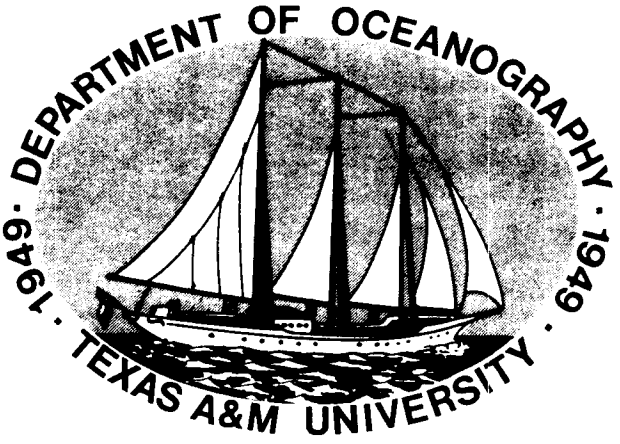

NORTHERN GULF OF MEXICO TOPOGRAPHIC FEATURES STUDY

FINAL REPORT

VOLUME THREE

Submitted to the
U.S. Department of the Interior
Bureau of Land Management
Outer Continental Shelf Office
New Orleans, Louisiana

Contract No. AA551-CT8-35

Department of Oceanography
Texas A&M University
College Station, Texas

Technical Report No. 81-2-T

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This volume has been reviewed by the Bureau of Land Management and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Bureau, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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CHAPTER X

THE FLOWER GARDEN BANKS

INTRODUCTION

East Flower Garden

Studies at the East Flower Garden Bank continued those begun with the 1976 contract (#AA550-CT6-18). Under that contract, mapping was conducted and bathymetric profiles were supplemented by side-scan sonar, 3.5 kHz high resolution sub-bottom profiling, and a Del Norte mini sparker. Characterization of the geology of the bank was not required. Post-drilling assessments of epibenthic and groundfish communities were made, and environmental monitoring of reef communities was initiated.

The present contract continues the environmental monitoring activities, including intensive sampling and a variety of in-water sampling and observational activities both by SCUBA and from the DRV DIAPHUS submersible. Also included is characterization of the bottom sediments, suspended sediments, hydrography, and biology and chemistry of the bottom sediments and selected organisms. Results from these studies are presented in four sections: A- Geology and Structure; B- Water and Sediment Dynamics; C- Biological Monitoring Studies; D- Chemistry. The present contract does not include interpretation of the seismic and side-scan sonar records.

West Flower Garden

Most of the work at the West Flower Garden is presently under way and will be reported later. This work includes: 1) bathymetric and sub-sea mapping, including side-scan sonar; 2) sampling and observational activities to assess the biota, geology, and hydrography; and 3) hydrocarbon analyses of bottom sediments and Spondylus. In most cases, the reporting requirement for interpretation of West Flower Garden data was allocated to the final report on BLM-TAMRF Contract #AA851-CT0-25.

PART A: GEOLOGY AND STRUCTURE

R. Rezak

GENERAL DESCRIPTION

The West Flower Garden Bank is located at 93°48'47"W longitude and 27°52'27"N latitude in Blocks 383-85, 397-99, and 401 of the High Island Area, and Block 134 of the Garden Banks Area. This bank will be described in the Final Report for Contract #AA851-CT0-25.

The East Flower Garden Bank is located at 27°54'32"N latitude and 93°36'W longitude in Blocks A-366, 367, 374, 375, 388, and 389 of the High Island Area (Volume One, Figure III-1). The bank is pear-shaped and covers an area of about 67 km^2 (Figure X-A-1). Steep slopes occur on the east and south sides of the bank with gentle slopes on the west and north sides. The shallowest depth on the bank is about 20 m in the northeastern part of Block 388. The surrounding water depths are about 100 m to the west and north and about 120 m on the east and south sides. An elongate depression in the north-central part of Block 389 has a depth of 136 m.

PHYSIOGRAPHY AND STRUCTURE

The West Flower Garden Bank was mapped at a scale of 1:12,000 and at a contour interval of two metres (Figure X-A-2). Also, a side-scan sonar mosaic of the EG&G-SMS-960 data has been prepared. Interpretation of the side-scan and seismic data is presently being conducted.

For the East Flower Garden Bank, there has been no requirement in the contracts to work up the data from the side-scan and seismic profiles since 1976, when the bank was surveyed. A general discussion of the structure of the bank is given in Volume One, Chapter III, under the heading "Diapirism."

SEDIMENTOLOGY

West Flower Garden

At the West Flower Garden, two bottom sediment samples were taken at each of three stations (Figure X-A-2) for hydrocarbon analyses. These results are reported below under Chemistry. Sediment texture parameters and mineralogy will be reported under Contract #AA851-CT0-25.

East Flower Garden

Data for the East Flower Garden sediment distribution map include samples from 33 stations scattered about the area of the bank and 12

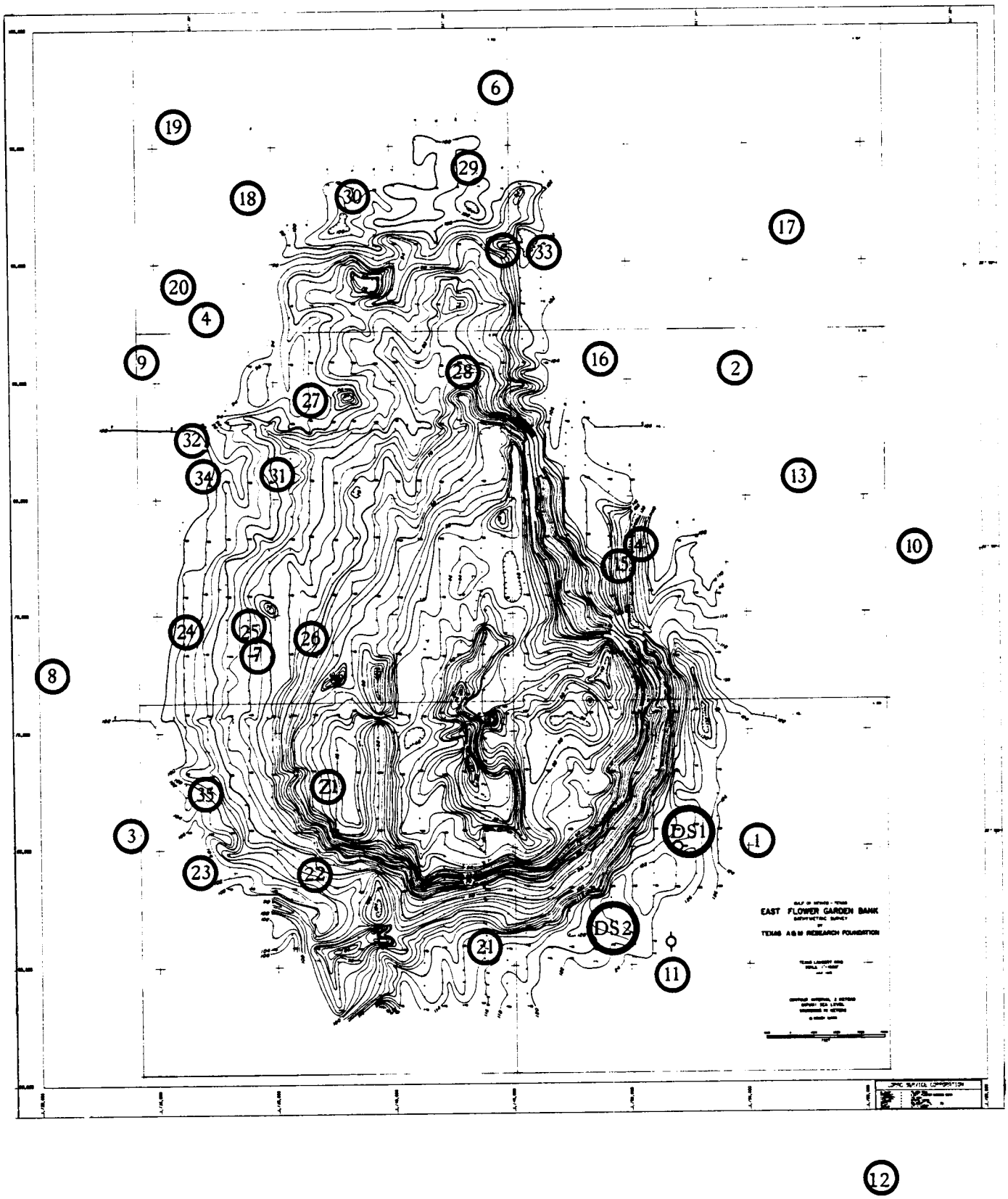

Figure X-A-1. Bathymetry and sediment stations on East Flower Garden Bank.

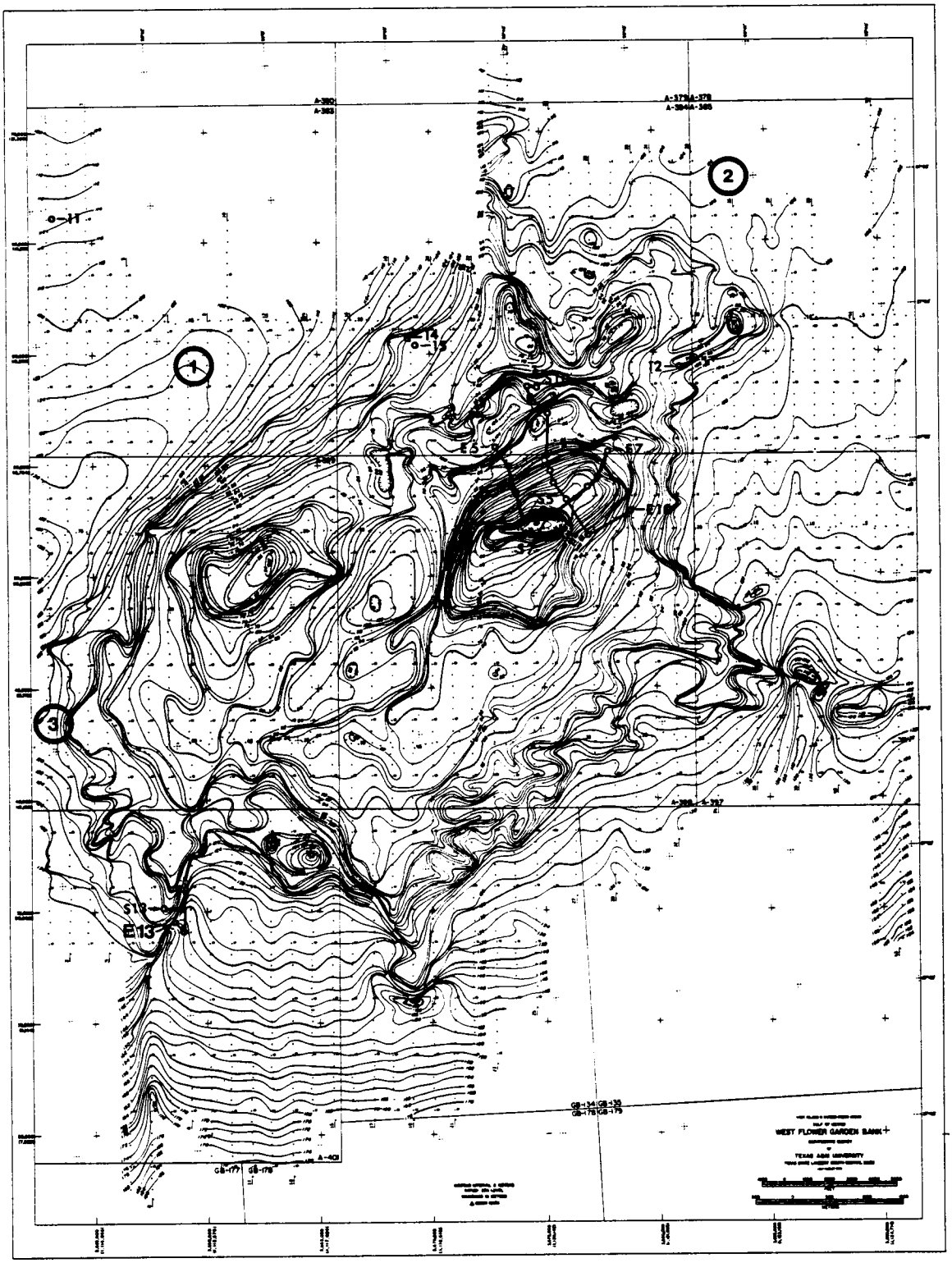

Figure X-A-2. Bathymetry, sediment sample locations, and submersible transects, dives 5, 7, 10, and 13 (S = Start, E = End) at the West Flower Garden Bank.

stations around each of two drill sites near the southeast margin of the bank (Figure X-A-1). The shallower portions of the bank, those underlain by the hard bottoms of the living coral reef and the Gypsina-Lithothamnium Zone, were impossible to sample properly with the Smith-McIntyre grab. Facies boundaries in these areas were delineated on the basis of submersible observations (Figure X-A-3) and side-scan sonar.

Sediment analysis data are presented in Volume One, Appendix A, Tables III-1 through 5. The sediment distribution on and around the bank is shown on Figure X-A-4.

Living Coral Reef

The biota of the living reef has been described by Bright and Rezak (1978a). Sedimentologically, the zone consists of the hard substrates created by the reef biota and the coarse sands and gravels derived from the mechanical breakdown of skeletal carbonate. This zone extends down to a depth of about 50 m, where the sands and gravels merge with the Coral Debris Facies.

Coral Debris Facies

The Coral Debris Facies is derived from the living reef and consists of a coarse coral sand and gravel with minor amounts of mollusc and coralline algae fragments. The facies ranges in depth from approximately 46 to 50 m. Large patches of this sand occur in basins and valleys between coral heads on the living reef. The sands are moved down the valleys to chutes which carry the sand to the sediment apron surrounding the living reef. Because the sand movement is mainly due to gravity, the facies is restricted to a narrow band around the base of the reef.

Gypsina-Lithothamnium Facies

This facies ranges in depth from between 40-50 m to 60-75 m. At the shallower depths, the facies is composed of nodules of encrusting coralline algae that are being formed in situ. At greater depths, the growth form changes to a platy or free crust that blankets the loose sediment. The surface is a smooth pavement of coralline algae at any depth within this facies where drowned reefs occur.

The nodules vary in size from granules to cobbles. As would be expected, sorting in this facies is very poor. Both the upper and lower boundaries of the facies are transitional rather than sharp.

Amphistegina Sand Facies

This facies ranges in depth from 60-75 m to 90-100 m. It consists mainly of the dead skeletons of the foraminifer Amphistegina, which grow attached to the surfaces of the coralline algal-nodules in the Gypsina-Lithothamnium facies. Upon dying, these sand size skeletons move downslope to form the Amphistegina sand. Sand size fragments of

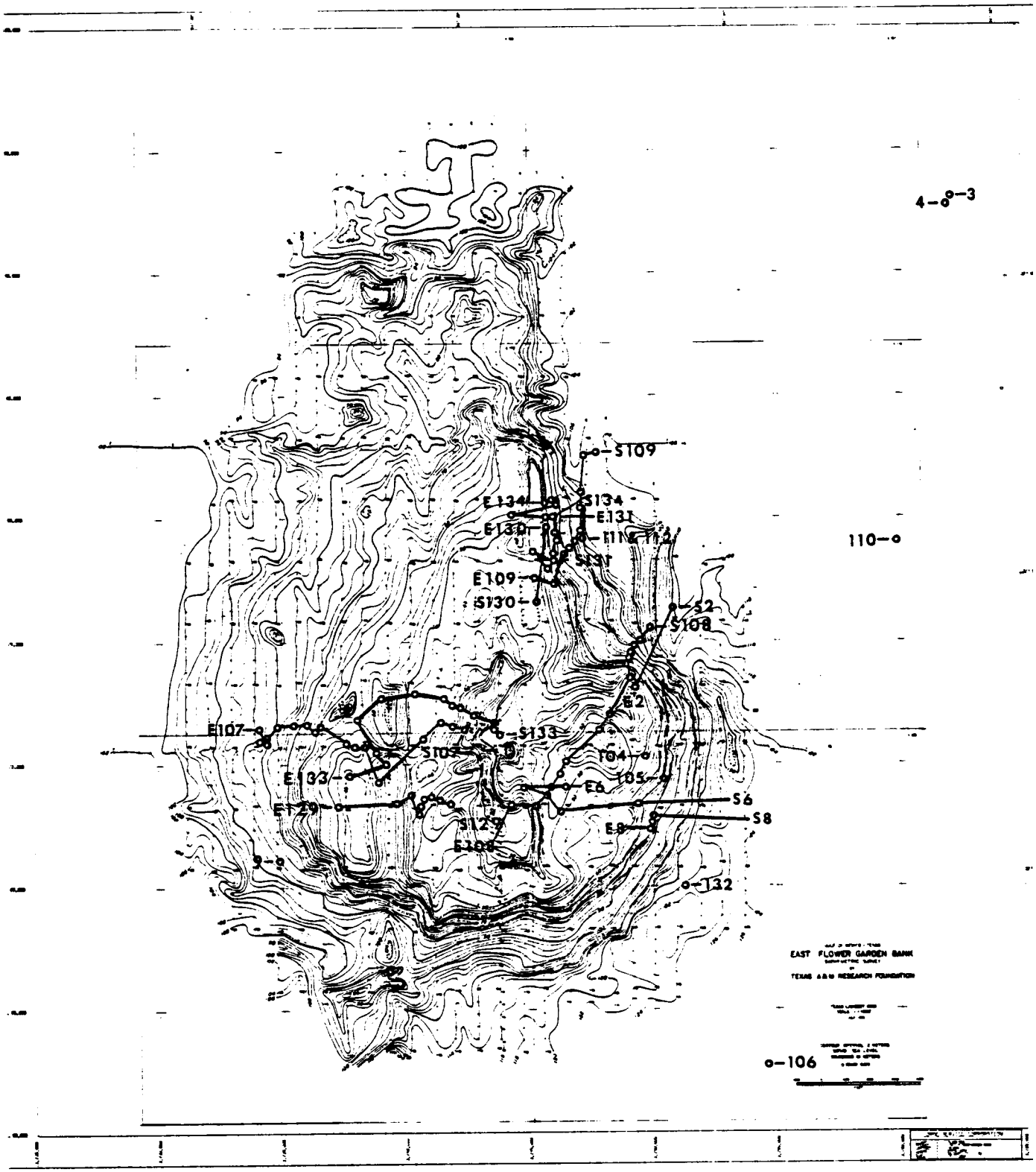

Figure X-A-3. Submersible transects at the East Flower Garden Bank. S = Start, E = End.

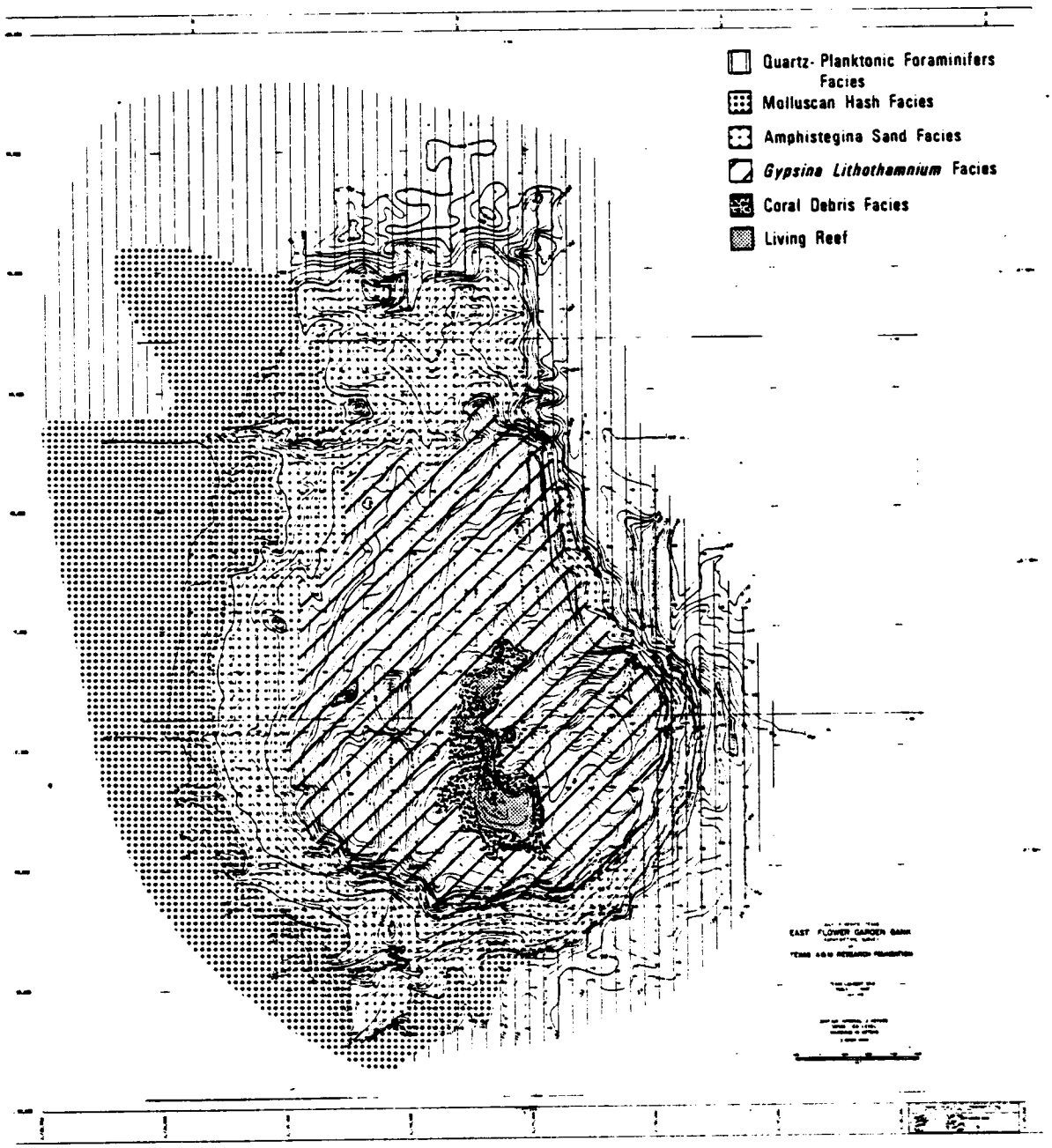

Figure X-A-4. Recent sediment facies, East Flower Garden Bank.

coralline algae, coral, and molluscs also occur in this facies. Much of this material is derived from the bioerosion of drowned reefs (described below) that are common at these depths.

Tests of Amphistegina form up to 57% of the sediment, with the tests varying in appearance from whole tests to stained and rounded tests. The stained and rounded tests are reworked from older deposits that are exposed on the seafloor.

Quartz-Planktonic Foraminifers Facies

This facies occurs on the northern and eastern sides of the bank below depths of approximately 85-100 m. As originally defined by Edwards (1971), the facies ranges from 10% silt and fine sand size quartz grains and 10% planktonic foraminifers to a terrigenous silty sand with few carbonate particles. At the East Flower Garden, the facies contains from 2.5-76% quartz grains and from 9.2-79.6% planktonic foraminifers. The silt-plus-clay fraction varies from 24-100%, with an average of 82%.

On the southeast margin of the bank, where the steepest slopes occur, this facies is in direct contact with the Gypsina-Lithothamnium Facies.

Molluscan Hash Facies

This facies occurs on the western and southwestern margins of the bank below depths of 85-100 m. The facies has not been recognized previously as it apparently does not occur on the West Flower Garden Bank.

As here defined, the facies is composed of from 15-54% sand size mollusc fragments and from 0-34.5% quartz grains. The silt-plus-clay fraction ranges from 5-62%, with an average of 22%. It is easily distinguished from the Quartz-Planktonic Foraminifers Facies by its low content of planktonic foraminifers (0.5-13.3%) and its low mud content. Also, the percentage of molluscs in the Quartz-Planktonic Foraminifers Facies is much less, ranging from 1.0-14.6%.

CONCLUSIONS AND RECOMMENDATIONS

As can be seen from the discussion in Volume One, Chapter III, no significant normal faulting has taken place at the East Flower Garden Bank. However, this study has documented the dissolution and removal of prodigious amounts of salt from the crest of the diapir and the roofs of the large voids created by this salt removal will eventually collapse to form a central graben on the bank. When that happens, it is conceivable that the living reef will be displaced downward into depths too great for the growth of the reef biota. At that time, the reef will become another drowned reef similar to those we have seen on all of the banks we have examined. It is strongly recommended that sensors be emplaced at several sites on the East Flower Garden Bank in order to determine the amount and direction of movement occurring at the crest of the bank.

PART B: WATER AND SEDIMENT DYNAMICS

D. McGrail, D. Horne

INTRODUCTION

Studies of water and sediment dynamics were carried out during three seasonal cruises to the East Flower Garden Bank (January, April, and July 1979: see Volume One, Table II-5). Data gathering for information on stratification, transmissivity, and velocity was attempted on all three cruises, but only two sampling cruises (April 1979 and July 1979) yielded usable data. Time series current meter measurements were also undertaken during three sampling periods in 1979: January-April, April-July, and July-September.

SEASONAL SAMPLING CRUISES

January 1979

Extreme storm conditions were experienced during the January cruise with one norther following upon another. Seas rising to over 7 m caused damage to the electronic equipment which could not be repaired at sea and posed a real hazard to human life. For these reasons the January sampling cruise was aborted after the deployment of the current meter arrays.

April 1979

Overview

Conditions prevailing during the April cruise were unique among all we have observed at any bank, at any time. The most unusual feature was that the currents were nearly barotropic (depth independent) and nearly uniform at all stations. With the exception of one station, the flow was from east to west at 80 to 100 cm/sec (Figures X-B-1 through 13). The exception was station 15 (Figure X-B-8), which showed westerly flow at approximately 60 cm/sec.

In retrospect, the station distribution (Figure X-B-1) was unfortunate for hydrographic studies because none of the stations were on the bank proper. Rather, they were clustered around the northern flanks of the bank in response to the need to fill in samples for the sediment distribution map. Adjustments were not made at sea because the raw velocity data contain ship drift so that the magnitude and steadiness of the current were not evident until the data were processed back in the laboratory. Still, a great deal of information was obtained, some of it very hard to interpret.

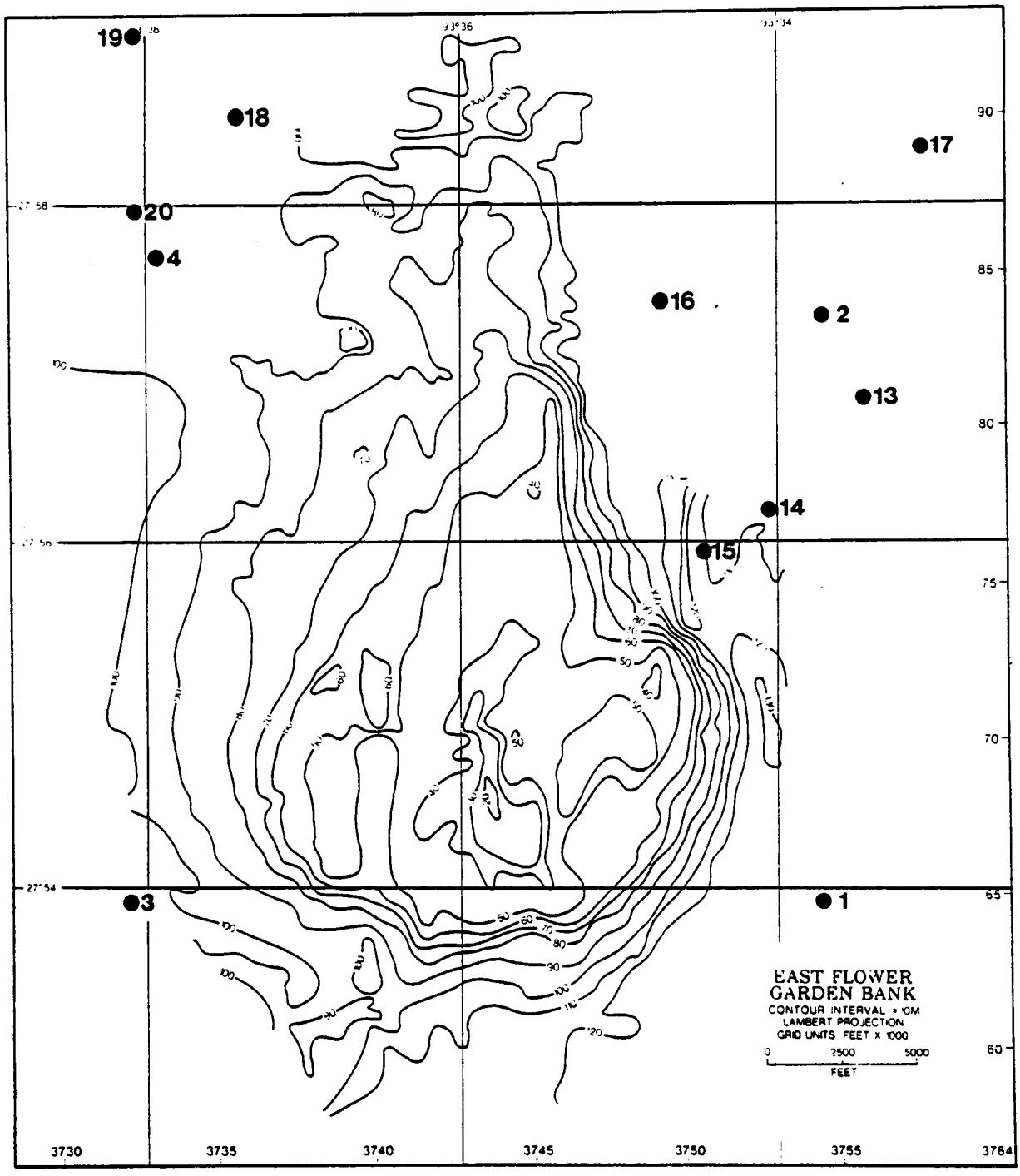

Figure X-B-1. Location map for April 1979 hydrographic sampling.

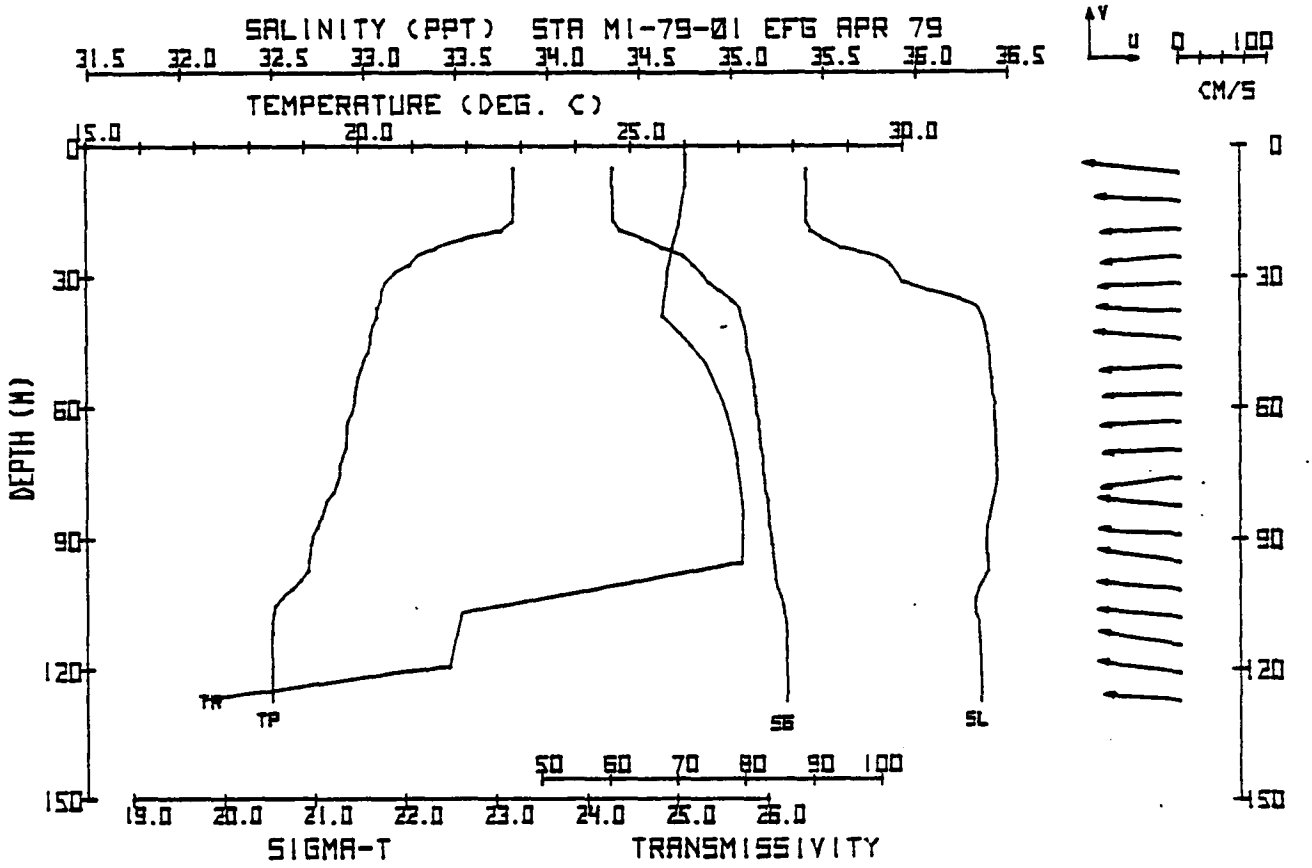

Figure X-B-2. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 1 (April 1979).

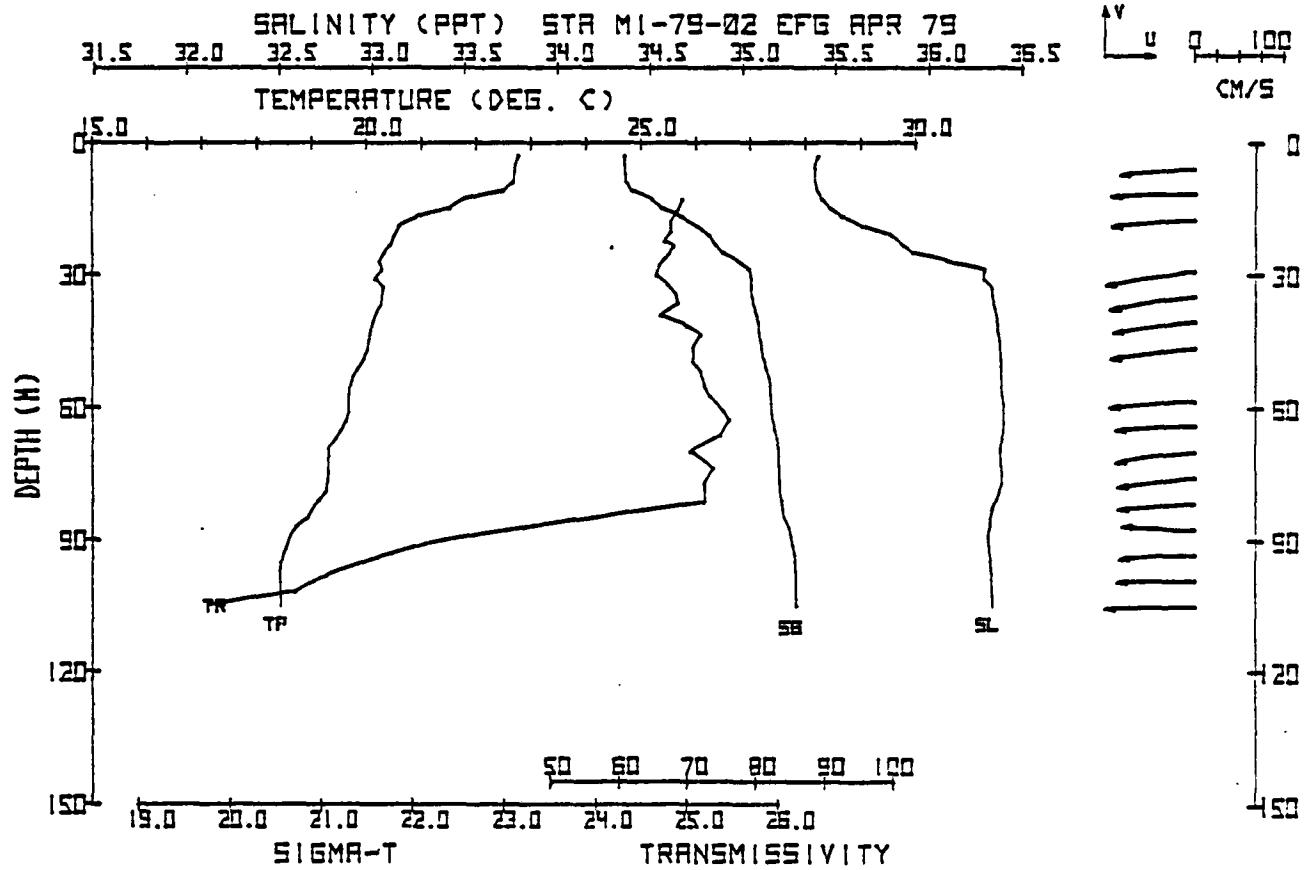

Figure X-B-3. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 2 (April 1979).

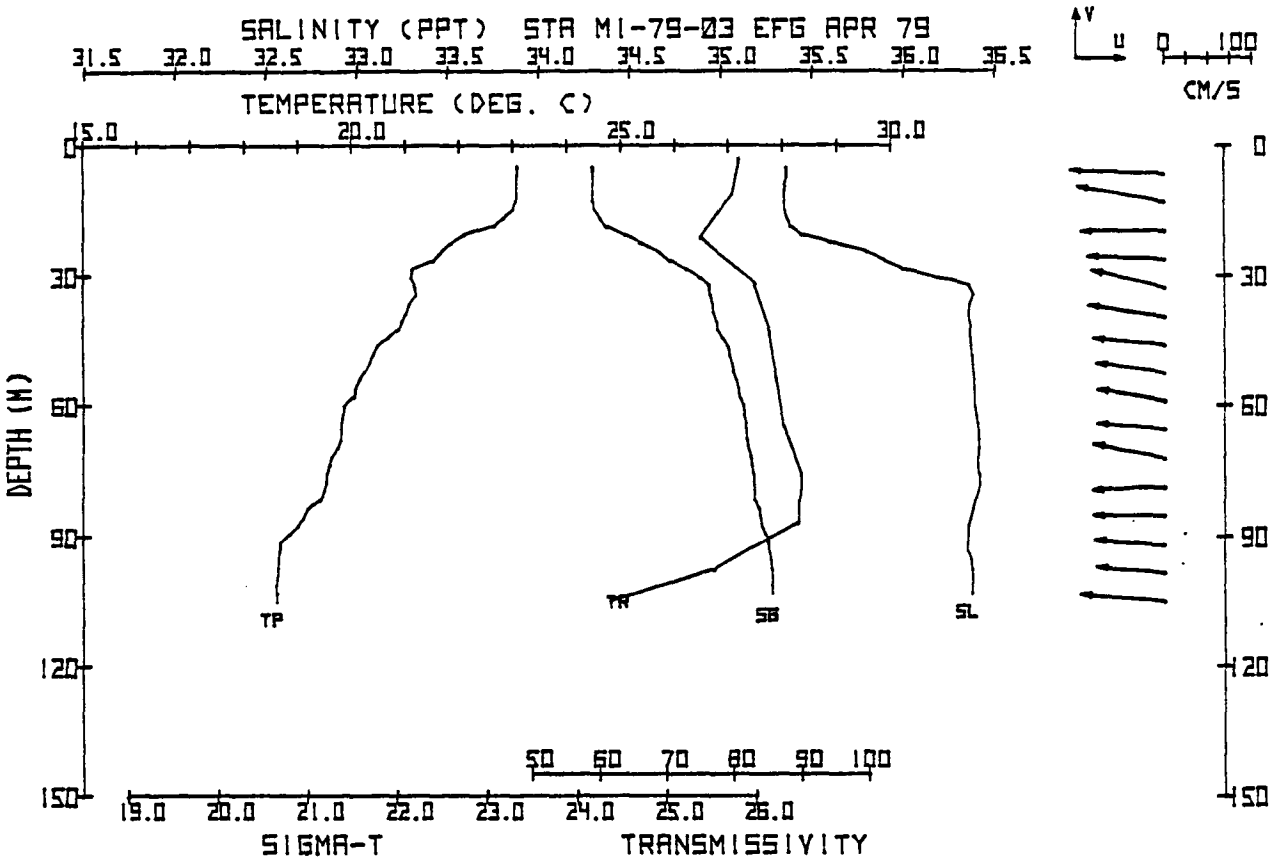

Figure X-B-4. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 3 (April 1979).

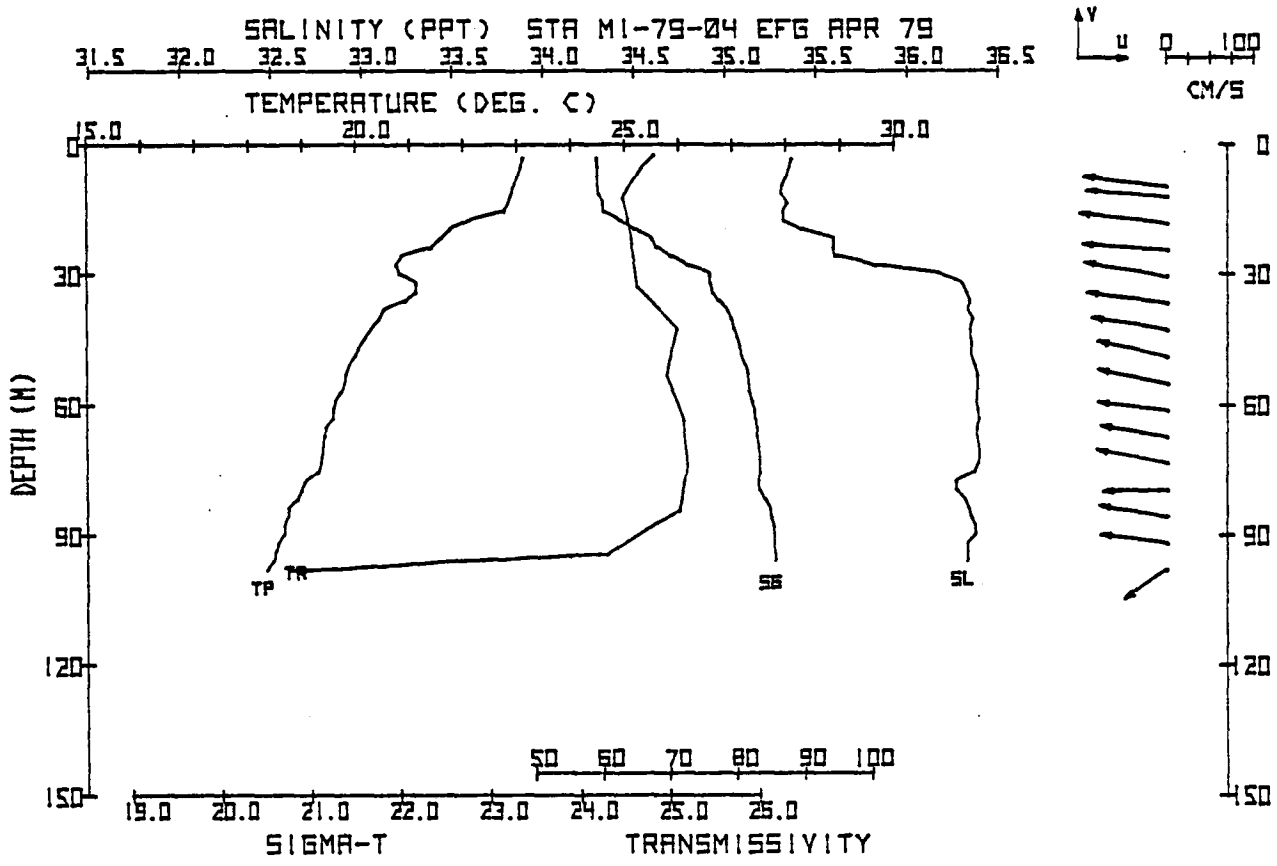

Figure X-B-5. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 4 (April 1979).

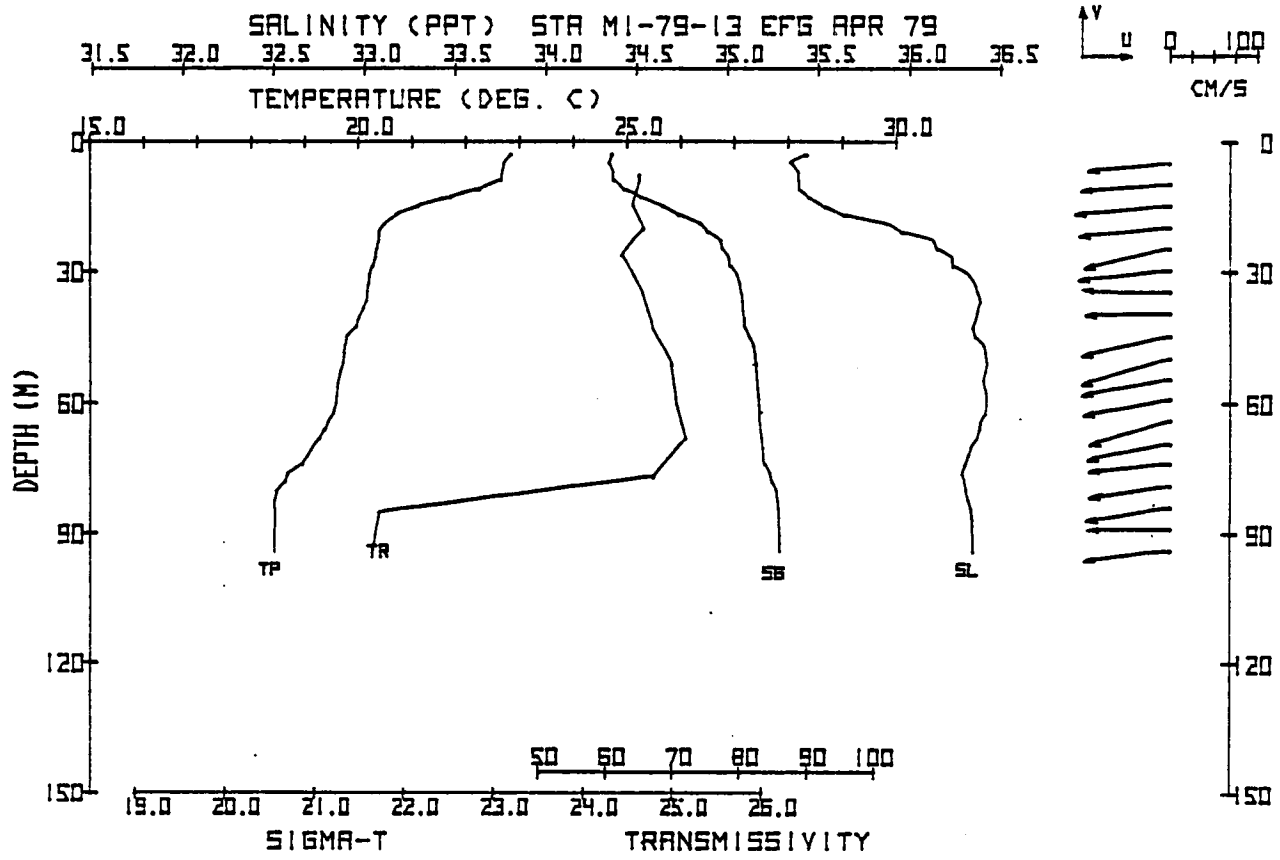

Figure X-B-6. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 13 (April 1979).

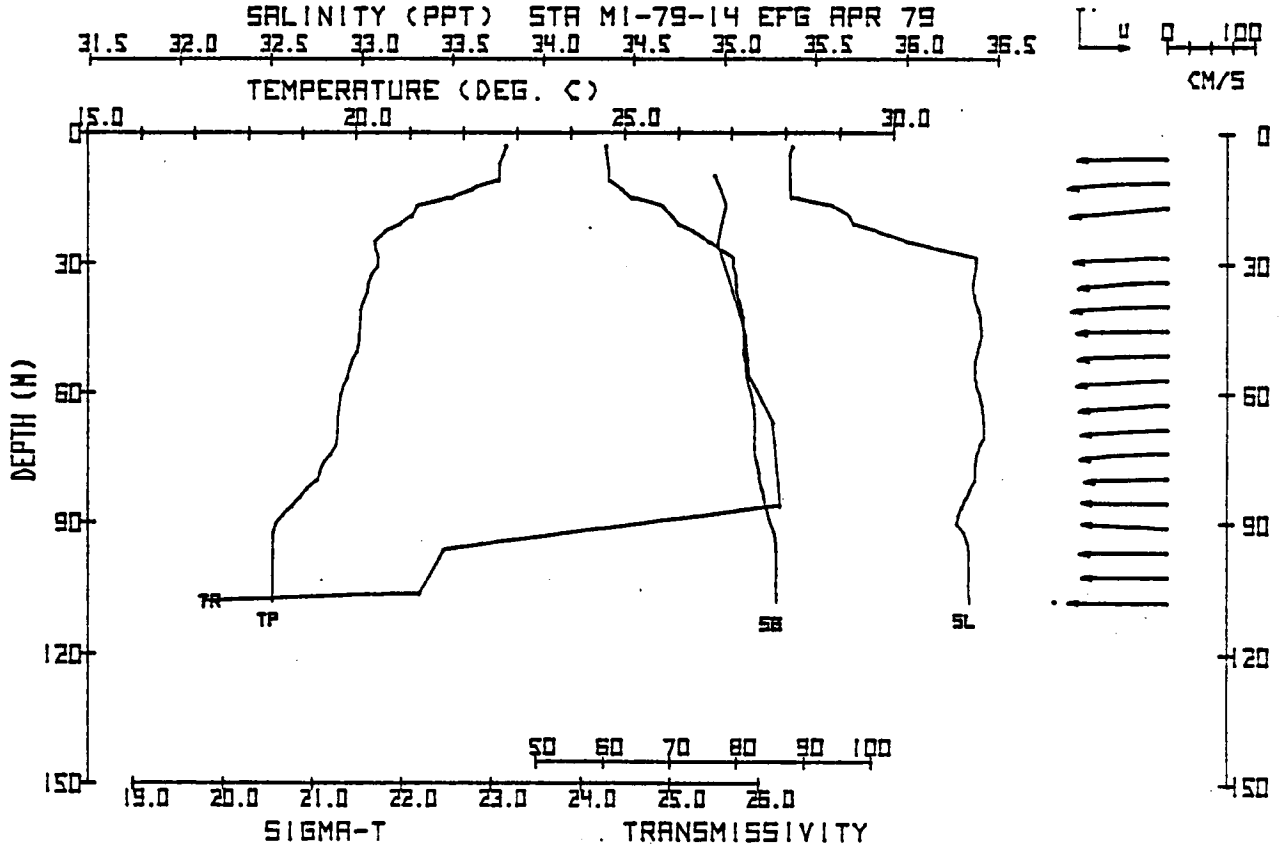

Figure X-B-7. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 14 (April 1979).

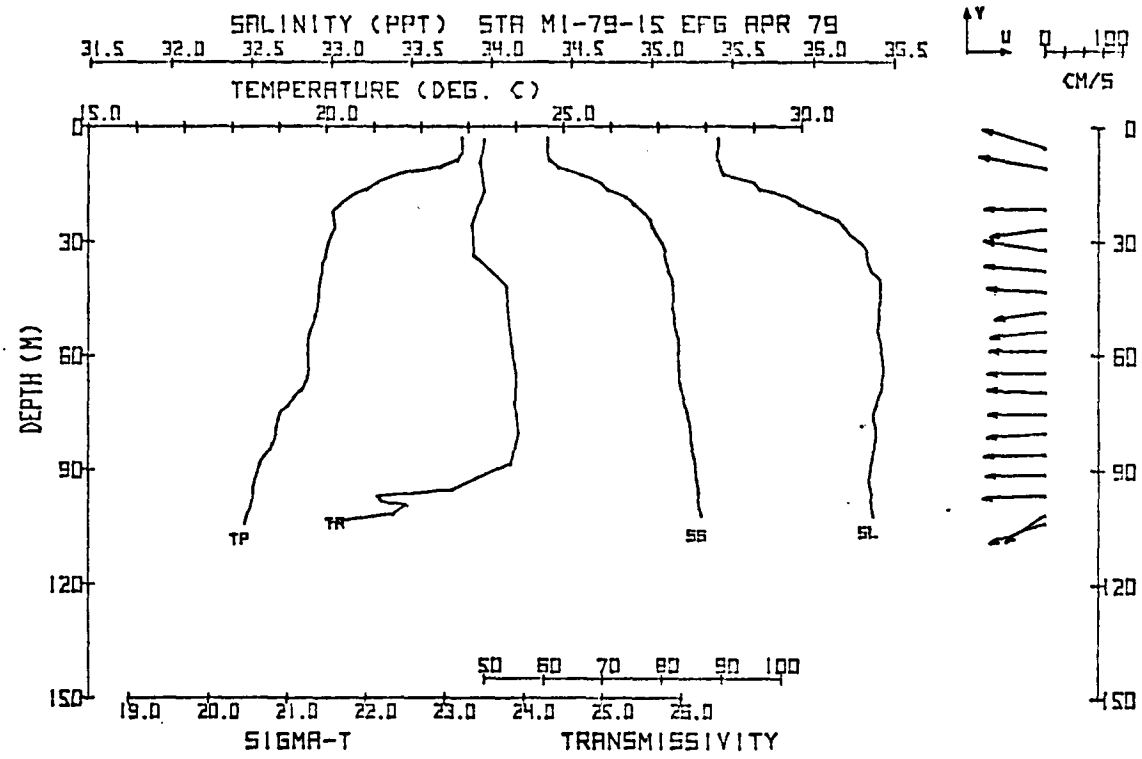

Figure X-B-8. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 15 (April 1979).

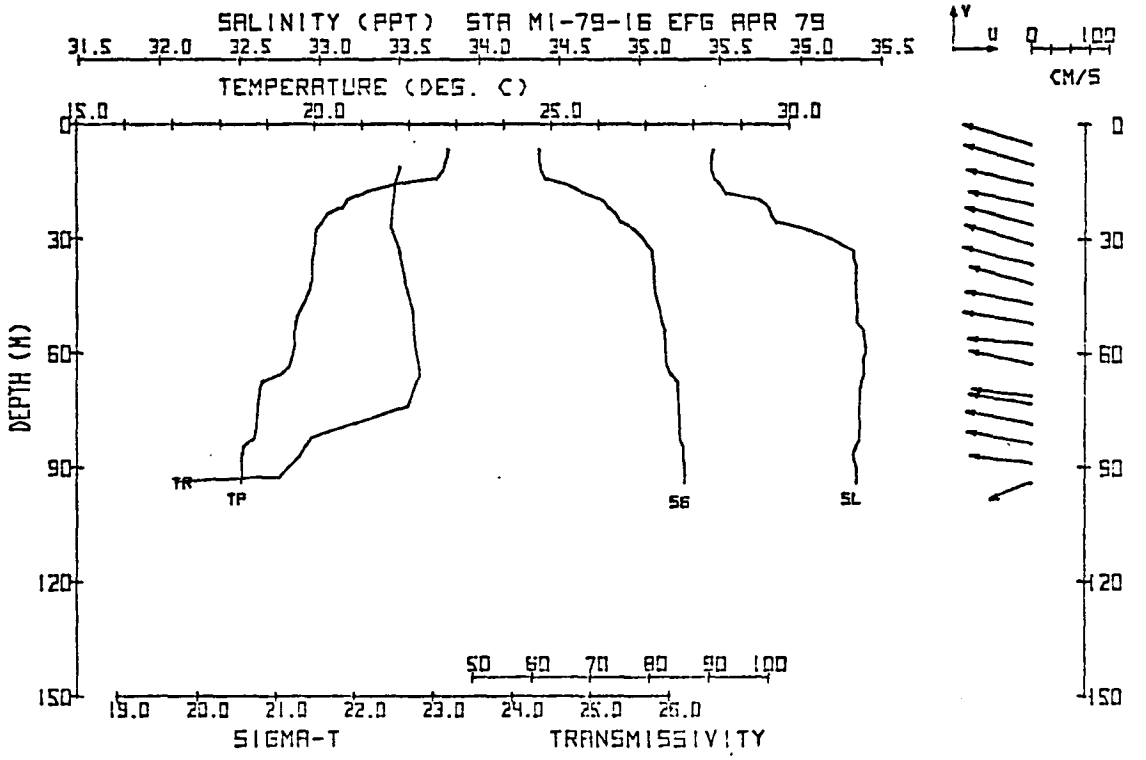

Figure X-B-9. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 16 (April 1979).

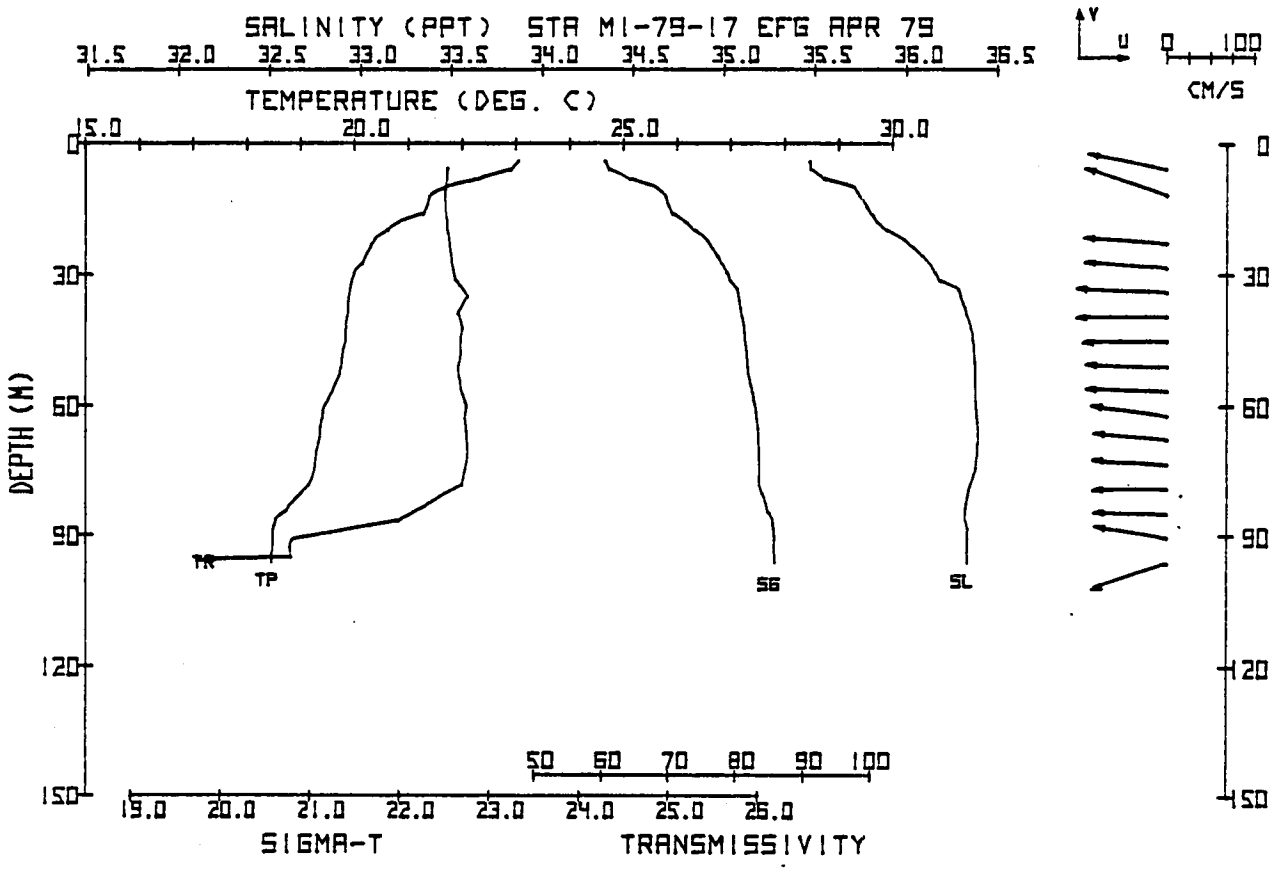

Figure X-B-10. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 17 (April 1979).

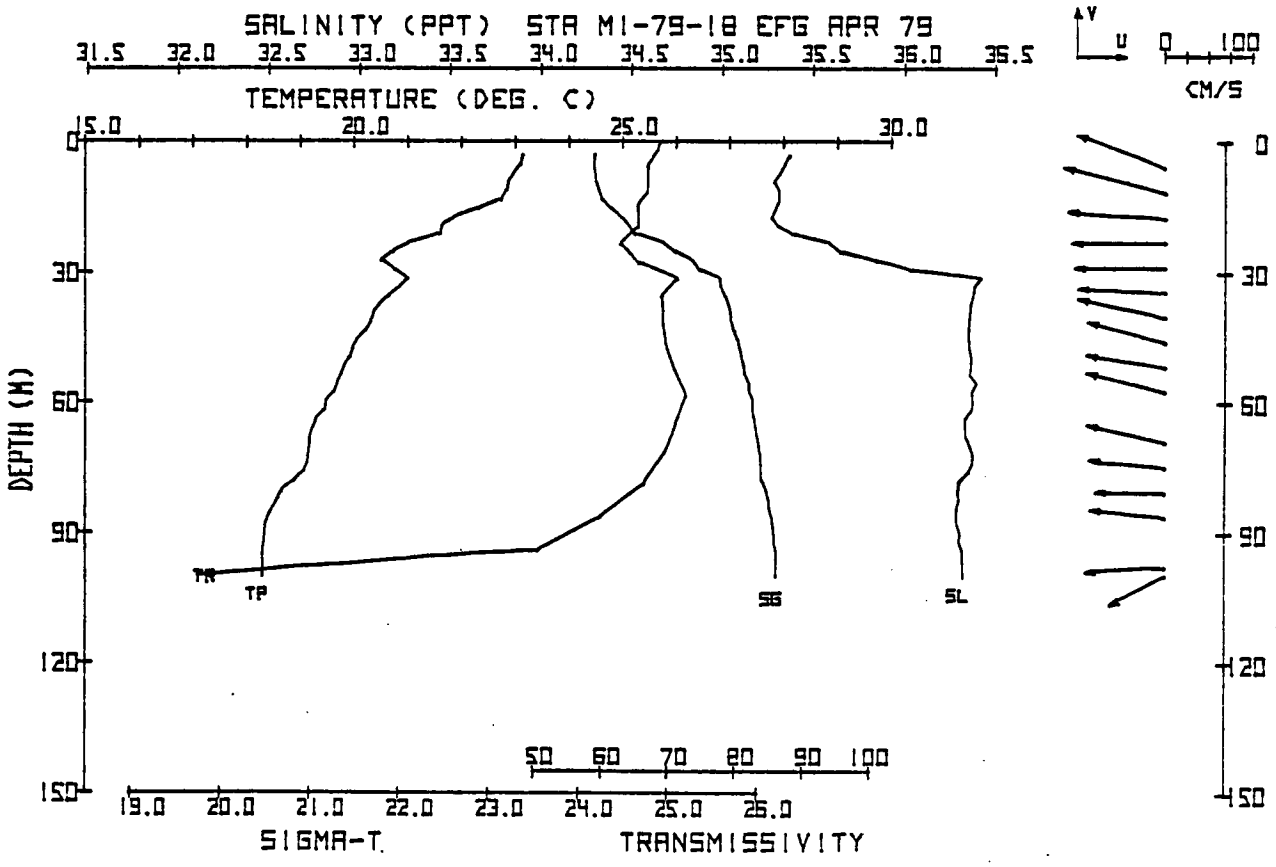

Figure X-B-11. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 18 (April 1979).

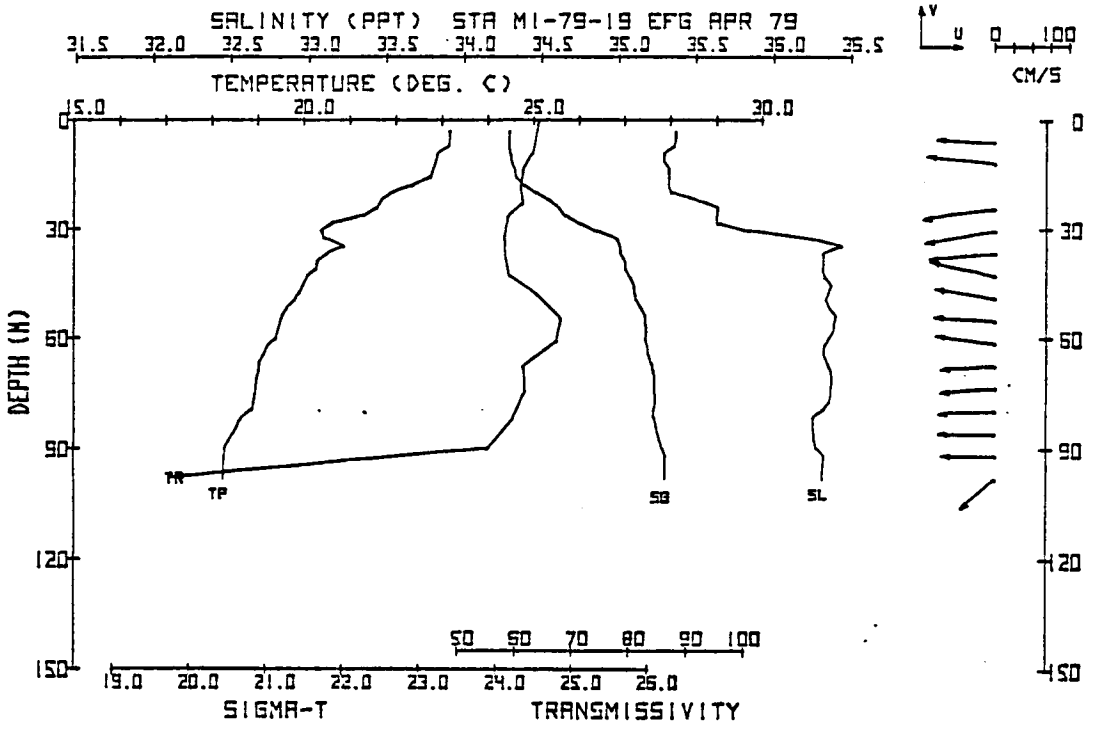

Figure X-B-12. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 19 (April 1979).

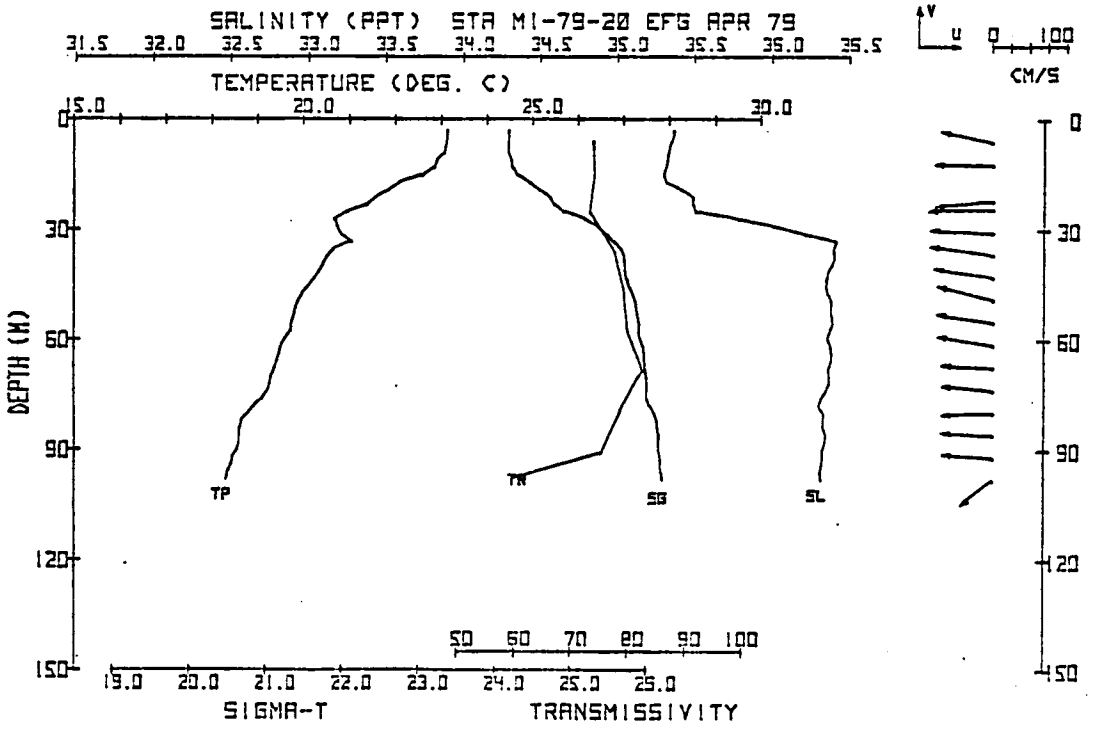

Figure X-B-13. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 20 (April 1979).

Stratification

The water column was weakly stratified with the strongest vertical density gradient between approximately 18 and 30 m in a modest pycnocline created by both temperature and salinity gradients. The temperature contrasts were on the order of 2°C, from approximately 23°C at the surface to approximately 21°C at 30 m. Over the same interval, the salinity varied from about 35.5 °/oo to 36.5 °/oo. The total change in density over that interval was on the order of 2×10^{-3} gm/cm^3.

The surface mixed layer varied in both thickness and structure over the sampling area. Using the 22.5°C isotherm as the base of the surface mixed layer, one finds a 12 m range in thicknesses. There was also a range in surface temperatures (measured at 4 m to avoid contamination from local or diurnal sources). The warmest water, 23.20°C, occurred at station 19, and the coolest, 22.78°C, at station 2 (Figure X-B-1; see above, p. 10). There was, however, no correlation between thickness of the mixed layer and surface temperature.

The configuration of the isothermal surfaces on the east side of the bank (Figure X-B-14) could be explained if the impingement of the flow on the bank generated internal wave. This wave would have a propagation speed of

$$c = \left(g \frac{\Delta \rho}{\rho_0} h_1 \right)^{1/2}$$

where c = phase speed of the wave
$\Delta \rho$ = change of density across the pycnocline
ρ_0 = mean density of the water
h_1 = depth of water below the pycnocline.

This formula yields a phase speed of 116 cm/sec when entered with variables appropriate to the conditions at the East Flower Garden Bank in April of 1979. Such a wave could, therefore, propagate upstream (to the east) at 16 to 36 cm/sec, depending on whether the magnitude of the westerly flow were 100 cm/sec or 80 cm/sec. Similarly, the displacement on the 20°C isothermal surface to the west of the bank suggests the presence of a substantially weaker lee wave (Figure X-B-14).

Even under these extreme conditions, the bottom boundary layer (BBL) did not thicken appreciably over those previously observed. The BBL at most stations was characterized by a 10-30 m unit at the base of the water column rendered completely isothermal and isohaline by turbulent mixing. At some stations, notably 4, 15, 16, 17, 18, 19, and 20, the bottom-most velocity vector was sheared to the southwest. That is the correct sense of rotation for Ekman-type shearing, but it is by

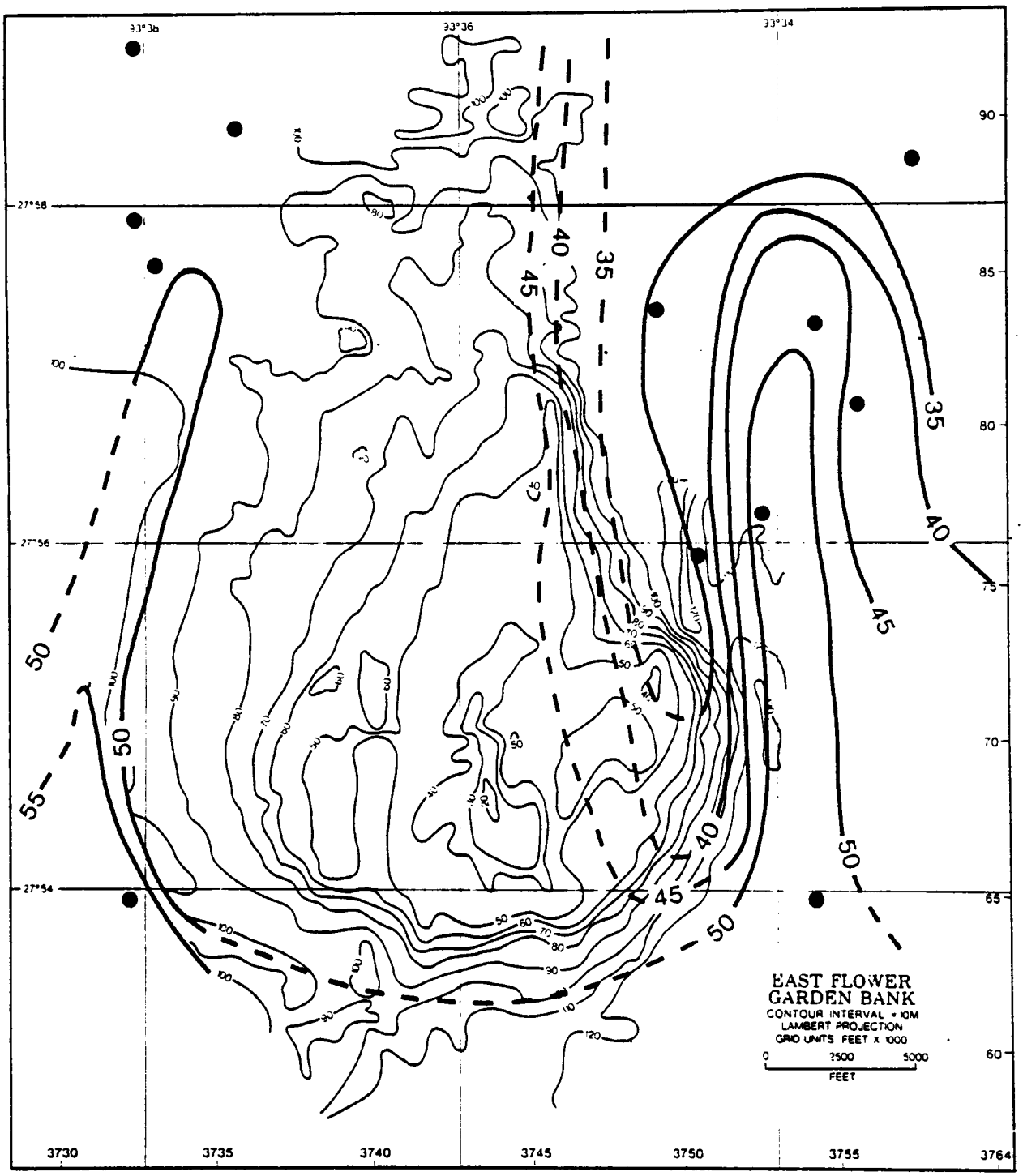

Figure X-B-14. Depth contours on the 20°C isothermal surface during April 1979 sampling period. Contours in metres.

no means clear whether the shearing was caused by friction or by topographic influence.

An inexplicable feature in the observations was the presence of a slight temperature inversion in all of the stations to the west of the bank. This was accompanied by sufficient shift in salinity to make the layer stable. The water about 30 m deep on the west side of the bank, therefore, had no counterpart on the east side. The magnitude of this feature also decreased from north to south, suggesting a northerly source. However, no north-south component of flow was present to support this hypothesis.

Transmissivity

Transmissivity profiles at stations 15, 16, and 17 were offset to artifically low values by a malfunction in the transmissometer. The shapes of those profiles are correct, but the absolute values are too low by as much as 100%. Because the exact value of the shift is unknown, these profiles are presented as is, with no attempt to correct by approximation.

As has been observed in previous studies (McGrail, 1978a,b), the nepheloid layer was entirely trapped within the BBL at every station. The shallowest occurrence of truly turbid water (76 m) was found at station 16 (Figure X-B-8; see above, p. 14). This was shallower than previously observed by about 4 m, but not unexpected considering the strength of the flow.

The step-like features in the transmissivity profiles of stations 1, 14, and 16 are almost certainly artifacts due to the transmissometer hitting bottom. The finger-like projection in the profile at station 15, however, is real and represents material picked up on the subtle ridge to the east of the station (Figure X-B-1; see above, p. 10). No other isolated turbid layers were observed and no evidence of turbid water rising toward, or descending from the bank top was detected.

From the shape of the profiles it is clear that a much greater volume of sediment was suspended in the bottom waters east of the bank than in that to the west. The reason for this phenomenon is the difference in sediment texture from one side of the bank to the other. The sediment on the western flank is considerably coarser. It is evident, then, that very high volumes of suspended sediment can be maintained in the BBL in regions where the substrate offers a continuous supply of fine sediment. This high volume of suspended sediment appears to result from a delicate balance between upward turbulent diffusion from the sediment water interface and differential advection with respect to height above the bottom. In a steady, high velocity flow, high concentrations of suspended sediment will occur as long as upward diffusion of the sediment balances that lost from the area by rapid horizontal advection in the upper layers of the BBL. As long as there is a ready supply of entrainable sediment at the interface, this condition will likely be met. But if the flow is over a substrate poor in fine sediment, the rate of supply could fall below the rate at which it was diffused upward and advected away. The local concentration would

then diminish rapidly without any loss through deposition.

Velocity

The dominant characteristics of the velocity profiles are the strength, uniformity, and steadiness of the flow. The driving mechanism for such a flow is not intuitively obvious, although the duration and spatial scale of the flow suggest that it must be at least quasi-geostrophic. Tide tables for Galveston show that the sampling period did not coincide with a spring tide. The winds were only 4.4 m/sec to 7.2 m/sec from the southeast, and since conventional wisdom holds that the surface current is about 3% of the wind speed, one could only expect a flow of 13 cm/sec to 22 cm/sec from the wind. One can, therefore, offer only conjecture regarding the motive force behind this event. It may, for example, represent a large eddy shed by the loop current, an eddy, which, in its upper 100 m or so, was completely barotropic.

One question sure to be raised by the uniformity of flow at all stations is: how does one account for westerly flow in the lee of the bank unless the flow went up and over the bank? The answer is that the flow diverged around the bank, running right along the contours in a narrow band and converging on the lee side. The direct evidence for this conclusion is the attenuation of velocity at station 15, which suggests the conversion of velocity into pressure near the bank. The increased pressure would deflect the flow laterally around the bank. Also, the velocity vectors at station 16 were rotated slightly to the north as though the flow were rounding the northern end of the bank. Hypothetical streamlines for flow around the East Flower Garden Bank appear in Figure X-B-15.

Those areas where the streamlines converge would possess accelerated flow. Since the principal directions of flow along the shelf are east and west, the areas of accelerated flow would remain rather constant. This may account for the partial moating around the bank because the accelerated flow would inhibit deposition.

July 1979

Overview

Stations occupied during the July cruise were more favorably positioned for hydrodynamic work than were those occupied in April. Two of the stations occupied during the summer sampling were actually on the bank proper (Figure X-B-16), which permitted testing of our hypothesis regarding topographic steering of the currents.

The water column was much more strongly stratified than it had been during the April sampling cruise. A thin layer of low salinity water at the surface combined with summer solar heating to produce this increased stratification. The influence of the stratification is apparent in the baroclinic (depth dependent) structure of the velocity

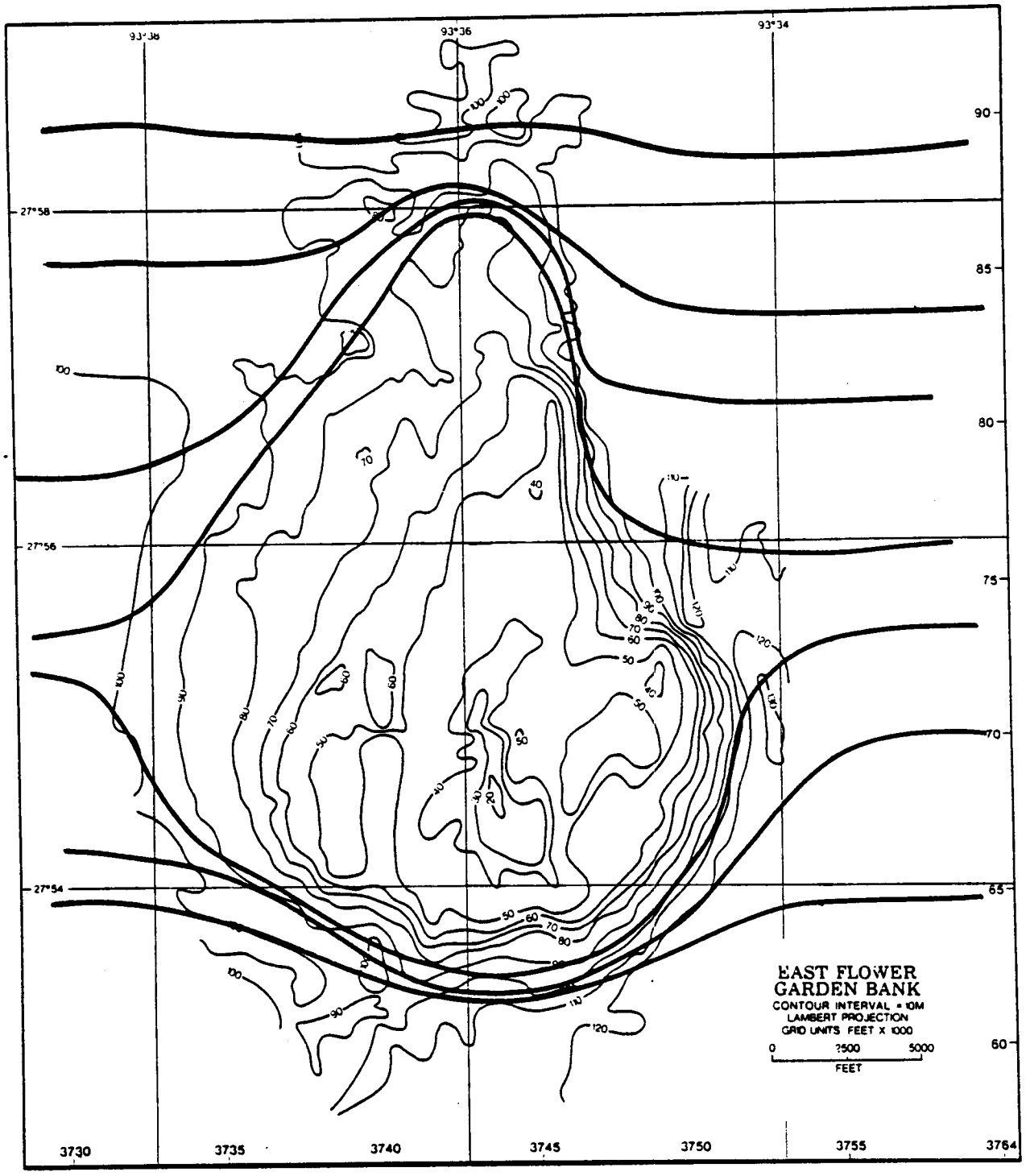

Figure X-B-15. Hypothetical streamlines at 90 m depth during the April 1979 sampling period.

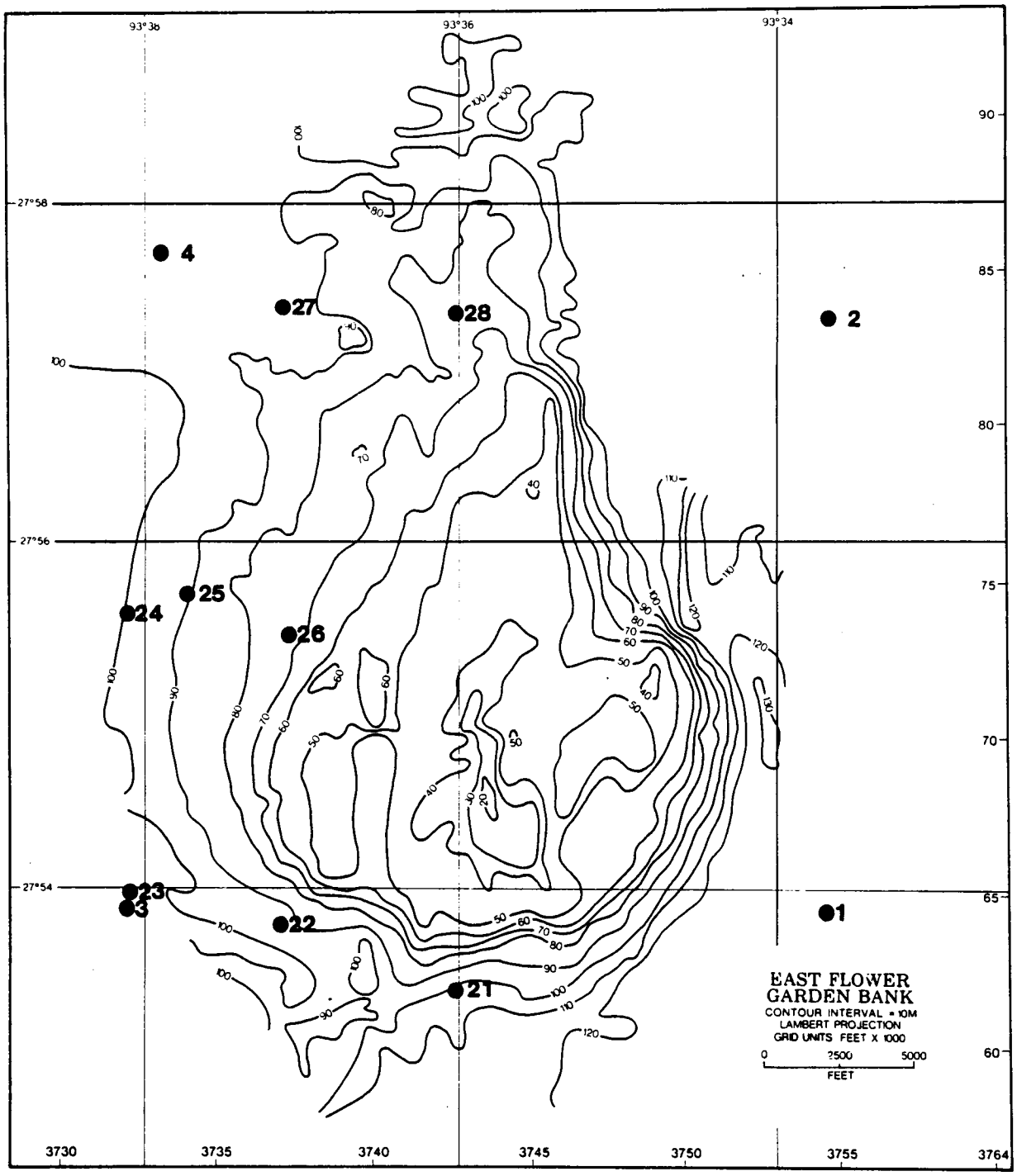

Figure X-B-16. Station location map for July 1979 hydrographic sampling.

profiles. The primary direction of flow was from west to east during the cruise. From the records of the moored current meters, it is clear that the current persisted in that direction until 23 July 1979 with only moderate modulation by the diurnal tide.

Stratification

The vertical density gradient in July was about three times as great as that measured in April. The density varied from about 20 σ_t at the surface to near 26 σ_t at the bottom (Figures X-B-17 through 28; see below, pp. 25 through 30). The surface waters were warmer by approximately 6°C and were fresher by about 4‰ in July. The low salinity water appears to have resulted from the heavy spring runoff in 1979. The surface mixed layer varied in thickness from 6 to 16 m, with the variance due to motion in the water column rather than temporal and lateral changes in the local wind stress.

The configuration of the isothermal surfaces indicates that the easterly flow created an internal wave on the upstream side of the bank. At station 26 (Figure X-B-26; see below, p. 29), the 28°C isothermal surface (top of the thermocline) was 6 to 7 m shallower than at stations 3, 4, 23, 24, 27, and 28. That same surface was, however, about 8 m deeper than average at station 25, which is located due west of station 26. This phenomenon is surely due to the impingement of the flow onto the bank. As the flow struck the bank, a portion of the flow's kinetic energy was converted into potential energy as the isopycnal surfaces were raised above equilibrium. Even in this energetic flow (up to 60 cm/sec) the maximum displacement was, however, only 7 m.

Because of the sparcity of stations on the east side of the bank in July, it was not possible to discern whether a lee wave had formed or not.

In stations 4, 27, 28, and 2, the BBL was characterized by a well developed mixed layer. At the remaining stations, centrifugal accelerations from topographic deformation of the flow set up secondary motions which destroyed the boundary layer's isothermal-isohaline structure.

Transmissivity

When considered with previously obtained data, the transmissivity profiles from July provide a great deal of information about the interplay among flow, substrate, and density distribution in the development of the nepheloid layer. First, the sediment on the western side of the East Flower Garden Bank is deficient in clay- and silt-size particles relative to the sediment on the east side of the bank. Next, the flow in July was from west to east (Figures X-B-17 through 28; see below, pp. 25 through 30), whereas in April it had been from the opposite direction. In July, therefore, the flow upstream of the bank passed over a substrate deficient in fine material--and all of the transmissivity

profiles from July reveal a thinner nepheloid layer with less suspended sediment in it compared to the conditions observed in April.

Granted, the current in April was stronger than in July, but not that much stronger. The evidence is clear. The nepheloid layer is primarily a local phenomenon due to the resuspension of silt- and clay-size material in the substrate. Lower transmissivity values (greater amounts of suspended sediment) in the nepheloid layer west of the bank in April relative to those in July do indicate that a well developed nepheloid layer will persist for several kilometres after flow leaves a substrate rich in silt and clay. Stated differently, even though diffusion and differential advection attenuate the nepheloid layer noticeably from the east to the west side of the bank, the excess concentration of suspended sediment over that which could be locally derived on the west side of the bank was still substantial.

Of major importance is the fact that **no station shallower than 90 m possessed the slightest indication of a nepheloid layer.** This is true in spite of a high velocity current impinging directly on the west side of the bank where the stations were concentrated.

Velocity

The magnitude of the current in July was only slightly diminished from that measured in April. The mean direction of the flow was from the west (180° different from April), and the velocity profiles were more depth dependent than in April. The distribution of stations in July was well suited to measuring the behavior of the current as it impinged on the bank. The results of sampling were gratifying because they substantiated our hypothesis that the current would be deflected to follow the isobaths with only a minor vertical excursion up the side of the bank. Figure X-B-29 (see below, p. 31) is a plot of the bottom velocity vectors from the 12 July 1979 stations, with a schematic pattern of inferred flow. Compare this plot with Figure X-B-15 (above, p. 21), which was drawn without reference to the July data. Because the moored current meters were in place during the July cruise, it was also possible to plot a mean vector for the bottom current meters on array II for 16 and 17 July 1979. This also appears in Figure X-B-29 (see below, p. 31). Perusal of Figures X-B-17 through 28 will show that it is the water closest to the bottom that undergoes the most extreme deflection. That is to be expected in situations where the flow is intersecting a sloping boundary.

The wind during the July sampling operation was from the southeast during the first day, then became very light and variable. It is, therefore, unlikely that the current was wind driven at the local scale. It was also surprising that the current should persist in an easterly flow since conventional wisdom suggests that the regional wind field (southeast winds in the summer) should set up a westerly flow below the surface mixed layer. The easterly flow may be due to the presence of a shelf edge front along which one might expect a jet-like easterly flow.

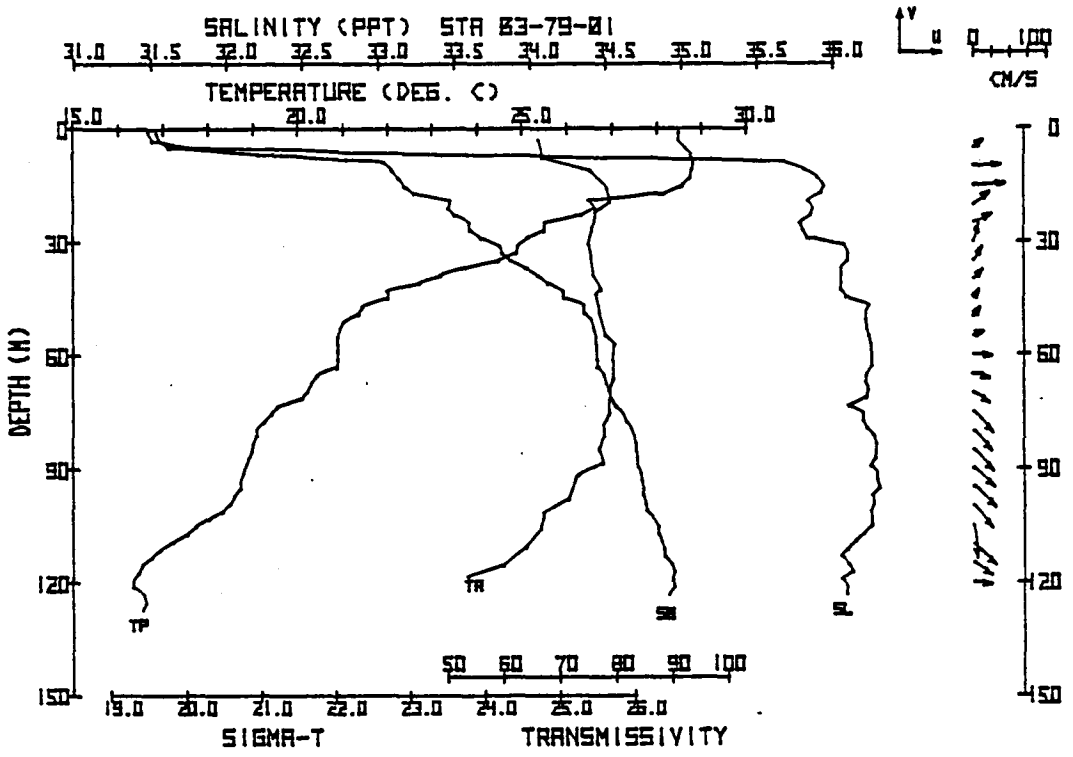

Figure X-B-17. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 1 (July 1979).

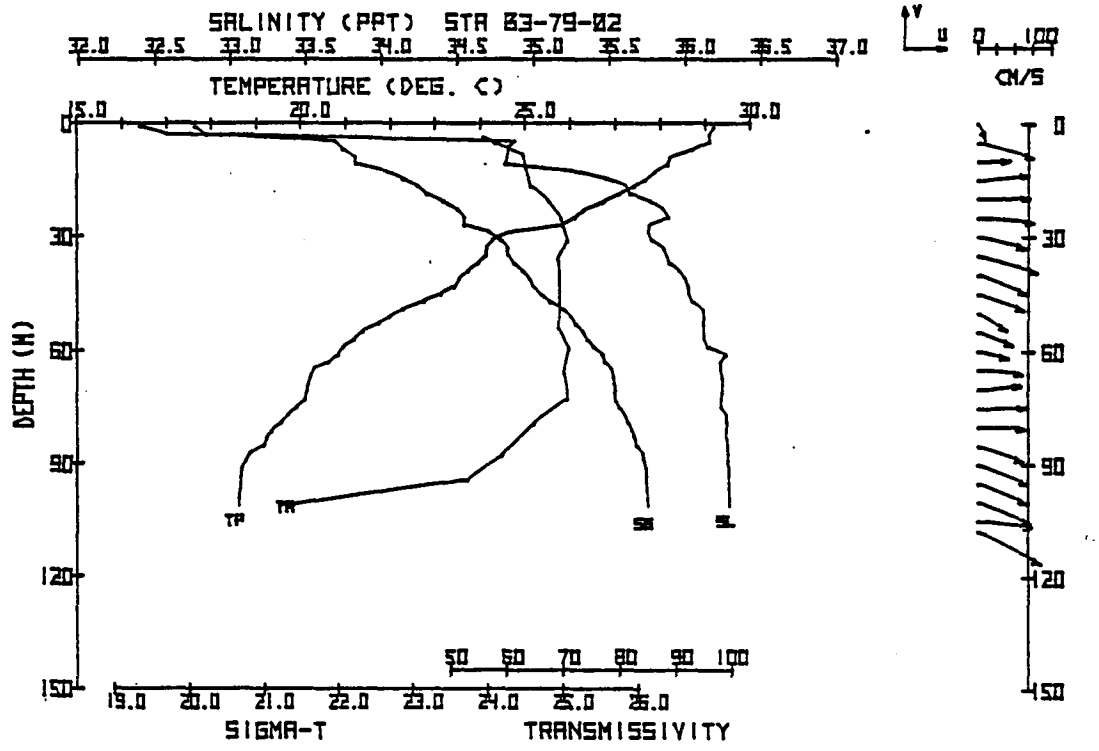

Figure X-B-18. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 2 (July 1979).

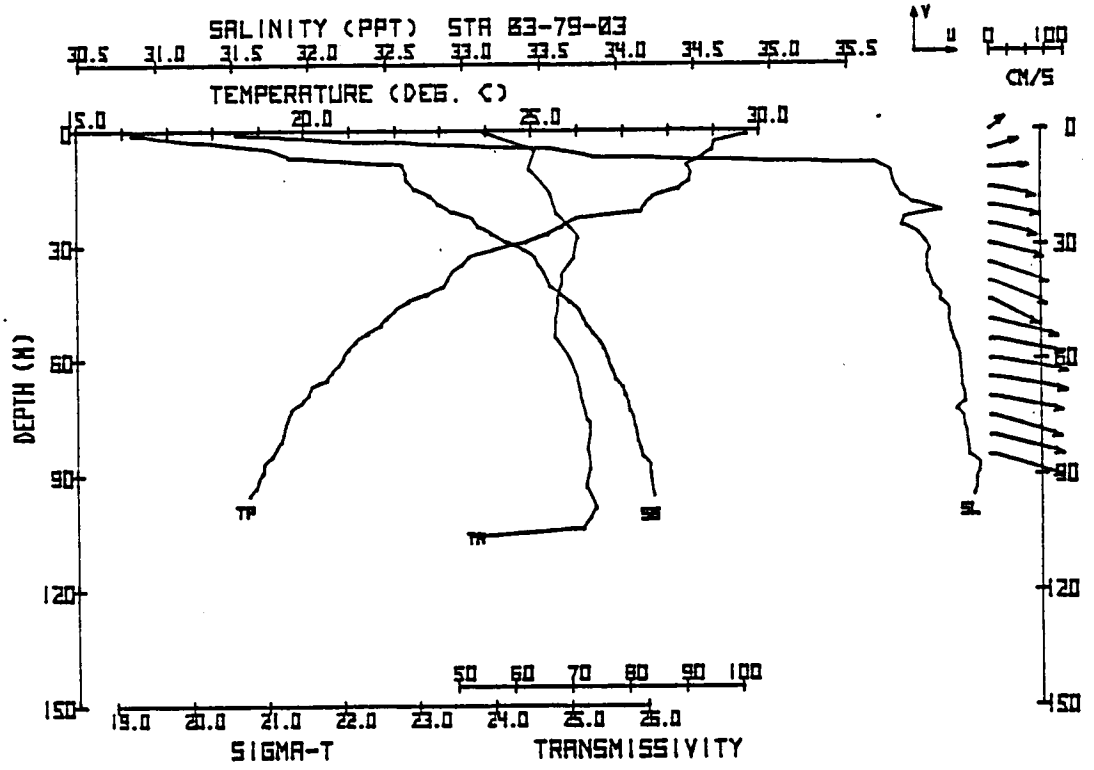

Figure X-B-19. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 3 (July 1979).

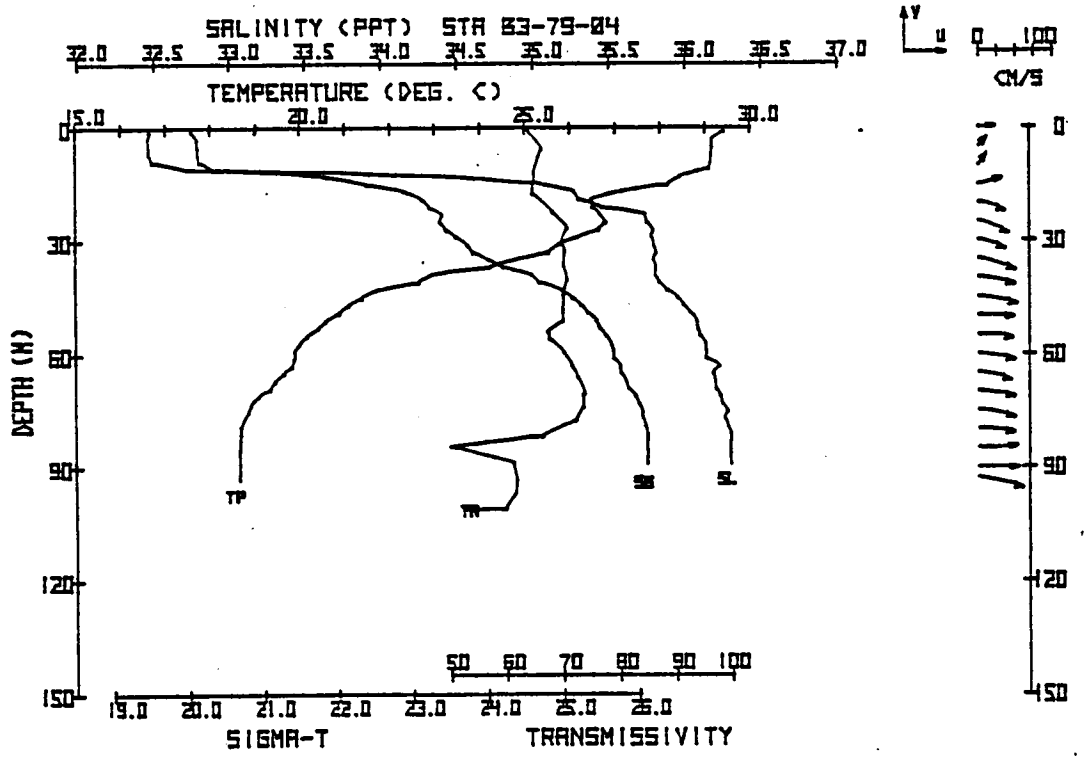

Figure X-B-20. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 4 (July 1979).

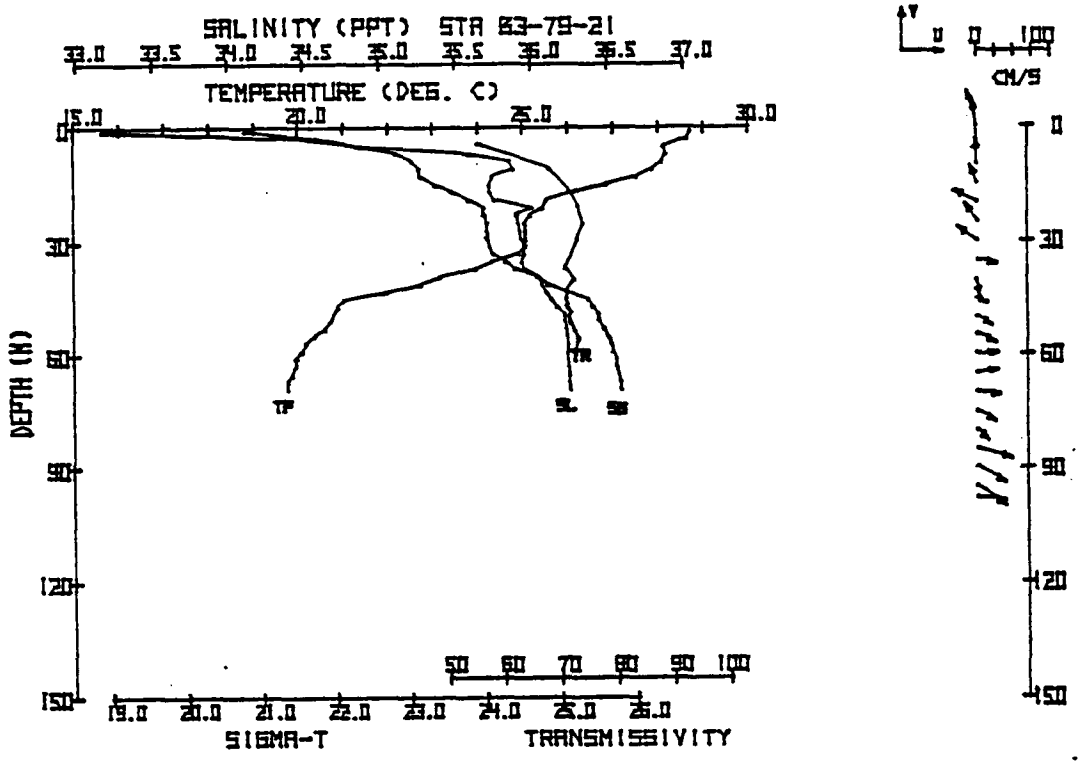

Figure X-B-21. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 21 (July 1979).

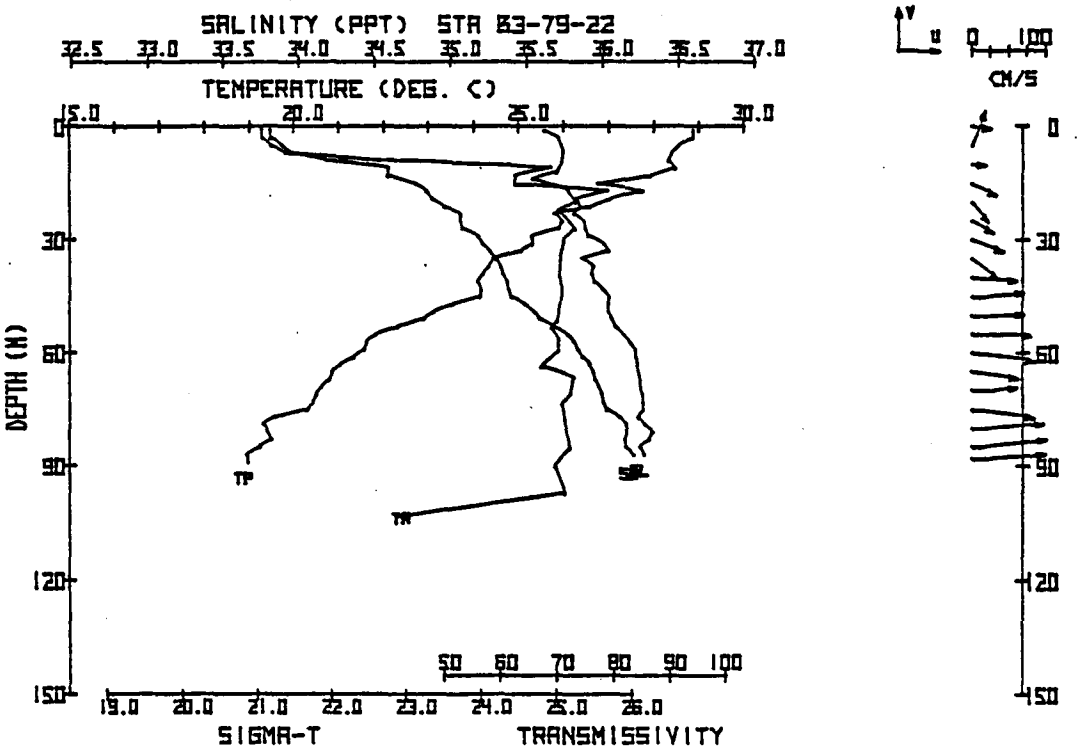

Figure X-B-22. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 22 (July 1979).

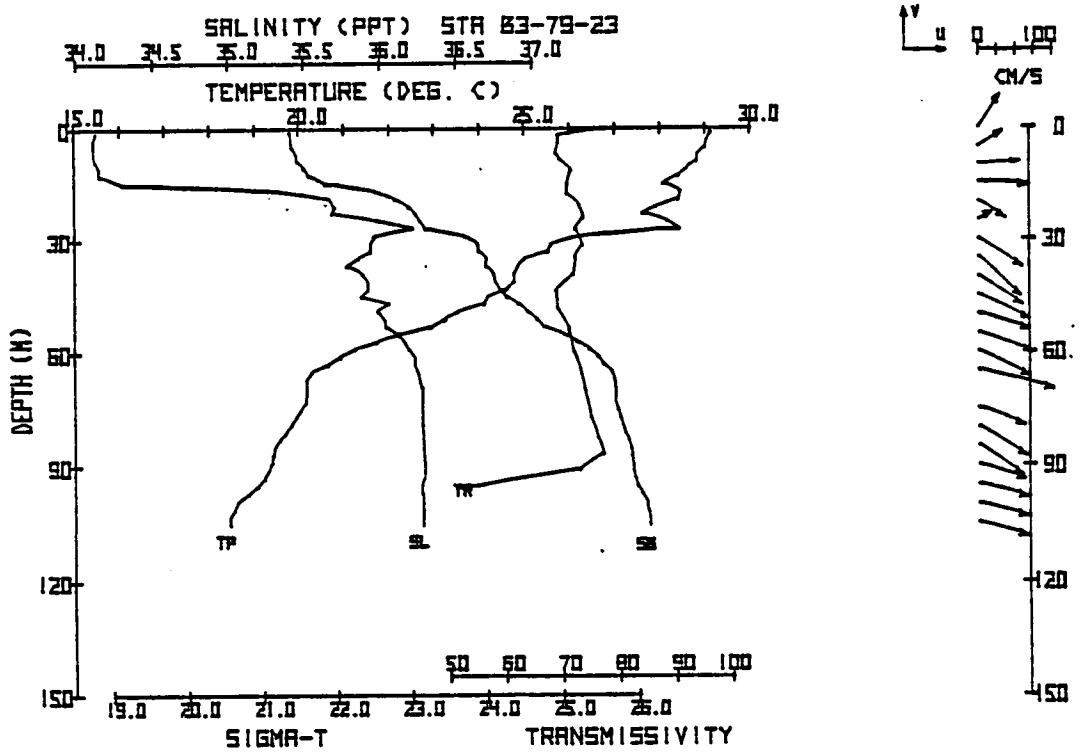

Figure X-B-23. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 23 (July 1979).

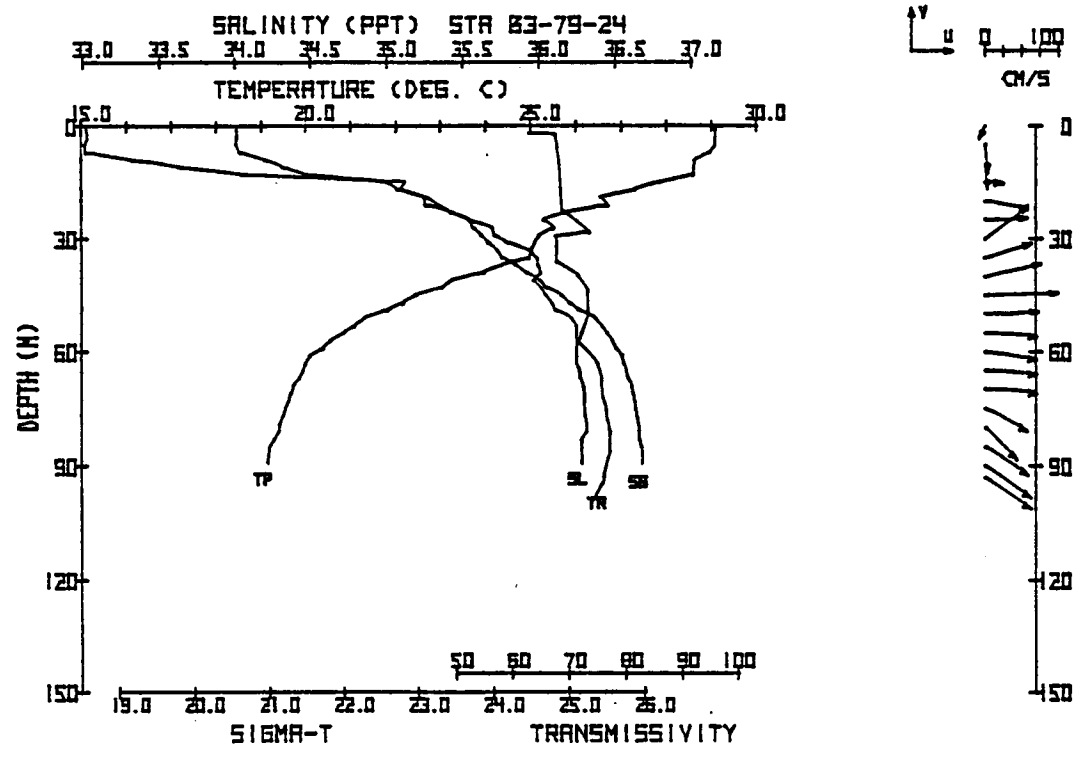

Figure X-B-24. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 24 (July 1979).

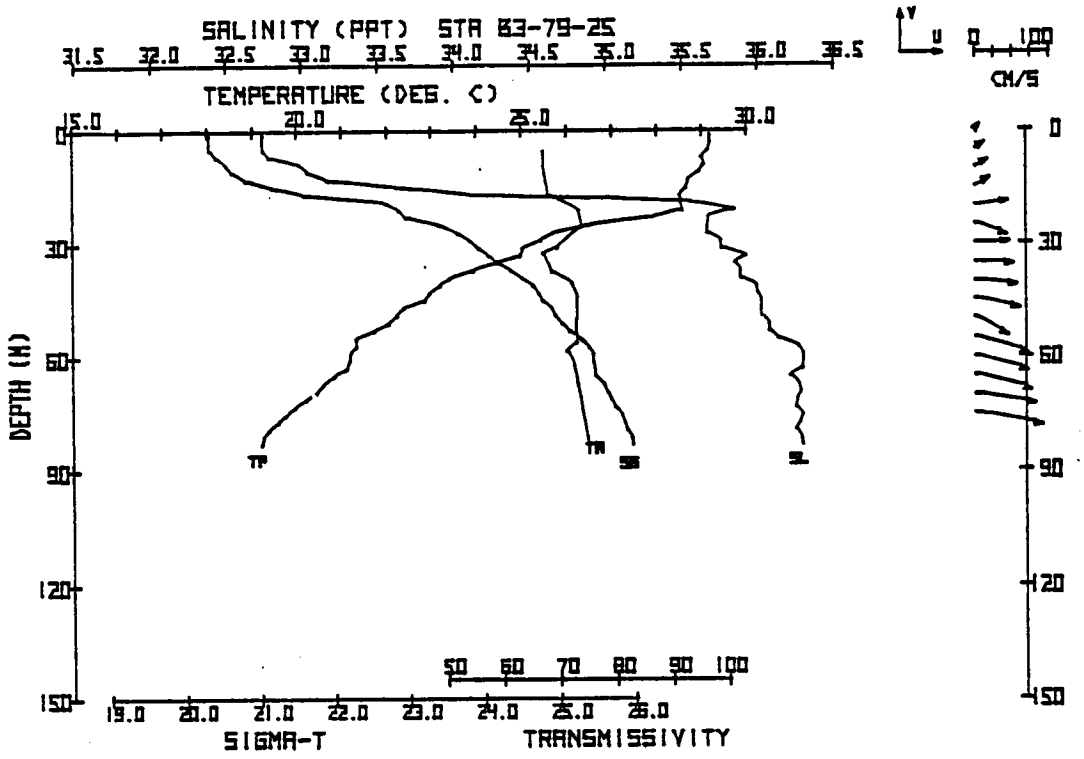

Figure X-B-25. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 25 (July 1979).

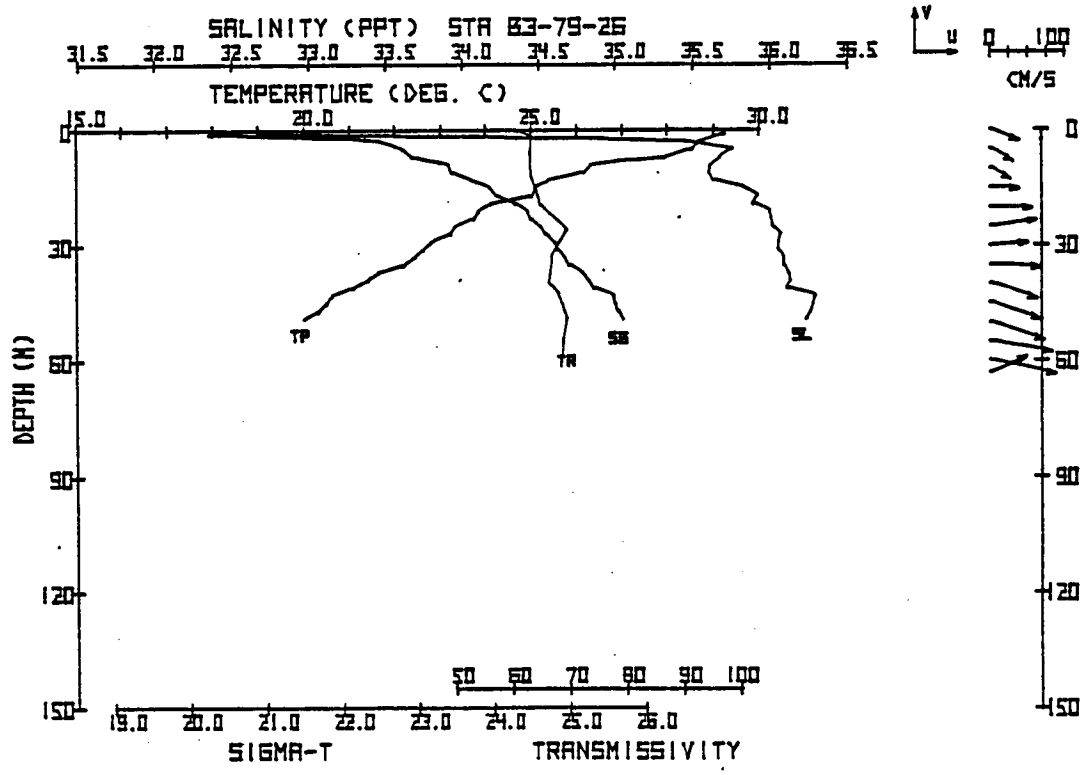

Figure X-B-26. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 26 (July 1979).

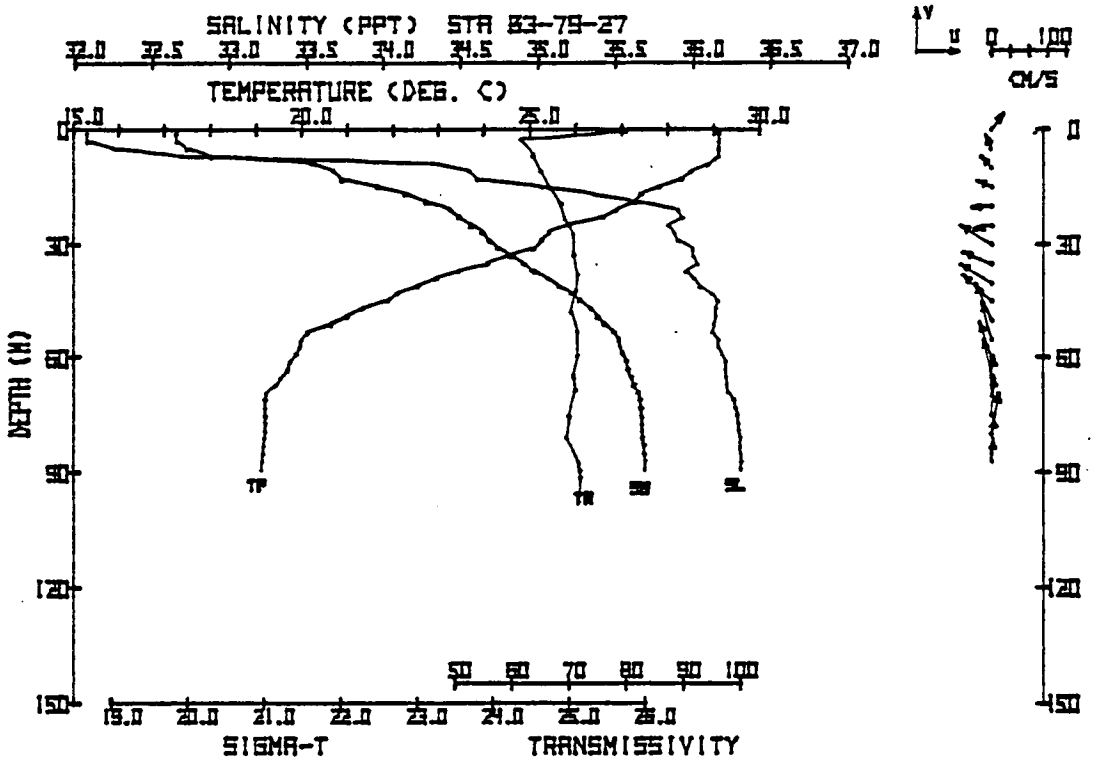

Figure X-B-27. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 27 (July 1979).

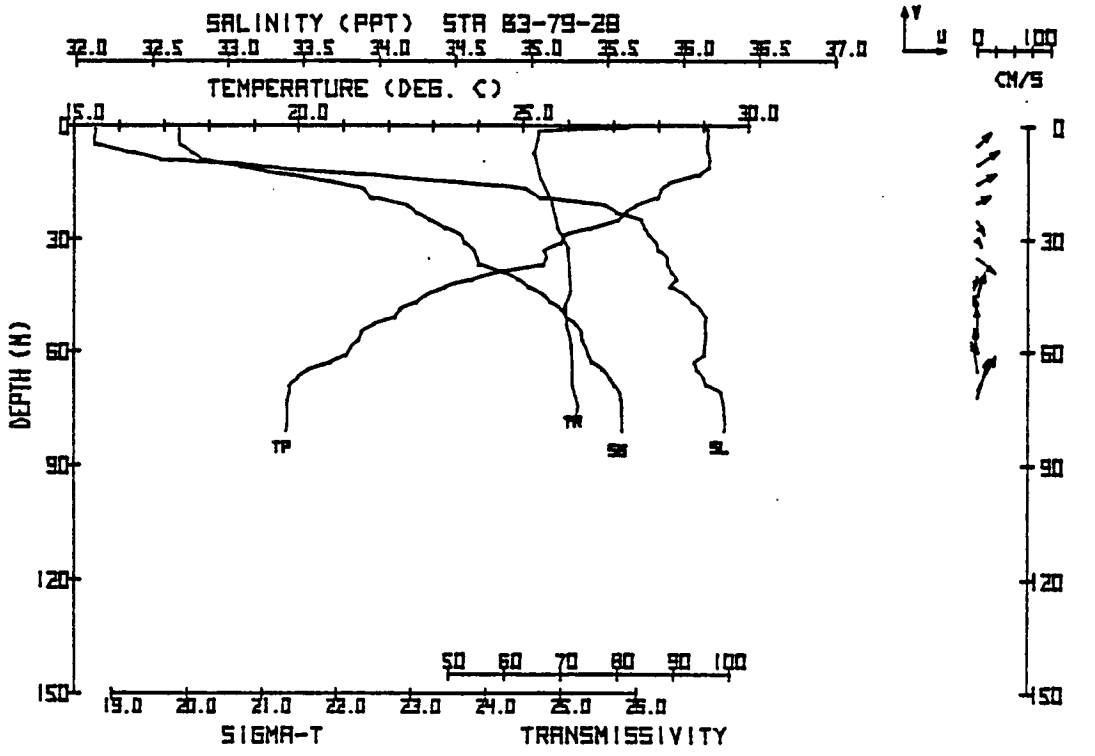

Figure X-B-28. Plot of salinity (SL), temperature (TP), transmissivity (TR), and sigma-t (SG) from EFG station 28 (July 1979).

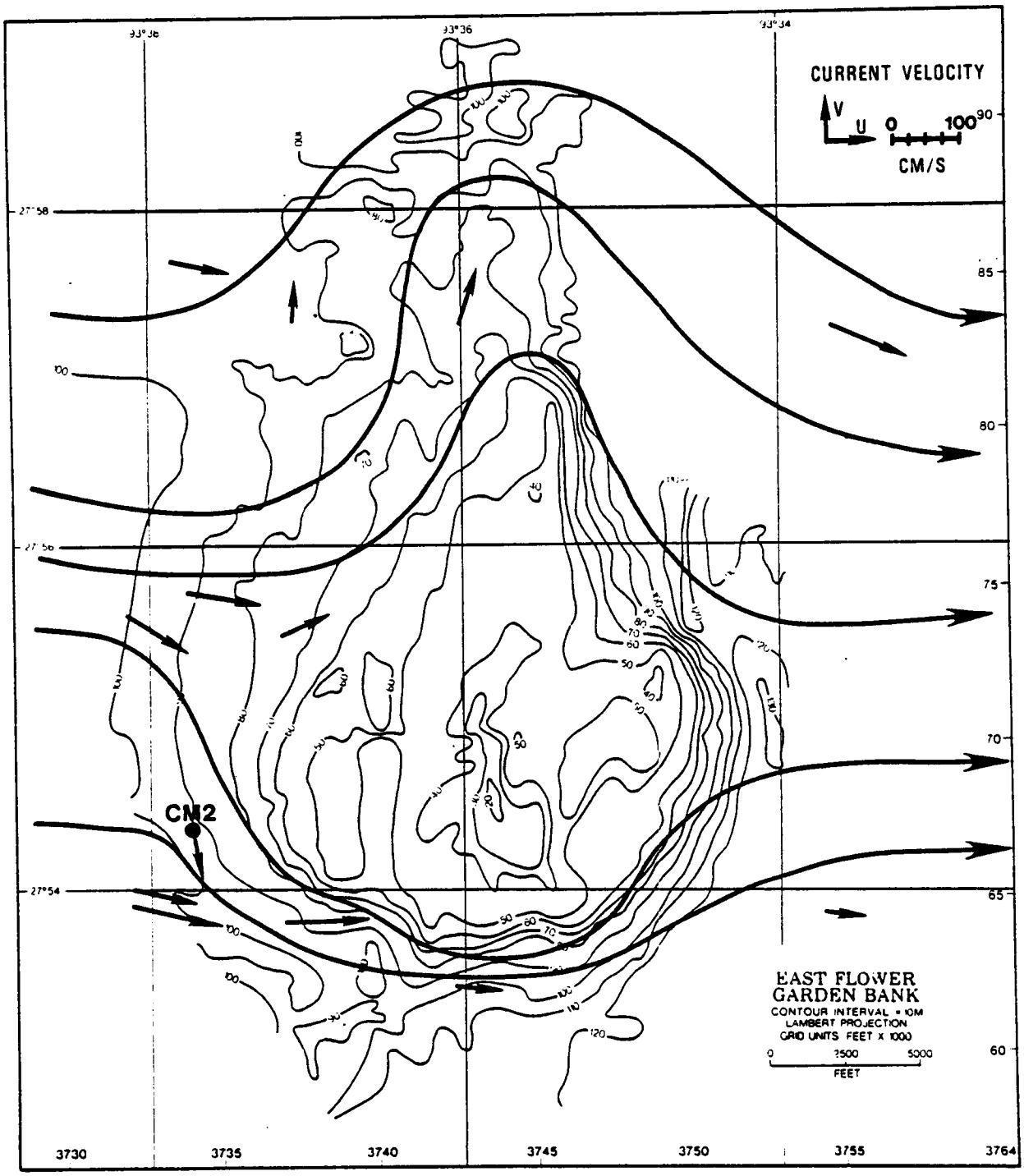

Figure X-B-29. Bottom velocity vectors from all July stations plotted with directional sense only (no magnitude implied). The lines connecting stations of like depth are inferred streamlines. Mean directions for the lowest current meter for 16-17 July 1979 are also plotted and demonstrate the consistency of the two types of measurement.

TIME SERIES CURRENT MEASUREMENTS

Research Design

The program for long-term current measurement at the East Flower Garden Bank commenced in January 1979 with the deployment of two moored arrays and one rigidly mounted instrument. Array I was established just to the northeast of the East Flower Garden Bank (Figure X-B-30) for the purpose of measuring currents that should be only slightly deformed by the presence of the bank. Array II was set in 100 m of water on the southwestern periphery of the bank for the express purpose of measuring the current's response to the bank. On the initial deployment each array was comprised of three Savonius rotor and vane type current meters. The upper meters were placed at 40 m depth to monitor the flow at the level of the broad platform on East Flower Garden Bank at the base of the main reef. The lower meters were set at 4 and 6 m off the bottom at each location to record the behavior of the flow in the bottom boundary layer. Each instrument was also equipped with a very sensitive thermistor for measuring temperature.

The sampling rate on the instruments was set so that one record was taken every six minutes. This rate was chosen so that the current behavior due to high frequency internal waves could be recorded, should internal waves be present.

An electromagnetic current meter (ECM) was rigidly mounted on a stand at the BLM reef monitoring site near the summit of the bank (see below, Figure X-C-1, station BLM, p. 49). It was necessary to employ this type of current meter on the crest of the bank because the influence of surface gravity waves is expected to penetrate to that depth (30 m) fairly often. ECM's provide more accurate velocity data than do Savonius rotor type sensors when surface gravity waves cause high frequency changes in velocity.

Analysis of Current Meter Deployment Problems

January

Several factors combined to make the January deployment rather disappointing. In an effort to minimize mooring motion contamination of the records from the two deepest meters on each array, they were deployed on a rigid frame. Despite repeated efforts to reinforce the frames, they were badly damaged on launch because of the severe weather conditions. Because the acoustic release on Array I failed, the instruments could not be recovered and redeployed for the April to July period. Array I was recovered later, intact, by dragging for it from a shrimp boat. The rotors of most recovered instruments were heavily biofouled, and the speed records were sharply abbreviated.

Initially, it was assumed that the biofouling had caused the speed drop-out. Careful analysis of the instruments later proved this to be an incorrect assumption. In essence, the problem turned out to be a design flaw on the part of the manufacturer. As long as the batteries were fresh, they served as filters in the system, suppressing power

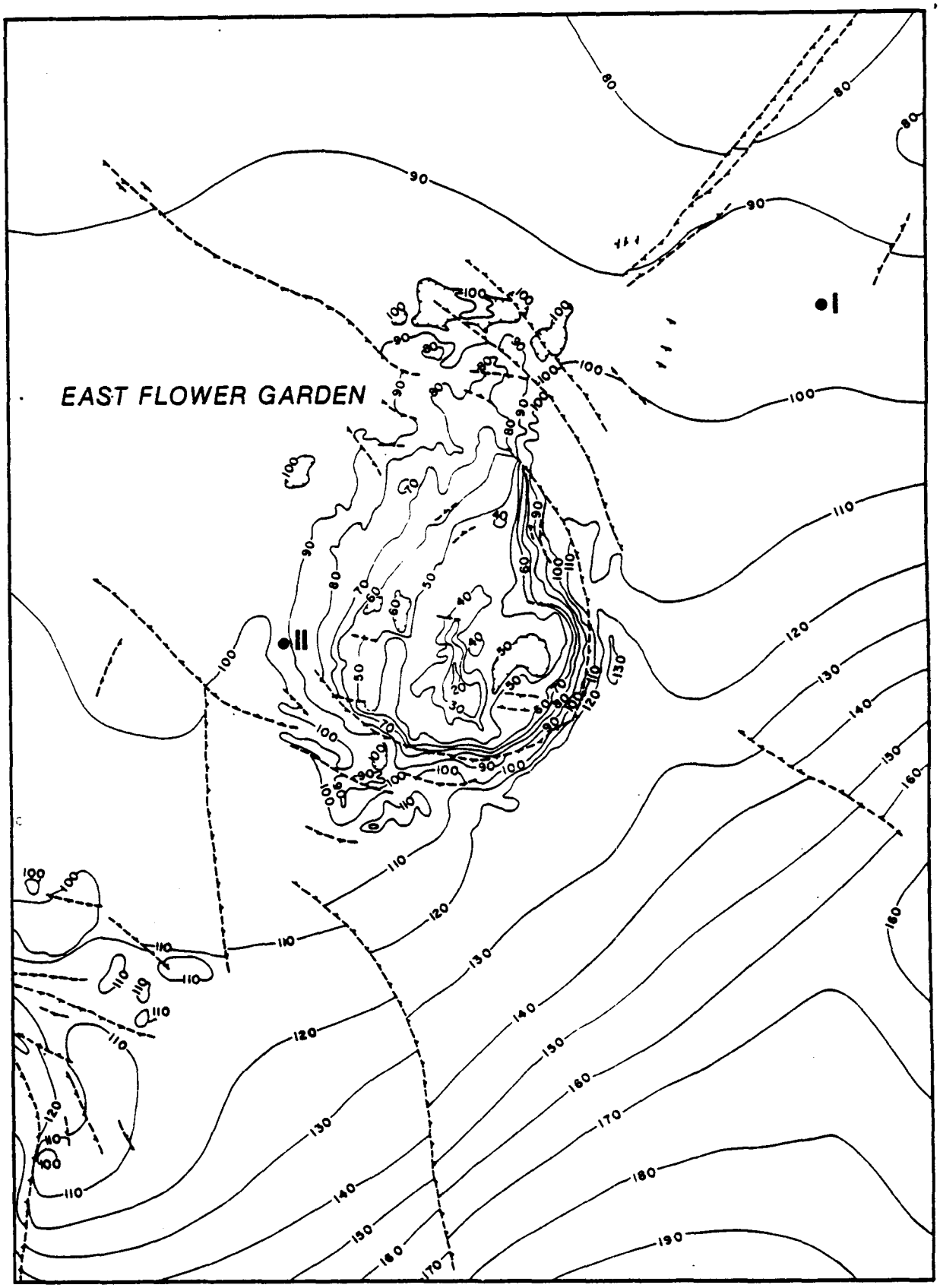

Figure X-B-30. Location of current meter Array I and II.

spikes when the current meter was in operation. This filtering capacity diminished rapidly with use so that, even though the batteries were providing the specified voltages, they permitted a power spike to enter the system during each recording cycle of the meter. This spiking saturated a comparator circuit in the speed sensing components so that no speed signal was detected.

The result of these problems is that only the ECM and the top meter on Array II returned complete and usable data. The remaining instruments recorded temperature and current direction data only. The directional data of all near-bottom instruments were suspect because the instruments may have been fouled in the damaged frames.

April-July

Only Array II and the ECM were deployed during the April 1979-July 1979 period. Again, because of a manufacturing design problem, data were lost. The lower two meter housings sheared off the streaming rod assembly. The manufacturer replaced the lost meters and retrofitted the other current meters with redesigned streaming rod assemblies. The upper meter failed early because of the speed drop-out.

By July, our own Electronics Technician determined that the manufacturer's alignment procedures were incorrect. He improved all calibration and checkout procedures so that, in spite of the then unresolved speed drop-out problems, we obtained nearly complete records from four of the six Savonius rotor current meters. The ECM also yielded a good data set. The location of the moorings during the deployments is shown in Figure X-B-30 (see above, p. 33).

Current Record Analysis

Each record was subjected to a cascading Butterworth type filter (Roberts and Roberts, 1978) to achieve a low-pass record with a half power at approximately 30 hours. The raw data and the low-pass filtered data were then simultaneously plotted as "stick diagrams" (Figures X-B-31 through 38; see below, pp. 39 through 43).

Spectral Analysis. The first diagnostic analyses performed on the records were various spectral analyses. These measure the variance (power) of a time series as a function of frequency. If, for example, a steady current existed somewhere, modulated solely by the semidiurnal tide current, the power spectrum of a time series record of the flow would contain a single peak at 8×10^{-2} cycles per hour (cph) (frequency) or 12.5 hours (period). The purpose of the spectral analyses is to determine at what frequencies the current changes and to determine how energetic that change is. An example of the spectra appears as Figures X-B-39 through 42 (see below, pp. 44 through 45). Information of this type can be used to infer the mechanism driving the oscillations in the current. Rotary spectra partition the energy by whether the oscillation is due to a disturbance having a clockwise or counterclockwise sense of rotation. This rotary spectra can also be used to

discriminate among the many possible modes of motion which could be represented by an oscillation.

Directional Analysis of Variance. The records were also subjected to a directional analysis of variance. In this analysis, the variance tensor is calculated. Two components, the major and minor axes of variance (which are orthogonal), are computed. These are the axes of an ellipse containing the current vectors. The orientation and relative lengths of the axes reveal any directional bias in the oscillating portion of the flow.

January-April 1979

As stated above, information about currents during this period was limited to records of the upper meter (60 m depth) on Array II (Figure X-B-30) and the electromagnetic current meter at the bank crest (Figure X-B-1; see above, p. 10).

The most obvious feature in the Array II record is its polarization along a nearly north-south axis. The analysis of variance (Freeland, Rhines, and Rossby, 1975) revealed that approximately 79% of the energy in the flow was aligned with a tangent to the trend of the 90 m isobath just to the east of Array II. This is clear evidence of the strong deformation of the flow by the bank even at 40 m above the bottom. During only one period (21 January-22 January) was there any appreciable flow directed across isobaths. This was sufficient, however, to bias the mean of the record so that it was to the east-northeast at 6 cm/sec.

The various spectra showed no strong peaks in the high frequency range ($> 2 \times 10^{-1}$ cph). That means that high frequency internal waves contributed no significant energy to the flow. Since stratification was at a minimum during this period, the observation was expected.

Strong modulation of the flow was found at the semi-diurnal tidal period (about 12.5 hours), and at several discrete lower frequencies. A great deal of energy was clustered about the diurnal period (about 25 hours). This cluster is to be expected, however, because: a) the tide in the Gulf of Mexico is primarily diurnal, b) the local inertial frequency is about 24.8 hours, and c) the Gulf of Mexico may resonate at about 28 hours (Dr. Robert Whittaker, personal communication).

In the lower frequency range ($< 3 \times 10^{-2}$ cph, or 30 hours), very large concentrations of energy were found at periods of about five and eight days.* The five-day concentrations probably represent forced oscillations driven by storms known as northers. The eight-day concentrations may be due to long waves excited by the storms. Known as shelf waves, these typically have wavelengths measured in hundreds of kilometres. Two somewhat smaller energy peaks occurred at about two-

*The two-day, five-day, eight-day, and fourteen-day periods are all approximations.

and fourteen-day periods. The fourteen-day oscillations are probably caused by the fortnightly tidal forcing. Though it is by no means certain, it appears likely that the two-day oscillations are also free waves excited by the northers.

The rotary spectra showed no significant partition of energy between cyclonic and anti-cyclonic events. This lack of partition is explained by the fact that the flow tended to flip from north to south parallel to the local isobaths without any appreciable rotation.
Peak velocities during the storm events were on the order of 50 cm/sec (1 knot) at 60 m depth. This velocity was accompanied by a temperature depression of nearly 1°C.

Velocities from the ECM were quite subdued by comparison with those recorded by the current meter on Array II. The reason for this is that the ECM was located so close to the bottom that it was in the logarithmic sublayer of the bottom boundary layer. That is, the flow at the level of the ECM had been slowed significantly by the drag of the surrounding reef. The mean flow from this record was southeasterly. This flow may have been caused by strong local topographic steering along a trough in the coral in which the ECM was located. Spectra from this record were similar to those derived from the record of upper meter Array II, with one exception. The rotary spectra revealed that both diurnal and semi-diurnal frequency energy peaks were primarily due to anticlockwise rotational events. On the other hand, both the two-day and eight-day period oscillations appeared to be caused by clockwise rotational events. This observation is consistent with the suggestion that the two-day and eight-day phenomena may be continental shelf waves.

May-July 1979

By May, the thermocline had become well established. This can be seen by the substantial fluctuations in the record from the temperature probe mounted alongside the ECM. This record (Figure X-B-33; see below, p. 40) shows that the tidal components have very strong temperature signals. The obvious conclusion is that the diurnal and semi-diurnal components of the tide generate rather energetic internal waves.

At the diurnal frequency, the spectra from the unfiltered data set of the ECM have a spike that is nearly an order of magnitude larger than any other peak present. It is also largely an anticlockwise rotational event. The semidiurnal tidal component was the second most energetic peak; it, too, possessed much more energy in the anticlockwise spectrum than in the clockwise spectrum. That is consistent with most models of the Gulf of Mexico, which show the diurnal and semi-diurnal tides as waves with an anticlockwise rotational sense. In the spectrum of the low-pass filtered temperature data, there were peaks at the two-day period and the eight-day period, as well as the fourteen-day period. The spectra of the current velocity components possessed the same peaks.

For some as yet inexplicable reason, the diurnal tide possessed much more energy than the semidiurnal tide during this period of increasing stratification. It should be recognized that the amplification of the diurnal components of the tide may be a local effect only. That is, it may be due to the presence of the bank, and therefore not typical of the shelf edge in general.

There was less energy in the five-day period portion of the spectrum relative to the January-April period. Doubtless this reflects the diminished number and intensity of the northers with the progression of the seasons.

July-September 1979

The July-September sampling period represents the most complete data set available during any sample period. This data set permitted a comparison between measured flow close to the bank (Array II) and that somewhat removed from the bank (Array I).

Array I. The upper meter on Array I (60 m depth; see Figure X-B-34, below, p. 40) recorded very energetic oscillatory flow, but rather meager mean flow (7.4 cm/sec toward 259°). The major axis of variance was oriented east northeast-west southwest (114°-294°), with 80% of the currents' variance along that axis. During the passage of a tropical low depression in the atmosphere, maximum velocities were approximately 70 cm/sec. At the middle meter (94 m depth), the current was much less energetic, with maximum velocities of about 40 cm/sec. Not only that, but the mean flow was in nearly the opposite direction, or 6.2 cm/sec toward 137°. This mean reflects a much more persistent directional trend in the flow at 94 m than at 60 m. The offshore flow near the bottom would be consistent with the idea of return flow along the bottom to compensate for water driven onshore by the persistent southeasterly winds common to the western Gulf of Mexico of the summer months. However, it is perplexing that flow at 30 m depth recorded by the ECM on the top of the East Flower Garden Bank was to the southeast (119° at over 11 cm/sec). While some alteration of the flow may have been due to local topographic steering, it is not reasonable to expect that the topography would have completely reversed the flow.

In general, the flow at Array I during the summer was subject to more cross-isobath flow than that at Array II. The mean flow at 60 m and the most energetic oscillations were, however, aligned with the local trend of the isobaths. At 94 m the mean flow was cross-isobathyal, probably in response to boundary layer dynamics, but the major axis of the variance tensor was more nearly parallel to the trend of the local topography.

Array II. The near-bottom flow at Array II was much stronger than that at Array I and in a quite different direction. At Array II the mean flow at 94 m depth was directed toward 152° at over 8 cm/sec, while that at 96 m depth was toward 176° at over 10 cm/sec. The variance tensor revealed a similar shift. The major axis of variance from the 94 m depth was oriented along 341°-161°, with 96% of the variance;

that at 96 m depth was oriented along 351°-171°, with fully 97% of the variance. The only reasonable explanation for the difference in bottom flow between the two arrays is that the flow at Array II was turned to the south along the isobaths and accelerated by convergence. This also explains the acceleration toward the bottom and the 10° shift in vectors in a clockwise sense (looking down) from 94 m to 96 m. If this hypothesis is true, adjustment to the topography is strongest near the bottom.

Tidal oscillations at Array II were much stronger than those at Array I. This finding strongly suggests that the sharp spectral peaks at 12.5 and 25 hours (seen in spectra of records from the ECM and from the meters on Array II) are due to topographic amplification of the tidal wave as it impinges on the bank. These peaks are present in the spectra of the meters on Array I, but they are more diffuse and contain less energy. The two-day and eight-day peaks are nearly equal in the spectra from the two arrays, suggesting that these longer wavelength features undergo less amplitude modification as they interact with the bank.

CONCLUSIONS

(See also Volume One, Chapter V)

The most important result of the study is the observation from Array II that **cross-isobath flow rarely occurs and is minimal when it does happen.** It is quite clear that **the current is constrained to flow around the bank rather than over it throughout the range of velocities encountered from January through September 1979.** It should be remembered that the meters were first deployed during extreme storm conditions, with seas of nearly 7 m arising just after the meters were set.

From the records of the near-bottom meters, it appears that one should expect frequent resuspension of silt- and clay-size sediment, particularly at the various tidal frequencies. In light of this observation, neither the presence of the nepheloid layer nor its spatial and temporal changes is surprising.

With continued data acquisition it should be possible to derive more information about the outer shelf dynamics. This information will ultimately enable us to produce at least stochastic models of the flow. These in turn will suggest the probable lines of transport of material which may be shunted to the bottom during drilling operations in this area.

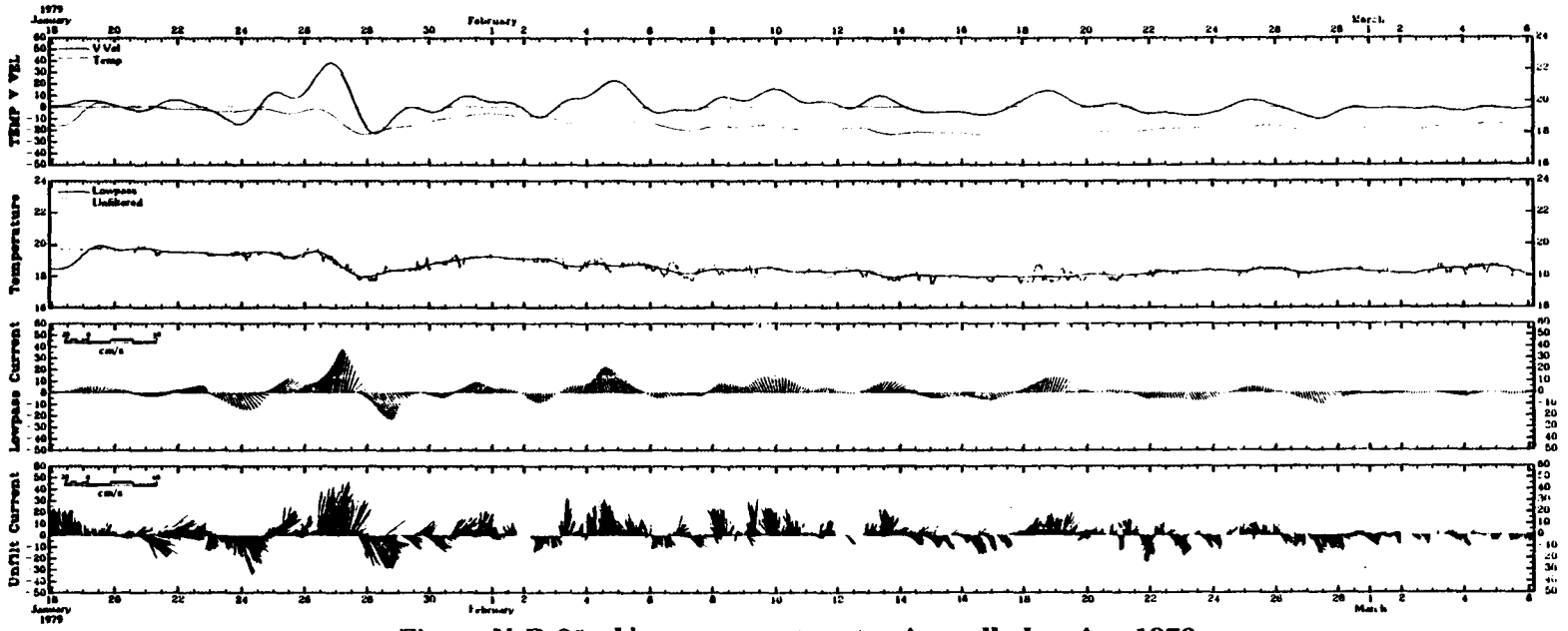

Figure X-B-31. Upper current meter Array II, Jan-Apr 1979.

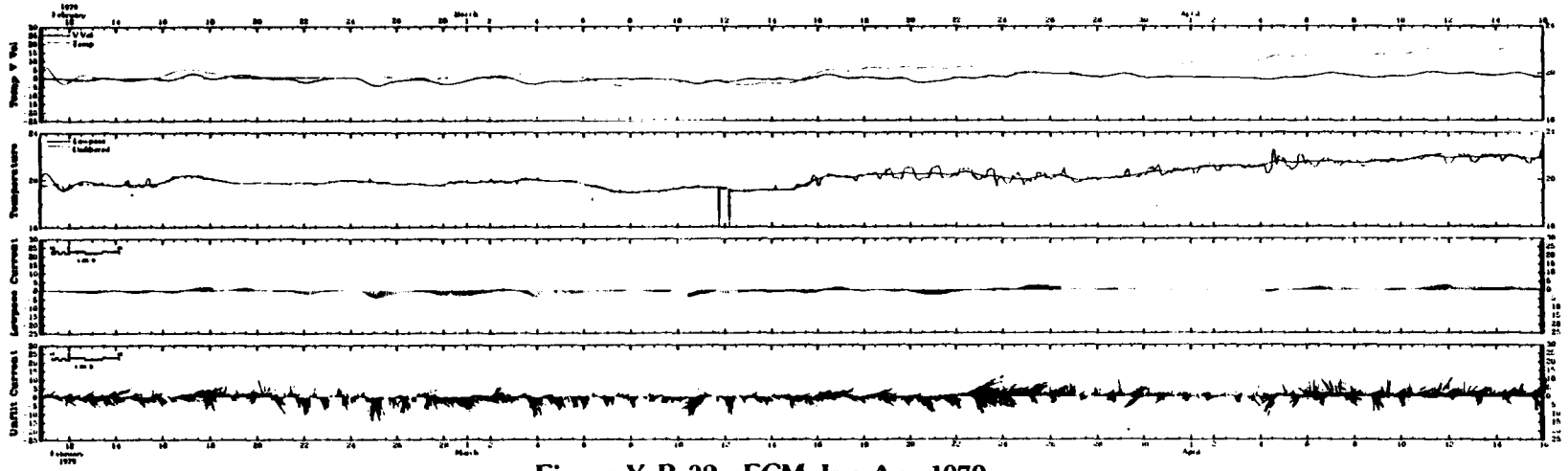

Figure X-B-32. ECM Jan-Apr 1979.

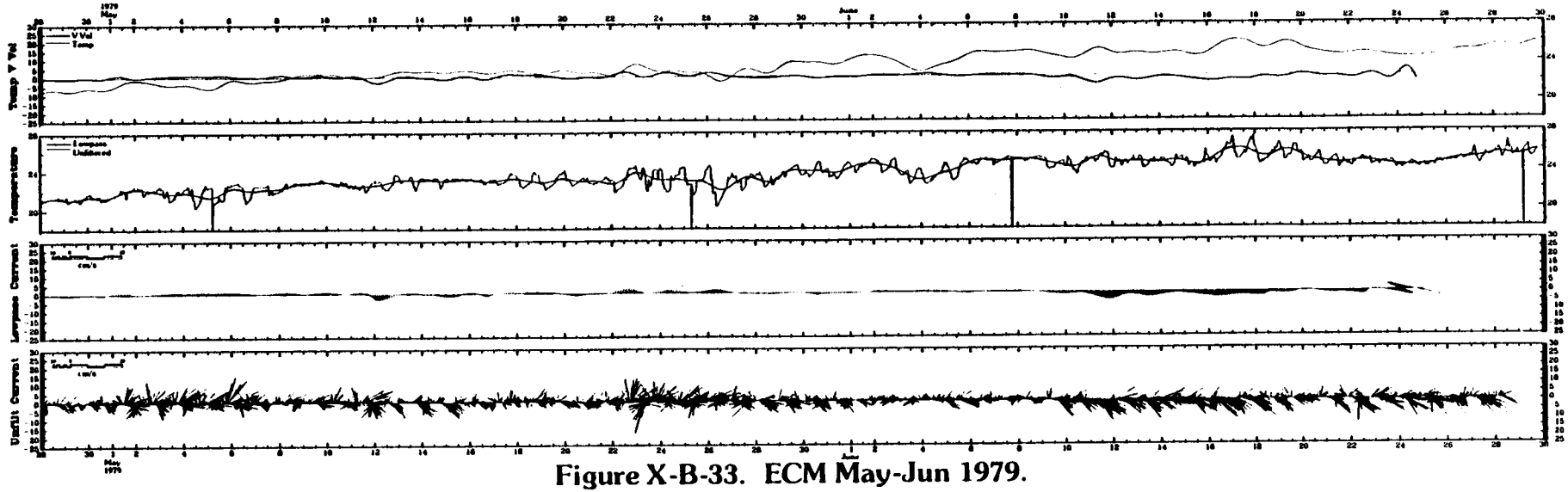

Figure X-B-33. ECM May-Jun 1979.

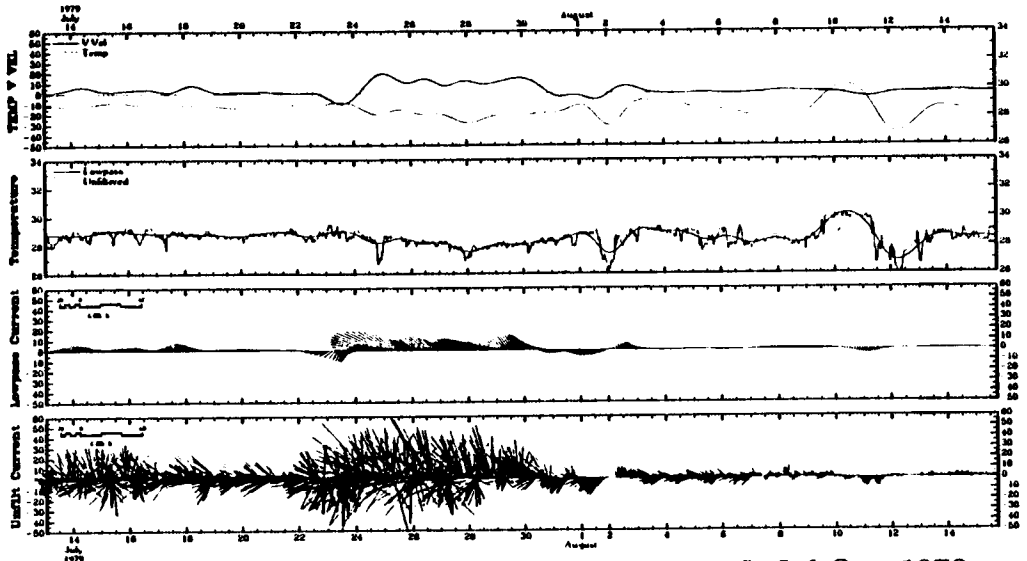

Figure X-B-34. Upper current meter Array I, Jul-Sep 1979.

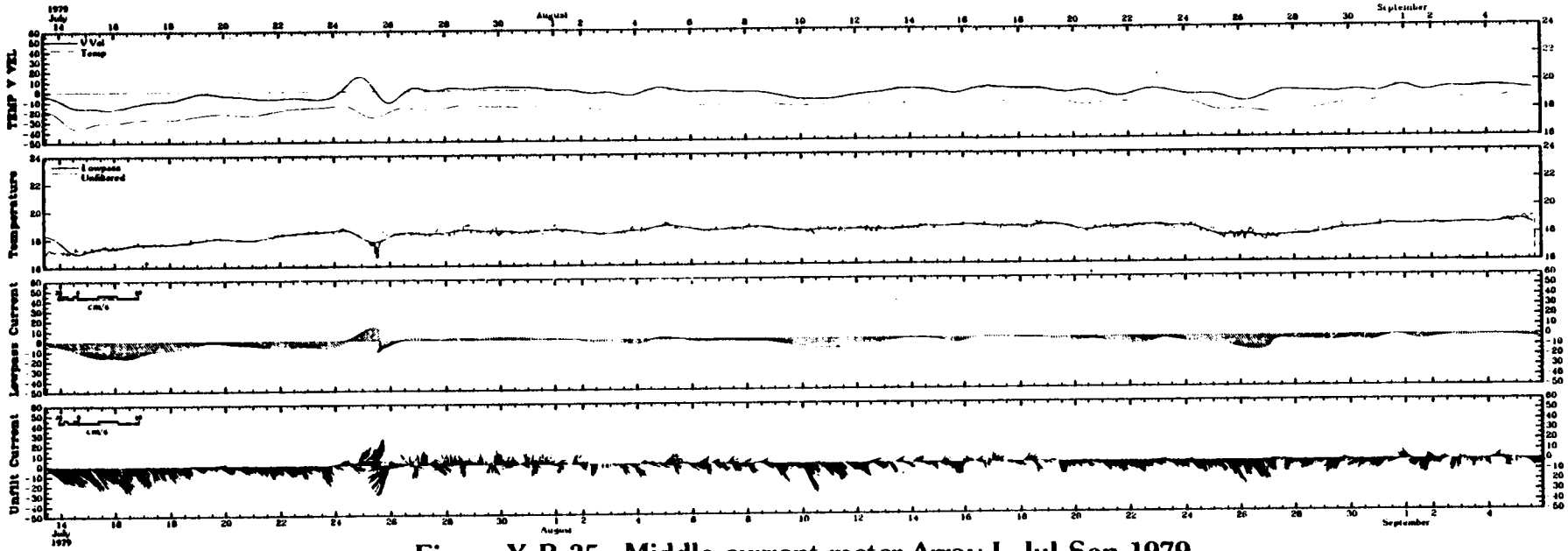

Figure X-B-35. Middle current meter Array I, Jul-Sep 1979.

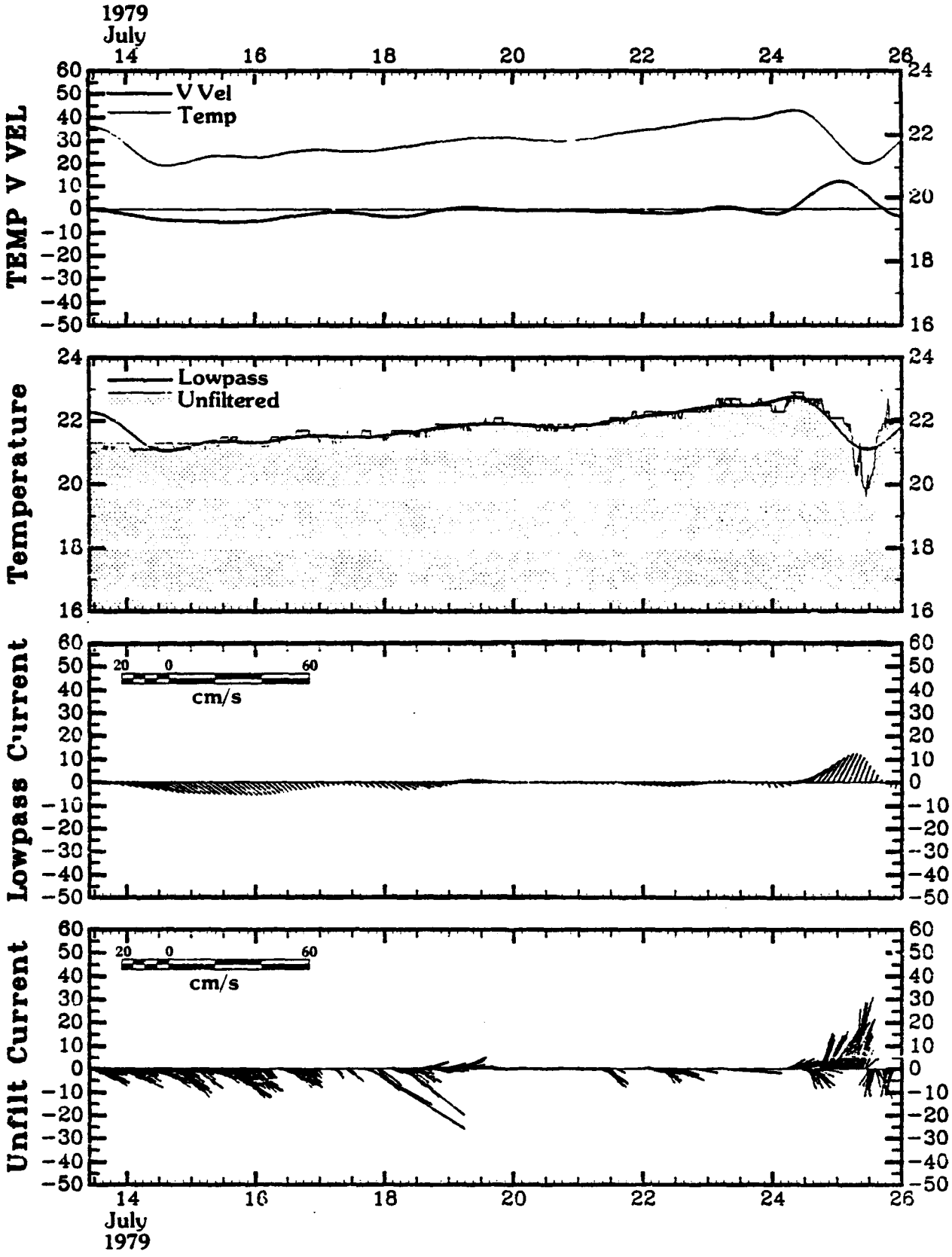

Figure X-B-36. Bottom current meter Array I, Jul-Sep 1979.

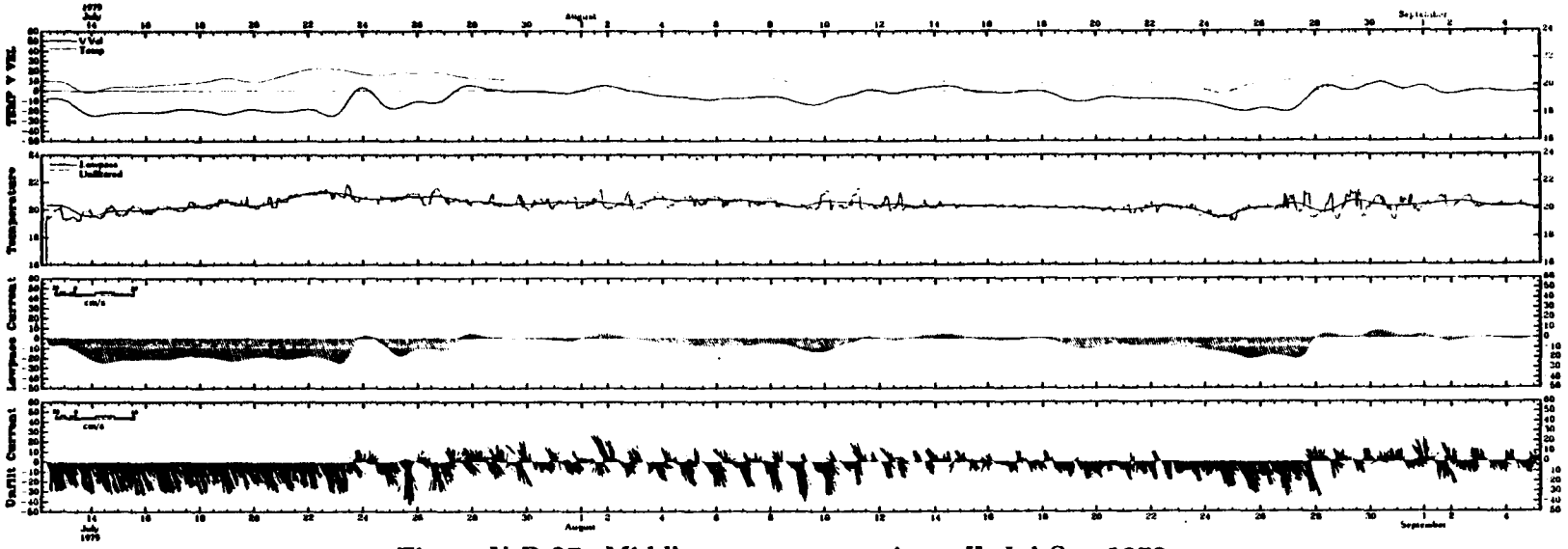

Figure X-B-37. Middle current meter Array II, Jul-Sep 1979.

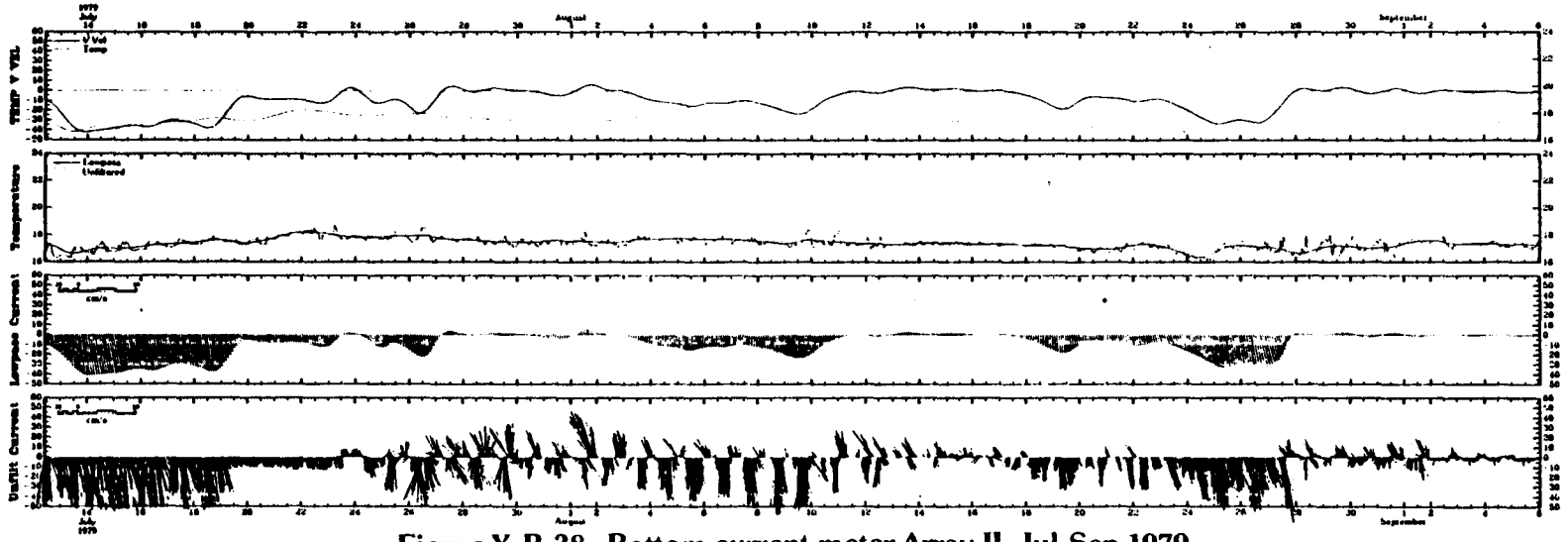

Figure X-B-38. Bottom current meter Array II, Jul-Sep 1979.

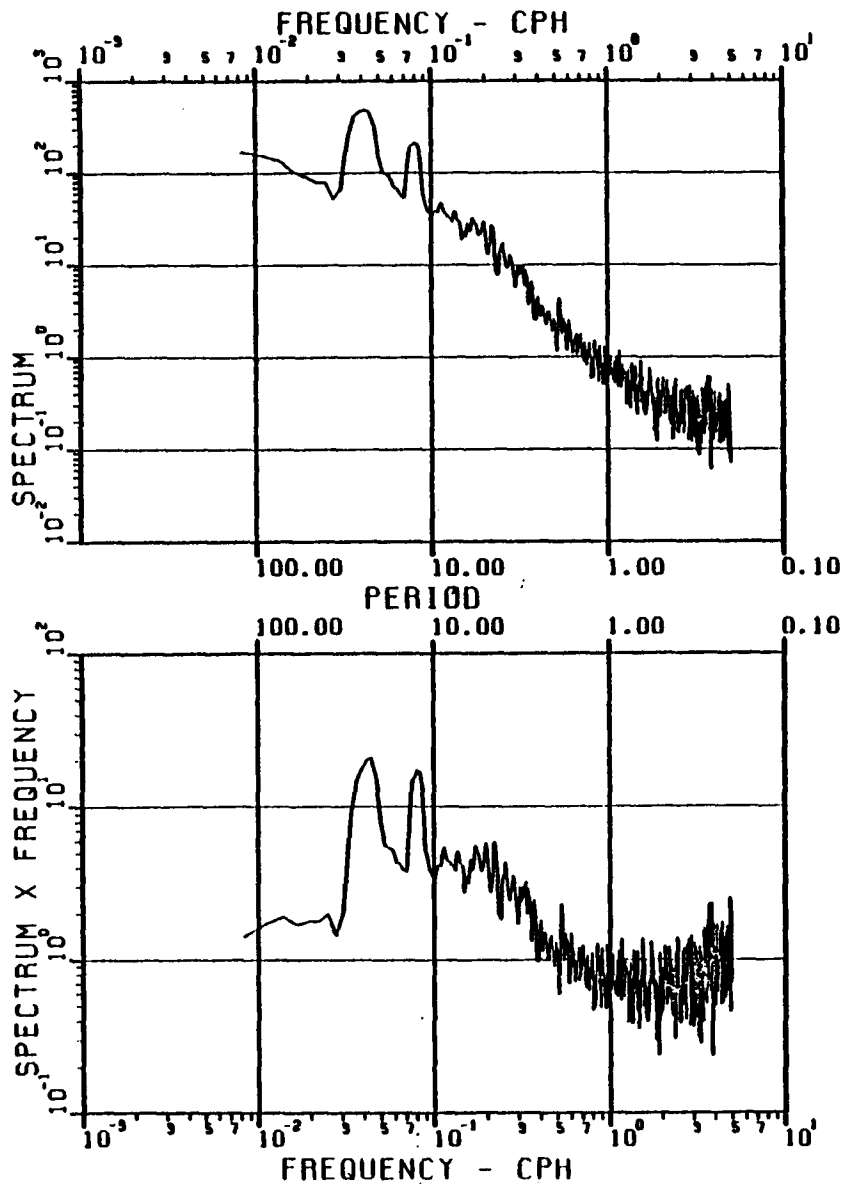

*Figure X-B-39. U auto spectra of middle current meter Array II. Series length = 21504.0 min. Number of segments = 3. Cosine taper bands averaged = 5.

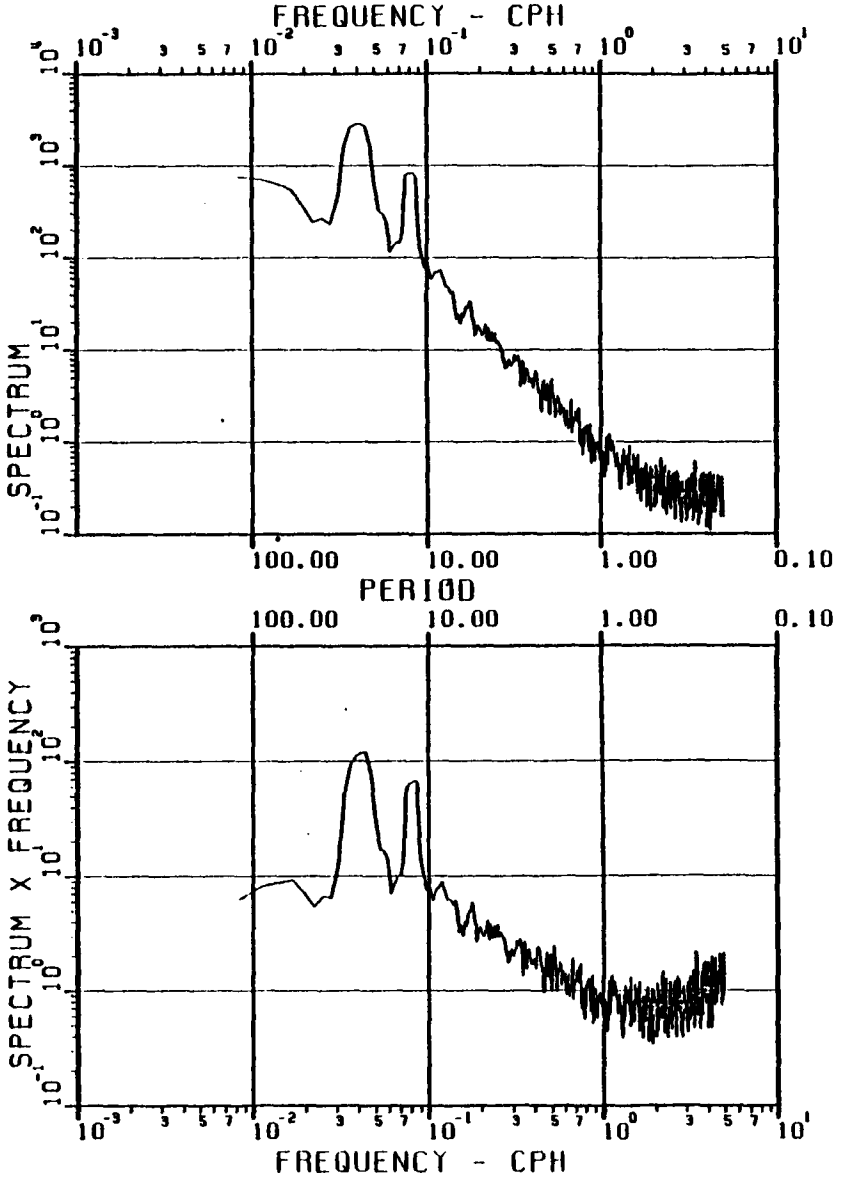

Figure X-B-40. U auto spectra of middle current meter Array II. Series length = 21504.0 min. Number of segments = 3. Cosine taper bands averaged = 5.

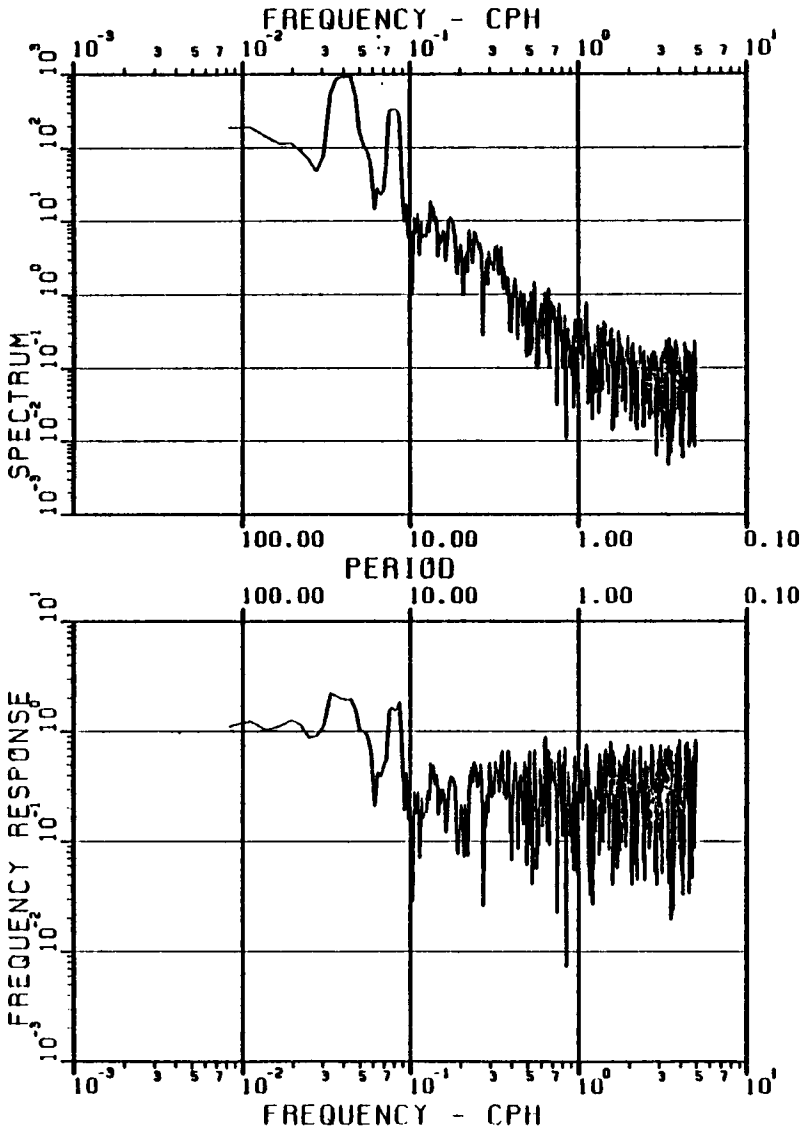

Figure X-B-41. U-V cross amplitude of middle current meter Array II. Series length = 21504.0 min. Number of segments = 3. Cosine taper bands averaged = 5.

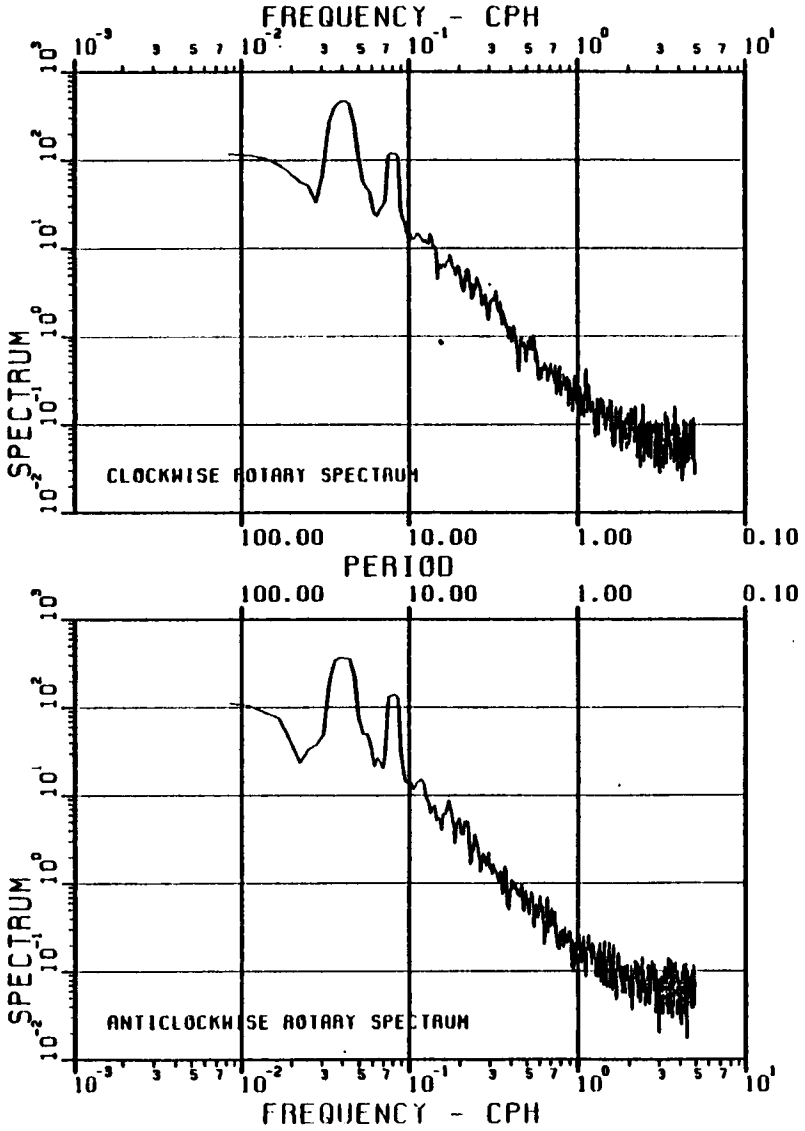

Figure X-B-42. U-V rotary spectra of middle current meter Array II. Series length = 21504.0 min. Number of segments = 3. Cosine taper bands averaged = 5.

*U= E-W component of velocity; when value is positive, current is toward east; when negative, current is toward west.
V= N-S component of velocity; when value is positive, current is toward north; when negative, current is toward south.

PART C: BIOLOGICAL MONITORING STUDY

T. Bright, S. Viada, C. Combs, G. Dennis, E. Powell, G. Denoux

INTRODUCTION

Biological monitoring at the East Flower Garden has been directed toward identifying and gaining an understanding of the biological populations and ecological processes of primary importance to the continued "health" of the reef and hard-bank communities. Corals and coralline algae are undoubtedly the dominant organisms at the bank, building substratum and providing essential habitat for the other species comprising the hard-bottom communities. Monitoring efforts were directed toward a consideration of population dynamics and ecology of the overwhelmingly important corals and coralline algae. Non-destructive field methodologies which maximize the amount of data gathered per day at sea have been developed

The study has evolved into a long-term quantitative assessment of population parameters, reproduction, recruitment, growth, and mortality of corals and coralline algae on the coral reef. From a submersible, yearly qualitative examinations of deep bank communities were performed to detect mass mortalities or apparent change in benthic populations. A short-term study of leafy algae populations near the top of the bank has been completed. Certain efforts, namely coral behavior studies and observations of fish and invertebrate activity cycles, have been abandoned because logistical limitations preclude gathering enough data to permit meaningful quantitative interpretation for purposes of long-term biological monitoring. Such techniques are better suited to short-term intense monitoring efforts during drilling.

It is certain that, using the growing base of quantitative information we have gathered, we will be able to reliably detect any future changes in community structure, coral and coralline algae population parameters, rates of recruitment, and growth and mortality of corals and coralline algae.

As part of a modification to the present contract, an identical monitoring study was undertaken at the West Flower Garden. Two biological and two geological submersible transects were made (Figure X-A-2, above), and observations were recorded on color video tape and 35 mm still photos. A total of ten (10) plotless line transects (PLTs) were established in the existing study area in order to study population levels of corals, lateral encrusting growth, and mortality rates of dominant species of coral and coralline algae. All West Flower Garden biological data will be reduced and reported under Contract #AA851-CT0-25.

CORAL AND CORALLINE ALGAE POPULATION LEVELS

Introduction

Both the East Flower Garden and the similar West Flower Garden, 22.2 km (12 nautical miles) to the west, can be classified as submerged reef-banks: inorganic banks capped by organic buildups rising above the supporting foundation to various elevations, below 9.15 m in depth (Logan et al., 1969). From a rather extensive biological and geological reconnaissance of the Flower Garden Banks, Bright and Rezak (1977) found that at depths above 45 to 49 m, the East and West Flower Garden Banks are covered with thriving submerged coral reefs, which are devoid of shallow water alcyonarians. Unlike the West Flower Garden, the East Flower Garden harbors sizable knolls of the branching scleractinian coral, Madracis mirabilis. In addition, other knolls at the East Flower Garden are covered with lush growths of leafy algae including Caulerpa, Chrysymenia, Halymenia, Gloiophlaea, Lobophora, Microdictyon, and others. The East Flower Garden displays a greater degree of lateral biotic variability than is found on the West Flower Garden. This difference is attributed to the East Flower Garden's "Leafy Algae Zone" and "Madracis Zone," as well as knolls of intermediate biotic composition which bear various types of sponges, Madracis clumps, patches of leafy algae, and extensive coralline algae. Epibenthic assemblages of organisms at the East Flower Garden can be characterized by a distinctive biotic zonation (Edwards, 1971; Bright et al., 1974; Abbott, 1975; Bright, 1977).

The East and West Flower Garden Banks represent the northernmost thriving shallow-water coral reefs on the continental shelf of North America (Bright et al., 1974). The study of coral and coralline algae populations focuses on the uppermost zone, the Diploria-Montastrea-Porites community (from Logan et al., 1969), which occupies depths of 19-37 m, and harbors at least 18 species of scleractinean corals and associated West Indian and West Atlantic reef fauna and flora.

The invertebrate communities to be studied at the East Flower Garden Bank are benthic and sessile in nature, and therefore are substantially similar to terrestrial plant communities. Therefore, test concepts and techniques used by plant ecologists were employed in this study to determine population levels for scleractinean corals and other hard-bottom benthos, such as coralline and filamentous algae populations and sponges. These methods, as well as detailed descriptions of equipment and procedure, may be found in Volume Two, Chapter VII.

This study had two primary emphases:

(1) quantitative assessment of the population levels of scleractinean corals, coralline and filamentous algae, and sponges from the Diploria-Montastrea-Porites Zone of the East Flower Garden Bank by means of stratified random line transect analysis; and

(2) determination and description of the species of scleractinean reef corals within this zone of the bank.

Methods

Field Procedure

Data were collected during six cruises (see Volume Two, Table II-5). Two established study sites at the East Flower Garden were chosen as reference points for this sampling program: the BLM site, established by the 1977 Texas A&M University monitoring study at 27°54'01.28"N, 93°34'38.27"W, and the CSA-A site established by Continental Shelf Associates (Tequesta, FL) during the 1978 monitoring study at 27°54'37.37"N, 93°35'55.79"W. Both sites are located within the Diploria-Montastrea-Porites Zone at the East Flower Garden Bank (Figure X-C-1).

The two stations represent different community types. The CSA-A station, centrally located within the Diploria-Montastrea-Porites Zone, represents a "top reef" community, with reef crest depths of approximately 19 to 21 m. The BLM station, located about 400 m south of the CSA-A station, is closer to the transition zone between the Diploria-Montastrea-Porites Zone and the Madracis-Algae Zone. Thus it represents a "reef edge" community, with reef crest depths of approximately 21 to 24 m.

Sampling was accomplished by taking a series of 34 stratified random 10 m line transects, using a modified form of the method described by Loya (1972). Instead of measuring the dimensions of various biotic components of the transect in situ, a camera jig apparatus was used to create photographic mosaics of the transects. A fiberglass fabric metric measuring tape was initially stretched over randomly selected areas of the hard-bottom portion of the reef, to designate the boundaries of the 10 m transects. The photographs were taken along the length of the measuring tape, allowing a certain degree of overlap, such that a complete photographic mosaic of the transect area could subsequently be pieced together in the laboratory. Six random transects per cruise were taken on each site. In choosing the positions of each transect, the diver-photographer descended to the bottom in the general vicinity of the sandflats, which served as central reference points for the two sites. Choosing a random direction, the diver would then swim an unprescribed distance from the sandflat and lay out the measuring tape.

The collection of corals for the determination of species composition within this zone of the East Flower Garden Bank served to verify the identifications of corals measured in the transect photographs. Dives were conducted in random locations around the two study sites on the reef for collection of coral colony sections, or in some cases, individual coral polyps, for confirmation of in situ systematic determinations. Prior to collection, the coral species collected were photographed in situ.

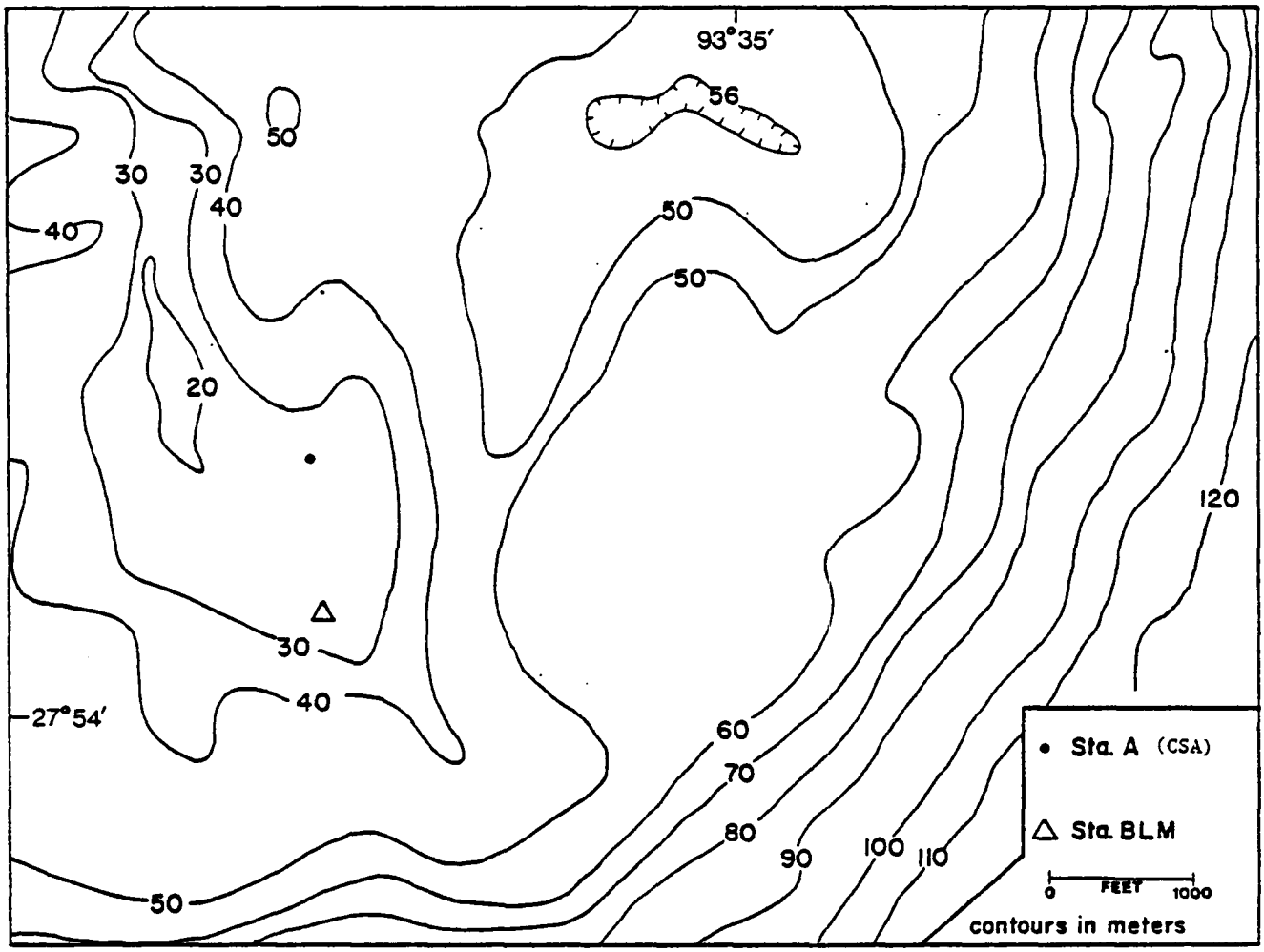

Figure X-C-1. Locations of the two East Flower Garden reef monitoring sites.

Statistical Methods for Transect Analysis

Line transect data were analysed with a statistical program originally designed for analysis of range vegetation distributions determined by using the same line intercept method. Volume Two, Chapter VII-E provides a review of literature about this analytical method.

The statistical analysis compared line transect data from the two study stations (i.e., BLM and CSA-A) to determine relationships of coral species populations. Data were analyzed to determine and record the total number of individuals of each species, the total of intercept lengths for each species, and the number of transects in which each coral species occurred. From these values, appropriate parameters were selected, based on studies involving population levels and distributions of terrestrial vegetation. Using a FORTRAN computer program, eight parameters were calculated: 1) species dominance; 2) relative dominance; 3) relative density; 4) frequency; 5) relative frequency; 6) species diversity; 7) species evenness; and 8) species richness. Except for relative dominance and relative density calculations, these parameters were calculated for coral species only. For both relative dominance and relative density, separate calculations were made for coral and coralline algae to suggest relative proportions between all of the major carbonate producers on the reef.

Sample means were calculated for each species at each station (BLM and CSA-A) for five parameters: dominance, relative dominance, relative density, frequency, and relative frequency (Appendix C, Tables X-C-1 through 26). Species diversity, evenness, and richness were calculated for each transect and for both stations (Appendix C, Tables X-C-27 and 28).

Calculations of these parameters are as follows:

Species Dominance

Species dominance is a measure of size, based on percent cover along the entire length of a transect. This parameter depicts percent coverage of coralline algae and coral species. The parameter is calculated as follows:

$$\text{Species Dominance} = \frac{\text{Total of Intercept Lengths for Species "A"}}{\text{Total Transect Length}}$$

Relative Dominance

Relative dominance measures the size of individual coral colonies in relation to each other, on the basis of percent cover for each colony. The formula for calculating relative dominance is as follows:

$$\text{Relative Dominance} = \frac{\text{Total of Intercept Lengths for Coral Species "A"}}{\text{Total of Intercept Lengths for all Coral Species Within the Transect}} \times 100$$

Relative Density

Relative density (abundance) describes the number of individual colonies of each coral species within a transect, relative to each other. This parameter is calculated as follows:

$$\text{Relative Density} = \frac{\text{Total Number of Colonies of Species "A"}}{\text{Total Number of Colonies of All Species}}$$

Frequency

The frequency calculation relates the number of transects in which an individual coral species occurs to the total number of transects, as follows:

$$\text{Frequency} = \frac{\text{Transect in Which Species "A" Occurs}}{\text{Total Number of Transects}}$$

Diversity

The Shannon-Weaver Index of Diversity (H") (Shannon and Weaver, 1949) was used to measure diversity of coral species, because this index is reasonably independent of sample size and normally distributed. The formula for species diversity is:

$$H'' = -\sum_{i=1}^{s} \frac{n_i}{N} \ln \frac{n_i}{N}$$

where

s = total number of species
n_i = number of individuals in the ith species
N = the total number of individuals (s) in the collection, which is $\sum_{i=1}^{s} n_i$

Species Evenness

Species evenness indicates numerically how coral species are distributed with respect to relative density (abundance) and dominance (cover) within each transect. The formula for calculating species evenness (J) is as follows:

$$J = \frac{H''}{H_{max}} = \frac{H''}{\ln S}$$

where

J = evenness
H'' = species diversity
H_{max} = the maximum possible value of H"
and
S = the number of coral species

Species Richness

Species richness measures the ratio of number of species present over the number of individuals present, as follows:

$$D = \frac{S - 1}{\ln N}$$

where

D = species richness
S = the number of species present
and
N = the number of individuals present

Other Statistical Tests

The F-test was used to test sample variances for similarity. Sample means were then compared for statistical similarity, using Student's t-test. Confidence limits at the 95% level were placed around the sample mean values for each parameter.

Species Composition of Scleractinean Corals at the Flower Gardens

Most of the post-Paleozoic fossil and Recent hermatypic (reef-building) corals are classified within the order Scleractinia (Vaughn and Wells, 1943). This order is distinguished by a calcareous external skeleton which consists of radial partitions or septa situated between the mesenteries (radial partitions of the gastrovascular cavity of each polyp) together with an external sheathing and variously developed attendant supporting structures (Wells, 1956). Coral reefs flourish in waters where the mean annual water temperatures are approximately 23-25°C. Coral reefs are therefore confined to tropical and near tropical regions (Wells, 1957). Caribbean and West Atlantic reefs are much less diverse in coral species composition and reef development than are Indo-Pacific reefs (Milliman, 1973).

The Flower Garden coral reefs reside near the northern border of the Caribbean province, but physiographic and ecological conditions on

the reef are within the limits for reef development (Edwards, 1971). Prior to 1963, the scientific literature treated the Flower Garden Banks as dead reefs. Stetson (1953) recovered five species of coral from the Flower Garden Banks, one of which (Madracis mirabilis) was living. Parker and Curray (1956) recovered fragments, small colonies of dead corals, and one species (Madracis mirabilis) of living coral from the East Flower Garden. They concluded that there were no large reefs comprised of living hermatypic corals on the Flower Garden Banks. Pulley (1963) was the first to discover that the Flower Garden Banks were indeed flourishing healthy reefs. The first detailed study of the Flower Garden coral fauna was that of Edwards (1971), who collected and identified 13 coral specimens from the West Flower Garden. A more comprehensive study of coral species composition and abundance at the West Flower Garden was by Tresslar (in Bright and Pequegnat, 1974). Tresslar found that the majority of the reefal accumulations of scleractinean corals occurred above 27 m (90 ft) on the bank. The coral fauna consisted of 17 species of scleractineans of the families Astrocoeniidae, Pocilloporidae, Agariciidae, Siderastreidae, Poritidae, Faviidae, Oculinidae, Mussidae, and one species of the family Milliporidae (Table X-C-1). Species diversity of corals was found to be lower than that on many of the Caribbean reefs, but was similar to several other Gulf of Mexico reefs. Edwards (1971) believed that the sources of West Flower Garden fauna are the southern Gulf of Mexico and the Caribbean Sea, and that the geographical distance from these sources, rather than unfavorable environmental conditions, limits the West Flower Garden biota. Until now, no comprehensive description of the scleractinean coral species assemblage at the East Flower Garden Bank has been undertaken.

Results and Discussion

Results from the line transect data indicate some significant differences in the population levels of individual species of corals at the "reef edge" (BLM station) compared to the "top reef" (CSA-A station) of the East Flower Garden Bank. The data revealed, however, that species diversity, evenness, and richness values from the two study stations were not significantly different. Thus, whereas species diversity, evenness, and richness of the coral assemblage as a whole may be similar over most of the reef, variability may exist in details of coral community structure from place to place on the reef, when comparisons are made within or between species (Tables X-C-2 and 3).

Montastrea annularis proved to be the most dominant and abundant coral species at both stations. Percent coverage (dominance) of M. annularis at the BLM station was significantly higher than at the CSA-A station. Relative density (abundance) figures revealed no statistically significant differences between the two stations. These data suggest that the individual colonies of M. annularis at the two stations were equally abundant, but colonies at the BLM station were significantly larger than those found at the CSA-A station. M. annularis was found on all transects from both stations (frequency of occurrence equal to 100%).

TABLE X-C-1
CORAL SPECIES LIST

FAMILY ASTROCOENIIDAE

Stephanocoenia intersepta (Esper)

FAMILY POCILLOPORIDAE

Madracis decactis (Lyman, 1859)
Madracis asperula? Milne-Edwards & Haime, 1850
Madracis mirabilis (Duchassaing & Michelotti)

FAMILY AGARICIIDAE

Agaricia agaricites (Linnaeus, 1758)
Helioceris cucullata (Ellis & Solander, 1786)

FAMILY SIDERASTREIDAE

Siderastrea siderea (Ellis & Solander, 1876)

FAMILY PORITIDAE

Porites astreoides Lamarck, 1816
Porites furcata Lamarck, 1816

FAMILY FAVIIDAE

Diploria strigosa (Dana, 1846)
Colpophyllia natans (Muller, 1775)
Colpophyllia amaranthus (Muller, 1775)
Montastrea annularis (Ellis & Solander, 1786)
Montastrea cavernosa (Linnaeus, 1766)

FAMILY MUSSIDAE

Mussa angulosa (Pallus)
Scolymia cubensis (Milne-Edwards & Haime, 1849)

FAMILY MILLEPORIDAE

Millepora alcicornis Linnaeus, 1758

TABLE X-C-2

POPULATION LEVELS OF CORALS AND CORALLINE ALGAE AT THE EAST FLOWER GARDEN BLM STATION (REEF EDGE), LISTED IN ORDER OF IMPORTANCE

PARAMETERS

DOMINANCE	REL. DOMINANCE (CORALS)	REL. DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)
1. M. annularis	1. M. annularis	1. M. annularis	1. M. annularis
2. Colpophyllia spp.	2. Colpophyllia spp.	2. Colpophyllia spp.	2. Colpophyllia spp.
3. M. cavernosa	3. M. cavernosa	3. M. cavernosa	3. Millepora sp.
4. Coralline algae	4. Millepora sp.	4. Coralline algae	4. P. astreoides
5. Madracis decactis	5. D. strigosa	5. Millepora sp.	5. M. decactis
6. Millepora sp.	6. M. decactis	6. D. strigosa	6. Agaricia spp.
7. Diploria strigosa	7. P. astreoides	7. M. decactis	7. M. cavernosa
8. Porites astreoides	8. M. angulosa	8. P. astreoides	8. D. strigosa
9. Agaricia spp.	9. Agaricia spp.	9. M. angulosa	9. M. angulosa
10. M. angulosa	10. S. intersepta	10. Agaricia spp.	10. S. intersepta
11. S. intersepta	11. Scolymia sp.	11. S. intersepta	11. Scolymia sp.
12. Scolymia sp.	12. S. siderea	12. Scolymia sp.	12. S. siderea
13. S. siderea		13. S. siderea	

REL. DENS. (CORAL & COR. ALGAE)	FREQUENCY	RELATIVE FREQUENCY
1. M. annularis	1. M. annularis = Cor. algae	
2. Coralline algae	2. Colpophyllia spp. = Millepora	
3. Colpophyllia spp.	3. P. astreoides	Same
4. Millepora sp.	4. Agaricia spp.	
5. P. astreoides	5. M. decactis = M. cavernosa =	as
6. M. decactis	D. strigosa = M. angulosa	
7. Agaricia spp.	6. S. intersepta	Frequency
8. M. cavernosa	7. Scolymia sp.	
9. D. strigosa	8. S. siderea	
10. M. angulosa		
11. S. intersepta		
12. Scolymia sp.		
13. S. siderea		

TABLE X-C-3

POPULATION LEVELS OF CORALS AND CORALLINE ALGAE AT THE EAST FLOWER GARDEN CSA-A STATION (TOP REEF), LISTED IN ORDER OF IMPORTANCE

PARAMETERS

DOMINANCE	REL. DOMINANCE (CORALS)	REL. DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)
1. M. annularis	1. M. annularis	1. M. annularis	1. M. annularis
2. D. strigosa	2. Colpophyllia spp.	2. Colpophyllia spp.	2. P. astreoides
3. Colpophyllia spp.	3. D. strigosa	3. D. strigosa	3. Colpophyllia spp.
4. Coralline algae	4. Millepora sp.	4. Coralline algae	4. D. strigosa
5. Millepora sp.	5. M. cavernosa	5. Millepora sp.	5. Millepora sp.
6. M. cavernosa	6. P. astreoides	6. M. cavernosa	6. M. cavernosa
7. P. astreoides	7. S. siderea	7. P. astreoides	7. Agaricia spp.
8. S. siderea	8. M. decactis	8. S. siderea	8. S. siderea
9. M. decactis	9. Agaricia spp.	9. M. decactis	9. M. decactis
10. Agaricia sp.	10. Scolymia sp.	10. Agaricia spp.	10. Scolymia sp.
11. Scolymia sp.	11. S. intersepta = M. angulosa	11. Scolymia sp.	11. S. intersepta = M. angulosa
12. M. angulosa = S. interspeta		12. S. intersepta = M. angulosa	

REL. DENS. (CORAL & COR. ALGAE)	FREQUENCY	REL. FREQUENCY
1. Coralline algae	1. M. annularis = Cor. algae	1. M. annularis = Cor. algae
2. M. annularis	2. P. astreoides	2. P. astreoides
3. P. astreoides	3. Colpophyllia spp.	3. Colpophyllia spp.
4. D. strigosa	4. D. strigosa = Agaricia spp.	4. D. strigosa = Agarcia spp.
5. Colpophyllia spp.	5. M. cavernosa	5. M. cavernosa
6. Millepora sp.	6. Millepora sp.	6. Millepora sp.
7. Agaricia spp.	7. M. decactis	7. M. decactis
8. M. cavernosa	8. S. siderea	8. S. siderea
9. M. decactis	9. Scolymia sp.	9. Scolymia sp.
10. S. Siderea	10. S. intersepta = M. angulosa	10. S. intersepta = M. angulosa
11. Scolymia sp.		
12. S. intersepta = M. angulosa		

Diploria strigosa constituted substantially higher percent coverage (i.e., dominance) in CSA-A transects than in BLM transects. The relative density (abundance) of D. strigosa at CSA-A far exceeded those values determined from BLM transect data, indicating that the abundance (numbers of colonies) of this coral could be far higher at the CSA-A station than at the BLM station. The frequency of occurrence values of D. strigosa were also much higher at CSA-A than at the BLM station.

Colpophyllia natans and C. amaranthus were indistinguishable from one another in the transect photograph mosaics, and therefore had to be grouped together in the analysis. Dominance and relative dominance were statistically similar at the BLM and CSA-A stations. The calculated values of relative density were also statistically similar, suggesting that the population levels of Colpophyllia spp., in terms of percent coverage and abundance (relative density), are quite similar at both stations. Frequency values of Colpophyllia spp. were slightly higher at the BLM station than at the CSA-A station.

Montastrea cavernosa percent coverage and density were rather low at both stations. There were no statistically significant differences in these parameters at either station. Frequency of M. cavernosa at the CSA-A station was slightly higher than that at the BLM station.

Millepora sp. also constituted a rather small percentage of transect cover and relative density, with no significant differences in values from both stations. Frequency for Millepora sp. at the BLM station was far greater than that for CSA-A. It is possible that the distribution of Millepora sp. could be composed of relatively larger colonies at the CSA-A station, and more widely scattered, smaller, but more numerous colonies at the BLM station.

Madracis decactis percent cover and relative density were rather low, with no significant differences between the two stations in either of these two parameters. Frequency for M. decactis at the BLM station was somewhat higher than that found at the CSA-A station.

Calculated percent coverage (dominance) and relative dominance values for Porites astreoides were low at both study stations, but both relative density (abundance) and frequency of occurrence were high. For this species, there was no significant difference between stations in any of the tested parameters. The data indicate that P. astreoides is distributed in small, yet abundant colonies, which are commonplace in both areas of the reef.

Population parameters for Agaricia spp. revealed the same trends as indicated for P. astreoides, with no significant difference in either station. Thus, Agaricia spp. must also exist in small, abundant colonies within the two study areas. However, the data for Agaricia spp. probably provide only a rough estimate of the actual population levels of this genus. Quite commonly, Agariciids tend to grow underneath coral edges and outcrops, and would not have been seen in the transect photographs. Therefore, the information on population

levels of this genus is probably a slight underestimate of the true values.

Siderastrea siderea was not recorded in transects at the BLM station, but has been seen during diving operations at that location. Frequency for S. siderea was quite low at the CSA-A station, but exhibited rather high corresponding percent cover and relative density values. These data seem to indicate that S. siderea is distributed in discrete units, each consisting of several colonies, yet is rare enough to be missed altogether by transects at the BLM station.

Stephanocoenia intersepta was not recorded at the CSA-A station, but has been sighted during diving operations. It was found within four of the BLM transects, but constituted only a small percentage of the total transect lengths, with low relative density and abundance values. There were obvious statistically significant differences between all tested population level parameters from the two stations. The data from the BLM station suggest that S. intersepta is distributed as rather small isolated colonies within the reef edge area.

Mussa angulosa was also not recorded at the CSA-A station, but has been sighted during diving operations. At the BLM station, dominance, relative dominance, as well as relative density values were all quite low. Frequency of occurrence was found to by 47.06% at the BLM station, and it is probable that the population distribution of M. angulosa is in small isolated colonies, or units, occurring rather commonly within the BLM reef edge area.

Scolymia sp. is a solitary form, occupying only a small percentage of the transects in which it was found. Occasionally, it was found in small clusters, but generally, relative density figures were quite low. Frequency of occurrence values were also quite low, but Scolymia sp. is a species which tends to reside below the large semihemispherical mounds of the more dominant forms, and the data might tend to slightly underestimate the actual population levels.

The species Madracis mirabilis and Porites furcata were not recorded in any of the transects. M. mirabilis populations are most prominent at depths below 30 m, within the transition area between the Diploria-Montastrea-Porites Zone and the deeper Algal-Sponge Zone. In the areas sampled, Porites furcata abundance and coverage was so small that no colonies were recorded in any transects. This species, as well as M. mirabilis has, however, been seen and collected in previous diving operations.

Coralline algae occupied a fairly high percent of all transects analyzed from the East Flower Garden. They were statistically more dominant and abundant at the CSA-A site than at the BLM site. Frequency of occurrence at both stations was 100%. Coralline algae also occupy space below and between coral mounds and overhangs, and the calculated population levels at the two stations are probably underestimated.

Comparison of Station Findings
(Appendix C, Tables X-C-1 through 28)

1. Montastrea annularis constituted the highest percent cover and relative density of all coral species and algae at both stations of the East Flower Garden. M. annularis was present in all transects from both stations. Percent cover (dominance) values for all other corals and coralline algae were substantially lower than those found in M. annularis.

2. Dominance (percent cover) of Montastrea annularis, Stephanocoenia intersepta, and Mussa angulosa was found to be statistically higher on the reef edge station (BLM) than on the top reef station (CSA-A), whereas dominance of Siderastrea siderea, Diploria strigosa, and coralline algae was higher on the top reef area than on the reef edge (See Table X-C-4). All other coral species revealed statistically similar values between the two stations.

3. Average live coral cover was 61.60% on the reef edge station (BLM) and 52.22% on the top reef station (CSA-A).

4. Species diversity, evenness, and richness values for the reef edge (BLM) and top reef (CSA-A) areas revealed no statistically significant differences.

GROWTH AND MORTALITY OF HERMATYPIC CORALS

Accretionary growth rates for the coral Montastrea annularis were determined by sclerochronological analysis of 12 cores from massive heads at 20 m depth on the East Flower Garden reef (Hudson and Robbin, in press). Hudson and Robbin's results indicate stable growth conditions for M. annularis at the East Flower Garden from 1907 to 1957, with growth rates averaging 8.9 mm/yr. From 1957 to 1979 the growth of M. annularis averaged only 7.2 mm/yr. These rates are comparable to growth rates for the same species in the Florida reef tract.

Sclerochronological Analysis

Sclerochronological analysis of a specimen of Stephanocoenia michelini (synonymous with S. intersepta) collected from 38.5 m at the East Flower Garden in 1974 indicated a mean growth rate of 5.8 mm/yr over a 44 year period (Table X-C-5, Figure X-C-2), with a 95% confidence interval of 5.5 to 6.2 mm/yr. These rates and those of Hudson and Robbin for M. annularis imply that environmental conditions at the East Flower Garden have favored growth of hermatypic corals for many decades, and some of the live coral heads existing at the East Flower Garden are well over 80 years old.

Encrusting Growth and Mortality

Sclerochronological determinations of accretionary growth are appropriate measures of the long-term or historical circumstances of

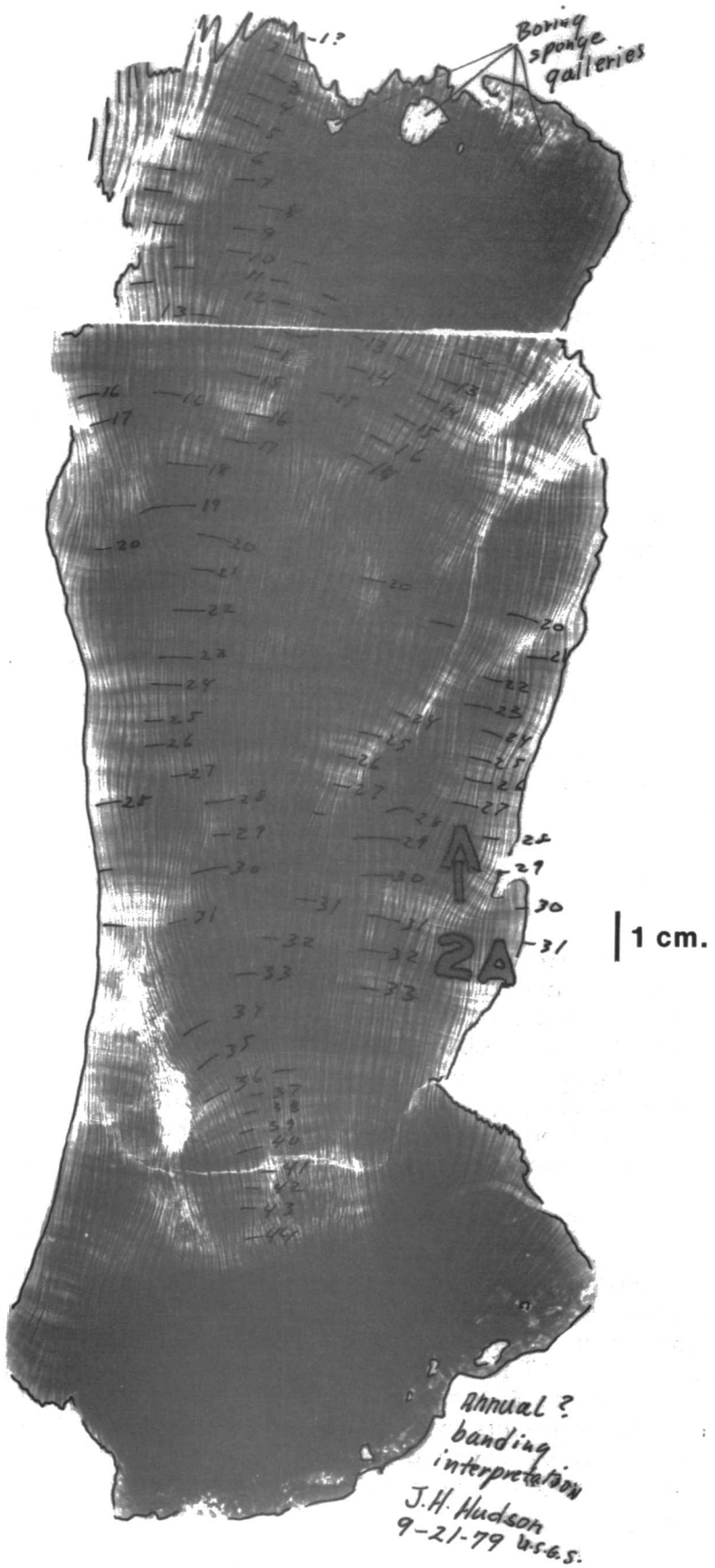

Figure X-C-2. X-radiograph of section of Stephanocoenia michelini from the East Flower Garden, 38.5 m depth, collected in 1974. Supposed "annual bands" identified and marked by J.H. Hudson, U.S. Geological Survey, Miami, Florida.

TABLE X-C-4
POPULATION LEVELS OF CORALS AT
EAST FLOWER GARDEN MONITORING STATIONS*

Coral Species	Dominance (Percent Cover)			
	CSA-A (top reef)		BLM (reef edge)	
	Range	Mean	Range	Mean
Montastrea annularis	14.89-31.09	(22.99)	31.19-42.33	(36.76)
Colpophyllia spp.	3.87-11.37	(7.62)	3.45-12.46	(7.95)
Diploria strigosa	3.76-12.62	(8.19)	0.97- 5.20	(3.09)
Coralline algae	3.84- 9.84	(6.84)	2.40- 5.00	(3.70)
Montastrea cavernosa	0.74- 6.24	(3.49)	1.15- 7.59	(4.35)
Millepora sp.	1.01- 6.60	(3.81)	1.89- 4.47	(3.18)
Porites astreoids	1.20- 3.09	(2.16)	1.02- 3.18	(2.10)
Madracis decactis	0.12- 1.62	(0.87)	0.00- 6.59	(3.26)
Siderastrea sp.	0.00- 4.45	(1.66)	0.00- 0.00	(0.00)
Agaricia spp.	0.37- 1.11	(0.74)	0.19- 1.11	(0.65)
Scolymia sp.	0.00- 0.12	(0.04)	0.00- 0.09	(0.03)
Mussa angulosa	0.00- 0.00	(0.00)	0.00- 1.17	(0.65)
Stephanocoenia intersepta	0.00- 0.00	(0.00)	0.01- 0.43	(0.22)
Indices of Diversity	**CSA-A**		**BLM**	
Shannon-Weaver Diversity Index	1.34- 1.60	(1.47)	1.38- 1.66	(1.52)
Evenness	0.52- 0.62	(0.57)	0.54- 0.65	(0.59)
Richness	3.87- 4.25	(4.07)	3.71- 3.97	(3.84)

*Expression of population levels is in terms of percent of hard bottom covered, which is also used as an indication of dominance. Means are enclosed in parentheses; the range is the 95% confidence interval of the mean. Dimensionless indices of diversity, evenness, and richness are shown for both stations in a similar fashion.

TABLE X-C-5
SCLEROCHRONOLOGICAL ANALYSIS OF ONE SPECIMEN OF
STEPHANOCOENIA MICHELINI FROM 38.5 m DEPTH
AT THE EAST FLOWER GARDEN

Growth Band Widths in mm	Number of Bands
3.0	2
3.5	2
3.75	1
4.0	3
4.5	3
4.75	7
5.0	7
5.25	1
5.5	1
5.75	1
6.0	2
6.5	3
6.75	4
7.0	7
7.5	1
8.0	4
9.0	1
9.5	1
11.0	1

Average band width, $\bar{X}$ = 5.812 mm
Standard deviation, s = 1.44
The 95% confidence limit for a "Student's" t distribution with N-1 degrees of freedom is,

$$\bar{X} \pm t_c \frac{s}{\sqrt{N-1}} ,$$

which for $\bar{X}$ = 5.812 mm, N-1 = 71, t_c = 2.00, s = 1.44 mm yields confidence limits of (5.47 mm, 6.16 mm).

reef development. Contemporary health and condition of coral populations are, however, better reflected over the short term in measurements of percent cover of living corals, rates of lateral encrusting growth (occupation of bare reef rock by advancing live tissue), and mortality rates (loss of living coral cover due to death of tissue).

Encrusting growth and mortality were measured at the two East Flower Garden monitoring sites (Figure X-C-1, above) using seasonally repetitive close-up photographic techniques of 19 specific coral heads. Photographs taken of each head during the various seasonal cruises were compared planimetrically to determine gains or losses of live coral cover (Tables X-C-6 through 10). Growth or mortality data are expressed as average linear advance or retreat of coral tissue over a selected segment of live coral colony border.

The data were normalized to a 30.42 day month, and for each species the mean growth or mortality rates, ranges of measured rates, standard deviations, and 95% confidence limits of the means were calculated (all expressed as mm/month growth or mortality (Table X-C-11). Statistical interpretation of the data with so few observations and such high variability in growth and mortality rates is not feasible. It does appear, however, that where mortality occurs it proceeds at a substantially greater rate than does encrusting growth. Our preliminary results indicate that random observations in greater numbers are required per species studied. Our strategy in the future will be to study only M. annularis as a representative massive hermatypic coral and maximize the number of observations on the species in order to obtain a statistically useful sample size.

The following section considers the growth and mortality observations on a station by station basis, with qualitative explanations of conditions at each station. All stations were located within an approximately 20 m radius of the center of each monitoring site (BLM, CSA-A).

Observations by Station

BLM Station 1

Station 1 depicts lateral encrusting growth of Millepora sp. across a knoll of dead M. annularis, which is eroded and partially covered with a thin layer of encrusting coralline algae and filamentous green algae. The surface of the dead corallum is also perforated in places, probably resulting from the growth of boring sponges (Clionids).

Period 1 (Sep 78 to Feb 79)

The growth of Millepora sp. has proceeded as a very thin veneer, approximately 1 mm in thickness, at a rate of 16.24 mm^2 per millimetre of border length. During this period, the Millepora tissue approached a colony of Porites astreoides and initiated growth over the pre-existing P. astreoides tissue, without exhibiting typical

TABLE X-C-6
GROWTH (+) OR REGRESSION (-) OF DIPLORIA STRIGOSA IN MM

SEASON	STATION 3 BLM	6 BLM	10 BLM	12 BLM	13 BLM	4 CSA	7 CSA	8 CSA
Period 1 9/78 - 2/79	N.A.	-0.233 (F)	N.A.	0 (C)	N.A.	0 (C)	+1.64 (F)	-14.71 (F)
Period 2 2/79 - 5/79	N.A.	0 (F)	N.A.	0 (C)	N.A.	0 (C)	0 (F)	-2.31 (F)
Period 3 5/79 - 8/79	-15.67 (F)	0 (F)	-5.38 (F)	0 (C)	+2.28 (F)	0 (C)	0 (F)	-45.47 (F)

TABLE X-C-7
GROWTH (+) OR REGRESSION (-) OF MONTASTREA ANNULARIS IN MM

SEASON	STATION 2 BLM	8 BLM	12 BLM	15 BLM	4 CSA	11 CSA
Period 1 9/78 - 2/79	N.A.	+0.8 (C)	0 (C)	-1.94 (F)	0 (C)	N.A.
Period 2 2/79 - 5/79	+10.19 (C)	+1.32 (C)	0 (C)	-0.59 (F)	0 (C)	N.A.
Period 3 5/79 - 8/79	N.A.	N.A.	-5.19 (C)	N.A.	0 (C)	+2.21 (C)

TABLE X-C-8
GROWTH (+) OR REGRESSION (-) OF MONTASTREA CAVERNOSA IN MM

SEASON	STATION 8 BLM	19 BLM	3 CSA	5 CSA	6 CSA	15 CSA	16 CSA
Period 1 9/78 - 2/79	-0.8 (C)	N.A.	+1.1 (F)	+2.9 (F)	0 (F)	N.A	N.A.
Period 2 2/79 - 5/79	-1.32 (C)	+0.99 (F)	+0.46 (F)	0 (F)	0 (F)	+6.78 (C)	0 (F)
Period 3 5/79 - 8/79	N.A.	N.A.	N.A.	0 (F)	0 (F)	+1.82 (C)	+0.65 (F)

\+ = growth
\- = regression
C = growth or regression in competitive situation (border of competition)
F = growth or regression otherwise ("free" borders)
N.A. = data not available

TABLE X-C-9
GROWTH (+) OR REGRESSION (-) OF PORITES ASTREOIDES IN MM

SEASON	STATION 1 BLM	8 BLM	12 BLM	15 BLM	4 CSA	11 CSA
Period 1 9/78 - 2/79	-14.85 (C)	+0.8 (C)	0 (C)	-1.94 (F)	0 (C)	N.A.
Period 2 2/79 - 5/79	0 (C)	+1.32 (C)	0 (C)	-0.59 (F)	0 (C)	N.A.
Period 3 5/79 - 8/79	0 (C)	N.A.	-5.19 (C)	N.A.	0 (C)	+2.21 (C)

TABLE X-C-10
GROWTH (+) OR REGRESSION (-) OF MILLEPORA SP. IN MM

SEASON	STATION 1 BLM	8 BLM	12 BLM	15 BLM	4 CSA	11 CSA
Period 1 9/78 - 2/79	+16.24 (F)	+0.8 (C)	0 (C)	-1.94 (F)	0 (C)	N.A.
Period 2 2/79 - 5/79	0 (F)	+1.32 (C)	0 (C)	-0.59 (F)	0 (C)	N.A.
Period 3 5/79 - 8/79	0 (F)	N.A.	-5.19 (C)	N.A.	0 (C)	+2.21 (C)

\+ = growth
\- = regression
C = growth or regression in competitive situation (border of competition)
F = growth or regression otherwise ("free" borders)
N.A.= data not available

TABLE X-C-11
COMBINED RESULTS OF ALL GROWTH MEASUREMENTS, POOLED ON A PER-SPECIES BASIS

GROWTH mm/mo

	X	Range	S	95% confidence limits of mean	n
D. strigosa	0.096	0 to .73	0.240	(-0.057 to 0.248)	12
M. annularis	0.456	0 to 2.81	0.919	(-0.252 to 1.163)	9
M. cavernosa	.3085	0 to 1.87	0.522	(.007 to .624)	13
P. astreoides	0.000	-	0.000	Not valid	2
Millepora	1.210	0 to 3.63	2.096	(-0.223 to 2.643)	3

MORTALITY mm/mo

	X	Range	S	95% confidence limits of mean	n
D. strigosa	4.448	.05 to 15.52	5.751	(-0.878 to 9.773)	6
M. annularis	0.787	.16 to 1.77	0.862	(-1.354 to 2.927	3
M. cavernosa	0.270	.18 to .36	0.127	(-0.874 to 1.414)	2
P. astreoides	3.320	-	-	-	2
Millepora	-	-	-	-	-

competitive behavior, in the form of a band of denuded corallum at the border between the two coral species involved.

Period 2 (Feb 1979 to May 1979)

The lateral encrusting growth of Millepora sp. has essentially ceased, both on the knoll of M. annularis corallum and across the living P. astreoides colony. During this period, the Millepora colony has initiated the growth of vertical spires, which average between 1.0 to 1.5 cm in height. The projections are common for this species of Millepora.

The P. astreoides colony has developed randomly spaced, blanched patches and now harbors a developing Spirobranchus giganteus polychaete. The calcareous tube of the S. giganteus has grown 17 mm in the 3-month period.

Period 3 (May 79 to Aug 79)

There appears to be a lateral encrusting growth in Millepora as of May. The growth is now in a vertical accretionary or thickening phase, filling the spaces between the spires formed in Period 2. In some areas, this accretionary growth has covered up these spires completely. The small mound of P. astreoides has regained normal coloration and has extended new tissue over the developing S. giganteus tube, except in the area of the tube aperture.

BLM Station 2

At Station 2, there is interspecific competition between M. annularis and Colpophyllia sp. The M. annularis colony resides in the space between two colonies of Colpophyllia, and it is demonstrating expansion of its range by means of lateral encrusting growth across denuded Colpophyllia corallum it has obtained through competitive interaction. The typical band of denuded corallum (in this case, Colpophyllia sp.) is present, indicating the direction of growth of M. annularis.

Period 1 (Sep 78 to Feb 79)

Photographs from cruise 2 (February 1979) are difficult to compare* with cruise 1 (September 1978) for accurate measurement. The photographs qualitatively show, however, differential growth rates for M. annularis along the borders.

Period 2 (Feb 79 to May 79)

Sequential photographs from cruise 3 (May-June 1979) indicate growth rates from September 1978. Over an average border length of 9 mm, the average growth of Montastrea annularis was found to be 91.7 mm^2, or 10.19 mm^2 per millimetre border length.

*Sample error (in this case photographic angle) prevented accurate comparison of these two photographs.

Period 3 (May 79 to Aug 79)

Photographs from this period show a similar trend, with continued growth of M. annularis via extratentacular budding across denuded Colpophyllia corallum. Quantitative data for this period are not available.

BLM Station 3

The subject of station 3 is a large colony of Diploria strigosa which has undergone extensive tissue regression in the form of so-called "ridge mortality." Exposed corallum along the tops of the ridges are subsequently colonized by filamentous green algae. These areas are then subject to extensive bioerosion through the feeding activities of organisms such as the urchin Diadema antillarum, Parrotfishes, etc. As a result, the dead corallum has been eroded to a level approximately 1.5 to 2.0 cm below the pre-existing live coral tissue. The progress of erosion has shown no apparent seasonal variation and is proceeding at an average of 15.67 mm^2 per millimetre of border for the entire year.

Small knolls of coralline algae and Agaricia spp. have developed along the layer of eroded corallum, approximately 25 cm behind the active D. strigosa border. The Agaricia knolls measure 342.8 mm^2 and 295.71 mm^2. The 11 rounded knolls of coralline algae range from 28.57 mm^2 to 114.29 mm^2. Formation of these colonies originated between September 1978 and February 1979. The Agaricia knolls have developed blanched spots in the period between May and August 1979, probably due to mechanical damage from organisms grazing on adjacent corallum.

BLM Station 6

The subject of station 6 is a hemispherically shaped colony of D. strigosa which has undergone past mortality. The exposed corallum is encrusted with coralline and filamentous green algae. The process of regression appears to be another example of the "ridge mortality" syndrome. The algal mat on the exposed corallum is quite lush, which is atypical, since grazing activity serves to crop algal growth back.

On all cruises, a pomacentrid damsel fish (Pomacentrus) has been sighted in immediate proximity to this algal mat. Possibly this area serves as the damselfish's "cultivated algal garden." If this is the case, all potential grazers are warded away, and subsequent heavy algae growth is seen. This station does not exhibit the extensive erosion process on the algae-infested corallum seen at station 3.

On the active tissue border edge of the D. strigosa colony, denuded ridges of the corallum extend across the healthy tissue as far as 4 to 5 cm. As of August 1979, these ridges seem to have regained tissue. A small, semicircular segment of D. strigosa, along the lower border of the colony, has undergone some measurable regression. From September 1978, the areal rate of regression was found to be 35 mm^2 around a border length of 150 mm, or 0.233 mm2 per millimetre of

border. The remainder of the D. strigosa colony does not show measurable regression nor growth.

BLM Station 8

At this station, there is interspecific competition between a colony of M. annularis and an adjacent colony of Montastrea cavernosa. In this case, M. cavernosa is encroaching the corallum of M. annularis, whose tissue border is bleached, and has consequently regressed. The strip of bare corallum separating the advancing M. cavernosa and receding M. annularis has been encrusted with coralline algae, filamentous green algae, and sponge. The width of this "competition zone" has remained fairly constant during the year, indicating that the rate of M. annularis regression is equivalent to the growth and advance of M. cavernosa. The tissue border of M. cavernosa displays a "ledge" effect, wherein new corallum is extended over the partially encrusted reef rock, forming a ledge-like process along the advancing border, with no tissue discoloration or irregularities. In contrast, the receding M. annularis border is blanched, and individual polyps along the border edge show various degrees of mortality with no smooth edges such as M. cavernosa displays.

The length of M. cavernosa border which was analyzed extends approximately 70 mm from the marker rail. The area of each polyp was measured each season and integrated for a total growth per length figure.

Data indicate that average growth for this segment of M. cavernosa for the period of 9 months was 4.02 mm^2 per millimetre of border length. Growth rate appears to have increased slightly between February and May 1979, compared to the period between September 1978 and February 1979.

BLM Station 10

The subject of this station is a large D. strigosa colony with a semicircular area of past mortality. The exposed corallum is lightly encrusted with epibenthic fauna, coralline algae, and filamentous green algae. This area appears to be frequently grazed upon by organisms such as Diadema antillarum, as indicated by characteristic scouring and erosion of the corallum, as well as by numerous fecal pellets adhering to the algal mat, believed to be from this echinoid.

The analysis of the tissue border edge revealed areas of regression (up to 2 mm in some areas). Erosion of corallum, via grazing, was seen in close proximity to the border, which appears to be blanched in some areas. During period 3 (May 1979 to August 1979), an area of recent tissue destruction was revealed, measuring 1129.61 mm^2 over a border of 210 mm, or 5.38 mm^2 per millimetre border length. The damage occurred along the colony edge, below the study site, and is believed to be quite recent (August 1979) since the dead corallum was fresh and devoid of epiphytic and epizoic encrustation. The study area, however, showed negligible growth and regression for the entire nine months.

BLM Station 12

At this station, D. strigosa, Mussa angulosa, and M. annularis colonies are growing in competition for space. The M. annularis colony appears to have advanced upon both M. angulosa and D. strigosa colonies but has essentially been halted since September 1978. A band of encrusting coralline algae isolates the M. angulosa colony from the D. strigosa colony. There was no detectable change in growth or regression of coral tissue from September 1978 to May 1979. During period 3 (May to August 1979), the colony of M. annularis regressed 187 mm^2 over a border length of 36 mm, or 5.19 mm^2 per millimetre border length. The border is adjacent to dead D. strigosa corallum, encrusted with filamentous green algae, and frequently grazed upon by herbivores. The M. annularis tissue appears to have been removed during the process of grazing, for the coral's calyx structure along this border is substantially eroded, and blanching of tissue surrounding this dead area is apparent.

BLM Station 13

At station 13, three colonies of D. strigosa exhibit lateral encrusting growth over what appears to be an area of massive mortality for one or two of the colonies. This dead corallum is encrusted with algae and substantially eroded. The three D. strigosa colonies are growing together in all directions around the dead corallum. It appears that during the time when D. strigosa tissue was receding, a small, semicircular section of coral remained undamaged and is now between the two advancing colonies. The growth of this small segment has been used to measure the relative growth of D. strigosa at this station.

Period 1 (Sep 78 to May 79)

No data were obtained from cruise 2 (February 1979), so measurements pertain to the time between September 1978 and May 1979. The areal increase, or growth, of the D. strigosa segment was found to be 343.75 mm^2 over a length of 150.81 mm, or 2.28 mm^2 per millimetre of border. By August 1979, the segment was partially overgrown by the other two D. strigosa colonies, and subsequently, it has decreased in areal measure.

BLM Station 15

Period 1 (Sep 78 to Feb 79)

The tissue border at the periphery of the patch of bare corallum is slowly regressing. For the period between September 1978 and February 1979 average regression was found to be 91 mm^2 over a study length of 47 mm, or 1.94 mm^2 per millimetre length. It appears that this area is frequently grazed, as the corallum is heavily eroded and fecal material of the echinoid Diadema is seen trapped on the algal mat.

Period 2 (Feb 79 to May 79)

The period between February and May 1979 showed a decrease in the rate of tissue regression, with a mean value of 27.75 mm^2, over a 47 mm border, or 0.59 mm^2 per millimetre length. The total mean value for tissue regression at this station for the period September 1978 to May 1979 was 118.75 mm^2 over a 47 mm border, or 2.53 mm^2 per millimetre border.

Period 3 (May 79 to Aug 79)

No data available.

BLM Station 19

At station 19 a colony of Montastrea cavernosa and Millepora sp. are experiencing tissue regression and subsequent lateral encrusting regrowth. The mound of corallum is of M. cavernosa origin, with filamentous green algae, epifauna such as hydroids, and a thin veneer of Millepora sp. occupying or encroaching the bare areas. A small segment of the colony, wherein exist all three components of the corallum (M. cavernosa, Millepora sp., and encrusting algae and epifauna), has been isolated for analysis of growth and regression.

Period 1 (Sep 78 to Feb 79)

During this period, there has been substantial regression of both M. cavernosa and Millepora sp. tissue and an associated increase in algal growth. The M. cavernosa tissue (photographed September 1978) shows definite "infection" by filamentous green algae. By February 1979, the algae appeared to have been partially scoured via grazing herbivores. The Millepora tissue has been "infected" by this algae to some degree. The tissue border of M. cavernosa appears to have stabilized after the halt in regression.

Period 2 (Feb 79 to May 79)

During this period, the M. cavernosa colony has advanced laterally across the now scoured and eroded corallum at a rate of 898.3 mm^2 over a border length of 89.22 mm, or 0.99 mm^2 per millimetre length. The Millepora tissue appears to have stabilized, with no traces of the algal infestation seen in February 1979. There is, however, no discernible growth of Millepora.

Period 3 (May 79 to Aug 79)

No data available.

CSA-A Station 3

At station 3 there is lateral encrusting growth of M. cavernosa across eroded corallum which is encrusted with calcareous red and filamentous green algae and is frequently grazed by herbivores. In this case, each polyp along a given length of active tissue border was

measured for areal expansion or regression and integrated over the total border length analyzed.

Period 1 (Sep 78 to Feb 79)

Areal growth for this period was found to be 1.1 mm^2 per millimetre of border length.

Period 2 (Feb 79 to May 79)

During this period, lateral growth rate decreased to 0.46 mm^2 per millimetre of border.

Period 3 (May 79 to Aug 79)

No data available. Total growth for the entire border betwen September 1978 and May 1979 was found to be 1.56 mm^2 per millimetre of border.

CSA-A Station 4

Station 4 involves interspecific competition between D. strigosa and an encroaching colony of M. annularis. The large knoll of D. strigosa has undergone extensive mortality and erosion, and living tissue is now limited to isolated patches. Extensive bioerosion shows that the dead corallum is intensively grazed. The encroaching M. annularis colony has progressed up the side of the D. strigosa knoll blanketing an entire side of the structure. However, its progression has essentially ceased, as close examination reveals no measurable growth during all seasons. The leading tissue border is in close proximity to the D. strigosa tissue and appears to have been the cause of some tissue regression. Other areas of M. annularis tissue appear to have grown solely over dead corallum.

CSA-A Station 5

At this station there is lateral encrusting growth of M. cavernosa, sealing a small, semicircular patch of dead corallum on the colony's surface. The tissue borders during all cruises appeared healthy, and thus regrowth was completed by February 1979. The rate of growth during the period from September 1978 to February 1979 was 145 mm^2 over a 50 mm border length, or 2.9 mm^2 per millimetre of border.

CSA-A Station 6

At this station are a series of M. cavernosa knolls which have been subject to rather severe past mortality, subsequent to an extensive loss of zooxanthellae from the coral's tissue. The resultant dead corallum has been colonized by filamentous green algae, and thus heavily eroded, due to the grazing activities of organisms such as Diadema and parrotfishes (scaridae). Regrowth of M. cavernosa tissue over this area of dead corallum, however, has not taken place. No growth or additional regression has been detected at this station since

September 1978, even though the tissue borders appear to be in a good state of health.

CSA-A Station 7

Station 7 depicts lateral encrusting growth of D. strigosa, closing a cleft-shaped gap in the colony's surface. This gap, which measured 86.25 mm^2 in September 1978, had been completely sealed as of May 1979, at a rate of 1.64 mm^2 per millimetre of border length. This seal left a thin, whitish scar in the area where the two growing borders came into contact. As of August 1979, a slight separation of the colony's unity at the lower portion of the gap, via tissue regression, was seen. This area measured 25 mm^2.

CSA-A Station 8

This station depicts massive regression of D. strigosa tissue by means of (so-called) "ridge mortality." The resultant denuded corallum has been intensively grazed, followed by the establishment of small knolls of coralline algae, P. astreoides, Agariciids, and an encroaching colony of Millepora. Total areal regression of D. strigosa has been analyzed.

Period 1 (Sep 78 to Feb 79)

The rate of regression during this period was found to be 17,351.93 mm^2 over a border of 1179.29 mm, or 14.71 mm^2 per millimetre of border.

Period 2 (Feb 79 to May 79)

The rate of tissue regression during this period decreased to 2914.00 mm^2 over a border length of 1260.7 mm, or 2.31 mm^2 per millimetre of border.

Period 3 (May 79 to Aug 79)

No data available.

Total regression for the period September 1978 to May 1979 was 20,266.13 mm^2 over a 445.7 mm border, or 45.47 mm^2 per millimetre length.

CSA-A Station 10

At station 10 there is interspecific competition between M. decactis and Agaricia sp. for available substrate. The Agaricia colony appears to have grown over an area of denuded corallum previously occupied by the M. decactis colony. Other areas of corallum are occupied by sponge and coralline algae. The relative growth and regression of both coral species has been negligible since September 1978. The growth of coralline algae among the remaining patches of dead corallum is measurable, however.

Period 1 (Sep 78 to Feb 79)

No data available.

Period 2 (Feb 79 to May 79)

No measurable growth for both coral and coralline algae.

Period 3 (May 79 to Aug 79)

Summer growth of coralline algae was found to average 66.94 mm^2 over an average border length of 9 mm, at a rate of 7.44 mm^2 per millemetre of border.

CSA-A Station 11

At station 11 there is interspecific competition between M. annularis and D. strigosa. In this case, the M. annularis colony is advancing across D. strigosa corallum and is separated from the receding D. strigosa tissue border by a characteristic band of dead corallum which is encrusted with coralline and filamentous algae. Data are unavailable on both cruise 1 and cruise 3 (Sep/Oct 78 and May/Jun 79). Growth of M. annularis between February 1979 and August 1979 was found to be 210 mm^2 over a border of 95.2 mm, or 2.21 mm^2 growth per millimetre of border. A segment of coralline algae, which is adjacent to the advancing M. annularis tissue border, has regressed 288 mm^2 over a border of 75.6 mm, or 3.8 mm^2 regression per millimetre of border.

CSA-A Station 15

At station 15 there is interspecific competition between a colony of M. cavernosa and Siderastrea sp. The M. cavernosa colony is encroaching Siderastrea corallum via lateral encrusting growth. The band of dead Siderastrea corallum which separates the two coral species is lightly encrusted with filamentous green algae. The rates of M. cavernosa growth and Siderastrea regression are quite slow at this station.

Period 1 (Sep 78 to Feb 79)

No data available.

Period 2 (Feb 79 to May 79)

M. cavernosa growth during this period was found to be 847.05 mm^2 over a border length of 125 mm, or 6.78 mm^2 per millimetre of border. The rate of Siderastrea tissue regression was estimated to be equivalent to M. cavernosa advance, as the band of dead Siderastrea corallum separating the two coral species remained essentially the same width during all seasons.

Period 3 (May 79 to Aug 79)

During this period, the rate of M. cavernosa growth, and therefore Siderastrea regression, decreased to 190.5 mm^2 over the border length of 104.5 mm, which indicated a rate of 1.82 mm^2 per millimetre of border.

The total growth of M. cavernosa over the period February 1979 to August 1979 was found to be 1037.55 mm^2, or 2.07 mm^2 per millimetre of border.

CSA-A Station 16

At station 16, there is lateral encrusting growth of M. cavernosa across corallum occupied by filamentous and coralline algae. This area represents previous regression of the M. cavernosa tissue, following a period of apparent stress, characterized by a rather extensive loss of zooxanthellae. The dead M. cavernosa corallum is frequently grazed upon by herbivores such as Diadema. Data are not available from cruises 1 and 2 (Sep/Oct 78 and Feb 79). In May 1979, small whitish spots appeared on the coenosarc areas, between polyps. By August 1979, the leading edge of tissue had extended slightly over the dead corallum, and new polyps developed from the whitish spots seen in May 1979. The average polyp size was 10.93 mm^2 over a border length of 16.76 mm, or 0.65 mm^2 per millimetre of border.

RECRUITMENT AND EARLY GROWTH OF CORALS AND CORALLINE ALGAE

Introduction

Because the East and West Flower Garden Banks are the northernmost known living coral reefs found within the Gulf of Mexico (Bright et al., 1974), an understanding of the biological sensitivity of corals and coralline algae of these reefs to the environment, and to potential pollution, is of particular interest (see Johannes and Betzer, 1975). Johannes (1975) provides an excellent review of studies concerning the severity and long-term effects of damage to coral reef communities, such as might be caused by man.

The coral and coralline algae recruitment studies at the East and West Flower Garden Banks have two purposes. The primary purpose is to examine "natural" recruitment, or settlement rates, and early growth rates of reef-building corals and coralline algae at these sites. A secondary purpose is to explore possible long-term effects of barite on recruitment and early growth of corals and coralline algae.

For the study of natural recruitment, a sampling system which permits collecting and replacing samplers on a periodic basis was needed. Thus, a "prototype" sampling system was designed and built in April/May 1979, and on May 31, 1979, deployed on the BLM site at the East Flower Garden Bank at a depth of 27 m. The purpose of the prototype system was to test the feasibility of collecting quantifiable samples of

newly settled coral and coralline algae, and to determine an appropriate configuration for such a system prior to finalizing a design. A system of replaceable "control" sampling plates composed of Portland cement, and functioning as an artificial substrate of fixed size, was used to quantitatively examine these parameters.

For the study of long-term effects of barite (the single most common component of oil and gas well-drilling muds), special sampling plates were added to the sampling system. These sampling plates, composed of a 2:1 ratio mixture of Portland cement and barite, were deployed September 24, 1979. Results from this part of the study are not yet available but will be reported on Contract #AA851-CTO-25. Previous studies have considered immediate and short-term effects of barite on marine communities, both in the laboratory (e.g., Tagatz and Tobia, 1978; Cantelmo et al., 1979) and in the field (e.g., Thompson and Bright, 1977).

A description of the sampling system and analysis procedures, as well as the construction of the settling plates and rack, is included in Volume Two, Chapter VII.

Initially, we also wished to examine the possible effects of grazing by fishes and invertebrates upon the settling rates of corals, such as that observed by Sammarco (1978, 1980) in a shallow reef community. He had used small enclosures which surrounded both living and dead coral substrata, and with which the spiny urchin Diadema could be included in controlled numbers, or excluded (some enclosures permitted entry of fishes, while others did not). In work predating the sampling plate study reported here, a similar enclosure, constructed using panels of plastic "egg-crate" lighting fixture grating, had been built by Mr. Stephen Viada, Texas A&M, and placed at the East Flower Garden BLM site in February 1979. The enclosure was a box measuring approximately 60 cm^2, with five pieces of bleached and washed coral secured to the inside bottom and five to the outside on the upper surface. The prototype sampling system superseded this design.

Quantifiable field studies on recruitment rates and early growth rates of corals and coralline algae have not been previously conducted. Neither have scientists examined the effects of barite already bound into a limestone substrate (such as might occur in nature via reefal encrusting activities) on early benthic community development. It is felt that knowledge of recruitment and early growth of corals and coralline algae at the Flower Garden banks is essential if one is to understand and monitor critical processes relating to the health and condition of the reef. The effect of barite on settling of corals is of obvious interest in relation to offshore drilling and its potential impact on these or similar reefs.

Prototype Rack Sampling Strategy
(Figures X-C-3 and 4)

The design of the prototype rack (Figure X-C-4) was intended to permit collection of designated rods on each cruise, replacing these

rods with new ones; both "seasonal" and longer-term samples were desired. The pilot study was initiated on 31 May 1979. The first samples were obtained on 16 July 1979, when one seasonal rod was collected and replaced.

On 30 August 1979, a seasonal rod (from 16 July 1979) was collected as well as a longer-term rod (from 31 May 1979), and both were replaced.

In addition to comparison of settlement rates over time (on long-term and short-term rods), five settling plates, were housed in plastic cages and designated "protected" plates, for comparison with "unprotected" plates on the rack. On 31 May 1979, protected plates #2 and #4 were removed from rod 1 (see Figure X-C-4) and placed within a plastic cage. Prior to the July 1979 cruise, a replacement rod was constructed which included three protected plates (#21, #23, and #25) individually housed in small cages and separated on the rod by unprotected plates #22 and #24.

All of these activities were preliminary, aimed at obtaining sufficient information from samples collected in July 1979 (6.5-week samples) and August 1979 (13-week samples) to permit study-design completion. The full scale experiment was initiated in September 1979 and will be reported in the final report for Contract #AA851-CT0-25.

Results

All newly settled corals collected between 31 May and 16 July 1979 (6.5 weeks) on unprotected plates #1, #3, and #5, were found attached to the plate undersides (Table X-C-12). Plate topsides were uniformly covered with a mat of filamentous green algae and a few bryozoans; this algal mat did not extend under the plates. Protected plate #2, removed from within the plastic cage, collected four coral polyps on its upper surface during this first sampling period. Slight algae fouling occurred on the upper surface of plate #2 but not on the underside. Heavy fouling by algae and bryozoans was noted on the top and side surfaces of the cage.

Both unprotected and protected plates from the 16 July 1979 collection appeared to be acceptable to coral larvae as suitable substrate. The two configurations recruited larvae differently in that a relatively larger average number of polyps attached to unprotected plates than to the single protected plate, and the upper and lower surfaces were differentially attractive according to plate-type (Table X-C-12).

The second collection, on 30 August 1979, included samples spanning the 13-week period since 31 May 1979, and the 6.5-week period, 6 July-30 August 1979. Unprotected plates #17, #18, #19, and #20, which had been exposed for the entire 13 weeks, or twice the time span of samplers which had been collected on 16 July, had also collected twice the number of newly settled coral polyps. Plate #16 was broken and lost. An average of nearly 22 polyps per unprotected plate was

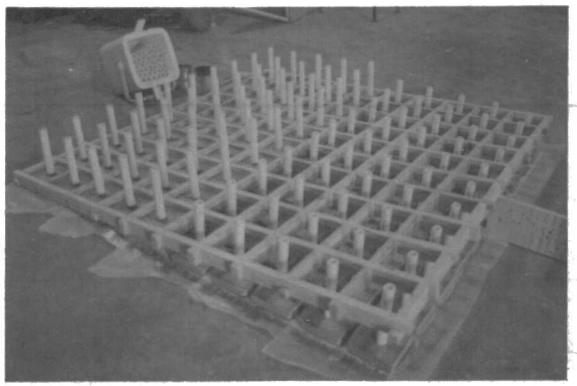

Figure X-C-3. Batch of 100 sampling plates being removed from molding framework.

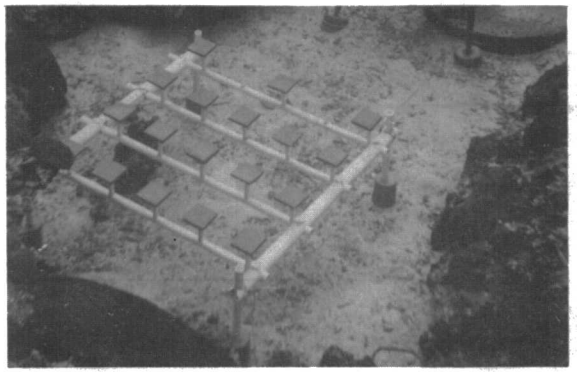

Figure X-C-4. Prototype Rack at "BLM Site," 27 m depth (Rod 1, upper right).

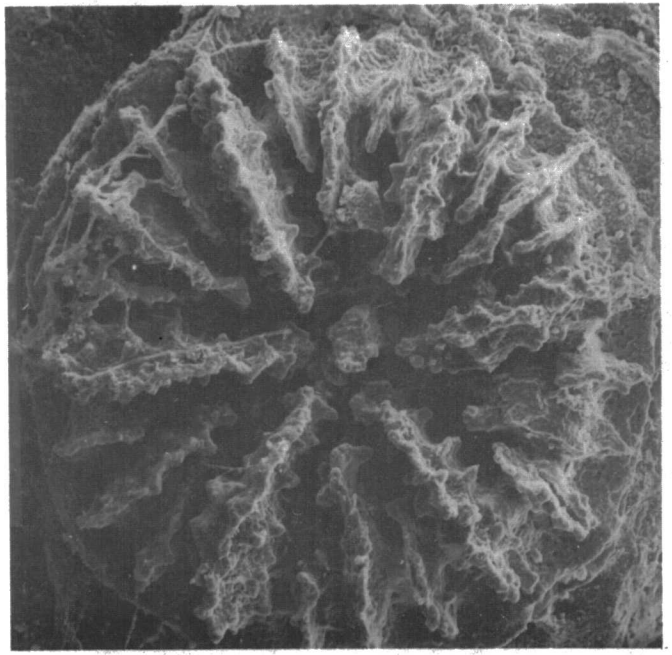

Figure X-C-5. Type I coral polyp, 24 septa; SEM photograph, X60.

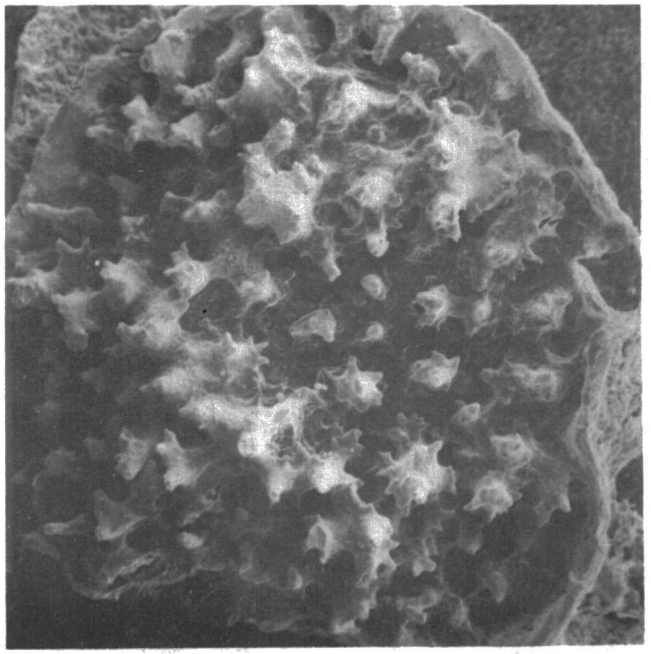

Figure X-C-6. Type II coral polyp; SEM photograph, X55.

TABLE X-C-12
TOTAL NUMBERS OF CORAL POLYPS SETTLING ON TOPSIDES OR UNDERSIDES
OF UNPROTECTED AND PROTECTED SETTLING PLATES, 31 MAY-24 SEPTEMBER 1979

1979 Date	Plate No.	UNPROTECTED CONTROL No. Polyps Topside	UNPROTECTED CONTROL No. Polyps Underside	PROTECTED CONTROL No. Polyps Topside	PROTECTED CONTROL No. Polyps Underside
5/31-7/16	1	0	9	-	-
(6.5 weeks)	3	0	18	-	-
	5	0	7	-	-
	2			4	0
Averages:		0	11.3	4	0
7/16-8/30	22	0	0	-	-
(6.5 weeks)	24	5	0	-	-
	21	-	-	7	0
	23	-	-	7	0
	25	-	-	7	0
Averages:		2.5	0	7	0
5/31-8/30	17	0	27	-	-
(13 weeks)	18	0	17	-	-
	19	3	21	-	-
	20	0	22	-	-
	4			8	1
Averages:		0.8	21.8	8	1
5/31-9/24	6	0	49	-	-
(16.5 weeks)	7	0	38	-	-
Averages:		0	43.5	-	-
Overall Averages:		0.7	18.9	6.6	0.2

TABLE X-C-13
CORAL POLYP SIZE-CLASSES ACCORDING TO NUMBER OF SEPTA, 31 MAY-24 SEPTEMBER 1979
(SAMPLING PLATES #1, 3, 5, 17, 18, 19, 20, 6, 7)

Polyp Type	Number of Septa	Number of Polyps (n)	Mean Diameter of Basal Disc (mm)	Size Range (mm)	Variance (mm)
I	6	0	-	-	-
	12	43	0.89	0.55-1.10	0.03
	24	112	1.28	0.65-2.00	0.07
	48	12	2.32	1.80-3.30	0.14
II	-	28	1.27	0.60-2.05	0.28

collected in 13 weeks, and settling polyps preferred plate undersides, as seen previously (Table X-C-12). During 13 weeks, protected plate #4, from within the plastic cage, had also collected twice as many polyps as plate #2, which had sampled only the first 6.5 week period. All polyps on both plates had settled on the topside, which in both instances was slightly fouled with algae and bryozoans, while the undersides were unfouled. Unprotected plates #22 and #24, which were placed on a single rod between individually caged protected plates #21, #23, and #25, collected few polyps as compared to other unprotected plates. Unprotected plate #22 had collected no corals, whereas unprotected plate #24 collected polyps on the upper surface rather than the underside as seen in other unprotected samples (Table X-C-12). Protected samples #21, #23, and #25 collected polyps on plate topsides as previously seen in protected samples #2 and #4, but yielded low average polyp counts per plate as compared to unprotected samples. Algal and bryozoan fouling was observed on the small, individual cages, as previously observed on the large cage.

Coral polyps were either classified as "Type I," which were believed to be members of the Faviidae, or as "Type II," believed to be Poritidae. Typical specimens of each type were photographed at low and high magnifications using the Scanning Electron Microscope (SEM), and later taxonomic identification is planned (see Figures X-C-5 and 6).

Only Type I corals were separated into size-classes, as it was noted that the number of septa generally increased with increasing basal-disc diameter (Table X-C-13, above). Type II corals were lumped into one group and comprised about 14% of all corals observed on the nine unprotected plates observed between 31 May and 24 September 1979 (Figure X-C-7; Table X-C-13).

Relative abundance of coral polyps according to size-class varied with time (Figure X-C-7). The 12-septa size-class was similar in abundance during each of the three different sampling periods, while the 24-septa size-class substantially increased in abundance during the same time-span. Polyps with 48 septa were not seen until the 16.5-week samples were collected (Table X-C-13). Type II polyps showed no such obvious patterns during 16.5 weeks, other than a general increase in numbers of individuals.

No results are yet available on coralline algae populations.

Discussion

At the outset of the study, it was expected that primary settling of coral larvae would occur on the 100 cm^2 upper surface of sampling plates. First results, which indicated primary settling on plate undersides, were therefore surprising. It is possible that algal mats which grow on upper surfaces may suppress settlement of corals due to competition for space, sediment-trapping by algae, or because of reduced grazing pressure on algae caused by aggressive behavior and territoriality of resident damselfishes, such as that observed by Potts (1977).

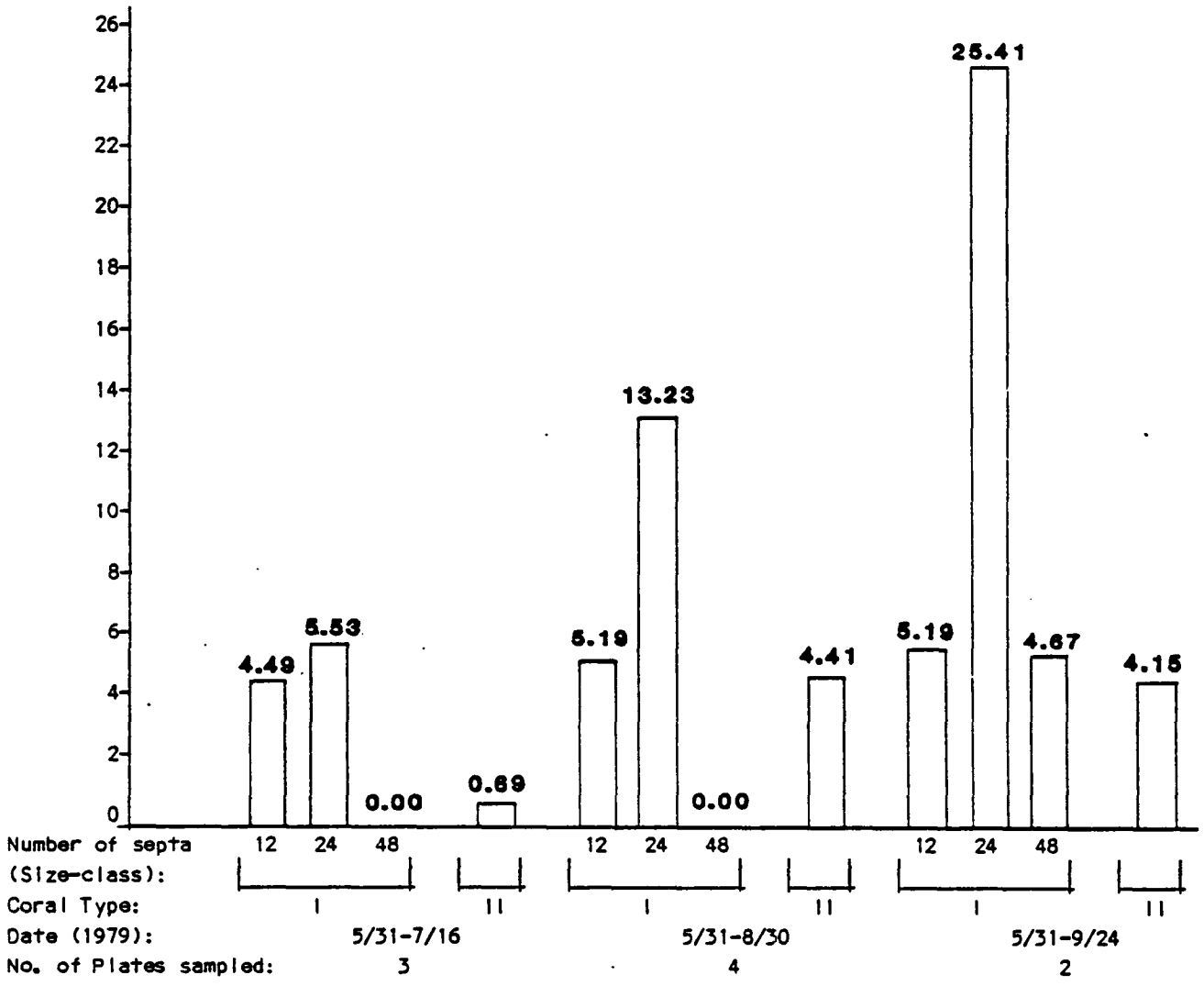

Figure X-C-7. Adjusted average number of coral polyps per unprotected plate, by size-class and sampling period. (Sampling plates #1, 3, 5, 17, 18, 19, 20 6, 7.)

The reduced numbers of polyps settling on protected plates was suspected to be caused by restriction of water flow and reduced light levels within cages which had become heavily fouled. Therefore, following examination of the second set of samplers, it was decided to delete protected samplers from the remainder of this study.

Juvenile corals collected on unprotected plate #9 (Figure X-C-12, below, p. 101) are similar in appearance to those identified as Agaricia by Sammarco (1978, Fig. 21, p. 298). Sammarco has also published an SEM photograph (see Sammarco, 1980, p. 268) of a coral spat identified by him as Porites, which in appearance is very similar to our Type II.

For analysis of size-classes of juvenile corals, only specimens from unprotected plates #1, #3, #5, #17, #19, #20, #6, and #7 were used. Plates #6 and #7 (31 May - 24 September 1979) were added to this report as a first indicator of samples recently obtained and analyzed, but do not constitute the total available sample from that sampling period. Table X-C-12 (above) indicates considerable overlap in size ranges of Type I polyps with differing numbers of septa, partly reflecting the fact that new sets of septa may begin development at various basal-disc sizes, and partly reflecting an inherent difficulty in subjectively deciding when such new development is evident. Figure X-C-5 (above) represents a Type I coral with 24 septa; all specimens are not so classic in appearance, nor so easily classified according to size-class.

Mean diameters of basal-discs according to size-class showed an expected progression (Table X-C-13, above). Despite the small sample sizes available to date, an interesting trend is indicated, as seen in Figure X-C-7, where the relative increase in numbers of 24-septa polyps per sampling plate per time period is evident. Although more samples are needed before statistical analysis of such data is appropriate, these data suggest that during the initial 6.5-week sampling period (31 May - 16 July 1979) two different "groups" of coral larvae settled on the plates at two relatively distinct times, resulting in the presence of two size-classes composed of approximately equal numbers of individuals. Work done by Atoda (1974), Stimson (1978), and others, indicates that some species of corals will planulate, or shed larvae, according to lunar phase: some will planulate near the full moon while others will planulate near new-moon. During our first sampling period, new moon occured on 26 May and 24 June, and full moon occurred on 10 June and 9 July 1979 (U.S. Dept. of Commerce, 1978). Two separate groups of planulae larvae could have been derived from either new or full moon during that period: the first group to have settled could have grown to the 24-septa size, while the second group would have reached only the 12-septa size. Very few Type II polyps were seen in first samples, suggesting that planulation patterns may have differed from other corals observed. However, it should be kept in mind that Type I corals probably include more than one species, and therefore the above discussion is only conjecture at this point.

Plates collected on 30 August 1979, which sampled a time-span encompassing the first 6.5 weeks and the immediately following 6.5 weeks,

included Type I size-classes of both 12- and 24-septa, with the 24-septa group averaging between two and three times as many individuals per plate as during the first 6.5 weeks. None had grown sufficiently to become 48-septa polyps, but by the end of the 13-week period, those already present at the end of the first 6.5 weeks had not only grown but had been increased numerically by one or two groups of 12-septa polyps which had then matured to the 24-septa size-classes. At some point, an additional group had apparently settled and grown to the 12-septa size-class (Figure X-C-7). New moon occurred on 24 July and 22 August, and full moon on 8 August 1979 (U. S. Dept. of Commerce, 1978).

Results from unprotected plates #6 and #7, which sampled the 16.5 week period, 31 May-24 September 1979, suggest an extension of the above trend. Apparently the 24-septa size-class continued to grow in numbers, presumably additively, and another new group of 12-septa corals had been added. Additionally, a first group of 48-septa polyps was noted, probably derived from the original 24-septa group collected in the first sample-set (see Figure X-C-7). Full moon occurred on 6 September and new moon on 21 September 1979 (U.S. Dept. of Commerce, 1978).

Because polyps settled nearly exclusively on the underside of plates, the actual "sampling" surface was not 100 cm^2 as planned, but rather 96.4 cm^2, because the central stem had a diameter of 2.14 cm. Based upon a presently unverified assumption of random settlement of polyps, the observed average number of polyps per plate was therefore adjusted upward to a theoretical average number of polyps per 100 cm^2 sampling surface (as used in Figure X-C-7) by dividing the observed number of polyps per 96.4 cm^2 by the fraction 0.964. Since actual counts rather than adjusted counts per 100 cm^2 are preferred, and in order to avoid a continuing need to derive adjusted calculations, it was decided to invert sampling plates within the new experimental racks. The inverted 100 cm^2 surface thus became the "underside" of the plate and was designated as the "sampling surface" for purposes of of future data analysis. Those polyps settling elsewhere on the plate would continue to be monitored but would be reported separately. We have recently located a previous study (Lewis, 1974) in which it was learned that newly settled larvae of the coral genus Favia tended to settle on the underside of objects in a laboratory aquarium. This study also found that clean surfaces were preferred to surfaces covered with "biological slime," and that polyps which initially settled on upper surfaces of fragments would either crawl or swim to the underside of these fragments before becoming attached. Lewis (1974) found these results surprising, as had we in our study, but surmised that such behavior of coral larvae possibly served as a defense against early predation. His results tend to strengthen our preliminary conclusions.

Summary

Results from the prototype sampling system indicate that for purposes of this study, data collected from the undersides of cement

settling plates should provide a good first estimate of natural recruitment rates of corals at the Flower Garden Banks. Analysis of coralline algae recruitment awaits additional and larger samples, but it is anticipated that the sampling system will prove similarly effective. Other methods of examining coralline algae recruitment levels are under study and will be described in a later report. Final results of this study should prove useful to similar studies conducted on reefs elsewhere and should yield baseline data useful in monitoring the continuing health of the Flower Garden Banks as the impact of man becomes increasingly difficult to avoid.

COELENTERATE LARVAE AND OTHER ZOOPLANKTON

Thirty-nine zooplankton groups were identified from the buoy array samples at the East Flower Garden Bank. During the fall 1978 and spring 1979 monitoring cruises, the array sampled at 40, 30 and 20 m depth. One set was made during the spring for the surface and 10 m depths. During the winter monitoring cruise, the array was lost and an oblique plankton tow was made from 40 m to the surface. During the summer monitoring cruise, the array was sampled every 10 m from the surface down to 40 m.

Variability in the samples was high and zero occurrences were common with the less predominant groups. An analysis of variance of the randomized block design (ANOVA-RBD) was performed to test the significance of the variation found within samples taken on each monitoring cruise due to the depth of sample and the time of sampling. No comparisons were made between cruises because seasonality cannot be significantly determined from only four cruises. Since both day and night samples were taken during the spring monitoring cruise, the variation found, if significant, was partitioned using orthogonal comparisons to determine if it was due to day/night variation.

Eleven meroplanktonic groups were regularly found. The mean abundances are listed by depth of sample and monitoring cruise (Table X-C-14). Other meroplankton encountered sporadically were egg masses, trochophore larvae (polychaete), pilidium larvae (bryozoa), squid juveniles, barnacle nauplii, stomatopod larvae, asteroid post-larvae and ophiuroid post-larvae. Fourteen holoplanktonic groups were encountered (Table X-C-15). Several benthic groups were observed: chitons, tanaidaceans, isopods and leptocaridians. None were observed regularly and all were of very low abundances.

The most abundant meroplankters were echinoderm larvae and fish eggs. ANOVA-RBD analysis showed highly significant variation among depth of sample and time of sample for fish eggs during the spring monitoring cruise. The variation due to time was further partitioned, but no significant variation was found between day and night samples. No other significant variation was found between day and night samples, nor for echinoderm larvae or fish eggs.

TABLE X-C-14

MEAN ABUNDANCE (INDIVIDUALS/100 m^3) OF MEROPLANKTONIC GROUPS BY MONITORING CRUISE AND DEPTH OF SAMPLE

GROUP	FALL 1978			WINTER 1979	SPRING 1979					SUMMER 1979				
	40 m	30 m	20 m	0-40 m	40 m	30 m	20 m	10 m	0 m	40 m	30 m	20 m	10 m	0 m
COELENTERATA														
PLANULA	17.6	16.4	3.7	3.3	4.0	9.5	4.9	17.6	326.3	-	6.1	11.0	19.4	17.2
EDWARDSIA	1.6	5.6	-	-	-	0.9	0.7	-	2.0	2.3	-	-	-	1.4
ECHINODERMATA														
PLEUTEUS	14950.2	3468.6	4032.4	475.1	5.3	249.0	66.1	2.9	-	9.3	192.0	81.4	10.9	-
BIPINNARIA	1.2	13.6	14.9	-	0.8	2.8	-	-	-	-	-	4.4	-	-
BRACHIOLARIA	669.4	224.5	256.6	16.5	74.9	175.8	131.8	67.3	2.0	11.6	57.7	270.1	592.4	313.3
MOLLUSCA														
GASTROPODA	16.8	13.3	8.8	-	5.8	13.9	6.7	43.9	24.3	9.3	11.2	19.4	115.1	77.9
PELECYPODA	-	10.6	7.5	19.8	6.3	4.4	5.0	11.7	-	2.3	6.5	13.3	87.7	50.8
POLYCHAETA	24.1	1246.9	6804.4	16.5	2.7	9.2	5.2	2.9	-	4.6	1.9	1.6	37.2	5.0
ARTHROPODA														
DECAPODA	45.8	58.2	60.9	69.3	261.6	636.4	613.5	181.4	24.3	215.9	108.5	209.9	247.5	210.1
CHORDATA														
FISH EGGS	2563.0	526.3	707.1	178.2	50.4	190.1	78.6	17.6	3240.3	164.8	507.7	681.7	712.7	415.6
FISH LARVAE	34.7	-	3.5	-	3.9	10.0	9.5	38.0	-	7.0	17.7	54.1	111.9	53.2
OTHER LARVAE	1.6	5.6	-	5.6	-	19.1	8.0	-	73.0	39.5	13.3	6.4	19.6	26.6
TOTAL MEROPLANKTON	18326.0	5589.6	11899.8	784.3	415.7	1321.1	930.0	383.3	3692.2	466.6	922.6	1353.3	1954.4	1171.1
% OF TOTAL PLANKTON	80.0	83.7	86.7	19.2	24.4	34.4	39.5	10.7	92.7	44.9	49.5	41.2	27.8	26.9
NUMBER OF SAMPLES	3	3	3	1	4	4	4	1	1	1	2	2	2	2

TABLE X-C-15

MEAN ABUNDANCE (INDIVIDUALS/100 m^3) OF HOLOPLANKTONIC GROUPS BY MONITORING CRUISE AND DEPTH OF SAMPLE

GROUP	FALL 1978			WINTER 1979	SPRING 1979					SUMMER 1979				
	40 m	30 m	20 m	0-40 m	40 m	30 m	20 m	10 m	0 m	40 m	30 m	20 m	10 m	0 m
COELENTERATA														
MEDUSAE	72.1	14.8	11.1	3.3	14.7	5.2	8.8	55.6	2.0	-	1.1	7.4	13.1	5.7
SIPHONOPHORES	61.2	43.1	32.8	33.0	91.5	140.5	86.9	90.7	22.3	11.6	16.0	22.8	149.9	57.9
MOLLUSCA														
ATLANTIDAE	3.4	11.5	3.8	3.3	2.0	-	-	2.9	6.1	2.3	2.0	13.7	26.3	9.3
PTEROPODA	56.1	27.3	32.1	13.2	2.0	2.5	1.4	32.2	-	9.3	38.5	57.9	237.5	81.5
ARTHROPODA														
CALANOID COPEPODA	167.2	414.7	818.5	2289.6	390.7	544.7	354.2	804.6	73.0	294.8	423.1	1028.5	3017.0	1977.7
CYCLOPOID COPEPODA	1853.4	362.1	675.8	323.3	187.0	372.6	279.0	278.0	81.1	55.7	54.3	77.0	73.4	78.6
HARPACTICOID COPEPODA	0.3	3.8	1.9	-	1.2	2.3	3.6	-	2.0	-	-	1.6	-	-
HYPERIIDAE	5.9	10.3	3.7	9.9	13.5	11.8	5.5	29.3	4.1	32.6	15.6	31.1	81.2	59.6
OSTRACODA	108.7	6.3	14.1	151.7	94.2	96.5	30.2	-	-	62.7	77.6	108.5	229.1	125.8
CLADOCERA	47.5	14.1	3.7	-	94.3	121.3	40.2	61.4	18.2	-	7.6	48.3	113.6	198.3
SERGESTIDAE	18.0	-	4.0	33.0	6.7	14.3	6.8	-	2.0	4.6	7.4	25.2	52.7	70.5
CHAETOGNATHA	394.8	60.6	75.5	158.4	346.4	895.6	538.4	1802.3	79.0	95.2	201.9	281.8	416.0	400.5
CHORDATA														
THALIACEA	111.3	20.3	18.1	85.8	38.0	161.8	12.3	2.9	-	4.6	91.6	226.4	634.7	88.1
LARVACEA	140.9	96.9	132.2	188.1	5.5	148.8	59.4	43.9	4.1	-	3.0	3.0	10.8	11.5
TOTAL HOLOPLANKTON	4570.8	1085.8	1827.3	3292.6	1287.7	2517.9	1426.7	3203.8	289.8	573.4	939.7	1933.2	5068.4	3185.0
% OF TOTAL PLANKTON	20.0	16.3	13.3	80.8	75.6	65.6	60.5	89.3	7.3	55.1	50.5	58.8	72.2	73.2
NUMBER OF SAMPLES	3	3	3	1	4	4	4	1	1	1	2	2	2	2

The echinoderm larvae, in particular the pluteus stage, were extremely abundant during the fall Monitoring Cruise. Park (1979) reported a maximum of only 250/100 m^3 from the zooplankton project of the BLM South Texas Outer Continental Shelf Study (STOCS). Wormuth (1979) found a fall maximum of about 3700/100 m^3 in the neuston project of STOCS. The average for this study was 2344/100 m^3, with a maximum of 36,100/100 m^3. The source of these larvae is unknown. Comparisons with development stages, summarized in Dan (1968), were made and the age of the pluteus observed at least several days to a week.

The fish eggs were much younger. The eggs were small and typically at an early developmental stage, pre-gastrulation. Since the pre-gastrulation developmental time of many ground fish is usually 24 to 48 hours, release was probably occurring on or very near the reef. A highly significant variation (ANOVA-RBD) was observed among the depths of the samples during the spring monitoring cruise. The trend during most of the sampling periods was toward decrease in abundance of fish eggs with depth. The opposite results shown in the fall samples could be due to active release from the reef. The eggs should be released and float to the surface where they become part of the neuston community, as was demonstrated in the STOCS. No fish eggs were reported from the STOCS zooplankton project (Park, 1979), while abundances of around 400/100 m^3 were observed from the STOCS neuston project (Wormuth, 1979). The abundances in the BLM study were higher than the abundances reported in the neuston project during all the cruises, due to the differences in mesh (0.505 mm for Wormuth's neuston project versus 0.333 mm on our project).

Planulae, assumed to be coelenterate larvae, were observed throughout the year. The morphology was similar to that of zooanthids (Hyman, 1940), but the planulae at present are not identified. The maximum abundance of planulae was observed during the spring monitoring cruise (Table X-C-14). No report of this larval type was made from the STOCS projects (Park, 1979; Wormuth, 1979). The edwardsia stage, a presettlement stage, was observed sporadically throughout the study. Abundances were quite low (maximum of 11.5/100 m^3), averaging about 1.1/100 m^3 during the year. The maximum for the planula stage was 326/100 m^3, and the average was 21/100 m^3 during the study.

The morphology and duration of the planula stage is not known for most species. The time of development of coral planulae normally ranges from one to several days (Atoda, 1951a; Lewis, 1974). Ostarello (1976) reported that the planula of the hydrocoral Allopora californica was short-lived and that settlement occurred near the parent polyp. Longer times have been reported. Atoda (1951b) found free-swimming planulae after two months. The average was three weeks. He also reported two morphological types: a small, barrel-shaped swimming form and a larger, cylindrical crawling form. The swimming form was long-lived, while the crawling form was short-lived and did not leave the substrate. The shape of the crawling form is similar to that found in this study. The trends observed in this study reflect a positive phototaxis and/or negative geotaxis as commented on by Connell (1973).

Depending on duration of development and direction and velocity of the currents, these planulae could be transported to and from banks in the region with suitable substrate for them to settle.

The decapod larvae were also a numerically abundant group. No further taxonomic breakdown was made, but these larvae were morphologically diverse. The abundances were comparable to those of daytime estimates in the STOCS neuston project (Wormuth, 1979), and a significant increase was observed between day and night abundances. During the spring monitoring cruise, a significant variation was observed among the times of sampling (ANOVA-RBD), but this finding cannot be attributed to a day/night variation.

Gastropod, pelecypod, and polychaete larvae were found consistently throughout the year, but usually in low numbers. The high values for polychaete larvae during the fall monitoring cruise were due to a swarm of juvenile nereiid polychaetes. A maximum of 19,690/ 100 m^3 was observed. Abundance estimates for these larvae from the zooplankton STOCS project (Park, 1979) were higher by at least an order of magnitude. In that study, there was a decrease in abundance with increased distance offshore. The Flower Gardens are twice as far offshore as the STOCS project's farthest station. This difference may account for the decrease in abundances at the Flower Gardens. Gastropod and pelecypod larvae were also less abundant at the Flower Gardens than at the STOCS stations (Park, 1979).

The holoplankton abundance estimates for the Flower Gardens, in general, were lower than similar estimates for the northwestern Gulf (Park, 1979). This difference can probably be attributed to two sources: 1) the avoidance problem, and 2) the distance offshore. The relative speed of the water passing our net arrays was much lower, from 0.2 to 1.0 knots, compared to normal towing speeds of 1.5 to 2.0 knots. Also the net used was a 0.5 m net in this study compared to a 1.0 m net used by Park (1979). These two factors would account for our loss of more active swimmers due to avoidance, as is demonstrated by the copepods observed. In this study, copepods accounted for, at most, 58% of the sample and at times much less. Park (1979) reported that this group comprised about 70% of the sample throughout his study. His average abundance was 50,000/100 m^3 for copepods, while in this study it was only 920/100 m^3, almost a two order of magnitude difference. The two other active swimmers, chaetognaths and medusae, were observed in much lower numbers in our samples.

Larvaceans, thaliaceans, ostracods, cladocerans, and pteropods were not apparently lower in abundance in our samples compared to Park's. These groups are less active swimmers and would be sampled efficiently by our smaller net, which effectively moved slower through the water.

Decreases in abundance of certain groups of plankton in our samples compared to STOCS samples can also be attributed to inshore/ offshore variations. On the continental shelf, Park (1979) observed a decrease with distance offshore. On a larger scale, Howey (1976)

observed a similar phenomenon: with passage from the shelf to slope to oceanic waters, biomass decreased by 50%. The Flower Garden Banks are situated at the edge of the continental shelf and would be awash with oceanic slope waters at most times.

The percentage composition of the meroplankton was quite high throughout the study. Park (1979) reported a maximum of about 10%, which was the minimum for our study. If the avoiders were increased, the percentage of meroplanktors in our samples would decline but still would be higher than in previous studies. Abundance of several larval groups were an order of magnitude higher at the Flower Gardens, suggesting an increase in the reproductive activities of benthic invertebrates and fish in the region. The banks, being areas of increased benthic biomass, are the logical sources.

The importance of zooplankton for coral feeding could not be tested. Glynn (1973) observed a decline in zooplankton biomass downstream of a reef flat. While Glynn worked in an area that was only a few metres deep, the Flower Gardens are situated in waters greater than 20 m depth, with highly variable currents. Thus practical determinations of upstream-downstream positions are nearly impossible.

This project produced several important observations. Whereas planulae were being released throughout the year, the largest numbers of planulae were apparently released during the spring. The actual source of planulae was not identified, but it probably would be an area of anthozoans of a high density. This area could be the Flower Garden Banks. Secondly, there was a large density of larvae in general. Levels of several larval types were orders of magnitude higher than have been indicated in similar studies in the northwestern Gulf. The sources must be areas of higher densities of benthic invertebrates and fishes, namely the Flower Gardens and other nearby banks.

LEAFY ALGAE POPULATIONS

The leafy algae populations were characterized through analysis of seasonal samples taken on a knoll within the Leafy Algae Zone a short distance from the BLM monitoring site. Four 10 m long repetitive photographic plotless line transects and three 1/16 m^2 quadrat samples were taken during each East Flower Garden monitoring cruise. Voucher specimens were preserved, identified, and later submitted to Dr. Nat Eisman of the Harbor Branch Foundation, Ft. Pierce, Florida, for verification of our identification (Table X-C-16). The quadrat samples were split, half for total biomass determination and half for biomass determinations by dominant species (Figure X-C-8, and Tables X-C-17 through 20). Plotless line transect photographs were analyzed in the laboratory to determine percent cover of dominant species of algae (Table X-C-21). Representative temperatures, salinities, nutrient samples, and surface light intensity measurements were taken on all cruises, except that no light measurements were made in September 1978 (Tables X-C-21 through 23).

TABLE X-C-16
SPECIES LIST OF ALGAE FOR THE LEAFY ALGAL KNOLL SAMPLES AT THE EAST FLOWER GARDEN

Chlorophyta	Rhodophyta	Phaeophyta
Valonia ventricosa	Champia parvula	Dictyota bartayresii
Valonia macrophysa	Amphiroa tribulus	Dictyota dichotoma
Caulerpa peltata	Jania capillacea	Lobophora (Pocockiella) variegata
Caulerpa microphysa	Jania sp.	Sargassum hystrix
Acetabularia sp.	Peyssonnelia rubra	Stypopodium zonale
	Gracilaria sp.	3 or 4 unknowns
	4 or 5 unknowns	

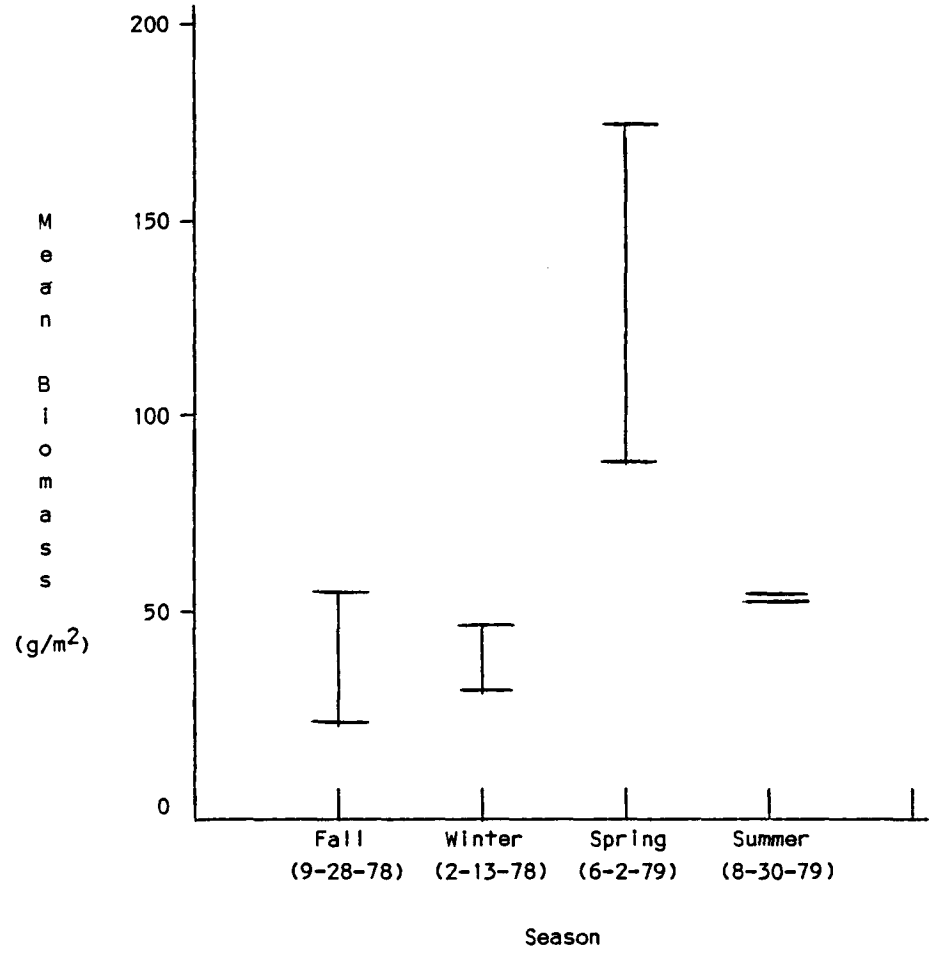

Figure X-C-8. Algae biomass by season (bar indicates standard deviation).

TABLE X-C-17
LIST OF ALGAE ABUNDANCE BY
AREA COVERAGE AND SEASON

	Percent Coverage
Fall (29 Sep 1978)	
Dictyota spp.*	26.0
Lobophora variegata	8.3
Peyssonnelia rubra	3.0
Stypopodium zonale	0.1
Winter (12 Feb 1979)	
Dictyota spp.*	12.8
Peyssonnelia rubra	11.2
Lobophora variegata	8.0
Spring (1-2 Jun 1979)	
Dictyota spp.*	35.6
Lobophora variegata	13.3
Peyssonnelia rubra	5.1
Stypopodium zonale	0.1
Summer (30 Aug 1979)	
Lobophora variegata	17.8
Peyssonnelia rubra	13.0
Dictyota spp.*	11.4
Stypopodium zonale	< 0.1

*Dictyota species composed of D. dichotoma and D. bartayresii

TABLE X-C-18
LIST OF DOMINANT ALGAE SPECIES BY BIOMASS AND SEASON

	Mean Dry Weight (g/m^2)	Percent of Total Dry Weight
Fall* (29 Sep 1978)		
Dictyota spp.**	18.6	54.0
Stypopodium zonale	4.6	13.3
Peyssonnelia rubra	1.7	4.9
Winter (13 Feb 1979)		
Dictyota spp.**	12.8	38.4
Peyssonnelia rubra	9.7	29.1
Lobophora variegata	2.6	7.8
Spring (2 Jun 1979)		
Dictyota spp.**	112.4	87.2
Graciliaria sp.	3.6	2.8
Lobophora variegata	2.6	2.0
Peyssonnelia rubra	2.6	2.0
Stypopodium zonale	1.4	1.1
Summer (30 Aug 1979)		
Peyssonnelia rubra	15.5	28.7
Stypopodium zonale	11.0	20.5
Lobophora variegata	8.1	15.1
Dictyota spp.**	4.6	8.5

*Fall biomass data calculated from only two samples; all other season computed from three samples.
**Dictyota species composed of D. dichotoma and D. bartayresii.

TABLE X-C-19
ALGAE BIOMASS DATA

Date	Replicate	Wet Weight (g/m^2)	Dry Weight (g/m^2)
09-29-78	1	226.8	22.3
	2	349.8	46.7
	3	1493.4	327.4
02-13-79	1	184.1	23.0
	2	255.2	36.1
	3	198.5	40.9
06-02-79	1	744.8	106.3
	2	1283.3	178.5
	3	846.7	102.1
08-30-79	1	303.7	54.6
	2	338.5	53.5
	3	315.6	53.7

TABLE X-C-20
RESULTS OF STATISTICAL ANALYSES OF ALGAE

A. ALGAE BIOMASS (g/m^2 dry weight) MEAN AND STANDARD DEVIATION BY SEASON

	Fall 09-29-78	Winter 02-13-79	Spring 06-02-79	Summer 08-30-79
Mean	34.5* [132.2]	33.3	129.0	53.9
Standard Deviation	17.2* [169.7]	9.3	42.9	0.6
Range	22.3-46.7*[327.4]	23.0-40.9	102.1-178.5	53.5-54.6

*Atypical sample removed and statistics adjusted; brackets indicate unadjusted statistics

B. Seasonal ANOVA Results Showing Percent Cover of Dominant Species of Algae

Fall vs Winter	$F_{1,4} = 1.41 \times 10^{-2}$
Summer vs Winter	$F_{1,5} = 18.46$**
Spring vs Winter	$F_{1,5} = 17.77$**
Spring vs Summer	$F_{1,5} = 11.44$**
Fall vs Spring	$F_{1,4} = 10.74$**
Fall vs Summer	$F_{1,4} = 6.09$

**Indicates significance at 5% level

C. Significant Differences in Seasons

	Spring (06-02-79)	Summer (08-30-78)	Fall (09-29-78)	Winter (02-13-79)
Mean	129.0	53.9	34.5	33.3

(Underline indicates no significant difference at the 5% level.)

TABLE X-C-21
WATER TEMPERATURE AND SALINITIES, EFG CRUISES I-IV (1978-79)

	Cruise I (September/Oct 1978)			Cruise II (February 1979)			Cruise III (May/June 1979)			Cruise IV (August 1979)		
	Date	Surface	Bottom	Date	Surface	Bottom	Date	Surface	Bottom	Date	Surface	Bottom
Water Temperature (°C)	9-27-78	28.5	29.5	2-10-79	20.0	20.0	5-29-79	25	24	8-28-79	31.0	30.5
	9-28-78	29.0	30.0	2-11-79	20.0	20.0	5-30-79	25	24	8-29-79	30.5	31.5
	9-29-78	28.0	29.5	2-12-79	20.0	20.0	5-31-79	25	24	8-30-79	32.0	33.0
	9-30-78	29.5	28.5	2-13-79	20.5	20.5	6-01-79	25	23			
	10-01-78	28.5	29.5				6-02-79	27	24			
							6-03-79	27	24			
Water Salinities (°/oo)	9-27-78	35	35	2-10-79	36	36	5-29-79	34	35	8-28-79	31.5	35
	9-28-78	35	35	2-11-79	35	35	5-30-79	35	35	8-29-79	32.0	34
	9-29-78	35	35	2-12-79	35	35	5-31-79	35	35	8-30-79	33.5	34.5
	9-30-78	35	35	2-13-79	35	35	6-01-79	35	35			
	10-01-78	34	34				6-02-79	35	35			
							6-03-79	34	35			

TABLE X-C-22

SURFACE LIGHT READINGS, FEBRUARY, MAY, JUNE, AND AUGUST, 1979*

CRUISE II (February 1979)			Cruise III** (May 1979)			Cruise III** (June 1979)			Cruise IV (August 1979)		
Date	Time	Foot Candles	Date	Time	Foot Candles	Date	Time	Foot Candles	Date	Time	Foot Candles
2-10-79	1630	3,120	5-30-79	1853	2,100	6-01-79	1400	8,000	8-29-79	1700	2,100
	1700	820		1900	1,700		1520	8,600		1730	1,600
	1715	500		1915	1,000		1600	8,200		1745	1,480
	1730	340		1930	700		1700	5,000		1800	1,300
	1745	184		1945	300		1800	2,300		1830	746
	1800	38.5		2000	210		1900	1,200		1845	580
	1810	6.8		2015	10.0		1915	900		1900	420
	1820	0.70		2030	0.37		1930	460		1923	105.0
	1830	0.08		2035	0.05		1945	220		1930	19.0
	1840	0.05	5-31-79	0515	0.00		2000	56.0		1945	8.6
	1850	0.05		0530	0.00		2020	3.40		2000	0.35
2-11-79	0550	0.05		0545	0.00		2030	0.60		2015	0.05
	0600	0.05		0600	0.00		2045	0.05		2030	0.00
	0610	0.05		0615	0.30	6-02-79	0500	0.00	8-30-79	0530	0.00
	0620	0.05		0630	2.40		0515	0.00		0540	0.00
	0630	0.22		0645	7.70		0530	0.05		0545	0.00
	0640	2.57		0700	35.0		0545	0.06		0600	0.00
	0650	18.5		0715	95.0		0600	1.10		0615	0.05
	0700	62.0		0730	150		0615	22.0		0620	0.08
	0710	142		0745	167		0630	115		0625	0.17
	0720	350		0800	265		0645	340		0630	0.50
	0730	650		0905	680		0700	320		0646	18.0
	0740	1,260		1000	900		0715	340		0700	-
	0750	1,680		1109	2,000		0730	2,400		0715	280
	0800	1,920		1200	2,100		0745	1,080		0730	1,000
	0805	2,100		1300	2,240		0800	1,600		0745	160
	0900	4,000		1400	5,000		0900	5,800		0803	290
	1000	5,500		1500	7,000		1000	4,400		0830	800
	1100	2,000		1600	2,800		1100	9,600		1020	960
	1200	7,200		1700	2,000		1200	8,800		1030	7,800
	1300	11,100					1300	11,000		1100	9,600
	1400	7,200					1400	11,000		1130	11,000
	1500	5,500					1500	7,400		1230	11,000
	1600	4,800					1600	9,000		1300	11,700
	1700	1,460					1700	5,000		1330	11,000
										1400	10,600
										1500	9,500
										1600	8,800

* All times were recorded at Central Daylight Savings time. Variance in significant digits of foot candle readings reflects changes in sensitivity ranges of the light meter.

** Since no light measurements were made on Cruise I (September 1978), two sets of readings were taken on Cruise III.

TABLE X-C-23
NUTRIENT DETERMINATIONS, EAST FLOWER GARDEN

Cast	Date	Depth (m)	Nitrate (μm)	Nitrite (μm)	Phosphate (μm)	Silicate (μm)	Dissolved O_2 (ml/l)
1	9-30-78	5	0.23	0.12	0.33	1.83	5.13
		25	0.23	0.12	0.27	1.50	5.49
		55	0.50	0.15	0.47	2.00	5.09
2	9-30-78	5	0.20	0.12	0.23	1.67	4.98
		25	0.23	0.12	0.23	1.67	4.29
		45	0.27	0.15	0.33	1.83	4.78
Upcurrent	2-13-79	5	0.31	0.20	0.50	1.7	----
		25	0.66	0.42	0.36	1.6	----
		50	1.66	0.56	0.41	2.1	----
Downcurrent	2-13-79	5	0.25	0.11	0.32	1.7	----
		25	0.34	0.14	0.32	1.7	----
		50	1.34	0.53	0.36	2.4	----
Upcurrent	6-3-79	10	0.29	0.17	0.25	1.1	----
		20	0.35	0.19	0.29	1.2	----
		30	0.41	0.19	0.42	1.4	----
Downcurrent	6-3-79	10	0.35	0.19	0.29	1.2	----
		20	0.35	0.17	0.35	1.4	----
		30	0.41	0.25	0.67	8.8	----

The most consistent dominant forms were Dictyota spp. (D. dichotoma and D. bartayresii), Peyssonnelia rubra, and Lobophora variegata. Ranking of these species in terms of relative abundance differs in the several seasonal samples (Tables X-C-17 and 18) and in transect and quadrat samples within seasons. These differences may be indicative of substantial lateral variation and seasonal variation in distribution and abundance of leafy algae species on the knoll sampled.

Statistical comparison of means and analysis of variance using the F-test for uneven sample size indicated significant differences between the means of spring total biomass samples and all other seasons (spring samples were higher in total biomass). Fall sample means did not differ significantly from winter or spring means, but summer total biomass was significantly higher than winter (Tables X-C-19 and 20). These data are preliminary, but there is a strong indication that the leafy algae population was substantially greater in the spring of 1979 than during other sampling periods.

Because of its growth form (dense, small clumps), when Stypopodium was collected in biomass samples, it represented a dominant algal type. One sample from the fall season was extremely atypical because it contained a large growth of Stypopodium, and its high biomass value caused problems in the analysis of variance. This value was removed to facilitate finding of significant differences between seasons. This removal was considered valid as the sample was consciously selected by divers because of the abundance of Stypopodium, whereas all other samples were more randomly selected.

In summary, over 16 species of leafy algae were identified from samples taken at 27 m depth from the knoll near the BLM monitoring site. Three or four species dominated throughout the year, with apparent seasonal changes in relative abundance and substantial lateral variation in distribution and abundance on the knoll. The largest populations seem to have occurred during the spring season.

ANCHORING

In the course of our research activities on the reefs at the East and West Flower Garden Banks, evidence of mechanical damage to living coral has repeatedly been observed. Such damage can be caused by the activities of certain marine organisms, by water movement during storms, and by man, primarily as a result of anchoring on the reef. Destruction of living coral cover by anchoring should be eliminated where possible if maximal protection of reefal communities is desired.

Two instances of anchoring at the East Flower Garden by oil tankers were observed during the spring and summer of 1979. The accompanying map (Figure X-C-9) shows the positions of the ships and their anchors relative to the reef and our reef monitoring station. It is felt that in both cases substantial damage to living coral on the reef must have resulted from the anchoring. This contention is based on the

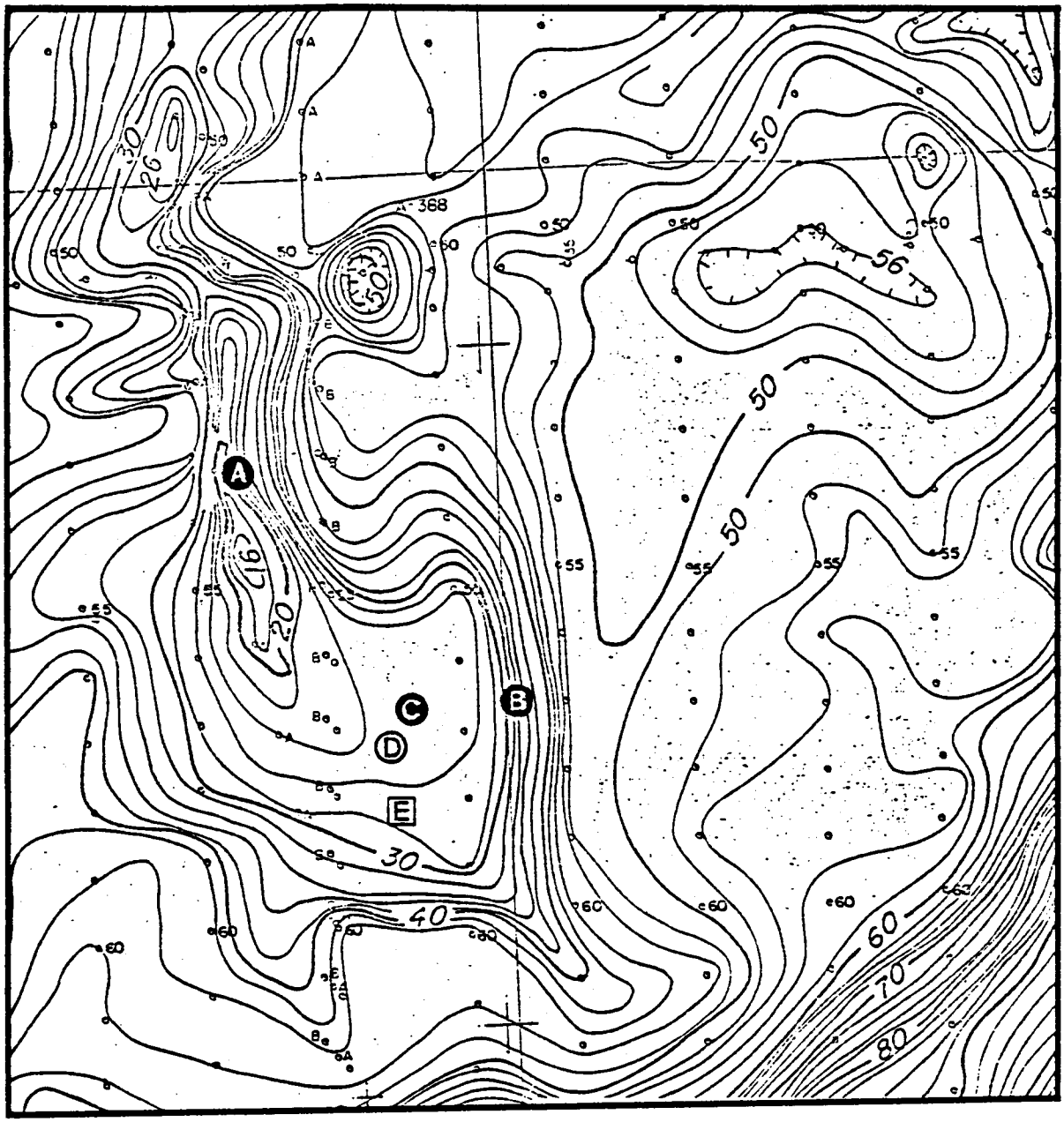

Figure X-C-9. Locations of petroleum tankers anchored at the East Flower Garden Reef. Depth contours in metres.

A - Bow of VENTURE TEXAS 25-27 April 1979
B - Anchor of OGDEN CHAMPION 11-12 July 1979
C - Bow of OGDEN CHAMPION 11-12 July 1979
D - BLM REEF MONITORING SITE
E - CSA Monitoring Site

fact that the locations of these vessels place them directly over the coral reef, the anchor chains descending vertically into the water. Both anchor chains undoubtedly lay across the reef for some distance contacting live coral, and in one case the anchor was dropped unmistakably on the reef.

In October 1978, the freighter TEXACO FLORIDA out of Wilmington, Delaware was seen anchored 3/8th of a nautical mile southwest of monitoring site CSA-A at the East Flower Garden. On February 19, 1980, the tanker WILLIAM LAMAR MELLON circled within 1/2 nautical mile of our research vessel at the West Flower Garden, intending to anchor. The WILLIAM LAMAR MELLON left the site willingly after being asked not to anchor on the reef.

Anchoring by such large vessels using massive anchors and chains is of particular concern due to the potential for large-scale mechanical damage to corals.

SOUTHEAST TRANSECT AND BRINE SEEP

(Figures X-C-10 through 14, Tables X-C-23, 24, and Appendix C, Table X-C-29)

T. Bright, R. Rezak, and E. Powell

Introduction

The purpose of traversing the southeast transect once a year is to determine, through visual observation from a submersible, whether or not there have been mass mortalities of components of the benthic community or apparent changes in community structure. The southeast transect (top of bank, 27°54'32.91", 93°35'51.33", to bank edge monitoring site, 27°54'1.28", 93°34'38.27") has been amply described in previous reports (Bright and Rezak, 1976, 1978a,b) and to do so again here would be redundant. Direct observation and video and photographic documentation by Dr. Tom Bright detected **no apparent changes** in the benthic assemblages on the southeast transect between September 1977 and September 1978.

Analysis of samples collected during the 1979 submersible dives has resulted in a number of new records for the Flower Gardens (Appendix C, Table X-C-29). Particularly noteworthy was the discovery of large populations of echinoids (Pseudoboletia maculata and Arbacia punctulata) and asteroids (Linckia nodosa) on the bank west of the main coral reef between 46 and 76 m. It is possible that the dense assemblages of P. maculata and L. nodosa (Figures X-C-10 and 11) were breeding aggregations, but this is speculation.

It has also become apparent that elasmobranch populations are seasonally high at the Flower Gardens, with large numbers of sharks often encountered in the winter and early spring. Though it is difficult to identify most sharks to species in the water, we have reliable sightings on the coral reef of Tiger sharks (Galeocerdo cuvier), Hammerhead sharks (Sphyrna sp.), and Sawfish (Pristis sp.). A large Angel shark (Squatina sp.), partly buried in the sediment at 87 m,

was seen from the submersible on the northeastern edge of the bank (Figure X-C-13).

The most unusual habitat at the East Flower Garden is that associated with a large brine system at one extremity of the southeast transect. From a management standpoint, the conclusions we have drawn concerning benthic populations in and around the system and the effect of the brine on nearby biota are very significant. To some extent, the brine mimics brine which may be discharged from an offshore oil or gas platform over years of production. Knowledge of the potential effects of such discharges on bank communities is, therefore, useful.

The brine system consists of inter-related components: 1) numerous seeps feeding 2) a brine lake that has 3) an outflow into a canyon that contains 4) a mixing stream that dilutes the brine to a hypersaline condition.

Methods

Direct observations of the East Flower Garden brine system, documented on video tape and film, were made from the Texas A&M research submersible DRV DIAPHUS in June 1974 and September 1976, 1977, and 1978. Rock, sediment, and biological samples were collected with a hydraulic manipulator arm, a sediment scoop, or an underwater "vacuum cleaner" device. Water samples for chemical and bacteriological analyses were drawn through a hose from the manipulator arm claw to a through-hull fitting and collected within the submersible. Precision navigation (LORAC) was used to determine the exact location of the brine lake. Side-scan sonar records aided in determining the dimensions of the basin and overflow canyon. Seismic records defined the configuration of salt deposits beneath the bank.

Description, Dynamics, and Origin of Brine Lake

General Description

The basin from which the brine flows is 60 m from the edge of the bank (27°54'31.64"N, 93°34'53.27"W), 4 m deep, roughly oval, approximately 50 m across from west-northwest to east-southeast, and 30 m from north-northeast to south-southwest (Figure X-C-14). Its wall slope varies from 25° on the north-northwest to almost vertical on the south-southeast. A brine lake approximately 25 cm deep occupies part of the slightly lower eastern and central basin floor at 71 depth. The lake is irregular in shape, having a cuspate periphery reminiscent of cusps and grooves sometimes encountered on beaches. A canyon approximately 10 m wide at the bottom, 15 m wide at the top, and 60 m in length extends from the east-southeast margin of the basin to the edge of the bank (79 m depth). Nowhere on the East Flower Garden Bank have we encountered similar basins or canyons, suggesting that the origin of the basin-canyon structure may be uniquely related to the brine seep.

Chemical aspects of the East Flower Garden brine were recently reported by Brooks *et al.*, 1979 (Table X-C-24). The brine is denser than seawater, anoxic, and contains exceptionally high levels of

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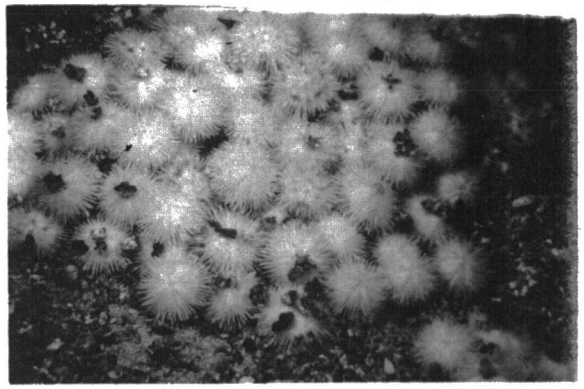

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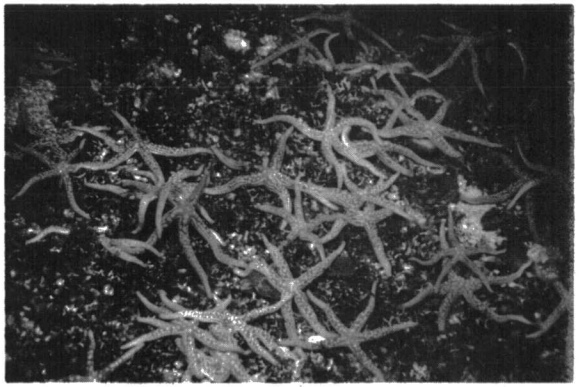

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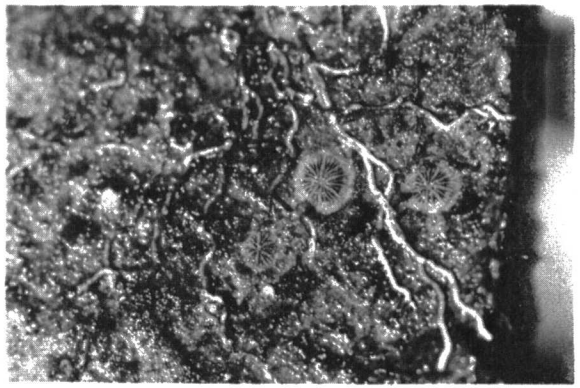

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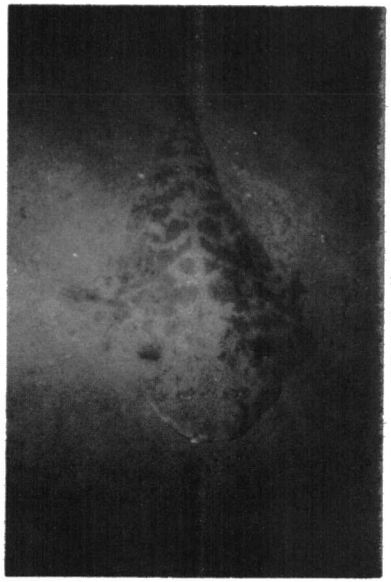

Figure X-10 (UL). East Flower Garden: aggregation of Pseudoboletia maculata at 59 m depth on nodule-covered bottom.

Figure X-11 (UR). East Flower Garden: aggregation of Lynckia nodosa at 53 m depth on nodule-covered bottom.

Figure X-12 (LL). East Flower Garden: encrusting growth on one of the settling plates used in study of coral and coralline algae recruitment. Three coral spat can be seen clearly.

Figure X-13 (LR). East Flower Garden: angel shark, Squatina sp., at 87 m depth.

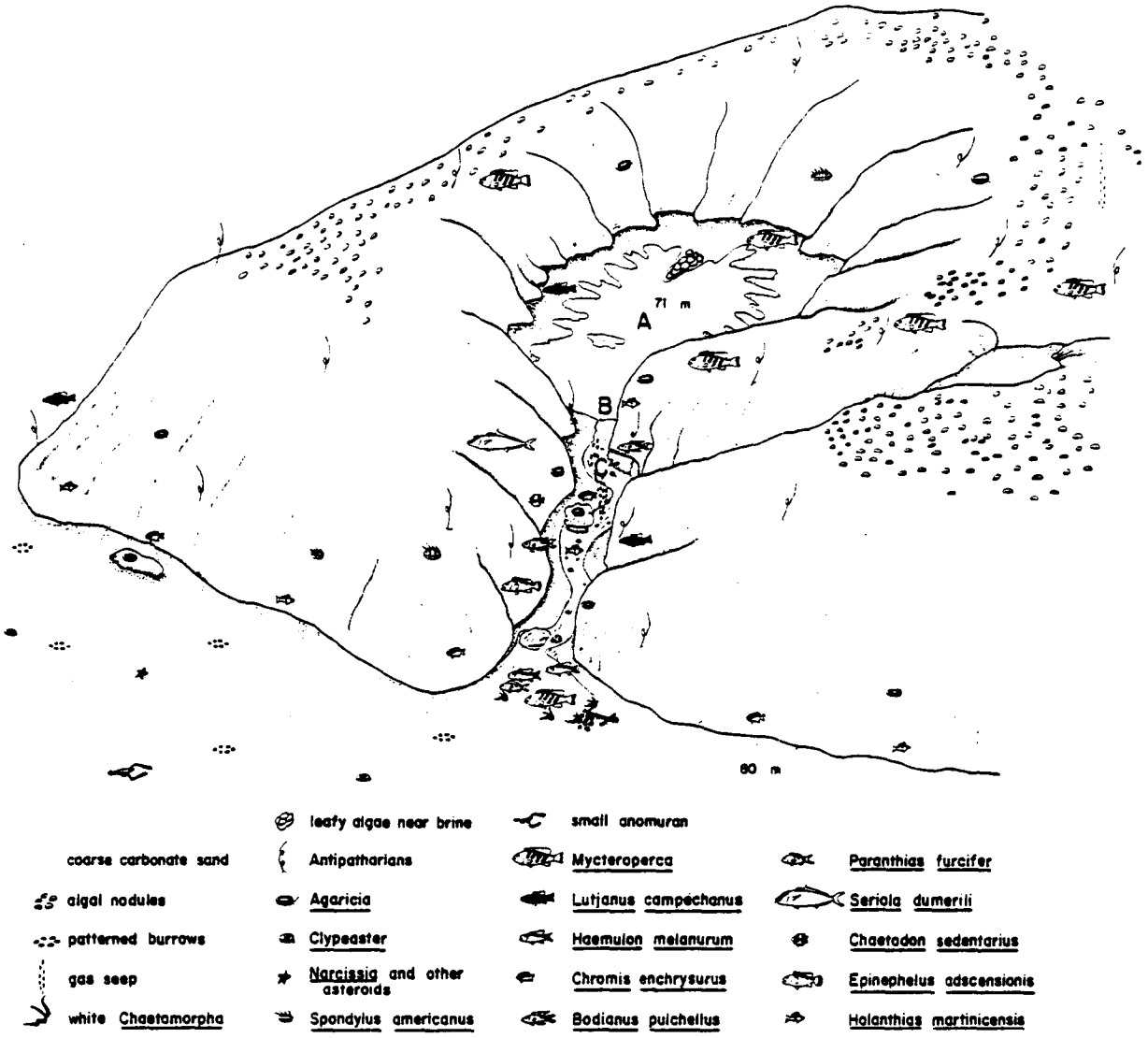

Figure X-C-14. Diagrammatic representation of the brine lake and outflow. A = brine; B = overflow from lake; C = stream of mixing brine and seawater.

TABLE X-C-24
CHEMICAL CHARACTERISTICS OF BRINE, BRINE-SEAWATER MOISTURE AND SEAWATER IN THE VICINITY OF THE BRINE LAKE

Chemical Characteristics	Brine Lake			Small Brine Pool Below Overflow	Lake Overflow	Mixing Stream Mid-Canyon	Mixing Stream Canyon Mouth	
	76	77	78	77	78	76	76	78
Salinity *, $g \cdot kg^{-1}$	188	195.2		198	-	48.4	39.6	-
Salinosity *, $g \cdot litre^{-1}$	211	215.6	196	219	55.5	48.5	39.7	38.0
Salinity (sum of ionic species), $g \cdot kg^{-1}$	191.4	217.8	-	219.1	-	46.0	40.6	-
Potassium, $g \cdot kg^{-1}$	0.375	0.363	-	0.353	-	0.426	0.421	-
Calcium, $g \cdot kg^{-1}$	1.309	1.617	-	1.653	-	0.513	0.446	-
Sodium, $g \cdot kg^{-1}$	61.1	79.3	-	75.8	-	12.7	13.3	-
Magnesium, $g \cdot kg^{-1}$	1.133	1.067	-	1.018	-	1.387	1.421	-
Chloride, $g \cdot kg^{-1}$	122.8	131.0	-	135.9	-	28.2	22.2	-
Sulfate, $g \cdot kg^{-1}$	4.70	4.42	-	4.37	-	2.81	2.82	-
Sulfate, $mmol \cdot litre^{-1}$	59.4	52.1	-	51.5	-	29.4	29.4	-
Sulfide (μM)	P	P	2200	P	300	P	P	70
ΣCO_2, $mgC \cdot litre^{-1}$	33.5	25.0	53.3	48.0	23.2	22.3	20.6	27.8
Methane, $\mu l \cdot litre^{-1}$	2,000	2,730	1,040	8,900	690	140	42	1.75
Ethane, $\mu l \cdot litre^{-1}$	240	414	99	500	41	9.5	2.8	0.32
Propane, $\mu l \cdot litre^{-1}$	1,210	14.7	-	18.6	-	< 10	< 10	-
Iso-butane, $\mu l \cdot litre^{-1}$	-	2.6	-	3.4	-	-	-	-
N-butane, $\mu l \cdot litre^{-1}$	-	0.45	-	< 0.3	-	-	-	-
$C_1:(C_2+C_3)$	8.3	6.4	-	17.2	-	15	15	-
Delta C-13 $[CH_4]$, °/oo	-42.5	-40.0	-44.6	-47.1	-52.4	-	-	-
Phosphate, μM	> 7.5	2.36	-	4.00	-	3.13	1.89	-
Nitrate, μM	3.6	0.8	-	0.3	-	7.9	8.1	-
Silicate, μM	16.3	203	-	192	-	5.3	3.8	-
ATP, $ng \cdot litre^{-1}$	-	83.3	-	-	-	-	-	-
Radium-226, $dpm \cdot litre^{-1}$	-	2.9±0.2	-	-	-	-	-	-
Helium, $\mu l \cdot litre^{-1}$	-	0.8	-	-	-	-	-	-
DOC, $mgC \cdot litre^{-1}$	4.56	-	-	-	-	1.37	1.62	-
Oxygen (ml/l)	-	0.0	-	0.0	-	-	-	-
Temp. (°C)	-	-	-	22.5	-	20.0	19.9	22.2
Density, $kg \cdot litre^{-1}$	-	1.104	-	1.106	1.040	1.034	1.028	1.027
Dilution $\left(\frac{\text{seawater}}{\text{brine}}\right)$	0.0	0.0	0.0	0.0	7.2	13.1	47.6	> 50

*Refractometer.
P = presence indicated by sample odor.
N = absence indicated by lack of sample odor.
Compiled in part from Bright (1977) and Brooks et al. (1979)

TABLE X-C-24 (Continued)

Chemical Characteristics	20 cm Above Brine Lake		20 cm Above Small Brine Pool		Local Sea Water at Depth	Orca Brine	Red Sea Brine
	76	77	76	77			
Salinity*, g • kg^{-1}	-	36.7	-	36.1	36	258.1	256.4
Salinosity*, g • $litre^{-1}$	-	36.7	-	36.1	36	-	-
Salinity (sum of ionic species), g • kg^{-1}	-	36.4	-	35.8	36	-	-
Potassium, g • kg^{-1}	-	0.407	-	0.391	0.40	0.63	2.16
Calcium, g • kg^{-1}	-	0.441	-	0.423	0.41	1.09	4.71
Sodium, g • kg^{-1}	-	11.3	-	11.2	10.8	91.5	92.9
Magnesium, g • kg^{-1}	-	1.327	-	1.326	1.29	1.05	0.81
Chloride, g • kg^{-1}	-	20.1	-	19.7	19.4	149.5	155.3
Sulfate, g • kg^{-1}	-	2.77	-	2.75	2.7	3.66	0.75
Sulfate, mmol • $litre^{-1}$	-	29.6	-	29.3	-	-	-
Sulfide (μM)	-	N	-	N	0.0	< 1	-
ΣCO_2, mgC • $litre^{-1}$	-	20.2	-	21.0	25	55	-
Methane, μl • $litre^{-1}$	-	940	-	-	50	24,000	-
Ethane, μl • $litre^{-1}$	-	54	-	-	0.5	29	-
Propane, μl • $litre^{-1}$	-	70	-	-	0.5	-	-
Iso-butane, μl • $litre^{-1}$	-	-	-	-	-	-	-
N-butane, μl • $litre^{-1}$	-	-	-	-	-	-	-
$C_1:(C_2+C_3)$	-	15.4	-	-	50	!800	-
Delta C-13 $[CH_4]$, °/oo	-	-	-	-	-	-74	-
Phosphate, μM	-	0.31	-	0.47	2.5	81.5	-
Nitrate, μM	-	1.1	-	1.3	23	0.0	0.8
Silicate, μM	-	27.2	-	30.6	25	235	235
ATP, ng•$litre^{-1}$	-	43.5	-	38.5	2.0	3-15	-
Radium-226, dpm • $litre^{-1}$	-	-	-	-	0.2	5	-
Helium, μl • $litre^{-1}$	-	-	-	-	0.04	-	-
DOC, mgC • $litre^{-1}$	-	-	-	-	0.8	3.5	-
Oxygen (ml/l)	-	3.0	-	4.4	5.0	0.0	0.0
Temp. (°C)	20.2	22.2	20.0	22.2	19.0-22.2	5.0	
Density kg • $litre^{-1}$	-	1.026	-	1.026	1.025	1.185	-
Dilution $\left(\frac{\text{seawater}}{\text{brine}}\right)$	-	-	-	-	-	0.0	0.0

*Refractometer.

P = presence indicated by sample odor.

N = absence indicated by lack of sample odor.

Compiled in part from Bright (1977) and Brooks *et al.* (1979)

substantially in height, and dissipates as it moves onto the level bottom adjacent to the bank.

The sand and rubble substratum of the canyon has obviously been affected by the flow. Well-sorted, coarse, carbonate sand has been piled in sand bars on either side of the stream channel and along the bases of the canyon walls. The stream channel bed is relatively rough, containing rubble, sizeable boulders, mollusk shells, and even a stick of waterlogged wood. Scour and erosional undercutting of carbonate rock is apparent where large boulders occur in the stream or where the stream contacts the canyon wall.

Natural gas seeps (primarily methane, with small amounts of ethane and propane) occur along the axis of the canyon, in the mixing stream, and on the canyon and basin walls. Typically, they emit series of small bubbles in intermittent bursts lasting several seconds. Such seeps are common over the entire East Flower Garden Bank (Bright, 1977) and on most other banks in the northwestern Gulf of Mexico (Bernard et al., 1976).

Geothermal warming of the brine is minimal. One temperature measurement in the mixing stream just below the lake overflow was 22.5°C (0.3°C higher than overlying water) (Table X-C-23, above). Measurements farther down the canyon indicated a lesser temperature differential. Due to instrument problems, no direct in situ temperature measurements were made of the brine; however, upon collecting the brine, no difference in its temperature was noticed compared to that of water samples taken above the brine-seawater interface (22.2°C in 1977, 20.3°C in 1976).

Origin and Geological Description

The East Flower Garden and most other banks off the Texas and Louisiana coasts are manifestations of upward intrusions of salt diapirs from deep-lying (6,000-9,000 m) Jurassic salt deposits. Documentation of these salt domes has been accomplished by gravity surveys, seismic profiling, and drilling. Lehner (1969) reported that salt was recovered from ten core holes drilled on diapiric features on the upper continental slope off Texas and Louisiana. Humphris (1979) reported that seven core holes drilled on diapiric salt features found caprock material, salt crystals in the sediment, or high salinity interstitial waters.

Depth of cap rock or salt varies with the stage of development of the diapirs. Lehner (1978) indicated that the shallowest salt found in his study of salt domes on the upper continental slope was at a depth of 58 m below the sea bottom. There is little doubt that the cap rock at the East Flower Garden is covered by only a thin veneer of Quaternary reef rock. Seismic records indicate that the East Flower Garden salt diapir has penetrated to within 150 m of the seafloor and possibly as close as 30 m.

Cap rock generally overlies the crest of a salt diapir and is formed by the dissolution of salt at the crest of the diapir. The salt normally contains gypsum or anhydrite which accumulates as a residue as the salt is dissolved, due to the higher solubility of the salt. Subsequent reduction of the SO_4^{2-} to native sulfur and H_2S occurs due to either the action of sulfate-reducing bacteria or the introduction of hydrocarbons into the cap rock. These chemical reactions result in the precipitation of $CaCO_3$, forming the limestone cap rock. Generally, the limestone cap rock is brecciated and contains deposits of sulfur and iron sulfides. Due to its porous nature, the limestone cap rock permits the movement of fluids which continue to dissolve the upper portions of the salt diapir. Continued dissolution of the salt beneath the cap rock creates voids that are the cause of gravity faulting of the cap rock and the overlying sediments. The small basin that contains the brine lake at the East Flower Garden conceivably could have been formed in this manner.

Seawater percolating through the reef rock and cap rock continues to dissolve salt, and the dense hypersaline fluids flow by gravity into the basin from the surrounding rocks. Comparison of the ^{226}Ra levels in the East Flower Garden brine and typical oil field brines in the Gulf Coast region lead Brooks et al. (1979) to suggest that the East Flower Garden brine is a product of dissolution of salt deposits within the bank. X-ray diffraction analysis of carbonate nodules collected from the brine pool reveals the presence of gypsum in the nodules, most probably derived from the cap rock (See Volume One, Chapter III).

The seep described above may not be the only one at the East Flower Garden Bank. In 1978 several small (1 m diameter) volcano-shaped structures were observed on the soft bottom at 100 m depth on the northeastern flank of the bank. No samples were taken nor measurements made, but the coloration of the substratum and associated surficial deposits suggested brine seepage, possibly intermittent.

Background

The overflow of the East Flower Garden brine lake is a natural example of a point source brine discharge and, as such, could provide a natural experiment on the as yet unknown long-term effects of brine discharges on the continental shelf benthic biota. Brines* as point

*The term "brine" has developed at least two distinct connotations. Discharged waters, usually having a salt content higher than the water of the receiving basin, are generally termed brines regardless of their absolute salinity (e.g., Mathis and Dorris, 1968; Moseley and Copeland, 1974; Bobb et al., 1971). A more stringent and biologically oriented definition is that of Kinne (1964), who restricts the term "brine" to water having a salt concentration above 80 °/oo (where selective ionic precipitation [Copeland, 1967] becomes important) and uses the term "hypersaline" for waters of 40-80 °/oo salinity.

source pollutants will probably become more and more common in coastal embayments and on the continental shelf with the increase in oil production (e.g., Shore et al., 1977), the development of a strategic petroleum reserve (Report to the FEA, 1977), and the development of desalination technology (e.g. Bobb et al., 1971). The effects of such brine discharges on the biota of the receiving basin have been reviewed recently by Moseley and Copeland (1974) and by Mackin (1973). This recent interest in man-made high salinity systems has somewhat obscured the fact that naturally occurring brine discharges and other high salinity systems are not uncommon, particularly in certain areas, such as the Gulf of Mexico, and may be important components of, and have important effects on, the natural ecosystem in these areas.

Naturally Occurring Systems

Naturally occurring brine and hypersaline systems have been described from a variety of locations (e.g., Kinne, 1964; Copeland and Nixon, 1974; Moseley and Copeland, 1974) and include large bodies of water, such as the Laguna Madre and Baffin Bay in Texas, and small bodies of water, such as Solar Lake, Sinai (Cohen et al., 1977a), in which the salinity is determined by local evaporation-precipitation regimes and local hydrodynamic conditions. In addition, a number of submarine brine lakes, such as the Red Sea brines (2000 m depth) (Degens and Ross, 1969), the Orca Basin (2100 m depth) (Shokes et al., 1977), and the East Flower Garden brine lake (71 m depth) (Bright, 1977), which occur in restricted basins within larger bodies of water, derive their high salinity from more unusual circumstances such as the dissolution of salt domes (Bright, 1977) or other evaporite deposits (Craig, 1969).

Although not uncommon, brine discharges and other high salinity systems that occur naturally are of limited areal extent today; and although changes in the biota locally can be significant, large scale biotic disturbances over wide areas certainly do not occur. The situation has been quite different during other periods of the earth's history when brines filled one or more major ocean basins (e.g., Holser, 1977; Thierstein and Berger, 1978; Berger and Thierstein, 1979), such as the Mediterranean Sea during the Miocene and the proto-South Atlantic during mid-Cretaceous times. In these cases, catastrophic or aperiodic additions of brines to adjoining basins probably caused significant and widespread faunal changes within major ocean basins (Thierstein and Berger, 1978). Thus, high salinity systems in general, and brine discharges in particular, are normal components of the marine ecosystem, the importance of which has changed from high significance during earlier periods of history to the relative insignificance of today.

The effects of man-made brine pollution on the marine ecosystem should be reproduced in the natural situations occurring today. A careful study of how natural brine discharges have affected the biotic composition of the receiving basin should be particularly useful, for example, in establishing the long-term effects of brine discharges on

marine communities and might suggest alternative management techniques for man-made discharges based on nature's strategies to deal with similar situations. The impact of a brine discharge on the community of the receiving basin is determined by a number of parameters: 1) the mixing or dispersion efficiency, 2) the volume of the receiving basin relative to the volume of the brine or the dilution efficiency, 3) the stability of the discharge volume over time, and 4) the chemistry of the brine, including its salinity relative to that of the receiving basin, its ionic composition, and its oxygen and H_2S content.

Mixing Efficiency

Mixing efficiency, which is determined by how well and how quickly the brine is mixed with the water of the receiving basin, has been the subject of a number of recent modeling efforts (e.g., Bobb et al., 1971; Shore et al., 1977). Among the factors affecting mixing efficiency are the rate at which the brine is added to the water and its method of dispersion at the point of discharge (e.g., Pincince and List, 1973), the strength of the external mixing agents present, and the topography of the receiving basin. Discharged brines are denser than the receiving medium and tend to sink to and flow along the bottom. They may accumulate in topographic lows. The formation of a strong pycnocline at the brine-seawater interface tends to damp out turbulent mixing. Modeling of brine discharges in estuaries (e.g., Bobb et al., 1971; Shore et al., 1977) and documentation of actual events (e.g., Cintron et al., 1970) show that, in the absence of a significant external mixing agent (such as currents, gravity flow, or winds), discharged brines maintain their integrity and flow across a level bottom for distances of a kilometre or more as a distinct high salinity layer. As Mackin (1971) has pointed out, the propensity for brines to flow across the bottom suggests that, in most cases, it is the benthic biota that should be affected. In fact, planktonic and nektonic communities, being relatively mobile vertically, may normally be completely unaffected except in those special cases where mixing efficiency is high and dilution efficiency is low, so that a vertically mixed high salinity system develops (e.g., at Chiltipin Creek; Moseley and Copeland, 1974; Spears, 1971).

Brine Chemistry

The chemistry of the brine will be important in determining the resulting biotic composition. A variety of stresses are imposed on vertically mixed high salinity, including osmotic stress (Kinne, 1964), a significant decrease in oxygen solubility (Copeland, 1967), and, at 80 °/oo and above (where selective ionic precipitation becomes important), changes in pH, alkalinity, and ionic composition (Copeland, 1967). Most naturally occurring brines are relict seawater with some changes in ionic composition, depending on the brine's history (Collins, 1967; Collins, 1970; Shokes et al., 1977). As such, the stresses caused by changes in ionic composition will depend on the dilution and mixing efficiency of the receiving basin. At the East Flower Garden, for example, the community of the brine lake is stressed

by both high salinity and changes in ionic composition. But by the time the brine reaches the surrounding soft-bottom community at the base of the outflow channel, dilution and mixing have returned the ionic composition to nearly that of seawater, whereas the salinity is still significantly increased. Some brines may be anoxic when discharged, so that oxygenation is closely tied to mixing efficiency. Many have a low redox potential (eh) (e.g., Collins, 1967; Collins, 1975). In seawater systems, low eh is normally created by the presence of hydrogen sulfide (e.g., Goldhaber and Kaplan, 1974). The brine of the East Flower Garden seeps, for example, contains H_2S and is, therefore, anoxic when discharged. H_2S is a metabolic toxin, and, at low concentrations, is lethal to most metazoans (e.g., Theede et al., 1969; Oseid and Smith, 1974).

Although certain invertebrates possess detoxification systems (Powell et al., 1979) and euryoxic metazoan communities are not uncommon (e.g., Nichols, 1976; Rosenberg, 1977), the simultaneous presence of H_2S, anoxia, and high salinity militates against the development of a normal metazoan community. In the East Flower Garden brine lake, for example, a sulfuretum develops under these conditions. The development of a more normal fauna adjacent to the lake is then closely tied to mixing efficiency and concomitant oxygenation. Brine discharge systems of this type and the development of a normal metazoan fauna correlated with oxygenation by mixing is the condition present at the East Flower Garden and, probably, at many other brine systems where brines of low redox potential are discharged. They remain essentially unstudied, with the exception of the East Flower Garden.

Stability of the brine flow is also important. As Sanders (1968) has emphasized, instability tends to be an added stress on biological communities, resulting in decreased diversity and often decreased biomass. Moseley and Copeland (1974) have stressed the importance of maintaining a constant volume of discharge in managing brine discharge systems. Under conditions of constant discharge, mixing, and dilution efficiency, high biomass may be maintained even with high salinity-induced low diversity. Cintron et al. (1970) have described the results of an unstable brine discharge scenario in which a sudden decrease in mixing efficiency allowed an anoxic layer to form along the bottom, destroying the aerobic benthic fauna.

Instability may be more subtle, however. In some cases brines travel considerable distances along the bottom before being diluted away. Temporal changes in current regimes may affect the direction and extent of flow so that the benthic biota see a widely fluctuating salinity regime at any one point. Obviously, any study of brine pollution must include bottom salinity measurements to map the brine flow. Given the typical resistance of interstitial water to short-term changes in overlying water chemistry, interstitial salinity may be an even more effective tracer, particularly for detecting long-term trends

in fluctuating salinity regimes. Unfortunately, data on bottom salinity are rare and on interstitial salinity apparently non-existent, so that the impact of these scenarios on the benthic biota is unknown.

Changes in Biotic Composition

Interesting changes in biotic composition can, however, be predicted. Attached epifauna, for example, should be more susceptible to fluctuating salinity regimes than are infauna. Many authors have documented behavioral mechanisms used by infauna to temporarily isolate themselves from deleterious conditions in the overlying water, such as salinity and temperature changes (e.g., Myers, 1979). Under these circumstances, the attached epifaunal composition may reflect worst case conditions, whereas infauna would respond more to long-term trends. Mobile epifauna, on the other hand, may be much less affected by occasional changes in brine flow conditions, since they can escape a short-term salinity increase and reoccupy the area when the current regime changes again. In addition, since larvae are usually more susceptible to salinity stress than adults (e.g., Kinne, 1964), epifauna and infauna that are mobile as adults may be able to immigrate into areas unsuitable for larval settlement (e.g., Chapman and Newell, 1949; Dean, 1978). The small size of the meiofauna and the low dispersal capabilities of many, such as those of the sulfide system (e.g., Gerlach, 1977), make them relatively immobile in comparison to many macrofaunal organisms. In addition, subsurface meiofauna are exposed directly to the interstitial water which, in many cases, is relatively insulated from changes in the chemical composition of the bottom water (Wieser, 1975). Thus, meiofaunal community composition may reflect the long-term trends or worst case in a fluctuating brine discharge regime (e.g., Phleger, 1977). The trend toward anoxia in many brine systems, coupled with the propensity for meiofauna to be associated with anoxic systems (e.g., Fenchel and Riedl, 1970; Fenchel, 1969), reinforces this opinion. Unfortunately, a detailed benthic community analysis required to determine the importance of these processes in the establishment and regulation of community structure in brine discharge regimes has not yet occurred.

At the East Flower Garden, the brine is presumed to be anoxic when discharged. Under conditions where anoxia is relatively permanent, a typical sulfuretum community develops. Although the presence of the brine is responsible for the anoxic conditions, the East Flower Garden system is dominated by anoxia rather than high salinity, and the resulting community structure, while probably modified to some extent by the salinity regime present, resembles other sulfureta rather than the more commonly known natural hypersaline or brine systems discussed by Copeland and Nixon (1974) and others.

On the other hand, in many naturally occurring brine and hypersaline evaporite systems, such as Baffin Bay or the Laguna Madre in Texas, oxygen is more or less continuously present. Most estuarine brine discharges are also likely to be of this type (e.g., Mackin, 1971). In these conditions, the mixing efficiency is sufficient to maintain oxygen continuously within the brine. The resulting community

composition is determined primarily by the resulting salinity and a variety of chemical and physiological consequences of increased salinity rather than anoxia. In most cases, dilution and mixing efficiency are sufficient to preclude significant changes in ionic composition relative to seawater, so that increased salinity is the parameter of importance.

Effects of Brine Discharge

The effects of this type of brine discharge on typical estuarine communities have been discussed by Mackin (1973) and by Moseley and Copeland (1974). Mackin (1973) distinguishes three distinct faunal zones: a so-called abiotic zone characterized by the absence of macrofauna at the point of discharge; a zone characterized by a decreased diversity and biomass near the discharge; and a zone of increased diversity and biomass farther from the discharge point. Decreased diversity is the most consistently noted characteristic of hypersaline and brine communities in general (e.g., Moseley and Copeland, 1974; Copeland and Nixon, 1974; Gunter, 1967). On the other hand, decreased biomass is apparently an anomaly. It is not caused by high salinity *per se*, but by fluctuating brine inputs resulting in a variable or unstable salinity regime (Moseley and Copeland, 1974, and references therein), since naturally stable hypersaline systems may not exhibit decreased biomass (e.g., Copeland and Nixon, 1974; Phleger, 1977, and references therein). The decrease in diversity is caused by a variety of stresses imposed on the biota by high salinity: 1) osmotic stress (e.g., Kinne, 1964); 2) a significant decrease in oxygen solubility (Copeland, 1967); and, at 80 °/oo and above (where selective ionic precipitation becomes important), 3) changes in ionic composition with concomitant changes in pH and alkalinity (Copeland, 1967). Generally, since these stresses increase with increasing salinity, diversity is inversely correlated with salinity. The low diversity is often accompanied by shortened food chains, low community production/respiration ratios [often less than 1 (e.g., Copeland and Jones, 1965)], and stunting in the adults of many species (Carpelan, 1967; Hallam, 1965).

In light of the normally encountered diversity decrease in naturally occurring hypersaline and brine systems, the zone of increased diversity and biomass noted by Mackin (1973) is unexpected. Similar phenomena have been noted by Mackin (1971), Mathis and Dorris (1968), and Menzel and Hopkins (1951). Both Mathis and Dorris (1968) and Mackin (1973) attribute this zone to a brine-induced stimulation of algal production.

Limitations of Previous Studies

To date, studies on brine discharges and the resulting effects on community structure have concentrated on the biota of coastal embayments such as estuaries and lagoons and on biota that are typically eurytopic (see Kinne, 1964) and are therefore better able to survive salinity increases. The biota of naturally occurring hypersaline lagoons, for example, are typically eurytopic forms (Carpelan, 1967;

Kinne, 1964). The continental shelf biota are classically considered to be more stenotopic and, as such, should be less resistant to brine discharges. Thus, the changes in community structure, if any, should be more extreme. In addition, the continental shelf biota should more accurately reflect the mechanisms behind the major faunal shifts that Thierstein and Berger (1978) have correlated with brine discharges during the Miocene and Cretaceous periods. More research on the impact of brine discharges on the estuarine and continental shelf biota is clearly required. In this light, the East Flower Garden brine system provides an excellent opportunity to study a natural experiment in brine pollution on the continental shelf.

Sulfuretum

General Description

A sulfuretum exists within the brine lake. Sulfureta are communities dominated by the sulfur cycle (Fenchel, 1969; Goldhaber and Kaplan, 1974; Pfennig, 1975), and therefore by the activities of a variety of sulfur bacteria, particularly the photo- and chemoautotrophs (e.g., Aleem, 1975; Pfenning, 1975; Truper, 1975). The dominant organisms in the East Flower Garden brine lake are bacteria. In September 1977, ATP levels in the brine, mixing zone, and overlying waters were 83.3, 38.5 and 43.5 ng/l, respectively (Table X-C-24). All of these values are 10-20 times greater than those expected in Gulf water at comparable depths (2.0-5.0 ng/l) and are equivalent to bacteria values obtained from surface waters in portions of the Gulf of Mexico.

The formation of a sulfuretum requires a source of hydrogen sulfide (H_2S) for the sulfur bacteria. Since H_2S reacts rapidly with oxygen (O'Brien and Birkner, 1977), an anoxic zone must be present. Many of the bacteria typical of sulfureta are obligate anaerobes. Others require both oxygen and H_2S. The effective boundary of the community, therefore, is the oxic-anoxic boundary (the redox potential discontinuity, RPD, or chemocline). The horizontal and vertical distribution of the biota and the species composition depend to a large extent on the location of the oxic-anoxic boundary relative to the bottom and to the photic zone. (For a more complete discussion, see Fenchel, 1969; and Reimers, 1976.)

The most commonly encountered sulfuretum occurs on intertidal and subtidal marine bottoms where the oxic-anoxic boundary is essentially equivalent to the sediment surface (Fenchel, 1969; Reimers, 1976). The community depends on sulfate reduction by bacteria such as Desulfovibrio (Goldhaber and Kaplan, 1974) in the anoxic sediment to produce sufficient H_2S to meet the bacterial needs, plus enough to remove oxygen chemically (O'Brien and Birkner, 1977) or biochemically (Jorgensen and Fenchel, 1974) and maintain the oxic-anoxic boundary at the sediment surface. If the bottom is in the photic zone, a bacterial mat composed of green and/or purple photosynthetic sulfur bacteria will develop in the sediment surface (Jorgensen and Fenchel, 1974).

Hydrogen sulfide is supplied to the mat from the anoxic sediment below. (See Jorgensen, 1977a, for sulfur redox reactions and the sulfur cycle.)

Under certain hydrodynamic and geological conditions, the RPD can move into the water column, leaving a relatively stagnant body of water between it and the bottom. The RPD, or chemocline, is usually associated with a pronounced thermocline and/or halocline, which documents the reduction in mixing normally required to limit oxygen input. Hydrogen sulfide production in the stagnant water or sediment below it must equal or exceed the rate at which oxygen moves across the pycnocline to maintain anoxia. Under these conditions, the sulfuretum can exist as a planktonic community in the water column. Particularly well developed examples occur in many lakes where the chemocline is in the photic zone and planktonic photosynthetic sulfur bacteria occur in high numbers (Cohen et al., 1977b; Takahashi and Ichimura, 1970; Culver and Brunskill, 1969; Czeczuga, 1968; Gorlenko et al., 1978). If the chemocline is below the photic zone, chemoautotrophs may become important (e.g., Orca Basin, LaRock et al., 1979; Cariaco Trench, Karl et al., 1977). If the photic zone includes the bottom, a benthic bacteria or blue-green algal mat can be present as well (e.g., Krumbein et al., 1977; Jorgensen and Cohen, 1977).

Algal Mat

The brine lake at the East Flower Garden resembles the blue-green algal mat type. The basin is filled with high salinity anoxic water and is within the photic zone. The lake contains a flocculose sulfur bacterial mat on the bottom (see Krumbein et al., 1977, for descriptions of various mat types). Judging from the color changes observed, several types of bacteria are present in a well developed zonation pattern. During all submersible dives, white patches, apparently of dense cell masses and elemental sulfur, were observed floating at the brine-seawater interface and adhering to the substratum everywhere the interface intersected the bottom. The interface between brine and overlying oxygenated seawater is sharp, with sulfide-rich anoxic water below and sulfide-deficient, oxygen-rich water above (Table X-C-24). This interface, or pycnocline, is favorable for growth of sulfide oxidizing bacteria which require both sulfide and oxygen for active development. A culture of sulfide-oxidizing, sulfur-producing bacteria, isolated by Dr. Paul LaRock from the 1977 East Flower Garden brine samples, produced sulfur deposits in the laboratory (Bright et al., in press). Evidence strongly indicates, therefore, that the white material in the lake is a sulfur bacterial mat. White mats also cover the bottom of the canyon where the stream of mixing water touches the substratum. Sulfide levels in the mixing water are high, even at the canyon mouth (Table X-C-24). The stream water is also oxygenated due to the admixture of seawater. Thus, the entire mixing stream represents a flowing zone of water a few metres wide and up to one metre thick, containing both oxygen and sulfide. The existence of sulfide-oxidizing bacteria should be favored in this stream as it contacts the substratum. It is probable that the fragile white mat covering the axis of the canyon and rocks bathed by the mixing stream is produced by sulfide-oxidizing bacteria.

Directly beneath and bordering the interface-related white mats in the lake there is almost always a narrow, dark-olive colored mat. Deeper in the brine, covering nearly all of the bottom of the lake, is a deposit of light-olive colored material of loose, fine, particulate consistency, which is easily resuspended. This deposit is several centimetres thick in the deeper parts of the lake and is presumably of organic origin. In 1976, thin, diffuse patches of purple were observed directly adjacent to the dark-olive mats near the lake borders. The purple color was absent in 1977. The olive mats and purple coloration are also thought to be of bacterial origin (cf. Jorgensen and Fenchel, 1974).

Productivity of Sulfureta

If conditions are right, sulfureta can be very productive. For example, production by the photosynthetic sulfur bacteria in or below the chemocline of many lakes contributes as much as 50-90% of the total primary production in the water column (e.g., 60-8000 mg C/m^2 a day*: Cohen et al., 1977b; Culver and Brunskill, 1969; Gorlenko et al., 1978; and references therein) even though the bacterial community often exists under very low light levels (e.g., 1% of surface light: Czeczuge, 1968; Takahashi and Ichimura, 1970). If the bottom is in the photic zone, the total primary production of the system can be increased considerably by the development of a photosynthetic bacterial (or blue-green algal) mat. In Solar Lake, production rates as high as 5 g C/m^2 a day have been measured in the flocculose mats below the chemocline, where light intensities are only 0.2% surface light (Krumbein et al., 1977). These productivities compare favorably with typical productivities of aerobic pelagic communities (e.g., El-Sayed, 1970; Walsh et al., 1977; Huntsman and Barber, 1977), particularly those producing at low light intensities (e.g., Bienfang and Gundersen, 1977; Venrick et al., 1971), and to aerobic benthic communities (e.g., Pomeroy, 1959; Leach, 1970). Clearly, sulfureta can be as productive as the most highly productive marine aerobic systems and, thus, might provide a substantial and important trophic base for a eukaryotic consumer community if the production can, in fact, be used by eukaryotes.

Formation of H_2S

The maintenance of an active sulfuretum depends on the presence of an H_2S source. An interesting implication of this dependence is whether the entire trophic balance of the system is heterotrophic or autotrophic. There are two predominant mechanisms for the production of H_2S in the marine environment. On the one hand, H_2S can be produced by dissimilatory sulfate reduction (Roy and Trudinger, 1970) or by sulfate-reducing bacteria like Desulfovibrio. This process requires an organic carbon source (Roy and Trudinger, 1970; Goldhaber and

*C/m^2 a day = milligrams of carbon per square metre per day.

Kaplan, 1974). Biochemical pathways used by typical chemo- or photoautotrophic sulfide oxidizers (e.g., Pfenning, 1975; Goldhaber and Kaplan, 1974) can fix no more CO_2 per H_2S molecule used (and probably much less since S° [elemental S] is the normal end-product) than sulfate reducers release per H_2S released (or SO_4^{2-} used). Thus, an organic carbon source must be supplied from the outside to fuel H_2S production. For example, detrital remains of leafy algae, sponges, and other invertebrates have been found in the East Flower Garden brine lake, indicating that input of organic carbon to the lake from the surrounding benthic community does occur. In the final analysis, such a system depends on the aerobic production of organic carbon, and its net effect is heterotrophic. This does not prevent the sulfuretum from being an important food source for the immediate area, however, since it may rework organic matter into a more usable form. Nearly all described sulfureta are of this type.

The second method of H_2S formation involves an inorganic reduction of SO_4^{2-} to H_2S. The formation of H_2S at rift valleys is a good example (Corliss et al., 1979). Sulfureta which depend on inorganically formed H_2S, and not dissimilatory sulfate reduction, can be true autotrophs. Examples probably include the sulfureta of the early earth (S^{-2} preceded water as an electron donor, Hall, 1971) and the Galapagos rift system (Corliss and Ballard, 1977; Corliss et al., 1979). The East Flower Garden seep probably behaves primarily as an autotrophic source over the life span of the seep (although over geological time it must be heterotrophic) and so mimics the Galapagos rift situation in this regard. The H_2S probably co-occurs with the brine itself in the source rock (see Collins, 1967, 1975) so that H_2S is continuously supplied to the sulfuretum with the brine seepage. In this respect, the seep has a significant energy subsidy (see Odum, 1971, for this concept) since H_2S is pumped through the bacterial mat constantly. High productivity should be the result. Observations on the rate at which pieces of the bacterial mat are swept out the outflow channel along with the brine certainly support the view that the seep is highly productive. It is likely that the Galapagos rift system has an energy subsidy of a similar kind and is also highly productive.

Soft-Bottom Macrobenthos Adjacent to the Brine Lake

In spite of the high salinity water, which probably modifies the community composition to some extent, the basic prokaryotic community structure of the brine lake itself is probably dependent, as it is in most sulfureta, on gradients of oxygen, hydrogen sulfide, and light. The resulting community probably resembles, in most respects, sulfureta of more normal salinity anoxic basins. Eukaryotes, however, should be severely limited by the high salinity within the seep, so that diversity should be low if any species are present at all.

The soft-bottom community adjacent to the outflow channel, on the other hand, exists at hypersaline salinities (40 °/oo) commonly inhabited by a variety of metazoans and protozoans (Kinne, 1964). Carbonate sand was collected from the canyon mouth, where the salinity was

38-40 °/oo and hydrogen sulfide was present. The sand contained (in decreasing order of abundance) live polychaetes, podocopid ostracods, nematodes, gammarid and caprellid amphipods, tanaidaceans, isopods, harpacticoid copepods, pelecypods, and gastropods.

The presence of an apparently rich and diverse fauna living downstream of the seep suggests a possibly important trophic role as a primary producer for the sulfuretum in the brine lake. The scientific literature contains few examples of eukaryotic consumer communities trophically based, at least in part, on primary production by sulfur bacteria. Recent work, however, has implicated sulfur bacteria as a significant food source in several cases. Successful exploitation, however, appears to be restricted to cases where the oxic-anoxic boundary is coincident with or below the sediment surface or where a physical process transports the bacteria out of the anoxic zone. For example, the sulfur bacteria probably supply a significant portion of the trophic base for the meiofauna of the sulfide system (Fenchel and Reidl, 1979) and the eukaryotic community associated with many benthic sulfureta (e.g., Fenchel, 1969; Reimers, 1976). These animals actually live in and below the redox potential discontinuity (RPD) in marine sediments and can directly exploit the sulfur bacteria as a food source where they grow. All are probably euryoxic or anaerobic, and all probably possess adaptations to detoxify H_2S (Powell et al., 1979) so that they can directly exploit anoxic benthic environments.

The presence of significant numbers of sulfur bacteria in normal marine sediments (e.g., Jorgensen, 1977b,c; Kepkay et al., 1979) suggests that sulfur bacteria may be a significant food source for macrofaunal deposit and detritus feeders as well. Although direct data are presently lacking, three factors imply a potentially significant trophic role for sulfur bacteria in most shallow water marine sediments: 1) the presence of deposit feeders which feed partially or exclusively below the RPD (see Rhoads, 1974; Powell, 1977); 2) the significance of coprophagy (e.g., Frankenberg and Smith, 1967), coupled with the role of fecal pellets as reduced microniches in oxidized sediment (Jorgensen, 1977b); and 3) the recent suggestions that Arenicola (Hylleberg, 1975) and Upogebia (Ott et al., 1976) may culture bacterial gardens.

On the other hand, whether for reasons of H_2S toxicity, anoxia, or other unknown factors, cases of metazoans, pelagic or benthic, crossing or living in or below a waterborne chemocline are apparently very rare (see Rhoads and Morse, 1971). Thus eukaryotes are, for the most part, prevented from directly exploiting the primary production of anoxic basins, including the brine lake. The primary production will be used by a heterotrophic prokaryotic biota within the sulfuretum (e.g., Solar Lake, Cohen et al., 1977c) unless a mechanism exists to transport the production across the oxic-anoxic boundary. Two mechanisms are known. Grazing at the edges of these basins provides one, albeit probably highly inefficient, mechanism. Zooplankton, for example, graze on sulfur bacteria just above the chemocline in many lakes (e.g., Cohen et al., 1977c; Culver and Brunskill, 1969). The presence of a well-developed euryoxic benthic biota at the edges of some

anoxic basins (e.g., Nichols, 1976; Rosenberg, 1977) suggests a similar scenario in the benthic community.

A second mechanism uses a physical agent to transport the production out of the sulfuretum and on to a typical benthic community. The discovery of a flourishing suspension-feeding community at the Galapagos rift (Corliss and Ballard, 1977; Corliss et al., 1979) provides a good example of how a productive sulfur bacterial community can become the trophic base for a eukaryotic community when a physical process is present to advect the bacteria from the sulfuretum to the oxic environment. In this case, water circulation associated with active spreading centers produces currents issuing from vents along the rift valley. These currents supply H_2S to the sulfur bacteria, which probably live in the vents, and simultaneously advect a portion of the bacterial production to the suspension feeding community living around the vents (Rau and Hedges, 1979).

The second example of such a mechanism is present at the East Flower Garden, where outflowing brine continuously sweeps portions of the bacterial mat down the outflow channel and onto the soft bottom. When the brine has dissipated, the bacteria remain as a potentially important food source for the soft-bottom community. In this case, the deleterious effects of the brine itself may be outweighed by the positive effects of a greatly increased food source.

On a global scale, communities dependent on a sulfuretum as a trophic base are relatively rare because anoxic systems are of limited areal extent. Evidence exists, however, suggesting that anoxic systems were much more common during earlier periods of the earth's history. During portions of the Precambrian, for example, sulfide oxidation provided the sole source of photosynthetic carbon. Since the introduction of oxygen into the marine system during the Precambrian (Cloud, 1976), anoxic waters suitable for sulfureta must have become less and less common. Nevertheless, conditions conducive to the formation of large scale anoxia in the major ocean basins have occurred throughout history (e.g., Ryan and Cita, 1977; Berry and Wilde, 1978; Gartner and Keany, 1978), and on several occasions may have been created by large scale brine discharges from tectonically created basins (e.g., Thierstein and Berger, 1978). In each case, the potential for the development of a sulfuretum existed, and a trophically important food source could have been present if conditions for exploitation were appropriate. It appears likely, therefore, that production by sulfur bacteria has been an important food source over wide areas of the ocean during the Phanerozoic and that it may be of less importance today than at many times in the past. The East Flower Garden and the community downstream of it may exemplify a system that has played a significant role in the trophic structure of the ocean basins throughout history. Such communities as the sulfide system, euryoxic fauna near anoxic basins, and the benthic sulfureta of Fenchel (1969) and others may, thus, be the present-day relicts of widespread and important marine communities of the past.

Reef Biota Adjacent to the Brine System

Since the attached epibenthic biota are particularly susceptible to frequent changes in local environmental conditions, gradients in their community structure should reflect the hydrodynamic conditions in the area of the brine lake and particularly the significance of the upward transport of salt and H_2S across the pycnocline for the nearby reef community. Such gradients probably depend on the equilibrium between the upward transport of salt and advective phenomena in the overlying water, which control the rate of dispersion of the salt. Observations of the distribution of the epibenthic macrobiota suggest that the effects of the brine are localized and, in fact, confined to an area within 2 m of the brine mixing stream (Table X-C-24).

For example, coralline algae (Lithothamnium and Lithophyllum) are the dominant organisms on the East Flower Garden at the depth of the brine lake (Bright and Rezak, 1977). Coralline algae crusts cover 50% to 90% of the exposed rock, nodules, and rubble (which are deposited primarily by the algae). As the primary substratum producers, these algae create and maintain the essential habitat for attached and mobile benthic organisms associated with the periphery of the hard bank. The distribution and apparent health of coralline algae adjacent to the brine are, therefore, of some importance.

Interestingly, it appears that coralline algae populations are affected to a greater extent in the overflow canyon than in the basin containing undiluted brine. One nodule which was only partly immersed in the brine lake was collected. That part of the nodule which was below the brine-seawater interface housed no live macroscopic organisms. However, the upper surface of the nodule, 1 to 4 cm above the interface, was encrusted with healthy coralline algae. The depth of the brine pool must be stable relative to the life span of the algae, and the rate of salt transport by molecular diffusion across the pycnocline must be relatively low since visual observations of the lake indicate that coralline algae populations are apparently normal a few centimetres above the lake interface wherever it contacts hard substratum.

In the overflow canyon, there is no stable, sharp interface between the mixing stream and adjacent seawater. The lower limit of apparent healthy encrustations of coralline algae on the walls of the canyon corresponds generally to the rather diffuse top of the mixing stream.

Filamentous, white-colored algae of the genus Chaetomorpha (and/or Cladophora) were collected from rocks at the canyon mouth, where the brine-seawater mixture was 38-40 °/oo and contained lesser amounts of hydrogen sulfide (Table X-C-25). Green Chaetomorpha and Cladophora occur elsewhere on the East Flower Garden Bank. Apparently, unpigmented forms of these filamentous algae may survive in very dilute brine where sulfur bacterial activity is no longer favored and toxicity to macrobenthic plants and animals is marginal. Similar white,

filamentous organisms have been seen surrounding the points of emission of natural gas seeps on the East Flower Garden and other banks.

Filamentous algae occur immediately above the lake's brine-seawater interface. A few centimetres above the brine, the top of the algal nodule collected from the lake harbored species of algae belonging to the genera Cladophora, Dictyota, and Microdictyon. In September 1976, a substantial population of Microdictyon, green Chaetomorpha, Rhizoclonium, and other species of leafy algae were collected from a slight elevation of the sandy substratum along the "shoreline" of the brine lake. The algae were growing in seemingly healthy condition only 2 cm away from the brine. The same location was devoid of filamentous algae in September 1977. Such populations must be subject to substantial seasonal and/or year-to-year variation. Population changes may also result from fluctuations in discharge rates of the brine, resulting in local variations in the extent of soft bottom contacted by the brine. Dead remains of the leafy algae and invertebrates, such as the demosponge Agelas and the whelk Busycon, were found in the brine lake. These were probably washed in from the surrounding bank. In contrast to the fish, no invertebrates were seen to willfully cross the pycnocline and enter the brine pool or the mixing stream in the canyon.

Effects of the brine on the distribution of epibenthic invertebrates are apparently similar to those described for algae (Table X-C-25). Live foraminifera, sponges, bryozoans, anemones, polychaetes, sipunculids, amphipods, and pelecypods were found 1 or 2 cm above the brine-seawater interface on the aforementioned nodule taken from the brine lake. Small, healthy, saucer-sized colonies of hermatypic, agariciid corals were observed within 3 m lateral distance and 0.5 m above the edge of the brine lake. The same corals occur on top of a large rock in the axis of the canyon less than 1 m above the upper limit of the mixing stream. Sponges were seen on the canyon walls within 1 m of the mixing stream.

Qualitative, visual assessment of attached epibenthic communities occupying the hard substratum immediately adjacent to the brine lake and mixing stream reveals no obvious differences between them and communities at the same depth some distance away in terms of composition and condition of large, conspicuous benthic organisms. Nevertheless, more systematic quantitative observations of the diversity and biomass of these communities are necessary before conclusive interpretations can be made concerning effects of the brine system on the attached epibenthos. Observations of the long-lived immobile portion of the community, for example, may be expected to reveal whether any long-term instability exists in the brine-seawater hydrodynamic system.

Fishes

At least 29 species of fishes were seen within the brine seep basin and canyon (Table X-C-25). All are typical inhabitants of the

TABLE X-C-25
ORGANISMS ASSOCIATED WITH THE EAST FLOWER GARDEN BRINE LAKE

ORGANISMS	In Brine Lake 200 °/oo	In Mixing Stream 39-55 °/oo*	Within 1 m of Lake Interface 36 °/oo	Within 1 m of Mixing Stream 36 °/oo	Canyon and Basin Walls 36 °/oo	Elsewhere on EFG Bank
Bacteria						
Sulfur bacteria mat	+	+				
Algae						
†Chaetomorpha sp. (white)		+39				
Chaetomorpha sp. (green)			+			+
Cladophora sp.			+			+
Rhizoclonium sp.			+			+
Dictyota sp.			+			+
Microdictyon sp.			+			+
Halimeda sp.					+	+
Coralline algae		+39	+	+	+	+
Sponges						
Unidentified sponges			+	+	+	+
Neofibularia nolitangere					+	+
Scleractinian Corals						
Agariciidae			+	+	+	+
Antipatharians						
Cirripathes sp.			+	+	+	+
Echinoderms						
Diadema antillarum					+	+
Fishes						
Mymnothorax sp. (Moray eel)		+39		+		+
Synodus sp. (lizardfish)		+39		+		+
Holocentrus sp. (squirrelfish)				+		+
Gonioplectrus hispanus (Spanish flag)		+48		+		
Liopropoma eukrines (Wrasse bass)				+	+	+
Paranthias furcifer (Creole fish)				+	+	+
Epinephelus inermis (Marbled grouper)		+48		+	+	+
Epinephelus adscensionis (Rock hind)				+		+
Mycteroperca sp. (grouper)		55 +48 39	+	+	+	+
Holanthias martinicensis (Roughtongue bass)		+48		+		+

TABLE X-C-25 (Continued)

ORGANISMS	In Brine Lake 200 °/oo	In Mixing Stream 39-55 °/oo*	Within 1 m of Lake Interface 36 °/oo	Within 1 m of Mixing Stream 36 °/oo	Canyon and Basin Walls 36 °/oo	Elsewhere on EFG Bank
Priacanthus sp. (Bigeye)					+	+
Apogon sp. (cardinalfish)				+		+
				+		+
Caranx sp. (jack)					+	+
Seriola dumerili (Greater amberjack)	+		+		+	+
Lutjanus sp. (snapper)	+		+	+		+
Haemulon melanurum (Cottonwick)		+39		+	+	+
		48				
Calamus sp. (porgy)			+	+	+	+
Equetus sp.				+		+
Pseudupeneus maculatus (Spotted goatfish)					+	+
Holacanthus tricolor (Rock beauty)				+		+
Holacanthus ciliaris (Queen angelfish)					+	+
Holacanthus bermudensis (Blue angelfish)		+48		+	+	+
Prognathodes aculeatus (Longsnout butterflyfish)				+		+
Chaetodon sedentarius (Reef butterflyfish)				+	+	+
Chromis enchrysurus (Yellowtail reeffish)			+	+	+	+
Bodianus pulchellus (Spotfin hogfish)		+48		+	+	+
Sphyraena barracuda (Great barracuda)					+	+
Acanthurus sp. (surgeonfish)				+	+	+
Balistes capriscus (Gray triggerfish)				+	+	+
Malacanthus plumieri burrow (Sand tilefish)					+	+

*salinities indicated in column
tand/or Cladophora

East Flower Garden at the depths in question. Only one, Gonioplectrus hispanus, has not been seen previously on the bank, but it occurs at comparable depths on the West Flower Garden Bank, 25 km away. Groupers (mostly Mycteroperca phenax) and members of a large school (100 or more) of Cottonwick, Haemulon melanurum, were the most frequently encountered fish in the canyon.

Of the 29 species, 21 were observed within 1 m distance of the mixing stream, usually on the canyon wall near its base. All behaved in apparently normal fashion. Only 4 species were seen within 1 m of the lake's brine-seawater interface. The lake, however, being surrounded by sand for the most part, is rather isolated from the basin walls and rocky substratum which would attract reef fishes. A Sand tilefish, Malacanthus plumieri, had constructed a burrow in the sandy bottom near the basin's western wall, 15 or 20 m from the lake margin.

Nine species of fish entered the mixing stream. Most of these occurrences were near mid-canyon at a 2 m high boulder, the lower half of which was immersed in the stream. Salinity in the stream axis at this location was 48 °/oo, with dissolved sulfide, methane, and presumably oxygen present (Table X-C-25). The smaller fishes (several Holanthias martinicensis, a young Gonioplectrus hispanus, and Bodianus pulchellus) swam along the surface of the boulder, repeatedly entering and leaving the mixed water, with no apparent change in behavior as they did so. One large Blue angelfish, Holacanthus bermudensis, swam completely across the axis of the stream along the bottom, taking two bites from the stream bed, as if feeding. This fish then swam over the surface of the boulder, entering and leaving the mixed water several times, apparently ignoring the difference in water types.

Several fishes exhibited behavior which could be interpreted as purposeful entry into the water of the hypersaline mixing stream and hypersaline brine of the lake. From mid-canyon to the canyon mouth, groupers and Cottonwicks swam in and out of the mixed water, usually with no particular behavioral changes other than a tendency to turn upstream swimming gently against the current while holding their position. Frequently, however, individual Cottonwicks were observed to sweep downward into the stream axis, swim quickly and somewhat erratically upstream for a short distance, and then leave the stream. This maneuver, which lasted only 1 or 2 seconds, was repeated frequently by individual fishes. The fishes may have been responding primarily to the presence of a bottom current rather than to chemical characteristics of the approximately 48 °/oo water.

On three occasions, large Greater amberjack, Seriola dumerili, swam rapidly downward toward the brine-seawater interface of the lake, turned on their sides as they approached the bottom, entered the hypersaline brine (200 °/oo), flapped violently along the bottom on their sides for a few strokes, and then swam upward. One large snapper, Lutjanus sp., apparently performed a similar action; it was seen swimming quickly away from a stirred-up spot in the lake. This is typical behavior for jacks and other large fishes on sandy bottoms in the absence of brine and may not have been elicited by the presence of

brine. Nevertheless, these fish did briefly enter the anoxic, sulfide-rich brine, stirring it up considerably. These observations, plus those of Baird et al. (1973) and Wilson (1972) for the Cariaco Trench, indicate that successful roundtrip excursions by fish across pycnoclines into anoxic basins are more common than is generally appreciated and in marked contrast to the apparently infrequent excursions by the mobile portion of the invertebrate population.

Summary and Conclusions

Anoxic sulfide-rich brine (approx. 200 °/oo) of nearly ambient temperature percolates from the seafloor, forming a small, shallow lake of dense water in a depression at the eastern margin of the East Flower Garden Bank. Residence time for the brine in the lake is less than one day (probably 2-7 hours). Significant mixing of the brine with overlying seawater apparently does not occur across the interface, although organic gases, sulfate, and other dissolved components of the brine diffuse across the interface into the overlying seawater. Brine overflows the lake and is substantially mixed with seawater in the axis of a 60 m long canyon extending from the lake to the bank edge, where dilutions of greater than 50:1 occur.

An intrusion of Jurassic salt, from depths of 6000 m or more, penetrates to within 150 m of the seafloor (possibly 30 m) directly beneath the bank. The chemical composition of the brine indicates that it is a product of dissolution of this salt by seawater percolating through cracks, faults, or permeable reef rock.

Sulfide-oxidizing bacteria are abundant at the brine-seawater interface and on the canyon floor, where mixing brine and entrained seawater flow in a recognizable stream along the bottom. In both cases, hydrogen sulfide and oxygen are present in quantities necessary to support such bacterial activity, resulting in the production of substantial amounts of elemental sulfur and organic matter.

Although the anoxic, sulfide-rich brine and oxygenated brine-seawater mixtures are obviously toxic to normal bank biota, deleterious effects on surrounding epibenthic communities are minimal and restricted to a zone several centimetres to 2 m wide surrounding the lake and mixing stream. No living macroscopic plants or animals occur in the brine or in the mixing stream for most of its length. However, living coralline algae, leafy algae, foraminifers, sponges, bryozoans, anemones, polychaetes, sipunculids, amphipods, and pelecypods occur 1 or 2 cm above the brine seawater interface. Scleractinian corals, antipatharians, and a seemingly normal assemblage of epibenthic organisms occupy the hard substratum 1 to 3 m away from the lake interface and mixing stream.

Toxicity of the brine decreases as it is diluted with overlying seawater, and certain epibenthos and infauna can exist in the mixing stream where the ratio of seawater to brine approaches 50:1 (38 to 40 °/oo salinity, limited sulfide). Under these conditions, white-colored, filamentous Cladophorales algae grow on the hard substratum,

and coarse carbonate sand harbors polychaetes, podocopid ostracods, nematodes, gammarid and caprellid amphipods, tanaidaceans, isopods, harpacticoid copepods, pelecypods, and gastropods.

Demersal fishes repeatedly pass in and out of the mixing stream, where seawater dilution is moderate to high. Several species will briefly enter the full-strength brine in the lake.

In light of the interest over the past 10-20 years in the effects of brine discharges on the communities of the receiving basin, the impact of the East Flower Garden brine discharge on a relatively fragile ecosystem such as the deep water reef is particularly important. The biota of the seep itself is unquestionably markedly changed. The typical aerobic community has been replaced by an anaerobic one. On the other hand, the remainder of the reef community appears not to be visibly affected by the brine except in a narrow 1-2 m wide bank around the seep. This is certainly not unexpected given the well-known stability of strong pycnoclines and the fortuitous presence of an overflow channel which regulates the level of the brine lake.

Turbulent flow down the overflow channel effectively mixes the brine with normal seawater. Although the effects of moderately increased salinity on the adjacent soft-bottom community are not known, the invertebrate population is clearly sizeable and surprisingly diverse. The effect of the hypersaline water on this community may not be wholly negative. The brine system may provide a significant food source. Continual gravity flow down the outflow channel serves to advect this production to the user community below. This increased food supply may at least ameliorate the effects of the salinity increase. After a detailed study of the brine seep area is completed, the possibility remains that the most important effect of the seep's presence will be shown to be the increased food supply it provides rather than the salinity stress it imposes on the immediately adjacent area.

Petroleum production and desalination operations require the discharge of brines into seawater. Construction of certain regional petroleum reserve storage facilities involve dissolution by seawater of the cores of salt domes (similar to the one beneath the East Flower Garden) and the discharge of resulting brines into the ocean. Brine pollution may become increasingly important in the near future. The East Flower Garden brine system provides an example of a possible management technique for brine discharges. As Moseley and Copeland (1974) have pointed out, oxic hypersaline systems can be very productive and have a high biomass present even though diversity remains low. Instability, however, in the rate of discharge, or in mixing efficiency which controls oxygenation, results in greatly decreased production and biomass. The propensity for brines to become anoxic and the high productivity of sulfureta suggest that the cultivation of an anoxic system to produce food for a euryhaline biota may be possible and, at the same time, be less susceptible to fluctuating discharge rates. A brine discharge could be used to create conditions favorable for sulfureta in

in a brine pool and at the same time provide the transport mechanism to sweep the bacteria out of the sulfuretum to a euryhaline user community. The apparently highly productive suspension feeding community at the Galapagos rift (Corliss et al., 1979) provides an example of what may be possible. The adaptation of such a mechanism to the forming of euryhaline suspension feeders such as oysters should be considered.

PART D: CHEMISTRY

TRACE METALS ANALYSIS

B. Presley, P. Boothe

Sediments

Samples for sediment trace metals analysis were collected at four East Flower Garden sites (for full details, see Volume Two, Chapter IX-A). Sediment samples from the west side of the bank are mostly reef-derived, whereas those from the east side are not. Although this basic difference in sediment source might be expected to strongly influence the trace metals concentrations, no influence has been detected.

Concentrations of Al, Ca, Cd, Cr, Cu, Fe, Ni, V, and Zn were found to be highly variable on and near the bank. Most of this variability is due to variations in the $CaCO_3$ content of the samples, as $CaCO_3$ is very low in these metals. Measured levels of the nine metals listed above are considered to be normal for the sediment type considered, and there is little reason to believe they have been influenced by man.

A few samples, however, contained Pb concentrations about 50% higher than would be expected, and a few contained Ba as much as ten times above expected levels. These samples were almost all taken very near sites of exploratory oil well drilling and thus are likely to be due to drilling. (Sample locations and drill sites are shown in Volume Two, Figure IX-A-1.)

Given the high $CaCO_3$ content of the sediment, trace metal concentrations are generally low around the East Flower Garden Bank. Such sediment, however, can be easily contaminated by relatively small additions of trace metals by man, and the evidence strongly indicates such contamination with Pb and Ba. Future activities by man at this bank should be conducted in such a way as to minimize additions of trace metals to the bottom sediments.

Spondylus

The concentrations of ten trace metals (Al, Ca, Cd, Cr, Cu, Fe, Ni, Pb, V, Zn) have been determined in 19 individual *Spondylus americanus* (Spiny oyster) from the East Flower Garden Bank. These *Spondylus* were collected over the three years of the Topographic Features Study (3 in 1976, 1 in 1977, and 15 in 1978). Trace metal levels observed are very similar among all three years except for the anomalously high levels of Cu and Pb in the 1976 samples (see Volume Two, Chapter IX-A, Table IX-A-2). The reason for these higher levels is unclear, but they certainly do not represent any trend. Four metals (Cu, Fe, Pb, and Zn) were significantly correlated with the size of *Spondylus* analyzed. These relationships accounted for 60-90% of the variability in trace element levels observed among these individuals.

HIGH MOLECULAR WEIGHT HYDROCARBONS IN SPONDYLUS AND MACRONEKTON

C. Giam, G. Neff

As a test for possible petroleum contamination, 21 Spondylus americanus samples and 2 macronekton species (Pagrus sedecim, Red porgy; and Lutjanus campechanus, Red snapper) were collected from four banks for analysis for high molecular weight hydrocarbons. From the East Flower Garden Bank, 15 Spondylus samples (13 in October 1978, 2 in September 1979), and two Lutjanus campechanus samples (8 individuals, fall 1979) were collected. All Spondylus samples were analyzed as whole organisms, less shell. For the macronekton samples, muscle, liver, and gonad tissues were analyzed.

In general, the results of the analyses (see Chapter IX-B) were similar to those seen in the previous years of this study. Liver and gonad samples had higher concentrations and broader distributions of hydrocarbons than muscle and Spondylus samples. Squalene was the only compound detected in the aromatic fraction.

However, two fall 1979 samples of Spondylus from the southeast area of the East Flower Garden had slightly higher concentrations and broader distributions of hydrocarbons than the average (see Volume Two, Tables IX-B-7 and 9, Samples SAC and SAE). These findings suggest possible low-level petroleum contamination of that area. While no firm conclusions can be drawn in the absence of other typical petroleum indicators, such as aromatic hydrocarbons, this is the first time any level of petroleum contamination has been suggested by the hydrocarbon analyses. Thus, these results do indicate a need for further monitoring of the area to determine if petroleum contamination is occurring.

HIGH MOLECULAR WEIGHT HYDROCARBONS, DELTA C-13, AND TOTAL ORGANIC CARBONS IN SEDIMENTS

P. Parker, J. Winters, R. Scalan, D. Boatwright

Introduction

Analyses for levels of high molecular weight hydrocarbons Delta C-13, and total organic carbon in sediments at the East and West Flower Garden Banks were based on thirty sediment samples from the East Flower Garden and three samples from the West Flower Garden. Full details of results of these analyses are reported in Volume Two, Chapter IX-C. Results are summarized below.

High Molecular Weight Hydrocarbons

The high molecular weight hydrocarbon composition, pristane-phytane ratios (Pr/Ph), odd-even ratios (OEP), and GC/MS confirmation of aromatic hydrocarbons were used as indicator parameters of petroleum contamination. In addition to sampling around the perimeter of the East Flower Garden Bank, two drill sites, Drill Site 1 (DS1) and Drill Site 2 (DS2), were extensively sampled. While no significant

difference was noted in the various petroleum indicator parameters, many of the samples from DS2 possessed unique features. These can be attributed to the sediment biota, viz., an even carbon predominance in the C_{12}-C_{20} range, and large amounts of monounsaturated n-C_{14} and n-C_{16} hydrocarbons and n-C_{22}. Although the presence of aromatic hydrocarbons was observed in virtually all samples, the levels were quite low and may reflect general baseline levels as contrasted to site-specific enrichment.

The results of the sediment hydrocarbon analyses for this year indicate that the Flower Garden Banks remain a relatively clean environment. However, the slight increase in total hydrocarbon levels at the East Flower Garden, and the low, albeit detectable, levels of aromatic hydrocarbons at both banks warrant continued monitoring of this unique and sensitive environment.

Delta C-13

The range of Delta C-13 values for the thirty East Flower Garden sediment samples was -20.04 to -21.78; for the three West Flower Garden samples, range was -21.0 to 21.7. These values are slightly lower (approx. 1 per mil) than the 1977 values (-19.52 to -20.38), but still consistent with the assessment that the Flower Garden Banks are relatively clean. However, the possibility that this shift is the beginning of a long-term trend warrants continued monitoring.

Total Organic Carbon

The total organic carbon (TOC) values from the thirty East Flower Garden sediment samples ranged from 0.68 to 1.49%; range for the three West Flower Garden samples was 0.58 to 1.36%. These are similar to the 1977 values (1.18 to 1.39%) and, again, consistent with the assessment that the Flower Gardens are relatively clean. Although three of the thirty East Flower Garden samples were collected four months after the blow-out of the IXTOC-I well in the Bay of Campeche, no difference in the TOC values was observed. This is consistent with the University of Texas observations that the IXTOC oil was concentrated in the nearshore zone.

APPENDIX C

RAW DATA TABLES

TABLE X-C-1
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Montastrea annularis

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	27.37	43.03	40.11	43.48	38.46
1 RPLT -2	19.50	45.61	35.62	32.14	25.71
1 HPLT -1	47.50	68.47	65.74	78.26	64.29
1 HPLT -2	9.25	19.63	18.05	28.57	22.22
1 HPLT -3	47.75	76.25	72.21	52.17	42.86
2 HPLT -1	35.50	62.01	56.02	34.62	25.00
2 HPLT -2	43.12	65.09	64.73	31.58	30.00
2 HPLT -3	42.75	73.08	68.67	53.33	44.44
3 HPLT -1	30.50	58.10	53.86	39.13	32.14
3 HPLT -2	33.19	48.23	46.95	27.59	24.24
3 HPLT -3	49.87	71.12	68.44	43.33	35.14
4 HPLT -1	41.25	78.48	72.77	40.00	28.57
4 HPLT -2	32.12	61.93	58.14	51.61	42.11
4 HPLT -3	39.62	61.32	58.38	36.36	29.63
5 HPLT -1	48.50	66.90	64.03	36.84	28.00
5 HPLT -2	38.25	52.40	51.78	38.89	36.84
5 HPLT -3	38.81	45.70	44.29	26.67	20.00
MEAN VALUE	36.76	58.67	55.28	40.86	33.51

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE % COVER	REL. DOM. (CORALS)	REL DOM. CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY CORAL & COR. ALGAE)
S^2/S	110.28/10.50	209.06/14.46	202.69/14.24	152.02/12.33	110.57/10.51
F test	2.11 Acc. Ho	2.73 Rej. Ho	2.27 Acc. Ho	1.68 Acc. Ho	1.51 Acc. Ho
t test	2.97 Rej. Ho	2.23 Rej. Ho	2.66 Rej. Ho	1.26 Acc. Ho	1.92 Acc. Ho
C.I. (0.05)	31.19-42.33	51.01-66.33	47.74-62.82	34.32-47.39	27.94-39.08

FREQUENCY - 100%
REL FREQ. - 9.19%

TABLE X-C-2
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Montastrea annularis

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	2.75	6.06	4.28	15.79	9.09
1 RPLT -2	27.12	60.45	42.05	40.00	26.32
1 HPLT -1	42.50	71.73	66.02	53.85	43.75
1 HPLT -2	4.75	9.13	8.52	5.26	4.17
1 HPLT -3	16.50	58.93	39.17	50.00	21.88
2 HPLT -1	6.00	17.65	17.20	15.38	12.50
2 HPLT -2	23.12	43.12	37.30	24.00	18.18
2 HPLT -3	21.37	50.89	45.48	33.33	23.33
3 HPLT -1	9.75	29.00	22.29	21.05	18.18
3 HPLT -2	50.75	80.72	73.29	61.54	47.06
3 HPLT -3	51.50??	75.56	74.28	50.00	42.86
4 HPLT -1	32.12	72.60	61.05	38.89	26.92
4 HPLT -2	16.69	37.93	37.19	35.29	31.58
4 HPLT -3	34.00	55.85	53.97	54.17	43.33
5 HPLT -1	13.00	19.17	18.10	24.14	16.28
5 HPLT -2	27.00	34.95	33.64	45.00	36.00
5 HPLT -3	8.87	16.14	14.92	18.75	12.50
MEAN VALUE	22.99	43.52	38.16	34.50	25.52

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE % COVER	REL. DOM. (CORALS)	REL DOM. CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY CORAL & COR. ALGAE)
S^2/S	233.63/15.28	570.34/23.88	461.22/21.48	256.0/16.0	167.02/12.92
F test	2.12 Acc. Ho	2.73 Rej. Ho	2.27 Acc. Ho	1.68 Acc. Ho	1.51 Acc. Ho
t test	2.97 Rej. Ho	2.23 Rej. Ho	2.66 Rej. Ho	1.26 Acc. Ho	1.92 Acc. Ho
C.I. (0.05)	14.89-31.09	30.86-56.18	26.78-49.54	26.02-42.98	18.67-32.37

FREQUENCY - 100%
REL. FREQ.- 10.06%

TABLE X-C-3
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Diploria strigosa

TRANSECT -	DOMINANCE % COVER	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	1.00	2.34	1.83	3.57	2.86
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	10.37	15.66	15.57	15.79	15.00
2 HPLT -3	0	0	0	0	0
3 HPLT -1	10.00	19.05	17.66	13.04	10.71
3 HPLT -2	7.12	10.35	10.08	13.79	12.12
3 HPLT -3	10.00	14.26	13.72	6.67	5.41
4 HPLT -1	0	0	0	0	0
4 HPLT -2	6.75	13.01	12.22	9.68	7.89
4 HPLT -3	0	0	0	0	0
5 HPLT -1	2.62	3.62	3.47	10.53	8.00
5 HPLT -2	4.75	6.51	6.43	5.56	5.26
5 HPLT -3	0	0	0	0	0
MEAN VALUE	3.09	4.99	4.76	4.62	3.96

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE % COVER	REL. DOM. (CORALS)	REL DOM. CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY CORAL & COR. ALGAE)
S^2/S	15.97/4.0	42.70/6.53	39.09/6.25	31.68/5.63	24.23/4.92
F test	4.38 Rej. Ho	4.54 Rej. Ho	1.09 Acc. Ho	4.81 Rej. Ho	4.53 Rej. Ho
t test	2.27 Rej. Ho	2.51 Rej. Ho	2.38 Rej. Ho	2.26 Rej. Ho	2.0 Acc. Ho
C.I. (0.05)	0.97-5.20	1.53-8.45	1.45-8.07	1.64-7.60	1.35-6.57

FREQUENCY - 47.06%
REL FREQ. - 4.32%

TABLE X-C-4
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Diploria strigosa

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	2.37	5.29	3.68	4.00	2.63
1 HPLT -1	1.75	2.95	2.72	7.69	6.25
1 HPLT -2	5.62	10.82	10.09	15.79	12.50
1 HPLT -3	0	0	0	0	0
2 HPLT -1	7.25	21.32	20.79	38.46	31.25
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	6.37	10.14	9.21	23.08	17.65
3 HPLT -3	11.87	16.46	16.18	16.67	14.29
4 HPLT -1	5.25	11.86	9.98	11.11	7.69
4 HPLT -2	16.94	38.49	37.74	41.18	36.84
4 HPLT -3	13.37	21.97	21.23	12.50	10.00
5 HPLT -1	22.87	33.73	31.85	17.24	11.63
5 HPLT -2	23.12	29.94	28.82	5.00	4.00
5 HPLT -3	22.50	40.91	37.82	12.50	8.33
MEAN VALUE	8.19	14.35	13.54	12.07	9.59

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	70.02/8.37	193.88/13.92	178.64/13.36	152.40/12.34	109.85/10.48
F test	4.38 Rej. Ho	4.54 Rej. Ho	1.09 Acc. Ho	4.81 Rej. Ho	4.53 Rej. Ho
t test	2.27 Rej. Ho	2.51 Rej. Ho	2.38 Rej. Ho	2.26 Rej. Ho	2.00 Acc. Ho
C.I. (0.05)	3.76-12.62	10.39-18.3	6.46-20.62	5.53-18.61	4.03-15.14

FREQUENCY - 70.59%
REL FREQ. - 7.10%

TABLE X-C-5
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Colpophyllia spp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	16.00	25.15	23.44	21.74	19.23
1 RPLT -2	2.37	5.56	4.34	7.14	5.71
1 HPLT -1	0.50	0.72	0.69	4.35	3.57
1 HPLT -2	32.25	68.43	62.93	47.62	37.04
1 HPLT -3	1.62	2.59	2.46	8.70	7.14
2 HPLT -1	3.37	5.90	5.33	7.69	5.56
2 HPLT -2	9.75	14.72	14.63	26.32	25.00
2 HPLT -3	0	0	0	0	0
3 HPLT -1	1.87	3.57	3.31	4.35	3.57
3 HPLT -2	20.81	30.25	29.44	24.14	21.21
3 HPLT -3	1.87	2.67	2.57	6.67	5.41
4 HPLT -1	0	0	0	0	0
4 HPLT -2	4.00	7.71	7.24	3.23	2.63
4 HPLT -3	8.75	13.54	12.89	4.55	3.70
5 HPLT -1	9.62	13.28	12.71	21.05	16.00
5 HPLT -2	14.50	19.86	19.63	22.22	21.05
5 HPLT -3	7.87	9.27	8.99	6.67	5.00
MEAN VALUE	7.95	13.13	12.39	12.73	10.69

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	72.58/8.52	265.19/16.28	229.53/15.14	149.45/12.22	105.06/10.25
F test	1.45 Acc. Ho	1.24 Acc. Ho	1.45 Acc. Ho	1.04 Acc. Ho	1.51 Acc. Ho
t test	-.12 Acc. Ho	.49 Acc. Ho	.211 Acc. Ho	0.09 Acc. Ho	0.64 Acc. Ho
C.I. (0.05)	3.45-12.46	4.50-21.76	4.36-20.42	6.25-19.21	5.26-16.12

FREQUENCY - 88.24%
REL FREQ. - 8.11%

TABLE X-C-6
POPULATION LEVEL PARAMETERS*
STATION - CSA-A *Colpophyllia* spp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	20.25	44.63	31.52	36.84	21.21
1 RPLT -2	0	0	0	0	0
1 HPLT -1	12.62	21.31	19.61	15.38	12.50
1 HPLT -2	26.50	50.96	47.53	36.84	29.17
1 HPLT -3	6.12	21.88	14.54	21.43	9.38
2 HPLT -1	9.50	27.94	27.24	7.69	6.25
2 HPLT -2	10.25	19.11	16.53	28.00	21.21
2 HPLT -3	8.50	20.24	18.09	19.05	13.33
3 HPLT -1	4.12	12.27	9.43	5.26	4.55
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0.62	1.41	1.19	5.56	3.85
4 HPLT -2	0	0	0	0	0
4 HPLT -3	8.00	13.14	12.70	12.50	10.00
5 HPLT -1	7.00	10.32	9.75	3.45	2.33
5 HPLT -2	6.50	8.41	8.10	5.00	4.00
5 HPLT -3	9.50	17.27	15.97	12.50	8.33
MEAN VALUE	7.62	15.82	13.66	12.32	8.59

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	50.19/7.08	213.24/14.6	158.05/12.57	143.67/12.00	69.54/8.34
F test	1.45 Acc. Ho	1.24 Acc. Ho	1.45 Acc. Ho	1.04 Acc. Ho	1.51 Acc. Ho
t test	-.12 Acc. Ho	.49 Acc. Ho	.211 Acc. Ho	0.09 Acc. Ho	0.64 Acc. Ho
C.I. (0.05)	3.87-11.37	8.08-23.56	7.00-20.32	5.97-18.67	4.17-13.01

FREQUENCY - 76.47%
REL FREQ. - 7.69%

TABLE X-C-7
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Montastrea cavernosa

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	11.87	18.66	17.40	13.04	11.54
1 RPLT -2	8.37	19.57	15.30	14.29	11.43
1 HPLT -1	21.37	30.81	29.58	17.39	14.29
1 HPLT -2	0	0	0	0	0
1 HPLT -3	7.25	11.58	10.96	8.70	7.14
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	4.50	8.57	7.95	4.35	3.57
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0.25	0.39	0.37	4.55	3.70
5 HPLT -1	0	0	0	0	0
5 HPLT -2	12.37	16.95	16.75	11.11	10.53
5 HPLT -3	8.00	9.42	9.13	10.00	7.50
MEAN VALUE	4.35	6.82	6.32	4.91	4.1

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	37.39/6.11	86.67/9.31	75.30/8.68	35.64/5.97	25.11/5.01
F test	1.38 Acc. Ho	1.2 Acc. Ho	1.46 Acc. Ho	2.54 Acc. Ho	2.03 Acc. Ho
t test	0.5 Acc. Ho	0.11 Acc. Ho	0.28 Acc. Ho	0.36 Acc. Ho	0.62 Acc. Ho
C.I. (0.05)	1.15-7.59	1.89-11.75	1.72-10.92	1.75-8.07	1.44-6.76

FREQUENCY - 47.06%
REL FREQ. - 4.32%

TABLE X-C-8
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Montastrea cavernosa

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	9.38	20.89	14.53	24.00	15.79
1 HPLT -1	0.62	1.05	0.97	3.85	3.13
1 HPLT -2	0	0	0	0	0
1 HPLT -3	3.50	12.50	8.31	14.29	6.25
2 HPLT -1	2.25	6.62	6.45	7.69	6.25
2 HPLT -2	12.50	23.31	20.16	16.00	12.12
2 HPLT -3	2.37	5.67	5.05	4.76	3.33
3 HPLT -1	0	0	0	0	0
3 HPLT -2	3.87	6.16	5.60	3.85	2.94
3 HPLT -3	4.00	5.55	5.45	8.33	7.14
4 HPLT -1	0	0	0	0	0
4 HPLT -2	1.37	3.13	3.06	5.88	5.26
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0.37	0.55	0.52	3.45	2.33
5 HPLT -2	19.12	24.76	23.83	35.00	28.00
5 HPLT -3	0	0	0	0	0
MEAN VALUE	3.49	6.11	5.52	7.48	5.44

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	26.99/5.20	72.02/8.49	51.42/7.17	90.48/9.51	51.07/7.15
F test	1.38 Acc. Ho	1.2 Acc. Ho	1.46 Acc. Ho	2.54 Acc. Ho	2.03 Acc. Ho
t test	0.5 Acc. Ho	0.11 Acc. Ho	0.28 Acc. Ho	0.36 Acc. Ho	0.62 Acc. Ho
C.I. (0.05)	0.74-6.24	1.61-10.61	1.72-9.32	2.44-12.52	1.65-9.23

FREQUENCY - 64.71%
REL FREQ. - 6.51%

TABLE X-C-9
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Millepora sp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	5.75	9.04	8.42	8.70	7.69
1 RPLT -2	1.12	2.63	2.05	3.57	2.86
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	1.37	2.20	2.08	8.70	7.14
2 HPLT -1	2.75	4.80	4.34	3.85	2.78
2 HPLT -2	0.50	0.75	0.75	5.26	5.00
2 HPLT -3	6.25	10.68	10.04	13.33	11.11
3 HPLT -1	2.87	5.48	5.08	26.09	21.43
3 HPLT -2	5.00	7.27	7.07	13.79	12.12
3 HPLT -3	1.00	1.43	1.37	3.33	2.70
4 HPLT -1	2.19	4.16	3.86	10.00	7.14
4 HPLT -2	5.37	10.36	9.73	19.35	15.79
4 HPLT -3	7.25	11.22	10.68	22.73	18.52
5 HPLT -1	7.50	10.34	9.90	15.79	12.00
5 HPLT -2	2.87	3.94	3.89	16.67	15.79
5 HPLT -3	2.25	2.65	2.57	10.00	7.50
MEAN VALUE	3.18	5.11	4.81	10.66	8.80

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	5.96/2.44	14.78/3.84	13.37/3.65	56.12/7.49	39.11/6.25
F test	4.68 Rej. Ho	9.19 Rej. Ho	7.74 Rej. Ho	1.87 Acc. Ho	1.54 Acc. Ho
t test	-.45 Acc. Ho	1.08 Acc. Ho	1.00 Acc. Ho	0.885 Acc. Ho	1.16 Acc. Ho
C.I. (0.05)	1.89-4.47	3.07-7.15	2.87-6.75	6.69-14.63	5.48-12.11

FREQUENCY - 88.24%
REL FREQ. - 8.11%

TABLE X-C-10
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Millepora sp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	2.12	4.74	3.29	8.00	5.26
1 HPLT -1	0	0	0	0	0
1 HPLT -2	4.50	8.65	8.07	10.53	8.33
1 HPLT -3	0	0	0	0	0
2 HPLT -1	8.50	25.00	24.37	23.08	18.75
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	12.87	38.29	29.43	26.32	22.73
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	1.62	3.67	3.09	11.11	7.69
4 HPLT -2	7.37	16.76	16.43	5.88	5.26
4 HPLT -3	0	0	0	0	0
5 HPLT -1	16.75	24.70	23.32	17.24	11.63
5 HPLT -2	0	0	0	0	0
5 HPLT -3	11.00	20.00	18.49	31.25	20.83
MEAN VALUE	3.81	8.34	7.44	7.85	5.91

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	27.92/5.28	135.88/11.66	103.53/10.17	105.0/10.25	60.43/7.77
F test	4.68 Rej. Ho	9.19 Rej. Ho	7.74 Rej. Ho	1.87 Acc. Ho	1.54 Acc. Ho
t test	-.45 Acc. Ho	1.08 Acc. Ho	1.00 Acc. Ho	0.885 Acc. Ho	1.16 Acc. Ho
C.I. (0.05)	1.01-6.6	2.16-14.52	2.05-12.83	2.42-13.28	1.79-10.03

FREQUENCY - 47.06%
REL FREQ. - 4.73%

TABLE X-C-11
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Madracis decactis

TRANSECT -	DOMINANCE (% COVER(	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0.62	0.98	0.92	4.35	3.85
1 RPLT -2	2.50	5.85	4.57	7.14	5.71
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0.75	1.20	1.13	4.35	3.57
2 HPLT -1	7.37	12.88	11.64	23.08	16.67
2 HPLT -2	0	0	0	0	0
2 HPLT -3	6.12	10.47	9.84	6.67	5.56
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	3.75	7.13	6.62	15.00	10.71
4 HPLT -2	0	0	0	0	0
4 HPLT -3	8.37	12.96	12.34	27.27	22.22
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	25.87	30.46	29.53	36.67	27.50
MEAN VALUE	3.26	4.82	4.50	7.32	5.63

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	39.54/6.29	62.58/7.91	57.55/7.59	121.59/11.03	70.23/8.38
F test	19.77 Rej. Ho	7.83 Rej. Ho	9.06 Rej. Ho	6.73 Rej. Ho	7.54 Rej. Ho
t test	-1.53 Acc. Ho	1.53 Rej. Ho	1.55 Acc. Ho	1.74 Acc. Ho	1.77 Acc. Ho
C.I. (0.05)	0-6.59	0.63-9.01	0.48-8.52	1.48-13.16	3.47-10.07

FREQUENCY - 47.06%
REL FREQ. - 4.32%

TABLE X-C-12
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Madracis decactis

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	1.75	3.90	2.71	12.00	7.89
1 HPLT -1	0	0	0	0	0
1 HPLT -2	2.62	5.05	4.71	5.26	4.17
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	3.00	5.59	4.84	4.00	6.06
2 HPLT -3	3.87	9.23	8.24	4.76	3.33
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	3.62	5.35	5.05	13.79	9.30
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	0.87	1.71	1.50	2.34	1.81

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	2.00/1.41	7.99/2.83	6.35/2.52	18.07/4.25	9.31/3.05
F test	19.77 Rej. Ho	7.83 Rej. Ho	9.06 Acc. Ho	6.73 Rej. Ho	7.54 Rej. Ho
t test	-1.53 Acc. Ho	1.53 Rej. Ho	1.55 Rej. Ho	1.74 Acc. Ho	1.77 Acc. Ho
C.I. (0.05)	0.12-1.62	0.21-3.21	0.16-2.83	0.09-4.59	0.19-3.43

FREQUENCY - 29.41%
REL FREQ. - 2.96%

TABLE X-C-13
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Porites astreoides

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	2.00	3.14	2.93	8.70	7.69
1 RPLT -2	6.12	14.33	11.19	21.43	17.14
1 HPLT -1	0	0	0	0	0
1 HPLT -2	2.37	5.04	4.63	14.29	11.11
1 HPLT -3	0	0	0	0	0
2 HPLT -1	6.50	11.35	10.26	15.38	11.11
2 HPLT -2	1.37	2.08	2.06	5.26	5.00
2 HPLT -3	0	0	0	0	0
3 HPLT -1	1.50	2.86	2.65	4.35	3.57
3 HPLT -2	1.44	2.09	2.03	6.90	6.06
3 HPLT -3	3.62	5.17	4.97	16.67	13.51
4 HPLT -1	3.62	6.90	6.39	20.00	14.29
4 HPLT -2	2.37	4.58	4.30	6.45	5.26
4 HPLT -3	0.37	0.58	0.55	4.55	3.70
5 HPLT -1	4.25	5.86	5.61	15.79	12.00
5 HPLT -2	0.25	0.34	0.34	5.56	5.26
5 HPLT -3	0	0	0	0	0
MEAN VALUE	2.10	3.78	3.41	8.55	6.81

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	4.13/2.03	16.06/4.01	11.44/3.38	49.88/7.06	28.62/5.35
F test	1.35 Acc. Ho	1.32 Acc. Ho	1.18 Acc. Ho	1.92 Acc. Ho	2.30 Acc. Ho
t test	.09 Acc. Ho	0.63 Acc. Ho	0.49 Acc. Ho	1.48 Acc. Ho	1.15 Acc. Ho
C.I. (0.05)	1.02-3.18	1.66-5.90	1.62-5.20	4.81-12.29	3.97-9.64

FREQUENCY - 76.47%
REL FREQ. - 7.03%

TABLE X-C-14
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Porites astreoides

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0.50	1.10	0.78	15.79	9.09
1 RPLT -2	1.62	3.62	2.52	8.00	5.26
1 HPLT -1	0	0	0	0	0
1 HPLT -2	1.25	2.40	2.24	10.53	8.33
1 HPLT -3	1.87	6.70	4.45	14.29	6.25
2 HPLT -1	0.50	1.47	1.43	7.69	6.25
2 HPLT -2	2.25	4.20	3.63	8.00	6.06
2 HPLT -3	3.75	8.93	7.98	19.05	13.33
3 HPLT -1	6.50	19.33	14.86	42.11	36.36
3 HPLT -2	0.87	1.39	1.26	3.85	2.94
3 HPLT -3	0.75	1.04	1.02	8.33	7.14
4 HPLT -1	3.87	8.76	7.36	27.78	19.23
4 HPLT -2	1.25	2.84	2.79	5.88	5.26
4 HPLT -3	5.50	9.03	8.73	20.83	16.67
5 HPLT -1	2.56	3.78	3.57	6.90	4.65
5 HPLT -2	1.50	1.94	1.87	10.00	8.00
5 HPLT -3	2.25	4.09	3.78	12.50	8.33
MEAN VALUE	2.16	4.74	4.02	13.03	9.60

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	3.05/1.75	21.17/4.6	13.45/3.67	95.83/9.79	65.79/8.11
F test	1.35 Acc. Ho	1.32 Acc. Ho	1.18 Acc. Ho	1.92 Acc. Ho	2.30 Acc. Ho
t test	.09 Acc. Ho	0.63 Acc. Ho	0.49 Acc. Ho	1.48 Acc. Ho	1.15 Acc. Ho
C.I. (0.05)	1.2-3.09	2.3-7.18	2.08-5.96	7.84-18.22	5.30-13.90

FREQUENCY - 94.12%
REL FREQ. - 9.47%

TABLE X-C-15
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Agaricia spp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0.75	1.75	1.37	7.14	5.71
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0.75	1.20	1.13	8.70	7.14
2 HPLT -1	1.75	3.06	2.76	15.38	11.11
2 HPLT -2	0.87	1.32	1.31	10.53	10.00
2 HPLT -3	2.25	3.85	3.61	13.33	11.11
3 HPLT -1	0.25	0.48	0.44	4.35	3.57
3 HPLT -2	0.25	0.36	0.35	3.45	3.03
3 HPLT -3	3.00	4.28	4.12	20.00	16.22
4 HPLT -1	0.62	1.19	1.10	10.00	7.14
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0.62	0.74	0.71	3.33	2.50
MEAN VALUE	.65	1.07	.99	5.66	4.56

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	0.74/.86	1.85/1.36	1.63/1.28	38.19/6.18	24.65/4.96
F test	1.51 Acc. Ho	1.02 Acc. Ho	1.07 Acc. Ho	1.15 Acc. Ho	1.05 Acc. Ho
t test	.31 Acc. Ho	0.7 Acc. Ho	0.593 Acc. Ho	0.8 Acc. Ho	0.621 Acc. Ho
C.I. (0.05)	0.19-1.11	0.35-1.79	0.31-1.67	2.38-8.93	1.93-7.19

FREQUENCY - 58.82%
REL FREQ. - 5.41%

TABLE X-C-16
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES Agaricia spp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0.50	1.11	0.78	4.00	2.63
1 HPLT -1	1.75	2.95	2.72	19.23	15.63
1 HPLT -2	0.37	0.72	0.67	5.26	4.17
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	1.87	3.50	3.02	12.00	9.09
2 HPLT -3	2.12	5.06	4.52	19.05	13.33
3 HPLT -1	0.37	1.12	0.86	5.26	4.55
3 HPLT -2	1.00	1.59	1.44	7.69	5.88
3 HPLT -3	1.00	1.39	1.36	16.67	14.29
4 HPLT -1	0.75	1.69	1.43	5.56	3.85
4 HPLT -2	0.37	0.85	0.84	5.88	5.26
4 HPLT -3	0	0	0	0	0
5 HPLT -1	1.62	2.40	2.26	13.79	9.30
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0.87	1.59	1.47	12.50	8.33
MEAN VALUE	0.74	1.41	1.26	7.46	5.66

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	0.49/0.7	1.89/1.37	1.52/1.23	44.11/6.64	25.95/5.09
F test	1.51 Acc. Ho	1.02 Acc. Ho	1.07 Acc. Ho	1.15 Acc. Ho	1.05 Acc. Ho
t test	.31 Acc. Ho	0.7 Acc. Ho	0.593 Acc. Ho	0.80 Acc. Ho	0.621 Acc. Ho
C.I. (0.05)	.37-1.11	0.68-2.14	0.61-1.91	3.94-10.98	2.96-8.36

FREQUENCY - 70.59%
REL FREQ. - 7.10%

TABLE X-C-17
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Siderastrea siderea

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	0	0	0	0	0

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	0/0	0/0	0/0	0/0	0/0
F test	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho
t test	1.30 Acc. Ho	1.27 Acc. Ho	1.33 Acc. Ho	1.38 Acc. Ho	1.40 Acc. Ho
C.I. (0.05)	0	0	0	0	0

FREQUENCY - 0%
REL FREQ. - 0%

TABLE X-C-18
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Siderastrea siderea

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	21.88	48.21	34.05	31.58	18.18
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	6.37	12.26	11.43	10.53	8.33
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	1.66	3.56	2.67	2.48	1.56

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	27.79/5.27	132.91/11.53	68.73/8.29	59.05/7.68	21.09/4.59
F test	! Rej. Ho	! Rej. Ho	! Rej. Ho	! Rej. Ho	! Rej. Ho
t test	1.30 Acc. Ho	1.27 Acc. Ho	1.33 Acc. Ho	1.38 Acc. Ho	1.40 Acc. Ho
C.I. (0.05)	0-4.45	0-9.67	0-7.06	0-6.55	0-3.99

FREQUENCY - 11.76%
REL FREQ. - 1.18%

TABLE X-C-19
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Stephanocoenia intersepta

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	1.00	1.90	1.77	4.35	3.57
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0.75	1.07	1.03	3.33	2.70
4 HPLT -1	1.12	2.14	1.98	5.00	3.57
4 HPLT -2	0.87	1.69	1.58	6.45	5.26
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	.22	.40	.37	1.12	.89

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	.162/.40	.56/.75	0.48/0.70	4.42/2.10	2.77/1.66
F test	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho
t test	2.25 Rej. Ho	.10 Acc. Ho	2.20 Rej. Ho	2.20 Rej. Ho	2.20 Rej. Ho
C.I. (0.05)	.01-.43	.003-.80	0-0.74	.006-2.23	0.01-1.77

FREQUENCY - 23.53%
REL FREQ. - 2.16%

TABLE X-C-20
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Stephanocoenia intersepta

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	0	0	0	0	0

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	0/0	0/0	0/0	0/0	0/0
F test	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho
t test	2.25 Rej. Ho	.10 Acc. Ho	2.20 Rej. Ho	2.20 Rej. Ho	2.20 Rej. Ho
C.I. (0.05)	0	0	0	0	0

FREQUENCY - 0%
REL FREQ. - 0%

TABLE X-C-21
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Mussa angulosa

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0.78	15.79	9.09
1 RPLT -2	1.00	2.34	2.52	8.60	5.26
1 HPLT -1	0	0	0	0	0
1 HPLT -2	2.87	6.10	2.24	10.53	8.33
1 HPLT -3	3.13	4.99	4.45	14.29	6.25
2 HPLT -1	0	0	1.43	7.69	6.25
2 HPLT -2	0.25	0.38	3.63	8.60	6.06
2 HPLT -3	1.12	1.92	7.98	19.05	13.33
3 HPLT -1	0	0	14.86	42.11	36.36
3 HPLT -2	0.75	1.09	1.26	3.85	2.94
3 HPLT -3	0	0	1.02	8.33	7.14
4 HPLT -1	0	0	7.36	27.78	19.23
4 HPLT -2	0.37	0	2.79	5.88	5.26
4 HPLT -3	0	0	8.73	20.83	16.67
5 HPLT -1	0	0	3.57	6.90	4.65
5 HPLT -2	0	0	1.87	10.60	8.00
5 HPLT -3	1.50	1.77	3.78	12.50	8.33
MEAN VALUE	.65	1.09	4.02	13.03	9.60

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	.95/.98	3.26/1.80	2.79/1.67	15.66/3.96	10.87/3.30
F test	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho	Rej. Ho
t test	2.71 Rej. Ho	2.49 Rej. Ho	2.49 Rej. Ho	3.01 Rej. Ho	3.00 Rej. Ho
C.I. (0.05)	0-1.17	.133-2.05	0.12-1.89	10.79-5.00	0.65-4.15

FREQUENCY - 47.06%
REL FREQ. - 4.32%

TABLE X-C-22
POPULATION LEVEL PARAMETERS*
STATION - CSA-A Mussa angulosa

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	0	0	0	0	0

*The statistical analysis os population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	0/0	0/0	0/0	0/0	0/0
F test	/! Rej. Ho	! Rej. Ho	! Rej. Ho	! Rej. Ho	! Rej. Ho
t test	2.71 Rej. Ho	2.49 Rej. Ho	2.49 Rej. Ho	3.01 Rej. Ho	3.00 Rej. Ho
C.I. (0.05)	0	0	0	0	0

FREQUENCY - 0%
REL FREQ. - 0%

TABLE X-C-23
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Scolymia sp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0.37	0.80	0.73	4.76	3.70
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0	0	0	0	0
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0.25	0.36	0.35	3.45	3.03
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	.04	.07	.06	.48	.40

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	.01/.1	.04/0.2	0.03/0.19	1.80/1.34	1.19/1.09
F test	2.1 Acc. Ho	2.0 Acc. Ho	1.87 Acc. Ho	1.97 Acc. Ho	1.70 Acc. Ho
t test	0 Acc. Ho	.007 Acc. Ho	0.05 Acc. Ho	.02 Acc. Ho	0.09 Acc. Ho
C.I. (0.05)	0-.09	0-0.18	0-0.15	0-1.19	0-0.98

FREQUENCY - 11.76%
REL FREQ. - 1.08%

TABLE X-C-24
POPULATION LEVEL PARAMETERS*
STATION - CSA-A SPECIES - Scolymia sp.

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	0	0	0	0	0
1 RPLT -2	0	0	0	0	0
1 HPLT -1	0	0	0	0	0
1 HPLT -2	0	0	0	0	0
1 HPLT -3	0	0	0	0	0
2 HPLT -1	0	0	0	0	0
2 HPLT -2	0.62	1.17	1.01	8.00	6.06
2 HPLT -3	0	0	0	0	0
3 HPLT -1	0	0	0	0	0
3 HPLT -2	0	0	0	0	0
3 HPLT -3	0	0	0	0	0
4 HPLT -1	0	0	0	0	0
4 HPLT -2	0	0	0	0	0
4 HPLT -3	0	0	0	0	0
5 HPLT -1	0	0	0	0	0
5 HPLT -2	0	0	0	0	0
5 HPLT -3	0	0	0	0	0
MEAN VALUE	0.04	0.07	0.06	0.47	0.36

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	.021/.146	.08/.27	0.56/0.24	3.54/1.88	2.03/1.43
F test	2.1 Acc. Ho	2.0 Acc. Ho	1.87 Acc. Ho	1.97 Acc. Ho	1.70 Acc. Ho
t test	0 Acc. Ho	.007 Acc. Ho	.05 Acc. Ho	.02 Acc. Ho	0.09 Acc. Ho
C.I. (0.05)	0-.12	0-0.22	0-0.18	0-1.47	0-1.11

FREQUENCY - 5.88%
REL FREQ. - 0.59%

TABLE X-C-25
POPULATION LEVEL PARAMETERS*
STATION - BLM SPECIES - Coralline Algae

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	4.62		6.78		11.54
1 RPLT -2	12.00		21.92		20.00
1 HPLT -1	2.87		3.98		17.86
1 HPLT -2	4.12		8.05		22.22
1 HPLT -3	3.50		5.29		17.86
2 HPLT -1	6.12		9.66		27.78
2 HPLT -2	0.37		0.56		5.00
2 HPLT -3	3.75		6.02		16.67
3 HPLT -1	4.12		7.28		17.86
3 HPLT -2	1.87		2.65		12.12
3 HPLT -3	7.75		3.77		18.92
4 HPLT -1	4.12		7.28		28.57
4 HPLT -2	3.37		6.11		18.42
4 HPLT -3	3.25		4.79		18.52
5 HPLT -1	3.25		4.29		24.00
5 HPLT -2	0.87		1.18		5.26
5 HPLT -3	2.69		3.07		25.00
MEAN VALUE	3.7		6.04		18.09

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	5.98/2.45		21.26/4.61		42.63/6.53
F test	5.37 Rej. Ho		4.98 Rej. Ho		2.94 Rej. Ho
t test	2.09 Rej. Ho		2.24 Rej. Ho		2.55 Acc. Ho
C.I. (0.05)	2.4-5.0		3.60-8.48		14.63-25.01

FREQUENCY - 100%
REL FREQ. - 9.19%

TABLE X-C-26
POPULATION LEVEL PARAMETERS
STATION - CSA-A SPECIES - Coralline algae

TRANSECT -	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
1 RPLT -1	18.87		29.38		42.42
1 RPLT -2	19.62		30.43		34.21
1 HPLT -1	5.12		7.96		18.75
1 HPLT -2	3.75		6.73		20.83
1 HPLT -3	14.12		33.53		56.25
2 HPLT -1	0.87		2.51		18.75
2 HPLT -2	8.37		13.51		24.24
2 HPLT -3	5.00		10.64		30.00
3 HPLT -1	10.12		23.14		13.64
3 HPLT -2	6.37		9.21		23.53
3 HPLT -3	1.25		1.70		14.29
4 HPLT -1	8.37		15.91		30.77
4 HPLT -2	0.87		1.95		10.53
4 HPLT -3	2.12		3.37		20.00
5 HPLT -1	4.00		5.57		32.56
5 HPLT -2	3.00		3.74		20.00
5 HPLT -3	4.50		7.56		33.33
MEAN VALUE	6.84		12.17		26.12

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	DOMINANCE (% COVER)	REL. DOM. (CORALS)	REL DOM. (CORAL & COR. ALGAE)	REL. DENSITY (CORALS)	REL. DENSITY (CORAL & COR. ALGAE)
S^2/S	32.1/5.67		105.95/10.29		125.27/11.19
F test	5.37 Rej. Ho		4.98 Rej. Ho		2.94 Rej. Ho
t test	2.09 Rej. Ho		2.24 Rej. Ho		2.55 Rej. Ho
C.I. (0.05)	3.84-9.84		6.71-17.62		20.19-32.05

FREQUENCY - 100%
REL FREQ. - 10.00%

TABLE X-C-27
POPULATION LEVEL PARAMETERS*
STATION - BLM

TRANSECT -	S-W DIVERSITY	EVENNESS	RICHNESS
1 RPLT -1	1.521	0.593	3.827
1 RPLT -2	1.895	0.739	3.601
1 HPLT -1	0.632	0.247	3.827
1 HPLT -2	1.279	0.499	3.942
1 HPLT -3	1.538	0.599	3.827
2 HPLT -1	1.604	0.625	3.683
2 HPLT -2	1.709	0.666	4.075
2 HPLT -3	1.322	0.515	4.431
3 HPLT -1	1.665	0.649	3.827
3 HPLT -2	1.846	0.720	3.564
3 HPLT -3	1.571	0.612	3.528
4 HPLT -1	1.583	0.617	4.006
4 HPLT -2	1.460	0.569	3.494
4 HPLT -3	1.480	0.577	3.882
5 HPLT -1	1.516	0.591	4.075
5 HPLT -2	1.565	0.610	4.152
5 HPLT -3	1.655	0.645	3.528
AVG. VALUES	1.520	0.592	3.839

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	S-W DIVERSITY	EVENNESS	RICHNESS
S^2/S	.072/.27	.011/0.1	0.63/.251
F test	1.27 Acc. Ho	1.22 Acc. Ho	2.03 Acc. Ho
t test	0.53 Acc. Ho	0.52 Acc. Ho	2.07 Acc. Ho
C.I. (0.05)	1.38-1.66	0.54-0.65	3.71-3.97

TABLE X-C-28
POPULATION LEVEL PARAMETERS*
STATION - CSA-A

TRANSECT -	S-W DIVERSITY	EVENNESS	RICHNESS
1 RPLT -1	1.315	0.513	4.075
1 RPLT -2	1.625	0.634	3.728
1 HPLT -1	1.261	0.492	3.683
1 HPLT -2	1.835	0.715	4.075
1 HPLT -3	1.233	0.481	4.547
2 HPLT -1	1.586	0.618	4.678
2 HPLT -2	1.779	0.694	3.728
2 HPLT -3	1.604	0.625	3.942
3 HPLT -1	1.353	0.528	4.075
3 HPLT -2	1.085	0.423	3.683
3 HPLT -3	1.358	0.529	4.829
4 HPLT -1	1.533	0.597	4.152
4 HPLT -2	1.400	0.546	4.235
4 HPLT -3	1.179	0.460	3.776
5 HPLT -1	1.912	0.746	3.564
5 HPLT -2	1.257	0.490	4.006
5 HPLT -3	1.717	0.669	4.328
AVG. VALUES	1.472	0.574	4.065

*The statistical analysis of population level parameters is as follows.

STATISTICAL VALUES	S-W DIVERSITY	EVENNESS	RICHNESS
S^2/S	.057/.240	.009/.09	.128/.357
F test	1.27 Acc. Ho	1.22 Acc. Ho	2.03 Acc. Ho
t test	0.53 Acc. Ho	0.52 Acc. Ho	2.07 Acc. Ho
C.I. (0.05)	1.34-1.60	0.52-0.62	3.87-4.25

TABLE X-C-29
EAST FLOWER GARDEN BANK SPECIES LIST
(SPECIES COLLECTED DURING 1978 ON CRUISE 78G9-111)

SPECIES	STATION(s)/ DIVE(d)	NO. OF SPECIMENS
Sponges		
Agelas dispar	d 130	
Aplysina (=Verongia) cauliformis rufa	d 129	
Axinella reticulata	d 6	
Axinellidae	d 130	
Epipolasidae	d 130	
Erylus alleni	W tr* d 5	
Halichondridae	d 129	
Ircinia strobilina	d 134	
Keratose sponge	d 130	
Leuconia aspera	N tr* d 7	
Myriastrea fibrosa	d 133	
Plakinidae	d 133	
Spinosella (=Callyspongia) vaginalis	d 129	
Spongia sp.	d 130,133	
Hydroids		
Halopterus catharina	d 5	
Plumularia sp.	d 134	
Thyroscyphus marginatus	d 129	
Scleractinian Corals		
Helioseris cucullata	d 133	
Madracis asperula	d 5,129	
Polychaetes		
Ceratonereis mirabilis	d 134	4
Eunice aphroditois	d 134	1
Eunice vittata	NE tr* d 6	1
Eunice sp.	d 134	1
Eurythoe complanata		
?*Harmothoe* sp.	d 134	2
Hesionidae	d 134	2
Hypsicomus sp.	d 134	1
Kefersteinia cirrata	d 134	1
Nicon sp. A	d 134	4
Subprotula sp. A (cf. *longiseta*?)	d 134	1
Syllis gracilis	d 134	1
Trypanosyllis sp.	d 134	2
Typosyllis regulata carolinae	d 134	2
Typosyllis sp.	d 134	4
Unidentified polychaetes (small)	d 6	> 1000
Unidentified polychaetes (small)	d 129	> 100
Unidentified polychaetes (small)	d 130	50
Unidentified polychaetes (small)	d 131	2
Unidentified polychaetes (small)	d 133	15
Bivalve Mollusks		
Arca zebra	W tr* d 5	3
Chama sp.	d 130, 134	3
Coralliophila caribaea	?	1

* W tr = west transect; N tr = north transect; NE tr = northeast transect.

TABLE X-C-29 (Continued)

East Flower Garden

SPECIES	STATION(s)/ DIVE(d)	NO. OF SPECIMENS
Gregariella coralliophaga	d 133	1
Pinna sp. (cf. P. carnea)	d 129	1 juv.
Pinnidae (juvenile)	d 131	1 juv.
Gastropod Mollusks		
Acmaea pustulata	d 129	3 dead
Astraea phoebia	d 6	1
Cantharus multangulus	d 129	1
Cavolina sp.	d 134	1 dead
Cerithiopsis sp.	W tr* d 5	1 dead
Cerithiopsis sp.	d 134	1
Cerithium litteratum	d 129,134	6
Conus ermineus	d 134	
Costellaria sykesi	d 129	1
Crepidula plana	d 129,134	3
Cypraea spurca acicularis	d 130	2 (1 dead)
Emarginula sicula	W tr* d 5	1
Turbo cailletti	d 130	1
Polyplacophorans		
Acanthechitona sp.	d 133	1 juv.
Lepidochitona liozonis	d 130	2
Undescribed chiton	d 134	1
Amphipod crustaceans		
Ampithoe sp.	d 5,134	2
Ceradocus sheardi	d 129	1
Colomastix pusilla	1979,d 6	1
Elasmopus rapax	d 130,133	2
Leucothoe spinicarpa	d 129,130,134	6
Liljeborgia bousfieldi	d 134	1
Lysianassa alba	d 5	1
Corophiidae	d 5,134	2
Decapod Crustaceans (Natantia)		
Alpheus beanii	d 129	7
Hippolytid shrimp	d 5, 129,133	7
Palaemonid shrimp	d 129	1
Periclimenaeus cf. periatus	NE tr* d 6	7
?Salmoneus ortmanni	d 133	1
Synalpheus fritzmeulleri	d 129, 130	2
Synalpheus townsendi	d 133	1
Decapod Crustaceans (Reptantia)		
Actaea sp. (rufopunctata complex)	d 5	1
Dardanus sp. (cf. D. insignis)	d 131	1
Melybia thalamita	d 5	1
Micropanope nuttingi	d 130	1
Micropanope ?sculptipes (juvenile)	d 130	1
Munida simplex	d 5, 129, 133	10
Pagurus brevidactylus	d 129, 130	3

*W tr = west transect; NE tr = northeast transect.

TABLE X-C-29 (Continued)

East Flower Garden

SPECIES		STATION(s)/ DIVE(d)	NO. OF SPECIMENS
Parapinnixa sp. (juvenile)		d 5	1
Pilumnus floridanus		d 133	1
Stenorynchus setlcornis		d 133	1
Isopod Crustaceans			
Cirolana mayana	W tr*	d 5	2
Tanaidacean Crustaceans			
Leptochelia sp. A		d 130	1
Asteroids			
Asterinopsis lymani		d 134	1
Astropecten comptus	NE tr*	d 6	1
Chaetaster nodosus	NE tr*	d 6	1
Coronaster briareus		d 5	1
Goniaster tessellatus		d 5,133	2
Linckia nodosa		d 129	1
Crinoids			
?Hypalometra defecta		d 5	1
Echinoids			
Arbacia punctulata		d 6,122,129,130	15
Eucidaris tribuloides		d 133	1
Pseudoboletia maculata maculata	W tr*	d 5	1
Stylocidaris affinis	W tr*	d 5	1
Ophiuroids			
Amphiodia pulchella		d 5,7,130	3
Ophiactis quinqueradia		d 130,133,134	8
Ophiactis savignyi		d 130,134	3
Ophiactis algicola		d 129,130,133	17
?Ophiocoma wendti (juvenile)		d 129	1
Ophiostigma isacanthum		d 130,133	3
Ophiothrix angulata		d 6,131	4
Ophiurochaeta littoralis		d 131	1
Bryozoans			
Alderina smitti		d 5	
Aplousina filum		d 134	
Arthropoma cecilii		d 134	
Bracebridgia subsulcata		d 129,130	
Canda retiformis		d 134	
Cauloramphus brunea		d 134	
Celleporaria albirostris		d 5,134	
?Celleporaria magnifica		d 131	
Celleporaria mordax		d 134	
Celleporaria tubulosa		d 130,134	
Cigclisula turrita		d 5,130,134	
Cigclisula protecta		d 5	
Cleidochasma contractum		d 134	
Cleidochasma porcellanum		d 130,134	
Colletosia radiata		d 5,130,134	
Crepidacantha longiseta		d 130	

* W tr = west transect; NE tr = northeast transect.

TABLE X-C-29 (Continued)

East Flower Garden

SPECIES	STATION(s)/ DIVE(d)	NO. OF SPECIMENS
Crepidacantha poissonii var. teres	d 5	
Crisia eburnea	d 134	
Drepanophora tuberculatum	d 5,134	
Escharina pesanseris	d 5,134	
Hippoporella gorgonensis	d 5	
Labioporella granulosa	d 5	
Labioporella sinuosa	d 5	
Lichenopora radiata	d 134	
Mastigophora porosa	d 134	
Membraniporella aragoi	d 134	
Mollia patellaria	d 5,134	
Parasmittina spathulata	d 5,130,134	
Parasmittina sp.	d 5,134	
Plagioecia sp.	d 130	
Proboscina sp.	d 134	
Retevirgula flectospinata	d 5	
Retevirgula tubulata	d 5,130,134	
Rhynchozoon bispinosum	d 5	
Rhynchozoon spicatum	d 130,134	
Rhynchozoon verruculatum	d 5	
Scrupocellaria cf. pusilla	d 134	
Scrupocellaria regularis	d 5	
Smittipora levinseni	d 130,134	
Steganoporella magnilabris	d 5	
Tremoschizodina lata	d 134	
Triporula stellata	d 134	
Tubulipora sp.	d 5	

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.