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ANALYSIS OF A HUGH M. SMITH OCEANOGRAPHIC SECTION FROM HONOLULU SOUTHWARD ACROSS THE EQUATOR

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ABSTRACT

Observations from a line of stations made in February–March 1950 extending from 5° S to 21° N along meridian 158° W are analyzed, and the results are presented as distributions of sigma-τ, salinity, oxygen, and phosphate in the vertical section. The method of analysis is partly new and is designed to achieve consistency among the several variables. This section is one of a number made in the central Pacific by the U. S. Fish and Wildlife Service.

Pacific Oceanic Fishery Investigations of the U. S. Fish and Wildlife Service executed during 1950–1952, from the research vessel HUGH M. SMITH, 365 serial oceanographic stations constituting 15 or more meridional sections across the equator in the central Pacific (Cromwell, 1953). The previous temperature-salinity sections crossing the equator in this region were obtained by the CHALLENGER (Wüst, 1929) and CARNEGIE (Sverdrup, et al., 1944), by Operation Crossroads (Barnes, et al., 1948) and by the ALBATROSS (Jerlov, 1953). It is noteworthy that more meridional sections have now been made in the central Pacific than in the equatorial Atlantic or Indian oceans. Cromwell (1953) has discussed the circulation in the central equatorial Pacific by using as examples two of the new sections (172° W January–February 1950, 158° W July–August 1950). The present paper depicts a third section (158° W February–March 1950).

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When all of the observations collected so far can be studied together, further important conclusions about the structure and circulation of the ocean can be expected, but such study will be possible only when all of the individual sections have been analyzed. The present paper has the limited objective of giving a reasonably thorough pictorial analysis of a single section.

METHOD

The data for this section consist of bathythermograms and 23 serial stations made during the interval 18 February to 2 March 1950. The stations lie within 28 miles of the meridian 158° W, the northernmost station being 25 miles from Honolulu. Bathythermograph lowerings to a nominal depth of 900 feet were made at the start and finish of each station and at 10-mile intervals between stations. The stations, spaced 60 or 120 miles apart, include serial measurements of temperature and depth by reversing thermometer; the corresponding water samples were chemically measured for salinity, oxygen, and phosphate phosphorus.

The guiding principles of the analysis are (1) to use all of the data and achieve consistency among the several variables and (2) to present the results in such a way that the relations among the several fields are readily visible. In other words, the procedure is to avoid an independent analysis of each variable (temperature, salinity, ...).

The vertical spacing of the serial observations is too coarse to reveal the structure of the thermocline, but the bathythermograms extend down past the maximum temperature gradient. A temperature-depth curve for each station has therefore been so drawn as not only to pass through the reversing-thermometer points but also to be similar in shape to the bathythermograms for the station, as illustrated in Fig. 1.

The following characteristic curves, also shown in Fig. 1, have been drawn for each station: temperature-salinity, temperature-oxygen, and temperature-phosphate. Each curve passes through the observed points for the station, but the interpolation between points is guided by consideration of observations from adjacent stations of the section and from other stations. (After preliminary drawing of all curves, the graph of each station was superposed on the graphs of the two adjacent stations, and its characteristic curves were adjusted to give as much continuity from station to station as was permitted by the observed points.)

Thus the common scale for the four station curves is temperature; these four curves were chosen because temperature is the only vari-
Figure 1. Depth, salinity, oxygen, and phosphate phosphorus against temperature at station 38, 3°02'N, 157°51'W, 23 February 1950. Observations by reversing thermometer and water bottle are represented by dots. One of the station's two bathythermograms is reproduced as the dashed line.

...able observed continuously with depth. The temperature-depth curve and the three characteristic curves determine the continuous vertical distributions of salinity, oxygen, phosphate, and sigma-t. The last is conveniently represented by sigma-t isopleths printed on the temperature-salinity diagram, as in Fig. 1.

It may be noted that only four such curves can be drawn independently. To draw in addition any of the other four vertical distributions or any of the other seven characteristic curves (temperature against sigma-t, oxygen against phosphate, etc.) is undesirable, because, to avoid inconsistency, each additional curve must laboriously be made to agree with those already drawn, and any subsequent adjustment of one curve involves the adjustment of one or more others.

Sigma-t (in common use but regrettably nameless) for a point in the ocean is the excess, above one gram per milliliter, of the density of water of the same temperature and salinity but at a pressure of one atmosphere.
With all variables continuously specified for each station vertical, the next question is how best to represent the variables in two-dimensional fields for the vertical section. As with station curves, superfluous fields offer difficulty. Temperature, salinity, and \( \sigma_t \) are interdependent, so representation of all three is undesirable because of the practical difficulty of drawing the three fields so that they agree everywhere. Two of the three and oxygen and phosphate remain to be depicted.

In order to make the relations among these four fields visible, they might all be superposed in one drawing if that were feasible, but experience indicates that no more than two fields can be adequately depicted in one drawing (except for the further addition of very simple fields). To depict all possible pairs combined from the four variables would require six drawings. It may suffice, however, if a particular variable can serve as an adequate reference, to present only the three drawings that depict the reference field in combination with each of the others.

As reference variable, temperature would have advantages, because it can be measured most easily and it can be measured continuously with depth. \( \sigma_t \), however, is chosen as reference variable in the present paper. An important consideration influencing this choice is that \( \sigma_t \) more than any other variable approaches a monotonic function of depth at any vertical and therefore has the simplest field.

With \( \sigma_t \) already chosen, salinity is preferable to temperature as the other of these three to be represented. The reason for this choice is that \( \sigma_t \) and temperature are so nearly parallel on a vertical section that the superposed fields are difficult to comprehend, while \( \sigma_t \) and salinity can be superposed and remain clear.

The vertical section of \( \sigma_t \) was constructed first. The serial observations of \( \sigma_t \) were plotted, and the depths of each \( \sigma_t \) isopleth at each station were plotted from the station curves. Instead of being drawn precisely through the points plotted from the station curves, the isopleths were smoothed somewhat but without violation of the observed points. The smoothing might have been achieved in an unobjectionable way by making reasonable adjustments in the station curves while keeping the vertical section consistent with the station curves.

To construct the salinity, oxygen, and phosphate fields, the serial observations and isopleth depths from station curves were plotted as for \( \sigma_t \). The isopleths were then drawn on a work sheet superposed on the \( \sigma_t \) section. Some liberty was permitted in drawing the isopleths, particularly in allowing them to run more
nearly parallel with the isopleths of sigma-t, but again the observed points were not violated.

The sigma-t section in Fig. 2 extends down to 1700 m so as to include all observed points, but the vertical scale is too small to show the thermocline to advantage. Figs. 3–6 show the upper 500 m of the four fields on larger vertical scale. The distributions of salinity, oxygen, and phosphate below 500 m are omitted.

The field of sigma-t alone (Fig. 3) is included in addition to the minimum three drawings (Figs. 4–6). One practical advantage of this repetition is that some of the details of the thermocline shown in Fig. 3 could be omitted from Figs. 4–6.

Although the temperature field is not shown, a rough indication of temperature is provided by marking the depth of each whole degree centigrade at both ends of the section.

The bathythermograms between stations provide valuable information that can be incorporated in sigma-t sections. All isothermal layers from all bathythermograms were drawn as vertical lines on the work sheet. These vertical lines served as barriers forbidden to be crossed by the sigma-t isopleths, which therefore either avoid vertically isothermal regions altogether or traverse them vertically.

The thermocline on bathythermograms between stations should have been utilized also, but actually it was not. A suitable procedure would be to use all bathythermograms in constructing a temperature section, which would then serve as a guide on which the sigma-t
Figure 3. Sigma-t in grams per liter. Temperature at ends of section is shown by a tooth for each degree centigrade. Vertical exaggeration 4633.

Figure 4. Salinity in per mille. Most of the sigma-t isopleths are repeated from Fig. 3 and are labeled at right in grams per liter.
Figure 5. Oxygen in milliliters (NTP) per liter.

Figure 6. Phosphate phosphorus in microgram-atoms per liter.
section could be superposed while constructing the isopleths. This procedure would place the latitudes of maxima and minima in depth of sigma-t isopleths more precisely than they are shown in the present drawings.

DISCUSSION

It is clear from Fig. 3 that bathythermograms in conjunction with rather coarse vertical spacing of serial observations reveal much sharper density gradients and more detail than would the serial observations alone. The horizontal detail also would have been increased if the close spacing of the bathythermograms had been fully utilized. Furthermore, it is clear that, if the salinity, oxygen, and phosphate fields were constructed quite independently of the density field, they would come out markedly different from those in Figs. 3–6, and the four fields would be inconsistent.

Some features of the section may be mentioned, although the primary purpose has been accomplished by presenting the method and pictorial results of the analysis.

Typical of equatorial waters, there is great contrast between the high degree of homogeneity of the surface layer and the large gradients of the thermocline. Bathythermograms are essential for revealing the full magnitude of this contrast.

The sloping thermocline from 5° N to 10° N marks the zone of the Equatorial Countercurrent. The greatest density gradients occur in the upper part of the thermocline near the northern edge of the Countercurrent.

A trough at 12½° N and a ridge at 14° N in the sigma-t isopleths of the lower part of the thermocline mark an unusually large disturbance within the North Equatorial Current. At 14° N the layer containing the salinity maximum appears to be absent, as though pinched off, although the water samples are too widely spaced to determine the salinity distribution with certainty.

The salinity maximum in the thermocline south of the equator seems to stop abruptly near the equator. The presence of the maximum proves that there is no transfer of water between the surface layer and the water beneath the maximum. Where the maximum is absent, as it appears to be from 1° N to 5° N, this proof is lacking.
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