

AN ABSTRACT OF THE THESIS OF  
DAVID STEPHEN BALL for the Master of Science  
in Chemical Oceanography presented on March 16, 1970  
SEASONAL DISTRIBUTION OF NUTRIENTS OFF  
THE COAST OF OREGON, 1968

Abstract approved: Redacted for Privacy

Phosphate, silicate and nitrate concentrations in the sea off the coast of Oregon were determined to study their seasonal distribution patterns. The water samples were collected monthly along the east-west hydrographic line off Newport, Oregon, from the shore to 165 miles (310 km) offshore. The samples were analyzed by both a Technicon Autoanalyzer<sup>®</sup> and by manual methods.

Phosphate in January was greater than  $0.5\mu\text{M}$  at the surface, increasing to a  $3.3\mu\text{M}$  maximum at 1000m. A phosphate maximum occurred at 1000m throughout the year. With the onset of photosynthetic activity, there was a general decrease in surface concentrations. Concentrations decrease to less than  $0.1\mu\text{M}$  in October with surface concentrations increasing in November and December, reaching a maximum in January.

Silicate concentration was approximately  $170\mu\text{M}$  at 2600m during the entire year. In January, surface silicate increased from less than  $5\mu\text{M}$  offshore to  $13\mu\text{M}$  nearshore; a weak silicate minimum was

observed at a depth of 60m offshore and at 5m near the coast. In March nearshore surface concentrations were greater than  $15\mu\text{M}$  due to increased coastal river runoff; the silicate concentrations of Oregon coastal rivers were  $150\text{-}250\mu\text{M}$ . In July, a pronounced minimum occurred at 40-50m depth, where the concentration was less than  $2\mu\text{M}$ . Summer surface concentrations were less than  $2\mu\text{M}$  offshore, increasing to  $40\mu\text{M}$  nearshore as a result of coastal upwelling. Surface concentrations in October were generally less than  $5\mu\text{M}$  along the Newport hydrographic line with increased nearshore concentrations due to river runoff.

The nitrate maximum of  $40\text{-}45\mu\text{M}$  existed at 1000-1200m. In January surface concentrations ranged from  $3\mu\text{M}$  offshore to  $6\mu\text{M}$  nearshore. March values were lower, ranging from  $1\mu\text{M}$  offshore to  $5\mu\text{M}$  nearshore at NH-3 (6 km). In July patches of nitrate-free water were observed at 40-50m depth offshore, disappearing at 25 miles (46 km) off the coast, at station NH-25, as a result of the influence of upwelled and nitrate containing water. Late in October, nitrate concentrations were higher,  $5\text{-}6\mu\text{M}$ , near the coast, and dropping to less than  $0.1\mu\text{M}$  offshore. Patches of nitrate-free water were found from May to November.

The existence of nitrate-free water near the surface indicated that the feature was formed by the photosynthetic activities of phytoplankton. The formation of the silicate minimum and oxygen

maximum below or near the bottom of the Columbia River Plume during summer months indicated intense photosynthetic activity.

Neither preformed phosphate nor preformed nitrate changed with depth below the layers of active photosynthetic processes. Preformed phosphate was generally 1.0-1.2 $\mu$ M below 200m with variation occurring in surface waters. For surface values, 1.2 $\mu$ M, the highest of the year, was observed in July in upwelled water; 0.4 $\mu$ M, the lowest, also occurred in July within the influence of the Columbia River Plume.

The vertical distribution of preformed nitrate seemed to be random and may have reflected analytical techniques. The range was between 5 and 10 $\mu$ M with a maximum at 12 $\mu$ M. The 5 $\mu$ M values were found at approximately 200m with a maximum observed at 1000m deep. The highest surface values of preformed nitrate, 2.0-5.0 $\mu$ M, were observed in January and the lowest, 1.0-1.5 $\mu$ M, in July. March and October values were between the above extremes (1.1-2.0 $\mu$ M).

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Coast of Oregon, 1968

by

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## TABLE OF CONTENTS

INTRODUCTION	1
OBSERVATIONS	8
Manual Nutrient Analysis	9
Automated Nutrient Analysis	9
RESULTS	12
Temperature	12
Salinity	23
Sigma-t	24
Oxygen	25
Silicate	26
Phosphate	26
Nitrate	27
Preformed Phosphate and Nitrate	27
DISCUSSION	29
Temperature and Salinity	29
Sigma-t	36
Oxygen	37
Nutrients	39
Gas-Nutrient Relationships	49
Preformed Nutrients	54
BIBLIOGRAPHY	59
APPENDIX	64



## LIST OF FIGURES AND TABLES

Figure		Page
1	Diagrammatic representation of the seasonal cycles in light, nitrate or phosphate and phytoplankton in a typical northern temperate sea with non-upwelling conditions. Adapted from Raymont (1963, p. 194).	2
2	Vertical distributions of temperature, salinity, sigma-t, oxygen, silicate, phosphate, nitrate, preformed phosphate, and preformed nitrate to a depth of 2600m along the Newport hydrographic line for January, 1968.	13
3	Vertical distributions of temperature to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	14
4	Vertical distributions of salinity to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	15
5	Vertical distributions of sigma-t to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	16
6	Vertical distributions of oxygen to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	17
7	Vertical distributions of silicate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	18
8	Vertical distributions of phosphate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	19

LIST OF FIGURES AND TABLES (CONTINUED)

Figure		Page
9	Vertical distributions of nitrate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	20
10	Vertical distributions of preformed phosphate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	21
11	Vertical distributions of preformed nitrate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.	22
12	Vertical distributions of salinities along the Newport hydrographic line at selected stations for 1968. Notice the influence of the Columbia River Plume (NH-65, -85 and -165) and upwelling (NH-3) in July as compared to similar stations in January.	32
13	Bivariant plots of salinity and temperature along the Newport hydrographic line to a depth of 50m for quarters of 1968. Process vectors (solid lines) and process sectors (dashed lines and labeled areas) are also presented.	33
14	Percent oxygen saturation at NH-85 for 1968 to a depth of 175m.	40
15	Apparent oxygen utilization (AOU) at NH-85 for 1968 to a depth of 175m. Apparent oxygen production (AOP) is equal to negative AOU.	41
16	Three-point mixing of Columbia River Plume water, upwelled water and open ocean water with surface values for the Newport hydrographic line in July, 1968 are plotted. January values are plotted for comparison.	44

LIST OF FIGURES AND TABLES (CONTINUED)

Figure		Page
17	Salinity-nutrient and salinity-AOU relationships for stations NH-45, -65, -85, -105 and -125 to a depth of 150m for January-February and July-August, 1968.	47
18	Bivariant plots of salinity and silicate along the Newport hydrographic line to a depth of 50m for quarters of 1968. Process vectors (solid lines) and process sectors (labeled areas) are also presented.	48
19	AOU-nutrient relationships for selected stations along the Newport hydrographic line for January and July, 1968. The straight lines are from the biochemical oxidation model of Richards (1965) and from Park (1967). Numerical values are depths in meters.	51
20	AOP-nutrient relationships along the Newport hydrographic line during January-February and July-August, 1968. Note scale changes for silicate and nitrate between January-February and July-August.	53
21	AOU-preformed phosphate relationships for January and July, 1968 to a depth of 600m.	56
 Table		
1	Summary of cruises.	9
2	Comparison of selected values for January and July, 1968 for the Columbia River, NH-3 and NH-165.	45

## Seasonal Distribution of Nutrients off the Coast of Oregon, 1968

### INTRODUCTION

Nutrients are those elements and inorganic compounds which are essential for phytoplankton production and growth. They may represent the limiting factor, in accordance with the Liebig's law of the minimum (Sverdrup, Johnson, and Fleming, 1942, p. 768) which states that growth is limited by the factor that is present in the minimal quantity. Nitrogen and phosphorous nutrients are present in minute amounts in seawater. Silica, although relatively abundant, could become the limiting nutrient when the bacillariophytes, such as diatoms, requiring siliceous material for tests grow intensely.

When a nutrient becomes limiting, phytoplankton production can be correlated, to some extent, with the abundance of the limiting nutrient. In temperate latitudes the "typical" seasonal cycle of phytoplankton production in an area of nutrient limitation shows a decrease in the nutrient concentration with increased phytoplankton production (Figure 1). The spring bloom results in high production that drops to lower levels in late spring and summer. The seasonal cycle is not observed in areas of strong upwelling, such as off the Oregon coast, where a lack of water-column stability during the summer insures resupply of nutrients from the deep. This "pipeline"

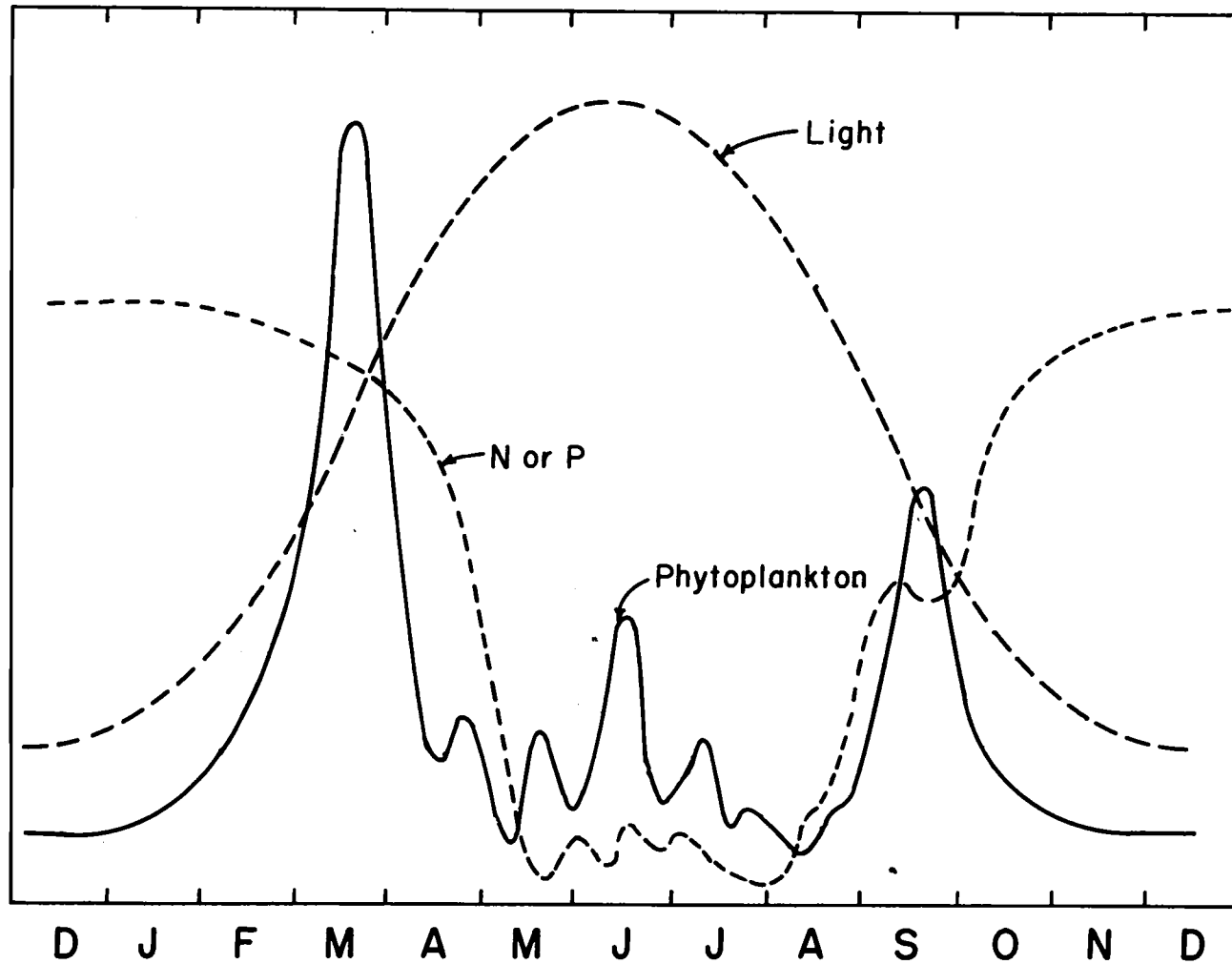


Figure 1. Diagrammatic representation of the seasonal cycles in light, nitrate or phosphate and phytoplankton in a typical northern temperate sea with non-upwelling conditions. Adapted from Raymont (1963, p. 194).

from deep water to the surface results in sustained higher phytoplankton production.

Studies on oceanic nutrients were reviewed by Redfield, Ketchum and Richards (1963). Recent reviews include the discussion of silicon and phosphorous by Armstrong (1965a, 1965b) and inorganic nitrogen by Vaccaro (1965).

Off the Oregon coast, Stefánsson and Richards (1963, 1964) discussed the basic nutrient distribution. Park (1967) discussed the relationships between nutrients and preformed nutrients for the Oregon waters. Park, Osterberg and Forster (1970) and Park et al. (1970) considered nutrients added by the Columbia River to oceanic waters. Silicate concentrations, including biological uptake and the three point mixing of river water, surface and upwelled waters for determining silicate distribution have been described by Hager (1969).

While phytoplankton activities alter the nutrient distribution, physical factors also affect the distribution patterns. The main physical factors are the current regime, continental runoff and upwelling.

Off Oregon the current system consists primarily of the California Current, fed by the divergence of the West-Wind Drift as it approaches near the North American continent (Dodimead, Favorite and Hirano, 1963). Therefore, a southward moving current results. The Davidson Current, a secondary nearshore current, flows

northward near the coast during the months October through February. It is observed when upwelling ceases and the normal subsurface countercurrent is re-established (Sverdrup et al. 1942, p. 727).

Tibby (1941) and Rosenberg (1962) analyzed the region off the Oregon and Washington coasts for water-mass characteristics. Rosenberg (1962) noted the presence of four water masses, Subarctic, Equatorial and two other unidentified, which contribute to the overall water masses.

The Columbia River is the greatest single source of fresh water for the coastal environment between southeastern Alaska and southern California. Its fresh water discharge markedly affects the oceanic condition off Oregon. Of the total fresh water added to the northeastern Pacific Ocean, the Columbia River may contribute 95 percent during the late spring and early summer when the river discharge is the highest and coastal runoff is the lowest. The total percent contribution decreases during the winter when the river runoff is not maximum and the coastal runoff is high. In this case, the Columbia River contributes about 65 percent of the total fresh water input (Budinger, Coachman and Barnes, 1964). An average annual input of  $2.1 \times 10^{14}$  liters of water was noted by Park, Osterberg and Forster (1970). Discharge in the lower Columbia River Basin for 1928-1965 was presented by Orem (1968).

Anderson et al. (1961) reviewed the chemical literature and cruise data available prior to 1961 for the plume. The chemical features of the summer Columbia River plume off Oregon in 1967 were studied by Cissell (1969).

Behavior of the Columbia River Plume in winter is different from that of in summer. The summer plume extends to the south and southwest of the river mouth due to prevailing southerly summer winds. The winter plume extends northward remaining close to the Washington coast as a result of prevailing northerly winter winds.

The influence of the plume with respect to area and depth differs with the seasons and years. This is a function of the seasonal and yearly river flows and meteorological conditions. Thus, the plume has little effect on the Oregon coastal water in the winter. Calm summer weather produces little vertical mixing, confining the plume influence to shallow depth.

Upwelling is the process by which surface water is moved offshore under the influence of southerly (from the north) winds blowing parallel to the coast in the Northern Hemisphere. As the lighter surface water is transported away from the coast, there is a replacement near the coast by heavier subsurface water. Upwelled water is characterized by increased salinity and nutrients and decreased temperature and oxygen. Park, Pattullo and Wyatt (1962) presented hydrogen ion concentration and salinity diagrams; these properties



were representatives of chemical property distributions during upwelling and non-upwelling periods.

The summer plume and nearshore provinces defined by Owen (1967, 1968) lie within the area investigated in this study. The nearshore province lies along the coast in summer as a band of cold saline water about 50 miles wide, interrupted by fresh water from the coastal streams. This region is dominated by the effects of coastal upwelling. Intense horizontal gradients are encountered from the surface to depths exceeding 250m. The plume province is characterized by the low salinity of the near-surface water from the Columbia River input. This water enters the ocean at approximately ambient shore temperatures. Temperature data are presented by Park, Osterberg and Forster (1970) and Moore (1968) for the lower Columbia River which has an average temperature of 13° C.

The offshore province of the summer regime is similar in character with the eastern extreme of the subarctic region "Transition Domain" described by Dodimead et al. (1963) and Dodimead (1968). It is subarctic water with temperatures in excess of 7° C at the top of the ~~isohaline~~ <sup>pycnocline?</sup> ~~isohaline~~ <sup>halocline?</sup>. This region exhibits the vertical salinity and temperature structure characteristic of the eastern subarctic area. During the winter, this region should move shoreward in the absence of the plume province when the Columbia River Plume is shifted northward.

For a discussion of the differences between river water, open ocean water and upwelled water, it is necessary to determine the plume boundary conditions. Budinger et al. (1964) use a 32.5‰ salinity as an approximation of the plume boundary. Park (1966) showed that the plume boundary sometimes possesses a salinity less than 32.5‰. Owen (1968), using the 32.0‰ isohaline as the criterion of the plume limit, notes that the plume in summer is detectable as far as 300 miles offshore, although the plume province itself does not extend that far.

The purpose of this thesis is to investigate the basic seasonal nutrient distribution of nutrients off the coast of Oregon for 1968 with respect to the influence of biological uptake of nutrients, nutrient input by the Columbia River, and the influence of upwelling.

## OBSERVATIONS

Physical and chemical data from the Newport hydrographic line during 1968 have been used for this study (Barstow, Gilbert and Wyatt, 1969b). Derived chemical parameters, such as AOU, oxygen saturation and preformed nutrient concentrations, were calculated using a Control Data Corporation 3300 computer (see Appendix).

Hydrographic stations are numbered by miles offshore along an east-west line off Newport, Oregon,  $44^{\circ}39'N$ . NH is the abbreviation for the Newport line. Hydrographic casts are normally to near-bottom at NH-3, -5, -15, -25, -35 and -45 (6, 9, 28, 45, 65 and 83 km offshore respectively). At NH-85, -125 and -145 (158, 232 and 269 km offshore), hydrographic casts are to 1200m while water samples extend to 2600m at NH-65, -105 and -165 (121, 195 and 306 km offshore). Stations and depths, as well as nutrient analytical methods, are summarized in Table 1.

Temperature and oxygen were determined at sea while salinity, phosphate, nitrate and silicate were analyzed ashore. Salinities were determined using an inductive salinometer manufactured by Industria Manufacturing Engineers Pty. Ltd., Sydney, Australia (Brown and Hamon, 1961). The method of Strickland and Parsons (1968) was used for oxygen. Nutrient samples were frozen untreated in 250-ml polyethylene bottles except samples from cruise C6809-D were

Table 1. Summary of cruises.

Cruise No.	Date 1968	Number of Stations		Methods of Analysis		
		Total	No. deeper than 1200m	PO <sub>4</sub>	NO <sub>3</sub> <sup>1</sup>	SiO <sub>4</sub> <sup>1</sup>
Y6801-A	2- 4 January	12	3	man <sup>2</sup>	man	man
Y6802-A	20-22 February	12	3	SnCl <sub>2</sub>	A. A.	A. A.
Y6803-B	9-11 March	11	0	SnCl <sub>2</sub>	A. A.	A. A.
Y6804-C	8- 9 April	12	3	SnCl <sub>2</sub>	A. A.	A. A.
Y6805-A	6- 8 May	12	3	SnCl <sub>2</sub>	A. A.	A. A.
		(NH-3 to -25)		man	A. A.	A. A.
		(NH-35 to -165)				
Y6807-A	8-11 July	12	3	man	A. A.	A. A.
Y6808-A	4- 6 August	16	0	man	A. A.	A. A.
C6809-D	24-26 September	11	0	Grasshoff	A. A.	A. A.
Y6810-E	17-19 October	12	3	SnCl <sub>2</sub>	A. A.	A. A.
Y6811-D	17-19 November	10	2	man	A. A.	A. A.
Y6812-B	16-18 December	7	1	man	A. A.	A. A.

man = manual methods using Beckman DU Spectrophotometer

A. A. = Technicon Autoanalyzer<sup>R</sup>

SnCl<sub>2</sub> = Stannous chloride method of Wooster and Rakestraw (1951) modified by Hager et al. (1968)

Grasshoff = Ascorbic acid method of Armstrong et al. (1967) modified by Grasshoff (personal communication) (Barstow et al. 1969b)

<sup>1</sup>Armstrong, Stearns and Strickland (1967) as modified by Hager et al. (1968) for automated analysis

<sup>2</sup>Methods described by Barstow et al. (1969b)

frozen with added chloroform (Gilmartin, 1967) in 50-ml polyethylene bottles.

#### Manual Nutrient Analysis

Silicate, phosphate and nitrate-nitrite were determined on a Beckman DU Spectrophotometer by the methods described in the data report of Barstow et al. (1969b) (Table 1).

#### Automated Nutrient Analysis

A Technicon Autoanalyzer<sup>®</sup> was used for the automated analyses. Silicate was determined according to Armstrong, Stearns and Strickland (1967), as modified by Hager, Gordon and Park (1968) with the addition of a 0.1 ml/min tube for the measurement of silicate values up to 250 $\mu$ M.

For nitrate-nitrite analysis the Autoanalyzer<sup>®</sup> method of Armstrong et al. (1967) was used with two sample tubes (3.4 ml/min and 0.42 ml/min) for improved precision and ease of analysis (Hager et al. 1968).

The phosphate analyses and problems encountered have been described by Barstow et al. (1969b). The stannous chloride method of Wooster and Rakestraw (1951) was modified by Hager et al. (1968). The Grasshoff modification (personal communication) we employed was a modification of the method of Armstrong et al. (1967). Reagent

concentrations have been increased, pump tubing diameters reduced, and omitting the potassium antimony tartrate catalyst in favor of heating.

Strickland and Parsons (1968) present a section concerning the use of the Autoanalyzer<sup>®</sup> with a description of procedures, calculations and apparatus layout.

Comparisons of the nutrient data from this study (Barstow et al. 1969b) with previous data (Wyatt and Kujala, 1963, Wyatt and Gilbert, 1967, Wyatt et al. 1967, Barstow et al. 1968, Barstow et al. 1969a) are difficult due to lack of data. However, Bruyevich (1966) reports a maximum of 3.5 $\mu$ M phosphate, 45 $\mu$ M nitrate and 160 $\mu$ M silicate for the northeastern Pacific Ocean; similar values have been noted by Park (1967) and Stefansson and Richards (1963).

## RESULTS

Oceanic temperature stratification shows three features. The mixed surface layer reflects the average temperature of the latitude. A deep layer reflects the origin of the water in the high latitudes. In the thermocline layer between about 200m and 1000m, the temperature decreases rapidly from the higher surface values to the lower deep values. The thermocline zone is of high stability and for this reason the water of the surface zone is separated from the water of the deep zone (Pickard, 1963, p. 33). Chemical parameters in Oregon waters should show similar effects so that water shallower than 200m will show variations with time while water at depths greater than 200m would be relatively constant. Representative profiles of the deep water to 2600m for January, 1968 are shown in Figure 2 while the profiles for 1968 to 600m depth are presented in Figures 3-11.

### Temperature

Temperature patterns (Figure 3) show the effects of river runoff and upwelling. The Columbia River Plume and the associated warm water has its greatest effect from May to October with surface temperatures greater than 16.0° C. Upwelling during this same period is shown by surface temperatures less than 12.0° C as indicated by the upward diverging isotherms as the coast is approached.

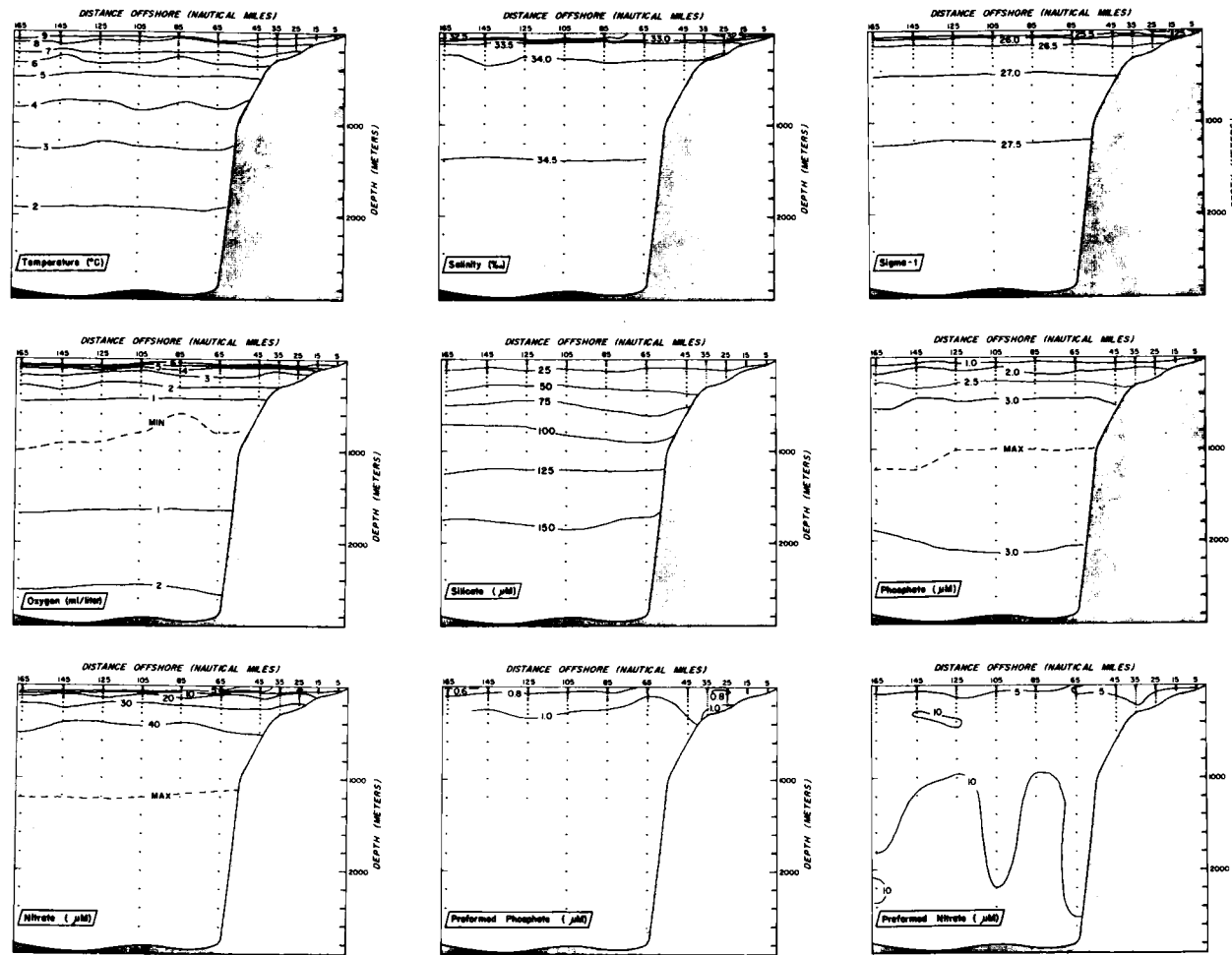


Figure 2. Vertical distributions of temperature, salinity, sigma-t, oxygen, silicate, phosphate, nitrate, preformed phosphate, and preformed nitrate to a depth of 2600m along the Newport hydrographic line for January, 1968.



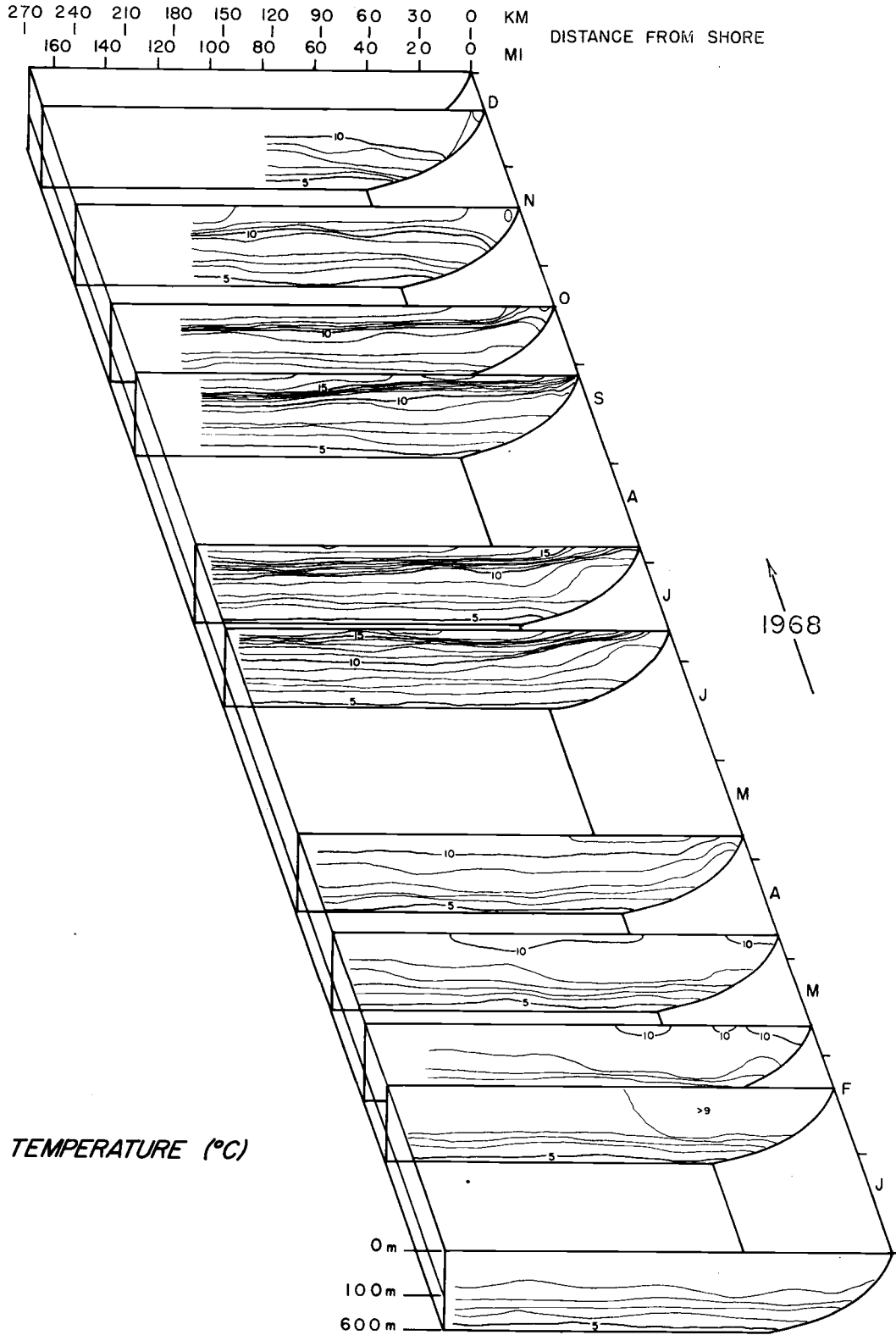


Figure 3. Vertical distributions of temperature to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

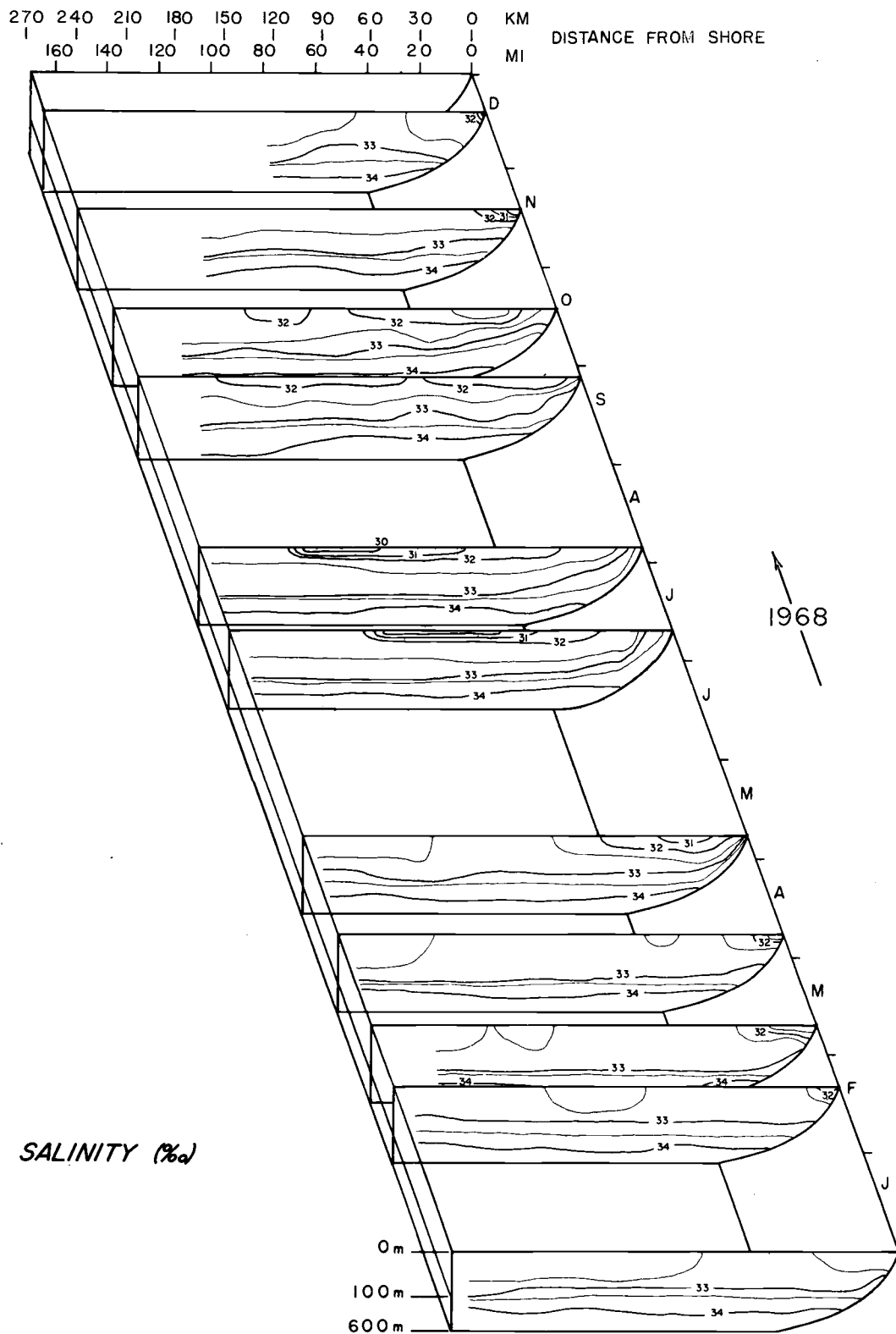


Figure 4. Vertical distributions of salinity to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

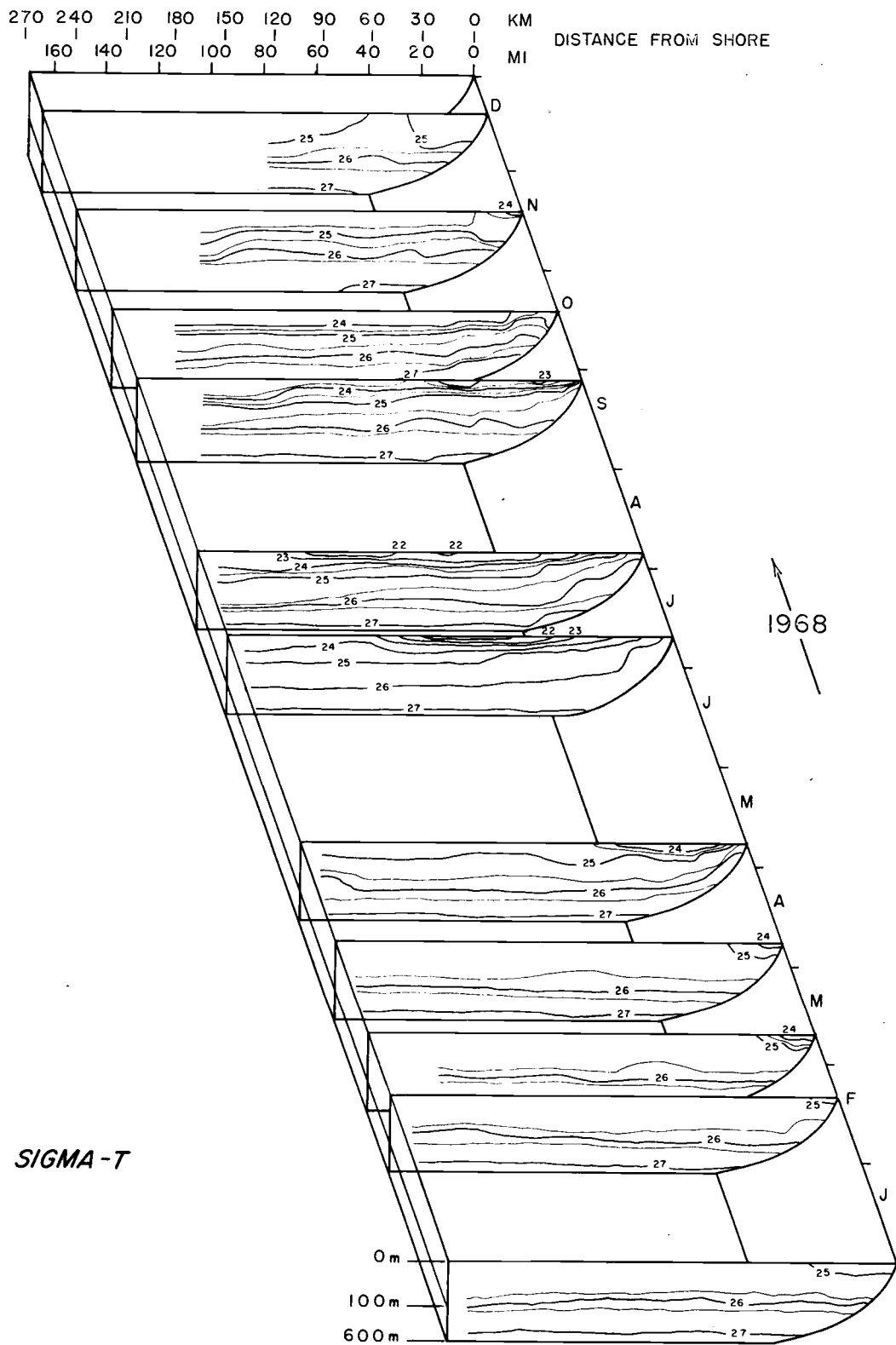


Figure 5. Vertical distributions of sigma-t to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

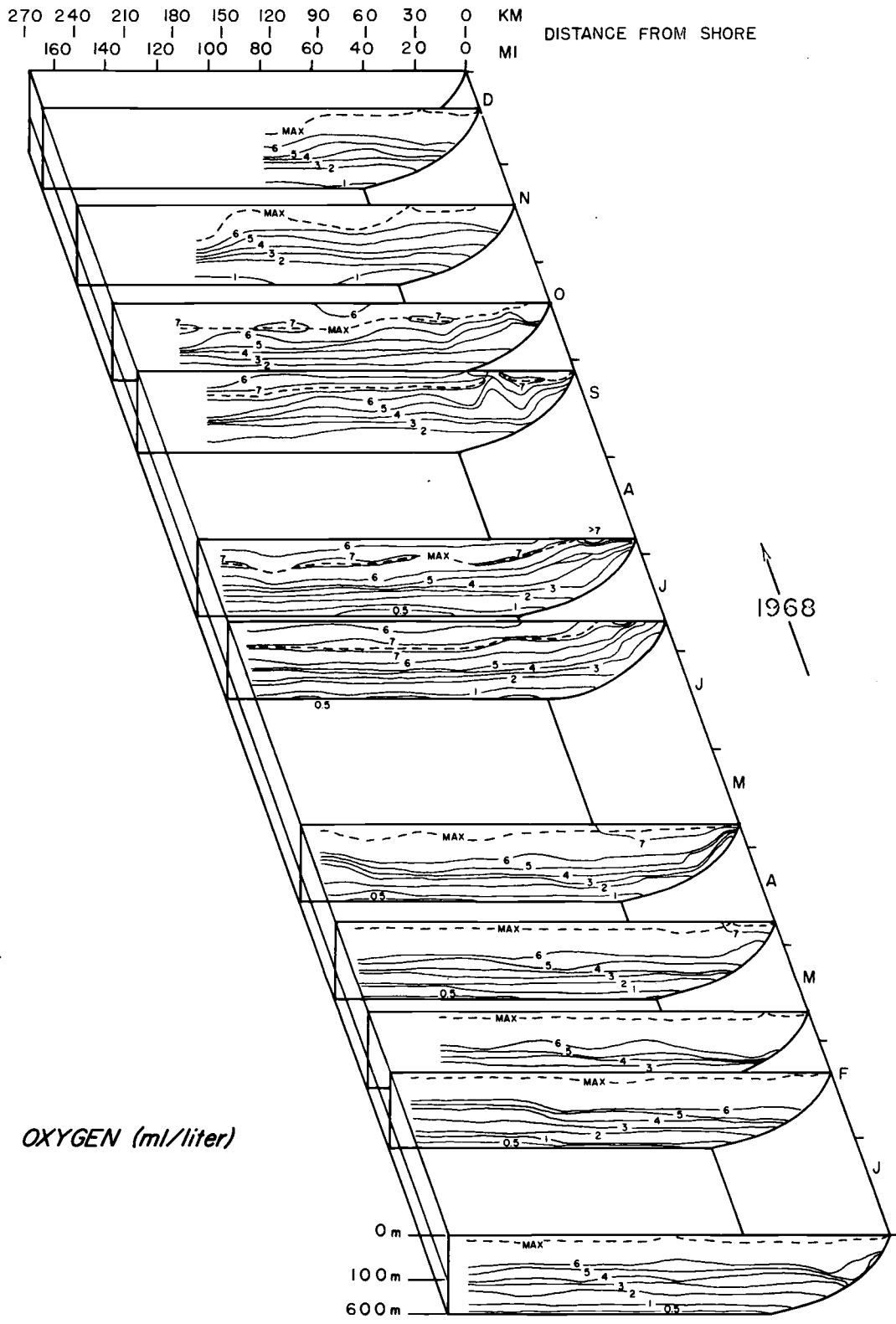


Figure 6. Vertical distributions of oxygen to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

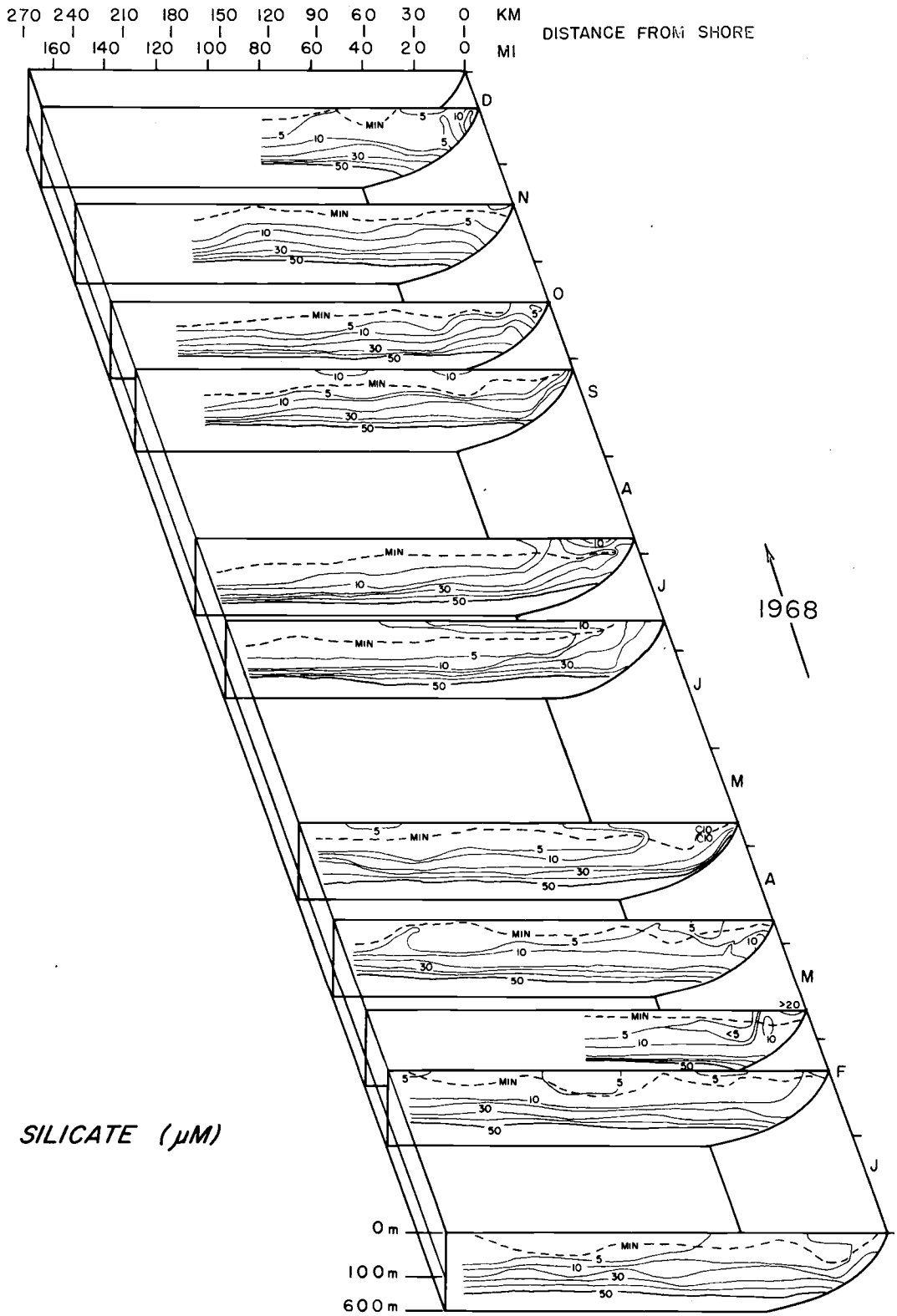


Figure 7. Vertical distributions of silicate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

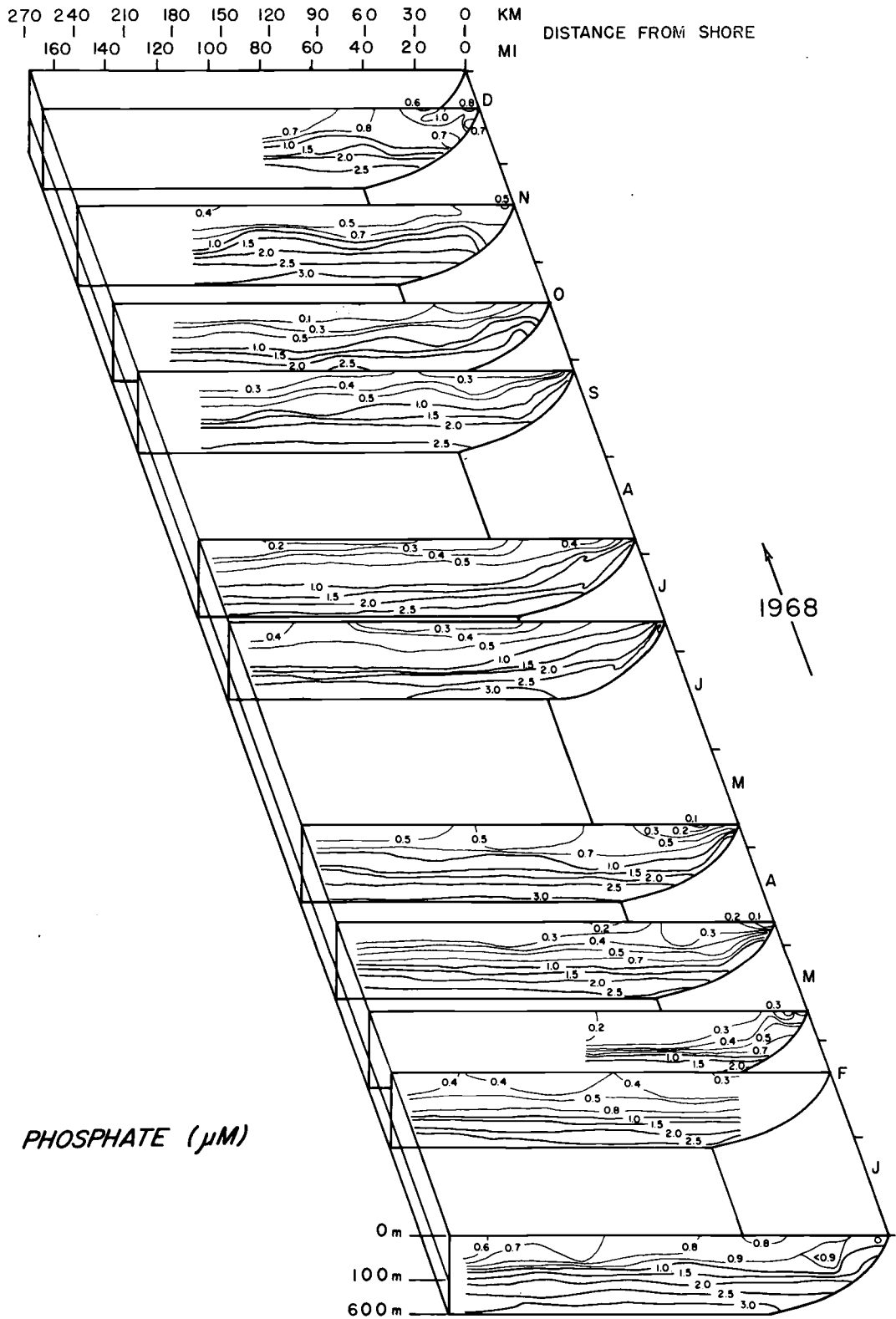


Figure 8. Vertical distributions of phosphate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

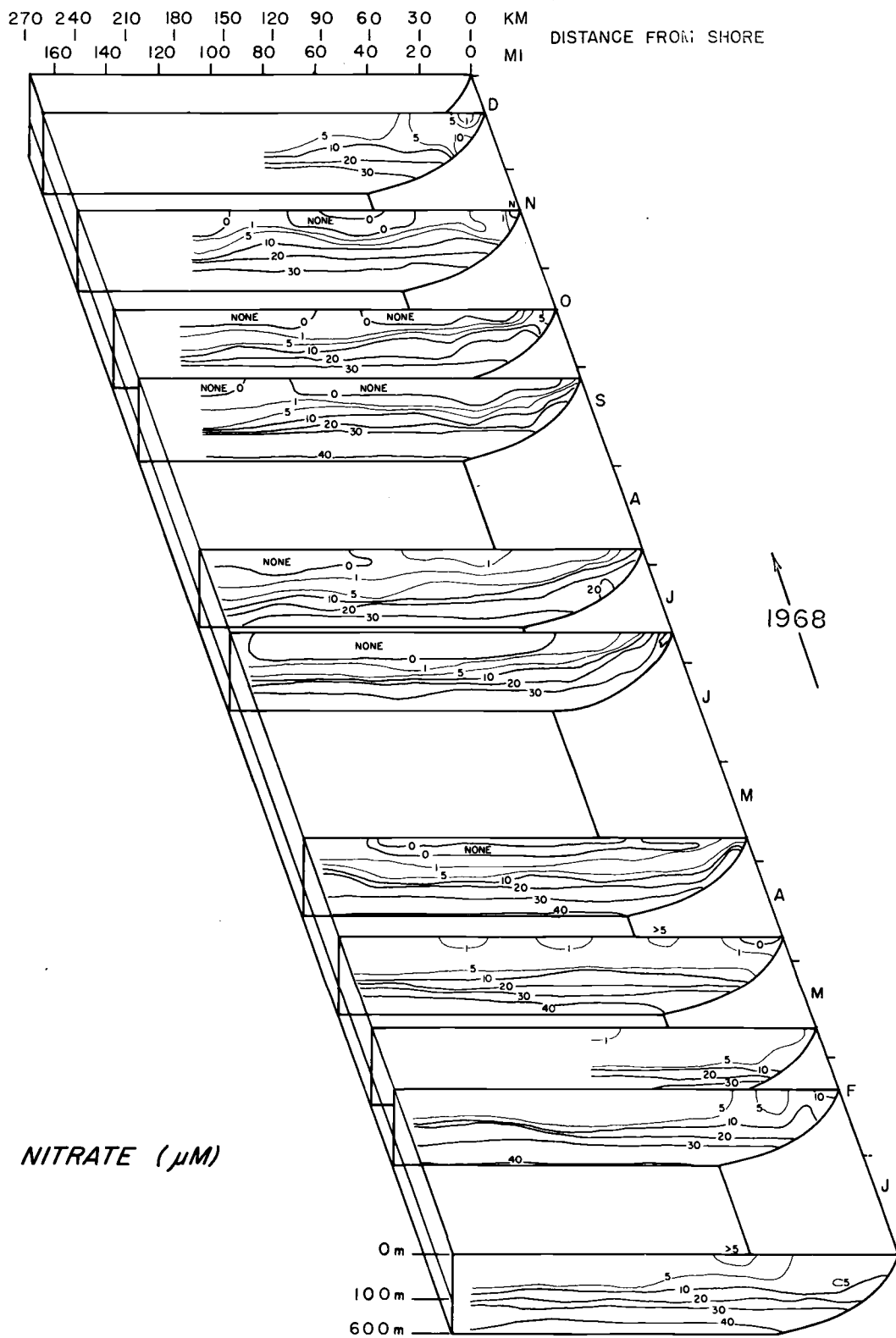


Figure 9. Vertical distributions of nitrate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

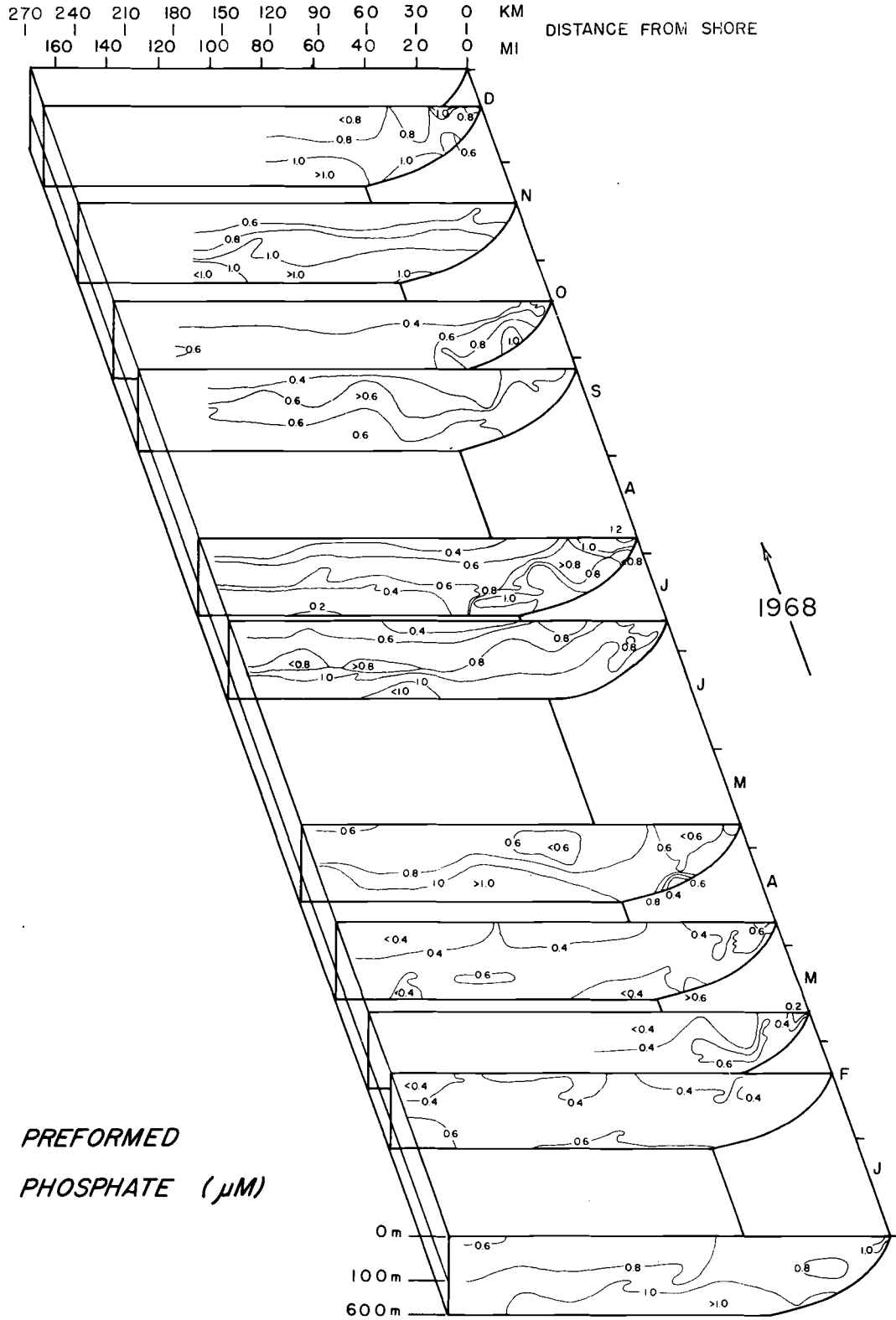


Figure 10. Vertical distributions of preformed phosphate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.



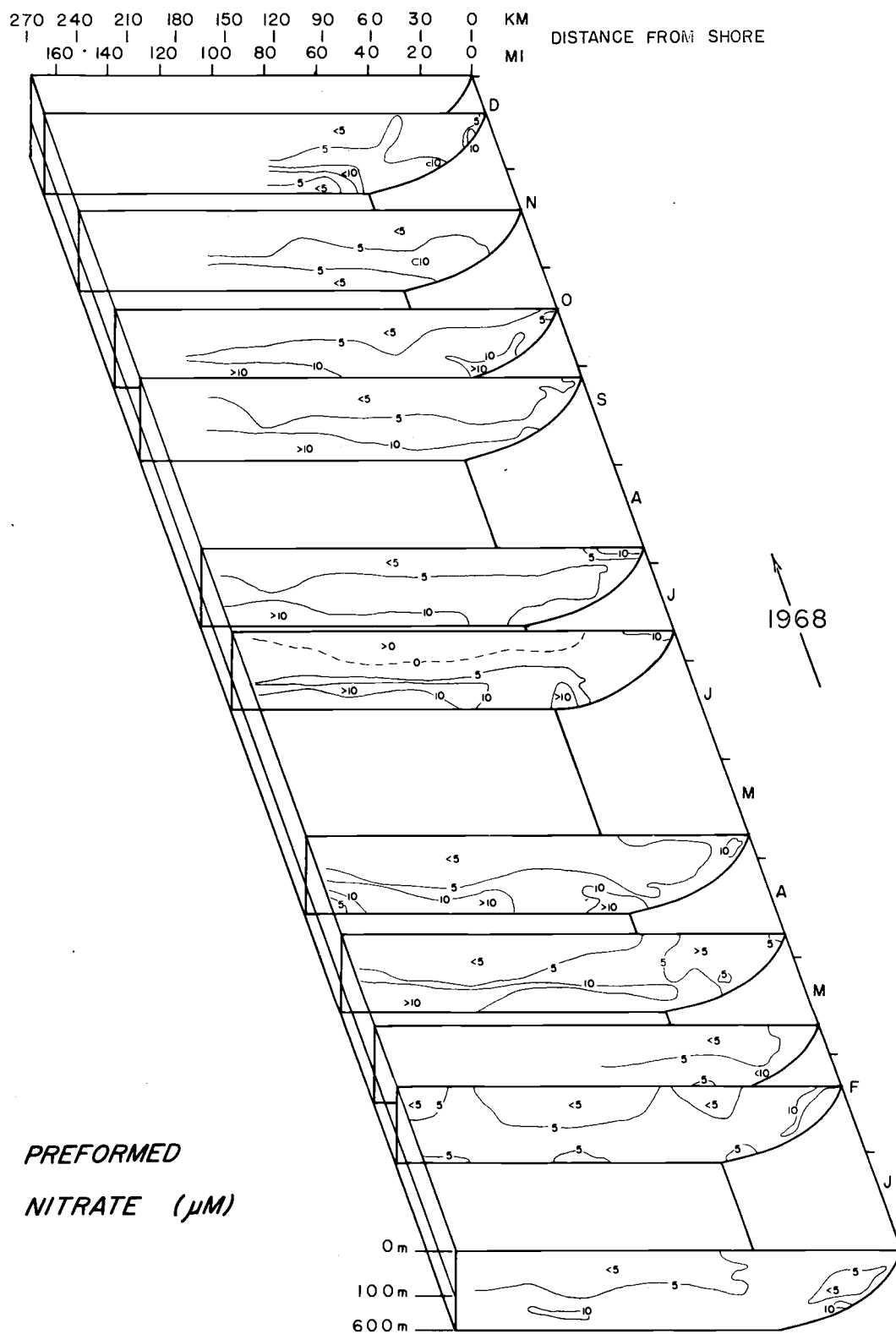


Figure 11. Vertical distributions of preformed nitrate to a depth of 600m along the Newport hydrographic line for 1968. Depth scale is logarithmic.

Plume water extends down to less than 50m depth. For water below 100m at a distance greater than 30 miles (56 km) offshore, we observe little seasonal change.

Between November and April the temperature distribution shows a decrease in surface temperatures with a minimum at nearshore in January. The offshore minimum occurs in February and its extension nearshore is interrupted by the intrusion of water warmer than 9.0° C.

### Salinity

Salinity distribution (Figure 4) also shows the influence of runoff and upwelling. With the plume influence at its greatest in July and August, the surface salinity decreases to less than 30.0‰ with the 32.5‰ isohaline delimiting the plume found at a depth of 50m. Below this depth there is an absence of water less than 32.5‰. At the same time, however, coastal upwelling is noted by the 33.5‰ isopleth which is found at the surface at NH-5. Based on surface salinities, there is a shift in the plume axis from NH-65 in July to NH-125 in August, showing time dependency. September and October still show upward diverging isopleths but surface salinities are comparatively low, 31.5 to 32.5‰. Upwelled water appears to come from a depth of 100-200m.

During the remainder of the year, the surface salinity pattern becomes complex. Nearshore low salinities, 30.0 to 32.0‰, are due to runoff with the apparent maximum in February and March correlating with the temperature distribution. The offshore distribution becomes more complicated with patchiness of salinities of approximately 32.0 to 33.0‰.

### Sigma-t

Sigma-t distribution, a function of temperature and salinity, shows water-mass movement (Figure 5). Patterns observed here are similar to those observed for other parameters. Low density water, sigma-t of less than 25.0, found nearshore in fall and winter, is due to coastal river runoff. The winter, January to April, offshore water is approximately sigma-t equal 25.0 with a decrease in early spring. The least dense water, corresponding to the plume, is approximately equal to a sigma-t of 21.0 in July. Based on this minimum density, the main plume axis is found at NH-85. In early fall sigma-t begins to increase, indicating denser water, with a return to the mid-winter values.

Upwelling begins in May with an upward divergence of the 26.0 and 26.5 sigma-t isopleths from 100-200m. Upwelled water in July rises from the depth of 200-300m, water below 400m showing no seasonal change. The close spacing of the 25.5, 26.0 and 26.5

sigma-t isopleths showing the permanent thermocline is found at 80-100m depth offshore at distances greater than 40 miles (74 km).

### Oxygen

Oxygen contours (Figure 6) become complex at the onset of upwelling with the highest levels (8.0 ml/liter) found in July and August. The maximum at about 40m depth correlates with the silicate minimum (Figure 7) near the bottom of the plume. The high oxygen isopleth of 7.0 ml/liter corresponds to the low silicate minimum. September and October show a similar situation, but the value is slightly decreased. Nearshore water has a low oxygen content of 3.0 to 4.0 ml/liter. Offshore concentrations are greater than 5.0 ml/liter; the maximum surface oxygen is found adjacent to the shore.

Between November and May, the maximum is found partially or completely within 10m of the surface. November and December maxima move upward but nearshore portions are at 10m. Surface oxygen concentrations are greater than 6.0 ml/liter with 7.0 ml/liter nearshore water in April and May. The correlation between the oxygen maxima and silicate minima is not as good as during upwelling; the silicate isopleth is not horizontal, but varies between 10m and 45m depth. This is probably due to winter mixing processes, reduced silicate input and reduced photosynthesis.

Water having oxygen concentration of less than 2.0 ml/liter exists below 300m and is undisturbed throughout the year.

### Silicate

Silicate (Figure 7) appears to be an effective indicator for oceanographic processes. With peak upwelling and photosynthesis in July and August, the silicate minima become more pronounced than any other time of the year. The increased surface silicate reflects upwelling from 200-300m. The minimum seems to correlate with the bottom of the plume. In September a slight upward divergence of isopleths may be also due to upwelling since winds were still from the north.

During the remainder of the year with decreased photosynthetic activity and wind mixing, the minima become poorly developed and are almost nonexistent in November and December. Nearshore concentrations (5-20 $\mu$ M) are due to river runoff.

### Phosphate

Phosphate contours (Figure 8) are complex. Surface concentrations are lowest in October, slightly greater than 0.0 $\mu$ M, rising to the greatest concentrations, 0.5 $\mu$ M, in December. The surface concentration increases in November to about 0.4 $\mu$ M. Upwelling is not as well indicated by phosphate as are other properties; higher

phosphate concentrations are confined to within 10 miles (19 km) of the shore. Nearshore concentrations decrease from January to April ( $0.9\mu\text{M}$  down to  $0.1\mu\text{M}$ ). From July to October phosphate concentrations vary from  $1.0$  to  $0.5\mu\text{M}$ .

### Nitrate

Patches of nitrate-free water (Figure 9) are found down to 30 to 40m deep from May to November. This pattern of no nitrate persists longer than the reduced silicate and phosphate levels. Upwelling patterns and shoreward contours are similar to previous contours. The  $30\mu\text{M}$  level is horizontal at about 200m except when it upwells to the surface in July. Between October and March nearshore values generally range between  $5\mu\text{M}$  and  $10\mu\text{M}$ .

### Preformed Phosphate and Nitrate

Preformed nutrients (Figures 10 and 11) are conservative properties of a water mass (Redfield et al. 1963) and are defined as the amount of inorganic nutrients existing in the water before sinking from the surface layers. Total inorganic nutrients, but not preformed nutrient concentrations, are changed by the in situ oxidation of organic matter.

Preformed phosphate shows the most confusing pattern; little of the monthly consistency seen in other chemical properties is

observed. The greatest complexity occurs from July to October; concentrations at 600m vary from less than  $0.2\mu\text{M}$  to  $1\mu\text{M}$ . The highest ( $1.2\mu\text{M}$ ) and the lowest ( $0.2\mu\text{M}$ ) surface values of the year are observed in July; they are observed, respectively, in upwelled water and plume and open ocean waters.

Preformed nitrate has surface values ranging from  $6\mu\text{M}$  in January to  $0.6\mu\text{M}$  in November. Zero preformed nitrate is found in July along an isopleth running from the surface (40 mi or 74 km offshore) to a depth of 60m (80 to 130 mi or 148 to 240 km offshore).

## DISCUSSION

Temperature and Salinity

Regional winds affect the general water circulation, especially the movement and mixing of surface waters. Seasonal wind cycles over the northeast Pacific Ocean are determined by the circulation about the North Pacific high pressure and the Aleutian low pressure areas. The high reaches its greatest development during the summer months when the Aleutian low is almost nonexistent. This pattern favors predominant winds from the northwest and north over the coastal and nearshore areas off Oregon.

In October, the Pacific high extends from the United States Pacific Coast to the Asiatic mainland. With the approach of the winter season, the high weakens and by November it is little more than a weak high pressure belt lying between the Aleutian and equatorial lows. The Aleutian low, with its system of migratory lows, moves through the coastal areas in the winter season. Winter winds are from the southeast at the coast to southwest in the offshore regions (Budinger et al. 1964).

Wind effects are limited to relatively shallow water. The principle effects are wind mixing of surface waters and the movement of lighter river water by wind action, as observed in the shift of the Columbia River Plume from the Washington coast to off Oregon from



the winter to the summer months. This is seen by changes in the salinity distribution. Budinger et al. (1964) suggest the 32.5‰ isohaline as an index for the horizontal and vertical distribution of river effluent. While primarily for the Columbia River's large freshwater input, it can be used for the nearshore runoff from coastal rivers during the winter months and increased precipitation.

Temperature can be used as an indicator of water masses and is best used during the summer months when the plume is prominent. River temperatures differ considerably from surface seawater temperatures with a range from 7.0° C in February to 21.4° C in August for 1967 (Park, Osterberg and Forster, 1970). The annual range in the sea surface temperature is from 9.0° C in January and February to 16.0° C outside the plume area in July. It is evident, therefore, that the plume water, as a mixture of river water and seawater, would have temperature different than the normal sea surface temperatures.

With differences in the seawater and river water temperatures, there should be a maximum in the temperature along the plume axis. In August (Figure 3) an 18° C isotherm is observed which would indicate this fact. Support is provided by the salinity minimum (Figure 4) of about 29‰.

While the 32.5‰ isohaline is an accepted plume boundary and agrees with the extent of other chemical factors, it is not the best

criterion. Water with salinities less than 32.5 are found throughout the year; this can be used only as an approximate rule of thumb.

Alteration of the nominal 32.5‰ as a sea surface average is observed throughout the year as a result of runoff with surface salinities as low as 31.1‰ and as high as 33.6‰ during upwelling.

A plot of temperature vs. salinity (Figure 12) from upwelling and non-upwelling areas shows that below 200m all water is essentially similar; it is a mixture of Pacific Subarctic and Pacific Equatorial Waters, as noted by Rosenberg (1962). In July the plume axis is shown by the relatively warm water and low salinity (NH-65 and NH-85). The plot of NH-3 for the cruise Y6808 (August, 1968) shows water from 30m is similar to the 140 to 200m water for other stations.

Temperature-salinity relationships (Figure 13 a-e), after the fashion of Pattullo and Denner (1965), demonstrate the change in water characteristics during the year. Dividing the year into quarters and using the data of this thesis to 50m depth gives ample data points. From January to March (Figure 13 a) the temperature of the water is generally between 8.5 and 10.5° C with the salinity varying between 32.0 and 33.0‰. Points outside the above value ranges represent water modified by runoff from the Yaquina River (Gilbert and Wyatt, 1969). In April and May (Figure 13 b) the bulk of the values falls within the limits of the previous quarter. However, there is also a

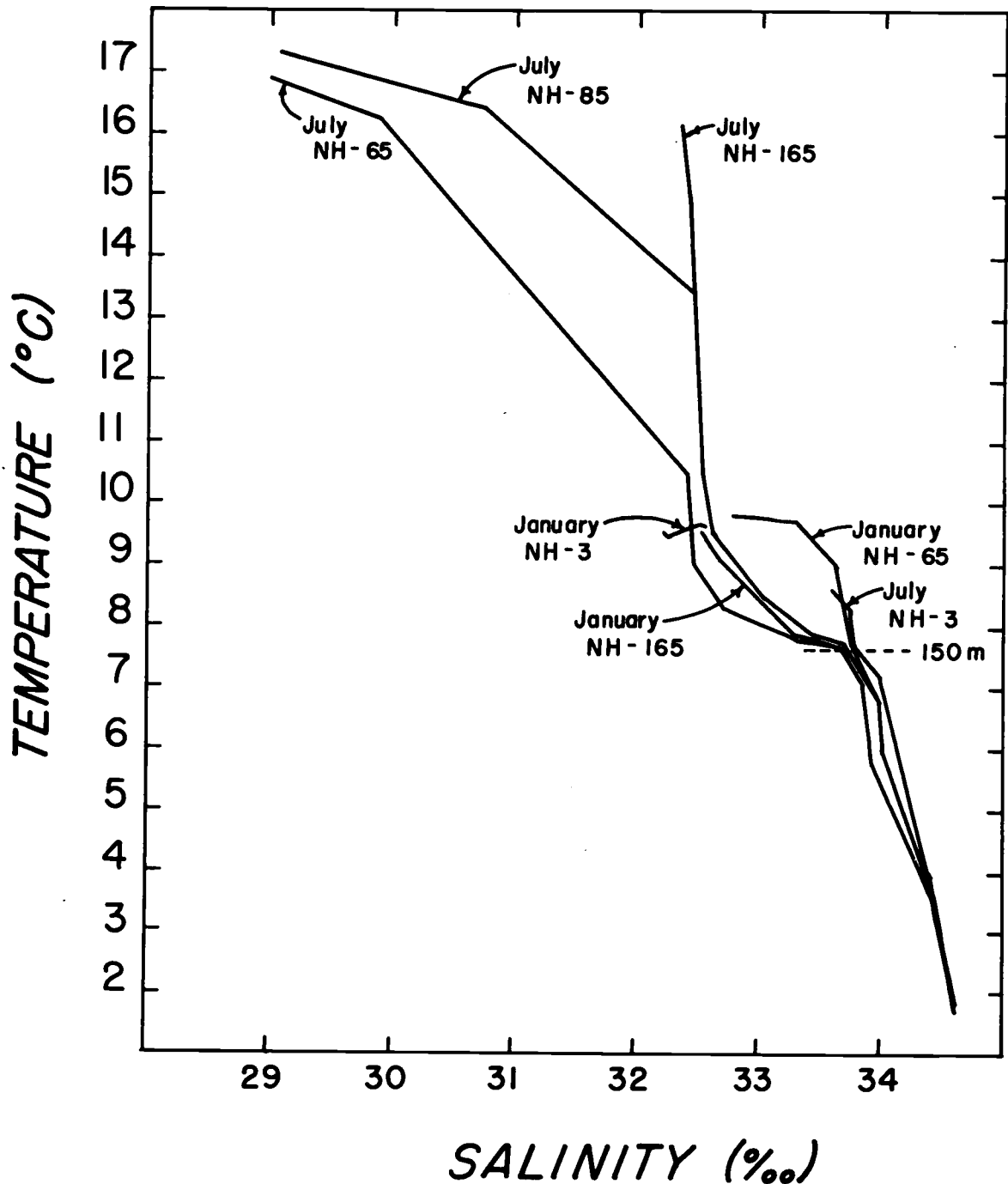


Figure 12. Vertical distributions of salinities along the Newport hydrographic line at selected stations for 1968. Notice the influence of the Columbia River Plume (NH-65, -85 and -165) and upwelling (NH-3) in July as compared to similar stations in January.

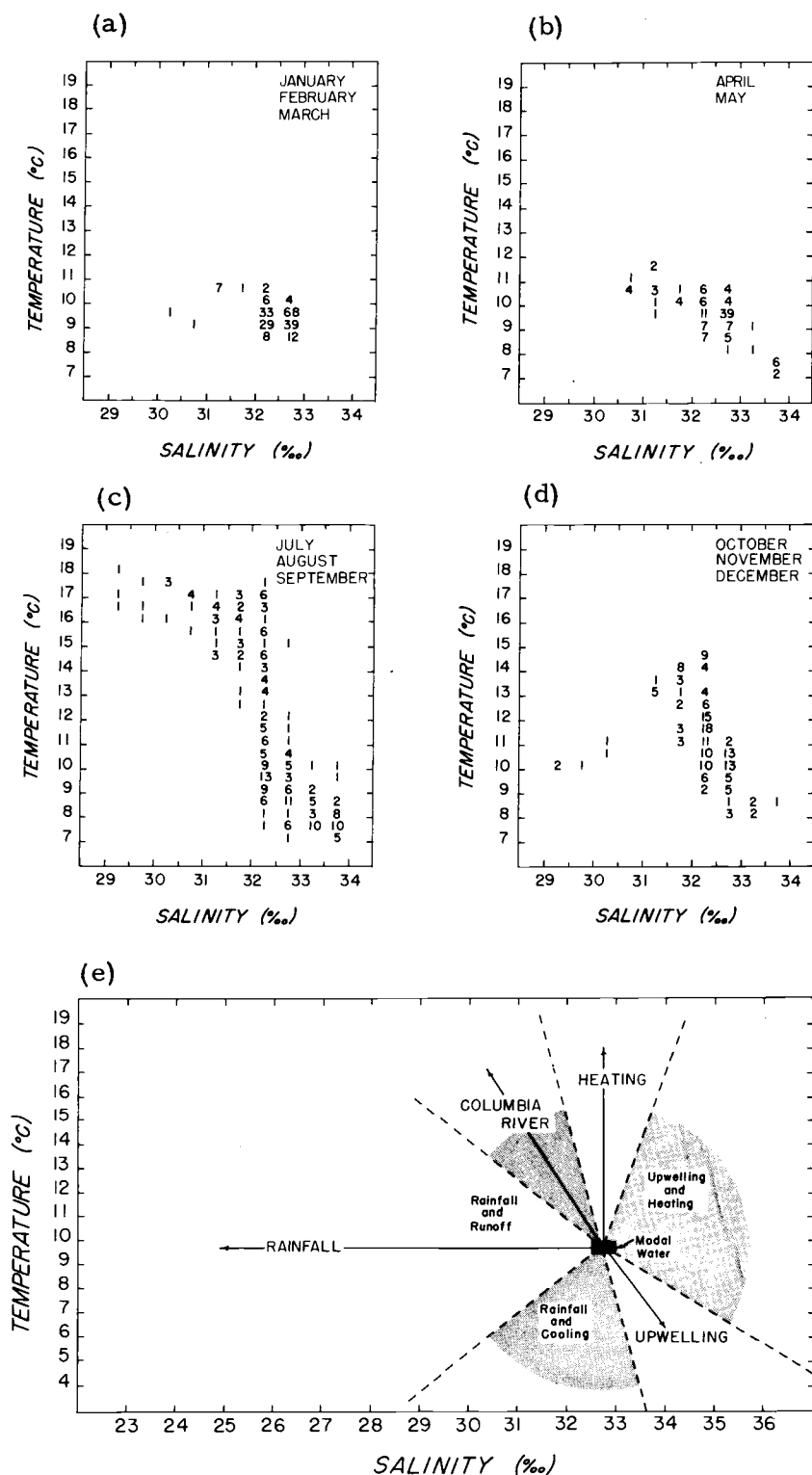


Figure 13. Bivariate plots of salinity and temperature along the Newport hydrographic line to a depth of 50m for quarters of 1968. Process vectors (solid lines) and process sectors (dashed lines and labeled areas) are also presented.

shift to higher temperatures--lower salinities and lower temperatures --higher salinities. These values cannot be correlated to the river runoff effects and are, therefore, due to the onset of upwelling and plume influence. Budinger et al. (1964) note that the plume shifts from along the Washington coast to the Oregon coast during the latter part of this quarter. The July, August and September (Figure 13 c) spread in values is more pronounced with temperatures ranging from 7.0° to 18.5°C and salinities ranging from 29.0 to 34.0‰. These ranges indicate that plume and upwelling effects are the most pronounced during this time of year. The decreased range in temperature and salinity in October, November and December (Figure 13 d) reflects a cessation of upwelling and the shift of the plume to the Washington coast. During this period there is a gradual return to the pattern previously observed for the first quarter of the year (Figure 13 a). A few values between 29.0 and 30.5‰ show the effect of runoff at NH-3 and NH-5 (6 and 9 km offshore).

A vector diagram (Figure 13 e) was constructed which defines the limits and the factors influencing the coastal water (Pattullo and Denner, 1965). Their work noted that the modal cell value, as indicated by the square with the greatest number of observations, would probably shift from year to year, depending upon the coastal conditions. Their data were from coastal stations while the data for this work represent the distribution of water along the length of the

Newport line and may represent a more real modal value. Their modal values of 10.0 to 11.0°C and 33.0 to 33.5‰ are slightly higher than my values of 9.5 to 10.0°C and 32.5 to 33.0‰.

In order to evaluate the validity of the modal cell found here, 4-year data from Oregon waters (Wyatt et al. 1967, Barstow et al. 1968, 1969a, b) were examined. The modal temperature was 9.0-9.5°C for 1966 and 1968 and 9.5-10.0°C for 1965 and 1967. In all cases the modal salinity was 32.5-33.0‰. Therefore, my choices of 9.5-10.0°C and 32.5-33.0‰ S as the modal cell for this study are representative for Oregon waters.

The effect of rainfall and runoff in Figure 13 e cannot be separated since both serve to dilute and decrease salinity. Incoming water is assumed to be of the same temperature as the sea surface. Heating should only increase the temperature, assuming no change in salinity. The influence of the Columbia River is determined from the average temperature and salinity during July and August (Barstow et al. 1969b) of approximately 17.1°C and 30.4‰. Upwelling was determined from values for water at depth off the coast. It can be seen that the values observed during the year fall within the above limits with the apparent effect of heating in the summer quarter.

Sigma-t

Correctly, water density is a function of the temperature, salinity and pressure, but for most purposes the pressure effect is not included; sigma-t values refer to the density at atmospheric pressure. Density can be used for tracing water masses, giving an indication of the source of water for the coastal processes. As shown earlier in Figure 5, the distribution of "normal" water, upwelled water and plume water may be observed. The decreasing surface density from winter through summer to autumn is due to the influence of the Columbia River Plume; its low density water increases in density as a result of entrainment and mixing of open ocean water. The main axis of the plume, as observed in temperature (Figure 3) and salinity (Figure 4) at NH-85, is also seen with a minimum density (sigma-t = 22.0).

In the autumn, the density increases to the winter maximum; the increase is due to the combination of the movement of the plume to the north, the cessation of the influx of freshwater and decreasing surface temperatures. All factors increase the density.

The permanent thermocline is found at 80-100m, showing the classical pattern used for defining the thermocline with a sharp decrease in temperature with depth. There is a sharp density change from sigma-t 25.5 to sigma-t 26.5 in a depth change of 20m. Water

of this same density is observed in the nearshore upwelling pattern. Upward divergence of water from approximately 200m is also observed. This correlates well with other parameters, especially silicates (Figure 7).

Density represents the best method for observing water masses since the parameters used for calculating densities are independent of biological activity and relatively conservative.

### Oxygen

High oxygen levels can be correlated with relatively high pH (Cissell, 1969). They can be correlated to high productivity. The oxygen maximum appears to be just below or near the bottom of the plume when comparing the depth of the oxygen maximum isopleth and 32.5‰ isohaline. The maxima from December to April are 10m below the surface. The movement of the maximum to deeper depths is probably due to the onset of deeper photosynthetic activity and summer degassing. The 7.0 ml/liter water found nearshore in April and May is due to either increased photosynthetic activity or runoff or both. Park, Osterberg and Forster (1970) show approximately 7.5 ml/liter for Columbia River water in April and May.

The subsurface maximum observed in the early months of 1968 may be due to degassing of oxygen from the surface layer into the atmosphere by increasing surface temperatures from winter to



summer (Pytkowicz, 1964). A density maximum occurs at the same depth (10m). Bruyevich (1966) notes a density "discontinuity" is related to the oxygen maximum. The discontinuity inhibits oxygen penetration into the depths. During the winter the layer of convection has free exchange with the atmosphere. The oxygen concentration is practically constant along the vertical since the near surface water is well-mixed. The persistence of the subsurface maximum is apparently due to both thermal and biological effects. With low oxygen concentration plume water overlying normal seawater in summer, the bulk of photosynthetic activity should occur below the plume. Oxygen isopleths in July and August rise nearer the surface in the nearshore waters where the plume water is not found. This is especially true in September when upwelling has subsided and plume water is still present. The oxygen concentration at the maximum increases from 6.7 ml/liter in January to 7.2 ml/liter in July with the increase due to photosynthesis. Anderson (1969) observed a chlorophyll maximum at 55-65m between two discontinuities--a seasonal halocline and pycnocline above and the permanent halocline and pycnocline below at approximately 40m and 100m. Phytoplankton at depth are apparently adapted to low light levels. The sinking of upwelled water, enriched in oxygen by photosynthesis, may also contribute to the maximum (Stefánsson and Richards, 1964).

The percent oxygen saturation as a function of depth is shown in Figure 14. Unfortunately, cast spacing leaves uncertainty as to the actual depth of the maximum. There is one discrepancy; in November the oxygen maximum lies at 30m while the saturation maximum lies at the surface. This could be due to either saturation by wind mixing or an error in the oxygen determination. Apparent oxygen utilization (AOU), defined as one hundred percent oxygen calculated from temperature and salinity minus measured oxygen, shows a similar pattern (Figure 15). The observed maximum can be correlated to the nitrate depletion with levels from 0.0 to 1.0 $\mu$ M (Figure 9). The silicate minimum is located at about the same depth (Figure 7). All are produced by photosynthetic activity.

### Nutrients

Several features in the nutrient distributions may be seen. The most striking are the widespread regions of nitrate-free water and the silicate minima. Low nitrate values would be expected; Park, Osterberg and Forster (1970) suggested that the limiting nutrient is nitrate. The preformed nitrate:preformed phosphate ratio is 7:1 while the normal assimilation ratio is 16:1 from the biochemical oxidation model (Richards, 1965a). Silicate is supplied by Columbia River effluent and upwelling and is not limiting.

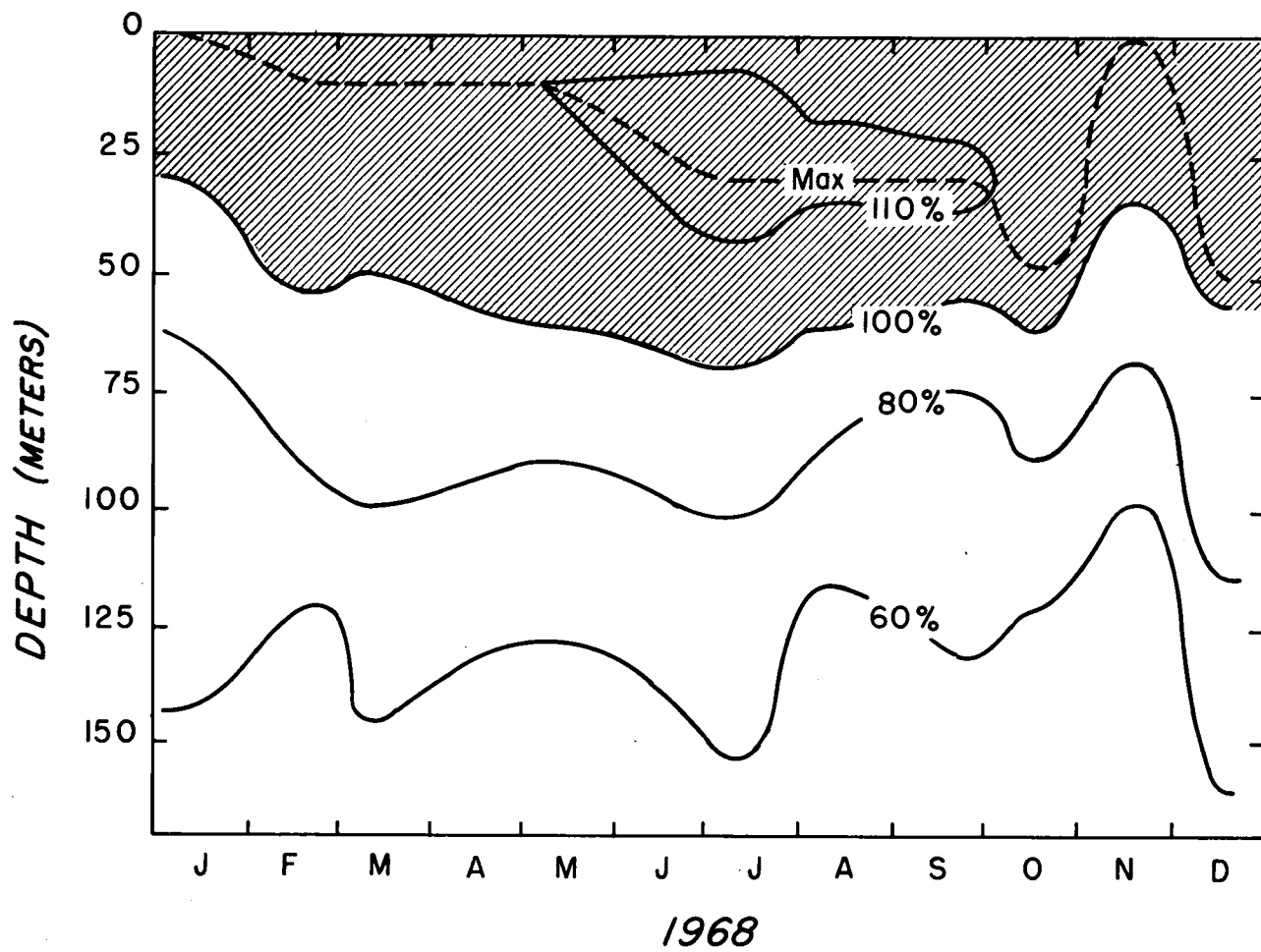


Figure 14. Percent oxygen saturation at NH-85 for 1968 to a depth of 175 m.

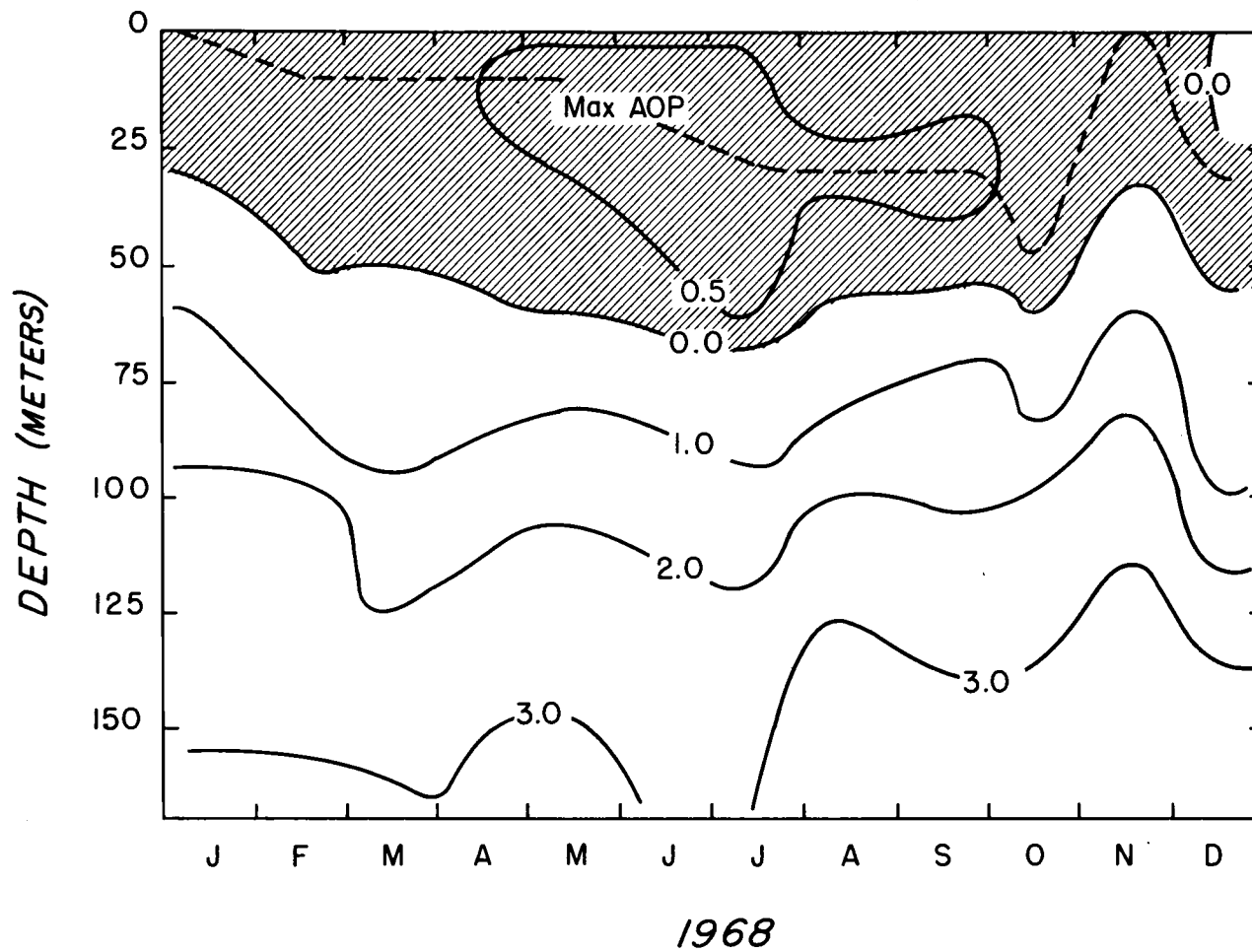


Figure 15. Apparent oxygen utilization (AOU) at NH-85 for 1968 to a depth of 175m. Apparent oxygen production (AOP) is equal to negative AOI.

"Nitrate," as used here, is actually the combined nitrate-nitrite fraction of the total nitrogen. From unpublished data (COOC-6, 1969), nitrite is less than  $2.0\mu\text{M}$  at about 55m, following a vertical distribution similar to Harvey (1963, p. 53). Nitrite within 25-30m of the surface is considerably less than  $1.0\mu\text{M}$ . Strickland et al. (1969), in an experiment with phytoplankton, demonstrated assimilation of ammonia first, followed by nitrate; nitrite remained unused throughout the duration of one experiment in which nitrite was mentioned. The concentration was less than  $0.1\mu\text{M}$  and might have been below the concentration phytoplankton can utilize effectively. Unfortunately, little work with ammonia has been done for Oregon waters.

Nitrate depletion to concentrations near zero is due to biological activity. The high negative AOU values (Figure 15) indicate increased oxygen production from photosynthesis. The depth to which the negative AOU, AOP or apparent oxygen production (defined as measured oxygen concentration minus one hundred percent oxygen saturation concentration), correlates with the depth of the nitrate-free water and the silicate minimum.

Photosynthetic activity, although reduced during winter months, would still produce oxygen, but the net effect would be utilization. The reduction of dissolved oxygen from over 7.0 ml/liter in July and August to about 6.5 ml/liter in November and December represents

biological utilization and air-sea exchange with a net transport of oxygen to the atmosphere.

The May silicate minimum (Figure 7) is generally greater than  $1.0\mu\text{M}$ . In July, a minimum of  $0.6\mu\text{M}$  ranges from NH-70 (130 km) to NH-125 (230 km), with higher nearshore concentrations from replenishment by upwelling and the river plume.

The most unusual feature of the phosphate distribution is a region of near zero phosphate in October. Maximum AOP (Figure 14) for October is found at 50m while it is at 30m for the summer months. There might have been some intense regional biological activity.

Offshore nutrients in summer are the result of three-point mixing of Columbia River effluent at 0.0‰ salinity, normal surface seawater (NH-165 or 310 km offshore) and upwelled water (NH-3 or 6 km offshore). Table 2 presents comparative values for January and July. Figure 16 is a three-point mixing system with the July surface data plotted. The Columbia River value is the average for June to September 1966 and 1967. Phosphate and nitrate show the greatest effect of biological activity. Silicate, on the other hand, shows a shift to slightly greater silicate concentrations in the lower salinity water of the plume. Points near upwelling reflect the high silicate of the upwelled water and its mixing with lower concentration silicate water as it moves offshore.

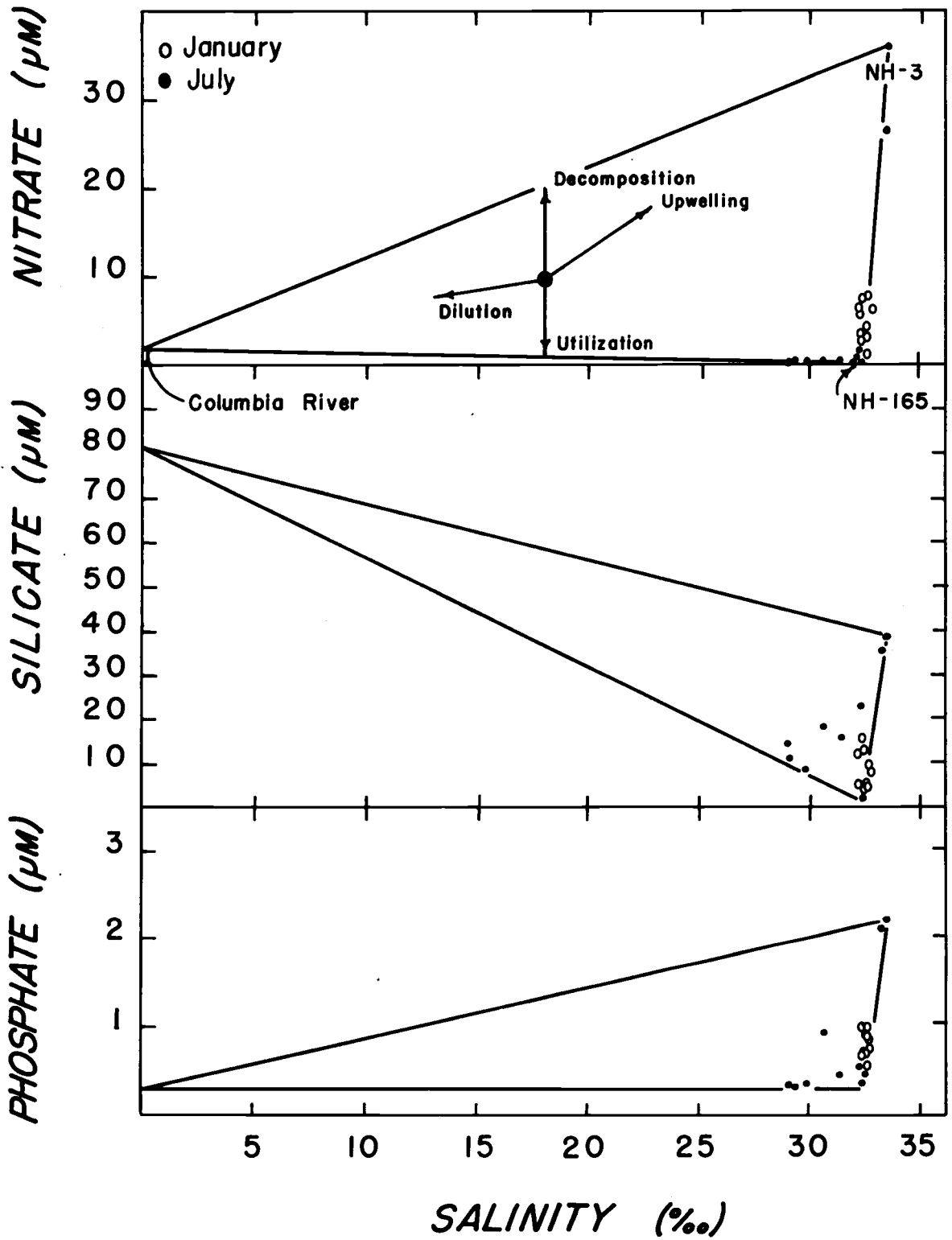


Figure 16. Three-point mixing of Columbia River Plume water, upwelled water and open ocean water with surface values for the Newport hydrographic line in July, 1968 are plotted. January values are plotted for comparison.

Table 2. Comparison of selected values for January and July for the Columbia River, NH-3 and NH-165.

		Temp (° C)	Salinity (‰)	Oxygen (ml/l)	Silicate (μM)
Columbia River	Jan.	6.0	0.0	8.1	231
	July	18.4	0.0	7.2	81
Upwelling (NH-3)	Jan.	----	-----	---	---
	July	8.6	33.59	3.8	38
Open Ocean (NH-165)	Jan.	9.6	33.45	6.5	2
	July	16.2	33.36	5.9	1

In winter, offshore nutrients can be correlated to mixing only by dilution by rainfall and higher silicate levels from runoff. This gives a two-point mixing system. Hager (1969) used the Columbia winter plume off the Washington coast and surface silicate to construct a two-point mixing system. Off Oregon this would not be practical since the coastal river input is of comparatively limited nearshore effect. Surface values for January are plotted in Figure 16 only as an indication of winter values.

Using Columbia River nutrient concentrations for July and nutrient data for a station outside the plume influence, Cissell (1969) was able to construct the equation of a line of salinity vs. nutrient concentration. No biological activity was assumed. The fit to actual data was poor due to biological activity influences. An attempt to



find a line which would have been independent of surface values was unsuccessful, giving meaningless values (Figure 17). Biological activity and errors in the nutrient analyses are probably the main reasons for lack of fit. Mixing of water masses of similar salinities but differing nutrients concentrations would also contribute errors. The scatter in values is considerably less in winter than during the summer. The same is true for AOU. Increased scatter probably is due to the combined effects of upwelling, the plume and biological activity.

Salinity versus silicate (Figure 18) can be plotted to demonstrate the processes which alter nutrient concentrations. Silicate has been chosen since its concentration span is the greatest of the nutrients under consideration. The year has been divided into quarters and the vector diagram has been presented. A winter modal cell was found at  $6-8\mu\text{M}$  and  $32.5$  to  $33.0\text{‰}$ . This salinity range corresponds to the value for the temperature-salinity plots (Figure 13). The winter quarter, however, shows much more scatter with the bulk of the points ranging between  $32.0$  and  $33.0\text{‰}$  and  $3-14\mu\text{M}$ ; higher values are found in the nearshore water with progressively decreasing silicate concentration offshore. During the spring months, March and April, the silicate range is  $0-48\mu\text{M}$ , with the onset of upwelling and the plume. An increase in the salinity range,  $31.0$  to  $33.0\text{‰}$ , is observed with few values falling outside this range.

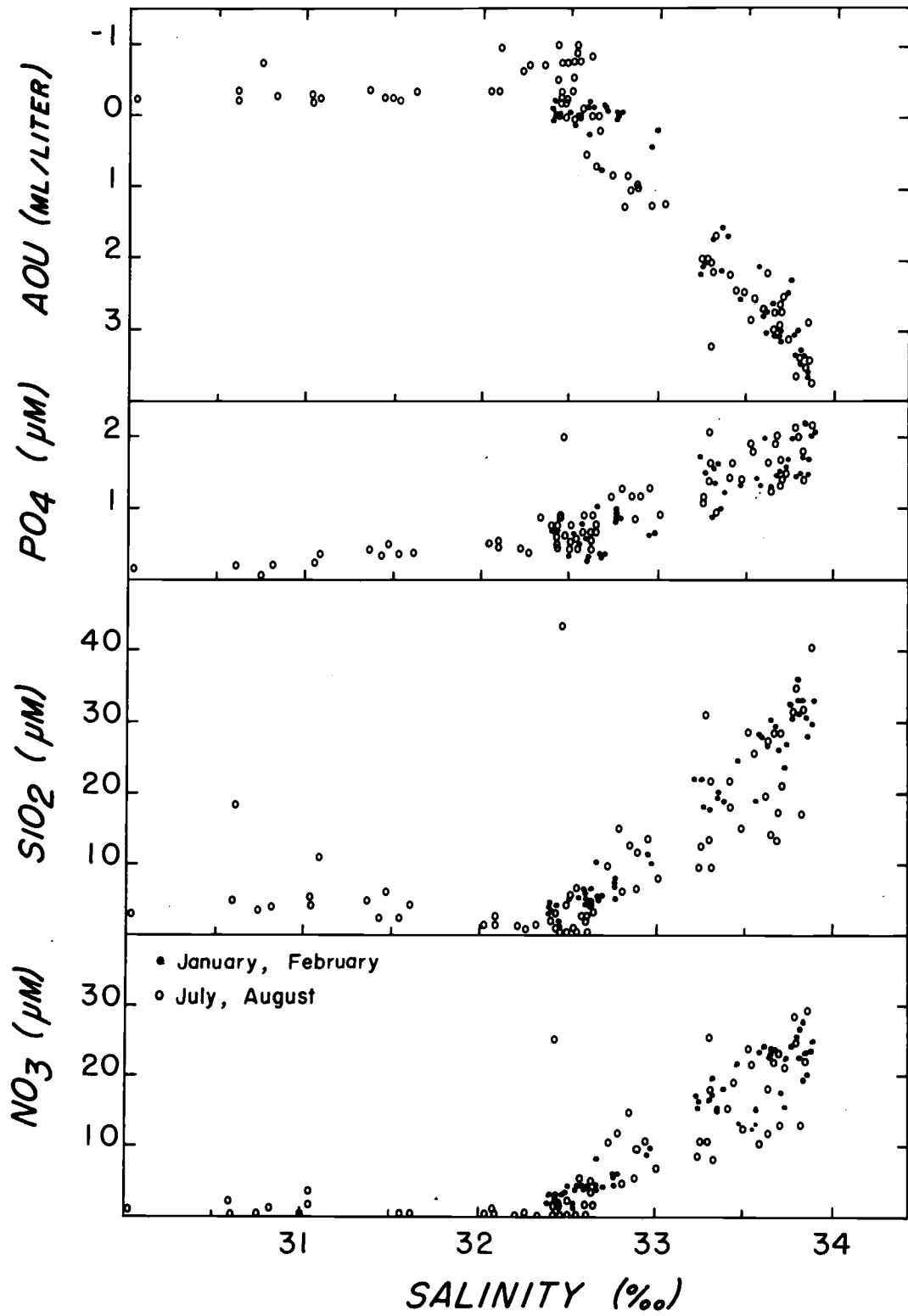


Figure 17. Salinity-nutrient and salinity-AOU relationships for stations NH-45, -65, -85, -105 and -125 to a depth of 150m for January-February and July-August, 1968.

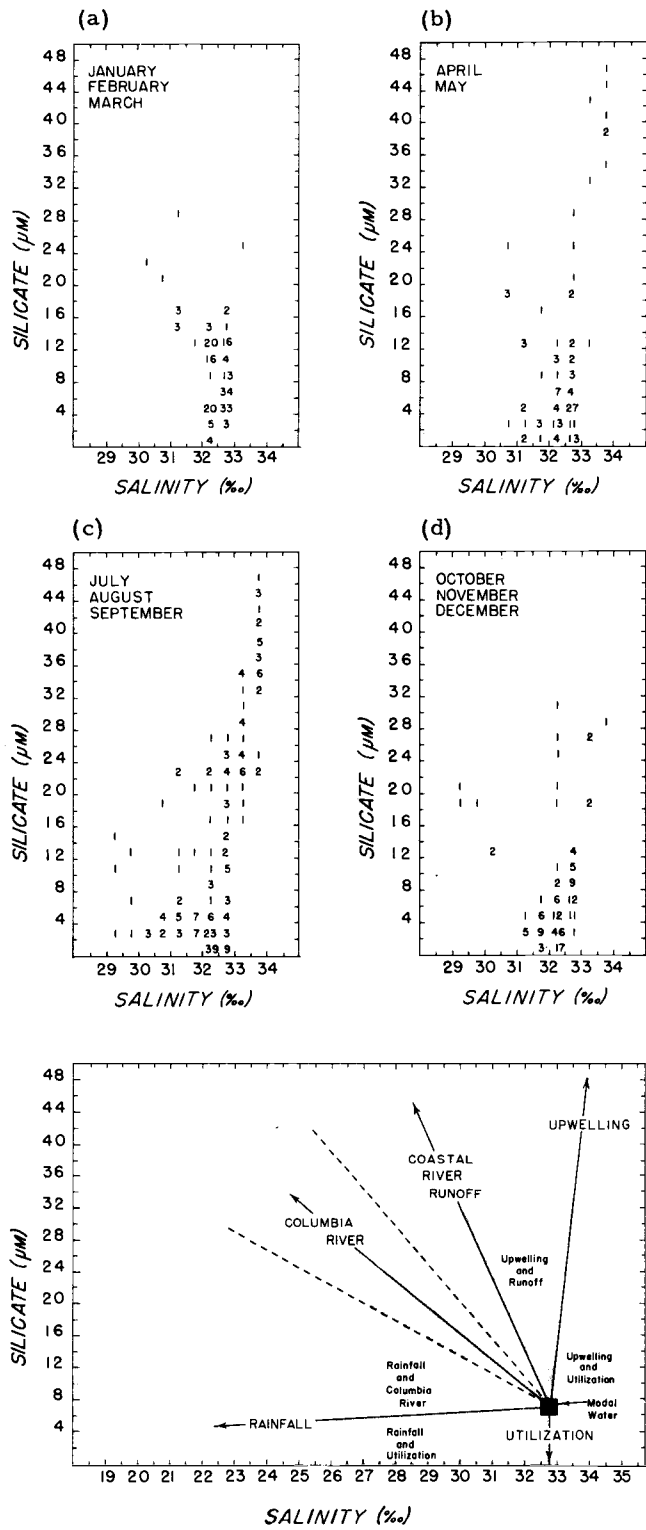


Figure 18. Bivariate plots of salinity and silicate along the Newport hydrographic line to a depth of 50m for quarters of 1968. Process vectors (solid lines) and process sectors (labeled areas) are also presented.

Summer months show the greatest scatter when the offshore processes are most intense. The observed silicate range is the same as during the spring, but more points are observed in the interval rather than the clustered points in spring. The scatter begins to decrease during the fall to the nominal winter values; most scatter is due to coastal runoff.

Constructing a vector diagram requires assumptions similar to those for temperature and salinity. Utilization assumes no change in salinity, only decreasing concentration. Rainfall is assumed to contain no silicates and represents simple dilution. Limits of the effect of the Columbia River are determined from the summer and spring and fall silicate levels. Zero salinity is assumed for the river. River runoff is determined from coastal stream averages (Clark, 1959, Livingstone, 1963). The vector magnitude is slightly misleading in that the primary runoff effects occur during the winter in the absence of the Columbia River influence. During summer its effect would be greatly reduced. Upwelling values are derived from vertical profiles of the nearshore region.

#### Gas-Nutrient Relationships

From Richards' (1965a) biochemical oxidation model and Park (1967), the O:C:Si:N:P ratio may be taken as 276:106:23:16:1 (by atoms). Oxygen is equivalent to  $138\mu\text{M}$  of the apparent oxygen

utilization (AOU) per  $1\mu\text{M}$  of phosphate change. Park found a ratio with AOUs:N:P:Si of 3.09 ml/liter: $16\mu\text{M}$ : $1\mu\text{M}$ : $23\mu\text{M}$ . A comparison of AOUs vs. nutrient concentrations (Figure 19) for January and July allows one to look at upwelling and non-upwelling conditions.

Below the plume influence, deep preformed phosphate gives a value of  $1.0\mu\text{M}$ . The line for upwelling stations (Figure 19 b) has been given the same slope and intercept as the deep plots. Although the nearshore data show much scatter, the fit is reasonable with preformed phosphate approximately  $1.0\mu\text{M}$ . Preformed silicate is  $10.0\mu\text{M}$ , showing a better fit during upwelling than for nitrate and phosphate. In January, preformed nitrate is  $6.5\mu\text{M}$  while in July it is  $5.0\mu\text{M}$ . As with phosphate, the nitrate plot for upwelling shows scatter but the best fit would be  $9.0\mu\text{M}$ ; this value agrees favorably with January. Park (1967) found the following preformed nutrient values: nitrate,  $8 \pm 3\mu\text{M}$ ; phosphate,  $1.1 \pm 0.1\mu\text{M}$ ; and silicate,  $12 \pm 4\mu\text{M}$ . The values derived here are within the limits assigned by Park.

The major in situ processes by which oxygen concentrations are altered are photosynthetic production, mixing and respiratory consumption. The former two are limited to the upper layers (photic zone) where there is sufficient light energy. Richards (1965b) noted that although photosynthesis is never limited by the availability of carbon, nutrient ions, generally nitrogen and phosphorous

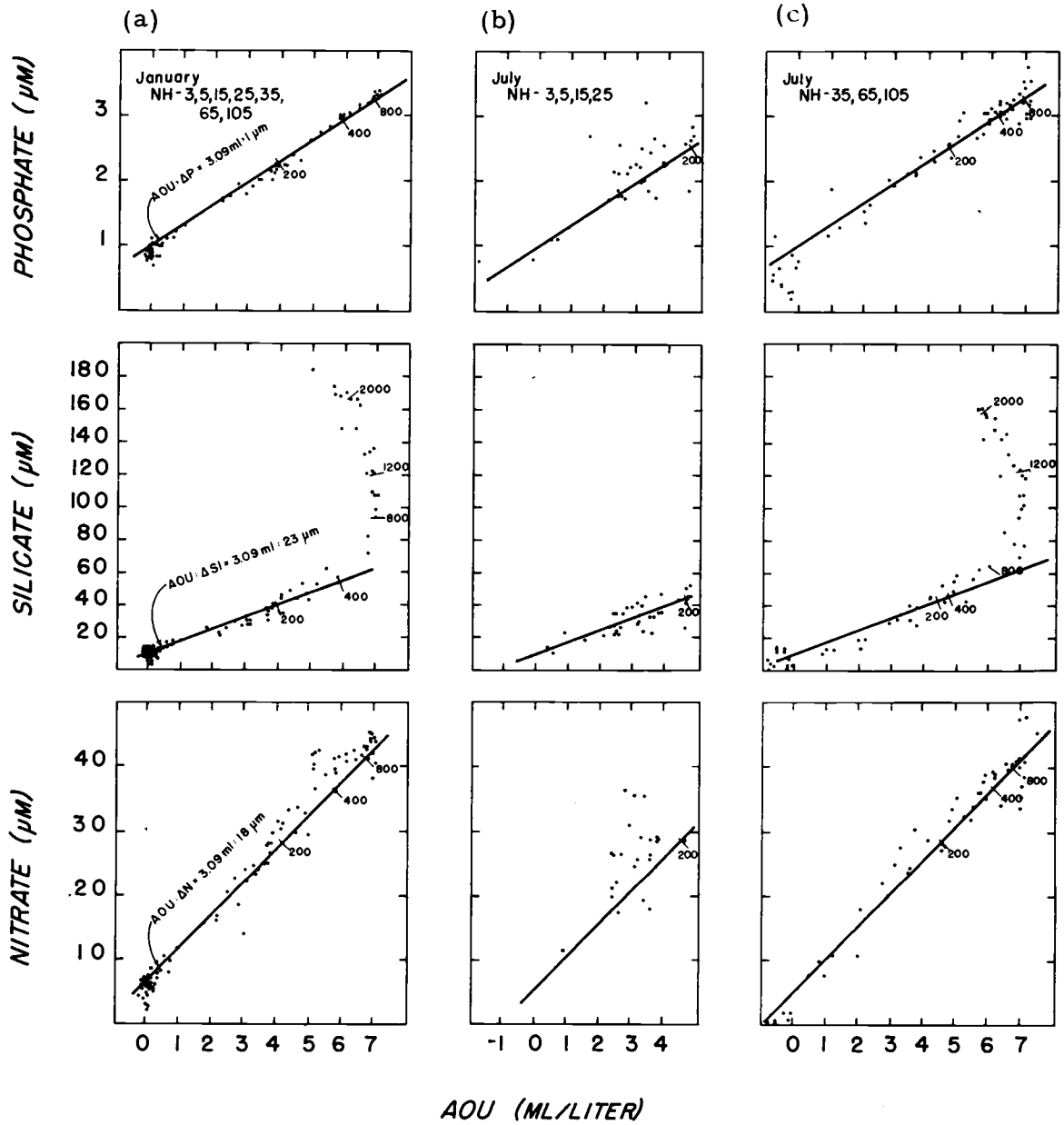


Figure 19. AOU-nutrient relationships for selected stations along the Newport hydrographic line for January and July, 1968. The straight lines are from the biochemical oxidation model of Richards (1965) and from Park (1967). Numerical values are depths in meters.

pounds, may be limiting. Oxygen concentrations greater than 100% saturation under certain hydrographic regimes is related to photosynthesis and nutrient uptake.

An alternate major process altering the oxygen concentration is air-sea exchange. Errors in the accuracy of previously accepted oxygen saturation values have created problems in sea surface equilibrium studies (Richards, 1965b). Richards also suggests that oversaturated waters are associated with regions of convergence or high winds. The Oregon offshore regions fit this category during the winter months. However, evaluation of the degree of equilibrium of surface layers is difficult since biological processes rapidly alter the oxygen concentration.

Negative AOU (or redefined as AOP) should be the net result of biological and exchange processes. The inverse relationship between AOP and nutrient concentration should be observed. For January (Figure 20), there seems to be an increased nutrient concentration with increased AOP so that there may be a net oxygen transport from the atmosphere to seawater. The biological changes in dissolved oxygen are about 0.5 ml/liter for  $23\mu\text{M}$  Si and  $16\mu\text{M}$  N, but 0.25 ml/liter for  $1\mu\text{M}$  P. In summer the reverse is true, with a net transport to the atmosphere. For phosphate,  $1\mu\text{M}$  change correlates to 2.37 ml/liter. This is less than the 3.09 ml/liter AOP: $1\mu\text{M}$  P expected from the assimilation ratio. Thus, there seems to be a net loss of

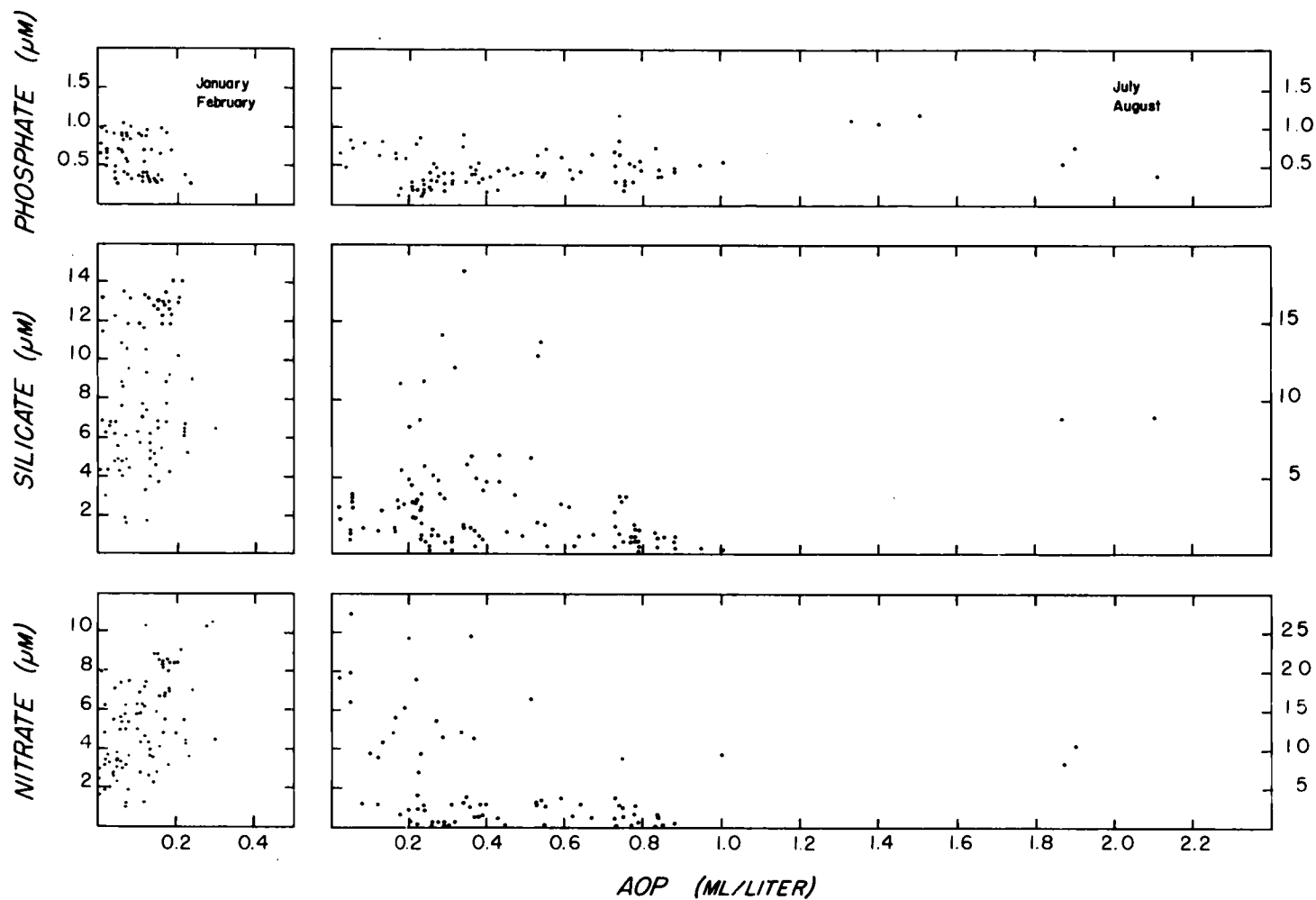


Figure 20. AOP-nutrient relationships along the Newport hydrographic line during January-February and July-August, 1968. Note scale changes for silicate and nitrate between January-February and July-August.



0.7 ml/liter into the atmosphere. Pytkowicz (1964) found that the subsurface oxygen maximum forms as the water temperature rises and oxygen is lost to the atmosphere.

For silicate and nitrate the same is not found. There is 3.49 ml/liter AOP:23 $\mu$ M Si and 5.90 ml/liter AOP:16 $\mu$ M N. This, contrasted to the phosphate, might indicate that assimilation ratios for nitrogen and silicon may not be typical for oceanic-plume conditions. Cissell (1969) found a similar situation.

Nitrate decrease to lower concentrations than silicate and phosphate with AOP increase correlates positively with photosynthetic activity. The low nitrate concentrations (less than 1.0 $\mu$ M) in the plume and near surface open ocean in summer indicate that nitrate is the limiting nutrient in phytoplankton productivity.

#### Preformed Nutrients

Preformed nutrients are essentially constant with depth and are conservative properties uninfluenced by oxidation of organic matter present in the water mass at the time it sank or which have accumulated in the water at depth. Values depend upon the degree to which sea surface conditions influence the synthetic processes at the time of water mass formation. In contrast, the apparent oxygen utilization, or its nutrient equivalent provides a measure of the effect of biological activity on the composition of the water since sinking

below the influence of the atmosphere (Redfield, et al. 1963). Park (1967) has shown that the relationship between preformed nutrient concentrations and AOU is linear with slopes approximating the nutrient ratios of the biochemical oxidation model (Richards, 1965a).

Biological effects and physical processes alter preformed nutrient concentrations. Wind mixing increases the oxygen in dissolved water. Photosynthesis reduces phosphate with subsequent oxygen production.

Relatively little biological activity occurs during the winter with wind mixing and dilution as the primary physical processes. Near-zero and slightly negative AOU's are found in surface waters with a steady increase to a depth of approximately 800m, following a similar pattern as phosphate and nitrate. With preformed nutrients essentially constant with depth, a plot of preformed nutrients vs. AOU should give a straight line. Figure 21 shows such a plot for the entire Newport hydrographic line to a depth of 600m.

Near zero or slightly negative AOU values are observed in surface waters with values increasing to the depth of the oxygen minimum. From Park (1967) preformed phosphate was constant with depth. Preformed phosphate vs. AOU should give a straight line with a zero slope. January data (Figure 21 a) shows a slope greater than zero. The points can be broken into two groups. Values greater than 1.0 ml/liter are for water deeper than 60m. For this section, a

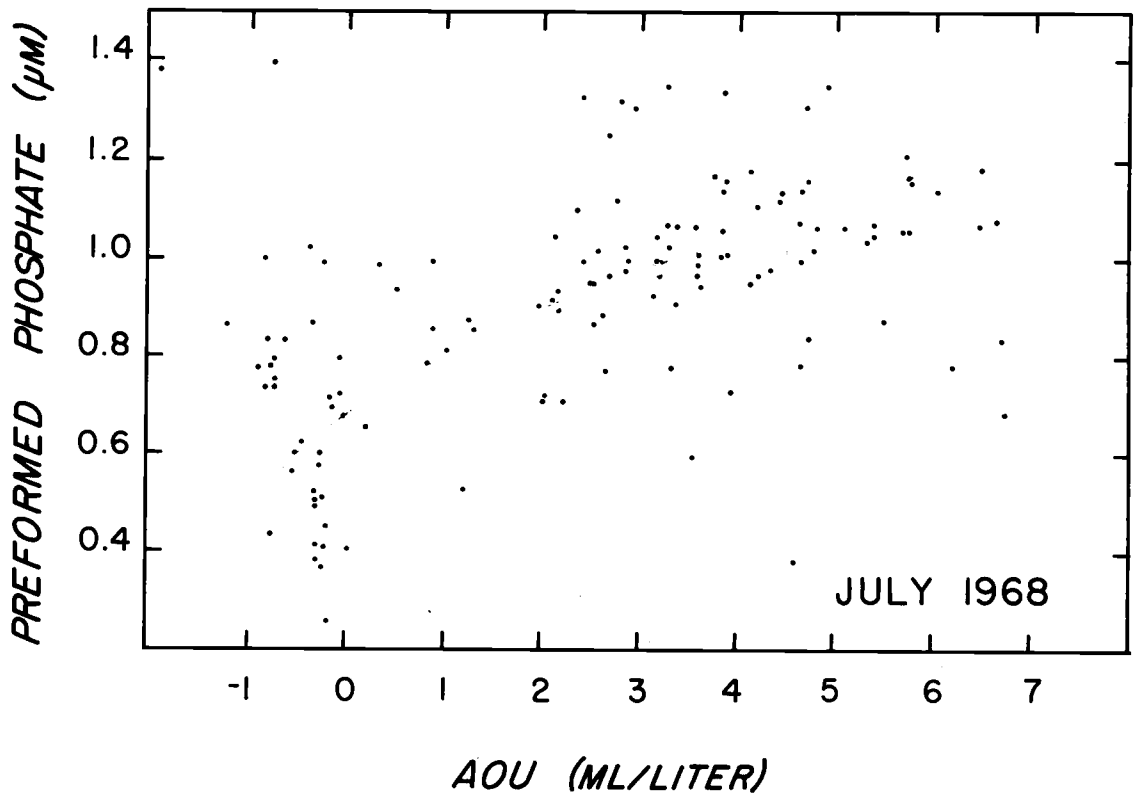
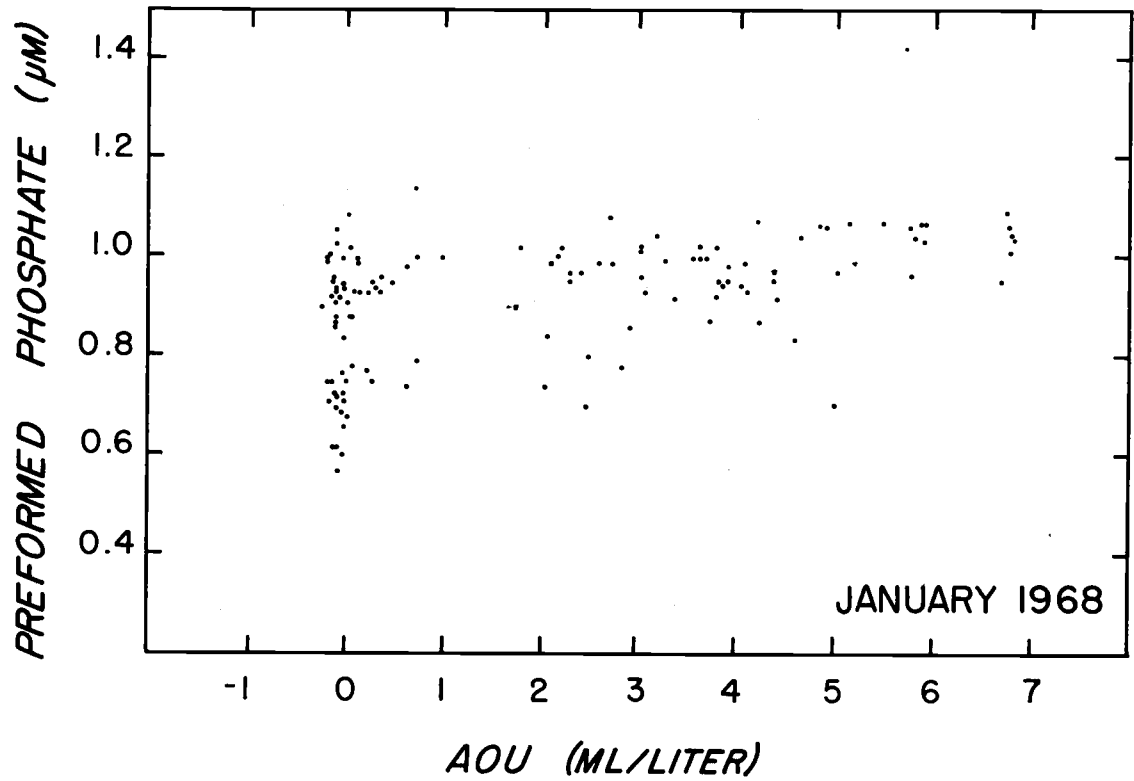


Figure 21. AOU-preformed phosphate relationships for January and July, 1968 to a depth of 600 m.

straight line with a slope of zero is apparent. Values less than 1.0 ml/liter show considerably more scatter, probably due to near-surface biological and physical processes.

In July a more pronounced deviation from the expected zero slope occurs. Biological and physical processes are at their peak with photosynthesis, upwelling and the influx of the plume. Negative AOU's (0 to -1.0 ml/liter are found in the plume water with the most negative values observed near the plume-oceanic "interface." Increasing AOU values are observed below the plume influence and in upwelled water. Upwelled water is lower in oxygen and slightly higher in nutrients and would be expected to fit the curve.

Part of the deviations observed in the line slopes may be due to analytical methods. Manual methods were used for January data while automated methods were used in July. Much of the scatter attributed to biological and physical processes may be due to chemical methods. This problem of slope would be cleared up if better automated methods or manual methods for both months were used.

During the year winter months are "static" in that processes are at their minimum while the summer is "dynamic" with maximum biological and physical processes occurring. The winter profiles are uniform from slightly offshore to the seaward limit of this investigation. Summer months are the most complicated with the combined influence of the Columbia River Plume and coastal upwelling.

However, for a more complete picture of the seasonal distribution of various parameters, several areas for future investigation have become apparent.

1. Improved nutrient methods (especially phosphate) are required which would reduce apparent data scatter.
2. Automated ammonia methods would complete the study of the major nitrogen species with respect to phytoplankton production.
3. A fluorimeter or other methods for chlorophyll would give a better indication of phytoplankton distribution and would give a better correlation to nutrients, oxygen, pH, etc.
4. More seasonal pH and dissolved carbon dioxide ( $P_{CO_2}$ ) studies could also be correlated to phytoplankton productivity and the influence of coastal upwelling and the Columbia River Plume.

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APPENDIX

## APPENDIX

Nutrient data for this thesis (Barstow et al. 1969b) were reduced using the computer program "Nutred." Using a Control Data Corporation 3300 computer, parameters based on oxygen, such as 100% oxygen saturation, apparent oxygen utilization (AOU) and preformed nutrients, were calculated simultaneously. Sample input and output data follow the program listing.

```

PROGRAM NITRED
DIMENSION A(40,19),IJ(40),SCASIO4(9),SCANQ3(6),SS(17)

C
C ARRAY SUBSCRIPT SIGNIFICANCE
C A(K,1)= DEPTH
C A(K,2)= TEMPERATURE
C A(K,3)= SALINITY
C A(K,4)= OXYGEN
C A(K,5)= PHOSPHATE TRANSMISSION (OR ABSORBANCE)
C A(K,6)= SILICATE TRANSMISSION (OR ABSORBANCE)
C A(K,7)= NITRATE TRANSMISSION (OR ABSORBANCE)
C A(K,8)= PHOSPHATE STANDARD CONCENTRATION
C A(K,9)= SILICATE STANDARD CONCENTRATION
C A(K,10)= NITRATE STANDARD CONCENTRATION
C A(K,11)= SILICATE TUBE SIZE
C A(K,12)= NITRATE TUBE SIZE
C A(K,13)= CHLORINITY
C A(K,14)= 100 PERCENT OXYGEN
C A(K,15)= PERCENT OXYGEN SATURATION
C A(K,16)= APPARENT OXYGEN UTILIZATION (AOU)
C A(K,17)= PHOSPHATE ABSORBANCE
C A(K,18)= SILICATE ABSORBANCE
C A(K,19)= NITRATE ABSORBANCE
C SCASIO4(1-3)= SILICATE, SIZE OF TUBE
C SCASIO4(4-6)= SILICATE, SUMMATION OF CONCENTRATIONS
C SCASIO4(7-9)= SILICATE, SUMMATION OF ABSORBANCES
C SCANQ3(1-2)= NITRATE, SIZE OF TUBE
C SCANQ3(3-4)= NITRATE, SUMMATION OF CONCENTRATIONS
C SCANQ3(5-6)= NITRATE, SUMMATION OF ABSORBANCES
C
100 FORMAT(F6.0,F6.2,F6.3,1X,F6.2,2F7.3,F6.2,F7.3,4F6.2)
C COLUMN PLACEMENT FOR PUNCHING
C COL 1-6 DEPTH
C COL 7-12 TEMPERATURE
C COL 13-18 SALINITY
C COL 19 BLANK
C COL 20-25 OXYGEN
C COL 26-32 PHOSPHATE TRANSMISSION OR ABSORBANCE (INCLUDING BLANK
C AND STANDARD VALUES)
C COL 33-39 SILICATE TRANSMISSION OR ABSORBANCE (INCLUDING BLANK
C AND STANDARD VALUES)
C COL 40-45 SILICATE TUBE SIZE
C COL 46-52 NITRATE TRANSMISSION OR ABSORBANCE (INCLUDING BLANK
C AND STANDARD VALUES)
C COL 53-58 NITRATE TUBE SIZE
C COL 59-64 PHOSPHATE STANDARD CONCENTRATION
C COL 65-70 SILICATE STANDARD CONCENTRATION
C COL 71-76 NITRATE STANDARD CONCENTRATION
C STATION HEADER CARD SHOULD START IN COLUMN NO. 2
C IT IS MANDATORY TO HAVE A BLANK AS THE FIRST AND LAST PIECES OF
C DATA FOR A STATION
C NEVER RUN A STANDARD IMMEDIATELY FOLLOWING THE INITIAL BLANK
C ABSORBANCES ENTERED AS .XXX
C PERCENT TRANSMISSION ENTERED AS XX.X (OR XXX.X WHEN GREATER
C THAN 100 PERCENT)
2 I=NCS=0
101 FORMAT(40H )
C READ(45,101)
C CHECK FOR END OF FILE (EOF)
C EQUIP 45 EQUIVALENT TO 60 FOR READING CARDS FROM BATCH
IF(EOF(45))49R,102
C WRITE STATION HEADER CARD

```

```

102 WRITE(40,101)
94  FORMAT(1H/)
   WRITE(40,94)
3   I=I+1
   READ(45,100) (A(I,J),J=1,6),A(I,11),A(I,7),A(I,12),A(I,8),A(I,9),
1A(I,10)
   JJ(I)=3
C   SETS INDICATOR FOR SAMPLES (AS PERCENT TRANSMISSION). FOR
C   SAMPLES (AS ABSORBANCE), BLANKS, AND STANDARDS, THE
C   INDICATOR IS RESET.
   IF(A(I,1).NE.0.0)GO TO 652
C   CHECK BY SUMMING TEMPERATURE AND SALINITY FOR
C   SAMPLES AT ZERO METERS
   U=A(I,2)+A(I,3)
   IF(U.NE.0.0)GO TO 652
C   CHECK FOR STANDARDS BY SUMMING STANDARD CONCENTRATIONS
   U=A(I,8)+A(I,9)+A(I,10)
   IF(U.GT.0.0)GO TO 651
   JJ(I)=1
C   SETS INDICATOR FOR BLANKS
   GO TO 653
651  JJ(I)=2
C   SETS INDICATOR FOR STANDARDS
   GO TO 653
C   CHECK WHETHER NUTRIENT VALUES ENTERED AS ABSORBANCE OR
C   PERCENT TRANSMISSION
652  IF(A(I,5).LT.2.0.AND.A(I,6).LT.2.0.AND.A(I,7).LT.2.0)GO TO 660
C   VALUES LESS THAN 2 ARE ABSORBANCES WHILE VALUES GREATER
C   THAN 2 ARE PERCENT TRANSMISSION
653  IF(A(I,5).EQ.0.0)GO TO 655
   IF(A(I,5).LT.2.0)GO TO 654
C   CONVERT XX.X TO .XXX (PHOSPHATE)
   A(I,5)=A(I,5)/100.
   GO TO 655
C   CONVERT PHOSPHATE ABSORBANCE TO PERCENT TRANSMISSION
654  A(I,5)=10.**(-A(I,5))
C   THIS IS USED WHEN OTHER NUTRIENTS ARE ENTERED AS PERCENT
C   TRANSMISSION
655  IF(A(I,6).EQ.0.0)GO TO 657
   IF(A(I,6).LT.2.0)GO TO 656
C   CONVERT XX.X TO .XXY (SILICATE)
   A(I,6)=A(I,6)/100.
   GO TO 657
C   CONVERT SILICATE ABSORBANCE TO PERCENT TRANSMISSION
656  A(I,6)=10.**(-A(I,6))
657  IF(A(I,7).EQ.0.0)GO TO 670
   IF(A(I,7).LT.2.0)GO TO 658
C   CONVERT XX.X TO .XXX (NITRATE)
   A(I,7)=A(I,7)/100.
   GO TO 670
C   CONVERT NITRATE ABSORBANCE TO PERCENT TRANSMISSION
658  A(I,7)=10.**(-A(I,7))
   GO TO 670
660  A(I,17)=A(I,5)
   A(I,18)=A(I,6)
   A(I,19)=A(I,7)
   JJ(I)=4
C   SETS INDICATOR FOR SAMPLES (AS ABSORBANCE)
670  IF(I.NE.JJ(I))GO TO 3
   IF(I.EQ.1) GO TO 3
C   LAST BLANK READ
   DO 20 K=1,I

```

```

IF (I.I(K).NE.3.AND.J.I(K).NE.4)GO TO 11
NOS=NOS+1
C NOS IS NUMBER OF SAMPLES (INCREMENTED EACH TIME)
C COMPUTE CL (PARTS/1000)
A(K,13)= A(K,3)/1.80655
CL=A(K,13)
T=A(K,2)
C IF NO TEMPERATURE, SALINITY, OR OXYGEN VALUE IS ENTERED, ZEROS
C ARE ENTERED FOR 100 PERCENT OXYGEN, PERCENT OXYGEN SATURATION,
C AND APPARENT OXYGEN UTILIZATION (AOU) IN THE APPROPRIATE ARRAY
C ELEMENT
IF (T.EQ.0.0.OR.A(K,3).EQ.0.0.OR.A(K,4).EQ.0.0)GO TO 202
GO TO 208
202 A(K,14)=A(K,15)=A(K,16)=0.
GO TO 10
C COMPUTE 100 PERCENT OXYGEN SATURATION IN SEAWATER FROM
C TEMPERATURE AND SALINITY. IT IS BASED ON A 3X3 POLYNOMIAL IN
C CHLORINITY AND TEMPERATURE.
208 A(K,14)=((-4.1749907550E-5*T+(-3.7407903703E-5*CL+4.9095207683E-3
1))*T+((-8.588928507E-6*CL+3.3908349454E-3)*CL-2.7301427953E-1
2))*T+((-5.4280676125E-6*CL+8.16735771E-4)*CL-0.12432467262)*CL+
3)).190218467
C COMPUTE PERCENT OXYGEN SATURATION
A(K,15)=(A(K,4)/A(K,14))*100.
C COMPUTE APPARENT OXYGEN UTILIZATION (AOU)
A(K,16)=A(K,14)-A(K,4)
C ARRAY CHANGED TO ABSORBANCE ARRAY WHEN VALUES ENTERED AS
C ABSORBANCE
10 IF (J.I(K).EQ.4)GO TO 20
C CALCULATE ABSORBANCE FOR PHOSPHATE, SILICATE, AND NITRATE
C CHECK. IF ZERO, SET APPROPRIATE ARRAY ELEMENT EQUAL TO ZERO
11 IF (A(K,5).NE.0.0)GO TO 12
A(K,17)=0.
GO TO 13
12 A(K,17)=-ALOG10(A(K,5))
13 IF (A(K,6).NE.0.0)GO TO 14
A(K,18)=0.
GO TO 15
14 A(K,18)=-ALOG10(A(K,6))
15 IF (A(K,7).NE.0.0)GO TO 16
A(K,19)=0.
GO TO 20
16 A(K,19)=-ALOG10(A(K,7))
20 CONTINUE
IL=I-1
C DIFFERENCE IN BLANKS (CORRECTION FACTOR)
CK=I-2
C CK IS NUMBER OF SAMPLES AND STANDARDS
C DIFFERENCE IN INITIAL AND FINAL BLANKS WITH INCREMENTATION FOR
C EACH SAMPLE AND STANDARD VALUE IS CALCULATED FROM THE SLOPE
AT17=(A(I,17)-A(1,17))/IL
AT18=(A(I,18)-A(1,18))/IL
AT19=(A(I,19)-A(1,19))/IL
DO 30 K=2,IL
C IL IS THE LAST SAMPLE OR STANDARD BEFORE THE FINAL BLANK
C=K-1
IF (A(K,17).NE.0.0) A(K,17)=A(K,17)-AT17*C-A(1,17)
IF (A(K,18).NE.0.0) A(K,18)=A(K,18)-AT18*C-A(1,18)
IF (A(K,19).NE.0.0) A(K,19)=A(K,19)-AT19*C-A(1,19)
30 CONTINUE
C COMPUTE OFFSET IF ADJUSTED ABSORBANCES ARE NEGATIVE
DO 403 I=17,19

```

```

CF=0.
DO 404 K=2,IL
404 IF(A(K,I).LT.CF) CF=A(K,I)
   IF(CF.F0.0.0)GO TO 403
   DO 405 K=2,IL
   IF(A(K,I).NE.0.0) A(K,I)=A(K,I)-CF
405 CONTINUE
403 CONTINUE
C   LINEAR INTERPOLATION OF BLANKS IS NOW COMPLETE
DO 33 K=1,9
33 SCAS104(K)=0.
C   CLEARS SCAS104 (THE SILICATE TUBE SIZE)
DO 34 K=1,6
34 SCAN03(K)=0.
C   CLEARS SCAN03 (THE NITRATE TUBE SIZE)
FPC4=SAP04=0.
C   FPC4 IS PHOSPHATE STANDARD CONCENTRATION
C   SAP04 IS ABSORBANCE OF PHOSPHATE STANDARDS
DO 50 K=2,IL
IF(JJ(K).NE.2) GO TO 50
FPC4=FPC4+A(K,8)
SAP04=SAP04+A(K,17)
C   THERE IS ONLY ONE TUBE SIZE FOR PHOSPHATE
DO 35 L=1,3
IF(SCAS104(L).EQ.A(K,11))GO TO 38
C   SCAS104 (1-3) IS THE SILICATE TUBE SIZE
C   IF THE PROPER TUBE SIZE IS FOUND GO TO 38
35 CONTINUE
DO 36 L=1,3
IF(SCAS104(L).EQ.0.0)GO TO 37
C   SEES IF THERE IS ROOM TO ADD A TUBE SIZE
36 CONTINUE
39 FORMAT(= ALLOWED NO. OF SILICATE TUBE SIZES EXCEEDED=)
WRITE(40,39)
GO TO 50
C   IF THERE IS NO ROOM TO PUT IN THE NEW SIZE IGNORE
37 SCAS104(L)=A(K,11)
38 SCAS104(L+3)=SCAS104(L+3)+A(K,9)
C   SCAS104 (4-6) IS THE SUMMATION OF SILICATE STANDARD CONCENTRATIONS
SCAS104(L+6)=SCAS104(L+6)+A(K,18)
C   SCAS104 (7-9) IS THE SUMMATION OF SILICATE STANDARD ABSORBANCES
C   COMPLETION OF SUMMATION OF CONCENTRATION AND ABSORBANCE FOR
C   SILICATE
DO 40 L=1,2
IF(SCAN03(L).EQ.A(K,12)) GO TO 43
C   SCAN03 (1-2) IS THE NITRATE TUBE SIZE
40 CONTINUE
DO 41 L=1,2
IF(SCAN03(L).EQ.0.0)GO TO 42
41 CONTINUE
44 FORMAT(= ALLOWED NO. OF NITRATE TUBE SIZES EXCEEDED=)
WRITE(40,44)
GO TO 50
42 SCAN03(L)=A(K,12)
43 SCAN03(L+2)=SCAN03(L+2)+A(K,10)
C   SCAN03 (3-4) IS THE SUMMATION OF NITRATE STANDARD CONCENTRATIONS
SCAN03(L+4)=SCAN03(L+4)+A(K,19)
C   SCAN03 (5-6) IS THE SUMMATION OF NITRATE STANDARD ABSORBANCES
50 CONTINUE
C   SUMMATION OF CONCENTRATIONS AND ABSORBANCES FOR PHOSPHATE,
C   SILICATE, AND NITRATE COMPLETE
IF(SAP04.NE.0.0) FPC4=FPC4/SAP04

```



```

C      FPC4 IS NOW THE FACTOR FOR PHOSPHATE
      DO 51 L=4,6
      IF(SCAST04(L+3).EQ.0.0)GO TO 51
      SCAST04(L)=SCAST04(L)/SCAST04(L+3)
C      SCAST04 (4,5,6) NOW HOLDS THE FACTORS FOR SILICATE
51    CONTINUE
      DO 52 L=3,4
      IF(SCAN03(L+2).EQ.0.0)GO TO 52
      SCAN03(L)=SCAN03(L)/SCAN03(L+2)
C      SCAN03 (3,4) NOW HOLDS THE FACTORS FOR NITRATE
52    CONTINUE
C      FACTOR CALCULATIONS ARE COMPLETE
C      PRINT DATA TABLE COLUMN HEADS
55    FORMAT(70      DEPTH      TEMP      SALINITY CHLORINITY 100% OXY #
14     OXYGEN  OXYSATN      AOU      CONC PO4  PRE  PO4  CONC SIO4 #
2# CONC NO3  PRE  NO3 #)
      WRITE(40,55)
      DO 70 L=2,IL
      IF(J1(L).NE.3.AND.J1(L).NE.4)GO TO 70
      DO 63 K=1,3
      IF(SCASIO4(K).EQ.A(L,11))GO TO 64
63    CONTINUE
      GO TO 69
64    DO 65 KK=1,2
      IF(SCAN03(KK).EQ.A(L,12))GO TO 66
65    CONTINUE
      GO TO 73
C      CALCULATION OF NUTRIENT CONCENTRATIONS AND PERFORMED PHOSPHATES
C      AND NITRATES
66    CP04=A(L,17)*FPC4
      CSIO4=A(L,18)*SCASIO4(K+3)
      CN03=A(L,19)*SCAN03(KK+2)
      IF(CP04.EQ.0.0.OR.A(L,16).EQ.0.0)GO TO 300
      GO TO 303
300    PPO4=0.
      GO TO 304
303    PPO4=CP04-0.324*A(L,15)
304    IF(CN03.EQ.0.0.OR.A(L,16).EQ.0.0)GO TO 305
      GO TO 306
305    PNO3=0.
      GO TO 310
306    PNO3=CN03-5.28*A(L,16)
C      PRINT DATA
67    FORMAT(1H0,2X,F8.0,2X,F8.2,2(2X,F8.3),9(2X,F8.2))
310   WRITE(40,67)A(L,1),A(L,2),A(L,3),A(L,13),A(L,14),
1A(L,4),A(L,15),A(L,16),CP04,PPO4,CSIO4,CN03,PNO3
      GO TO 70
68    FORMAT(1H0,2X,F8.0,2X,F8.2,2(2X,F8.3),4(2X,F8.2),#
1#SILICATE TUBE SIZE ERROR #)
C      ERROR = WRONG SIZE OR NO INFORMATION ON IT
69    WRITE(40,68)A(L,1),A(L,2),A(L,3),A(L,13),A(L,14),
1A(L,4),A(L,15),A(L,16)
71    FORMAT(1H0,2X,F8.0,2X,F8.2,2(2X,F8.3),4(2X,F8.2),#
1#NITRATE TUBE SIZE ERROR #)
73    WRITE(40,71)A(L,1),A(L,2),A(L,3),A(L,13),A(L,14),
1A(L,4),A(L,15),A(L,16)
70    CONTINUE
C      PRINT SILICATE FACTOR AND TUBE SIZE USED FOR FACTOR
80    FORMAT(# SIO4 F= #,F8.3,# TUBE SIZE = #,F8.1/)
      WRITE(40,80)
      DO 82 M=4,6
      IF(SCASIO4(M).EQ.0.0)GO TO 82

```

```
WRITE(40,80) SCAS104(M),SCAS104(M-3)
82 CONTINUE
C PRINT NITRATE FACTOR AND TUBE SIZE USED FOR FACTOR
83 FORMAT(7 NO3 F= *.F8.3.* TUBE SIZE = *.F8.1/)
DO 84 M=3,4
IF(SCAN03(M).EQ.0.0)GO TO 84
WRITE(40,83) SCAN03(M),SCAN03(M-2)
84 CONTINUE
90 FORMAT(7 PO4 F= *.F8.3)
C PRINT PHOSPHATE FACTOR
WRITE(40,90)FPO4
72 FORMAT(1H1)
WRITE(40,72)
GO TO 2
494 CONTINUE
END
```

**INPUT DATA**

C6809D NH-105 26 SEPT. 196A

Depth	Temp	Salinity	O <sub>2</sub>	PO <sub>4</sub>	SiO <sub>2</sub>	Tube size	NO <sub>3</sub>	Tube size	PO <sub>4</sub>	SiO <sub>2</sub>	NO <sub>3</sub>
0.	16.32	31.844	5.81	94.5	87.4	.6	99.6				
10.	16.33	31.844	5.73	94.0	87.2	.6	99.6				
31.	10.18	32.444	7.24	92.4	95.7	.6	99.5				
51.	8.64	32.562	5.89	87.0	78.5	.6	75.5				
76.	8.27	32.994	5.06	83.9	59.1	.6	62.0				
102.	8.13	33.520	3.91	75.3	41.4	.6	31.9				
127.	7.81	33.780	3.41	73.7	34.1	.6	27.6				
153.	7.40	33.879	3.12	72.5	28.7	.6	24.7				
177.	7.07	33.914	3.05	71.7	23.7	.1	23.7				
				68.4	21.1	.6	27.9	3.	50.	25.	
				58.6	21.2	.6	29.0	3.	50.	25.	
178.	6.98	33.918	3.21	72.0	25.7	.6	24.1				
204.	6.70	33.953	2.70	69.9	21.4	.6	20.5				
				59.4	74.7	.1	28.4	3.	50.	25.	
				59.5	74.7	.1	28.4	3.	50.	25.	
				99.7	99.2		99.0				

Transmission (%)

Standard (µM)

**OUTPUT DATA**

C6809D NH-105 26 SEPT. 196A

DEPTH	TEMP	SALINITY	CHLORINITY	100% OXY	OXYGEN	OXYSATN	AOU	CONC PO4	PRE PO4	CONC SiO4	CONC NO3	PRE NO3
0	16.32	31.844	17.627	5.65	5.81	102.44	-0.16	.27	.32	4.14	.00	.85
10	16.33	31.844	17.627	5.65	5.73	101.44	-0.08	.30	.33	4.23	0	0
31	10.18	32.444	17.959	6.40	7.24	113.18	-0.84	.40	.68	1.21	.02	4.47
51	8.64	32.562	18.024	6.62	5.89	89.01	.73	.75	.51	7.62	5.52	1.64
76	8.27	32.994	18.264	6.66	5.06	76.03	1.60	.96	.44	16.79	9.45	1.03
102	8.13	33.520	18.555	6.65	3.91	58.76	2.74	1.58	.69	28.30	22.71	8.22
127	7.81	33.780	18.699	6.69	3.41	50.96	3.28	1.71	.65	34.57	25.59	9.26
153	7.40	33.879	18.753	6.75	3.12	46.21	3.63	1.81	.63	40.14	27.81	8.63
177	7.07	33.914	18.773	6.80	3.05	44.44	3.75	1.87	.66	42.73	28.63	8.82
178	6.98	33.918	18.775	6.82	3.21	47.09	3.61	1.86	.69	43.40	28.29	9.25
204	6.70	33.953	18.794	6.86	2.70	39.36	4.16	2.03	.68	49.61	31.52	9.55

SiO<sub>4</sub> F = 74.440 TUBE SIZE = .6

SiO<sub>4</sub> F = 405.604 TUBE SIZE = .1

NO<sub>3</sub> F = 45.930 TUBE SIZE = 0

PO<sub>4</sub> F = 13.104