Brachyuran), which were found at most of the stations (table, p. 547), sometimes in numbers great enough to suggest active production near by. It has not been possible to identify any of these larvae specifically.

[1] For summary of its occurrence, see Hansen, 1915.

Appendicularians

The widespread occurrence of *Oikopleura labradorensis* Lohmann[1] is an interesting feature of the July plankton of the bay, illustrating the favorable environment that the cool updraft provides there for planktonic animals that, in general, are boreal or subarctic. Thus in the North Atlantic *O. Labradorensis* — a well-known species, easily recognized — is widespread from Davis Strait, west Greenland, and Spitzbergen, southward to the junction between Labrador current, and Gulf Stream drift in the one side, to the North Sea in the other, but is not known farther south (Apstein, 1911). But in the eastern Pacific it is not only common at the warmest season in Monterey Bay, at latitude 36° 30′–37°, but is even reported from time to time as far south as the La Jolla region during the cool months (Essenberg, 1926). Essenberg (1926) also found *O. vanhöffeni* there, a form still more typically arctic-subarctic, though it did not appear in our collections.

Off Monterey *O. labradorensis* was for the most part at 10 meters and deeper, i.e., living in temperatures lower than 12°. And since it is most plentiful in temperatures of 12°–13° at La Jolla, 12° may be set as its upper optimum in the northeastern Pacific.

Oikopleura dioica, the only member of its group that was sufficiently abundant to give character to any of our Monterey catches (Station 4, surface; Station 13, 10–0 meters; Station 18, surface), was to be expected regularly there, for it is present the year round at La Jolla (Essenberg, 1926), common in Japanese waters (Aida, 1907), and widespread near land in the Atlantic, as well as in the north and south Pacific and Indian Oceans. It is also known to inhabit a wide range of temperature and of salinity. It occurred chiefly in hauls from 10–0 meters and from the surface, evidence that the highest temperatures existing in the bay at the time (about 14°–15°) were not outside its normal optimum.

One other Oikopleura, apparently identical with *O. intermedia* Lohmann, was recognized in several of the tows (table, p. 547). If this identification be correct, its presence is interesting because this species has not been recorded previously from the Pacific.

This list is short, compared with the varied appendicularian fauna described by Essenberg (1926) for the San Diego region, to the south. But the regional contrast may not actually be as wide as it appears, because other species of Oikopleura, besides those just mentioned, may be represented among the juveniles that occurred in most of our tows.

[1]Identified by Mary Sears.

The seasonal aspect must also be taken into account, for Essenberg found the summer to be the season of minimum variety for this group near La Jolla.

D. Bathyplankton

The planktonic associations grouped under this heading, as existing off Monterey, include two bathymetric groups. One covers those which reach their most abundant development at depths greater than 100, or 150 meters, but which also occur normally, if sparsely, right up to within a few meters of the surface, if not actually at the surface. *Euphausia pacifica* and *Sagitta lyra* are typical examples. Most of the copepods that were taken exclusively in the deep hauls, if not all (table, p. 561), also belong in this bathymetric category.

The other chief group are most abundant somewhat deeper, and do not normally rise above the 100 meter level at this latitude in the eastern side of the North Pacific, unless it be in their larval stages. This is the case with *Eukrohnitta subtilis,* for example (von Ritter Zahony, 1911). Typical examples, represented in our deepest tows, are the deep-sea medusae Atolla, Periphylla, and Colobonema; the siphonophore Chuniphyes; and the chaetognaths Eukrohnia and *Sagitta maxima*. The representation of this group in our hauls is interesting, chiefly as proof that this shadow-plankton exists in full strength right up to the coastal slope of this part of California (hence that it is within easy reach of the Hopkins Marine Station); and that its qualitative composition is much the same there as it is over the Pacific, generally, in low and mid-latitudes.

In interpreting, in bathymetric terms, the occurrence of the various animals identified from these deep hauls, it must also be borne in mind that not all of them — even if taken exclusively by the deep tows — actually belong to the bathyplankton. Some, on the contrary, are members of the epiplankton, picked up near the surface by the net on its way down through the water, or up again. This almost certainly applies to the narcomedusae *Solmundella bitentaculata* and Aegina, both of which have been taken at or near the surface in other parts of the Pacific, on many occasions.

The following tables give particulars of the catches of the deep hauls, so far as these have yet been examined.

Occurrence of Characteristic Species Much More Prominent in the Deep Hauls than in the Shallow Hauls, though Taken in Both Series

	Sta. 8 280–0 m.	Sta. 17 475–0 m.	Sta. 27 550–0 m.
Nectodroma reticulata	D		X
Sagitta lyra	ca. 100	ca. 40	ca 40
Sagitta serratodentata	ca. 50	100	ca. 10
Euphausia pacifica	M	M	M

Occurrence of Representative Species that Were Taken Only in the Deep Hauls

Station Max. depth of haul, meters Av. depth of haul	8 280–0 125	17 475–0 390	27 550–0 275
Radiolarians			
Aulacantha		×	×
Aulagraphis		×	×
Aulatractus			×
Aulospathis			×
Coelographis			×
Sagenoarium			×
Siphonophores			
Clausophyes galatea			×
Chuniphyes multidentata		×	×
Vogtia pentacantha [1]		×	
Scyphomedusae			
Atolla wyvillei		×	×
Periphylla hyacinthina			×
Narcomedusae			
Aegina		×	×
Solmundella bitentaculata		×	
Solmissus incisa	×		×
Trachomedusae			
Halitrephes maasi			×
Colobonema typicum			×
Homoeonema glabrum [2]			×
Chaetognaths			
Eukrohnia hamata	×	×	×

[1] See footnote, p. 564.
[2] See p. 564.

Station Max. depth of haul meters Av. depth of haul	8 280–0 125	17 475–0 390	27 550–0 275
Krohnitta subtilis		×	
Sagitta decipiens [1]	×	×	×
Sagitta maxima		×	×
Sagitta planktonis		×	×
Annelids			
Tomopteris planktonis		×	×
Tomopteris septentrionalis			×
Copepods			
Arietellus setosus			×
Euchaeta elongata		×	×
Euchaeta tonsa			×
Eucheirella galatea		×	×
Eucheirella pulchra		×	×
Eucheirella rostrata	×		
Gaetanus cordani		×	×
Gaidius pungens [2]		×	×
Heterorhabdus spinifrons		×	×
Pleuromamma abdominalis			×
Scolecithrix frontalis			×
Scolecithrix persecans	×		×
Amphipods			
Eupronoe intermedia	×		
Lanceola serrata			×
Orchomena abyssorum			×
Paraphronima gracilis	×	×	
Phronimopsis spinifera	×		
Phronima	×		
Scina		×	×
Vibilia	×	×	
Euphausiids			
Nematoscelis microps	×		
Nematoscelis sp. ?		×	
Thysanoessa spinifera	×	×	
Decapods			
Pasiphaea	×		
Sergestes	×	×	

[1] See footnote, p. 564.

[2] According to A. Scott (1909), *G. pungens* Giesbrecht is a synonym of *G. similis* (T. Scott).

The depths of the hauls tabulated above, as calculated from the angle of the towing wire, show a rather definite stratification within the stratum bounded by the 200 meter and 500 meter levels, as well as between that depth zone as a whole and the upper 50 meters. Thus it was only in the two deepest hauls (475–0 and 550–0 M) that radiolarians were found of genera not also identified from hauls at 50 meters or still nearer the surface (table, p. 546). Strictly bathypelagic siphonophores (Chuniphyes and Vogtia) were also restricted to the deepest hauls; likewise five out of seven species of medusae. The percentage of copepod species recognized only in hauls from deeper than 400 meters was still higher (table, p. 561).

Two bathypelagic species of Sagittae were also taken exclusively in the two deepest tows. On the other hand a tow from 280–0 meters (8) yielded a considerably more varied representation of Hyperiid amphipods than did either of the deeper hauls.

These data, with previous knowledge of the bathymetric occurrence of the species concerned in other parts of the oceans, locate the upper boundary for the most typically bathyplanktonic of the radiolarians, siphonophores, trachomedusae, and scyphomedusae that were taken in any of the tows as lying between 300 and 400 meters depth, off Monterey, by day, in summer. Apparently this also applies to the chaetognaths *Sagitta maxima* and *S. planktonis*.

The case is not so clear for the several species of copepods that were recognized only in the hauls from deeper than 400 meters, because Esterly (1912) found that for at least five of these species,[1] 200 meters was the critical level, above which most of the stock migrate by night, to sink below it again by day. *Euchaeta tonsa* and *Eucheirella galatea* seem, however, to reach their highest development deeper than 200 meters off La Jolla, as well as off Monterey, while no statistical study of vertical distribution has ever been attempted for *Arietellus setosus*, for *Gaetanus cordani* or for *Heterorhabdus spinifrons*, so far as we are aware.

Hjort (1912) from the collections made in the North Atlantic by the "Michael Sars" in 1910, brought out the interesting fact that among the bathyplanktonic communities of animals of the high seas, a transparent-iridescent association of various groups, living the shoaler, can, in a rough way, be distinguished from a deeply pigmented category — the so-called "black fish-red prawn community" — which reaches its chief development considerably the deeper, with its centre of abundance

[1] *Eucheirella pulchra*, *Gaidius pungens*, *Pleuromamma abdominalis*, *Scolecithrix frontalis*, *Scolecithrix persecans*.

at about 500 meters in the North Atlantic. Subsequent analysis of earlier records has shown that a corresponding separation can be made of the bathyplanktonic medusae on the basis of correspondence between color and vertical distribution (Bigelow, 1911a, 1911b). In the eastern tropical Pacific, tows by the "Albatross" at the 600 meter level yielded a rich representation of both these categories, whether of fish, of crustacea, or of medusae. But the great majority of the bathypelagic animals taken in the tows from 475–0, and 550–0 meters off Monterey in July, 1928, belonged to the transparent-iridescent group. Thus seven species of medusae included only two of the red-black group (Atolla and Periphylla) and each of these was represented by a single juvenile specimen. The two bathypelagic siphonophores that were taken only in our deepest tows (Chuniphyes and Vogtia) are also transparent-iridescent, nor were any of the typically abyssal species of Pterophysa or Rhizophysidae taken, though a specimen of *Pterophysa grandis* Fewkes, picked up on a dredging wire, off Monterey, has been received from Mr. E. F. Ricketts.

Perhaps still more significant is the fact that even the deepest tows yielded none of the deeply pigmented red prawns so characteristic of the deep strata in the Atlantic, and Pacific as well, while the velvety-black bathypelagic fishes were represented only by odd specimens of a species (*Myctophum glaciale*) that is often taken in still shoaler hauls in the North Atlantic.

Our hauls, though so few in number, thus show that in the offing of Monterey the deeply pigmented community finds the upper boundary to its optimum depth-zone at a depth greater than 500 meters, except in early stages in development. This agrees in general with its vertical occurrence in corresponding latitudes in the North Atlantic.

The center of abundance for the transparent-iridescent community also lay at about the same depth off Monterey as in mid-latitudes in the North Atlantic — 300–500 meters by day — for our two deepest hauls yielded a list of species decidedly varied (table, p. 560) for tows too short (one-half hour) for more than rough sampling at so great a depth.

The data do not establish the upper limit to the regular occurrence of this community at the time and place, for the comparatively poor representation of it in the 280–0 meter haul may have been a matter of chance: a considerable number of hauls from the stratum between 100 and 250 meters would have been needed, for this purpose.

The capture of the particular species listed above (table, p. 560), is interesting chiefly as corroborating the general thesis that most of the members of the bathyplankton are cosmopolitan, in mid-depths, in the oceans, a rule already sufficiently established for many of them. Thus among the siphonophores, *Chuniphyes multidentata* and Vogtia,[1] the scyphomedusae *Atolla wyvillei* and *Periphylla hyacinthina,* the narcomedusa *Solmissus incisa,* were all to be expected off Monterey Bay, for all of them have already been reported in the northeastern Pacific to the north, as well as in the eastern side of the South Pacific; as well as widespread in the Atlantic. The status of *Homoeònema glabrum* is probably the same, for while it has been definitely reported only from the tropical Atlantic and Indian Oceans under this name, examination of the present series suggests identity with the form from the southeastern Pacific recorded (Bigelow 1909) as *H. alba* Vanhöffen. *Halitrephes maasi* Bigelow was originally described from the southeastern Pacific, hence is also widespread in that ocean. Of the chaetognaths taken in our deep hauls, Michael (1911) found *Eukrohnia hamata, Krohnitta subtilis,* and *Sagitta planktonis* frequent in the bathyplankton (occasional at the surface) off La Jolla, California. The first of these ranges from arctic to antarctic in the Atlantic, being confined to the bathyplankton in low and mid-latitudes, but extending its range upward indifferently to the surface in high. The known range of *K. subtilis* also includes the Atlantic, south to the Antarctic, while previous records for *S. planktonis* are from the North and South Atlantic North and South Pacific, Malaysia, Indian Ocean, and Antarctic. The discovery of *Sagitta maxima* off Monterey confirms von Ritter Zahony's (1911) expectation that it would eventually be found in the Pacific, and occupying the same bathymetric zone there as in the Atlantic, where it is typical of the bathyplankton from subarctic to subantarctic. It is also recorded from the Indian Ocean. *S. decipiens*[2] has likewise been taken in deep hauls at so many stations in the North and South Atlantic, in the Red Sea, in the Indian Ocean, and among the Malay Archipelago that it seems equally cosmopolitan in moderate latitudes, though apparently it does not extend to such high latitudes, in either hemisphere.[3]

Locality records for the two bathypelagic species of Tomopteris recognized in the deep hauls (table, p. 561) recently summarized by Huntsman (1920), show them to be equally widespread: one of them (*T. septentrionalis*) has already been reported off La Jolla (Treadwell,

[1] This is the species reported from Bering Sea by Bigelow (1913) as *V. pentacantha* Kölliker but which Moser (1916) believes to be referable to her new *V. serrata*.

[2] Von Ritter Zahoney (1911) points out that *S. sibogae* Fowler is a synonym of this species.

[3] For general summaries of the known distribution of the chaetognaths, see von Ritter Zahony (1911), Apstein (1911), and Huntsman (1919).

1914). But none of the new species of this group of pelagic worms that Chamberlain (1919) described from the southeastern Pacific have been recognized in our catches, though some may be represented among the more fragmentary specimens.

All of the species of copepods that were recognized exclusively in the three deep hauls have also long been known to be widespread in the Atlantic, except for *Euchaeta elongata*, a species described by Esterly (1913) from the La Jolla region. Most of them have also been reported elsewhere in the Pacific, likewise in Indo-Malaysian waters, hence are no doubt cosmopolitan in the bathyplankton and lower epiplankton. All of them have already been reported off southern California by Esterly (1905, 1912), with the exception of *Gaetanus cordani*.

The quantitive relationship of the different groups and species in the deeper strata off Monterey also deserves brief notice. In the haul from 280 meters (8), more than two thirds of the catch consisted of fragments of the siphonophore *Nectodroma reticulata*. And as one of the deeper hauls (17) failed to pick up a single fragment while the other (27) took a mass of it, the 300 meter level seems to have marked the lower limit to its abundant occurrence at the time.

One of the deeper tows (27) yielded chiefly *Euphausia pacifica*, Nectodroma, and medusae (most of them too battered for identification), the former being much the more numerous, though the latter formed the bulk of the catch because of their larger size: *Solmissus incisa* in particular. This haul was also notable for the considerable catch of *Sagitta decipiens*, likewise for the large variety of radiolarians and of copepods.

The tow from about the same depth at Station 17 was similarly characterized by an abundance of *Euphausia pacifica* (but no Nectodroma, and few medusae), while the several species of chaetognaths appeared in about the same ratio at the two stations, as appears from the following proportionate numbers in random samples.

	Sta. 17	Sta. 27
Sagitta bipunctata	ca. 10	4
Sagitta decipiens	> 100	>150
Sagitta lyra	ca. 40	ca. 40
Sagitta maxima	ca. 40	ca. 40
Sagitta planktonis	ca. 15	ca. 20
Sagitta serratodentata	< 100	ca. 10
Eukrohnia hamata	ca. 50	ca. 10
Krohnitta subtilis	6	0

But while Station 27 yielded twelve superior and fourteen inferior nectophores of *Chuniphyes multidentata*, only two nectophores of this bathyplanktonic siphonophore were found in the tow from about the same depth at Station 17.

The great variety of copepods in the deepest hauls (17, 27) contrasting with the predominance of one, or at most a few species within this group in the upper waters (p. 553), illustrated by the following table of percentages, based on random samples identified by C. V. MacCoy, is a state typical of the bathyplankton in general.

	Sta. 17 475–0 m.	Sta. 27 550–0 m.
Arietellus setosus	0	1
Calanus finmarchicus	38	2
Eucalanus elongatus	12	14
Euchaeta tonsa		7
juveniles	6	30
Eucheirella galatea	2	8
pulchra	6	4
Gaetanus cordani	2	2
Gaidius pungens	22	6
Heterorhabdus spinifrons	10	5
Pleuromamma abdominalis		2
Scolecithrix frontalis		2
persecans		2

In the 280–0 meter haul at Station 8, however, *Calanus finmarchicus* formed 90% of the large adult copepods in one sample examined by Mr. MacCoy, with a scattering of the other species listed above (table, p. 561) for that station.

The presence of this bathyplanktonic association of animals in the deep mouth of Monterey Bay, in depths no greater than 300–500 meters, with the fact that shoal hauls did not take any of its most representative members, is evidence that upwelling is not active enough to raise their upper boundary much nearer to the surface there than it is in other seas at corresponding latitudes. And this is in line with the very low velocity (30 m. per month) calculated for the updraft off San Diego by McEwen (1919, p. 378, 415; 1929, p. 258).

The fact that so varied a community exists in the depth zone in question, in this particular part of the Pacific, is also interesting, in connection with the very low values of dissolved oxygen at that depth

(p. 515). This is in line with Schmidt's (1925) discovery of an abundant bathyplanktonic fauna in mid-depths in the Gulf of Panama where the water was less than 5% saturated with oxygen, and corroborates his conclusion that a "wealth of bathypelagic animal life can exist in waters of a lower oxygen content than we had reason to suppose" (Schmidt, 1925, p. 593).

Schmidt gives no data as to the relative abundance of different groups. The Monterey tows are, therefore, the more welcome as showing that a paucity of oxygen is certainly no barrier to what are usually termed the lower groups (because morphologically the least complex) siphonophores, medusae, or chaetognaths. But it may be significant that none of our deep hauls yielded more than an odd fish of any species, and very few decapod crustacea.

VIII. Table of Stations, Temperatures, Salinities, Densities,[1] Silicates, Phosphates and Nitrates

Temperature is in degrees centigrade, salinity in parts per thousand, and density at the temperature *in situ*, but without correction for compression. For the latter, see Ekman (1910) and Bigelow (1927).

Silicates as SiO_2, phosphates as P_2O_5, and nitrates as NO_3, are stated in milligrams per liter. Oxygen is expressed both as cubic centimeters of O_2 per liter and as percentage saturation. For discussion of standards of accuracy, see p. 431.

Sta.	Date 1928	Position	Depth	Temp.	Sal.	Density	SiO_2	P_2O_5	NO_3
1	June 30	36°38.8′N. 121°56.5′W.	0	13.3	33.87	25.47			
2	June 30	36°37′ N. 121°52.5′W.	0	13.9	33.87	25.35			
3	July 2	36°41.5′N. 121°49.3′W.	0	14.2	33.84	25.27			
4	July 3	36°38′ N. 121°53.8′W.	0	14.0	33.87	25.34			
			25	9.9	33.95	26.17			
			50	9.1	34.00	26.36			

[1] (Specific gravity — 1) ×1000.

Sta.	Date 1928	Position	Depth	Temp.	Sal.	Density	SiO_2	P_2O_5	NO_3
5	July 5	36°38.6′N. 121°57′ W.	0	12.1					
			25	9.1	33.95	26.30			
			50	9.1	33.96	26.31			
6	July 9	36°43′ N. 121°54′ W.	0	11.8	33.84	25.75			
			25	9.2	33.87	26.22			
			50	9.0	33.96	26.32			
			75	8.9	33.98	26.37			
			100	8.8					
7	July 10	36°44′ N. 121°59.5′W.	0	12.1	33.80	25.67	0.78	0.054	0.08
			10	11.5	33.84	25.81	0.76	0.07	
			25	9.5	33.86	26.16	1.39	0.15	
			50	9.1	33.95	26.30	1.56	0.152	
			100	9.1	33.96	26.31	1.52	0.167	
			150	8.7	33.98	26.34	1.52	0.153	
			200	8.5	34.05	26.48	1.61	0.193	
8	July 11	36°38.5′N. 122°02.5′W.	0	12.2	33.87	25.69	0.446	0.046	
			5	11.8	33.89	25.79	0.770	0.058	
			10	11.2	33.87	25.89	0.650	0.088	
			25	10.8	33.89	25.98	0.971	0.096	
			50	9.5	33.89	26.17	1.376	0.147	
			100	8.9	33.98	26.35	2.083	0.146	
			200	8.2	34.09	26.55	2.410	0.153	
			300	7.6	34.16	26.64	2.680	0.167	
			400	6.8	34.20	26.83	2.912	0.185	
9	July 12	36°47.5′N. 121°52′ W.	0	13.6	33.87	25.41	0.286	0.012	
			10	11.8	33.87	25.77	0.588	0.050	
			25	10.0	33.84	26.07	1.363	0.123	
			50	9.3	33.93	26.25	1.500	0.125	
			100	9.0	33.96	26.32	1.596	0.196	
			200	8.3	34.04	26.50	2.041	0.142	
10	July 13	36°46.8′N. 122°01′ W.	0	13.1	33.86	25.51	0.283	0.027	0.038
			5	12.8	33.80	25.52	0.495	0.026	
			10	12.4			0.424	0.046	
			25	10.5	33.87	26.00	1.082	0.102	
			50	9.3			1.264	0.133	
			100	8.7	34.04	26.43	1.887	0.150	
			300	7.6			2.083	0.170	
			400	6.9	34.18	26.81	2.440	0.175	
			600	5.3	34.29	27.10	3.570	0.196	

Sta.	Date 1928	Position	Depth	Temp.	Sal.	Density	SiO_2	P_2O_5	NO_3
12	July 14	36°48.5′N. 122°02′ W.	0	13.1	33.91	25.56	0.263	0.017	0.013
			5	12.1	33.78	25.64	0.457	0.064	
			10	11.6	33.82	25.77	0.714	0.071	0.075
			25	9.7	33.73	26.03	1.240	0.118	0.136
			50	9.3	33.96	26.27	1.688	0.156	0.136
			100	8.6	34.05	26.45	1.766	0.156	0.292
13	July 16	36°41.5′N. 121°58′ W.	0	13.3	33.87	25.46	0.143	0.017	
			5	13.1	33.87	25.51	0.141	0.016	
			10	12.2	33.86	25.68	0.303	0.023	
			20	10.1	33.87	26.07	1.096	0.091	
			30	9.7	33.89	26.15	1.340	0.123	
			40	9.7	33.93	26.19	1.442	0.125	
			50	9.5	33.93	26.21	1.250	0.163	
			100	8.7	34.04	26.44	1.949	0.171	
14	July 16	36°38.8′N. 121°56.5′W.	0	12.8			0.377	0.020	
			5	12.5	33.87	25.63	0.411	0.018	
			10	12.5	33.91	25.66	0.400	0.022	
			25	9.8	33.98	26.21	1.456	0.114	
			50	9.6	34.00	26.26	1.563	0.153	
15	July 17	36°37.8′N. 121°53.8′W.	0	14.2	33.87	25.30	0.238	0.010	
			5	13.8	33.87	25.37	0.213	0.011	
			10	13.1	33.87	25.51	0.215	0.010	
			25	10.3	33.89	26.05	1.087	0.118	
			50	9.9	33.91	26.13	1.376	0.138	
16	July 17	36°41.5′N. 121°51′ W.	0	13.6	33.87	25.41	0.204	0.009	0.161
			5	13.2	33.87	25.48	0.196	0.010	
			10	11.5	33.87	25.81	0.862	0.087	
			25	10.2	33.87	26.05	1.163	0.109	
			50	9.7	33.93	26.18	1.442	0.140	0.174
17	July 18	36°38.5′N. 122°08.5′W.	0	12.5	33.86	25.62	0.390	0.060	0.071
			5	12.3	33.86	25.67	0.400	0.060	
			10	12.3	33.86	25.66	0.472	0.054	
			15	11.8	33.86	25.77	0.618	0.090	0.094
			25	9.1	33.86	26.24	1.000	0.120	0.151
			50	9.4	33.95	26.26	1.190	0.135	0.174
			100	8.8	34.02	26.40	1.470	0.134	0.181
			200	8.3	34.11	26.55	1.688	0.179	0.197
			600	5.5	34.29	27.07	3.060	0.217	0.266

Sta.	Date 1928	Position	Depth	Temp.	Sal.	Density	SiO_2	P_2O_5	NO_3
18	July 19	36°52′ N. 121°55′ W.	0	13.1	33.84	25.50	0.193		0.015
			5	12.5	33.84	25.61	0.260	0.019	
			10	12.1	33.80	25.66	0.290	0.022	
			15	11.6	33.82	25.77	0.538	0.030	
			25	9.9	33.71	26.03	1.020	0.124	
			50	9.4	33.91	26.22	1.442	0.143	0.161
19	July 19	36°48.2′N. 121°48′ W.	0	13.6	33.86	25.40	0.300	0.023	0.027
			5	13.3	33.86	25.45	0.295	0.015	
			10	12.7	33.87	25.59	0.291	0.021	
			15	12.3	33.87	25.66	0.610	0.031	
			25	11.7	33.87	25.79	0.833	0.081	
			50	9.6	33.93	26.20	1.905	0.143	
			100	7.9	34.00	26.52	2.410	0.168	0.174
20	July 20	36°50.5′N. 121°59′ W.	0	13.2	33.86	25.49			
			25	9.6	33.91	26.18			
			50	9.2	33.91	26.25			
			75	9.0	33.95	26.30			
21	July 21	36°44.5′N. 121°59′ W.	0	12.6	33.86	25.60	0.562	0.046	0
22	July 21	36°47′ N. 121° 0.5′W.	0	12.5	33.87	25.63	0.618	0.067	0
23	July 21	36°50.2′N. 122° 2.5′W.	0	12.7	33.87	25.59	0.490	0.031	0
24	July 21	36°53′ N. 122° 4.5′W.	0	13.6	33.87	25.41	0.413	0.018	0.008
			5	13.1	33.87	25.50	0.562	0.016	0.013
			10	12.7	33.87	25.58	0.439	0.023	0.038
			15	12.7	33.87	25.58	0.458	0.028	0.021
			25	9.9	33.87	26.11	1.531	0.133	0.174
			50	9.4	33.93	26.23	1.631	0.149	0.174
			70	9.3	33.93	26.26	1.650	0.156	0.151
25	July 21	36°56.7′N. 122° 6.5′W.	0	14.2	33.91	25.33			
			5	13.3	33.91	25.50			
			10	13.1	33.91	25.55			
			15	10.9	33.91	25.96			
			30	10.0	33.93	26.14			

Sta.	Date 1928	Position	Depth	Temp.	Sal.	Density	SiO_2	P_2O_5	NO_3
26	July 21	36°56.2′N. 121°58′ W.	0	15.8	33.87	24.94			
			5	13.0	33.87	25.54			
			10	11.5	33.87	25.82			
			15	10.2	33.87	26.05			
			20	10.3	33.89	26.05			
27	July 23	36°42.5′N. 122° 0.5′W.	0	13.5	33.86	25.43	0.476		0.018
			5	11.9	33.87	25.75	0.618	0.061	0.129
			10	11.9	33.87	25.74	0.595	0.075	0.141
			15	11.7	33.87	25.78	0.582	0.087	0.108
			25	10.5	33.87	26.00	0.603	0.118	0.137
			50	9.9	33.91	26.14	1.127	0.118	0.178
			100	9.1	33.96	26.31	1.579	0.154	0.188
			200	8.4	34.09	26.52	1.631	0.160	0.158
			600	5.5	34.29	27.07	3.190	0.208	0.263
28	July 23	36°38.8′N. 121°56.5′W.	0	12.4	33.89	25.67	0.715	0.069	0.119
			5	11.1	33.91	25.94	0.747	0.061	0.161
			10	11.1	33.91	25.94	0.880	0.080	0.133
			25	10.8	33.93	25.99	2.308	0.115	0.161
			50	9.8	33.96	26.19	1.876	0.144	0.178
29	July 24	36°46′ N. 121°58′ W.	0	12.4	33.80	25.60	0.770		0.133
			5	11.6					
			10	10.9					
			15	10.7					
			20	10.7					
			25	10.6	33.87	25.98	1.042		
			100	9.4	33.98	26.28	1.376		
			250	8.2	34.13	26.57	1.725		
			500	6.2	34.25	26.92	2.810		0.251

Table of Oxygen Determinations

I. *Serial Determinations*

Sta.	Depth	Oxygen (O_2) cc. per liter	Oxygen (O_2) % sat.
20	0	6.66	111.5
	25	2.99	46.9
	50	2.57	40.0
	75	2.38	36.8
29	0	5.20	85.7
	5	5.13	83.4
	10	4.26	68.3
	15	4.17	66.7
	20	4.17	66.7
	25	4.00	63.9
	100	2.46	38.3
	250	1.49	22.7
	500	0.63	9.2

II. *Additional Determinations at the Surface*

Date	Lat.	Long.	Temp.	O_2 cc. per liter	O_2 % sat.	Sal.
July 20	36°41.8′	121°57′		6.14		33.82
	36°44.5′	121°57.8′	12.4	5.65	92.9	
	36°47.5′	121°58.5′	12.5	6.10	100.1	
	36°50.5′	121°59′	13.2	6.66	111.5	33.86
	36°53.5′	122°00′	13.6	6.37	107.7	33.87
	36°55.2′	122° 0.5′	14.9	6.74	116.6	33.89
	36°37.6′	122°53.8′	14.9	6.80	117.8	33.91
July 24	36°43′	121°54′	13.9	7.33	124.5	

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