Deep Water Properties and Flow in the Central North Pacific[1]

R. K. Reed

Pacific Oceanographic Research Laboratory
Environmental Science Services Administration
Seattle, Washington 98102

ABSTRACT

Values of potential temperature, salinity, and dissolved oxygen at deep levels in the central North Pacific are presented and discussed, and the direction of flow is inferred. Deep water from the south appears to spread into the northern region by way of a western route rather than directly through the central region.

Introduction. The flow of Pacific deep water has been inferred by Knauss (1962) from the distribution of temperature, salinity, and radioactive carbon. He concluded that all water below 2500 m in the Pacific is from a single source to the south, that the flow is predominantly northward, and that the return flow occurs in the upper layers as a result of rising water in the North Pacific. At a given depth, the general trend is for temperature to increase and for salinity and dissolved oxygen to decrease toward the north, primarily because of mixing with overlying water that is warmer, less saline, and contains less oxygen than the source water. The effect of heat flow from the earth's interior was deemed by Knauss to be of less importance than a modification by upper water.

Recently, numerous deep measurements have been made in the central North Pacific. Many of the measurements were taken by the Coast and Geodetic Survey (C & GS) and by the Pacific Oceanographic Research Laboratory (PORL) as part of an ocean-survey program (SEAMAP). Although plans call for further work in this area and for an extension to the entire Pacific, it seems desirable at this time to present the results derived from existing data.

Methods. The C & GS-PORL cruises were designed so that certain sites were reoccupied during the 1961–1966 period. Table I is a summary of the

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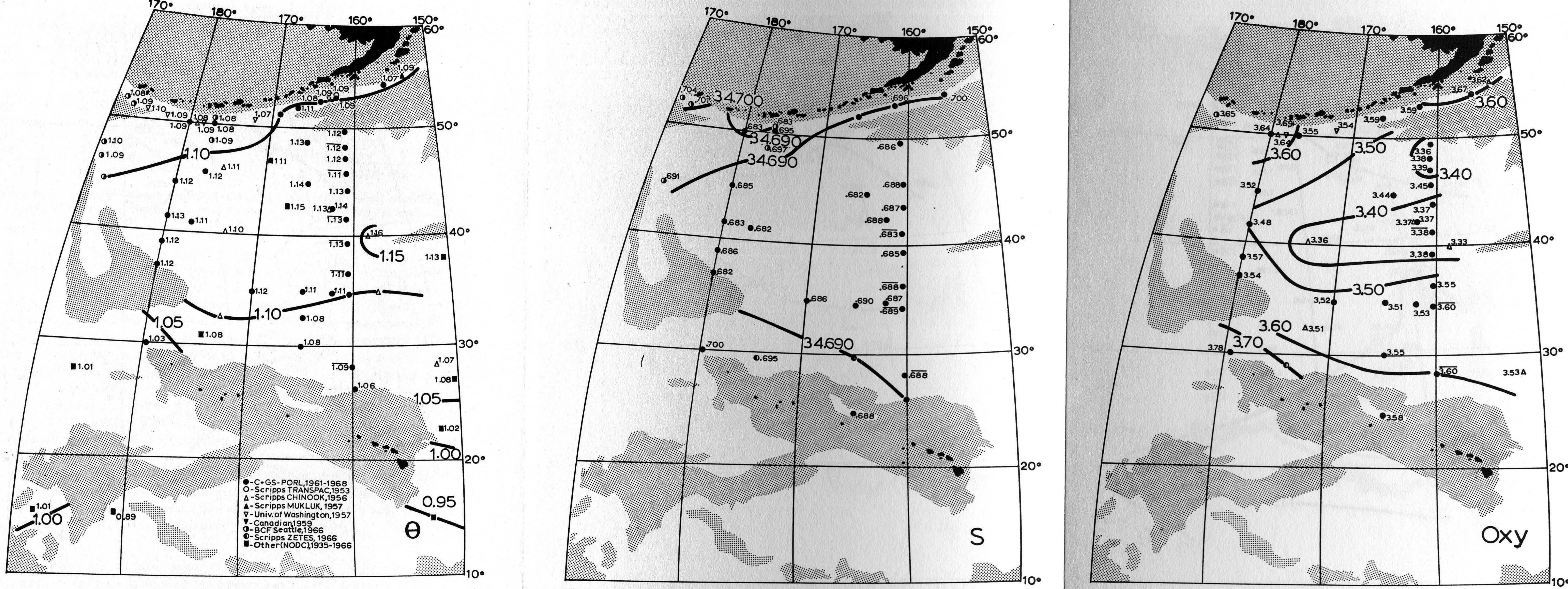

Figure 1. The distribution of potential temperature (θ), salinity (S), and dissolved oxygen (Oxy) at 5 km. Values on all charts representing the average from reoccupied sites are denoted by overbars.

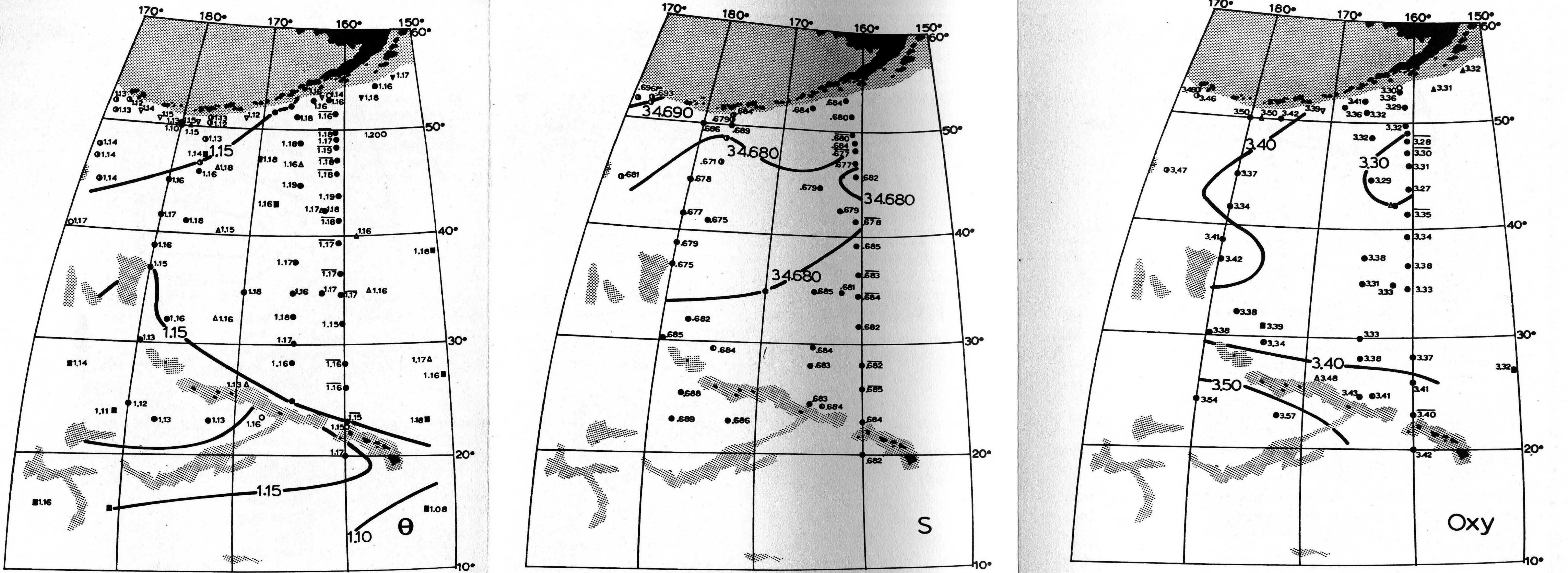

Figure 2. The distribution of potential temperature (θ), salinity (S), and dissolved oxygen (Oxy) at 4 km.

Table I. Deviations from the means of potential temperature, salinity, and dissolved oxygen at reoccupied sites (C&GS-PORL cruises, 1961–1966) at levels of 3, 4, and 5 km. The sites are indicated in Figs. 1 and 2 by bars over the plotted values.

Potential temperature (°C)		Salinity (‰)		Dissolved oxygen (ml/l)	
Deviation from mean	Number of values	Deviation from mean	Number of values	Deviation from mean	Number of values
0.00	33	0.000–0.004	52	0.00–0.04	36
0.01	38	0.005–0.008	29	0.05–0.08	33
0.02	16	0.009–0.012	4	0.09–0.12	12
0.03	4	total	85	0.13–0.16	3
0.04	2			0.17–0.18	2
total	93			total	86

Number of values exceeding 0.02°C = 6% of total. Number of values exceeding 0.008‰ = 5% of total. Number of values exceeding 0.12 ml/l = 6% of total.

deviations from the mean values found at these sites at depths of 3, 4, and 5 km. Approximately 95% of the temperatures do not vary from the means by more than 0.02° C; comparable values for salinity and dissolved oxygen are 0.008‰ and 0.12 ml/l. These values, except for dissolved oxygen, are close to most estimates of the random errors in these oceanographic measurements. Carritt and Carpenter (1966), however, showed that random and systematic errors in oxygen data may be as great as 1 ml/l; thus a value of 0.12 ml/l, coupled with the absence of trends, does not appear significant. Furthermore, temperature data taken over a span of more than a decade revealed no temporal changes of sufficient magnitude to influence the following analysis. Consequently, data from various periods and sources were used. Examination of all of the data allowed some random and systematic errors to be detected.

The data are identified in Table II and Fig. 1. Figs. 1 and 2 show the distribution of potential temperature (computed according to Fofonoff 1962), salinity (obtained with a salinometer), and dissolved oxygen at 5 and 4 km. The bathymetry shown is from Rechnitzer and Terry (1965).

Discussion. Fig. 1 shows that water colder than 1.05° C occurs in the southern sector of the area. Temperatures lower than 1.10° C appear in zones just north of the Hawaiian Rise and just south of the Aleutian Islands; between these areas the water is about 0.05° C warmer. As expected, the less-saline and less-oxygenated water generally coincides with the warmer water. Although dissolved oxygen is subject to change by biological processes, the fact that its distribution pattern is very similar to the distribution of temperature and salinity suggests that oxygen may be treated as a conservative property

Table II. Identification of data used.

Data	Year(s)	Source
C&GS-PORL	1961–1968	PORL files (unpublished; available at NODC)
Scripps TRANSPAC........	1953	**Oceanic Observations of the Pacific*
Scripps CHINOOK	1956	**Oceanic Observations of the Pacific*
Scripps MUKLUK.........	1957	**Oceanic Observations of the Pacific*
Univ. of Washington......	1957	**Oceanic Observations of the Pacific*
Canadian	1959	**Oceanic Observations of the Pacific*
BCF Seattle.............	1966	Bureau of Commercial Fisheries Report (unpublished)
Scripps ZETES	1966	Unpublished report, SIO Ref. 66–24
Other (NODC)	1935–1966	†National Oceanographic Data Center

* Scripps Instituion of Oceanography, Univ. of Calif. Press, Berkeley and Los Angeles.
† Various stations: Japanese, Swedish, Scripps, Russian, and U.S. Navy.

in the deep water in this region. Ranges of salinity and dissolved oxygen are about 0.02‰ and 0.4 ml/l, respectively, over the area north of the Hawaiian Islands.

The distribution at 4 km is shown in Fig. 2. A significant difference in the potential temperature patterns in Figs. 1 and 2 is the lack of a widespread cold zone south of 30°N at 4 km. Except for one value, the temperature increase from south to north at 4 km is only a few hundredths of a degree compared with a temperature range of at least 0.15°C at 5 km. Perhaps the water at 4 km is more uniform because of the lack of major bathymetric impediments to the flow. A 3-km chart was also prepared, but it is not shown because of its similarity to the distribution at 4 km.

Because all of the deep water is from a single source region, the differences in observed properties are usually considered to be a result of residence time in the Pacific, and the path of flow is assumed to be from areas of colder (newer) to areas of warmer (older) water. The temperature distribution at 5 km indicates that the warmer water in the central region cannot be the source of the colder water to the north, but this distribution does not preclude a northward flow below this level. The deepest water in the central region, however, is not as cold as water in the northern region at the bottom or at a depth of 5 km (see Figs. 3 and 1). Thus the deeper water in the northern region must arrive by way of a route other than one that would pass directly through the central region.

Figs. 1 and 2 reveal an increase in temperature from west to east between 45°N and 50°N. Salinity and oxygen exhibit comparable decreases toward the east. This fact, plus the marked similarity in properties on either side of the rise along 170°E (Bureau of Commercial Fisheries, unpublished data, 1966), suggests that the deeper water found near the Aleutians entered from the west, through a break in the rise between 46°N and 48°N. The inferred circulation is summarized in Fig. 4.

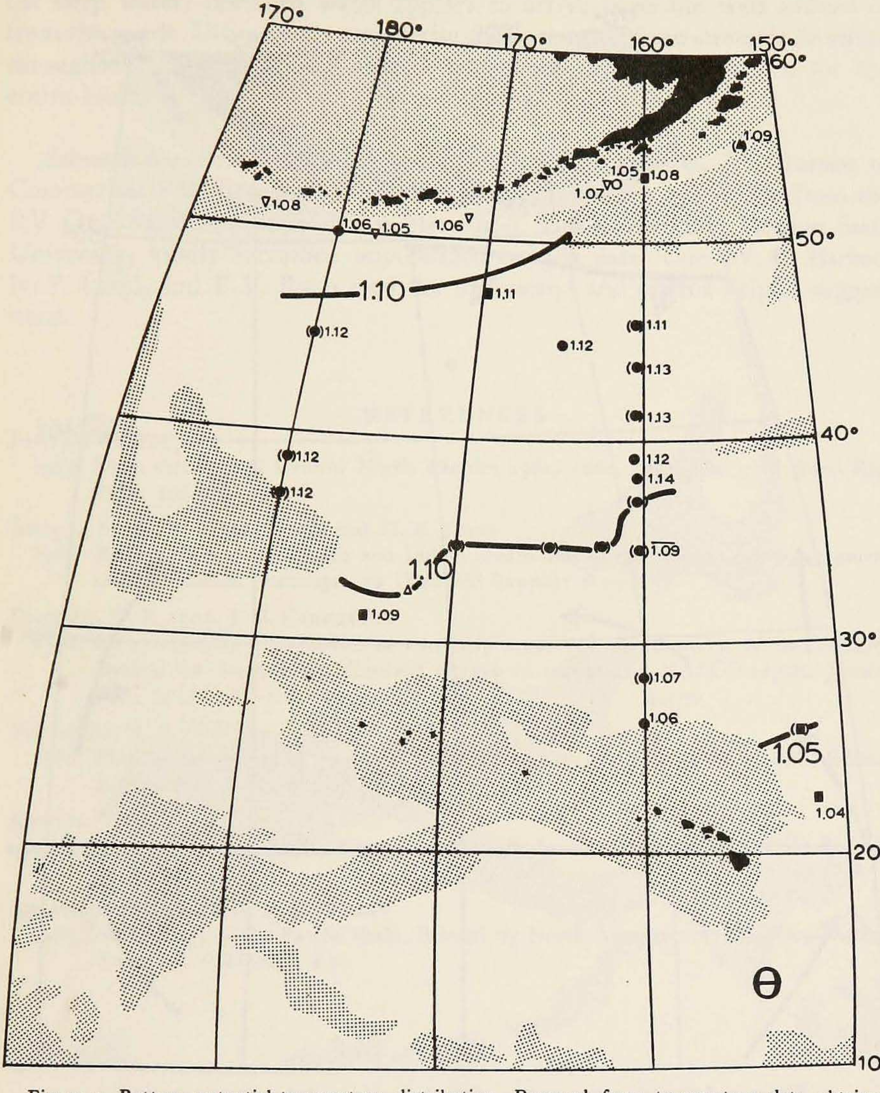

Figure 3. Bottom potential-temperature distribution. Prepared from temperature data obtained within 300 m of the bottom. Values for depths of less than 100 m from the bottom are denoted by the station symbol in parentheses. Water depths at these stations generally ranged from 5500 to 6000 m, except in the Aleutian Trench, where depths exceed 7000 m in the western part.

Considerations for the Future. Although direct current measurements have yielded interesting results, they have not given reliable values of the net transport of Pacific deep water. Because of fluctuating barotropic flows of 1 cm/sec

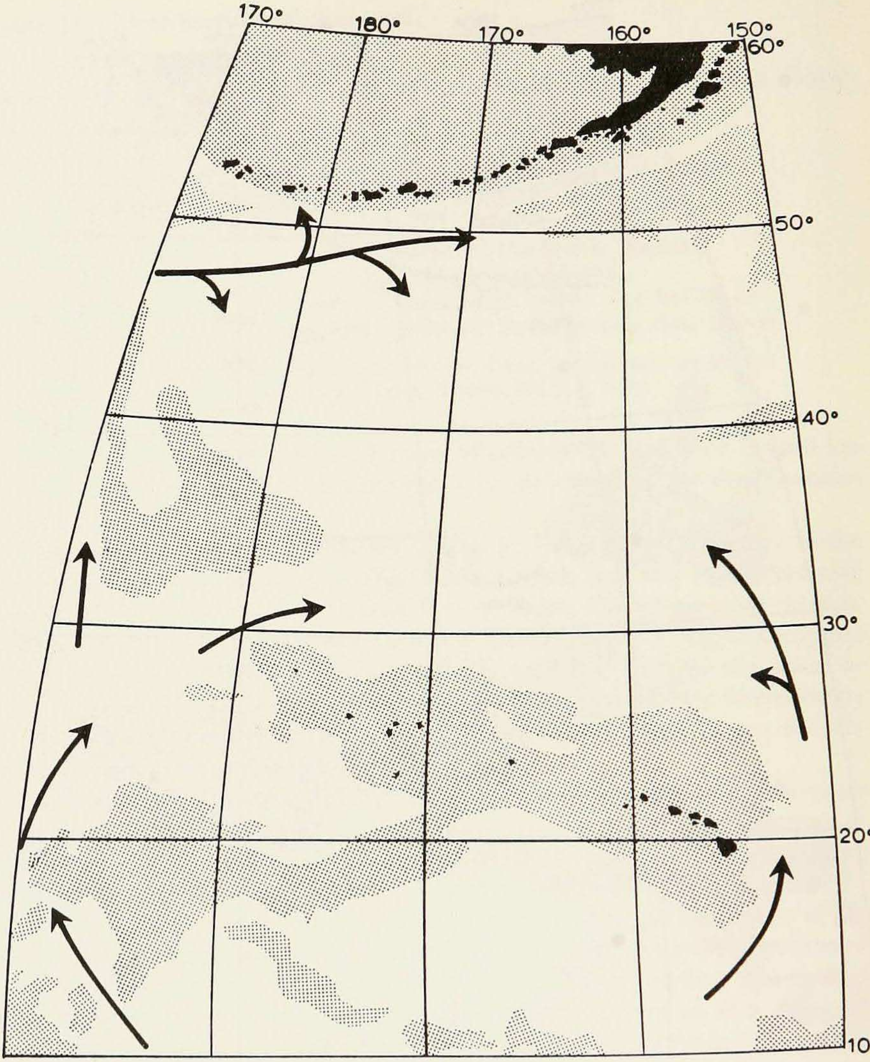

Figure 4. Schematic representation of the inferred circulation at 5 km and below.

or more (Barbee 1965) and deep tidal currents probably at least this great, it is very difficult to resolve net velocities on the order of 0.1 cm/sec (Knauss 1962, Bien et al. 1965). Thus the distributions of physical and chemical properties, plus results from isotope dating, are likely to remain for some time our main source of information on deep circulation in the Pacific.

The data presented here suggest an interesting and unanticipated path for the deep water; northern water appears to arrive from the west instead of from the south. Ultimately, very precise measurements from strategic locations throughout the Pacific may yield a convincing circulation pattern for the entire basin.

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