Lawrence Berkeley National Laboratory
Recent Work

Title
OCEAN THERMAL ENERGY CONVERSION (OTEC) PARTICULATE PROGRAM 1980, ST, CROIX (VOTEC)

Permalink
https://escholarship.org/uc/item/3k55c6dq

Authors
Knauer, G.A.
Flegal, A.R.

Publication Date
1981-08-01
OCEAN THERMAL ENERGY CONVERSION (OTEC)
PARTICULATE PROGRAM 1980, ST. CROIX (VOTEC)

George A. Knauer and A. Russell Flegal

August 1981

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 DE-AC03-76SF00098
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.
OCEAN THERMAL ENERGY CONVERSION (OTEC)
PARTICULATE PROGRAM 1980, ST. CROIX
(VOTEC)

Final Report
Subcontract Numbers 4511510 and 4984002
August 1981

George A. Knauer
A. Russell Flegal

Moss Landing Marine Laboratories
Moss Landing, California 95039

for

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

This work was supported by the Assistant Secretary for Conservation
and Renewable Energy, Office of Solar Applications, Ocean Energy
DE-AC03-76SF00098.
INTRODUCTION

The objectives of this project, Particulate Program (OTEC), were to develop and evaluate methods for sampling and analyzing the particulate matter in sea water at potential ocean thermal energy conversion (OTEC) sites. The capability to make such a characterization represents an essential factor for both the description of oceanic ecosystems and the prediction of OTEC-related alterations of the marine environment.

The principal sampling methods employed in this project were a particle interceptor trap system (PIT), large-volume water samplers (Go-Flo\textsuperscript{R}) and plankton nets. The analytical methods evaluated included atomic absorption spectrophotometry (AAS), neutron activation analysis (NAA), x-ray fluorescence (XRF) and isotope dilution mass spectrometry (IDMS).

Additional parameters were measured in order to obtain essential supporting data. These included temperature, salinity, labile nutrients, soluble trace elements, primary productivity and phytoplankton taxonomy. The sampling and analytical procedures utilized for measuring those parameters, as well as their values, are also included in this report.
SITE DESCRIPTION

St. Croix is one of the three principal islands in the U.S. Virgin Islands of the Greater Antilles, which are part of the island arc separating the Caribbean Sea from the Atlantic Ocean. Related OTEC reports describing various aspects of this general area include Atwood, Duncan, Stalcup and Barcelona (1976), Hirshman, Meier, Munier and Taylor (1977), Lee, Munier, and Chiu (1978) and Cummings, Atwood and Parker (1979).

The sample location (VOTEC Site #1) of this project was approximately 17°54'N 65°00'W, which is due west of Fredericksted, St. Croix. This site is beyond the steeply sloping edge of the island, where there is a relatively broad submarine plateau at 1000 m.

The PIT was deployed from the R/V PAUL LANGEVIN III on February 12, 1980 at 17°41'N 64°59'W. All other samples were collected from the Tracor marine barge YFN 1126 on February 13, 1980 and February 24-25, 1980.
METHODS

Trace Element Facilities

Other than sampling, all operations relating to the trace element analyses both at sea and at Moss Landing Marine Laboratories are normally conducted in ultra-clean laboratories meeting the requirements listed by Patterson and Settle (1976), except that the portable laboratory does not have a separate change room.

However, logistics dictated that a temporary facility be constructed on the barge for this study. It consisted of a small polyethylene-lined chamber with a small plastic hood. As such, the facility lacked a positive pressure filtered-air system, a horizontal laminar flow clean-air bench, a clean chelex column area, a clean work bench area and a clean storage area.

Sampling Methods for Trace Elements

a. Go-Flo$^R$ Samples

Prior to sampling, the 30-liter Teflon-coated polyvinylchloride Go-Flo$^R$ bottles were modified and cleaned at the University of Miami in the manner prescribed by Moss Landing Marine Laboratories. Specifically, the metal and rubber fittings on the nylon lanyards were removed, the standard stopcock was replaced with a Teflon stopcock, the standard gas pressure fitting was replaced with a nylon fitting, and all remaining metal was sprayed with a clear plastic resin or sealed with silicon. The bottles were soaked in a laboratory detergent (Micro$^R$), 0.5 N redistilled HNO$_3$, and 1% quartz-distilled HNO$_3$ for a week each.
To collect samples, the bottles were attached to a dacron-sheathed plastic hydrowire with a polypropylene-encased lead weight on the free end. The wire was wrapped on a winch drum covered with polyethylene and passed through a stainless steel meter wheel. The bottles entered the water in a closed position in order to eliminate surface film contamination (see Martin, Bruland and Broenkow, 1976), opened under pressure at 5-10 m, and then were closed with a Teflon messenger.

When a sampler was brought aboard, it was connected to a polyethylene line which drained into the temporary clean room below. That tubing was connected to a Millipore Teflon filter sandwich with a 142 mm diameter, 0.4 μm polycarbonate filter membrane on a polyethylene support. The filtered water then drained from Teflon tubing into calibrated effluent bottles. While the sample was being filtered, the Go-Flo® sampler was manually rigorously shaken to insure uniform particle distribution (see Gardner, 1977). Approximately 2-3 liters of water were filtered before any effluent samples (salinity, nutrients, metals) were collected and each bottle was rinsed three times before it was filled.

When the Go-Flo® bottle was empty, the water line was disconnected and rinsed with 2 N quartz-distilled HNO₃ and Milli-Q® water before the next sample. The filter was rinsed with 25 ml of pH-adjusted (8.2) Milli-Q® water to remove sea water salts, dried, folded with acid-cleaned Teflon forceps and placed in an acid-cleaned plastic bag. Two acid-cleaned 500 ml polyethylene bottles were used for organic extraction samples. After filling, these samples were acidified with 2 ml 6 N quartz-distilled HCl to prevent adsorption at high pH, and stored in double plastic bags at
room temperature. One 4-liter polyethylene bottle was taken for cation exchange resin extractions.

All polyethylene tubing in contact with the sample water was soaked in Micro\(^R\), 6 N reagent grade HCl, 2 N redistilled HNO\(_3\), and 2 N quartz-distilled HNO\(_3\). The tubing was thoroughly rinsed with Milli-Q\(^R\) water between each soaking. Organic extraction bottles were also cleaned as above, except they were finally filled with 0.5 N quartz-distilled HNO\(_3\). They were left soaking in the final solution until sample introduction.

Chelex bottles were soaked sequentially in Micro\(^R\), 6 N reagent-grade HCl, redistilled HNO\(_3\), 0.5 N quartz-distilled HNO\(_3\) and Milli-Q\(^R\) water. The bottles were thoroughly rinsed with Milli-Q\(^R\) water between each of these steps. Both chelex and organic extraction bottles were then triple-bagged in polyethylene. Teflon filter holders and polycarbonate filter membranes were cleaned in the same manner as the organic extraction bottles, except that the Micro\(^R\) soak was eliminated.

The filters were oven-dried in a dessicator at 70 °C following the cleaning procedure, and then weighed on a Perkin-Elmer AD-2 micro-balance to the nearest 0.001 mg. The filters were placed in polyethylene bags which had been cleaned in the same manner as the filters and sealed.

b. Surface Seawater Samples

Separate surface (0.5 m) samples were collected in 2- and 4-liter conventional polyethylene bottles from an inflatable raft several hundred meters away from the research vessel in the manner described in Patterson and Settle (1976) and in Bruland, Franks, Knauer and Martin (1979). These bottles were then triple-bagged in polyethylene. Some of the samples were
subsequently opened in the temporary clean room and treated in the same way as the Go-Flo samples, and some remained sealed until they were returned to a clean lab for analyses by isotopic dilution mass spectrometry.

c. Plankton Net Tows

The collection of net plankton involved the most thorough trace element cleaning and sampling procedures ever utilized. The plankton net was made of Nitex nylon monofilament bolting cloth (62 μm mesh opening [ASTM]) and nylon thread sewn under specific instructions to limit metal contamination. It was washed twice with a commercial detergent; rinsed with triple-distilled water; washed with acid-cleaned (reagent grade HCl), quartz-distilled chloroform five times; and soaked sequentially in three warm acid baths (1 N reagent grade HCl in triple-distilled water, 0.1 N reagent grade HCl in triple-distilled water, and 0.01 N NBS quartz, sub-boiling, double-distilled HCl in quartz-distilled water) for a total of three days. The bridle, tow line and line holding the cod end were also made of nylon and were cleaned in the same manner. The cod end was a 2-liter, wide-mouth bottle of conventional polyethylene, which had been cleaned with chloroform and then soaked in three hot acid baths (6 N reagent grade HNO₃ with triple-distilled water, 2 N reagent grade HNO₃ with triple-distilled water, and 0.1 N NBS quartz sub-boiling double-distilled HNO₃ with quartz-distilled water) for at least 48 hours each. (Unless stated otherwise, anything described in the plankton and IDMS sections as "acid cleaned" was cleaned in this manner.) The bridle ring (1/2 m diameter) was made with stainless steel. It was cleaned with hot acid (6 N reagent grade HNO₃ in triple-distilled water for 24 hours, coated with Teflon and then acid cleaned. These components were assembled in an ultra-clean laboratory.
(see Patterson and Settle, 1976) and wrapped in three polyethylene bags (the innermost of which was acid cleaned).

The net was removed from the bags while in an inflatable raft after it was rowed several hundred meters away from the barge and it was towed for two hours in the manner described by Martin and Knauer (1973). Additional samples were collected in the same manner off the R/V WECOMA during the FGGE Leg 10 transect from Hawaii to Tahiti from December 1979 to January 1980 as part of the NSF-sponsored research of Dr. C.C. Patterson. Sub-samples from those tows were included in the following analyses because they represented additional material characteristic of potential OTEC sites.

During the plankton tow and while processing the plankton, acid-cleaned (reagent grade conc HNO₃) polyethylene gloves were worn over shoulder-length polyethylene gloves, even though no direct contact was made with the plankton. It was transferred to acid-cleaned polyethylene vials after a subsample had been rinsed with quartz-distilled water (pH = 8) and frozen. The subsamples were later vacuum dried in an acid-cleaned (6 N reagent grade HNO₃) dessicator with a particle trap in an ultra-clean laboratory. Aliquots of the subsamples for different analyses were subsequently taken with acid-cleaned quartz spatulas.

d. Particle Interceptor Traps

Particulates falling through the water column were to be collected in an anchored particle interceptor trap (PIT) system, which was based on the free-floating PIT system previously described in Knauer, Martin and Bruland (1979). Laboratory and field studies of traps with this
design include Gardner (1977), Lau (1979), Hargrave and Burns (1979) and Knauer, et al. (1979). The system at Moss Landing Marine Laboratories is currently being intercalibrated with other systems in the National Science Foundation's Sediment Trap Intercalibration Experiment (STIE) and Vertical Exchange and Transport Experiment (VERTEX).

Briefly, the system consisted of eight separate acrylic collector tubes with an acrylic baffle system mounted on a polyvinylchloride cross frame. Each collector tube was cleaned with a laboratory detergent (MicroR) and dilute quartz-distilled HNO₃ and filled with a high-density (ρ = 1.07 g cm⁻³) reagent grade NaCl solution with 5% buffered formalin. The collectors were then enclosed with acid-cleaned (dilute quartz-distilled HNO₃) polyethylene sheets secured with a soluble release mechanism.

The traps were attached to a polypropylene hydroline which was anchored with lead weights encased in polyethylene in 1000 m of water at 500 m and 200 m depths on February 14, 1980. They were monitored visually and with a radiotransmitter for ten days.

**Extraction Methods for Trace Elements**

a. **Organic Extraction**

One 200 ml portion from each replicate sample bottle was organically extracted and analyzed by flameless atomic absorption spectrophotometry. The extraction method generally followed that of Bruland, et al. (1979), except samples were not back-extracted. Basically, each aliquot was added to a 250 ml Teflon separating funnel and extracted twice with 1% APDC-DDDC (ammonium 1-pyrrolidinedithiocarbamate and diethylammonium diethylidithiocarbamate) into chloroform. The chloroform was run into quartz beakers and
evaporated at low temperature on a hot plate. Then, 500 ul of concentrated quartz-distilled HNO₃ were added and evaporated. This procedure was repeated. Finally, 250 ul concentrated HNO₃ were added to the beaker followed by 1750 ul Milli-Q water, yielding a final volume of 2 ml.

b. Chelex Extraction

The first extraction with a cation exchange resin (chelex) was based on the procedure described by Riley and Taylor (1968). The polypropylene chelex columns were prepared in Moss Landing Marine Laboratories' clean room. Chelex-100 purchased in the sodium form was washed successively over a period of several months with HCl and HNO₃ to remove metal contaminants (Martin, et al., 1976). It was then converted to NH₄⁺ form and washed with Milli-Q water after being poured into columns. The 4-liter chelex sample was connected to the top of a column with teflon tubing. The bottom of the column was connected with Teflon tubing to tygon tubing which ran through a peristaltic pump and thence to 4-liter effluent bottles below. The peristaltic pump speed was adjusted to approximately 3 ml/min. After all sea water had passed through the column, it was capped, wrapped in a plastic bag, labeled and stored at room temperature.

The chelex column samples were eluted with 4N quartz-distilled HNO₃ into pre-cleaned polyethylene bottles after an initial wash with about 30 ml of Milli-Q water. A number of blank columns were also eluted in the same manner. The resulting solution has a very consistent matrix of Na, K, Ca and Mg ions that can interfere with atomic absorption analysis. Thus, a solution was made up in the appropriate proportion for each of the above ions using reagent grade salts and passed through a chelex column to remove
contaminating metals. The resulting clean chelex matrix solution was used for matrix matching (Bruland, et al., 1979) in preparing all metal standards.

c. **Chelex-Acetate Extraction**

Water samples were also preconcentrated with chelex using the technique of Kingston, et al. (1978) with some modifications. Samples were adjusted to a pH of 6 with NH₄OH (made by bubbling ethylenediamine tetraacetic acid (EDTA) scrubbed, anhydrous NH₃ through Milli-Q water). Approximately 2 liters of sea water were then passed through a chelex column in the previously described manner. After that, the columns were washed with 30 ml Milli-Q water, 70 ml 1.0 M ammonium acetate (pH = 5.4) and 15 ml Milli-Q water. Finally, the transition metals were eluted with 25 ml 2.5 N HNO₃.

d. **Dithizone-Chloroform Extraction**

See isotope dilution mass spectrometry.

e. **Bomb Digestion**

The polycarbonate filters containing the particulate trace metals were oven-dried in a dessicator at 70°C to constant weight and reweighed on a microbalance to the nearest 0.01 mg. The filters were then digested in Teflon digestion bombs following the basic procedure of Eggiman and Betzer (1976). The amount of reagent added to each sample was dependent on the sample weight. Initially, two ml 6 N double quartz-distilled HCl were added to the filter in a Teflon bomb. The bomb was sealed and heated at 95-100°C in a hot water bath for one hour. The bombs were removed, cooled and 0.5 to 1 ml concentrated quartz-distilled HNO₃ was added. Then, the bombs were sealed and reheated for one hour. After removal and cooling 0.2 ml 47% Ultrex HF were added and the bombs were sealed and heated for
another hour. After cooling, each bomb was opened and the filter and digest placed in a polyethylene vial followed by 1 ml rinses of the bomb with aliquots of Milli-Q® water. Finally, the samples were diluted with 8 ml of Milli-Q® water. Dilution weights were corrected for solution density and filter weight to yield a corrected volume.

Analytical Methods for Trace Elements

a. Atomic Absorption Spectrophotometry

Elemental analyses of the chelex, chelex-acetate and organic extractions of sea water and the bomb digested particulate samples were performed on either a Perkin-Elmer 305-B or Model 603 atomic absorption spectrometer. Samples were analyzed by flame or flameless (HGA-2100) atomic absorption spectroscopy (AAS), depending upon the analyte concentration. Matrix matching, dilution and standard additions were employed where necessary for the appropriate metal and sample type. Trace metal concentrations in procedural blank solutions were usually much smaller than sample concentrations.

b. Neutron Activation Analysis

Aliquots of the plankton from the net tows in St. Croix and the tropical Pacific were made into pellets with an aluminum oxide die with acid-cleaned (quartz distilled HNO₃) polyethylene and reagent grade cellulose. Solutions from the bomb digestions of filtered particulates were dried and pelletized in the same manner. The samples, along with procedural blanks and composite standard pellets, were irradiated in the TRIGA research reactor at the Lawrence Berkeley Laboratories (LBL) of the University
of California, Berkeley.

The accuracy and precision of this type of analysis are described in Perlman and Asaro (1969) and in Yellin, Perlman, Asaro, Michel and Mosier (1980). Additionally, as a preliminary part of this study, samples of phytoplankton, zooplankton, particulate detritus, filter and National Bureau of Standards river sediment (SRM 1645, which was submitted as an unidentified sediment) were sent to LBL for experimental analyses by NAA and XRF.

**c. X-Ray Fluorescence**

Aliquots of the net plankton, as well as the previously mentioned samples, were also analyzed by XRF at LBL using their standard procedures.

**d. Isotope Dilution Mass Spectrometry**

Surface seawater samples and aliquots of the net plankton were also analyzed for Pb, Cd and Th at Caltech using the ultra-clean techniques described by Patterson and Settle (1976) and Schaule and Patterson (1978). The dithizone-chloroform extraction and isotope dilution mass spectrometry analyses of sea water are currently being intercalibrated with the APDC-DDDC organic and cation exchange resin extractions and flameless atomic absorption spectrophotometry analyses described in Bruland, et al. (1979) at Moss Landing Marine Laboratories (Flegal, 1981).

The particulates were analyzed similarly for Pb, Cd, Tl, Ca and Ba with the procedures described in Burnett and Patterson (in prep.).

**Other Sampling and Analytical Methods**

**a. Temperature**

The vertical temperature profile was measured with an XBT.
b. **Salinity**

Salinity was measured with a salinometer (Autosal Model 8400).

c. **Nutrients**

Soluble phosphate was measured with a Varian Model 6345 spectrophotometer using the method of Murphy and Riley (1962). Particulate phosphate was also measured after the material was digested in the manner described in Martin and Knauer (1973) to insure the complete breakdown of phospholipids. Soluble phosphate, nitrate, nitrite and silicate were also measured with an autoanalyzer at the University of California, Santa Cruz.

d. **Carbon and Nitrogen**

C and N were measured in the particulates with a Hewlett-Packard Model 185-B CHN analyzer after treatment with dilute HCl to remove carbonates.

e. **Chlorophyll a**

Samples were collected in 5-liter Niskin bottles at five depths. The bottles were shaken prior to draining to prevent plankton from settling out. The particulates were collected on Whatman GF/F (4.25 cm) filters in a darkened room using vacuum filtration (≤ 6 psi). Ten ml of a saturated solution of MgCO₃ were added prior to the completion of the filtration; then the filters were dried and frozen. The Chl a analyses were made with the standard method described by Strickland and Parsons (1968) and the modifications recommended by the Scientific Committee on Oceanographic Research (UNESCO, 1973). Measurements were made both fluorometrically (Turner Model 111) and spectrometrically (Varian Series 634).

f. **Primary Productivity**

Estimates of primary production with ¹⁴C were derived using ultra-
clean collection and processing techniques developed at Moss Landing Marine Laboratories. We have found that failure to use such clean procedures can lead to severe metal contamination (e.g., Bruland, et al., 1979), resulting in both imprecise and inaccurate data. Five-liter Niskin bottles modified with specially designed closures consisting of surgical tubing encased in acid-washed plastic sheathing were used for sample collection. The bottles were hung on non-metallic Kevlar line. The polycarbonate productivity bottles were thoroughly cleaned with Micro, followed by three-day soakings in 1% quartz-distilled HNO₃ and repeated rinses with Milli-Q water. The °C solution was diluted with reagent grade Na (CO₃)₂ (2.1 mM, pH adjusted to 10 with NaOH) and stored as a single stock in Teflon bottles. We injected 250 μl of the ¹⁴C working solution into 260 ml productivity bottles with Eppendorf pipettes fitted with acid-washed tips.

The injection of 250 μl of the °C stock solution into 250 μl of sample was found to effectively dilute metal contaminants from this source to insignificant amounts (i.e., << 1 ng l⁻¹).

All samples were drawn from the Niskin bottles after gentle shaking (see Gardner, 1977) as quickly as possible and were innoculated rapidly as a single lot in a darkened room. Innoculation of all bottles was completed in less than five minutes.

Upon recovery, all bottles were immediately placed in a light-free box and removed to a darkened room for filtration. Samples were filtered through GF/F glass fiber filters, washed with 100 ml of filtered sea water, placed in 10 ml of Aquasol and counted in a liquid scintillation counter. Production was calculated from the equations of Strickland and Parsons (1972):
g. **Plankton Taxonomy**

A separate oblique plankton tow (53 μm mesh diameter) was made to 100 m from the barge in order to gain material for taxonomic identification. These samples were fixed with Lugil and surveyed with both light and scanning electron microscopes.

h. **Concurrent Measurements**

Dr. Garrett Brass (Rosenstiel School of Marine and Atmospheric Science, University of Miami) and Dr. Richard Dodge (Nova University) concurrently sampled suspended particulates to measure the Ra-226/Ra-228 ratio in order to determine their origin. Their data will be reported elsewhere.
RESULTS

Sampling Methods

a. Go-Flo^R Samples

The Go-Flo^R samples were deployed and five subsurface trace metal samples were collected and processed in the temporary clean lab within eight hours without a major mishap. However, the same samplers were used to collect other (radionuclide) samples under potentially metal-contaminating conditions immediately prior to this use for the trace metal samples in order to jointly accommodate two projects with limited amounts of time and resources.

Therefore, it is possible that some of the metal concentrations reported in the analytical results are contaminated. This may account for the unusual vertical distributions of some of the soluble and particulate elemental concentrations (e.g., those of Zn). Despite this qualification, the vertical profiles of some elements (e.g., soluble Mn) do not appear to be grossly contaminated (see analytical methods).

b. Sea Water Surface Samples

There were no problems encountered in the collection of surface sea water samples from the raft. Although it should be noted that this method and the ultra-clean plankton net tows are limited to the daylight hours of relatively calm periods, in contrast to the use of Go-Flo^R samplers.

There may have been an associated problem of contamination while processing the samples in the temporary clean area on the barge. The IDMS soluble Cd and Pb values of those samples from the bottles which were not opened on the barge are among the lowest ever reported (Flegal, 1981), but
some of the AAS elemental values (e.g., Zn) of the opened bottles are relatively high and more variable (see analytical section).

c. Plankton Net Tows

The plankton net tows were made without mishap. This method of collecting is a relatively fail-safe (during fair weather) complement to the filtration system used with the Go-Flo\textsuperscript{R} samples. Additionally, the relatively large amounts of material collected in the tows enable multiple analyses to be made.

d. Particle Interceptor Traps

After being successfully launched and remaining on-station for ten days, the PIT system sank. This was due to an error in a modified design, which has been corrected. The new design has since been successfully tested for one day in Monterey Bay and for 25 days in the North Pacific Gyre and over a three-week period in the California Current.

Seawater Analyses

a. Atomic Absorption Spectrophotometry

The data from the organic, chelex and chelex-acetate extractions and AAS analyses of filtered (0.4 μm) sea water are listed in Table 1. Some of the vertical distributions, including that of Mn are comparable with those reported for oceanic waters (e.g., Klinkhammer and Bender, 1980), while others, including that of Zn are not. The poor precision among the different Zn measurements from the same depth (e.g., 0.5 m) indicate that the samples were contaminated for at least some of the elements.

b. Isotope Dilution Mass Spectrometry

The Cd and Pb IDMS measurements of the surface (0.5 m) samples
(Table 2) are among the lowest ever observed in sea water. However, the Cd values are comparable to those in the tropical, oceanic Pacific (Flegal, 1981). The Pb values, while markedly lower than those in the oceanic Atlantic, are consistent with those in some coastal Atlantic waters (Ng and Patterson, ms in prep.).

Since these samples were not opened on the barge, their elemental values provide an indication of the extent of contamination of the AAS samples, which were opened on the ship.

Particulate Analyses

a. Atomic Absorption Spectrophotometry

The results of the bomb digestions and AAS analyses of the filtered particulates collected from the Go-Flo\textsuperscript{R} and surface sea water samples are listed in Table 3. Again, these data strongly suggest that at least some of those samples, like the filtered samples, were contaminated. For example, the Cu and Zn measurements at 0.5, 300 and 600 m are inconsistent with those at intermediate depths, and are considered to be exceptionally high for oceanic particulates.

b. Neutron Activation Analyses

The data listed in Table 4 represent the results of experimental analyses of different matrices by NAA. The principal objective of those analyses was to determine the optimum sample mass, as well as the irradiation and counting conditions, for the NAA of different particulate materials to be collected and analyzed in the OTEC program.

Based on the results of those analyses, new procedures were adopted to improve the sensitivity and precision of neutron activation analyses of
some elements in plankton (Asaro, Michel, Flegal and Hunt, 1980). Those modified procedures included pressing the pellets in a die of Al₂O₃ instead of stainless steel, using different irradiation and counting periods, and counting the samples on a 128 cc Ge-Li detector instead of a 7 cc Ge-Li detector.

The data obtained with the latter procedures for phytoplankton and planktonic fish collected from the central Pacific using the previously described ultra-clean sampling techniques are listed in Table 5. These data are considered to be the most accurate elemental measurements of these types of organisms that have ever been obtained because they combine the cleanest sampling techniques ever employed and the improved procedures for neutron activation analysis.

c. X-Ray Fluorescence

The accuracy of the XRF data from the analyses at LBL were limited by the high Sr content of the plankton, as indicated by the data in Table 6.

Other Analyses

a. Salinity

The salinity profile (Figure 1) is typical of the area, as described in Lee, et al., 1978. The 36% salinity of the tropical surface water (<100 m) indicates that the fresh water influence of the Amazon and Orinoco Rivers was minimal during the sampling period.

b. Nutrients

The nutrient concentrations listed in Table 1 are within the ranges compiled by Cummings, et al., 1979. An intercalibration with the Physical and Chemical Oceanographic Data Facility at Scripps Institution of Oceano-
graphy is being planned to evaluate the accuracy of the nutrient analyses at MLML.

c. **Chlorophyll a**

The two phytoplankton biomass measurements based on the Chl a analyses are listed in Table 7. These values are typical of those in the literature for similar water masses (e.g., Parsons and Takahashi, 1973).

d. **Primary Productivity**

The $^{14}$C measurements of primary productivity are listed in Table 8. They are also typical of the area (e.g., Parsons and Takahashi, 1973).

e. **Plankton Taxonomy**

The taxonomic survey, which was not quantitative, revealed a wide diversity in species. Most interesting from a biogeochemical point of view was the apparent abundance of plankton with different structural components (e.g., cellulose, calcium carbonate, silicate, strontium sulfate). Scanning electron photomicrographs of some of them are shown in Figure 2.
DISCUSSION

The principal objectives of the Particulate Program (OTEC), which were to develop and evaluate methods for sampling and analyzing the particulate matter at potential OTEC sites, were met with varying degrees of success.

Three different methods of collecting particulates were employed. Two of them (the Go-FloR samplers and the plankton net tows) were utilized without a major mishap. However, the third (the PIT system) was lost shortly before it was to be recovered. Since this loss was witnessed, the cause was recognized and the PIT system design has been improved and tested.

Four different methods of analysis were employed in the elemental measurements of the particulate material (AAS, NAA, XRF, IDMS). Each of those methods complements the others and contributes to the overall quality of the program. A large number of elements can be measured and the accuracy and precision of many elemental analyses can be determined by a comparison of the values obtained with different methods.

While essentially only one method (AAS) was employed in the complementary elemental analyses of filterable elemental concentrations, three different extraction processes were utilized. These increased the number of elements analyzed, and the multiple analyses of some elements provided an index of the accuracy and precision of those values. Additionally, the use of another method (IDMS) for a limited number of samples served the same functions.

The other supporting data on the distributions of salinity, suspended particulate load, nutrients, biomass, primary productivity and plankton taxonomy were collected to aid in the interpretation of the elemental data.
However, this has not been done because of the small number of elemental samples and the probability that at least some of them are contaminated.

Those restrictions on the data represent the principal limitation of the Particulate Program (OTEC) study. Yet, it should be re-emphasized that they were recognized as such prior to the initiation of the study as unavoidable consequences of its limited scope and resources.

In order to reduce the possibility that future studies do not suffer from the same limitations, several changes need to be made. These include using uncontaminated samplers, collecting at least twenty samples for a vertical profile and processing the samples in an ultra-clean laboratory.

Despite the litany of contamination which must be invoked with any discussion of the elemental data collected in this study, the geochemical aspects of it should be considered. These include the following: (1) The surface Pb values are among the lowest found in the North Atlantic, and the surface Cd values are among the lowest in the world. (2) The filtered Mn profile, which is believed to be the first in this area, is consistent with those in other regions. (3) Other elemental profiles, which appear contaminated because they are anomalous, may be due to the area's relatively unique oceanographic conditions. (4) The elemental analyses of plankton in this study constitute the most comprehensive measurement of samples collected with ultra-clean techniques ever made.
Literature Cited:


OTEC Particulate Program 1980, St. Croix (VOTEC)

Tables and Figures
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Cd</th>
<th>Cu</th>
<th>Mn</th>
<th>N:</th>
<th>Zn</th>
<th>Labile Nutrients (μmol/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>o.e.</td>
<td>pH6</td>
<td>pH8</td>
<td>o.e.</td>
<td>pH6</td>
<td>pH8</td>
</tr>
<tr>
<td>0.5</td>
<td>0.37/0.72</td>
<td>0.50</td>
<td>0.77</td>
<td>106</td>
<td>91</td>
<td>-</td>
</tr>
<tr>
<td>45</td>
<td>0.20</td>
<td>0.54</td>
<td>0.36</td>
<td>66</td>
<td>45</td>
<td>-</td>
</tr>
<tr>
<td>100</td>
<td>1.1/0.66</td>
<td>0.49</td>
<td>0.43</td>
<td>61</td>
<td>48</td>
<td>-</td>
</tr>
<tr>
<td>300</td>
<td>4.6/5.2</td>
<td>7.6</td>
<td>8.1</td>
<td>55</td>
<td>37</td>
<td>-</td>
</tr>
<tr>
<td>450</td>
<td>26.1/33.4</td>
<td>24.3</td>
<td>25.8</td>
<td>70</td>
<td>41</td>
<td>-</td>
</tr>
<tr>
<td>600</td>
<td>43.6/38.8</td>
<td>36.8</td>
<td>44.2</td>
<td>72</td>
<td>41</td>
<td>-</td>
</tr>
</tbody>
</table>

o.e. : concentration by organic extraction
pH6 : concentration by chelex-acetate extraction
pH7 : concentration by chelex extraction
TABLE 2. Soluble cadmium and lead concentrations at VOTEC Site #1 (February 1980) measured by isotope dilution mass spectrometry.

<table>
<thead>
<tr>
<th></th>
<th>Cd (ng/kg)</th>
<th>Pb (ng/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottle #1</td>
<td>0.14</td>
<td>7.6</td>
</tr>
<tr>
<td>Bottle #2</td>
<td>0.36</td>
<td>8.5</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.25</td>
<td>8.1</td>
</tr>
</tbody>
</table>
TABLE 3. Particulate elemental concentrations at VOTEC Site #1 (February 1980).

| Depth (m) | Ag  | Al  | Cd  | Cr  | Cu  | Fe  | Mn  | Ni  | Pb  | Ti  | Zn  |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0.5       | .37 | 380 | 1.4 | 1.1 | 2600| 200 | 12  | 5.8 | 91  | 36  | 1800|
| 45        | .15 | 850 | .2  | 2.2 | 56  | 840 | 21  | 4.8 | 10  | 85  | 83  |
| 100       | 1.00| 940 | 1.1 | 5.2 | 25  | 760 | 150 | 11.0| 16  | 160 | 45  |
| 300       | .41 | 1400| .8  | 2.4 | 1000| 870 | 590 | 7.2 | 64  | 72  | 900 |
| 450       | .21 | 2000| 1.0 | 7.8 | 13  | 1400| 43  | 7.4 | 11  | 180 | 18  |
| 600       | 1.00| 8800| 2.2 | 12.0| 5700| 4400| 170 | 24.0| 390 | 500 | 4600|

<table>
<thead>
<tr>
<th>ng/l</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>.29</td>
<td>300</td>
<td>1.1</td>
<td>.9</td>
<td>2000</td>
<td>160</td>
<td>9</td>
<td>4.6</td>
<td>71</td>
<td>29</td>
<td>1400</td>
</tr>
<tr>
<td>45</td>
<td>.08</td>
<td>460</td>
<td>.1</td>
<td>1.2</td>
<td>31</td>
<td>460</td>
<td>11</td>
<td>2.6</td>
<td>5</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>100</td>
<td>.09</td>
<td>83</td>
<td>.1</td>
<td>.5</td>
<td>2</td>
<td>67</td>
<td>13</td>
<td>1.0</td>
<td>1</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>300</td>
<td>.07</td>
<td>250</td>
<td>.1</td>
<td>.4</td>
<td>180</td>
<td>160</td>
<td>11</td>
<td>1.3</td>
<td>12</td>
<td>13</td>
<td>160</td>
</tr>
<tr>
<td>450</td>
<td>.04</td>
<td>370</td>
<td>.2</td>
<td>1.4</td>
<td>2</td>
<td>250</td>
<td>8</td>
<td>1.4</td>
<td>2</td>
<td>33</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>.06</td>
<td>490</td>
<td>.1</td>
<td>.6</td>
<td>320</td>
<td>240</td>
<td>9</td>
<td>1.3</td>
<td>22</td>
<td>28</td>
<td>250</td>
</tr>
</tbody>
</table>
TABLE 4. Elemental concentrations of marine particulates measured by neutron activation analysis.*

<table>
<thead>
<tr>
<th>Element</th>
<th>1088 E Phytoplankton</th>
<th>1088 F Zooplankton</th>
<th>1088 G Detritus</th>
<th>1088 H NBS #1645 Std. River Sediment</th>
<th>1088 J Biorad Filter</th>
<th>Corrected for Al foil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al %</td>
<td>&lt;.69</td>
<td>&lt;.64</td>
<td>2.7 ± .6</td>
<td>2.33 ± .13</td>
<td>&lt;.5</td>
<td>&lt;.13</td>
</tr>
<tr>
<td>Mg %</td>
<td>&lt;7.1</td>
<td>&lt;7.1</td>
<td>&lt;11.</td>
<td>1.0 ± .4</td>
<td>&lt;.03</td>
<td>&lt;.09</td>
</tr>
<tr>
<td>K %</td>
<td>1.49 ± .20</td>
<td>1.35 ± .19</td>
<td>&lt;.9</td>
<td>.98 ± .20</td>
<td>&lt;.09</td>
<td>&lt;.09</td>
</tr>
<tr>
<td>Ca %</td>
<td>&lt;1.0</td>
<td>&lt;2.6</td>
<td>&lt;7.4</td>
<td>2.74 ± .4</td>
<td>&lt;.09</td>
<td>&lt;.09</td>
</tr>
<tr>
<td>Cl %</td>
<td>12.7 ± .3</td>
<td>12.3 ± .3</td>
<td>24.0 ± .4</td>
<td>.0054 ± .0018</td>
<td>.0052 ± .0003</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Na %</td>
<td>7.68 ± .15</td>
<td>6.58 ± .13</td>
<td>16.4 ± .3</td>
<td>5.25 ± .11</td>
<td>45 ± 6 ppm</td>
<td>&lt;.011</td>
</tr>
<tr>
<td>U</td>
<td>.83 ± .05</td>
<td>.49 ± .06</td>
<td>1.54 ± .05</td>
<td>1.13 ± .05</td>
<td>4.2 ± 5.2</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Ba</td>
<td>&lt;84.</td>
<td>&lt;54.</td>
<td>123 ± 23</td>
<td>292 ± 25</td>
<td>2.2 ± 1.9</td>
<td>&lt;.19</td>
</tr>
<tr>
<td>Ti %</td>
<td>&lt;.51</td>
<td>&lt;.41</td>
<td>&lt;.74</td>
<td>&lt;.15</td>
<td>&lt;.025</td>
<td>&lt;.19</td>
</tr>
<tr>
<td>Mo</td>
<td>&lt;3.7</td>
<td>&lt;4.7</td>
<td>&lt;4.3</td>
<td>18.6 ± 1.9</td>
<td>&lt;.42</td>
<td>&lt;.19</td>
</tr>
<tr>
<td>W</td>
<td>&lt;7.8</td>
<td>&lt;5.1</td>
<td>&lt;5.8</td>
<td>&lt;9.1</td>
<td>&lt;.42</td>
<td>&lt;.42</td>
</tr>
<tr>
<td>As</td>
<td>&lt;21.</td>
<td>&lt;24.</td>
<td>&lt;17.</td>
<td>76.6 ± 3.3</td>
<td>&lt;.15</td>
<td>&lt;.42</td>
</tr>
<tr>
<td>Br2,3</td>
<td>628 ± 7</td>
<td>1220 ± 8</td>
<td>304 ± 6</td>
<td>&lt;7.0</td>
<td>&lt;3.0</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Mn</td>
<td>12 ± 5</td>
<td>70 ± 8</td>
<td>801 ± 16</td>
<td>.24 ± .07</td>
<td>&lt;.15</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Cr</td>
<td>12.3 ± .4</td>
<td>.76 ± .29</td>
<td>45.7 ± .8</td>
<td>3.36 ± .03%</td>
<td>1.92 ± .12</td>
<td>1.88 ± .12</td>
</tr>
<tr>
<td>Co</td>
<td>.388 ± .024</td>
<td>.111 ± .014</td>
<td>3.178 ± .072</td>
<td>9.11 ± .19</td>
<td>.149 ± .014</td>
<td>.138 ± .018</td>
</tr>
<tr>
<td>Rb</td>
<td>5.38 ± .83</td>
<td>4.05 ± .51</td>
<td>24.1 ± 2.2</td>
<td>&lt;34.</td>
<td>&lt;.6</td>
<td>&lt;.6</td>
</tr>
<tr>
<td>Sn3</td>
<td>&lt;.56.</td>
<td>&lt;.47.</td>
<td>&lt;.96</td>
<td>618 ± 63</td>
<td>&lt;7.4</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Ag3</td>
<td>&lt;.33</td>
<td>.28 ± .07</td>
<td>&lt;.16</td>
<td>1.54 ± .45</td>
<td>&lt;.08</td>
<td>&lt;.15</td>
</tr>
<tr>
<td>Cs</td>
<td>&lt;.10</td>
<td>.038 ± .016</td>
<td>1.55 ± .07</td>
<td>2.63 ± .11</td>
<td>&lt;.14</td>
<td>&lt;.14</td>
</tr>
<tr>
<td>Fe %</td>
<td>.109 ± .005</td>
<td>&lt;150 ppm</td>
<td>1.17 ± .02</td>
<td>12.0 ± 2.0</td>
<td>&lt;25 ppm</td>
<td>&lt;19. ppm</td>
</tr>
<tr>
<td>Sb</td>
<td>.511 ± .054</td>
<td>.029</td>
<td>.174 ± .046</td>
<td>40.5 ± 2.0</td>
<td>&lt;4.3</td>
<td>&lt;4.3</td>
</tr>
<tr>
<td>Ni</td>
<td>5.9 ± 2.2</td>
<td>6.3 ± 1.3</td>
<td>33.5 ± 4.4</td>
<td>62 ± 13</td>
<td>2.2 ± .5</td>
<td>1.9 ± .6</td>
</tr>
</tbody>
</table>
Table 4 (continued)

<table>
<thead>
<tr>
<th>Element</th>
<th>1088 E</th>
<th>1088 F</th>
<th>1088 G Particulate</th>
<th>1088 H NBS #1645</th>
<th>1088 J Biorad Filter</th>
<th>1088 J Corrected for Al foil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn³</td>
<td>638 ± 6</td>
<td>118 ± 3</td>
<td>31.3 ± 2.5</td>
<td>1758 ± 18</td>
<td>1.6 ± .4</td>
<td>&lt;1.8</td>
</tr>
<tr>
<td>Ta</td>
<td>&lt;.05</td>
<td>&lt;.02</td>
<td>.221 ± .005</td>
<td>.123 ± .007</td>
<td>.0040 ± .0006</td>
<td>.0024 ± .0021</td>
</tr>
<tr>
<td>Hf</td>
<td>&lt;.05</td>
<td>&lt;.05</td>
<td>.729 ± .069</td>
<td>.46 ± .13</td>
<td>&lt;.013</td>
<td></td>
</tr>
<tr>
<td>Se³</td>
<td>1.6 ± .3</td>
<td>2.4 ± .3</td>
<td>1.53 ± .34</td>
<td>2.30 ± .70</td>
<td>&lt;.12</td>
<td></td>
</tr>
<tr>
<td>Sc</td>
<td>.143 ± .008</td>
<td>.0326 ± .0034</td>
<td>4.59 ± .05</td>
<td>2.31 ± .04</td>
<td>.0136 ± .0013</td>
<td>&lt;.003</td>
</tr>
<tr>
<td>Hg 2,3</td>
<td>&lt;.23</td>
<td>&lt;.20</td>
<td>&lt;.36</td>
<td>&lt;1.8</td>
<td>&lt;.04</td>
<td></td>
</tr>
</tbody>
</table>

Footnotes


2. Some Br and Hg can be lost in sample preparation.

3. The Zn, Se, Hg, Ag, Sn, Br, and Hg are calibrated against flux monitors and therefore have a 10% uncertainty.

4. The maximum amount of Cr due to the tool steel die is .78 ppm.

*Analyses by F. Asaro and H.V. Michel at Lawrence Berkeley Laboratory.
Table 5

Estimates\(^{(4)}\) of abundances in plankton determined with a 128 cc Ge-Li detector\(^{*}\)

(expresses in parts-per-million)

<table>
<thead>
<tr>
<th>Sample</th>
<th>(\gamma) ray detector volume</th>
<th>Elements</th>
<th>Co(^{(5)})</th>
<th>Cr</th>
<th>Cs</th>
<th>Fe</th>
<th>Hf</th>
<th>Ir</th>
<th>Ni</th>
<th>Rb(^{(6)})</th>
<th>Sr(^{(7)})</th>
<th>Ta(^{(6)})</th>
<th>Th</th>
<th>Ag</th>
<th>Sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>P7</td>
<td>128cc(^{(1)})</td>
<td></td>
<td>.466±.006</td>
<td>1.06±.17</td>
<td>.006±.008</td>
<td>29.2±1.5</td>
<td>&lt;.010</td>
<td>&lt;.00028</td>
<td>5.84±.11</td>
<td>3.30±.21</td>
<td>.173±.004</td>
<td>.0055±.0005</td>
<td>&lt;.021</td>
<td>.04±.004</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>7cc(^{(2)})</td>
<td></td>
<td>.472±.026</td>
<td>&lt;1.9</td>
<td>.032±.018</td>
<td>.84</td>
<td>&lt;.07</td>
<td>&lt;.0018</td>
<td>6.4±1.0</td>
<td>2.0±.6</td>
<td>.138±.026</td>
<td>&lt;.020</td>
<td>&lt;.08</td>
<td>&lt;.16</td>
<td>-</td>
</tr>
<tr>
<td>FD</td>
<td>128cc(^{(3)})</td>
<td></td>
<td>.127±.007</td>
<td>.173±.04</td>
<td>.050±.0011</td>
<td>34.6±.9</td>
<td>&lt;.0032</td>
<td>&lt;.00099</td>
<td>1.60±.07</td>
<td>6.57±.18</td>
<td>.0154±.0012</td>
<td>.00135±.0008</td>
<td>&lt;.008</td>
<td>576±14</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>7cc(^{(2)})</td>
<td></td>
<td>.111±.018</td>
<td>&lt;1.2</td>
<td>.056±.016</td>
<td>&lt;.74</td>
<td>&lt;.07</td>
<td>&lt;.0035</td>
<td>&lt;3.2</td>
<td>7.5±.7</td>
<td>&lt;.029</td>
<td>&lt;.024</td>
<td>&lt;.05</td>
<td>460±110</td>
<td></td>
</tr>
</tbody>
</table>

(1) 464 minute gamma-ray count about 70 days after the end of the long irradiation.
(2) 60 minute gamma-ray count about 24 days after the end of the long irradiation.
(3) 754 minute gamma-ray count about 71 days after the end of the long irradiation.
(4) Only estimates were obtained for the measurements made with the 128 cc detector as flux monitors were used for all elements. Uncertainties (due to calibration) of ±10% are possible. The listed errors are in values of the counting error and would be the precision if a multielement standard were used.
(5) Abundances have been modified to reflect an estimated 0.3-0.4 ppm Co contribution from the Al wrapping foil.
(6) Estimated contaminants from the Al wrapping foil of <.001 ppm for Ta and <.01 ppm for Sb have not been removed. Accurate abundances of these elements can be obtained by removing the Al foil from each of the pills and measuring its gamma-ray spectrum.
(7) The \(^{87}\)Rb radiation is also produced by the reaction \(^{87}\)Sr (\(n,p\)) \(^{87}\)Rb. The Sr contribution has not been removed. Sea water and Sr probably account for all the \(^{87}\)Rb detected in P7 and very little of that detected in FD.

*Analyses by F. Asaro and H.V. Michel at Lawrence Berkeley Laboratory
TABLE 6 Elemental analysis of marine plankton and planktonic fishes by x-ray fluorescence analysis.*

<table>
<thead>
<tr>
<th>Element</th>
<th>Sample ID</th>
<th>C</th>
<th>P-3</th>
<th>P-5</th>
<th>P-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn (ppm)</td>
<td>~ 50</td>
<td>~ 20</td>
<td>~ 50</td>
<td>~ 20</td>
<td></td>
</tr>
<tr>
<td>Br (%)</td>
<td>~ 0.2</td>
<td>~ 0.2</td>
<td>~ 0.25</td>
<td>~ 0.16</td>
<td></td>
</tr>
<tr>
<td>Sr (%)</td>
<td>~ 6</td>
<td>~ 1</td>
<td>~ 2</td>
<td>~ 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.22±.18</td>
<td>1.02±.04</td>
<td>1.87±.06</td>
<td>2.75±.07</td>
<td></td>
</tr>
<tr>
<td>Cd (ppm)</td>
<td>~ 15</td>
<td>~ 6</td>
<td>~ 25</td>
<td>~ 10</td>
<td></td>
</tr>
<tr>
<td>I (ppm)</td>
<td>--</td>
<td>~300</td>
<td>~100</td>
<td>~100</td>
<td></td>
</tr>
<tr>
<td>Ba (ppm)</td>
<td>~150</td>
<td>~ 50</td>
<td>~ 50</td>
<td>~ 80</td>
<td></td>
</tr>
</tbody>
</table>

Elemental Concentrations of Planktonic Fishes

<table>
<thead>
<tr>
<th>Element</th>
<th>Sample F-D</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Zn</th>
<th>As</th>
<th>Se</th>
<th>Br</th>
<th>Rb</th>
<th>Sr</th>
<th>Cd</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5±2 ppm</td>
<td>67±3</td>
<td>4±1</td>
<td>11±1</td>
<td>68±3</td>
<td>6±1</td>
<td>8±1</td>
<td>180±8</td>
<td>8±2</td>
<td>780±30</td>
<td>&lt; 4</td>
<td>18±3</td>
</tr>
</tbody>
</table>

*Analyses by R. Giauque at Lawrence Berkeley Laboratory.

**The high Sr content in each of the four samples limited the accuracy to which trace elements could be determined; consequently, only estimated values are listed for elements easily detected as being present.
**TABLE 7** Phytoplankton biomass measured with Chlorophyll \( a \) (\( \mu \text{M/m}^3 \)) at VOTEC Site #1 (February 1980).

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Fluorometer</th>
<th>Spectrometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.085</td>
<td>0.107</td>
</tr>
<tr>
<td>30</td>
<td>0.119</td>
<td>1.179</td>
</tr>
<tr>
<td>65</td>
<td>0.124</td>
<td>0.173</td>
</tr>
<tr>
<td>100</td>
<td>0.314</td>
<td>0.316</td>
</tr>
<tr>
<td>150</td>
<td>0.142</td>
<td>0.177</td>
</tr>
</tbody>
</table>
TABLE 8  Surface primary productivity at VOTEC Site #1 (February 1980) measured with

<table>
<thead>
<tr>
<th>Bottle Number</th>
<th>my C m⁻³ hr⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.43</td>
</tr>
<tr>
<td>2</td>
<td>.31</td>
</tr>
<tr>
<td>3</td>
<td>.20</td>
</tr>
<tr>
<td>4</td>
<td>.20</td>
</tr>
<tr>
<td>5</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td>.28</td>
</tr>
</tbody>
</table>
Figure 1
Salinity profile at VOTEC site #1 (February 1980)
Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

1. unidentified Radiolarian
(silica)
700X
Figure 2a continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

2. *Spongaster* sp. and *Lamprocyclas* sp.
   (silica)
   400X
Figure 2a continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

3. Dinophysis (cellulose) 500X

XBB 821-783
Figure 2a continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

4. possibly Octopyle (silica)
500X
Figure 2b

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

1. Dinophysis sp. 
   (cellulose)
   500X
Figure 2b continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

2. *Globoratalia* sp.
   (calcium carbonate)
   400X
Figure 2b continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

3. *Pterocanium* (silica) 500X
Figure 2b continued

Scanning electron photomicrographs of net plankton collected in an oblique tow to 100m at VOTEC site #1 (February 1980).

(Structural composition in parenthesis.)

4. Ampholithium sp.
(strontium sulphate)
500X
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.