LBL-13209 c.2

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

EARTH SCIENCES DIVISION

Presented at the U.S. Department of Energy/Marine Technology Society 8th Ocean Energy Conference 1981, Washington, D.C., June 7-11, 1981

NUTRIENT AND DISSOLVED OXYGEN STUDIES AT OTEC SITES

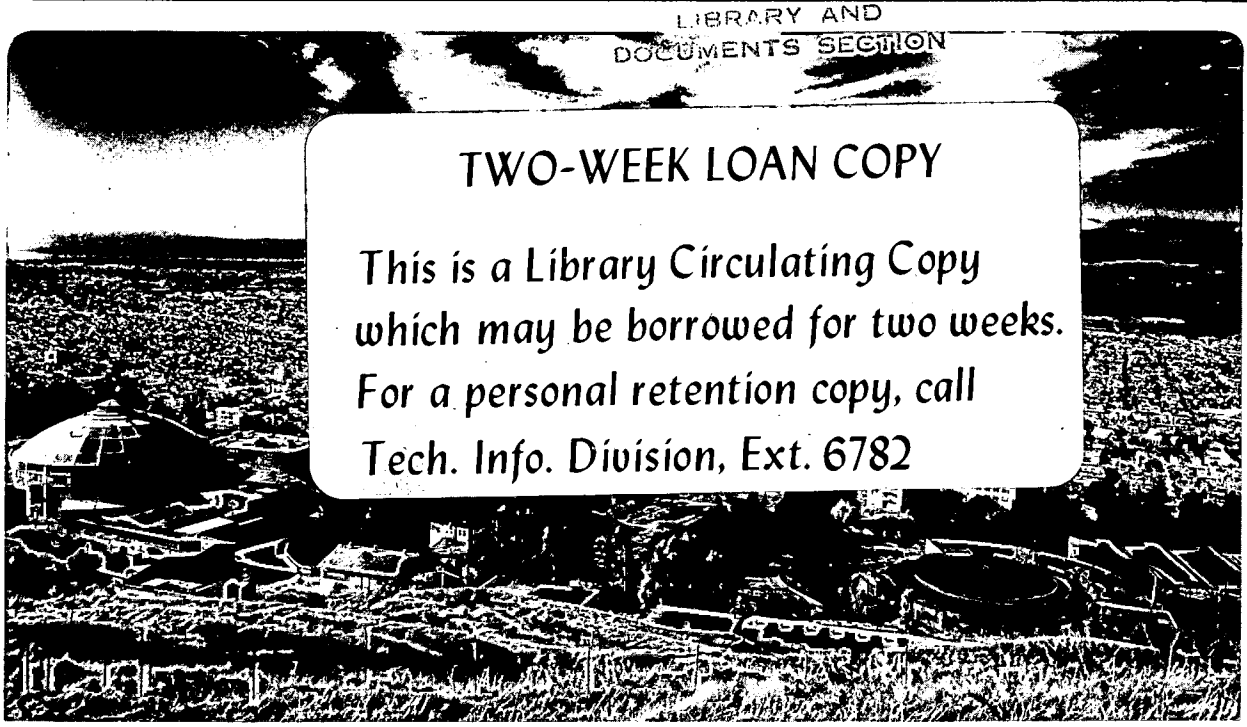
Mary S. Quinby-Hunt, Kent Fanning, David Ziemann, Ted W. Walsh, and George A. Knauer

July 1981

RECEIVED
LAWRENCE
BERKELEY LABORATORY

OCT 13 1981

LIBRARY AND
DOCUMENTS SECTION



TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 6782

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

LBL-13209 c.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL-13209

Nutrient and Dissolved Oxygen Studies at OTEC Sites

Mary S. Quinby-Hunt
Lawrence Berkeley Laboratory
University of California, Berkeley, CA 94720

Kent Fanning
Florida Institute for Oceanography
St. Petersburg, Florida

David Ziemann
Aecos, Inc.
Honolulu, Hawaii

Ted W. Walsh
Hawaii Institute of Marine Biology
Honolulu, Hawaii

George A. Knauer
Moss Landing Marine Laboratory
Moss Landing, California

July 1981

This work was prepared for the Assistant Secretary for Conservation and Renewable Energy, Office of Solar Power Applications, Division of Ocean Energy Systems, U.S. Department of Energy under contract W-7405-ENG-48.

Nutrient and Dissolved Oxygen Studies at OTEC sites

Mary S. Quinby-Hunt
Lawrence Berkeley Laboratory
Berkeley, California 94720

Kent Fanning
Florida Institute for Oceanography
St. Petersburg Florida

David Ziemann
Aecos, Inc.
Honolulu, Hawaii

Ted W. Walsh
Hawaii Institute of Marine Biology
Honolulu, Hawaii

George A. Knauer
Moss Landing Marine Laboratory
Moss Landing, California

Abstract

Significant differences between nutrient concentrations have been found at the Caribbean and Hawaiian sites. There is also evidence of seasonal variation at the Oahu site.

INTRODUCTION

Nutrients are chemical species necessary for the growth of marine organisms. These include compounds of nitrogen, phosphorus, silicon and some of the trace elements. Of particular importance are nitrates, ortho- (or reactive) phosphates and silicates. In the open ocean, these species are found in low levels near the surface and through the photic zone, then increase in concentration by several orders of magnitude with depth.

Dissolved oxygen, also important for most organisms in the upper ocean, is usually at a maximum near the surface. Below the mixed zone, the concentration declines to a minimum and then increases.

The operation of an Ocean Thermal Energy Conversion (OTEC) plant will transport nutrient-rich waters or oxygen poor waters from the deep ocean and discharge them into the nutrient poor waters nearer the surface. This artificial upwelling could potentially alter the local species composition near an OTEC site by increasing the local primary productivity.

In order to adequately assess the impact of artificial upwelling and other possible ecolgical impacts of OTEC operations on the chemistry of the water column at OTEC sites, studies were initiated at several potential OTEC sites; the Gulf of Mexico (GOTEC Sites, Mobile and Tampa), Puerto Rico (PROTEC Site), the South Atlantic (SOTEC), the U.S. Virgin Islands (VOTEC Site, off St. Croix), and Hawaii (the HOTEC site off the island of Hawaii and the O'OTEC site off Oahu). Serial data were taken at bimonthly intervals at the GOTEC, HOTEC and O'OTEC sites. At the PROTEC site data was collected on a seasonal basis. Four semi-annual cruises have gone to the SOTEC site and a single data set was collected at St. Croix as part of a particle study.

At most sites, hydrocasts were taken at approximately noon and midnight to a depth of about 1000m; samples were collected from about 15 depths to be analyzed for nitrates, nitrites, reactive phosphate, silicate and dissolved oxygen. At the O'OTEC, HOTEC, PROTEC and GOTEC sites samples were analyzed for various other parameters including ammonia, total organic phosphorus and carbonate alkalinity.

This paper will present and compare preliminary data on nitrates, phosphates, silicates and dissolved oxygen (D.O.) from several of these potential OTEC sites - HOTEC, O'OTEC, PROTEC and VOTEC. The Hawaiian sites are located on the west coast of the big island of Hawaii at 19° 56'N, 156° 08'W and off the western coast of Oahu at 21° 19'N, 158° 12'W, site 1, and 21° 24'N, 158° 16'W, site 2 (figure 1).

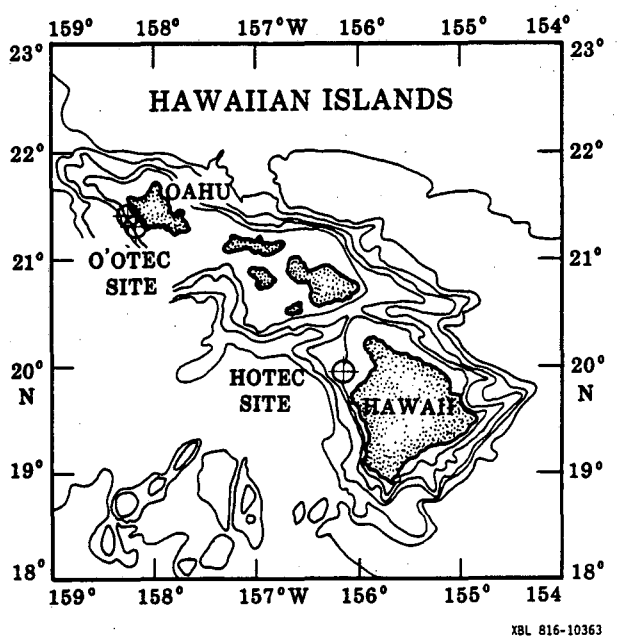


Figure 1. Map showing location of the HOTEC (Hawaii) and O'OTEC (Oahu) Sites.

The PROTEC site is located off Punta Tuna, Puerto Rico at 17°54′N, 65°45′W; the VOTEC site was on the south west corner of St. Croix, Virgin Islands at 17°41′N, 64°59′W (figure 2).

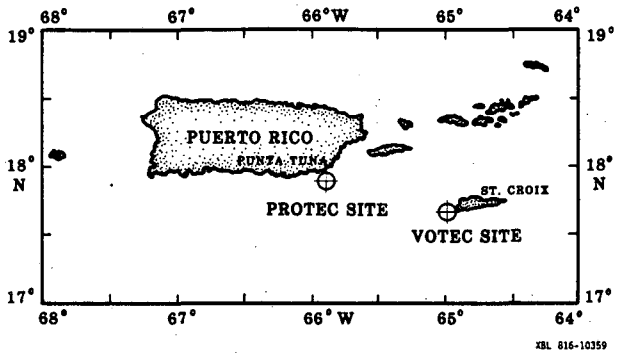


Figure 2. Map showing location of the PROTEC (Punta Tuna) and VOTEC (St. Croix, Virgin Islands) Sites. The data will also be compared to archival data from those locations.

1. DIFFERENCES OBSERVED BETWEEN THE CARIBBEAN AND PACIFIC SITES.

As observed by Sverdrup, Johnson and Fleming (1942), the nutrients and dissolved oxygen have distinctly different profiles in the Atlantic Ocean/Caribbean Sea and in the Pacific Ocean. Indeed a comparison of the data at the two Caribbean Sites and the Hawaiian sites (Figures 3 - 6) shows precisely those differences.

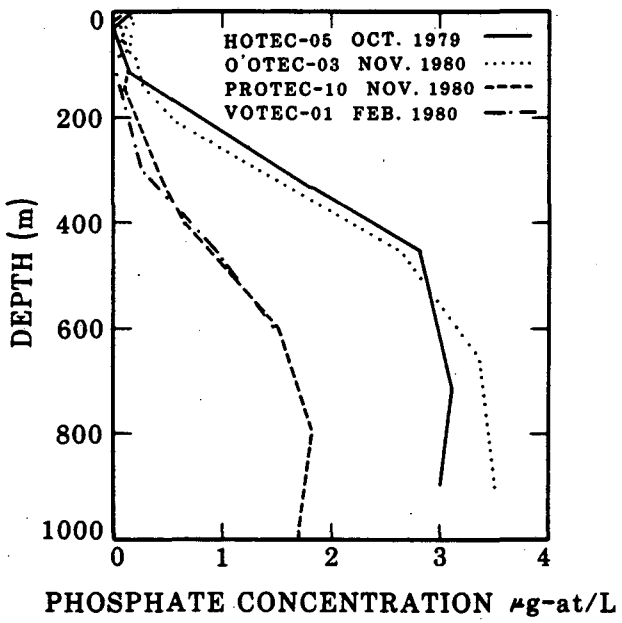


Figure 3 Plot of o-Phosphate concentration observed during October-November at the PROTEC (Puerto Rico), HOTEC (Hawaii) and O'OTEC (Oahu) Sites and February at the VOTEC (Virgin Islands).

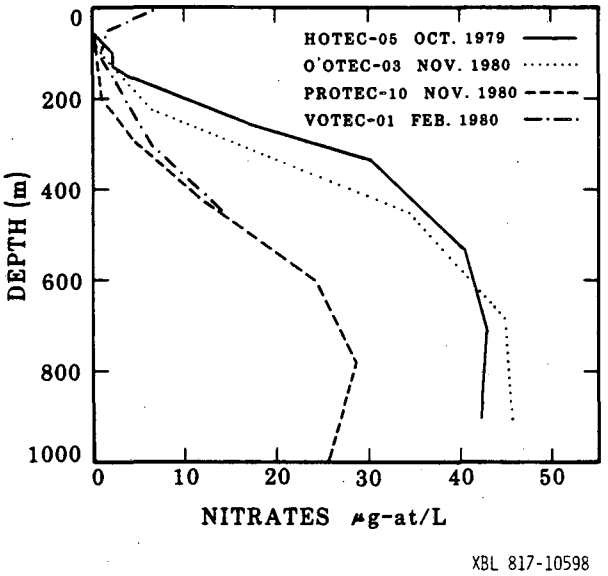


Figure 4. Plot of Nitrate concentration observed during October-November at the PROTEC (Puerto Rico), HOTEC (Hawaii) and O'OTEC (Oahu) Sites and February at the VOTEC (Virgin Islands) Site.

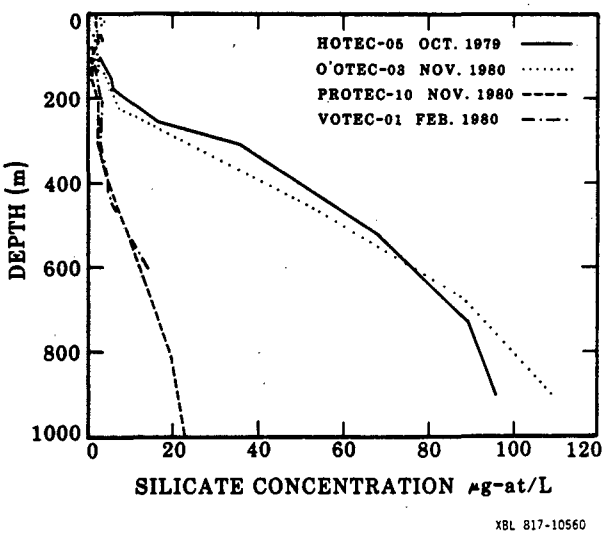


Figure 5. Plot of Silicate concentration observed during October-November at the PROTEC (Puerto Rico), HOTEC (Hawaii) and O'OTEC (Oahu) Sites and February at the VOTEC (Virgin Islands) Site.

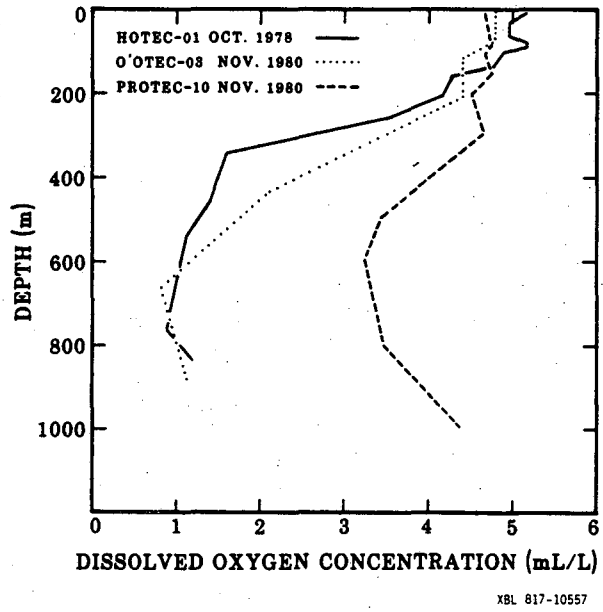


Figure 6. Plot of Dissolved Oxygen concentration observed during October-November at the PROTEC (Puerto Rico), HOTEC (Hawaii) and O'OTEC (Oahu) Site and February at the VOTEC (Virgin Islands) Site.

Figures 3, 4 and 5 show that nitrate, phosphate and silicate concentrations are uniformly low at the surface at all sites, but at depth, concentrations in the Pacific are much higher. Figure 6 shows that dissolved oxygen is comparable for both oceans in the mixed layer, but that in the Hawaiian sites the oxygen minimum is much more pronounced. The minimum concentration reported for the Punta Tuna site was about 3.2 mL/L whereas at the Hawaiian sites the minimum was closer to 1.0 mL/L. The extremely low concentration of D.O. observed in the Pacific may be important to OTEC in terms of biological impact and redox chemistry.

2. VARIABILITY OBSERVED AT THE CARIBBEAN AND PACIFIC SITES.

While the agreement between the two Caribbean sites appears excellent (figures 3 - 6), it is based on a very small data base. Only one cruise was conducted to the Virgin Island site and data is available from only two cruises to the Puerto Rican site. Further studies may be necessary to determine if there are significant differences between the two sites.

Detectable and reproducible differences were observed between the two Hawaiian sites. On cruises O'OTEC 01-03, the D.O. profile had a pronounced shoulder at about 225 m at the O'OTEC (Oahu) site, where none was observed in the HOTEC-01-06 (Hawaii) data (Figure 6). On cruises HOTEC-01-06 to the HOTEC site, the D.O. concentration decreased rapidly from about 100 m and reached its minimum at about 450 m. At the HOTEC site the minimum was below 600 m. On HOTEC's 11 and 12, the profile observed was similar to that observed at the O'OTEC site. It will be important to examine the possibility of operator variability.

The nutrient distribution at the O'OTEC (Oahu) site showed a nutricline with a lower slope (dConcentration/dDepth) than that observed at the HOTEC (Hawaii) site, but which continues to greater depth (Figure 3). While the differences observed are small, they are consistent for nitrate, phosphate and silicate. Other researchers have reported variable concentrations in the Pacific (Reid, 1), although such consistent variability between such closely spaced sites was somewhat unexpected. Archival nutrient data for these two particular areas is sparse. Gundersen and Palmer (2) determined dissolved oxygen and nitrate at Keahole Point (just south of the HOTEC study area). Gordon (3) measured dissolved oxygen and nitrate at station Gollum, 22° 10'N, 158° 00'W, 47 miles due north of Oahu. In addition, the GEOSECS expedition determined dissolved oxygen, nitrate, o-phosphate and silicate at three sites in the vicinity of the Hawaiian islands (Bainbridge, 4). The three GEOSECS sites, numbers 234 at 19°N 52', 163° 19'W, 235 at 16° 45'N, 161° 23'W, and 206 at 22° 9'N, 153° 50'W, Station Gollum and the Keahole Point site appear with the HOTEC and O'OTEC sites in figure 7.

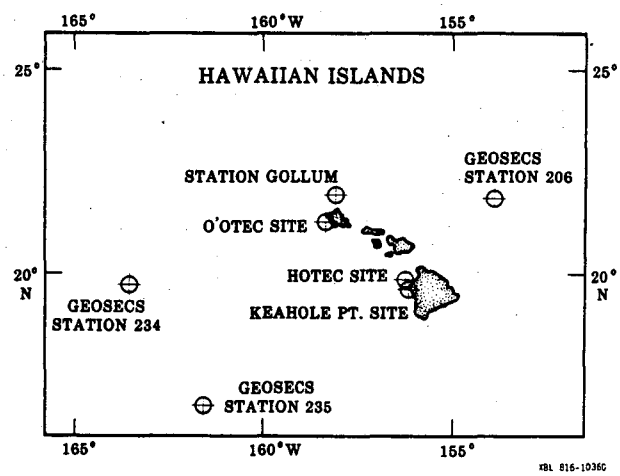


Figure 7. Map showing the locations of the O'OTEC (Oahu), HOTEC (Hawaii), and Keahole Point sites and Stations Gollum, GEOSECS 234, 235 and 206.

Figure 7 shows that most of the archival data is from sites at a fair distance from the OTEC site and may not be entirely representative of those sites. The data from the GEOSECS sites appear in figures 8-11. As expected, figures 8 through 11 show variable nutrient concentrations over the small area shown in figure 7.

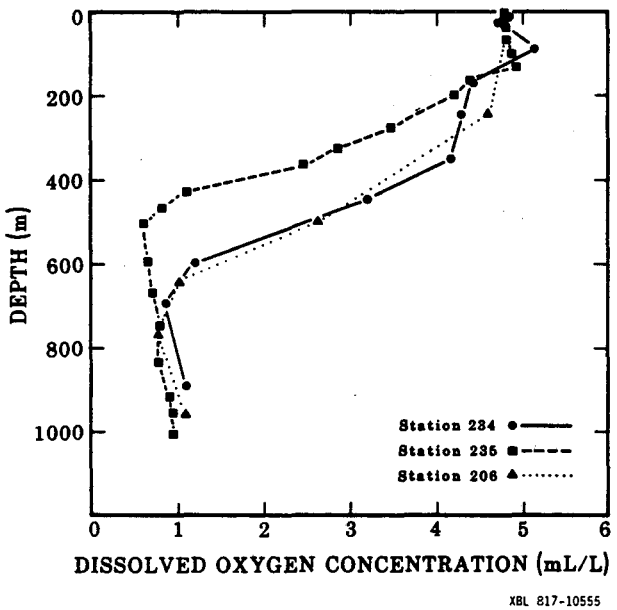


Figure 8 Dissolved Oxygen concentrations observed by the GEOSECS Expedition at Stations 234, 235 and 206.

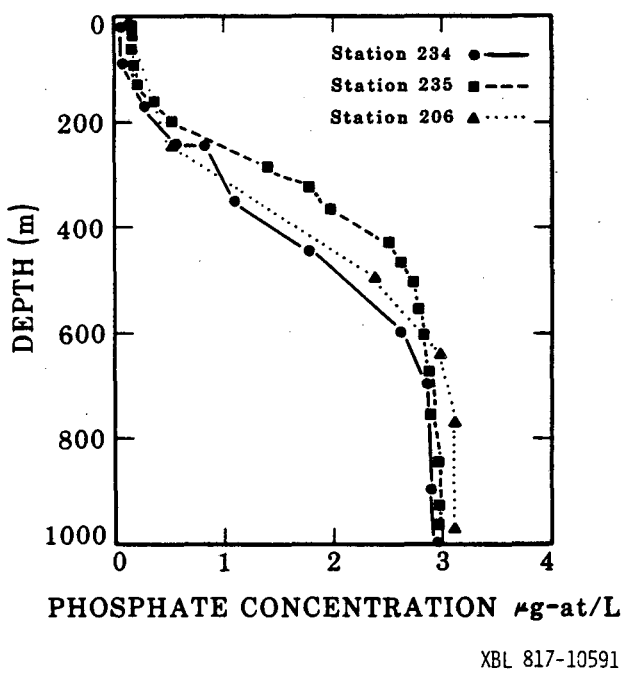


Figure 9. o-Phosphate concentrations observed by the GEOSECS Expedition at Stations 234, 235 and 206.

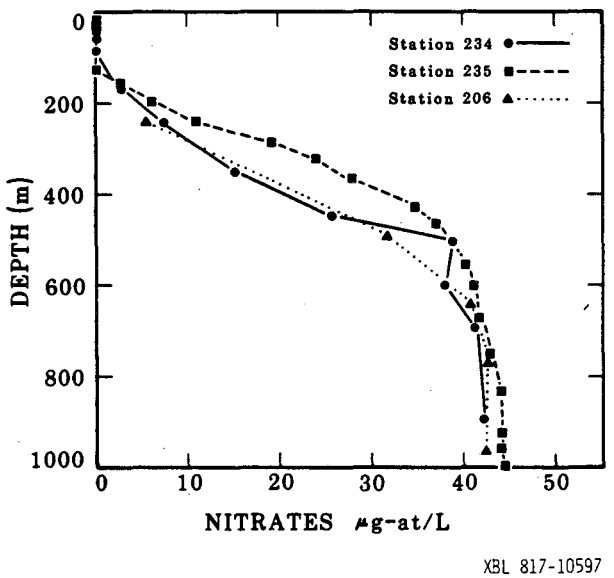


Figure 10. Nitrate concentrations observed by the GEOSECS Expedition at Stations 234, 235 and 206.

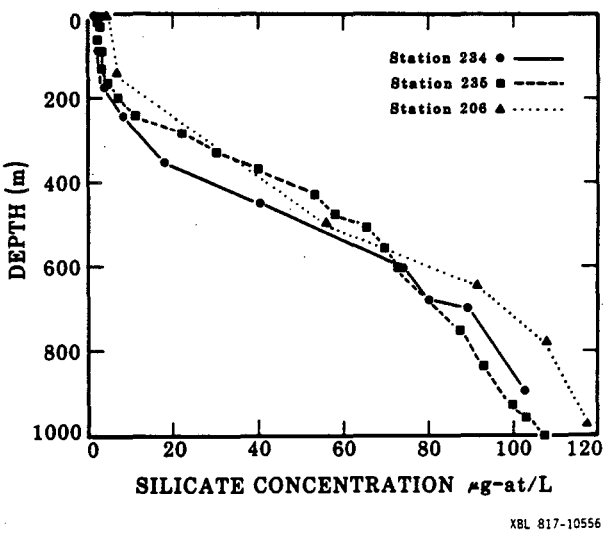


Figure 11. Silicate concentrations observed by the GEOSECS Expedition at Station 234, 235 and 206.

For ease in comparison the GEOSECS data has been converted from µM/kg to µg-at/L for the nutrients and mL/L for D.O.

The data from stations 234 and 235 show differences similar to those observed between the two OTEC sites. At station 234, the nutricline is less steep and levels at a greater depth than at station 235. The D.O. profile for station 234 shows a pronounced shoulder at about 300m which

does not appear in the data from station 235. At GEOSECS Station 234, a similar shoulder appears in the D.O. profile The shoulder does not appear in the profile from Station 235. The D.O. then decreased in concentration to about 0.8 mL/L at 650-700m. This oxygen minimum is 100-150m deeper than that observed at the HOTEC site, cruises HOTEC-01 - 06. The minimum observed at GEOSECS 234 also occurs from 100-200m deeper than at GEOSECS 235. It appears that there is some variability between these two Hawaiian sites, comparable to that observed between the two GEOSECS sites.

In fact all the nutrients showed the same consistent differences. While the absolute values observed at each pair of sites (O'OTEC and station 234, HOTEC and station 235) are not the same, the profiles have sufficiently distinct features as to be predictable.

Figure 7 shows that both station 234 and the O'OTEC (Oahu) site are located north of a line drawn through the Alenuihaha Channel. The HOTEC site and station 235 are south of that line. The third GEOSECS site, station 206, lies to the east of the Alenuihaha. The nutrients and D.O. at this station show the same pattern as observed at the O'OTEC site and station 234.

3. VARIABILITY AT VARIOUS OTEC SITES

When reviewing the data it became clear that there was considerable variability observed at each site.

3.1 The Hawaiian OTEC Sites

3.1.1 The HOTEC Site. Data from seven cruises to this site is now available. Analyses for the first six cruises were performed by Dr. David Ziemann of Aecos, Inc., analyses for HOTEC-11 were done by Ted Walsh of the Hawaiian Institute of Marine Biology.

3.1.1.1 Dissolved Oxygen. Dissolved oxygen averages about 5.3 mL/L at the surface ranging from approximately 5.0 to 5.8 mL/L (figure 12).

A subsurface maximum is observed near 50 - 100m, the depth of the maximum depending on the time of year. On the November and December cruises (HOTEC's 06 and 01), the maximum appears at greater depths than in the April, June, July and October cruise (HOTEC's 02-05). From about 100m to the oxygen minimum, at approximately 500-600m, the concentration declines steadily to about 1 mL/L. On the December cruise (HOTEC-06), an extremely low minimum was observed - 0.2 mL/L. It was observed on two separate casts at two depths, so the observation can not be easily rejected as an analytical anomaly. There is a fair degree of variability in the data, ± 0.5 mL/L to the depth of the oxygen minimum, then relatively low variability ± 0.2 mL/L.

The HOTEC profiles are in fair agreement with the profile from GEOSECS station 235, which shows a minimum of 0.6 mL/L at 500m. The subsurface maximum at 130m was even deeper than that observed on HOTEC-06. 100m.

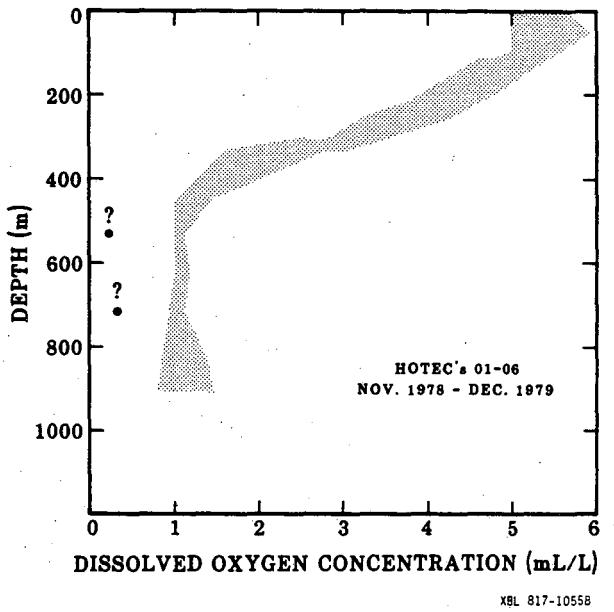


Figure 12. The range of dissolved oxygen concentrations observed during HOTECs-01-06 and HOTEC-11 at HOTEC site.

3.1.1.2 o-Phosphate. At the surface, the phosphate concentration averaged about 0.3 μg-at/L which immediately decreased to about 0.15 μg-at/L (figure 13).

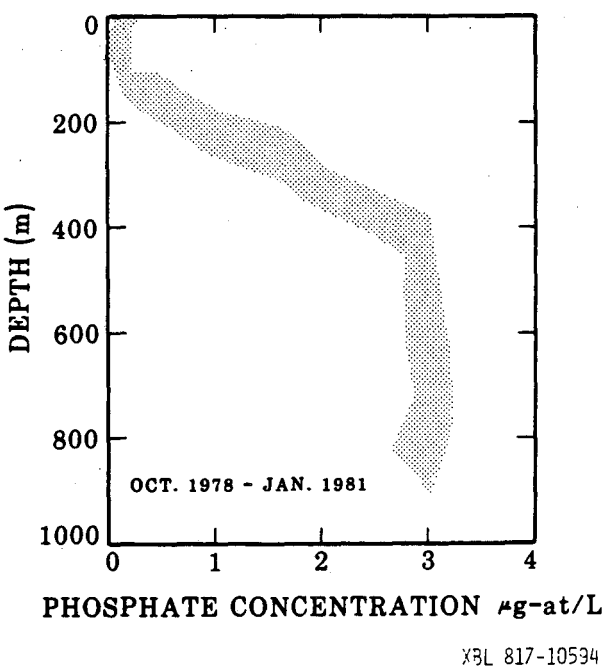


Figure 13. The range of o-phosphate concentrations observed at the HOTEC site during HOTEC's-01-06 and HOTEC-11.

Below 100m the concentration increased to about 3.0 μg-at/L at 400-450m. The concentration then remained constant. The variability of the data remained about ± 0.02 μg-at/L through out the profile. No variation could be linked directly with seasonality or time of data.

As mentioned in section 2, the profile of the phosphate data at the surface agrees with the GEOSECS data from station 235 (figure 9).

3.1 1.3 Nitrates. At the HOTEC site, nitrate remains virtually undetected until 100m; at greater depths the concentration increased to about 43 μg-at/L (figure 14).

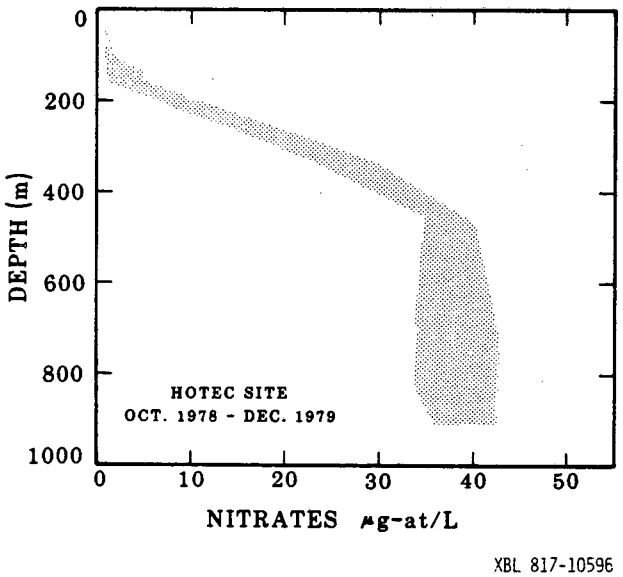


Figure 14. The range of nitrate concentrations observed at the HOTEC site during HOTEC's-01-06 and HOTEC-11.

Variability was about ± 2.5 μg-at/L near 100m increasing to ± 5 μg-at/L in the nutricline. No fluctuations could be attributed to seasonality. The data is in good agreement with the GEOSECS, station 235 results and with Gundersen and Palmer's data from Keahole point.

3.1.1 4 Silicate. Silicate concentrations averaged 2-3 μg-at/L at the surface to a depth of about 100m (figure 15).

The concentration the gradually increased to an average of about 90 μg-at/L. Although the variability in deep water was quite high, nearly ± 10 μg-at/L at 900m, no correlation could be made with the seasons. Agreement was good with the GEOSECS data (figure 11).

3.1 2 <u>The Oahu OTEC Site, O'OTEC</u>

Six cruises have gone to two sites in the area off the leeward side of Oahu, near Kahe Point (figure 16).

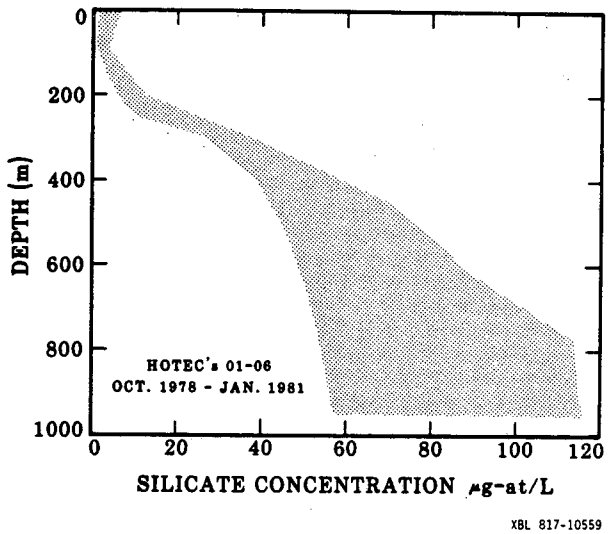


Figure 15. The range of silicate concentrations observed at the HOTEC site during HOTEC's 01-06 and HOTEC-11.

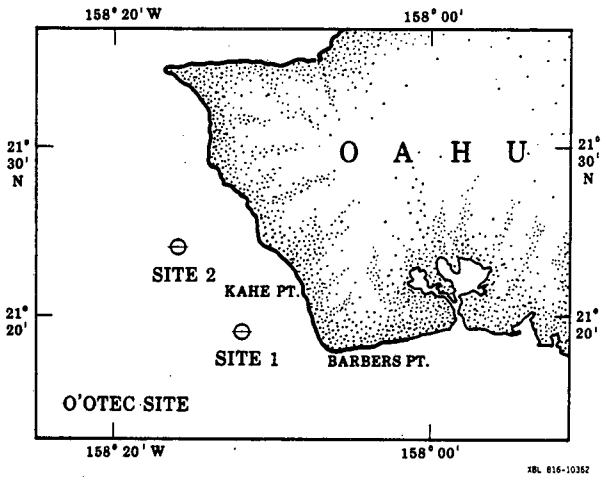


Figure 16. Map showing the location of the two O'OTEC sites off the south west coast of the island of Oahu.

Data is available from the first three cruises O'OTEC-01, 02 and 03, which took place on 25-26 May 1980, 27-28 August 1980 and 6-7 November 1980. Analyses were performed by Ted Walsh of Hawaiian Institute of Marine Biology. Samples were collected from two sites. Three hydrocasts were made at each site as rapidly as possible to test for bottle to bottle variability.

As at the HOTEC site, nutrient and D.O. concentrations varied with time throughout the water column. Standard deviations were low for dissolved oxygen, higher for nitrate and phosphate and very high for silicate. At the O'OTEC site, the greatest variability occurred around 700m, with very low standard deviations near 900m.

3.1 2.1 Dissolved Oxygen. At the surface, D.O. was found to be about 4.8 ± 0.04 mL/L (figure 6). The profile usually shows a subsurface maximum between 50 and 100m. From 100 to 250m, there is a shoulder in the profile when the concentration remains nearly constant, dropping 0.2 mL/L from 4.7 to 4.5 mL/L. As mentioned in section 2, this is in contrast to the HOTEC site data where the concentration dropped on the average 0.8 mL/L.

There are no significant differences between the data sets collected at the two different sites nor were the standard deviations calculated from the three consecutive hydrocasts high.

3.1.2.2 o-Phosphates. Phosphate concentrations averaged 0.1 μg-at/L at the surface (Figure 3). They remained at this concentration to a depth of about 115m, at the beginning of the nutricline. Concentrations increased to 3.1 μg-at/L at 800-900m on the May and August cruises (O'OTEC-01,02) and to 3.4 μg-at/L on the November cruise (O'OTEC-03). Tests will be conducted to determine whether this apparent seasonality was real.

Although the standard deviations observed at 900m were very low, at 450 and 670m they were considerably higher, often as high as 0.15 mL/L at 450m and greater than 0.2 mL/L at 670m (figure 17).

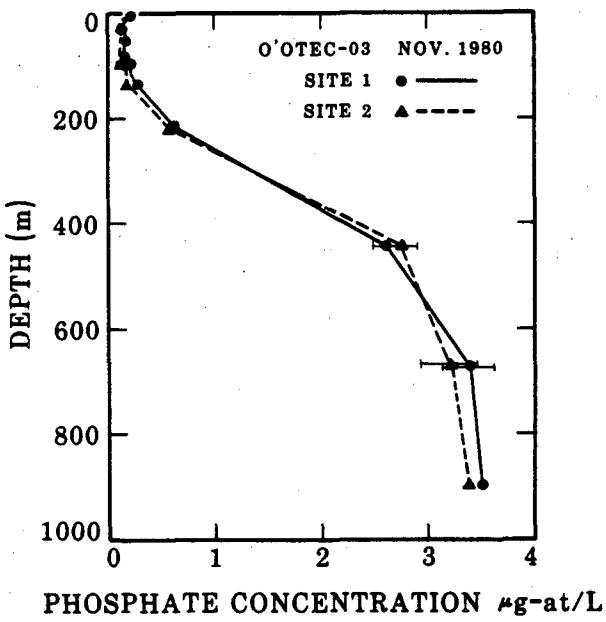


Figure 17. Concentration of o-phosphates vs. depth observed at the O'OTEC site during the O'OTEC-03 cruise, November, 1980. The standard deviation of the three consecutive hydrocasts at each site is also shown.

This pattern of variability was observed in all the nutrients (see figures 18, 19).

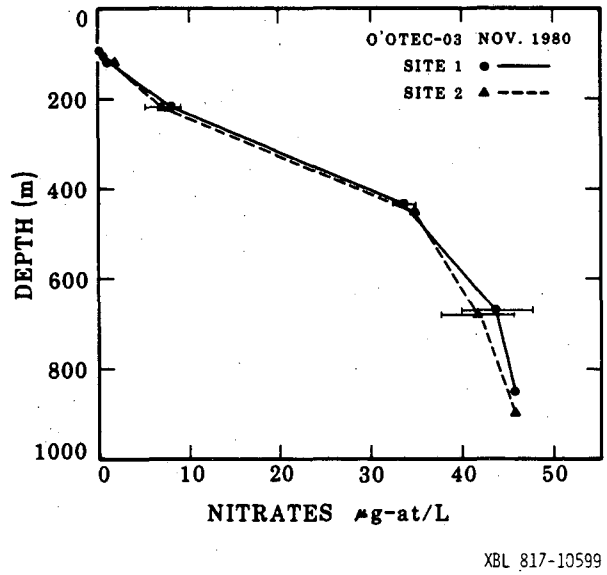


Figure 18. Concentration of nitrates vs. depth observed at the O'OTEC site during the O'OTEC-03 cruise, November, 1980. The standard deviation of the three consecutive hydrocasts at each site is also shown.

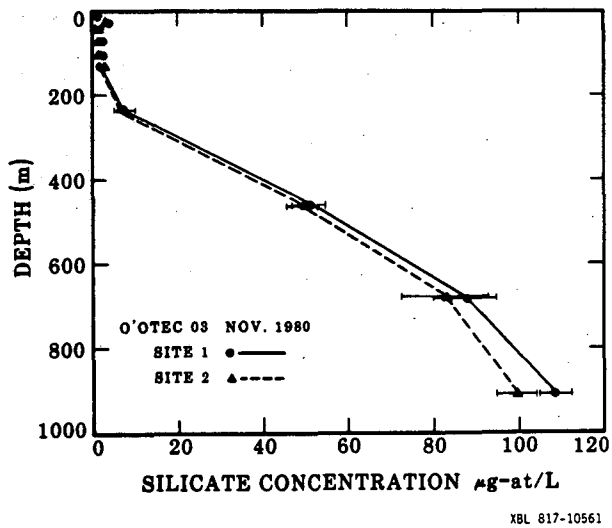


Figure 19. Concentration of silicates vs. depth observed at the O'OTEC site during the O'OTEC-03 cruise, November, 1980. The standard deviation of three consecutive hydrocasts at each site is also shown.

The May and August profiles are in agreement with the GEOSECS 234 data from the surface through the nutricline. The May profile agrees less well below 600m. The shape of the November profile is in agreement with the GEOSECS station 234 data although the absolute values fall within those at station 234 and 235.

3.1.2.3 Nitrates. Nitrates were virtually undetected in the first 115m of the water column at both O'OTEC sites. Concentrations increased steeply to about 40 μg-at/L at 650-700m and then increase only slightly with increasing depth.

The pattern of variability observed in the phosphates is echoed in the nitrates - on the O'OTEC-01 cruise there may be some difference between sites. At site 1 the concentration achieved at depth is lower by 12 μg-at/L than at site 2 (figure 20).

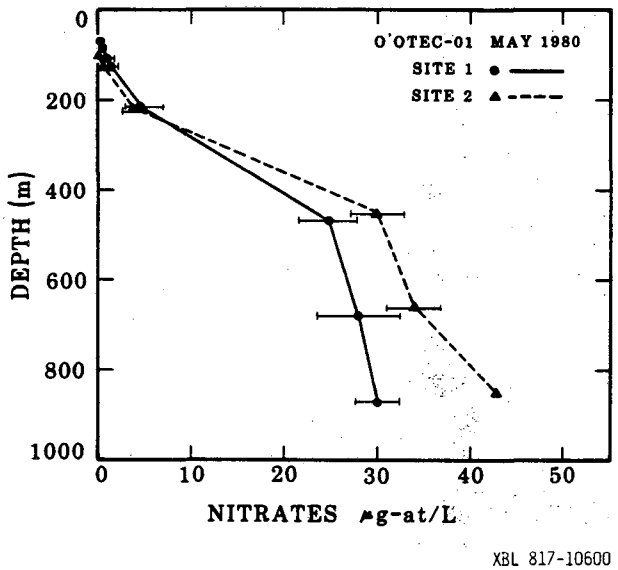


Figure 20. Concentration of nitrates vs depth observed at the O'OTEC site during the O'OTEC-01 cruise. The standard deviations of three consecutive hydrocasts at each site are shown.

Although the variability observed at Site 1 is not negligible, ± 2.4 μg-at/L, that at site 2 is low, ± 0.5 μg-at/L and the difference between them is greater than three standard deviations. The ratio of total nitrogen to total phosphate observed at each site was the same: 14.

Between the August and November cruises, O'OTEC-02,03, the difference observed in the 900m water may be significant and indicative of seasonal variability. Standard deviations observed in the replicate hydrocasts on each cruise are low, about ± 0.5 μg-at/L, however the difference observed is relatively small, 3 μg-at/L.

As observed in the phosphate analyses, the greatest ranges and standard deviations in nitrate detected were in the 450 and 700m depths (figure 19).

Agreement between the O'OTEC data and the GEOSECS data is similar to the agreement in the phosphate data. The O'OTEC data also falls within the ranges reported by Gundersen and Palmer and Gordon.

3.1.2.4 Silicates. Silicate concentrations are at about 2 μg-at/L through the mixed layer increasing to from 80 to 120 μ-at/L near 900m (figure 20). The pattern of variablility observed is similar to that of the nitrates and phosphates.

3.2 The Caribbean Sites.
Data from two cruises to the PROTEC (Punta Tuna) site and one to the VOTEC site is available. Analyses of the PROTEC samples was done by Dr. Kent Fanning of University of South Florida. The VOTEC samples were analyzed by Dr. George Knauer and his group.

3.2.1 The Virgin Island (VOTEC) Site. Since only one cruise was conducted to this site and only six depths were sampled, it is not possible to consider any site variability.

3.2.2 The Puerto Rican (PROTEC) Site. The two sets of data obtained are in very good agreement with each other, with the exception of the phosphates in the mixed layer which showed considerable spiking during the day casts (Figure 21).

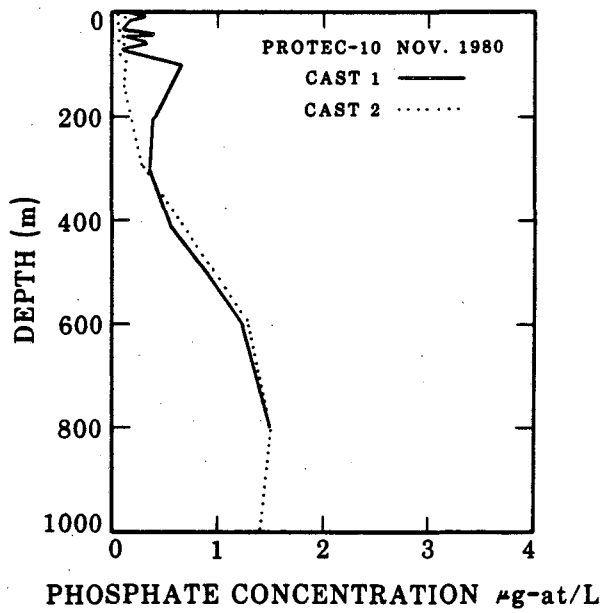


Figure 21. o-Phosphate concentration observed at the PROTEC site during PROTEC-01.

REFERENCES

(1) REID, J.L., Intermediate Waters of the Pacific Ocean, Johns Hopkins Press, Baltimore, 1965.

(2) GUNDERSON, K.R. and R.Q. PALMER, Report on Aquaculture and Ocean-Energy systems for the County of Hawaii, University of Hawaii, 1972.

(3) GORDON, D.C., Chemical and Biological Observations at Station Gollum, an Oceanic Station near Hawaii, Jan. 1969 to June 1970. The standard deviation of three consecutive hydrocasts at each site is also shown. Hawaiian Institute of Geophysics, Report No. HIG-70-22.

(4) BAINBRIDGE, A., GEOSECS Pacific Final Hydrographic Data Report, First Edition, 22 August 1973 to June 1974 R/V Melville, GOG Publication #32.

ACKNOWLEDGEMENT

This work was supported by the Assistant Secretary for Conservation & Renewable Energy, Office of Solar Power Applications, Division of Ocean Energy Systems, United States Department of Energy under contract number W-7405-ENG-48.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720