NUTRIENT INVERSIONS IN THE SOUTHEASTERN TROPICAL PACIFIC OCEAN [1, 2]

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ABSTRACT

Nutrient inversions in the offshore southeastern tropical Pacific Ocean are described. At a typical station nutrients such as nitrate and phosphate are high at the surface, are at a minimum at about 100 m depth, and then increase at greater depths. Silicate follows this distribution to a lesser degree. These inversions occur from lat 8 to 15°S and are more pronounced in sections along long 126°W and 119°W than in sections farther east. The nutrient minimum is associated with water having a salinity maximum. It is suggested that such water may have acquired its characteristics in the mixed layer in areas to the south or southeast where the nutrients were depleted by phytoplankton, and has then sunk below high-nutrient and relatively fresh water carried westward from the Peru Current. However, the nutrients may also have been depleted in situ since the low-nutrient water contains a maximum amount of chlorophyll.

In water where nutrients are limiting phytoplankton growth, they are typically at minimum concentrations in the surface and mixed layer, increase at the thermocline, and reach a maximum below this depth. Such typical distributions are shown by Sverdrup, Johnson, and Fleming (1942) and by Riley and Skirrow (1965). The EASTROPAC data show such distributions in all parts of the nutrient-poor water of the northeastern tropical Pacific Ocean (Thomas, 1970, 1971, and unpublished data).

The purpose of this paper is to describe a different distribution occurring in the south tropical Pacific Ocean in which nutrient concentrations are typically high at the surface, are at a minimum at depths just above the permanent thermocline, and then increase at greater depths. In this paper this unusual distribution is called a "nutrient inversion."

METHODS

The EASTROPAC sampling program and vessel track charts are given in the Introduction to the EASTROPAC Atlas (Love, 1970). Nutrients (nitrate, nitrite, phosphate, and silicate) from Nansen bottle samples were analyzed with the Technicon® Autoanalyzer[4] using the methods of Armstrong, Stearns, and Strickland (1967) or manually, using methods outlined by Strickland and Parsons (1968). Vertical sections along given longitudes were plotted by computer (Love, 1970).

RESULTS

During February-March 1967, nutrient inversions were found at several stations near lat 10°S and along long 112°W, 119°W, and 126°W. A typical inversion is shown in Figure 1 for EASTROPAC Station 11.140; three nutrients—nitrate, phosphate, and silicate—show minima at

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[4] Reference to trade names in this publication does not imply endorsement of commercial products by the National Marine Fisheries Service.

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about 60 to 140 m depth. The inversion is particularly pronounced for nitrate, where concentrations in the minimum reach nearly undetectable levels.

The inversions are also apparent in vertical sections. Section 11-NO_3-V2 from the EASTROPAC Atlas (Thomas, 1971) is shown in Figure 2. This section was taken along long 119°W in February 1967 and shows that the inversion extends from about lat 8° to 15°S.

Similar sections occupied in February-March 1967 showed the inversions along long 126°W (from lat 8° to 15°S) and along long 112°W (from lat 8° to 10°S). The nitrate data show inversions much more clearly than phosphate or silicate data. Inversions in nitrate concentration are barely detectable in sections to the east at these latitudes—along long 105°W, 98°W, or 92°W—because concentrations at similar depths are higher. The inversion phenomenon is most pronounced in the westerly sections of the EASTROPAC data.

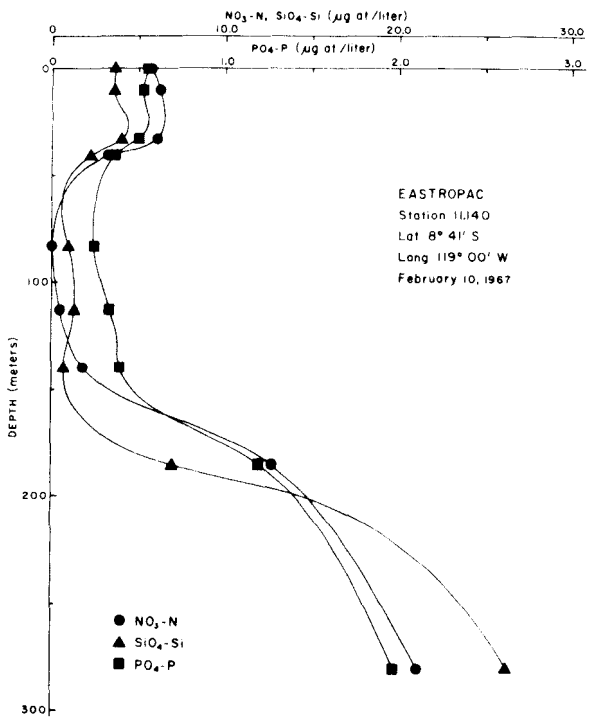

FIGURE 1.—Distribution of nitrate-N, silicate-Si, and phosphate-P concentrations with depth at EASTROPAC station 11.140, February 10, 1967.

The nitrate inversion was again detected in the southern summer of 1968 (February-March) during the third EASTROPAC survey (Thomas, unpublished Atlas data). At that time it was apparent along long 119°W (from lat 9° to 15°S), but not at more easterly longitudes. The long 126°W line was not sampled at this time.

It is not known whether inversions along these longitudes are permanent, nonseasonal features, since the second EASTROPAC survey during the southern winter (August-September 1967) and the EASTROPAC monitoring cruises (which took place between the multiship surveys) reached only lat 5°S. At this latitude inversions were not found.

DISCUSSION

Such nutrient inversions were not commented upon prior to EASTROPAC because this was the first expedition to measure a relatively complete suite of nutrients over a broad area of the eastern tropical Pacific Ocean. However, there are indications of such inversions in phosphate at many of the EQUAPAC stations taken in August-September 1956 during Cruise 35 of the RV *Hugh M. Smith* (Austin, 1957). The *Smith* traversed long 135°W, 143°W, 151°W, and 160°W from about lat 3°N to 19°S, and many of the stations taken from lat 5°S to 19°S show minimum phosphate values at about 100 to 160 m depth. The inversions probably would have been readily apparent if nitrate analyses had been made during *Smith* Cruise 35.

Such inversions are not found in stations taken from lat 7° to 15°S and long 162°W and 175°W in the nitrate, phosphate, or silicate data from cruise STYX in June-July 1968 (Reid, unpublished data). However, they are found to a slight extent in this same area when the nitrate data from a *Gascoyne* cruise in 1961 are examined (C.S.I.R.O., 1967).

This water having a minimum nutrient concentration has a high salinity. Figure 3 (from Tsuchiya, unpublished Atlas data) shows a salinity section along long 119°W in February 1967 from the EASTROPAC observations. The maximum in salinity clearly corresponds to the nutrient minimum shown in Figure 2.

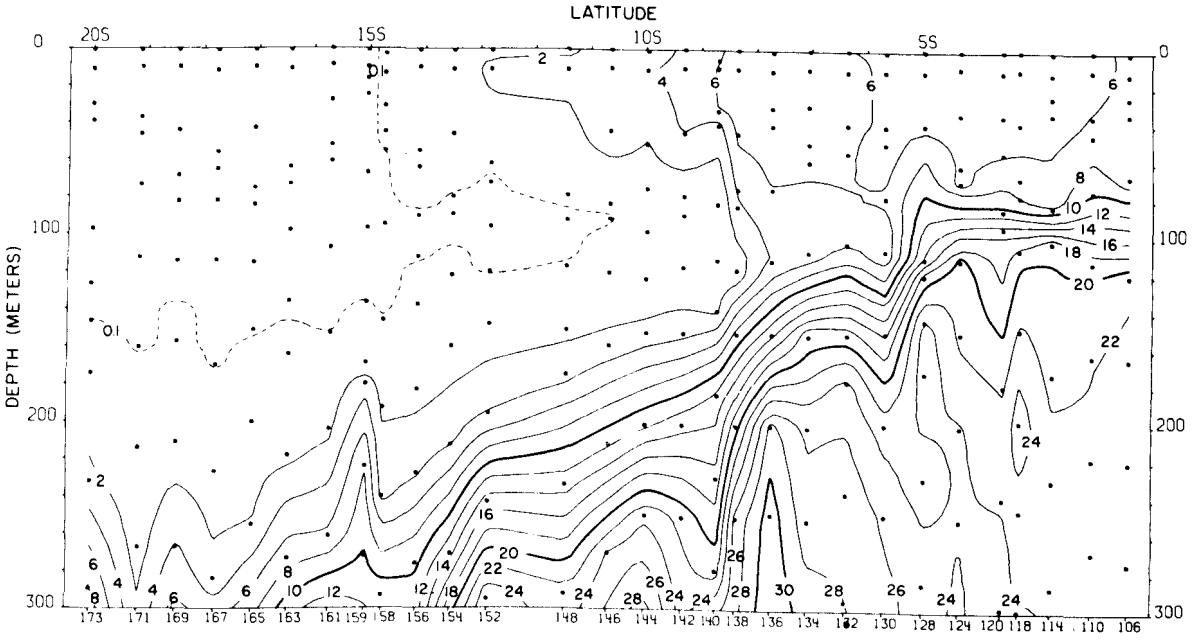

FIGURE 2.—Vertical distribution of nitrate-N (μg-at/liter) along long 119°W from lat 1°14'S to 20°00'S, February 7-14, 1967.

It is not easy to explain these distributions. There is a possibility that the subsurface water has been depleted of nutrients in situ since this water has a maximum chlorophyll concentration (Owen and Zeitzschel, 1971). On the other hand, one can envisage two water masses that impinge on each other. One of these, the low-salinity, high-nutrient, surface, and near-surface water, may have drifted to the west from the Peru Current via the South Equatorial Current. The horizontal maps of nutrients at 10 m (Thomas, 1971, and unpublished Atlas data) show that near-surface nutrients are high at these latitudes from Peru at least west to long 126°W, and Wyrtki (1966, Figures 1 and 2) indicates such westward surface currents. One can then envisage that the second water mass, containing high-salinity water that is depleted in nutrients, has its origin in the South Pacific Gyre and has sunk below the first water mass and drifted in from the southeast. Geostrophic flow of the maximum salinity water is predominantly from the east or southeast in the EASTROPAC area (Tsuchiya, unpublished Atlas observations) and similar flow from the east was shown by Tsuchiya (1968) in his Figure 6 for the 300 cl/t δ_t surface which has a depth of 50-100 m in this area. It should be mentioned that the data are very sparse in the area to the south and southeast of these inversions and their full explanation may await further data collection and analysis.

The nitrate data show the inversion more clearly than data for other nutrients, because nitrogen is more limiting to phytoplankton than phosphate or silicate in near-surface water to the south of these inversions (Thomas, 1969) and is possibly limiting in the water where the nutrients were depleted.

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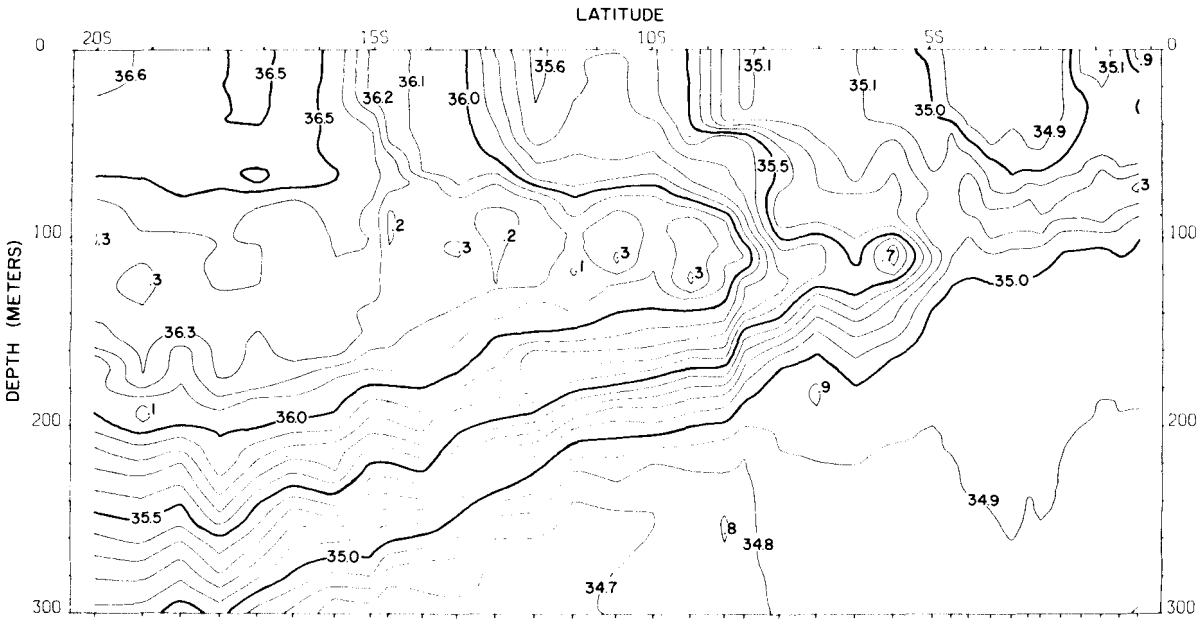

FIGURE 3.—Vertical distribution of salinity (‰) along long 119°W from lat 1°14'S to 20°00'S, February 7-14, 1967.

LITERATURE CITED

ARMSTRONG, F. A. J., C. R. STEARNS, AND J. D. H. STRICKLAND.
1967. The measurement of upwelling and subsequent biological processes by means of the Technicon Autoanalyzer® and associated equipment. Deep-Sea Res. 14:381-389.

AUSTIN, T. S.
1957. Summary, oceanographic and fishery data, Marquesas Islands area, August-September, 1956 (EQUAPAC). U.S. Fish. Wildl. Serv., Spec. Sci. Rep. Fish. 217, 186 p.

C.S.I.R.O. AUSTRALIA
1967. Oceanographic observations in the Pacific Ocean in 1961 H.M.A.S. *Gascoyne* Cruise G 3/61. C.S.I.R.O. (Commonw. Sci. Ind. Res. Organ.), Oceanogr. Cruise Rep. 12, 126 p.

LOVE, C. M. (editor).
1970. Introduction. EASTROPAC atlas, Vol. 4, p. 1-5. Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv. Circ. 330.

OWEN, R. W., JR., AND B. ZEITZSCHEL.
1970. Phytoplankton standing stocks and production. *In* C. M. Love (editor), EASTROPAC atlas, Vol. 4, p. 9-10. Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv., Circ. 330.
1971. Phytoplankton (64 maps). *In* C. M. Love (editor), EASTROPAC atlas, Vol. 2. Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv., Circ. 330.

RILEY, J. P., AND G. SKIRROW.
1965. Chemical Oceanography, Vol. I. Academic Press, Lond. and N.Y., 712 p.

STRICKLAND, J. D. H., AND T. R. PARSONS.
1968. A practical handbook of seawater analysis. Fish. Res. Board Can., Bull. 167, 311 p.

SVERDRUP, H. H., M. W. JOHNSON, AND R. H. FLEMING.
1942. The oceans, their physics, chemistry, and general biology. Prentice-Hall, N.Y., 1087 p.

THOMAS, W. H.
1969. Phytoplankton nutrient experiments off Baja California and in the eastern equatorial Pacific Ocean. J. Fish. Res. Board Can. 26:1133-1145.
1970. Nutrient chemistry. *In* C. M. Love (editor), EASTROPAC atlas, Vol. 4, p. 8. *Also* 66 nutrient chemistry maps. Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv., Circ. 330.
1971. Nutrient chemistry (106 maps). *In* C. M. Love (editor), EASTROPAC atlas, Vol. 2. Natl. Oceanic Atmos. Adm., Natl. Mar. Fish. Serv., Circ. 330.

TSUCHIYA, M.
1968. Upper waters of the intertropical Pacific Ocean. Johns Hopkins Oceanogr. Stud. 4, 50 p, 7 fig.

WYRTKI, K.
1966. Oceanography of the eastern equatorial Pacific Ocean. Oceanogr. Mar. Biol. Annu. Rev. 4: 33-68.