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THE WATER MASSES OFF THE WEST COAST OF NORTH AMERICA*

BY

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In reporting the results of the 1937 cruises of the "Bluefin" off southern California, Sverdrup and Fleming (in press) found that within the limited area which they investigated, two primary water masses were present, mixtures of which made up the water at depths between 200 meters and 400 meters in this region, and they developed a convenient method of using temperature-salinity relationships to study the processes of mixing. The present paper is an extension of the same method to all the waters which border on the west coast of North America from Alaska to Mexico.

A series of temperature-salinity curves from stations located at various points from the Gulf of Alaska to Central America show a regular transition in the character of the water masses from north to south and clearly indicate that the water along the entire coast is a mixture of two extreme water masses. The regions in which these masses lie have been called by Sverdrup, Johnson and Fleming (MS) the Subarctic North Pacific and the Equatorial Pacific regions, respectively. The former extends over the entire North Pacific at latitudes higher than about 43° N. and the latter covers a triangular area over the equatorial region of the Pacific, whose base lies in the western Pacific between about latitudes 20° N. and 15° S. and whose apex lies on the Equator at about longitude 130° E. The region of transition between the Subarctic and Equatorial waters includes that adjacent to the west coast of the United States and Mexico and extends to a distance of 400 to 600 miles or more from the coast. It was within this region of mixing that, in 1939, the "E. W. Scripps" occupied eighty hydrographic stations the locations of which are shown in Figure 15. The area indicated by the dashed line is that covered by the "Bluefin" in 1937. In Figure 16 is presented a series of T-S curves from the outermost stations (VIII 34-VIII 79) of the six station lines. Curves from four stations further to the north are included, those from "Catalyst" station C4843-12819 ($48^{\circ} 43' N.$ $128^{\circ} 19' W.$), "Carnegie"

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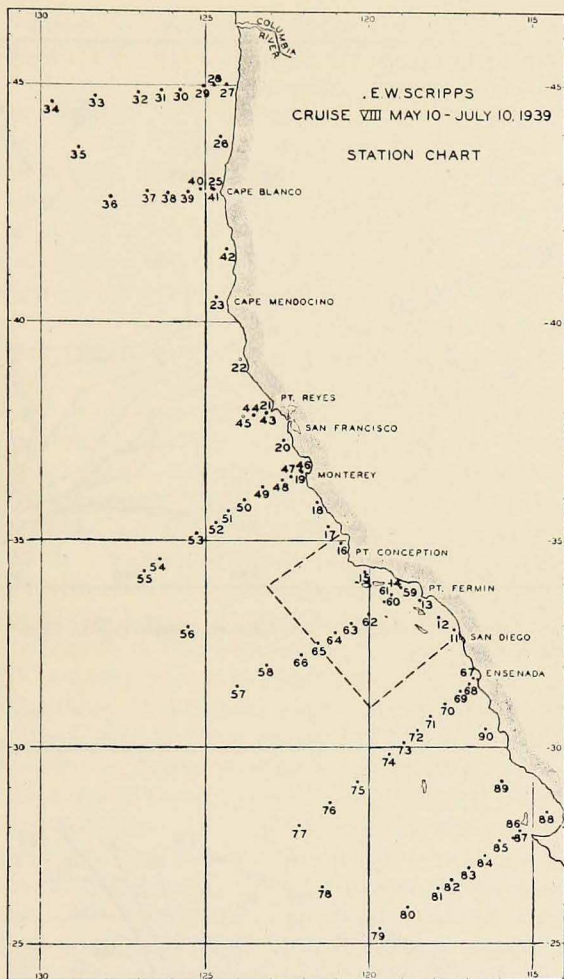


Figure 15. Station Chart, "E. W. Scripps" Cruise VIII.

stations 120 ($47^{\circ} 02' \text{ N. } 166^{\circ} 20' \text{ E.}$) and 124 ($52^{\circ} 19' \text{ N. } 162^{\circ} 02' \text{ W.}$) and "Bushnell" station *a*, 1934 ($50^{\circ} 30' \text{ N.}, 175^{\circ} 16.5' \text{ W.}$), and from two stations to the south, "Bushnell" stations 299 and 307, 1939 ($19^{\circ} 02' \text{ N.}, 86^{\circ} 50' \text{ W.}$, and $22^{\circ} 22.5' \text{ N.}, 111^{\circ} 25' \text{ W.}$).

The curve from "Carnegie" station 124 in the eastern part of the Subarctic North Pacific region is similar to those from "Carnegie" station 120 and "Bushnell" station *a* in the western and central parts,

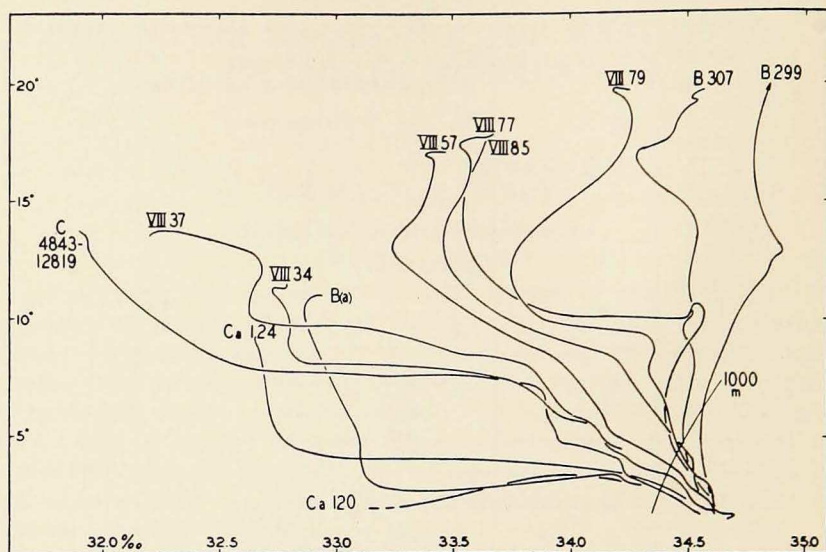


Figure 16. T-S Curves of Stations in the Eastern North Pacific from off the Aleutian Islands to Central America.

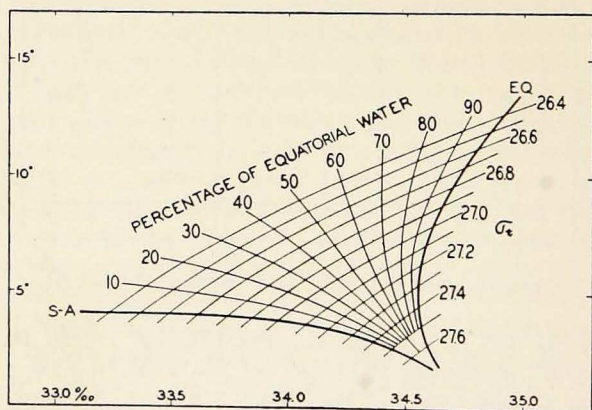


Figure 17. Graph showing T-S curves defining Subarctic North Pacific and Equatorial water, and curves for various percentages of Equatorial water assuming mixing along surfaces of equal σ_t .

and for our purpose is taken as defining the Subarctic water mass. The characteristic T-S curve defining the Equatorial water mass of the northeastern part of the Equatorial Pacific was obtained from "Bushnell" station 299. It is comparable to those from other "Bushnell," "Carnegie" and "Dana" stations in the region (Sverdrup, Johnson and Fleming, MS), and to the curve for Equatorial water derived by Fleming (1939). These characteristic T-S curves defining the Subarctic and Equatorial water masses are entered in Figure 17.

For further analysis it will be assumed that the observed distribution of temperature and salinity in the area of transition is maintained by horizontal flow and by lateral mixing of waters having the T-S relationships defined above, and that mixing takes place primarily along surfaces of equal σ_t . This latter assumption is equivalent to assuming nearly isentropic mixing. One cannot establish strictly isentropic surfaces in the ocean as Rossby (1939) has done for the atmosphere where, in dry air, they correspond to surfaces of equal potential temperature. Surfaces of equal density *in situ* do not fulfill the necessary conditions but those of equal σ_t closely approximate such isentropic surfaces. A body of water cannot be displaced even along a σ_t surface without somewhat altering the distribution of mass, nor will the mixing of two bodies of equal σ_t but of different temperatures and salinities result in a mass of the same σ_t . The departures are, however, small and may in a first approximation be disregarded.

On the assumption that water masses of intermediate character are formed by the mixing along σ_t surfaces of Subarctic and Equatorial waters, it is possible to prepare a diagram (Figure 17) from which the percentage of Equatorial water can be found for water of any observed temperature and salinity. In constructing this diagram, the σ_t lines were drawn between the two limiting T-S curves, SA and EQ, and were divided into the proportional parts from which smooth curves representing the several percentages of Equatorial water were drawn. It must be noted, however, that the determination of percentage composition by this means cannot be used for water above about 100 meters, since near the surface vertical mixing related to the effects of wind and local changes due to absorption of solar radiation, evaporation or precipitation are prominent and any mixing along σ_t surfaces will be more or less completely masked. This is especially true whenever the interval between stations in space or time is great. Below a depth of about 1000 meters the differences in the T-S relationships of the two extreme water masses are so small that application of the method is doubtful.

Figures 18 to 23 are vertical sections along the six station lines of Cruise VIII of the "E. W. Scripps" and were constructed from

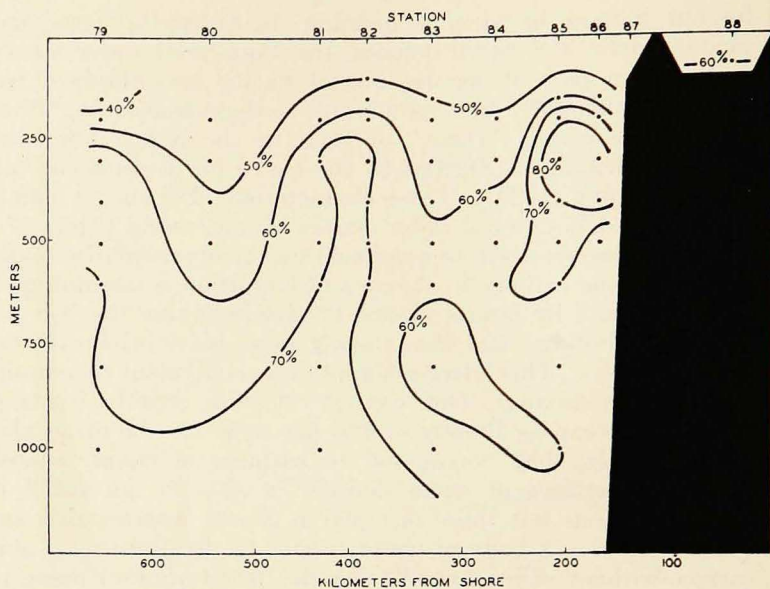


Figure 18. Section 6 off Cedros Island, Lower California, showing percentage of Equatorial water.

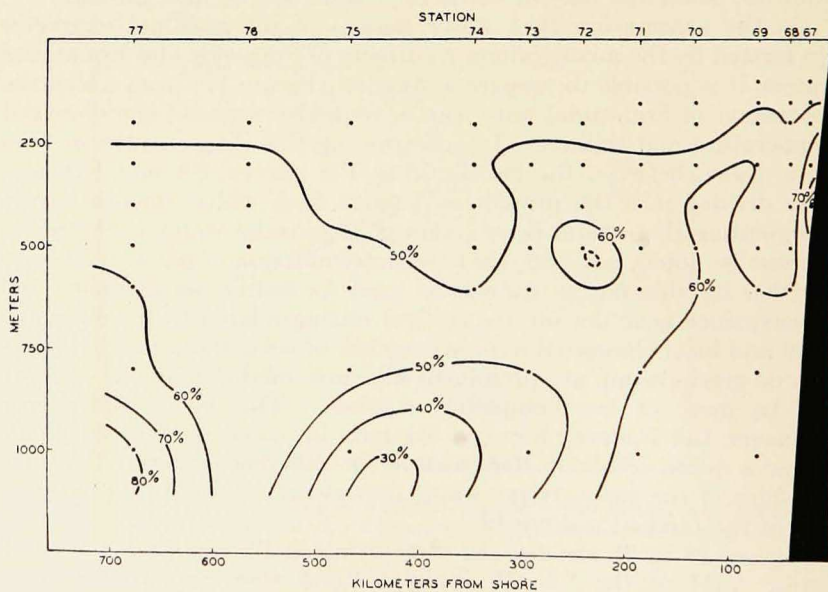


Figure 19. Section 5 off Ensenada, Lower California, showing percentage of Equatorial water.

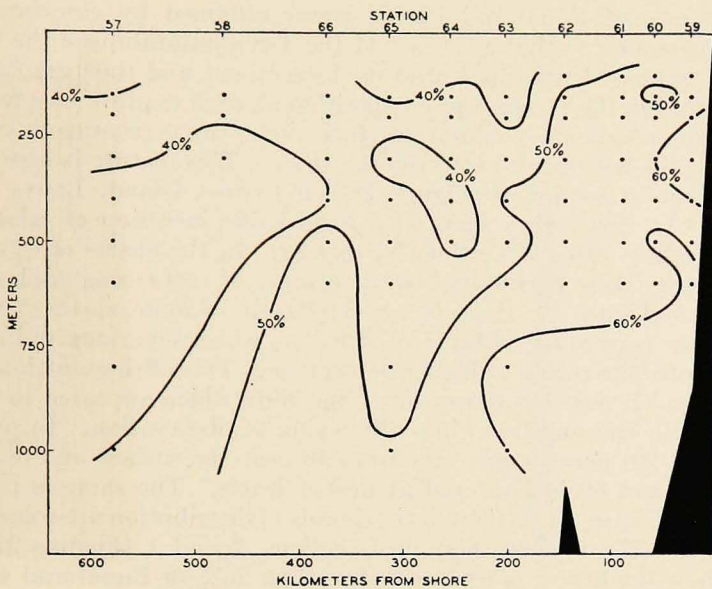


Figure 20. Section 4 off Point Dume, California, showing percentage of Equatorial water.

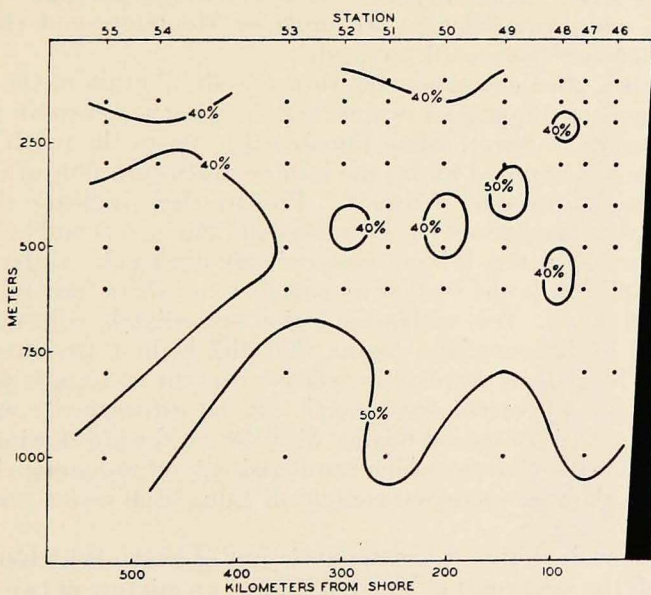


Figure 21. Section 3 off Monterey, California, showing percentage of Equatorial water.

percentages of Equatorial Pacific water obtained by entering in a diagram similar to that in Figure 17 the T-S relationships of the water at the various depths indicated in the sections, and then graphically interpolating the percentage composition at each depth. One feature of the distribution is common to all sections: the percentage is higher towards the bottom and towards the shore. This feature is especially prominent in section 6 (Figure 18) off Cedros Island, Lower California. In this region there is a remarkable intrusion of relatively warm, saline water at stations 81 and 82. In the charts of dynamic topography these correspond to the centers of two strong eddies. In section 5 (Figure 19) there is a central body of more northern water (e. g., low percentage of Equatorial water) which separates an inshore and an offshore region of higher percentage. This offshore region was, at station 77, near the center of a large eddy which appeared to bring water from the southwest into the region of observation. In section 4 (Figure 20) percentages vary from 40 near the surface and offshore to more than 60 inshore and at deeper levels. The same is true of section 3 (Figure 21) although the details of distribution are somewhat different. The two northernmost sections, 2 and 1 (Figures 22 and 23), show the lowest percentages, less than 25% of Equatorial water, but even these show some water of greater than 40%.

Figure 24 shows the percentages of Equatorial Pacific water at the 300 meter level. Again, in general, the percentages are higher inshore, the 50% curve extending as far north as Monterey, and there is a general decrease from south to north.

There is a good agreement between the distribution of the various percentages of Equatorial water and the known current pattern. The transport of warm, saline Equatorial water to the north appears to be largely accounted for by the inshore northward flow of the California Coastal Counter Current. Present data indicate that this current exists throughout the year at about 200 meters and below, and that above 200 meters it is encountered only during the winter months when it appears at the surface as a narrow, northerly coastal current (Tibby, in press). It is within the region immediately adjacent to the coast and at intermediate depths that the highest percentages are found. The general decrease in relative content of Equatorial water as the Counter Current flows north can be satisfactorily explained only on the basis of lateral mixing with the southward flowing waters of the California Current which were originally of Subarctic character and which show an increased content of Equatorial water toward the south.

It is shown here that the water at depths of from about 150 to 1000 meters off the west coast of North America is a mixture of two extreme

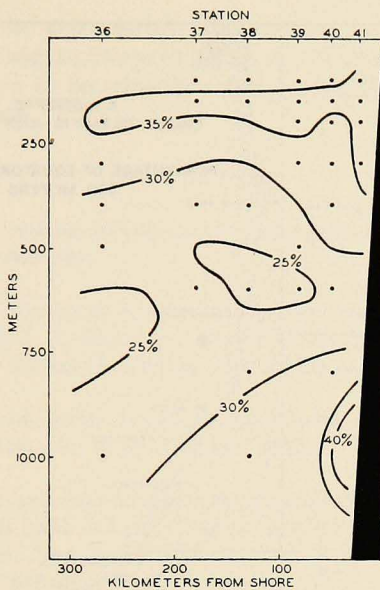


Figure 22. Section 2 off Cape Blanco, Oregon, showing percentage of Equatorial water.

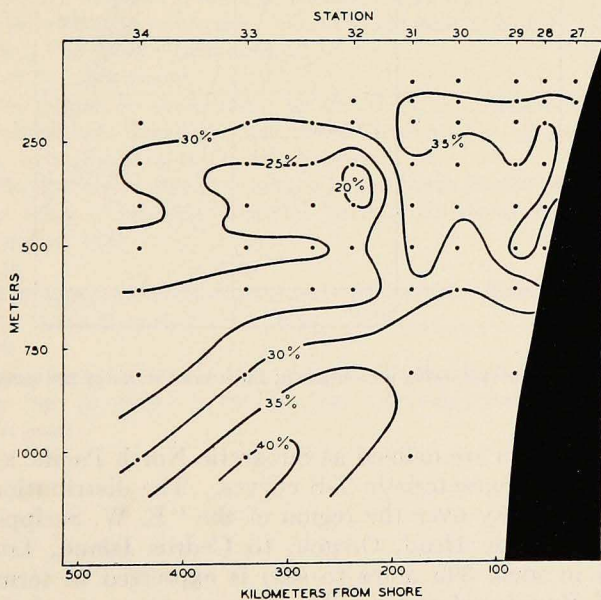


Figure 23. Section 1 off Cascade Head, Oregon, showing percentage of Equatorial water.

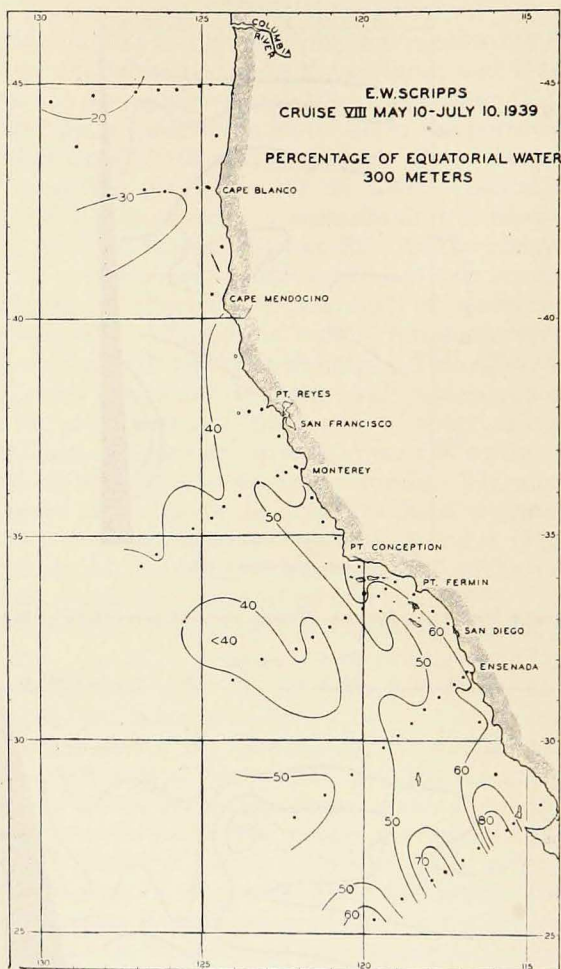


Figure 24. Chart showing percentage of Equatorial water at 300 meters.

water masses which are defined as Subarctic North Pacific and Equatorial Pacific by characteristic T-S curves. The distribution of temperature and salinity over the region of the "E. W. Scripps" Cruise VIII (from Cascade Head, Oregon, to Cedros Island, Lower California, and to some 300 miles to sea) is expressed in terms of percentages of Equatorial water. These percentages are derived by a

method based on the assumption that mixing between water masses takes place only along surfaces of equal σ_t . The distribution of these percentages is shown to be entirely consistent with the known pattern of flow in this region.

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