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BASELINE MONITORING STUDIES, MISSISSIPPI, ALABAMA, FLORIDA OUTER CONTINENTAL SHELF, 1975-1976

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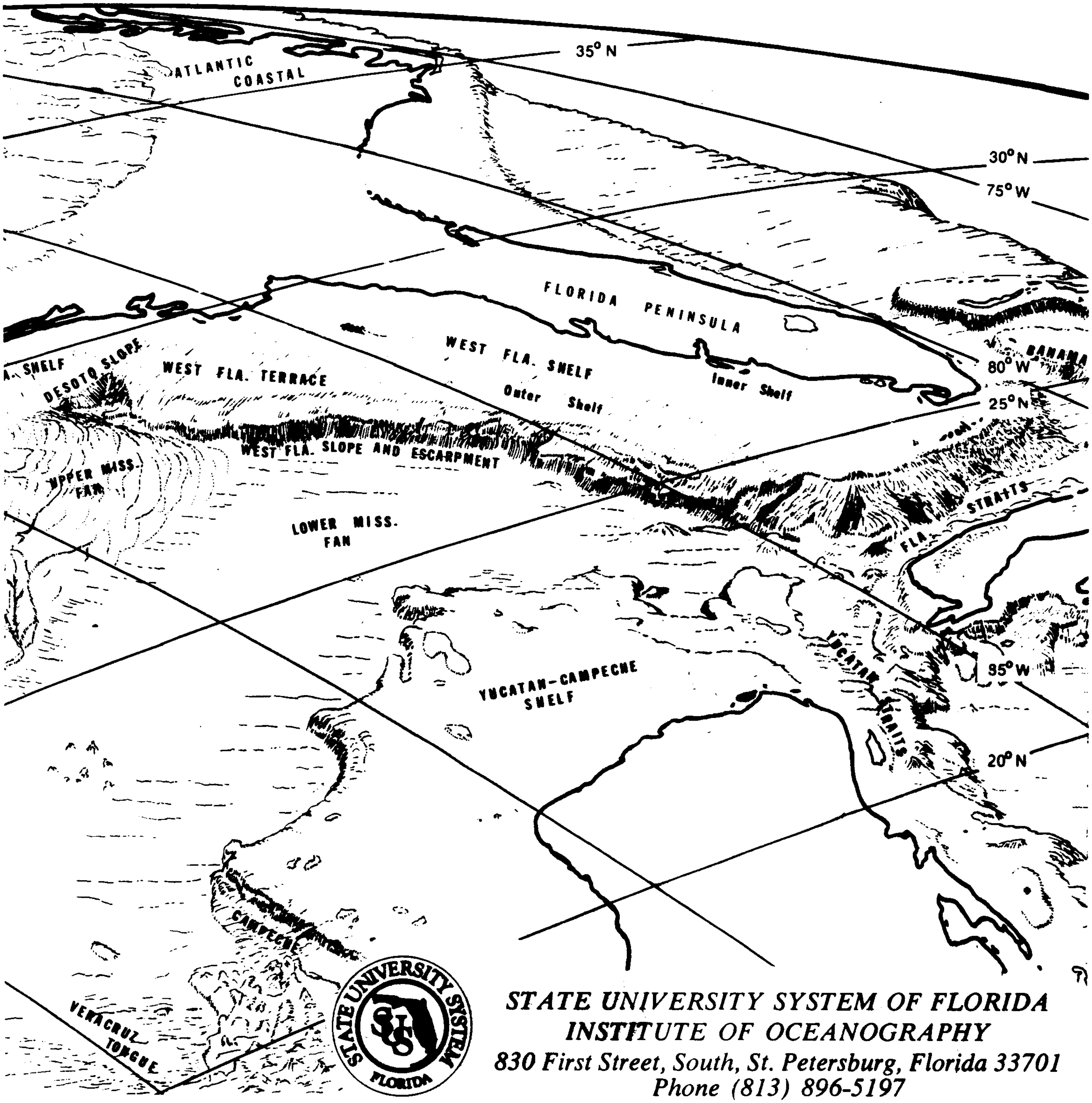
VOLUME IV

DISCUSSION



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DISCUSSION

Water Column

Mooers (1975) noted that (1) the diurnal tides in the Gulf of Mexico were dominant over the semi-diurnal tides in most localities of the MAFLA area, (2) the range of surface tides was on the order of 15 cm, (3) little tidal current data were available and that numerical models for semi-diurnal tides and tidal currents in the Gulf of Mexico reveal tidal current patterns which vary considerably throughout the Gulf, (4) internal (baroclinic) tides could be expected to be more prevalent in the summer than in the winter, and (5) that tidal velocities of five-20 cm/sec were observed in a study (Mooers and Price, 1974; Mooers and Van Leer, 1975) at 26°N latitude on the western Florida Continental Shelf with a diurnal ellipsis oriented north and south and a semi-diurnal ellipsis oriented east and west with both tidal species baroclinic and irregular with their amplitudes and phases varying with depth and time due to modulation by transient circulations. The inertial motion (which results primarily from meteorological disturbances) has a period dependent upon latitude transient circulations with a period varying from about 28 hr at Key West to 24 hr at Mobile Bay, which is near the diurnal tides and leads to irregular diurnal tidal behavior with observed velocities of ten-30 cm/sec on the West Florida Shelf. Those who have studied the tides within the area state with some confidence that the tide inertia motions produce particle orbits with a range in the order of several kilometers and orbital periods of 12-28 hr in the eastern Gulf of Mexico. As such, they would play an important role in the horizontal dispersion of materials from a source area. A prediction of actual dispersion patterns would require the establishment of a tidal study program. A comprehensive review of the surface tides on the Gulf of Mexico has been given by Zeller and Hansen (1972).

The forcing mechanism associated with river run-offs and drainage areas is apparent along the inshore stations on Transects I, II, III and IV. This influence was indicated by the inshore low salinity pockets or layers present on these transects.

The inshore stations along Transects I, II, III and IV were located between eight and 28.9 km offshore. In view of the fact that June, July, September and October represent times of extreme mean low run-off (SUSIO, 1975; Jones and Rinkel, 1973) and since the run-off characteristics of the area near the above transects were small, it was not surprising that little effects from run-off were noted along these transects.

There is another run-off effect that appears on all transects. This is the low salinity pocket situated either on the shelf (Transects I, II and IV) or along the slope of the Continental Shelf on Transect III. This low salinity pocket is associated with the Mississippi River drainage (WEST) system and is a separate run-off from that of the NORTHWEST drainage associated with the inshore low salinity pockets on Transects III and IV. Figure 106 depicts the horizontal distribution of surface salinity in June-July, 1975 which may be used to illustrate the feature of the transport of these drainage areas. The Mississippi River drainage system is to the east and appears to have been influenced by the two broken-off Loop Current eddies (Figure 11) which cause the movement of this water onto the

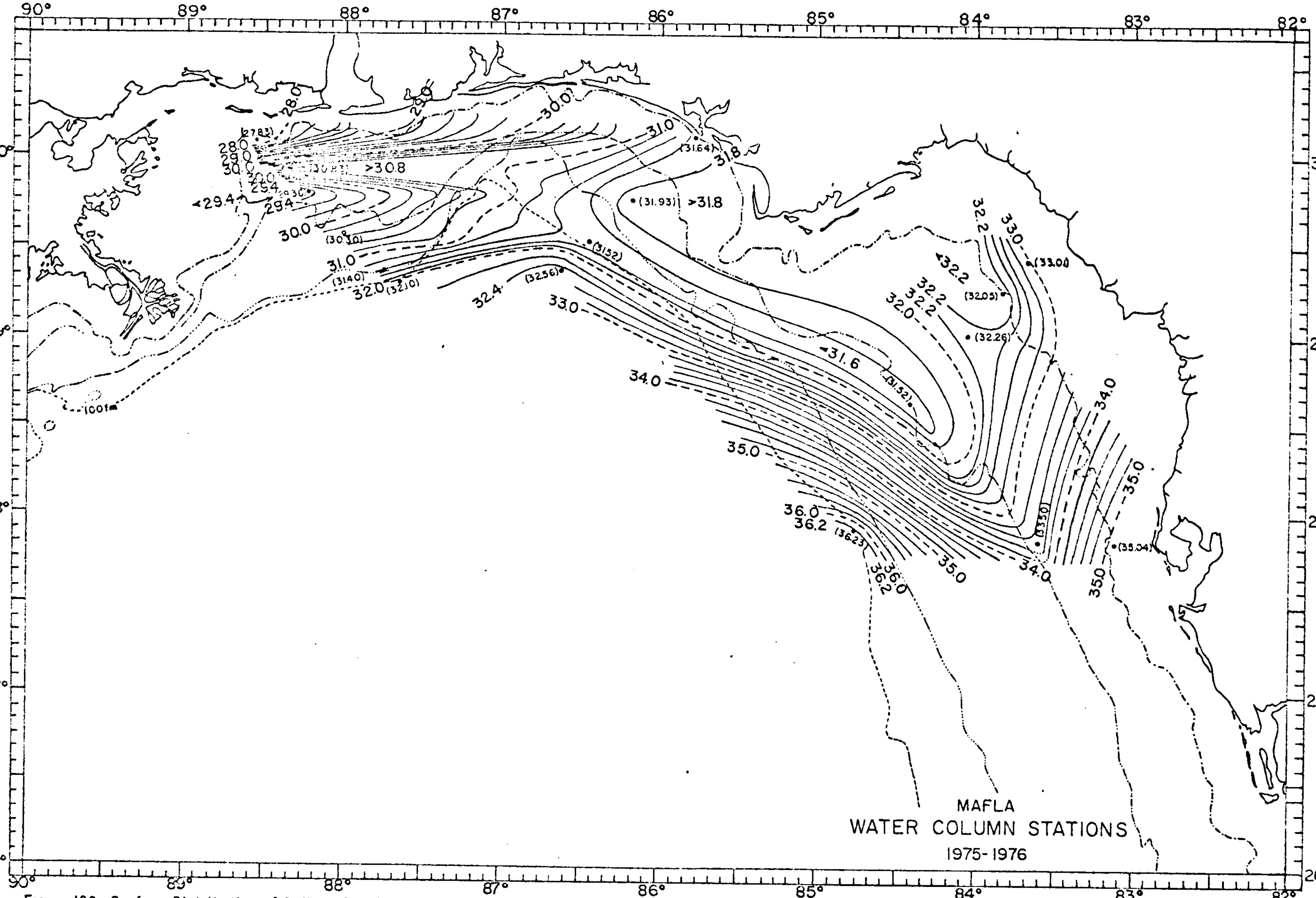


Figure 106 Surface Distribution of Salinity ‰ BLM-12 JUNE 19-JULY, 1975

shelf on Transect IV and outward to the Continental Shelf slope on Transect III. As it moves southward it is further influenced by the intrusion onto the shelf itself of core Loop Current water near Tampa Bay forcing this run-off water up onto the middle areas of the shelf on Transects I and II.

The NORTHWEST drainage flow as described by the nearshore low surface salinity on Transects III and IV apparently moves to the east in the summer and is forced to the south and east beyond Transect III by the geographical nature of the Cape San Blas region.

It is dangerous to use non-synoptic data to infer transport features by the use of the salinity distribution especially in the presence of broken-off Loop Current eddies, such as were occurring in June-July on the shelf. With this in mind the offshore low salinity distribution indicates the transport of the Mississippi River System drainage of over 433 km within 24 days.

In 1973 the salinity distribution pattern associated with the major flooding (a once in 100 years feature) from the Mississippi River System discharge showed a similar flow within a 30-day period. The water was moving with an average speed of 24 cm/sec. Mooers and Price (1975) recorded (from direct current measurements) mean velocities, over an approximate five-week period near 26°00'N at an outer and a middle shelf location at depths of 25-27 m, to be between 10-17 cm/sec. Using the measured currents of Mooers and Price, the mean flow time in the summer of 1975 would have been approximately 34 days. Using the average current of 24 cm/sec from 1973, it would have taken 24-25 days.

Previous drift bottle studies in the Horseshoe Bend area by Brucks (SUSIO, 1975), who used the observed sigma t values to determine the net movement patterns of the bottles and the presence of a high salinity ridge between the low salinity surface pockets on Transect II, indicate that the low salinity observed at Master Staton 1205 (S = 32.06 °/oo) in the summer (Figure 15) was the center of an eddy and was not connected or associated with either the WEST (Mississippi River System) or NORTHWEST drainage areas.

There was some evidence that this eddy may have been established as a result of the meteorological conditions present in June-July. Such evidence was derived from the data collected by the R/V BELLOWS and R/V TURSIOPS. The former was anchored at diving stations on or near Transect II during a period extending from 1 June, 1975 to 1 July, 1975 while the latter vessel was occupied with the water column sampling. These data are shown in Figure 107.

Wind velocities recorded on the R/V BELLOWS at the Florida Middle Ground (Figure 107) ranged from approximately 8.5-34 km/hr with a mean speed of approximately 20.4 km/hr. Wind flow patterns indicate the presence of both easterly and westerly components. In a period of 30 days it also shows that there were four reversals in the flow regime which is lower than the average number of fronts indicated by Fernandez-Partagas and Mooers (SUSIO, 1975). The wind data collected by the R/V TURSIOPS over the interval 19 June-17 July, 1975 differ from those collected by the R/V BELLOWS primarily in that the velocities in the northern region of the eastern Gulf appeared to be lower than those in the southern areas. This agrees with the data presented by Jordan (SUSIO, 1972).

Based on these weather observations and a cursory examination of the daily weather charts it would appear then that these observations would

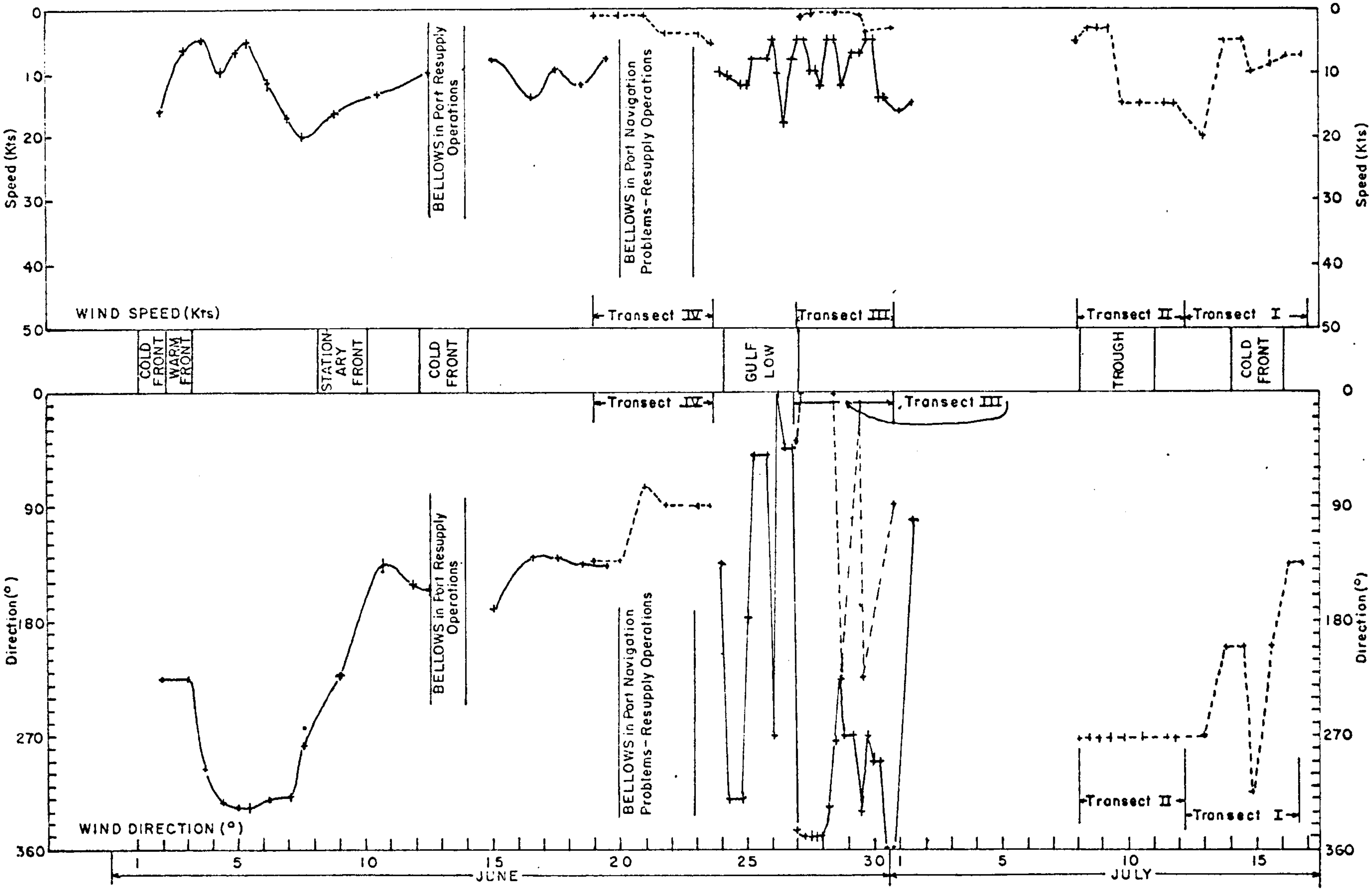


Figure 107. Wind Speed and Direction from R/V BELLOWS and TURSIOPS – June and July, 1975 in MAFLA Area. BELLOWS on Transect II +——+ TURSIOPS on all Transects + - - - - - +

fall into the average conditions shown in Tables 118a and 118b. Based on this and the presence of the predominantly easterly winds a circulation pattern would be established in which the effects of the Ekman spiral would tend to establish an eddy in the Horseshoe Bend area and further confirm the existence of a separate water mass in that area as indicated by the temperature and salinity fields.

The Loop Current is one of the forcing mechanisms that can influence the transport on the shelf. The location of this current (Master Stations 1415, 1311 and 1103) and its depth of occurrence would indicate that during the summer sampling in 1975 only the quality of the plankton (both taxonomically and chemically) would be affected at those stations. Further, while the Loop Current as a forcing mechanism was influencing the shelf circulation on Transects III and IV, its major effect was on Transect I where it would have caused the rapid transport of contaminants from the area to the southeast and then south and southwest off the shelf and into the Straits of Florida.

Figures 108a and b depict the horizontal distribution of salinity at ten meters and at the bottom during the summer. Unlike the surface salinity distribution the salinity at ten meters did not reflect the continuous flow of the Mississippi River System (WEST) on Transect IV. The reason for this has been discussed above. The lower salinity present on Transect II probably represents Mississippi River System water resulting from the mixing processes as that water mass moves to the east and south.

The distribution of the bottom salinities in the summer indicates that the entire shelf was covered with outer Shelf water (36.2 °/oo) except in the area of Horseshoe Bend and in the inner portion of Transect I.

TABLE 118a

Mean Seasonal Frequency (in occurrences per year) of low pressure centers which move inland in the indicated coastal sectors. Hurricane and tropical cyclones have been excluded.

	90° to Apalachicola (Zone A)	Apalachicola to 28.5°N (Zone B)	28.5°N to Ft. Myers (Zone B)	Ft. Myers to 25°N (Zone C)	All Sectors
Winter	1.6	2.2	0.2	0.4	4.4
Spring	0.7	1.0	0.3	0.2	2.2
Summer	0.7	0.6	0.2	0.1	1.6
Fall	1.6	0.6	0.2	0.1	2.9
TOTAL	4.6	4.8	0.9	0.8	11.1

From Table II, page 10, Hydro-Biological Zones of the Eastern Gulf of Mexico, 1972.

TABLE 118b

Wind Statistics for Marine Areas

	Area A		Area B	
	Sept.-Apr.	May-Aug.	Sept.-Apr.	May-Aug.
Main Speed (knots)	13.2	9.0	12.6	8.4
Less than 7 knots	16%	37%	19%	38%
Greater than 16 knots	26%	7%	22%	6%

Modified from Table VI, page 14, Hydro-biological Zones of the Eastern Gulf of Mexico, 1972.

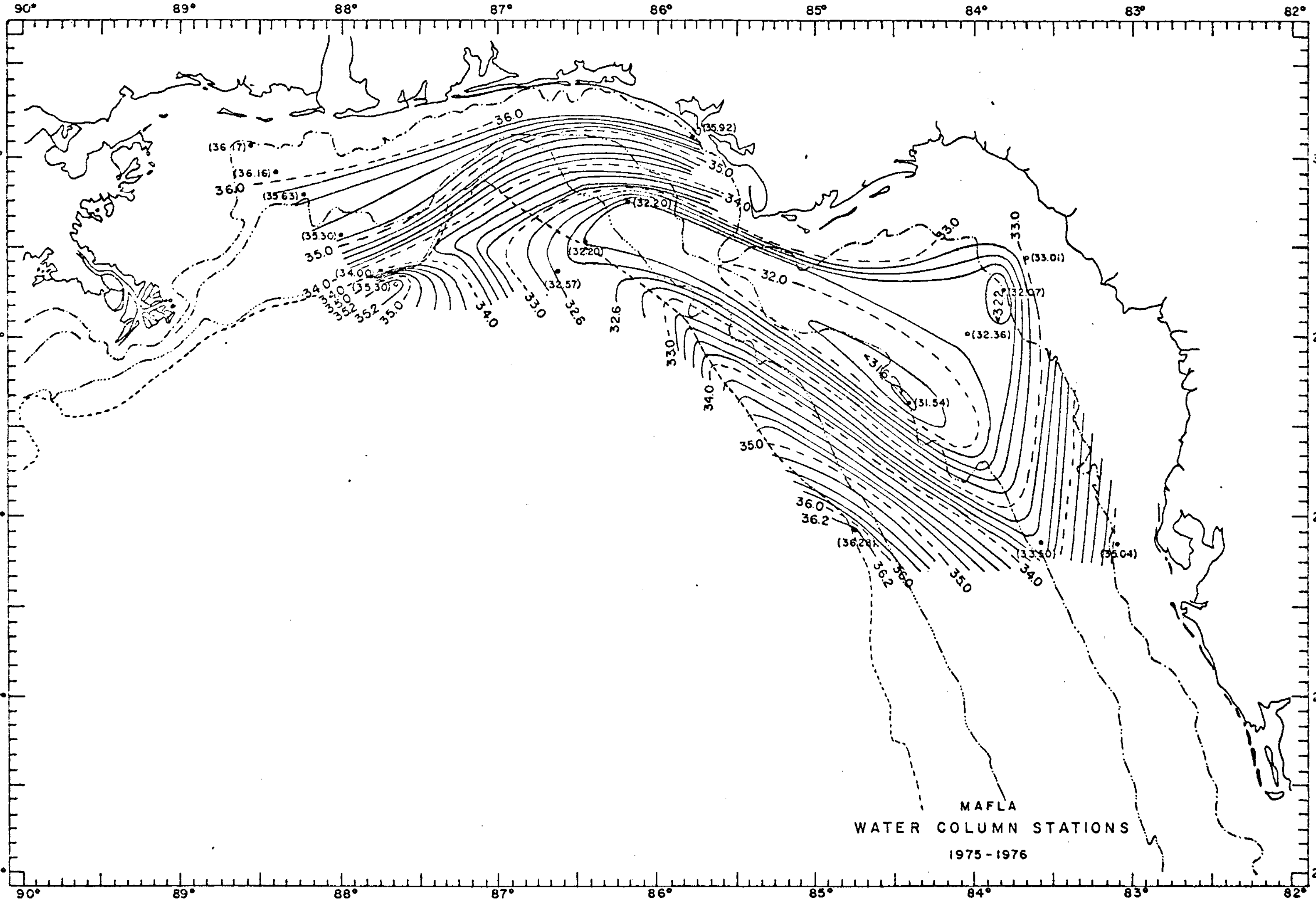


Figure 108a. 10 Meter Distribution Salinity ‰ BLM-12 JUNE 19,-JULY 15, 1975

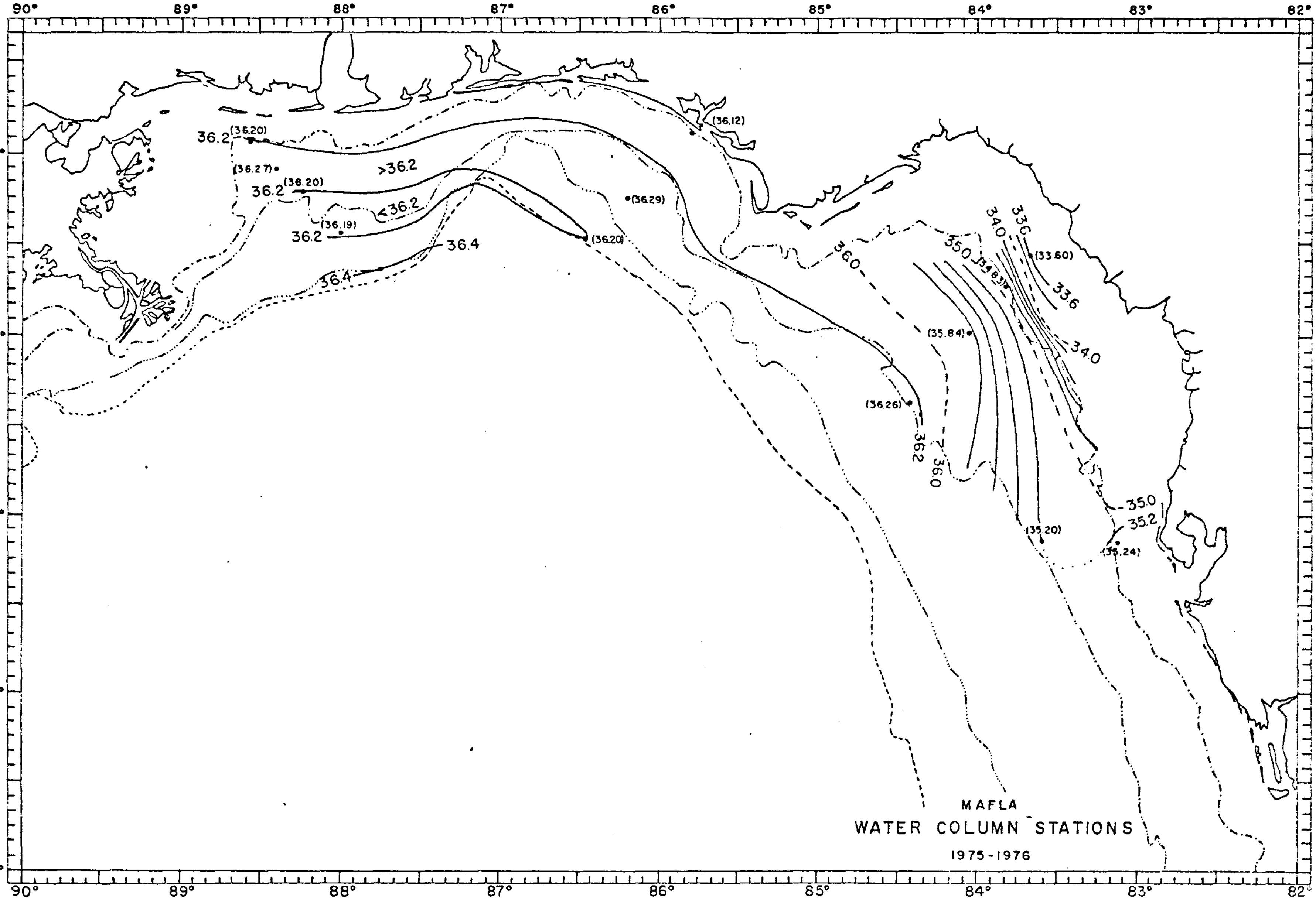


Figure 108b. Bottom Distribution of Salinity ‰ BLM-12 JUNE 19-JULY 15, 1975

This again indicates the separation of the water mass structures in the Horseshoe Bend area and its possible relationship to the inshore areas and drainage from the Tampa Bay complex. More importantly, the salinity contours generally follow the bottom-isobath and give further evidence for the flow of the bottom waters parallel to the bottom topography. This agrees with the current meter data collected between 26°31'N, 25°30'W as reported on by Price and Mooers (1974, 1975). These authors state that the average mean current over periods of a month or more tends to flow parallel to the isobaths (SUSIO, 1975).

Perhaps the most important phenomenon observed during this season's study, and which will become more apparent and important in the subsequent time series stations, which were occupied in the fall and winter seasons, was the variability both on a short and long term period of the parameters of salinity and temperature at the various master stations. Although no time series were taken during this season, there were duplicate STD lowerings on Master Stations 1101, 1204, 1308, 1412, and 1415. Master Stations 1101, 1204, 1308 and 1412 on Transects I, II, III and IV, respectively, were all inshore stations, and were affected by river run-offs. Under these conditions and depending upon the time of the year, strong horizontal gradients of temperature or salinity can be present in the distribution patterns.

The data contained in Table 119 represent the difference in the salinity and temperature values observed during all three seasons of the year on those stations at which two or more STD's and/or XBT's were taken.

Table 119. The range of temperature (°C) and salinity (°/oo) at the surface, ten meter and bottom on master stations at which either a time series study or two or more STD's or XBT's were taken.

Summer - BLM 12

Master Station	Depth Meter	Surface		Ten Meters		Bottom		Time Interval
		Temp.	Salinity	Temp.	Salinity	Temp.	Salinity	
1412	15	28.32	---	22.40	36.20	22.18	36.21	18 Hours
1412	15	28.25	27.83	22.19	36.17	22.19	36.20	
Range		0.07		0.21	0.03	0.01	0.01	
1308	17	27.74	31.64	24.50	35.92	21.34	36.12	1 Hour
1308	17	27.62	31.66	23.00	35.94	21.22	36.00	
Range		0.12	0.02	1.50	0.02	0.12	0.12	
1204	14	28.42	32.06	28.42	32.06	28.19	33.60	1 Hour
1204	14	28.38	33.01	28.38	33.01	28.25	32.60	
Range		0.04	0.95	0.04	0.95	0.06	1.00	
1101	21	28.37	34.95	28.50	35.20	28.52	35.20	13 Hours
1101	21	28.39	35.00	28.39	35.01	28.58	35.13	
1101	21	28.28	35.04	28.28	35.04	28.54	35.24	
Range		0.11	0.09	0.22	0.19	0.06	0.11	
1415	380	28.80	32.10	27.25	35.30	---	---	9 Hours
1415	380	28.51	32.38	27.90	35.00	---	---	
Range		0.29	0.28	0.65	0.30			
Fall - BLm 20								
1412	17	29.65	27.00	29.45	30.00	25.45	35.04	24 Hours
1412	17	28.84	26.63	29.00	29.00	24.84	34.62	
Range		0.81	0.37	0.45	1.00	0.61	0.42	
1414	110	29.33	35.07	29.21	35.16	---	---	7 Hours
1414	110	28.67	34.70	29.06	35.15	---	---	
Range		0.66	0.37	0.15	0.01			
1309	55	28.91	35.76	29.54	35.00	---	---	1 Hour
1302	55	28.86	35.76	29.00	33.80	---	---	
Range		0.05	0.00	0.54	1.20			
1204	13	28.26	31.93	28.52	32.40	28.52	32.43	30 Min.
1204	13	28.20	31.90	28.41	32.28	28.44	32.42	
Range		* 0.06	0.03	0.11	0.12	0.08	0.01	
1204	13	26.88	31.95	26.82	31.98	26.82	31.98	120 Hours
Range		** 1.38	.05	1.70	0.42	1.70	0.42	

* Difference before Hurricane ELOISE

** Difference after Hurricane ELOISE

Table 119. (continued)

Master Station	Depth Meter	Surface		Ten Meters		Bottom		Time Interval
		Temp.	Salinity	Temp.	Salinity	Temp.	Salinity	
				Fall - BLM 20				
1205	18	28.24	32.74	28.24	32.75	28.41	33.40	120 Hours
1205	18	26.89	32.98	26.91	32.98	26.92	32.98	
Range		** 1.35	0.24	1.33	0.23	1.49	0.42	
1207	35	26.43	34.91	26.41	35.10	---	---	24 Hours
1207	35	25.94	34.19	26.00	34.78	---	---	
Range		0.49	0.72	0.41	0.32			
				Winter - BLM 28				
1412	14	13.74	31.92	15.22	33.60	15.87	33.81	24 Hours
1412	14	13.50	30.37	13.90	31.91	14.04	32.08	
Range		.24	1.55	1.32	1.69	1.83	1.73	
1310	167	19.82	---	19.78	---	15.33	---	5 1/2 Hours
1310	167	19.29	---	19.29	---	14.86	---	
Range		.53		.49		.46		
1413	30	16.76	34.01	18.00	35.45	19.64	36.40	12 Days
1413	30	16.64	33.60	17.50	34.40	18.30	35.62	
Range		0.12	0.41	0.50	1.05	1.34	0.78	
1414	80	19.79	35.77	19.79	35.78	20.53	36.41	10 Days
1414	80	18.62	35.40	18.90	35.69	19.20	36.25	
Range		1.17	0.37	0.89	0.09	1.33	0.16	
1415	332	20.33	36.19	20.33	36.19	---	---	9 Days
1415	332	17.60	33.90	18.19	34.60	---	---	
Range		2.73	2.29	2.14	1.59			
1205	16	14.30	35.60	14.30	35.60	14.30	35.60	12 Hours
1205	16	14.15	35.54	14.15	35.54	14.15	35.54	
Range		0.15	0.06	0.15	0.06	0.15	0.06	
1207	36	17.79	36.28	17.70	36.28	17.62	36.29	24 Hours
1207	36	17.61	36.22	17.60	36.25	17.53	36.26	
Range		0.19	0.06	0.10	0.03	0.09	0.03	
1102	32	16.85	36.18	16.95	36.18	16.30	36.16	66 Hours
1102	32	36.17	36.17	15.89	36.17	15.24	36.10	
Range		0.96	0.01	1.06	0.01	1.06	0.06	
1101	18	14.12	35.17	14.14	35.16	14.16	35.15	38 Hours
1101	18	13.98	35.44	14.06	34.98	14.04	35.08	
Range		0.14	0.73	0.08	0.18	0.12	0.07	

** Difference after Hurricane ELOISE

The observed ranges at the inshore stations fall under the particle movement of the tidal oscillation and current patterns. These can move a particle on and offshore in an orbital pattern of 3.2-8.0 km and perpendicular to the coastline from 2.4-4.0 km as has been previously discussed under tides. These motions can result in rapid changes in temperature and salinity values with time.

Master Station 1204 appears to be an example of this phenomenon in which in approximately a one-hour time period a change of nearly 1.00 °/oo salinity occurred. On this transect (II), depending upon which of the two STD lowerings was taken, a pocket of high salinity would appear or not appear on the inshore station. This could lead to the interpretation of the water mass relationships as either the lack of run-off on Master Station 1204 or a considerable surface pocket of low salinity water extending out to Master Station 1205.

Based on the above discussion and the surface distribution patterns shown in Figure 106, the high salinity values at Master Station 1204 (Figure 15) could be the result of tidal oscillation as the strong horizontal gradients associated with the Horseshoe Bend water mass form a boundary condition at or near this location.

In the summer sampling program an attempt was made to review those items that acted as forcing mechanisms on the shelf circulation patterns. It was the intent that this procedure would be followed for the remaining sampling seasons throughout the three-year study. However, one of the forcing mechanisms which can cause major effects not only in the water column but also on the sea floor is a hurricane.

During the fall sampling season, Hurricane ELOISE occurred and moved through the Eastern Gulf of Mexico starting on September 21 and went ashore in the vicinity of Panama City on September 23. The track of this hurricane and its relationships to the water column transect are shown in Figure 109.

This hurricane caused the interruption of the water sampling during operations on Transect II and after the completion of sampling on Master Stations 1204 and 1205. It interrupted the box coring cruise while it was on Transect IV (the Horseshoe Bend transect, which corresponds to the water column Transect II) and the diving program in the Clearwater area. Further, it occurred before the start of the dredge and trawl cruises.

Between 1899 and 1971, approximately 600 tropical cyclones have been recorded over the North Atlantic (Brower, 1972). The occurrence of hurricanes on the Outer Continental Shelf in the Eastern Gulf of Mexico is most frequent in the extreme southern portion of peninsula Florida and in the Panhandle section (Dunn, 1960). In the MAFLA area the maximum possibility for the occurrence of either tropical cyclones or hurricanes is in the Panama City area on Transect III. Table 120 shows the frequency of these storms in the area between the Mississippi Delta and Cape San Blas for the years 1899 to 1971, which, as stated above, is the most frequent area to be affected by hurricanes. This table indicates that once in 3.8 yr a hurricane could affect the area. It would be possible, therefore, for a three-year study not to record the effects of a hurricane.

The tropical cyclone storm track rose shown in the lower lefthand corner of Figure 109 for September is based on data derived from the "Climatological and Oceanographic Atlas for Marine Areas, U. S. Department

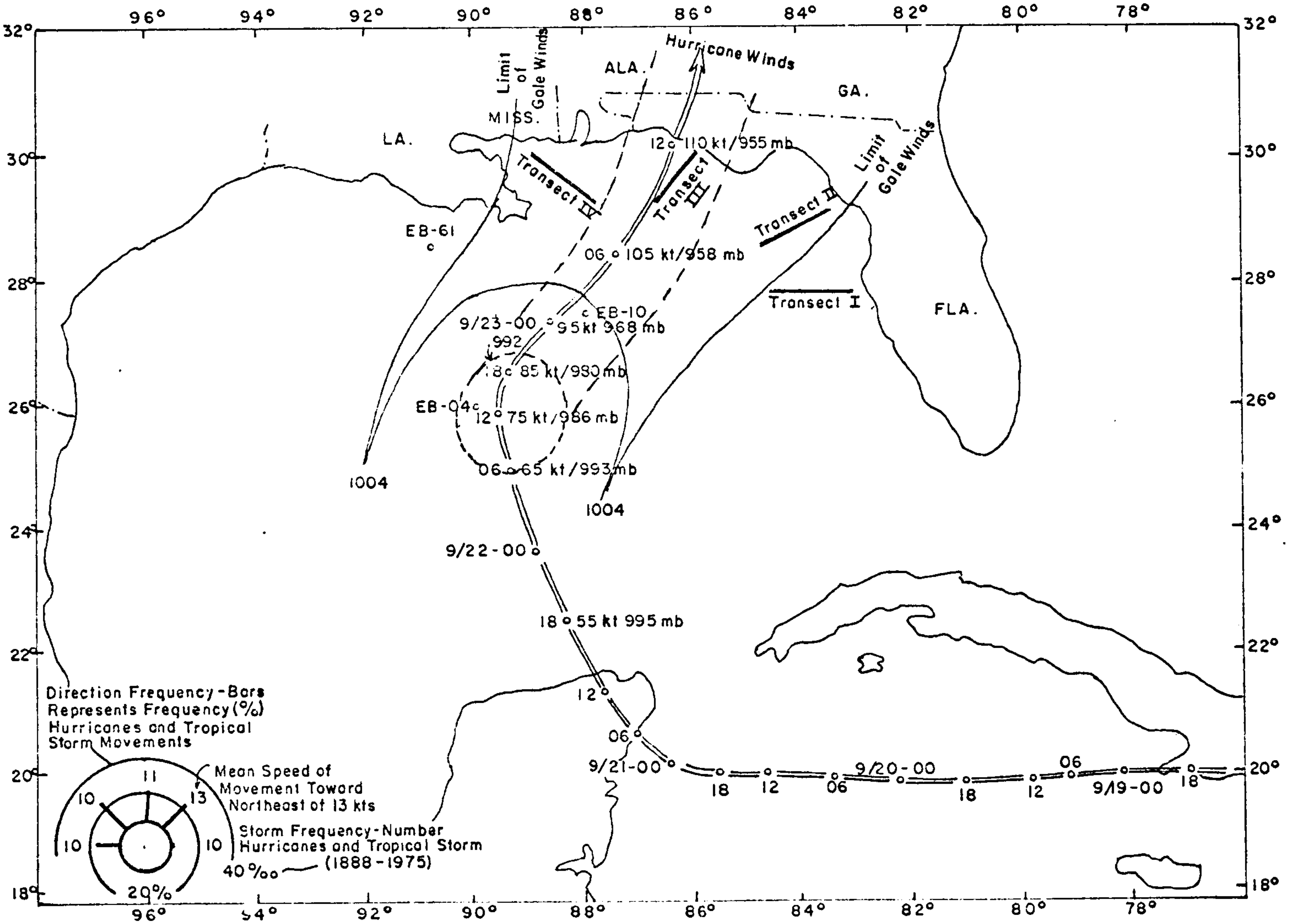


Figure 109. Official NHC Storm Track of Hurricane ELOISE with Significant Events and NDBO Buoy Positions Denoted

Table 120.

Frequency Of Tropical Cyclones And Hurricanes
In The Area Between Mississippi Delta And
Cape Blas For The Years 1899-1971

Storm Type	Southwest Pass Total No. 1899-1971	Southwest Pass Average No. of Yrs Between Occurrences	Mobile-Pascagoula Total No. 1899-1971	Mobile-Pascagoula Average No. of Yrs Between Occurrences	Panama City Total No. 1899-1971	Panama City Average No. of Yrs Between Occurrences
Tropical Cyclones (Winds $\geq$ 34 knots)	49	1.5	41	1.8	52	1.4
Hurricanes (Winds $\geq$ 64 knots)	18	4.1	15	4.9	19	3.8

Compiled from Brower (1972, pages 92, 110 and 129).

of Commerce and Navy, 1959." The direction of movement of these hurricanes and tropical cyclones as shown by this rose indicates that Hurricane ELOISE impacted on the shelf in a direction similar to 22% of the historical tropical cyclones and hurricanes.

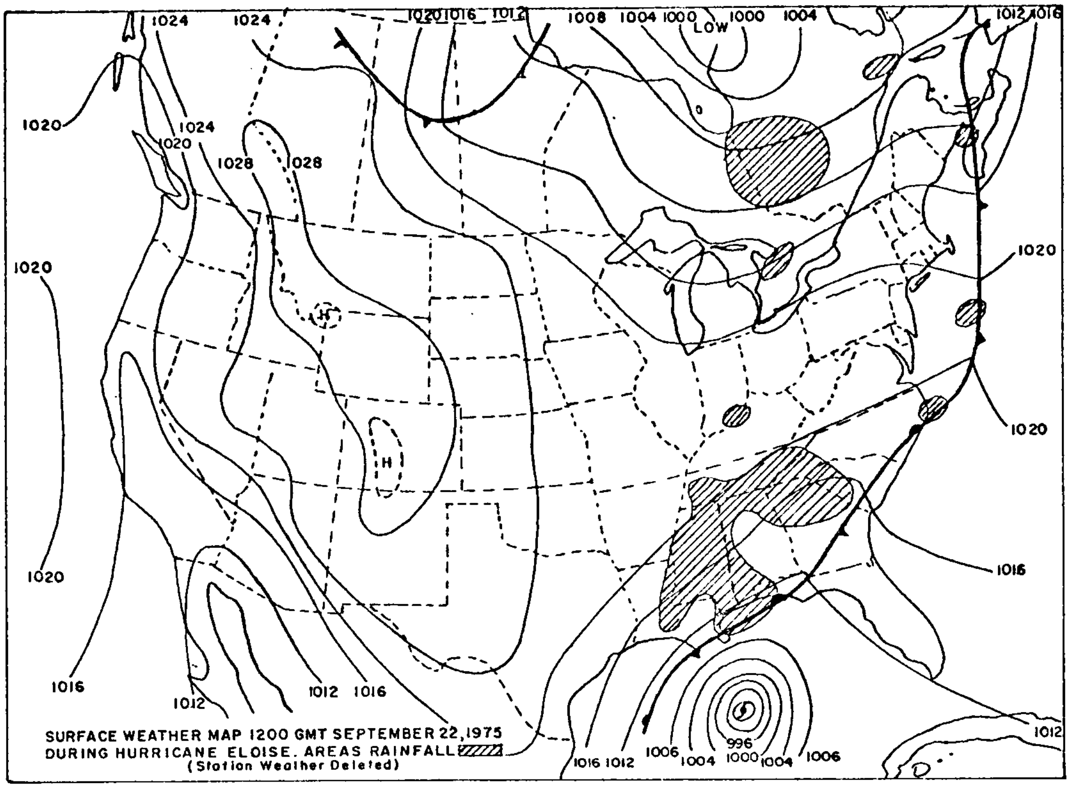
Before examining the water column sections it is important to understand the characteristics of the hurricanes and how they affect the hydrobiological zones in the area. The material that follows has been extracted from eleven sources, and no attempt will be made to reference each individual statement to its source; rather, it is suggested that those who are interested review these particular source materials for themselves. The source materials were Dunn (1960); Brower, et al. (1972); the "Daily Synoptic Weather Charts" put out by NOAA for September and October of 1975; "Data Report: Buoy Observations During Hurricane Eloise (September 19-October 11, 1974)"; "Marine Environmental Data Package Eloise, 1975"; "Natural Disaster Survey Report 75-1 Hurricane Eloise: The Gulf Coast. A Report to the Administrator, December, 1975"; "NODC Hydrographic Vertical Sections"; "Tide and Storm Surge Data"; "Tide and Storm Surges Curves"; "AXBT Log (Flight 750922)"; and "Stage I and Stage II Data Environmental Division, Naval Coastal Systems Laboratory."

The locations of maximum wind and rainfall vary with the development stage. For instance, intense immature storms seem to have more symmetrical wind fields with the strongest wind located in the wall cloud around the eye while on the other hand, in mature decadent storms the maximum winds can be found far from the center; and in poorly defined storms, hurricane winds may be observed only in one quarter. Further, the location and angle of inflow seems to vary considerably with individual storms - their size, their latitude, and other meteorological situations.

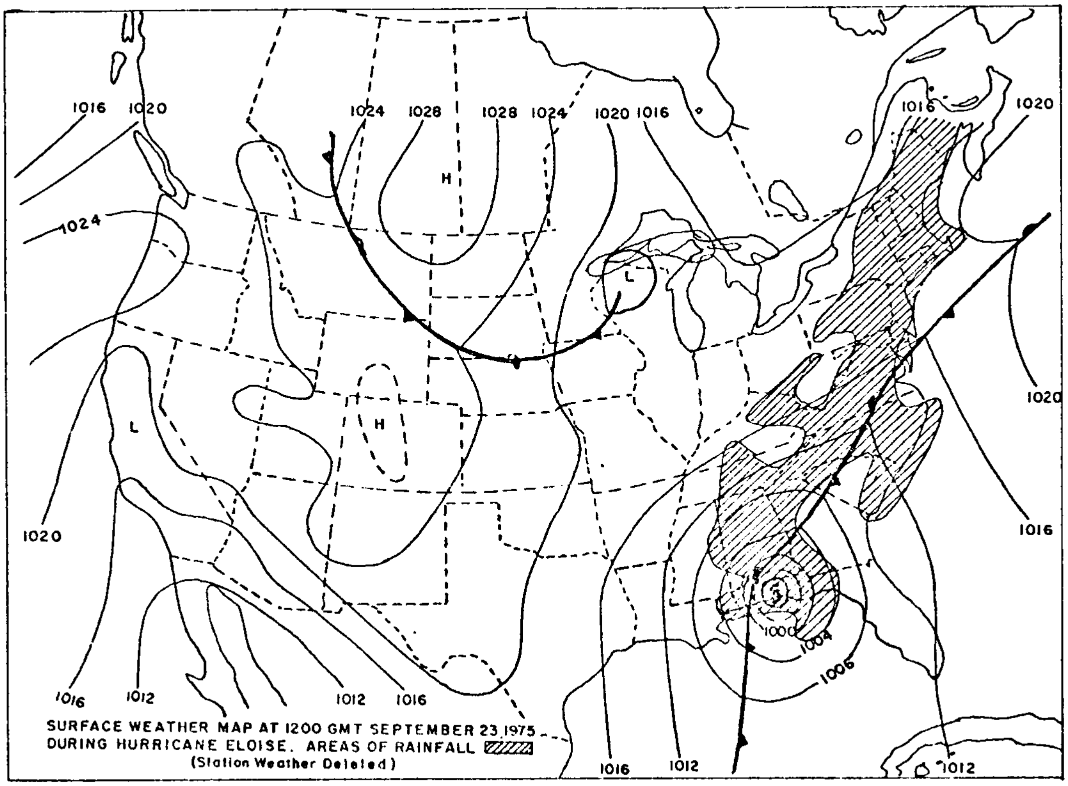
It is appropriate, therefore, to review the meteorological history of Hurricane ELOISE. This disturbance was spawned on the west coast of Africa on September 6, 1975, and by the 13th was a complete depression. By the 16th it had reached tropical storm strength and as a minimal hurricane struck the northeast coast of the Dominican Republic late on the 16th. Here it lost its intensity as it was circulating over land until it passed into the northwest Caribbean Sea as a minimal tropical storm with a marked decrease in associated rainfall. Even though the center was over the open warm waters of the Caribbean Sea, it remained poorly organized until it approached the northeast coast of Yucatan late on the 20th. And during its trip through the Caribbean, its size was 64-94 km in diameter. The existence of an upper level trough in the westerlies caused ELOISE to turn to the north, crossing the Yucatan Peninsula, and reaching the eastern Gulf of Mexico. ELOISE began a steady strengthening north of the Yucatan Peninsula gaining hurricane force in the central Gulf of Mexico about 561 km south of New Orleans, Louisiana, on the morning of 22 September. The hurricane continued to strengthen until landfall about midway between Fort Walton Beach and Panama City, Florida, shortly after 1200 GMT on the 23rd. In short, during the last portions of its history and particularly during the last 561 km (1200 September 22 to 1200 September 23) across the eastern Gulf of Mexico it was an intensifying immature hurricane the maximum velocity of which had increased from 110 km/hr at approximately

25°N to 187 km/hr with a steady intensification of the low pressure from 993 to 955 mbs as it struck land. Preliminary examination of the data indicates that gusts as high as 229 km/hr were measured as it crossed the Continental Shelf areas of Transect III (water column) in the MAFLA area.

Although not an absolute measurement, the barometric pressure in the center of a hurricane is a measure of its intensity. Since readings as low as 915 mbs in the western Caribbean and 935 mbs off Miami have been recorded, this is not an extremely intense pressure pattern. As it was a developing hurricane having reintensified after crossing the Yucatan Peninsula, its strongest winds should be located in the wall cloud around the eye with the winds inclining inward toward the center. The strongest winds will occur to the right and therefore would be along that side of the hurricane in the closest proximity to the Western Florida Continental Shelf. The size of a hurricane can be expressed in two additional ways. One is by the diameter of the hurricane and gale wind and the other by the diameter of the outer closed (roughly circular or elliptical) isobars. Figure 110 is the surface map from the "Daily Synoptic Weather Chart Series" for September 22 and September 23, 1975. If one uses the 1004 isobar as the outer limits for gales and the 992 isobar for hurricane winds from these two maps, they agree with the gales reported from the southwest Louisiana Delta and the New Orleans area to Cedar Key, Florida, and hurricane winds from extreme southeast Alabama to Panama City, Florida. This would indicate that gale winds were extending 208-240 km and hurricane winds were extending 40-48 km on either side of the center of the hurricane. It also indicates that all of Transect III was under hurricane



SURFACE WEATHER MAP 1200 GMT SEPTEMBER 22, 1975 DURING HURRICANE ELOISE. AREAS RAINFALL ▨
(Station Weather Deleted)



SURFACE WEATHER MAP AT 1200 GMT SEPTEMBER 23, 1975 DURING HURRICANE ELOISE. AREAS OF RAINFALL ▨
(Station Weather Deleted)

Figure 110. Surface Weather Map at 1200 GMT September 22, 1975 During ELOISE from Daily Synoptic Surface Weather Maps (NOAA)

wind conditions and all parts of Transect IV and Transect II and the outer portion of Transect I were under gale conditions.

The diameter of the eye of the hurricane was 64 km when it crossed the southwest Florida Panhandle. This is considerably larger than the average diameter of the eye of about 22 km.

In addition, for this particular hurricane, its track took it past four instrument buoys or towers of which two (buoys) were in deep water and two (towers) were on the Continental Shelf. It is possible by use of data from these instruments' locations to discuss in some detail and amplify on the characteristics of the hurricane.

In recent years the National Data Buoy Office (NDBO) of the National Oceanic and Atmospheric Administration (NOAA) has been operating deep ocean data buoys in the Gulf of Mexico. Two of these buoys were in operation in the eastern Gulf of Mexico during the passage of Hurricane ELOISE. These buoys are EB-04 and EB-10 located at 26°00'N, 90°00'W and 27°47'N, 88°02'W respectively. Since it is unusual to have open ocean wind wave height, precipitation, current speed, current direction, surface and at depth salinity and temperature values in connection with the passage of a hurricane, this set of data is unique. These buoys measured atmospheric pressure, wind speed and direction, air temperature, dew point, precipitation, shortwave solar radiation, longwave solar radiation, wave spectrum, wave period significant heights, pressure, current direction and speed, temperature, and salinity. Depending upon the buoy, some or all of these parameters were measured.

The Environmental Science Division of the Naval Coastal Systems Laboratory at Panama City, Florida, in recent years, have instrumented two towers along Transect III which have produced tidal wave heights, wind speed, and wind direction data for the period 0550 GMT hours, September 22, through 1127 GMT hours, September 23, 1975. These towers are identified as Stage I at 30°00.6'N, 85°54.2'W (approximately 19 km offshore from Panama City) and Stage II at 30°07.23'N, 85°46.5'W (approximately 24 km offshore). These towers produced data until the hurricane caused a power failure on shore preventing the transmittal of data. These towers feed their data to a computer that computes statistical values at approximately 30-minute intervals based on 1160 sampling points.

The hurricane passed within 27 km of Ocean Buoy EB-04 with the western fringe of the eye passing over it between 1300 and 1400 hours GMT on September 22, 1975. As the storm passed this buoy, it intensified to hurricane strength. At 0300 GMT on September 23, 1975, it appears that the storm center came within 16 km of Buoy EB-10. This would mean that the eye of the hurricane passed over this buoy, and for that reason the data from it represent a unique situation. It should be noted, however, that this buoy was not operational until 1200 hours GMT, September 20, 1975 since it was under repair until that time. In the data report, "Buoy Observations During Hurricane Eloise (September 19 to October 11, 1975)" issued by the Environmental Science Division, data is given for Buoy EB-04 from 1200 GMT on September 19 through 1200 GMT on September 25, 1975, for wind speed and direction and for Buoy EB-10 from 1200 GMT on September 20 through 1200 GMT on September 26 for wind speed and direction. At 1100 GMT, September 22, a maximum speed of 23.73 m/sec (85.2 km/hr) as the northwest edge of the eye passed over Buoy EB-04. At 1500 GMT on September 22 the southwest portion of the eye passed over EB-04 and by 1700 GMT the wind speed had reached its maximum value of 96.4 km/hr. The wind speeds and wind direction are given in Figure 111.

On EB-10 at 0100 GMT on September 23 the maximum wind speed of 126.4 km/hr was recorded as the eye of the hurricane moved across the buoy. By 0400 on September 23 the eye had crossed the buoy and the wind decreased to 125.3 km/hr. The wind directions and wind speeds for this buoy are shown in Figure 112.

At Stage I gale force winds began to occur at 0554 GMT on September 23 and reached hurricane force at 1127 GMT on September 23. Gale force winds were reached at Stage II at 0622 GMT on September 23 and had not reached hurricane force by the time power failure occurred after 1127 GMT on September 23. The wind directions and wind speeds are shown in Figure 113.

On Buoy EB-04 gale force winds were not reached until 0900 GMT on September 22 and terminated by 0200 GMT on September 23 while on Buoy EB-10 gale force winds were reached by 1400 GMT on September 22 and were over by 0900 GMT on September 23, 1975. This would mean that gale force winds or greater occurred at EB-04 for 17 hr and on EB-10 for 19 hr. Since no data were available after the hurricane on Stages I and II, it is difficult to determine the extent of gale force or greater winds at sea on the Continental Shelf. However, because of the speed of the hurricane, it seems reasonable to assume that the time period would not be greater than 22 hr.

Because of the course of the hurricane, the full hurricane wind effects were experienced along Transect III, which is nearly parallel to the track or in the right quadrant of the hurricane. The effects of the wind should have been felt strongly on the outer portion of this transect

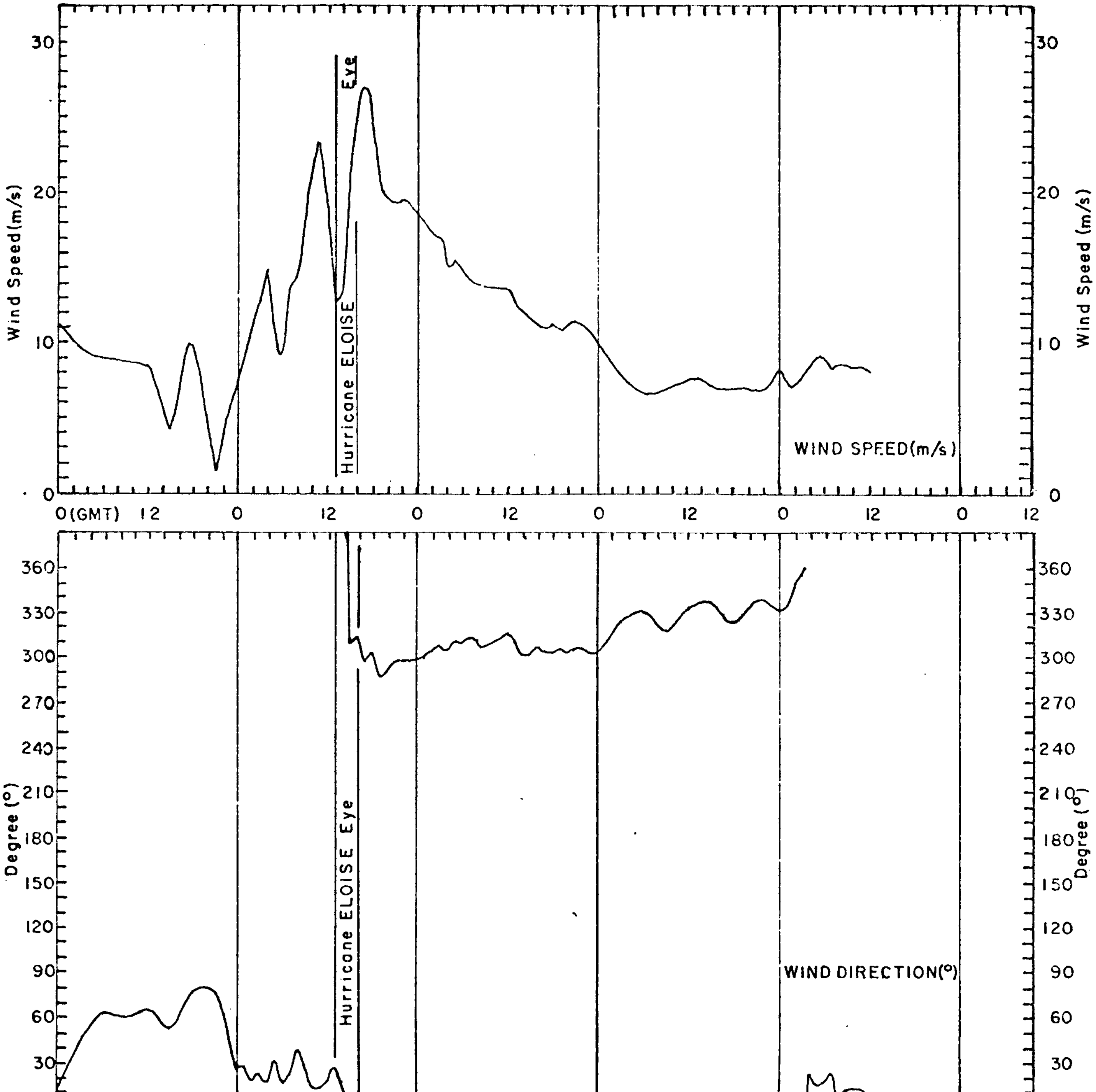


Figure III. Wind Speed and Direction from NDBO Buoy EB-04 26°00'N., 90°00'W. September 21-26, 1975

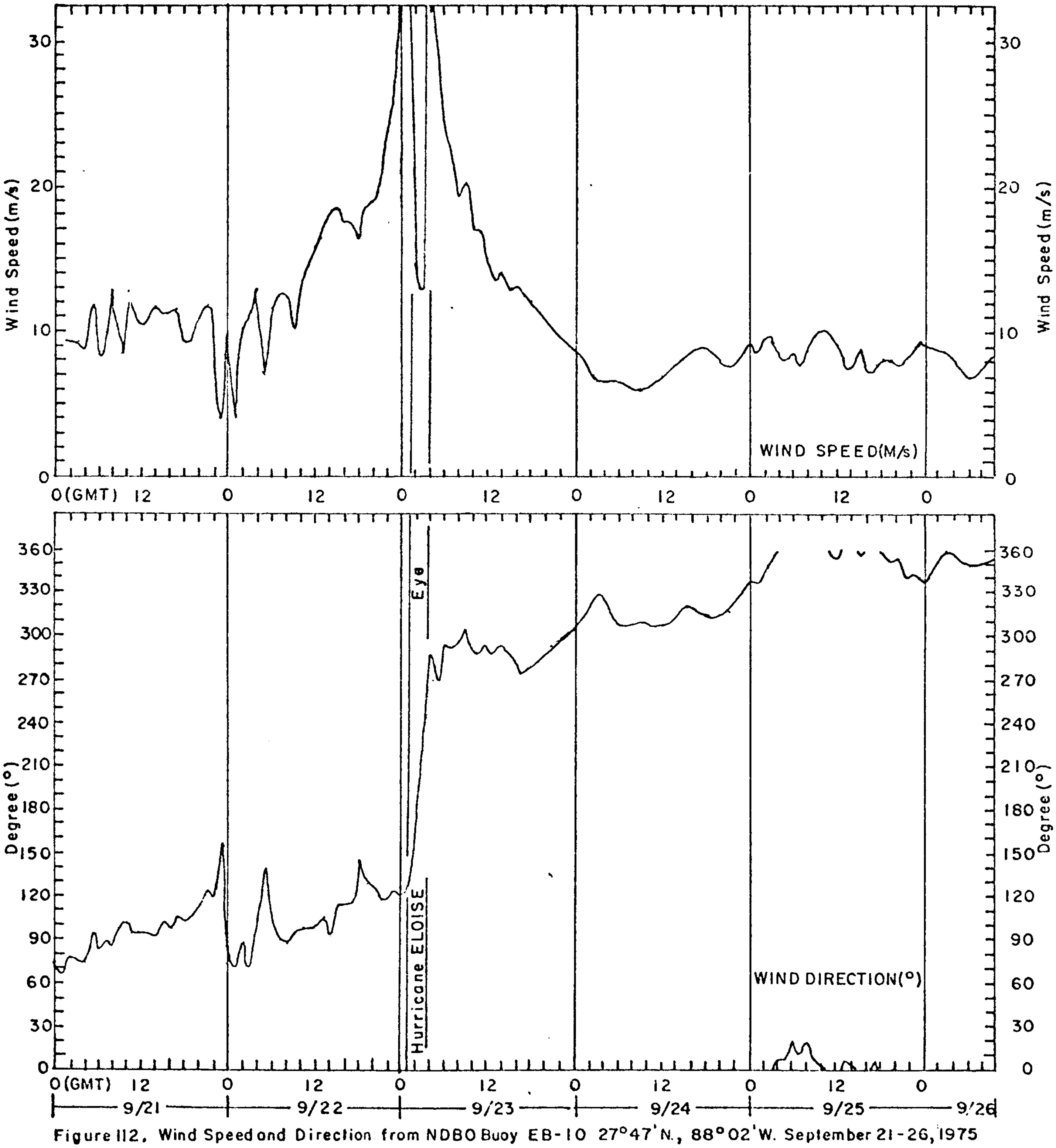


Figure 112. Wind Speed and Direction from NDBO Buoy EB-10 27°47'N., 88°02'W. September 21-26, 1975

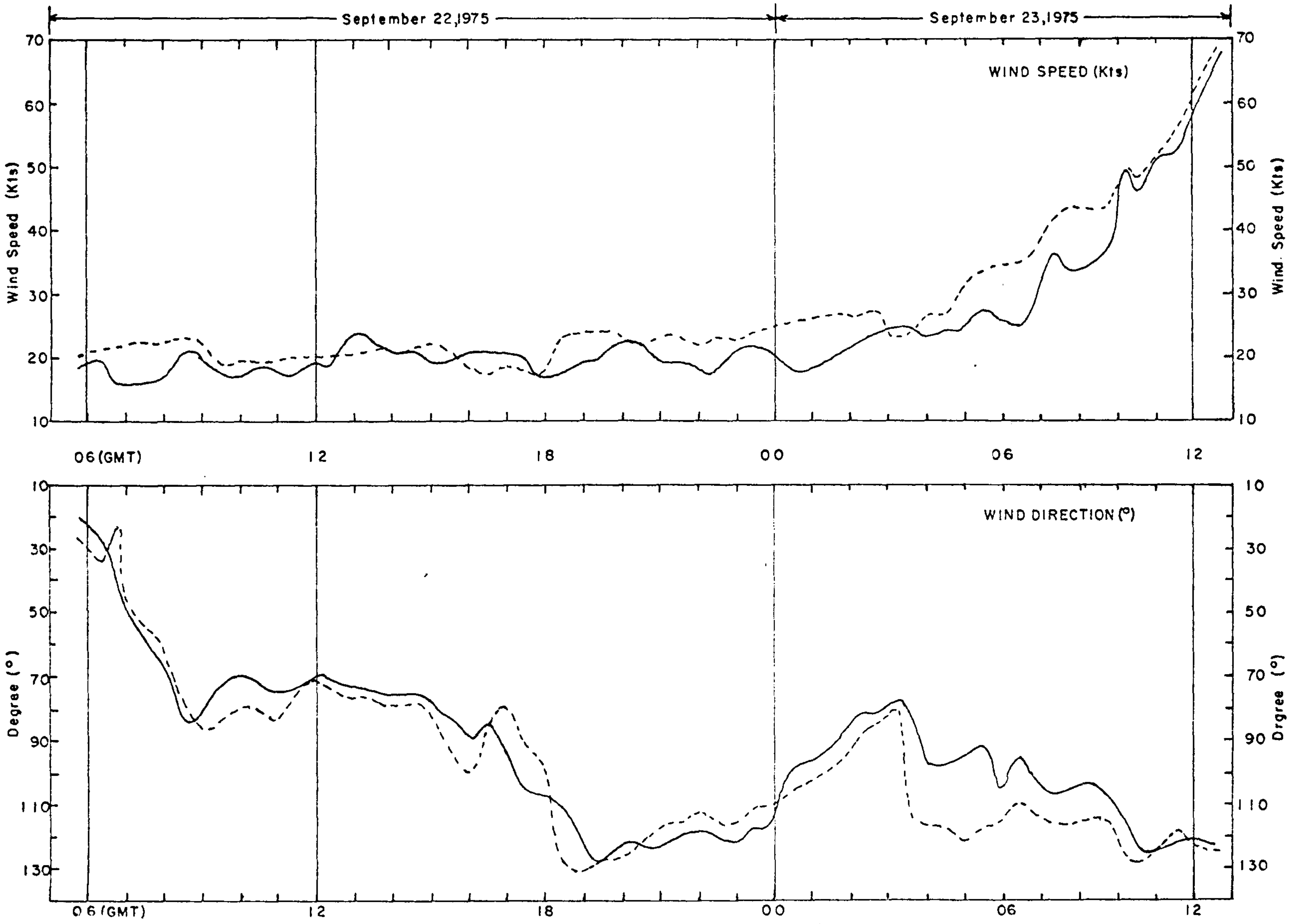


Figure 113. Wind Speed and Direction from Stage I 30° 00.6'N., 85°54.2'W. and Stage II 30°07.23'N., 85°46.5'W. September 22-23, 1975

(Master Station 1310 and Master Station 1311). On Transect II, which is nearly perpendicular to the pattern of the gale, winds of between 56 and 67 km/hr should have occurred along the entire transect. On the other hand, Transects I and IV, nearly perpendicular to the pattern of the hurricane, would have experienced steadily decreasing wind effects from the outer stations towards shore.

Some of the world's heaviest rainfalls have occurred in connection with hurricanes. The rainfall is always heavy, probably 7.5-15 cm on the average and frequently much more. The total accumulation of rain at a given locality is greatly dependent upon the forward speed of the hurricane simply because in slower moving storms the rain lasts a longer time. Although the quantitative aspects of rainfall distribution around hurricanes are still in the stage of development, it has been found in general that the distributions are quite asymmetrical around the storms along the Gulf Coast (provided the hurricane center was moving). In these cases, the areas of greatest intensity were found 96-128 km in front of the cyclone center and mostly to the right of the line along which the cyclone was advancing. However, such conclusions can be altered not only by the stages of development, but by the speed of motion and degree of curvature that occurs with each individual hurricane. In Hurricane ELOISE, which was a very "wet hurricane," rainfall amounts generally ranged from ten to 20 cm from extreme southeast Louisiana to west of the Panama City area. The greatest rainfall was 37.8 cm at Eglin Air Force Base at Fort Walton Beach, Florida. Unlike the normal hurricanes, the heaviest rainfalls occurred west and north of the storm track as the moist warm air associated with ELOISE overran the colder air behind the stagnant frontal zone extending from northern Alabama southward into the Gulf of Mexico (Figure 110). Most stations east of Panama City had less than 2.5 cm of rainfall as a tongue of dry air behind the frontal zone was drawn into the area of ELOISE circulation. This meant that heavy rainfall should have been experienced only on Transect IV. However, due to the rapid movement of the hurricane, excessive rainfall (that is, above the average of 7.5-15 cm) did not occur on Transect IV. The speed of advance of the hurricane and the meteorological conditions associated with the frontal conditions caused very little rain to fall on Transects III and II and little or no flooding was noted in the area. The rainfall associated with this hurricane is given below in Table 121.

Table 121. Rainfall associated with Hurricane ELOISE, September 22-23, 1975.

Station	Rainfall Storm Total in Centimeters	Dates
Boothville, Louisiana	12.0	21-23
Bay St. Louis, Mississippi	22.1	No date
Dauphin Island, Alabama	13.3	22-23
Mobile, Alabama	4.4	22-23
Pensacola, Florida	14.3	20-23
Crestview, Florida	24.1	22-24
Valparaiso, Florida	37.8	21-23
Panama City, Florida	1.9	23
Apalachicola, Florida	0.3	22-23
Tallahassee, Florida	2.3	23

Table 122 gives the September precipitation from several of the meteorological stations in the area of the hurricane. This table records the normal total, the maximum monthly, the minimum monthly, and the maximum in 24 hr of rainfall for September. Included as part of this table are the actual observed rainfall amounts for Hurricane ELOISE.

Table 122. Normal and Hurricane ELOISE associated rainfall at selected meteorological stations in the vicinity of the storm (centimeters).

		Precipitation - September			Hurricane ELOISE	
Station	Normal Total	Maximum Total	Minimum Total	Maximum in 24 hr	Storm Total	September Dates
New Orleans, Louisiana	12.78	42.52	0.61	16.51	11.99	21-23
Mobile, Alabama	15.88	34.57	1.47	16.71	4.42	22-23
Pensacola, Florida	19.53	26.11	6.05	25.45	14.28	20-23
Apalachicola, Florida	21.67	57.15	1.98	29.74	0.30	22-23

These data would indicate that the hurricane created rainfall amounts equal about 90% of the total normal rainfall for September in those areas west of the hurricane center except for Mobile. Looking at Table 121 it can be seen that at Dauphin Island on the coast south of Mobile that 13.3 cm of rain occurred which would be approximately ninety percent of the total normal rainfall for September at Mobile, Alabama.

To the east of the hurricane, the rainfall data at Apalachicola, Florida, indicate that only a nominal amount of rain fell in relation to the total normal monthly rainfall.

Of particular interest is the precipitation record from Buoy EB-10 durig the passage of the hurricane. Figure 114 shows the hourly rate and the

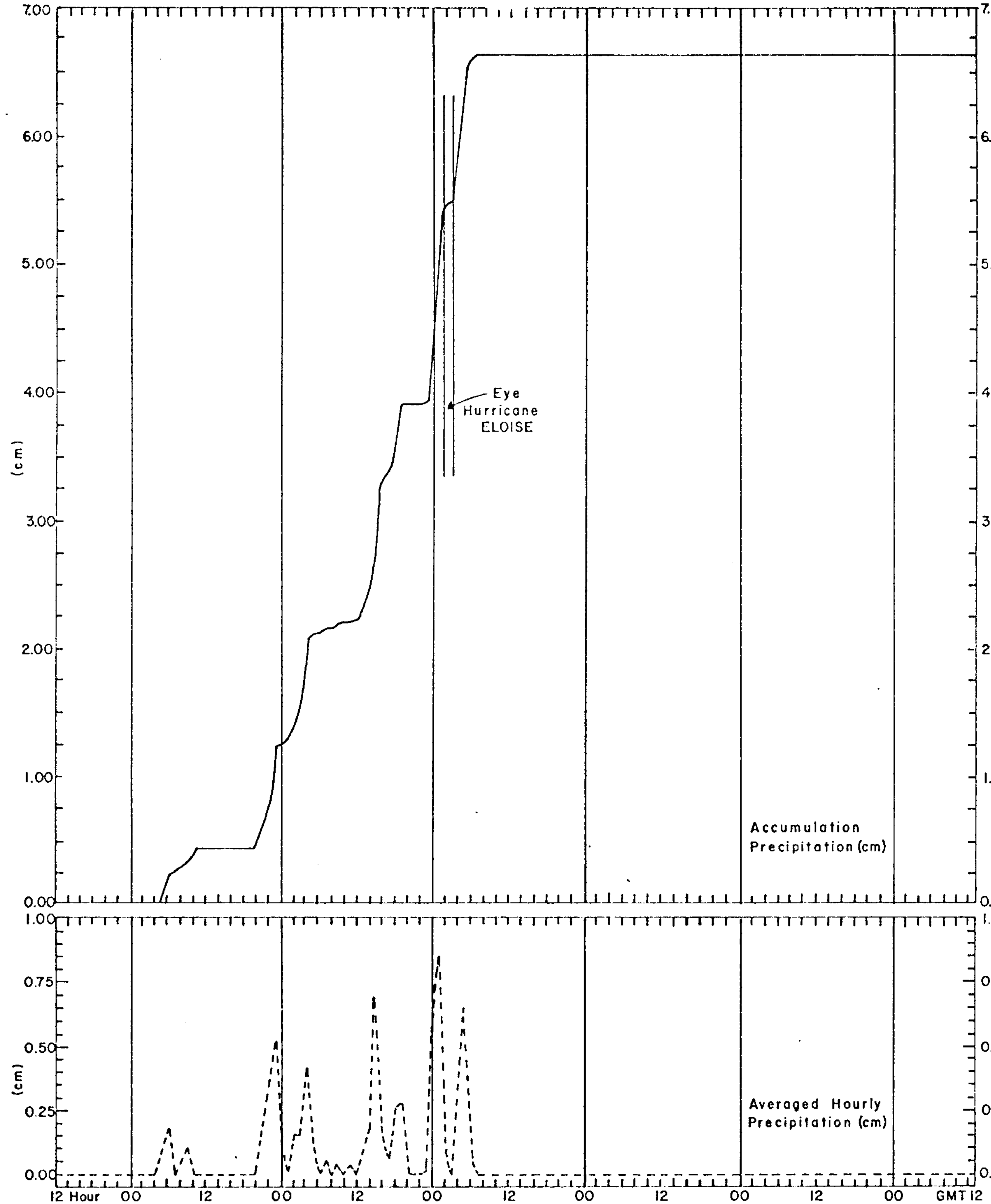


Figure 114. NDBO Buoy EB-10 Precipitation (cm) 1200 GMT, 20 September to 1200 GMT, 26 September, 1975.

accumulated precipitation in centimeters during this time period at a height of ten meters above sea level. The hourly rates are shown as dashed lines and the accumulated amounts as a solid line. This data along with variations in wind speed and wind direction indicate possible bands of activity, which were associated with the spiral effect noted in the structure of hurricanes. These can be seen by periods of rainfall on the 21st and 22nd which are separated by either no precipitation or very little and the increasing amount in the hourly rate as the hurricane approached the buoy. The maximum amount of rainfall per hour occurred just before the passage of the eye.

An important characteristic of any hurricane is the influence of the abnormal tides and storm surges associated with the passage of a hurricane. In this discussion the storm surge resulting from the hurricane is defined as a rise above normal water level on the open coast due to the action of wind stress on the water surface and the rise in level due to the atmospheric pressure reduction.

The highest waves are usually produced to the right of the hurricane center when the observer faces in the direction towards which the center is moving. It can be seen from Figure 109 that the inner part of Transect III would have received the highest waves. It can also be shown that the ocean waves travel with a speed somewhat faster than the winds which generate them, and normally they will precede the hurricane since the average movement of a hurricane is about twelve miles per hour, and the average movement of the waves is between thirty and fifty miles per hour. This hurricane, however, was not an average one in its rate of movement. By 0600 GMT on the 23rd its speed was approaching 27 km/hr and by the time it reached land it was moving at 34 km/hr.

Through the courtesy of NOAA/Marine Climatological Services Branch, graphs of the observed tide and storm surges from three NOS tide gauges located at Pensacola, Panama City, and Apalachicola, Florida, are shown in Figure 115. These curves are based on hourly values. The storm surge was determined by subtracting values of the astronomical tides from the observed.

As can be seen from Figure 115, the storm surge west of the hurricane center at Pensacola ranged between 0.30 and 0.60 m while the values at Panama City and Apalachicola to the east of the hurricane center ranged from 0.30 to 1.52 m. The influence of the hurricane on the water level can be noted as starting on the 21st and ending by the end of 24 September. Figure 115 graphically illustrates the location of the highest increase in water level to the right of the hurricane.

Preliminary measurements indicate that the storm surges were from 3.66 to 4.88 m above mean sea level (MSL) just east of Fort Walton Beach, 1.83 to 3.66 m eastward to Port St. Joe, from 0.91 to 1.52 m elsewhere in the gale wind area (Figure 109), and 0.61 to 0.91 m southward from Cedar Key to Naples, Florida.

The extent of maximum wave heights is a much more difficult problem to determine. The highest inside high water mark of 5.5 m above mean sea level occurred near Dune Allen Beach. The data from the towers indicate that at Stage II the maximum high was 2.9 m and at Stage I, 3.2 m representing conditions between Master Stations 1308 and 1309. The maximum observed wave height value on Buoy EB-10 was 8.1 m just before the passage of the eye of the hurricane and 8.8 m after its passage. If one removes the normal recorded wave action before and after the hurricane of approximately two

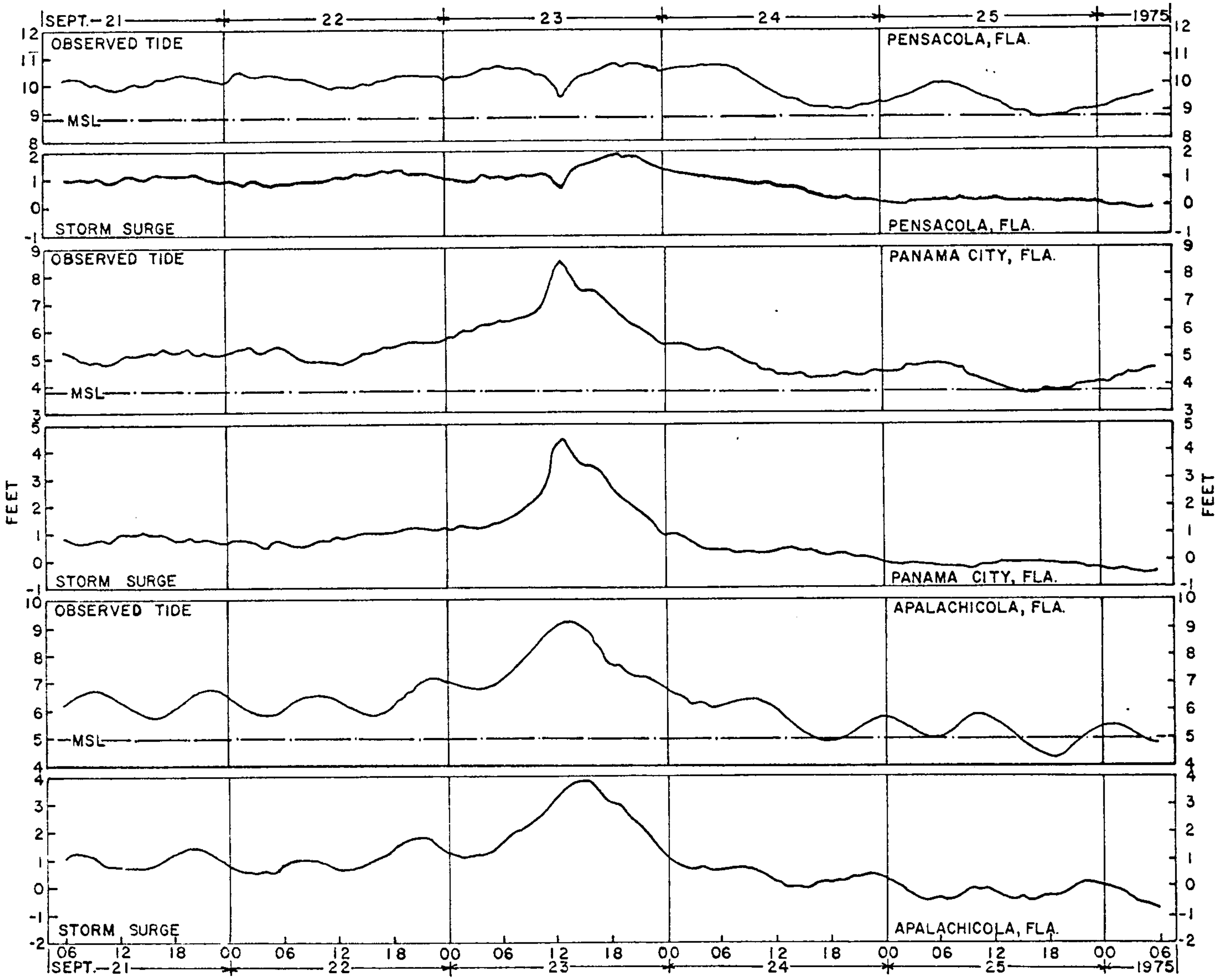


Figure 115. Observed Tide and Storm Surge from NOS Tide Gages at Pensacola, Panama City, and Apalachicola Florida During Hurricane ELOISE September 21-26, 1975 Based on Hourly Values. The Storm Surge is Determined by Subtracting Values of the Astronomical Tide from the Observed Tide. (Supplied by NOAA/Marine Climatological Services Branch)

meters from these values, one has wave heights of 6.1-6.7 m respectively. The position of the sensor and the buoy transfer functions indicate that the estimate of the total system accuracy is approximately 50% depending upon the statistical confidence required. -Taking this figure, the highest observed wave would be about 3.3 m which agrees rather well with the figures recorded at Stages I and II.

The horizontal movements of both temperature and salinity distribution patterns westward from the 25 m depth on the Continental Shelf indicate that these changes were not related to tidal oscillation patterns. The need for long-term time series studies at a fixed location at critical positions within the MAFLA area is apparent from the examination of the different distribution patterns of temperature, salinity, and sigma t which have resulted from the reoccupation of certain of these transects during the fall and winter seasons. This is further supported by the examination of the 24-hr time series stations taken in support of the transmissometer studies at Master Station 1412 and the Middle Ground position at Master Station 1207 during the fall and winter seasons. A similar situation exists in the data shown in Table 119 taken by repeated sampling at certain stations over the time intervals from thirty minutes to twelve days during the fall and winter season. Table 123 records the results of similar measurements in the summer and fall seasons at stations along Transect III from the historical data (SUSIO, 1975). In this table the station numbers to the left represent data from Gaul's work (1964, 1965, and 1966). The station numbers to the right represent station numbers from the BLM monitoring survey.

Table 123. Historical variations in temperature/salinity along Transect III.

JUNE		1964				1965				BLM 1975				
Station No.		Temp. Range	Salinity Range	Temp. 24H	Sal. 24H	Temp. Range	Salinity Range	Temp. 24H	Sal. 24H	Temp.	Sal.	Temp. 24H	Sal. 24H	Sta. No.
II	S	30.0-27.5=2.5	34.95-31.08=3.87	1.3	1.39	28.6-26.0=2.6	34.11-28.31=5.80	1.3	1.46	27.74	31.64			1308
	B	28.5-23.2=5.3	34.99-32.97=2.02	1.8	1.30	27.0-22.6=4.4	35.34-33.99=1.39	2.0	1.72	21.34	36.12			
I	S	30.3-28.2=2.1	33.49-29.47=4.02	1.1	1.75	27.6-26.4=1.2	35.22-32.66=2.56	1.2	0.96					
	B	26.4-22.6=3.8	35.35-34.27=1.08	3.2	0.89	26.8-21.1=5.7	35.70-34.90=0.80	1.3	0.96					
D-2	S	29.3-20.3=9.0	35.71-33.64=2.07			27.2-26.3=0.9				28.59	31.93			1309
	B					21.4-19.1=2.3				20.00	36.29			
D-5	S									28.65	31.52			1310
	B									16.50	36.20			
IV	S					27.0-26.7=0.3	36.34-30.67=5.67			28.15	32.56			1311
	B					13.5-12.2=1.3	35.68-35.53=0.15			13.80	35.81			

SEPT.		1964				1965				BLM 1975				
Station No.		Temp. Range	Salinity Range	Temp. 24H	Sal. 24H	Temp. Range	Salinity Rante	Temp. 24H	Sal. 24H	Temp.	Sal.	Temp. 24H	Sal. 24H	Sta. No.
II	S	29.7-21.8=7.8	34.76-31.15=3.64	0.2	0.20	28.1-28.0=0.1	33.39-32.82=0.57			28.2	31.686			1308
	B	26.9-21.6=5.3	36.24-33.62=2.62	0.1	0.29	27.4-27.3=0.1	34.87-34.51=0.36			23.3	35.92			
I	S	31.4-22.4=9.0	35.25-30.10=5.15	1.1	1.30	28.2-26.4=1.8	35.22-32.60=3.62	0.8	1.31					
	B	25.2-20.6=4.6	36.62-36.26=0.36	1.0	0.36	27.7-25.5=2.2	35.70-34.26=1.44	0.7	0.36					
D-2	S	29.9-23.9=6.0	35.82-32.00=3.82			28.0-27.5=0.5	35.53-34.70=0.83			28.91-28.86	33.76-33.76	0.05	0.00	1309
	B	23.7-19.6=4.1	36.55-35.50=1.05			26.6-22.1=4.5	36.23-35.69=0.54			23.40-23.13	36.19-36.18	0.27	0.01	
D-5	S									29.10	35.31			1310
	B									19.35	36.53			
IV	S					28.6-27.8=0.8	36.36-34.85=1.51	0.6	0.11	28.93	34.63			1311
	B					13.7-12.1=1.6	36.09-35.41=0.68	1.2	0.11					

S = Surface
B = Bottom

The distribution patterns discussed previously reveal that the Loop Current was not affecting water column conditions in the MAFLA area in the winter season. Neither direct intrusions of main stream Loop Current water (36.7 °/oo) nor eddy or boundary conditions of Loop Current water (36.55 °/oo) were present. Further, there is no eastern Gulf of Mexico water (36.4 °/oo) on the shelf although on Transects III and IV a very small wedge was present either at the break of the slope or on the slope itself. The patterns indicate that the circulation patterns were carrying outer shelf waters off of the shelf.

The effects of run-off can be seen on the inshore stations on each transect, and they do not appear to be extending out any further than those observed during the summer and fall periods. There is a difference, however, in their influence as represented by the isothermal and isohaline conditions on these inshore stations rather than the existence of surface pockets. Only on Transect I during the second sampling period were any surface pockets detected.

Figure 116 shows the monthly precipitation at Mobile, Pensacola, Apalachicola, and Tampa or very near the coast in the MAFLA area. Table 124 gives the maximum, minimum and normal monthly precipitation amounts at these meteorological stations and the monthly values for 1975 and 1976 for December, January, and February are recorded. These figures indicate that the January and February rainfall during 1976 was below normal except for the January data at Pensacola and Apalachicola, Florida. Examination of the daily precipitation rates shows that 9.27 of the 11.43 cm at Pensacola and 8.20 of the 17.20 cm at Apalachicola were recorded after the occupation

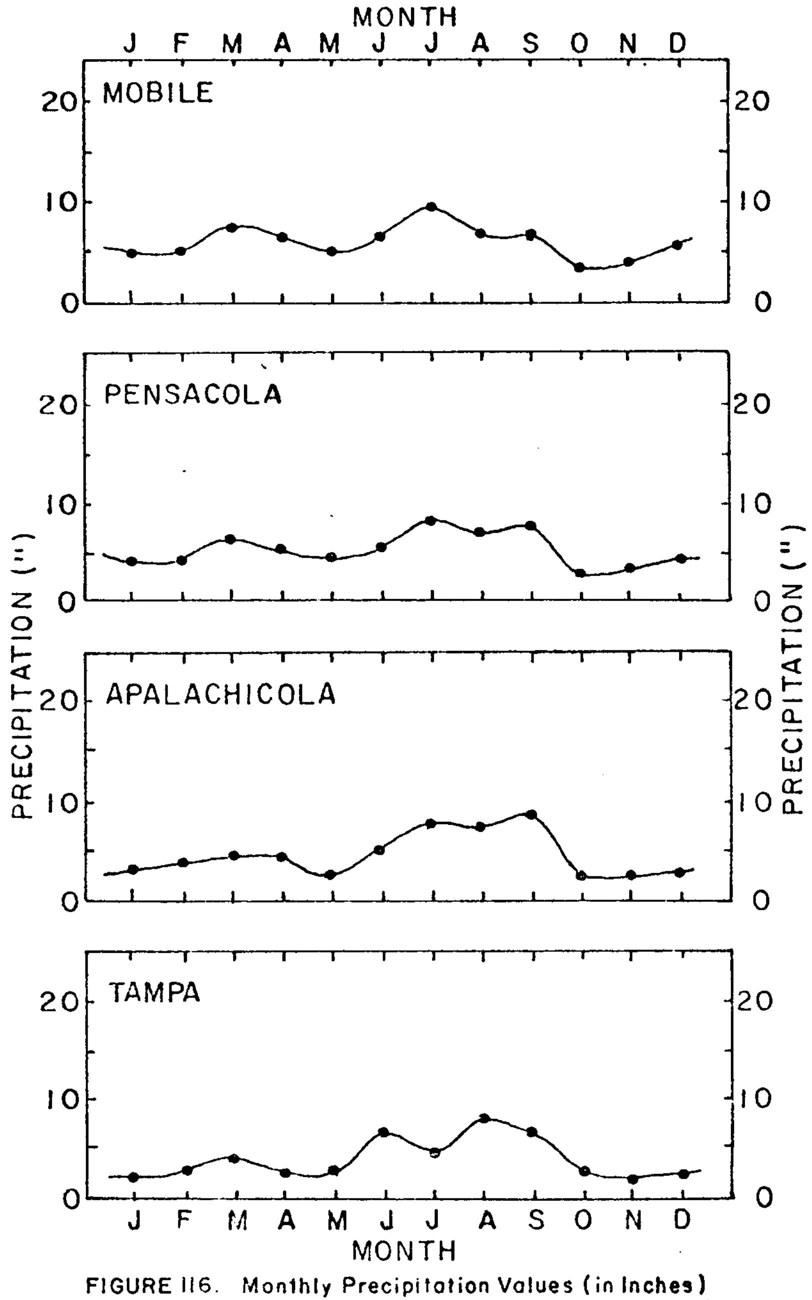


FIGURE 116. Monthly Precipitation Values (in Inches) at Mobile, Pensacola, Apalachicola, and Tampa.

Table 124. Monthly precipitation values in centimeters.

Station	Monthly Precipitation														
	Max Monthly			Min Monthly			Normal Total			1975			1976		
Month	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb
Mobile	28.91	23.75	22.89	3.81	2.48	3.33	15.04	11.96	12.09	12.65	8.71	9.52	-	4.57	5.99
Pensacola	16.59	30.05	29.62	8.79	3.10	7.06	11.83	11.10	11.91	8.05	11.45	10.87	-	15.52	7.80
Apalachicola	19.99	20.95	23.34	0.76	0.10	0.96	8.43	7.79	9.60	15.19	17.19	8.53	-	11.76	1.24
Tampa	-	-	-	-	-	-	5.53	5.36	7.26	2.21	2.31	3.96	-	1.02	1.24

of Transects IV and III. Taking this and the December and January records into account it would appear that the winter coastal drainage into the MAFLA area was lower than normal. Because of this and because of the data in the summer and fall seasons, the isothermal-isohaline conditions experienced on the inshore stations are not related to large run-off effects.

The only pocket of low salinity surface water which cannot be explained by run-off occurred on Transect IV on Master Station 1415. Based on the summer and fall horizontal distribution patterns and vertical sections, this water appears to be influenced by the Mississippi River System discharge.

Figure 117 is a horizontal distribution of salinity at the surface during the winter. Keeping in mind the limitations of the transect data as previously discussed, it would appear that the Mississippi River System drainage discharges were not moving to the east as was the case during the summer and fall seasons when Loop Current water and eddies were present. A similar condition was present in the ten-meter horizontal salinity distribution pattern. There was an indication that some form of upwelling was occurring along the DeSoto Canyon area. The Horseshoe Bend eddy water mass had established itself as a ridge of high salinity. Perhaps more important is the extent to which Outer Continental Shelf water has moved out onto the Continental Slope.

Figure 118 shows the bottom salinity and indicates that in general the bottom water flows along the isopleths. It also shows that the Outer Continental Shelf water has protruded well over half way onto the shelf on Transects I and II.

The effects of the short-term fluctuations, referred to above, can be seen on Figure 32 where the salinity value of 36.06 °/oo at Master

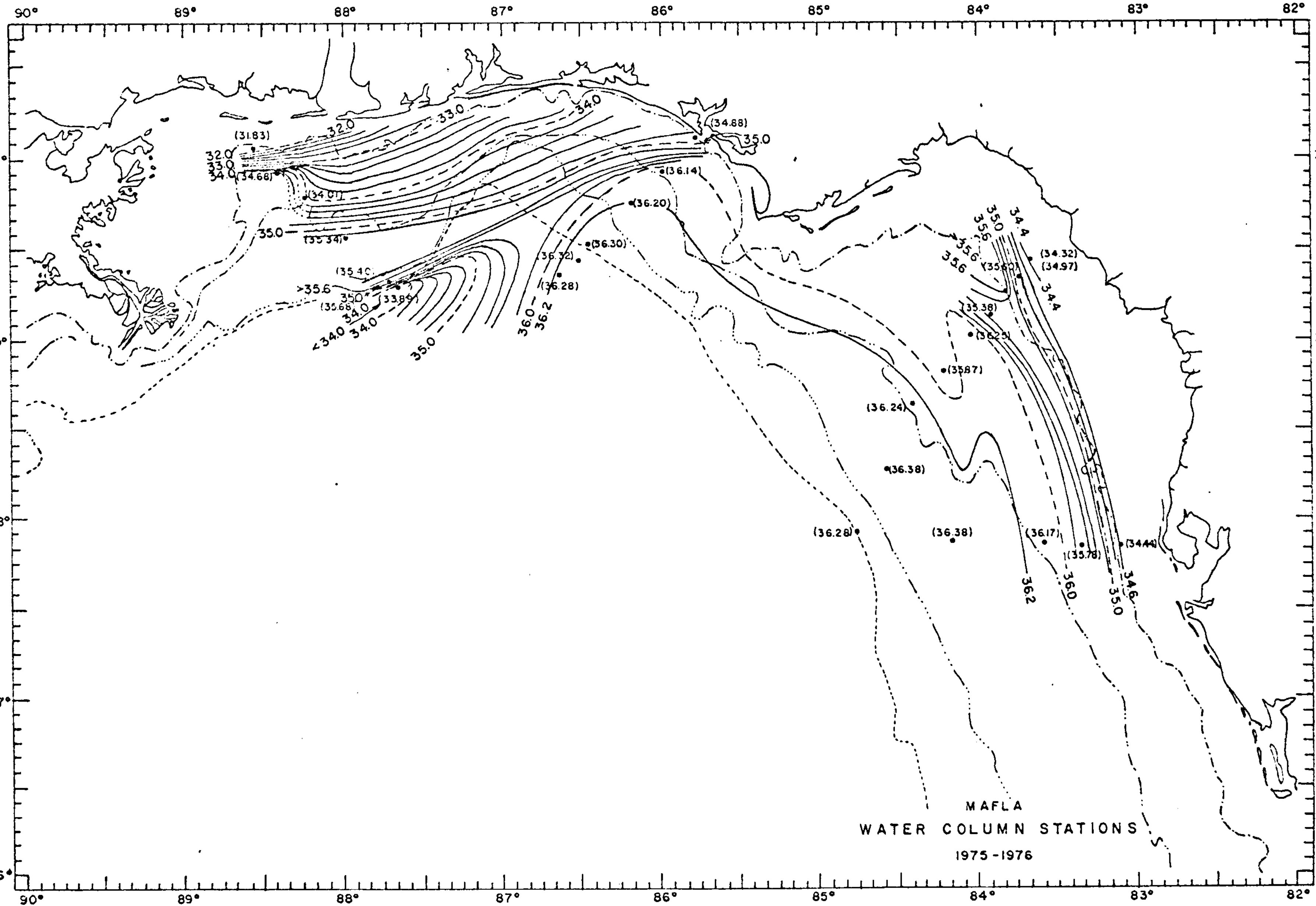


Figure 117. Surface Distribution Salinity ‰ BLM-28 JANUARY 9 - FEBRUARY 10, 1976

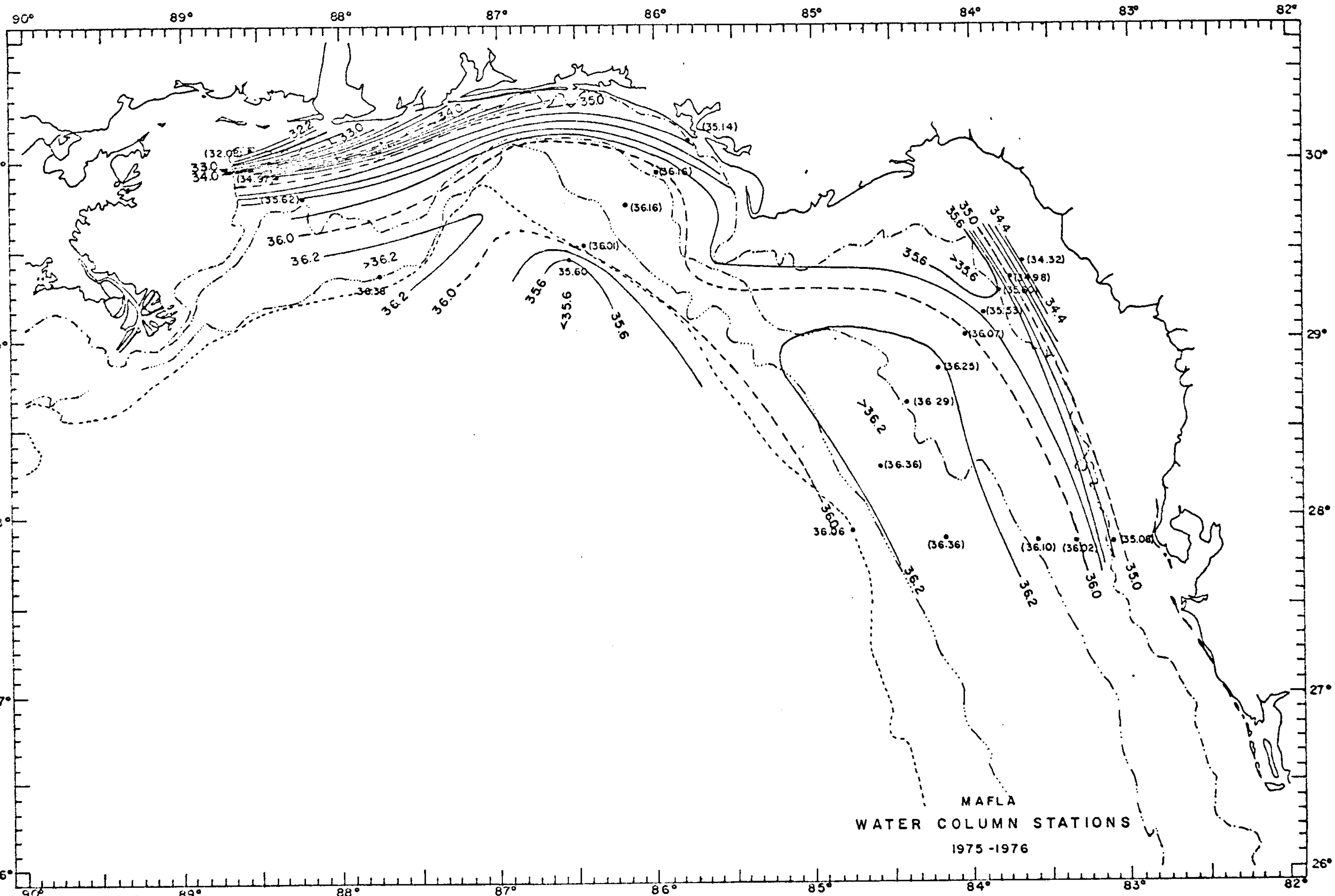


Figure 118. Bottom Distribution Salinity ‰ BLM-28 JANUARY 9 - FEBRUARY 10, 1976

Station 1103 was taken some three days before the remaining data on the transect (Figures 36 and 37). The inherent danger, therefore, in using non-synoptic data or not knowing the short-term fluctuations of the physical parameters at a fixed location can be illustrated by that data point, which, if contoured, would appear as a tongue of 36.20 $^{\circ}/_{\circ\circ}$ water extended out onto the shelf.

Dismissal of large run-offs and Loop Current effects as causes of the isothermal-isohaline conditions occurring over three quarters of the MAFLA (Transect I through Transect III) area out to a depth of approximately 50 m suggests that the homogeneous mixing of the water column can be attributed to wind stress. This was further supported by the examination of the data contained in the synoptic surface maps. These maps were examined for frontal conditions in the Eastern Gulf of Mexico (defined as being the location within the area limited by 21°N and 31°N parallels and 80°W and 90°W meridians). This area was also used by Fernandez-Partagas to characterize the frontal conditions over the eastern Gulf of Mexico and surrounding land areas (SUSIO, 1975). These frontal conditions show the passage of cold fronts on December 30 and 31, 1975, January 3 and 4, 7 and 8, 14 and 15, 20 and 23, 26 and 28, January 30 and February 1, 6 and 7, 18 and 19, 22 and 23, 26 and 27, 1976. There were warm fronts on the 6th and 7th and 12th and 13th of January and on the 19th and 20th of February. There were occluded fronts on the 16th and 17th of January and the 25th and 26th and 28th and 29th of February in the Miami area. Based on these charts there were six cold, two warm, and two occluded fronts in January and six cold, one warm, and two occluded fronts in February.

Fernandez-Partagas' study (SUSIO, 1975) was based on data over a ten-year period. If the 1976 cold front distributions are compared with the statistics from that study (in which frontal disturbance was defined as the approximate number of consecutive maps on which an individual warm or cold front could be identified in the sample area) there was an increase in the number of cold fronts and a decrease in the frontal passage time through the area from the mean. Similar statistics for the warm fronts indicate that the frontal duration of the warm fronts was markedly increased over the norm. To put it another way, only 14 days out of 31 (45%) in January and nine out of 29 (31%) in February were under the influence of cold fronts. Cursory examination of the weather charts for November and December, 1975, also indicated that this was an unusual winter season.

An examination of the surface charts indicated that the winds were moving over the subject area from either a north-northeast, east-southeast or southerly direction 63% of the time. These particular directions of flow would result in wind stress form the shore outward to the Continental Shelf over Transects I and II. Northeasterly and easterly winds have the same effect on Transect III. It is in these areas that the isothermals and isohalines were so well defined and extended out nearly to the edge of the shelf or across the shelf. Wind stressing from these directions would cause the transport of surface water off the shelf areas with a resulting inflow of water along the bottom of the shelf. Under these conditions, not only would the isothermal and isohaline layers be present, but the water temperatures themselves should be lower than normal.

As indication of the mixing of the water column except for the instrusion of 35.8 $^{\circ}/_{\circ\circ}$ water on the shelf (Figure 28), the thermocline is either at the bottom or very near the bottom throughout Transects I, III and IV. On Transect II it was out to the Master Station 1207 with two surface shallow thermoclines between Master Stations 1205 and 1206 and around 1207.

The historical data on the four transects (Figure 4) were examined for the winter months in regard to their distributions and the range of temperatures across the shelf. The historical and BLM cruise numbers, months, and years of this comparison are shown in Table 125. The results of this examination indicated that the winter of 1976 was not unique on Transect IV but was colder by one degree on Transect III, two degrees on Transect II, and three degrees on Transect I; further, the temperatures in 1976 were lower than or equal to the lowest temperatures observed in the historical past.

Although February is the month of maximum thermocline depths, the thermocline depths (particularly on Transect I) were abnormally deep. The depth of the thermocline, the coldness of the water, the reports from the diving program on the Florida Middle Ground, and the transmissometer readings indicate that the water column was well mixed. It was interesting to note that the transmissometer readings were lower in the winter months than those taken directly after the hurricane on Transect II. This indicates that unusual winter conditions may have a greater effect on the bottom than storm (hurricane) effects.

The well mixed character of this water would indicate that on Transects I, II and III those values measured at ten meters were representative of surface and bottom values. Further, these values represent the combined influence of the shelf circulation patterns.

Table 125. Historical and BLM Contract No. 08550-CT5-30 Cruise Numbers and Months on Transects I through IV within the MAFLA areas.

Transect No.

I	1965	1966	1967	1971	1972	1973	1974	1975	1976
Jan.-Feb.		HC-24	HC-36		B-7201	CI-7303			BLM#28
June-July		HC-29	HC-41	G-7117	G-7210	CI-7311		BLM #12	
October	HC-19	HC-32	HC-44		CI-7205			BLM #20	

II	1973	1974	1975	1976
Jan.-Feb.	CI-7303			BLM#28
July	CI-7311		BLM #12	
September			BLM #20	

III	1963	1964	1965		1976
January		D-1-64	D-1-65		BLM #28
June	D-6-63	D-6-64 D-7-64	D-9-65	BLM #12	
September	D-8-63	D-9-64	ST-3 D-13-65	BLM #20	

IV	1967	1968	1969	1971	1972	1973	1974	1975	1976
January	G-6701	G-6801	G-6901	G-7102	G-7201				BLM #28
June	G-6706	G-6806	G-6906	G-7106	G-7206			BLM #12	
September	G-6709	G-6809		G-7109	G-7209			BLM #20	

Many authors have reported the acucmulation of particles at density interfaces, especially at the top of the pycnocline. Jerlov (1950) attributed this phenomenon to the reduced mixing at that point as well as the increase of water density with depth. Usually the particles are predominantly organic, and large concentrations are likely to accumulate if the pycnocline starts in the euphotic zone (i.e. phytoplankton). With the establishment of a thermocline, particles are "trapped" and many phytoplankters are unable to migrate across the pycnocline (Bogorov, 1958; Raymont, 1963). This was evident in the sharp zone of increased turbidity at the halocline in Figure 119a. To various degrees, similar features have been observed elsewhere in the world oceans as indicated by studies in the Gulf of California (Kniefer and Austin, 1974), the Irish Sea (Heathershaw and Simpson, 1974), off Mission Beach, California (Ball and LaFond, 1964), and in the Eastern Gulf of Mexico (Carder and Schlemmer, 1973).

A near-bottom nepheloid layer is indicative of turbulence in the bottom water. This turbulence is usually caused either by the shear induced by the bottom on an overlying current, or by the interaction of wave-induced water motion with the bottom. Figure 119b provides an example of a near-bottom nepheloid layer that has been induced at least in part by a bottom current. Notice that the temperature and salinity were homogeneous from the bottom to about five meters above the bottom. This region also contains the major portion of the turbid matter. The SPM values associated with the 24% transmission value near the bottom would correspond to $\alpha = 1.58/\text{m}$ (or approximately 2.2 mg/ℓ).

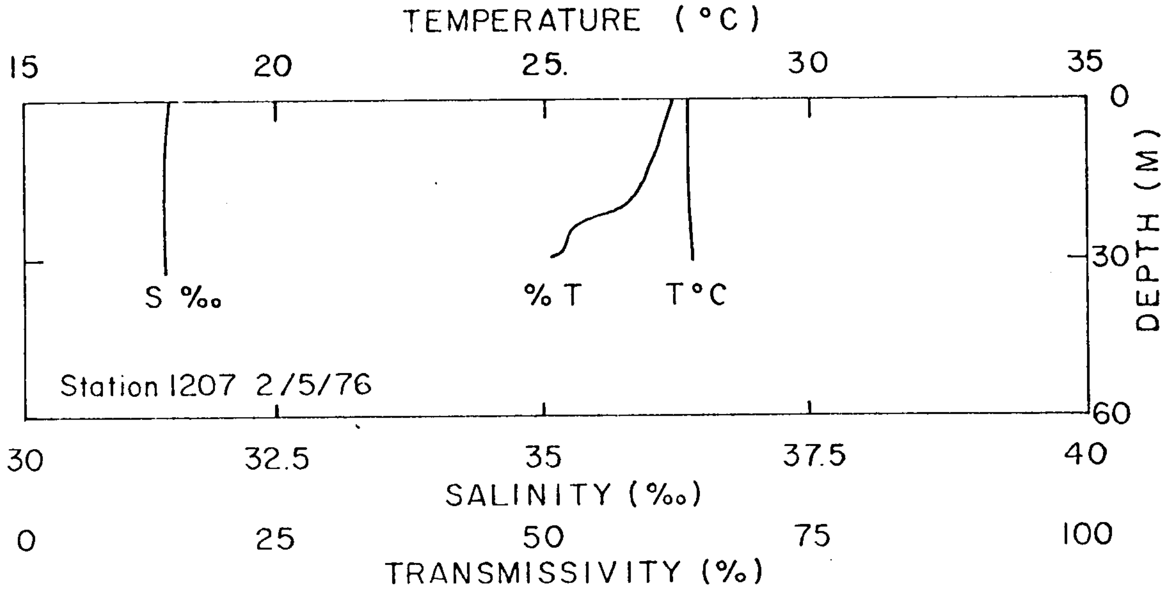


Fig. 119a. (Upper Figure) T°C, S(‰) and T(%) profiles for a well-mixed wated column.

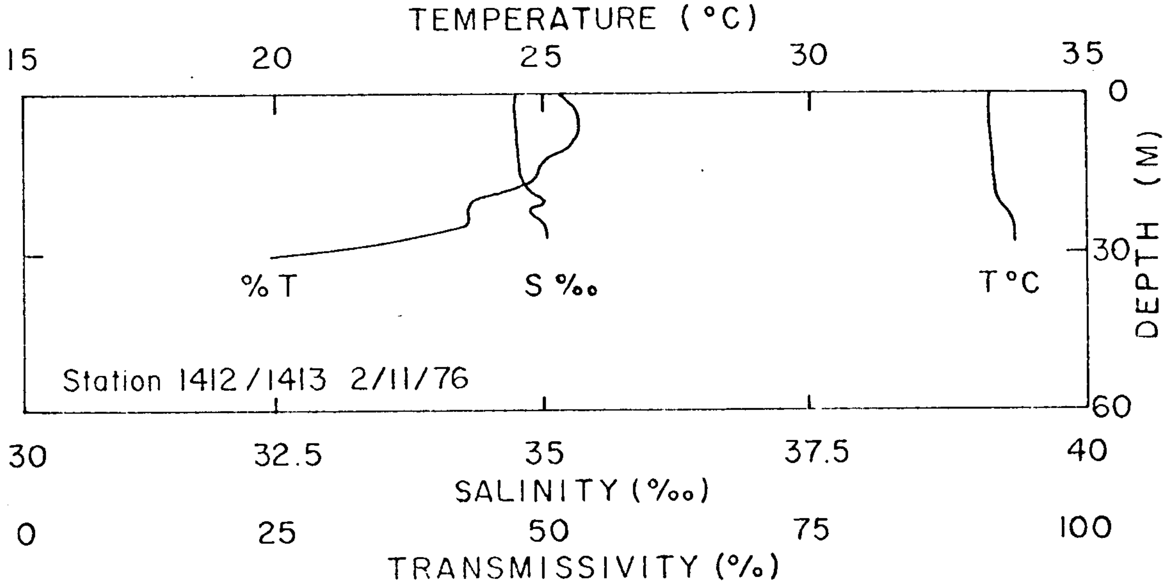


Fig. 119b. (Lower Figure) T°C, S(‰) and T(%) profiles for a partly stratified water column.

The entire water column was quite turbid, indicating that particles were being mixed all the way to the surface. If this turbidity profile had been the direct result of wind alone, the water column would have been vertically homogeneous in temperature and salinity. Hence we conclude that the profile was caused by a bottom current, perhaps in combination with wind waves.

Figure 119a provides an example of a well-mixed water column resulting from turbulence which was probably largely wave induced. Here the temperature and salinity values were uniform with depth, and the nepheloid layer extended all the way to the surface. Its turbidity was higher near the bottom since the upward mixing of particles is offset by downward settling. If a steady state existed for the particle concentrations at all depths, then a balance would have been established between the upward flux of particles caused by turbulent diffusion and the downward flux of particles caused by settling. This would have resulted in an exponential decrease in concentration of particles or α (increase in percent transmission) with distance above the bottom for a given particle size, shape and density. Such a distribution approximates the shape of the transmissivity curve in Figure 119b. For small, low-density particles the curve could become nearly uniform with depth, given sufficient turbulence. For larger, denser particles, a rapid decrease in concentration with distance above bottom would be expected.

The particle content of a water column is often indicative of its history. Figure 120 demonstrated a well-defined, turbid, and well-mixed layer between 185 and 215 m. This layer appears to have been in contact

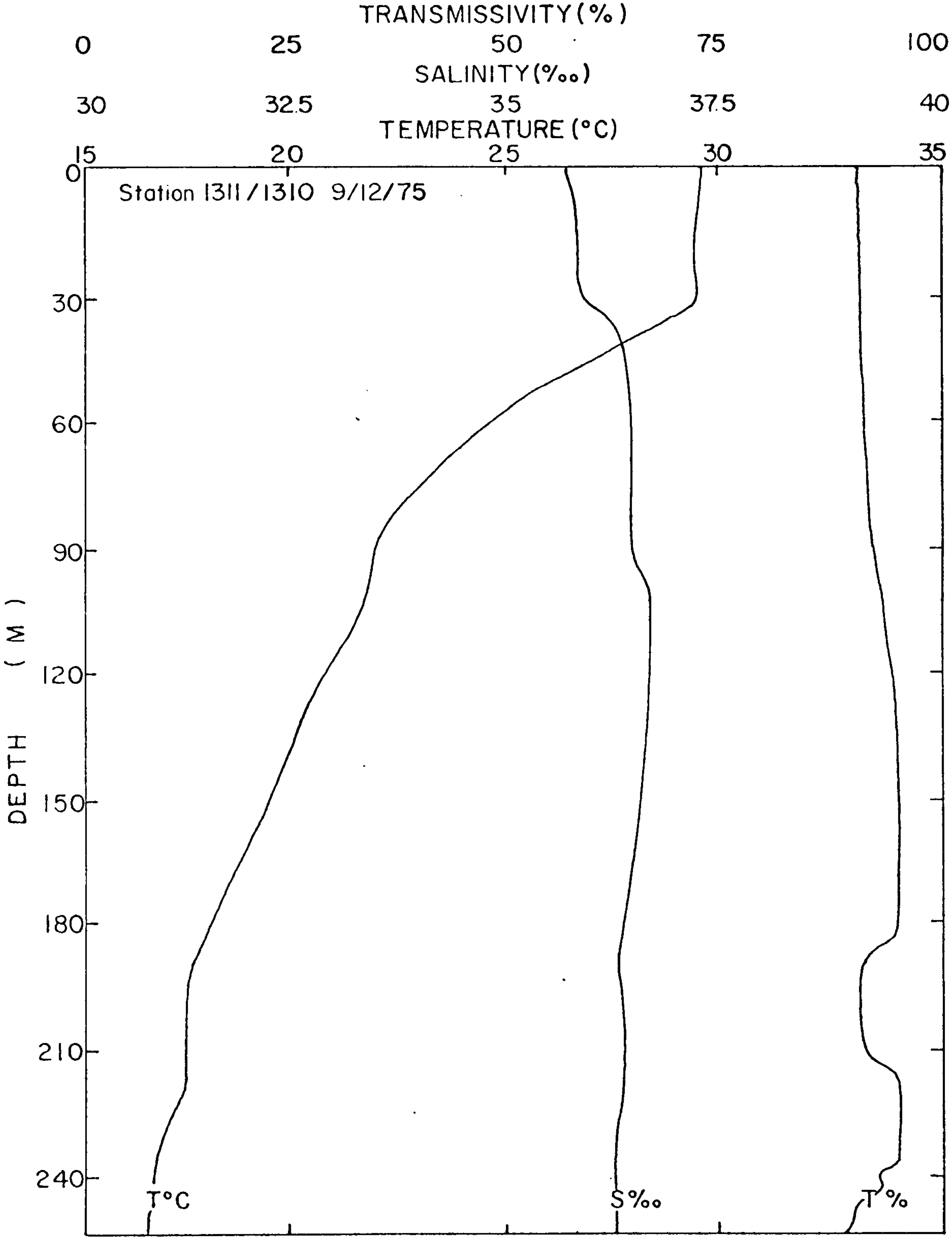


Figure 120. Vertical profile of transmissivity (%), salinity and temperature at station 1311/1310, in the fall, 1975. Note anomalous feature at about 200 m depth, and flattening of salinity and temperature.

with the bottom at some prior time. The percent transmission minimum was not an instrumental effect since both down and up traces repeated the pattern.

Mechanisms such as phytoplankton productivity, river plumes, and sediment erosion often result in particulate distribution patterns quite similar to those for salinity and/or temperature. For example, the % T patterns in Figure 121 parallel almost exactly the temperature trends. This apparently was the result of warm off-shore water being also clear relative to Mississippi Delta water. Other such similarities exist between % T and temperature and/or salinity distributions as illustrated in the next section.

Hurricane ELOISE and Turbidity-Water Mass Relationships

The eye of Hurricane ELOISE hit landfall at 0630 hours, September 23, 1975 just west of Panama City, Florida (Data of Naval Coastal Systems Laboratory). Transect II was sampled three days after the hurricane, with temperature, salinity and transmissometer measurements included in the sampling program. Some of the results are depicted in Figures 24 and 39b, showing salinity and percent transmission sections, respectively.

The inshore waters were vertically well-mixed and turbid while extreme stratification occurred at Master Stations 1206/1207. A turbid lens of cold, saline water was found on the bottom. This lens was much more dense ($\Delta\sigma_t$ = 1.2) than the adjacent seaward water. Such dense water would normally be expected to flow downhill; however, if it had sufficient longshore momentum (induced by the Loop Current, for instance), the landward acceleration

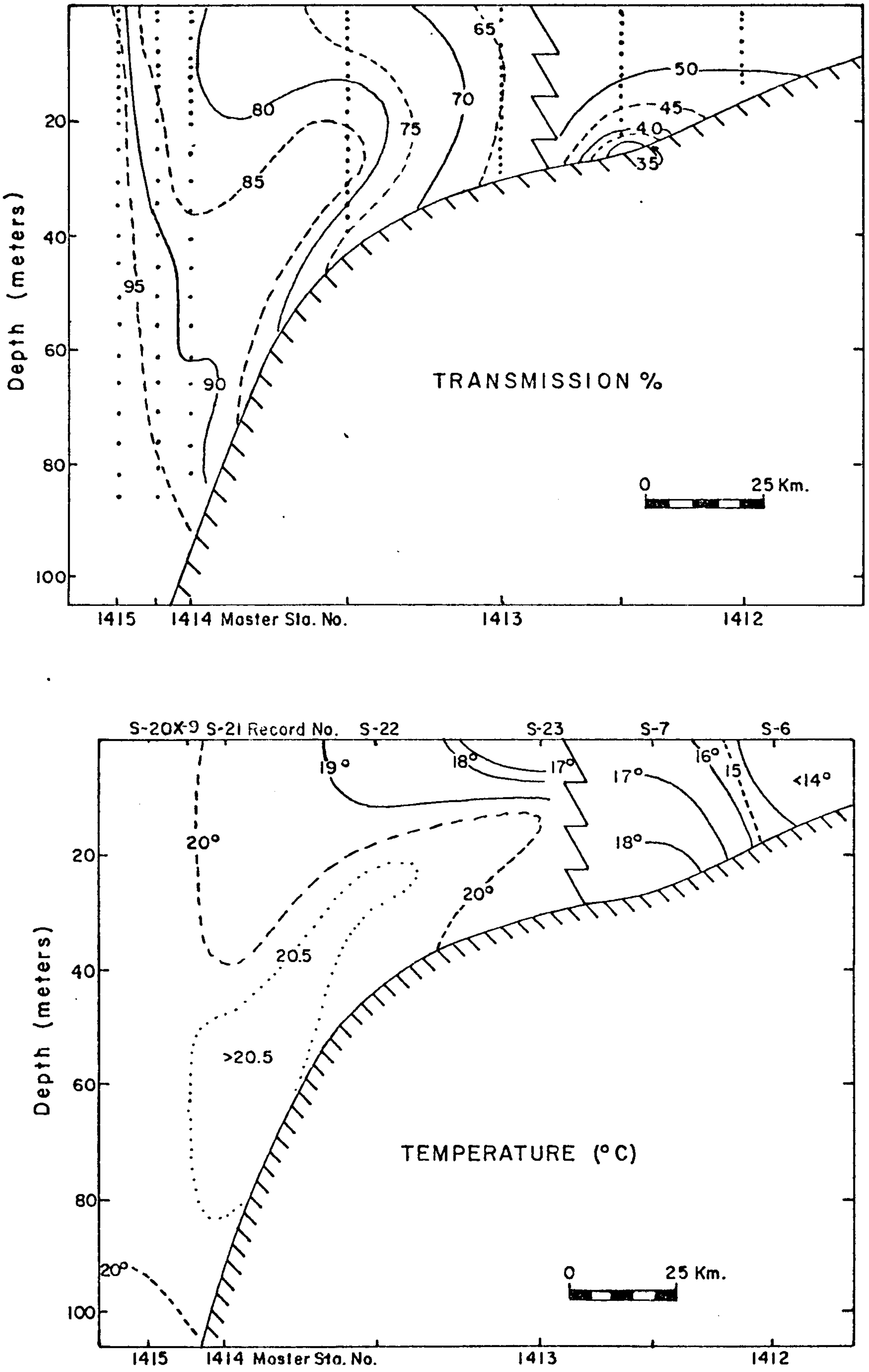


Figure 121. Transmissivity and temperature distributions for station IV, winter cruise, 1976. Note time break indicated by

associated with its vertical vorticity component could cause it to become a contour current. Thus, in seeking deeper waters it would probably flow generally along the shelf, crossing depth contours obliquely. Similar lenses of low temperature and high salinity have been found on the West Florida Shelf when hurricanes have not been present (SUSIO, 1975) but such lenses were not nearly as dense nor so isolated from the Loop Current as the one discussed above. Thus the hurricane appears to have enhanced a phenomenon which could be occurring each summer. The cool, saline nature of the water in question suggests that it was a remnant of Loop water which had been upwelled and stranded from the Loop Current, perhaps at some point near the DeSoto Canyon. It then may have progressed as a contour current driven by its increased density.

The magnitude of the flow can be estimated to some extent by the fact that the transmission values of the lens had a minimum of about 39% T, corresponding to SPM values of about 1.5 mg/ℓ. For such enrichment in particulate matter to occur in a region not overly populated by fine sediments suggests that the currents involved may have exceeded one knot (54 cm/sec). Visual evidence of scour and rearrangement of bottom epifauna (T. E. Hopkins, oral communication) confirmed this concept. For comparison, nepheloid layers associated with the Guiana Current have been reported to have SPM values of 700 μg/ℓ resulting from erosion due to 35-40 cm/sec currents.

A subsequent time series took place at Master Station 1207 (Figure 41a) where the turbid, dense lens reappeared about 12.5 hr after appearing at Master Station 1206-1207. This trend was even more apparent in the STD data. This indicates that the core of the flow traveled 26 km in 12.5 hr or about two kilometers per hour, or 56 cm/sec seaward, which would be only one component of the flow.

Such high water velocities are certainly compatible with the values of suspended aprticulate matter found in the nepheloid layer. Such currents are clearly capable of rearranging the distribution of fine sediments on the middle to outer shelf regions and transporting fine particles rather large distances.

The seasonal patterns of turbidity distribution have been commented on earlier. These and regional patterns have critical bearing on interpretation of chemical measurements of particulate properties. During the winter (January-February, 1976) season wind-wave, top-to-bottom mixing was extensive in the inshore stations. Only on approaching the outer shelf and slope did clearer water of the type noted closer to shore during summer and fall appear. Moreover, the rapidity with which new turbid distributions developed even within a few days, as demonstrated by reoccupation of stations, indicates that the sediments in question were of relatively local origin, probably fine mobile fractions stirred up from the bottom primarily by wave action. Data of Huang (1976 - this report) confirm this concept in that the mineralogy of the inshore suspensates strongly resembles the mineralogy of bottom sediments, and includes significant concentrates of carbonate minerals such as high and low magnesium carbonates and dolomite in given areas. Related observations were made by Hopkins (1976 - this report) in suggesting that the repeated effects of winter storms may exert a stronger erosive effect on the Middle Ground and its organisms than a few yearly events of hurricane force.

The significance of these observations is that during wind-agitated periods in winter, water samples from the middle of the water column probably reflect the total water column conditions with respect to particulate matter and perhaps phytoplankton, chlorophyll a and related measurements as well.

Not only do water column particulate samples provide a representative sampling for the water column, but they may even offer a rapid integrated sample of fine bottom particulates for local areas during turbulent seasons. Based on results from bottom sediment trace metal and particulate trace metal values in MAFLA baseline studies for 1974-1975 (Presley, 1975; Betzer, 1975) we may presume that a significant proportion of particulate trace metals for the winter season originate from the fine, mobile fraction of bottom sediments in inshore waters. Although one would expect a similar relationship between the particulate hydrocarbons derived from the fine mobile fraction of the bottom sediments, neither the aliphatic, the aromatic nor the total hydrocarbon fractions of either of these yielded significant correlations.

It is unfortunately not possible to estimate the percentage of particulate matter comprised by organic matter quantitatively, since comparison of SPM and POC shows POC values frequently exceeding SPM by considerable margins. Systematic errors in particulate determination virtually always occur on the high side; for this reason, and because the available SPM values agree well with transmissometry - SPM data from other areas, the conclusion is that the available particulate organic carbon (POC) data must be too high owing to some systematic factor.

Summer-fall water column conditions were entirely different from those of winter, owing to the significant transparency of the water column, and the strong vertical gradients in turbidity distributions. It is expected that at ten meters particulate organic carbon may well predominate over terrigenous or mineral detritus in these waters, and may be a result of long distance transport depending on physical oceanographic, meteorologic and other conditions. A single sample at ten meters or any other arbitrary depth would not be representative of the water column. However, depending on shelf water depth and complexity of particulate distributions, two or three samples may provide adequate characterization of particulates, if sampling depths were chosen after preliminary examination of turbidity distributions. For example, on Transect I, in the fall at least two samples, one in the clear water column and one in the bottom nepheloid zone would be needed to determine the end-member composition of the suspensates, and permit estimation of intermediate values if needed.

The turbidity distributions also have implications for coagulation and removal of oil slicks from the column by coascervation, zooplankton sweeping, and aggregation of detrital particles with adsorbed oil and subsequent sinking to the bottom. Such removal should be two-to ten-fold greater during winter than during the summer well-stratified periods.

Physical processes appear to be the primary cause of the seasonal differences in suspended load. Pierce (1976) has noted that in the presence of a strong halocline or thermocline, it would be doubtful if the mass of suspended material was ever sufficient to overcome the density differences imposed by temperature and salinity changes between water masses. Furthermore, Brewer and others (1976) have concluded that advection along isopycnals is an important process in controlling the distribution of suspended matter. Physical data, collected concurrently with our suspended material, disclosed stable water conditions (established thermocline and halocline) during the summer and fall in the northeastern Gulf of Mexico. As might be expected, the suspended material which was collected at or above the thermocline and/or halocline (ten meters) was dominated by biogenic (siliceous and calcareous) particles. The winter, however, displayed unstable water conditions (no thermocline or halocline) and intense mixing due to winter storms. This resulted in an alteration in both the quantity and composition of the suspended material.

An interesting corollary to the effect of physical processes on the suspended loads occurred during the second sampling period. Master Station 1205 was sampled immediately prior to Hurricane ELOISE and again after the hurricane. Suspended loads at the same station were approximately doubled (128 μg/ℓ to 210 μg/ℓ) by the physical mixing due to the hurricane forces. Similar observations were made off the North Carolina coast where suspended loads were more than doubled over pre-storm values by the passage of a hurricane, and within a week the concentration values had returned to pre-hurricane values (Rodolfo, _et al_., 1971).

The weak acid soluble composition of Master Station 1205 after the hurricane showed an increase in nickel, a doubling of lead, a four-fold increase in iron and a five-fold increase in calcium. Calcium carbonate content of the suspended load increased from 5.3% to 23% after the hurricane. The refractory fraction of Master Station 1205 showed an increase in silica, iron, aluminum, and vanadium. Silica to aluminum ratios decreased after the hurricane (12 to 4.1), possibly due to an increased clay content of the suspended matter. Mineralogical analysis of the suspended material, although not showing an increase in suspended clay content, did reveal a shift in mineral composition following the hurricane. The percentage of chlorite, illite, and feldspar increased while kaolinite decreased. Hurricanes generate physical mixing forces which alter the suspended loads and their composition. Similar physical processes (no thermocline, water of low stability, intense mixing) occur during the winter with similar results.

The composition of the weak acid soluble fraction of the suspended matter at the 15 stations for the three sampling periods indicated that weak acid soluble calcium comprised a consistent percentage (1.76±1.55) of the suspended material for all stations during the summer and fall. It has been previously noted that calcium values for the fall were elevated in comparison to the first sampling period. The winter's weak acid soluble calcium values were skewed with extremely high calcium values reported for Transects I and II ($\overline{X}$ = 12.2%) and values of one to two orders of magnitude lower for Transects III and IV ($\overline{X}$ = 0.23%). Using the mean calcium composition and mean suspended loads of Transects I and II, one finds that $CaCO_3$ comprises 1.8% and 6.2%, respectively, of the SPM in the summer and fall versus 30.5% of the SPM in the winter.

Weak acid soluble cadmium was relatively consistent throughout the sampling periods. Chromium, which was non-detectable during the first two sampling sessions, was detected during the winter at certain stations where suspended loads were relatively large (>200 μg/ℓ). Copper and lead values were highest for the first sampling session and somewhat lower in both subsequent sampling sessions. Weak acid soluble iron was lowest during the fall sampling period and comparable for summer and winter on all transects except for Transect IV during the winter. The iron concentration on Transect IV was 8-36 times greater during the winter (i.e., $\overline{X} = 0.93\%$ for winter, $\overline{X} = 0.021\%$ for fall, $\overline{X} = 0.10\%$ for summer) than in the fall and summer. Simultaneously, high refractory aluminum, iron and silicon values suggest that this weak acid soluble iron results from a poorly structured hydroxyoxide form in association with clay material. This is further discussed in another section of this report.

The composition of the refractory suspended matter for the three sampling periods show interesting trends and several differences were evident in this fraction. Aluminum, iron and silica concentrations were greatest during the winter sampling. This could have resulted from river runoff, resuspension of bottom sediments, and increased primary productivity (diatoms). It is likely that all three mechanisms were operating to elevate certain elements depending upon the sample location. An excellent tool for evaluating the origin of the particles is the weight ratios of each element to refractory aluminum (Tables 126a,b,c). Refractory aluminum is used since it is not greatly concentrated by organisms and has a primary source in clay minerals.

Diatoms, which utilize silica in their frustules, would, upon analysis show a high silicon/aluminum ratio (>6) since they incorporate minor amounts of aluminum (Bennekom and Gaast, 1976). However, clays, which are alumino-silicate minerals, would display low silicon/aluminum ratios (<6). Examination of the data shows low silicon/aluminum ratios on

Table 126a. Metal/aluminum ratios in the refractory fraction of the suspended matter - Summer, 1975.

	Weight Ratio of Each Element to Refractory Aluminum								
Station Number	Ca / Al	Cd* / Al	Cr* / Al	Cu* / Al	Fe / Al	Ni / Al	Pb* / Al	Si / Al	V / Al
1101	NA	0.03	0.59	0.17	0.87	**	0.31	15.97	**
1102	NA	**	1.10	**	0.92	**	0.13	14.29	**
1103	NA	0.06	0.77	0.54	0.85	**	1.37	4.74	**
1204	NA	0.16	1.94	0.97	1.21	**	1.46	16.90	**
1205	NA	0.11	1.46	0.90	0.94	**	1.79	14.27	**
1206	NA	**	1.68	1.44	1.04	**	0.48	17.89	**
1207	NA	**	1.94	1.59	1.07	**	3.08	22.26	**
1308	NA	0.07	0.71	5.50	0.60	**	1.72	6.59	**
1309	NA	0.32	1.74	16.40	1.37	**	2.84	10.54	**
1310	NA	0.09	0.57	2.08	0.20	**	0.95	3.16	**
1311	NA	0.23	1.10	8.76	0.54	**	2.03	6.65	**
1412	NA	0.02	0.15	0.34	0.44	**	0.36	7.21	**
1413	NA	0.03	0.25	2.06	0.66	**	0.50	8.77	**
1414	NA	0.07	4.52	2.90	0.77	**	1.96	50.68	**
1415	NA	1.65	1.32	7.38	0.59	**	0.66	25.33	**

* Ratio x 10^{-2}

** Not Detectable

Table 126b. Metal/aluminum ratios in the refractory fraction of the suspended matter - Fall, 1975.

	Weight Ratio of Each Element to Refractory Aluminum								
Station Number	Ca / Al	Cd* / Al	Cr* / Al	Cu* / Al	Fe / Al	Ni / Al	Pb* / Al	Si / Al	V / Al
1101	NA	0.30	1.77	0.44	0.66	**	5.69	29.47	**
1102	NA	2.71	7.12	4.07	0.76	**	14.92	54.44	**
1103	NA	2.86	9.01	**	3.12	**	9.89	33.67	**
1204	NA	0.07	1.17	**	0.43	**	1.07	10.08	**
1205	NA	0.18	1.21	**	0.43	**	1.80	12.28	**
1215	NA	0.03	0.36	0.06	0.37	**	0.44	4.07	**
1206	NA	0.18	1.18	0.52	0.43	**	2.03	10.24	**
1207	NA	0.12	0.31	0.22	0.39	**	0.76	3.30	**
1308	NA	2.01	5.40	**	0.99	**	5.86	26.82	**
1309	NA	0.64	3.32	**	0.54	**	8.04	16.06	**
1310	NA	0.59	41.62	**	2.27	**	5.59	20.61	**
1311	NA	0.11	0.85	**	0.38	**	0.87	6.32	**
1412	NA	1.35	2.90	4.35	0.64	**	8.80	14.32	**
1413	NA	0.07	3.21	**	0.45	**	4.01	11.94	**
1414	NA	1.05	4.19	**	0.99	**	8.38	21.10	**
1415	NA	0.09	3.12	**	0.38	**	4.25	14.40	**

* Ratio x 10^{-2}

** Not Detectable

Table 126c. Metal/aluminum ratios in the refractory fraction of the suspended matter - Winter, 1975.

	Weight Ratio of Each Element to Refractory Aluminum							
Station Number	Ca / Al	Cd* / Al	Cr* / Al	Cu* / Al	Fe / Al	Ni / Al	Pb* / Al	Si / Al	V / Al
1101	NA	**	0.28	**	0.43	**	0.21	8.32	**
1102	NA	0.03	0.25	**	0.44	**	0.09	4.81	**
1103	NA	**	1.37	**	0.63	**	2.69	21.43	**
1204	NA	**	0.27	**	0.46	**	0.29	10.04	**
1205	NA	1.00	0.75	**	0.54	**	1.53	17.68	**
1206	NA	0.03	0.18	**	0.35	**	0.06	4.32	**
1207	NA	**	0.33	**	0.50	**	0.12	8.71	**
1308	NA	**	0.21	**	0.39	**	0.20	6.03	**
1309	NA	**	0.31	**	0.46	**	0.18	4.33	**
1310	NA	0.43	0.59	4.35	0.88	**	3.21	23.29	**
1311	NA	**	2.25	**	0.77	**	3.80	52.71	**
1412	NA	**	0.11	**	0.29	**	0.09	3.08	**
1413	NA	**	0.10	**	0.43	**	0.06	3.10	**
1414	NA	**	0.32	**	0.52	**	0.23	4.18	**
1415	NA	**	0.23	**	0.52	**	0.16	4.74	**

* Ratio x 10^{-2}
** Not Detectable

Transect IV in the winter when compared to the previous two seasons. These alumino-silicate values result from an increased clay content of the winter suspended loads (~60%). Whereas high calcium values occur on the carbonate-rich West Florida Shelf (Davies and Moore, 1970), the high alumino-silicate values occur on the Mississippi-Alabama Shelf where clays are an important part of the bottom sediments (Griffin, 1962). This reflection of shelf sediment composition by the suspended matter implies that physical processes were sufficient to resuspend and transport bottom and river material during the winter in the northeastern Gulf of Nexico. The high silicon/aluminum ratios found on other transects and at other times of the year indicate increased silica concentrations resulting from biological sources or quartz sand which would essentially dilute the existing clay. Suspended mineralogy studies indicate quartz to be present in the SPM at 89% of the stations sampled in amounts sufficient to contribute significant quantities of silica.

The distribution of nearshore particulate iron has been found to be dominated by the presence of detrital silicates, although the concentration of marine organisms in surface waters can also be significant (Spencer, et al., 1972). It was therefore interesting to note the consistency of the Fe/Al ratios for the winter and fall sampling (Figure 122), except at those stations during the fall where high Cr/Al ratios were accompanied by high Fe/Al ratios (Master Stations 1310, 1103). A correlation coefficient of 0.96 was calculated between Al and Fe for the fall and winter (excluding

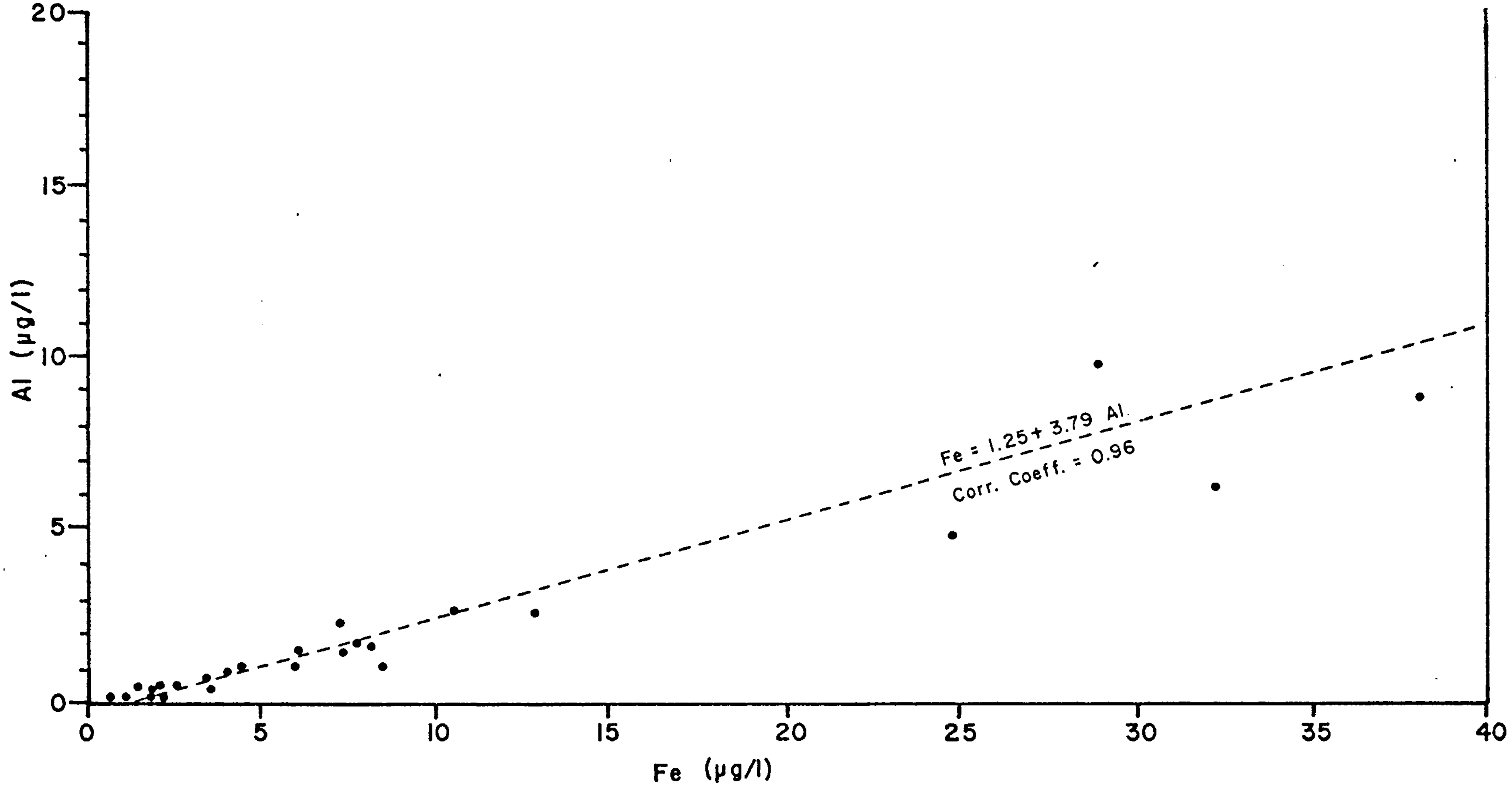


Figure 122. Refractory aluminum versus refractory iron during fall and winter, 1975/1976.

Master Stations 1310 and 1103 in the fall), whereas a correlation coefficient of 0.75 was calculated between Al and Fe for the summer. The lower correlation of the early summer is believed to have resulted from increased biological activity by amorphous silica concentrating organisms, notably diatoms. The high silica concentrations and high Si/Al ratios on all the transects during the summer indicate that diatoms may dominate the suspended composition and were incorporating iron, unsupported by aluminum during growth. However, the fall and winter periods were dominated by carbonate organisms and resuspended sediments respectively, and here the particulate iron was associated with detrital silicates. Thus it would seem that particulate iron in surface water of the northeastern Gulf of Mexico was primarily controlled by detrital silicates although biological organisms were important seasonally, depending on the concentration and type of organisms present.

Refractory iron concentrations were greatly elevated on Transect IV during the winter compared to other sampling seasons. This obviously resulted from increases in the contribution of clay minerals made to the suspended matter.

Mineralogical analysis of the suspended fraction from Transect IV showed that smectite and kaolinite were dominant during the winter. This assemblage of suspended clays should have a Fe:Al ratio of approximately 0.055 for smectite (Degens, 1965) and 0.051 for kaolinite (Weaver and Pollard, 1976). However, our data for Transect IV show Fe:Al ratios of 0.29-0.52. This discrepancy can be explained by either the existence of free ferric oxide particles, the adsorption of iron to the clay particles or both. Tieh and Pyle (1972) described cores from the same region composed of composite clay particles stained with iron oxides and/or hydroxides. The concurrently high weak acid soluble and refractory iron concentrations for Transect IV indicate iron to be partitioned at different oxidation states, possible indicative of either recently deposited sediments, river run-off or both.

Refractory chromium showed some interesting trends during the three sampling periods. During all seasons, chromium appears to increase from Transect I to Transect IV. High Cr/Al ratios were generally found at those stations with high Si/Al ratios, and it is possible that biological mechanisms may, in part, be responsible for the increased chromium concentrations in suspended matter.

Refractory lead was another element that appeared to be influenced by biological activity. High Pb/Al ratios were often matched with high Si/Al ratios, and this was particularly evident during the fall sampling session. It was noted that high Pb/Al and high Cr/Al ratios generally occurred at those stations where there were low suspended loads, which could result in artificially high element-to-aluminum ratios because of the increased possibility of contamination (although, with elevated Cr/Al ratios a corresponding increase in the Fe/Al ratio would be present if contamination occurred). This appeared to be the case for Master Stations 1103 and 1310 during the fall but still does not explain many other stations of the summer, fall and winter which have elevated Cr/Al and Pb/Al ratios occurring with high Si/Al ratios.

Comparison and interrelation of these data with the mineralogy of suspended matter and sediments provides further insights into these results. The dominant clay mineral on the Mississippi-Alabama shelf is smectite with both chlorite and chlorite-vermiculite mixed layers present in trace amounts. If the suspended mineralogy data from Transect IV is examined it is apparent that smectite was present at only one station for the summer and fall but present at all stations during the winter. Thus, it would appear that physical processes were causing the suspended mineralogy to more closely reflect the sediments' mineral composition during the winter. This is consistent with the conclusion that clays dominate the suspended material during the winter, but not during the remainder of the year on Transect IV.

Suspended mineralogy from the winter showed carbonates (aragonite, low magnesium calcite, high magnesium calcite and dolomite) present in appreciable amounts on Transect II which suggests that some resuspension of the bottom sediments may have occurred. This data corroborates the elevated carbonate values found on Transect I and II during the winter. Similarly, we also attribute resuspension of bottom sediments as the primary carbonate enrichment process.

The mean iron content of zooplankton during the winter is much higher than that of either the summer or fall. The concurrently high iron values for the weak acid soluble and refractory fraction of the suspended material indicate that suspended matter could be the cause of the elevated concentrations in zooplankton. In order to determine how much clay would have to be in the 0.5 g zooplankton samples to elevate the iron values above their previous levels, the following calculations were made.

The difference between the mean iron concentration for the winter and that of the summer and fall for Transect IV is 1008 μg/ℓ Fe/g of zooplankton.

Knowing the mean Fe/Al ratio (0.41) of the refractory suspended particulate materials for Transect IV of the winter, one would need ∿1,230 μg Al/0.5 g of zooplankton to account for the iron. According to the suspended mineralogy data the clay minerals were approximately 72% smectite and 17% kaolinite for Transect IV. Aluminum constitutes 20% of kaolinite (Weaver and Pollard, 1967) and 11% of smectite (Degens, 1965). Using these assumptions one finds that 11.2 mg of clay (2.2% of sample mass) were required to elevate iron levels in zooplankton.

The above calculation is based on the assumption that all the iron we found in the zooplankton is adsorbed on or contained in clay lattices. If a free ferric oxide form existed, then this amount of clay would obviously be reduced. The high weak acid soluble iron values for Transect IV indicate that a reduced form of iron could be available. Assuming the dry weight of an organism to be one-tenth of its wet weight, then 11.2 mg of clay would be 0.2% of the zooplankton (wet weight) or two percent of zooplankton (dry weight). Jorgensen (1966) has indicated that copepods show little selectivity in assimilating particles from 1-50 μm in diameter and can efficiently sweep water volumes ranging from 72 to >2,000 ml 24 hr^{-1} mg dry wt^{-1}. Since the dominant zooplankton of the offshore stations was Paracalanas, and the inshore station (1411) was characterized by the presence of Paracalanas, Eucalanas, and fish eggs, 11.2 mg of clay does not seem to be an unreasonable amount.

The concentrations of the remaining elements (Cd, Cr, Cu, Fe, Pb, Ni, V) were in good agreement with those reported by other authors (see Table 127). Variations that did occur between stations and transects were apparently due to taxonomic composition, population turnover rates and

Table 127. Average trace element content (ppm) of zooplankton collected in the MAFLA area, 1975-1976 ($\overline{X}$±1 S.D.)

	Cd	Cr	Cu	Fe	Ph	Ni	V
Summer (1975	7.00 ±3.1	0.67 ±0.75	15.09 ± 7.76	137.1 ±124.30	1.87 ±1.02	2.08 ±0.93	6.80 ±4.67
Fall (1975)	8.47 ±7.53	0.94 ±1.5	22.37 ±19.14	91.55 ±54.14	2.44 ±3.14	3.76 ±3.22	4.02 ±8.58
Winter (1976)	5.82 ±2.17	0.88 ±0.76	15.30 ± 3.63	549.6 ±701.1	2.34 ±3.45	2.41 ±1.25	5.02 ±6.68
Martin and Knauer (1972) Monterey Bay	6.2	-	5.4	344	6.9	3.9	-
Sims (1975)	1.9	-	16.2	1,181	10.0	3.9	-
Windom (1972	3.9	-	82.0	-	32.0	-	-
Martin 1970	-	-	41.0	1,200	49.3	42.0	-
Topping (1972)	1.0	-	16.2	-	15.0	-	-
Martin and Knauer (1974) Pacific	2.4	-	15.44	348	7.2	-	-

geographic location.

Despite the observed presence of tar balls in the neuston samples the distribution of vanadium in this group did not deviate from that of the other faunal samples (Figure 123).

The concentration of hydrocarbons in the water column of the MAFLA lease area compares well with the lower values reported in the literature for open ocean water. The overall average concentrations were 0.4 μg/ℓ dissolved hydrocarbons, and 0.3 μg/ℓ particulate or 0.7 μg/ℓ total resolved hydrocarbons. Brown, et al. (1975) determined that total hydrocarbons in the open Atlantic and Pacific were about 1 μg/ℓ. In the Mediterranean the concentration ranged from 2-8 μg/ℓ, and near Bermuda the concentration was 3-6 μg/ℓ and Levy (1971) reported values for total hydrocarbons of 2-13 μg/ℓ in the Atlantic off Halifax. Comparison of these results is made difficult because of the three different analytical methods used (G.C., IR, UVF) which are responsive to different portions of the hydrocarbons in the samples. Two reports of dissolved hydrocarbons by gravimetric analysis, which measures all hydrocarbons, indicate concentrations greater than reported above. Iliffe and Calder (1974) reported concentrations for aliphatic hydrocarbons of 12 μg/ℓ in the southeast Gulf of Mexico and Yucatan Straits and 47 μg/ℓ in the Florida Straits while Barbier, et al. (1973) reported values of 43 and 95 μg/ℓ of total dissolved hydrocarbons from water collected at 50 m off the west coast of Africa. The GC-derived concentrations do not include contributions from the unresolved envelope when it is present. In those cases, total hydrocarbon may be a factor of ten greater than reported.

There was a general trend in the eastern Gulf of Mexico for higher total resolved hydrocarbon concentrations near shore in both the dissolved

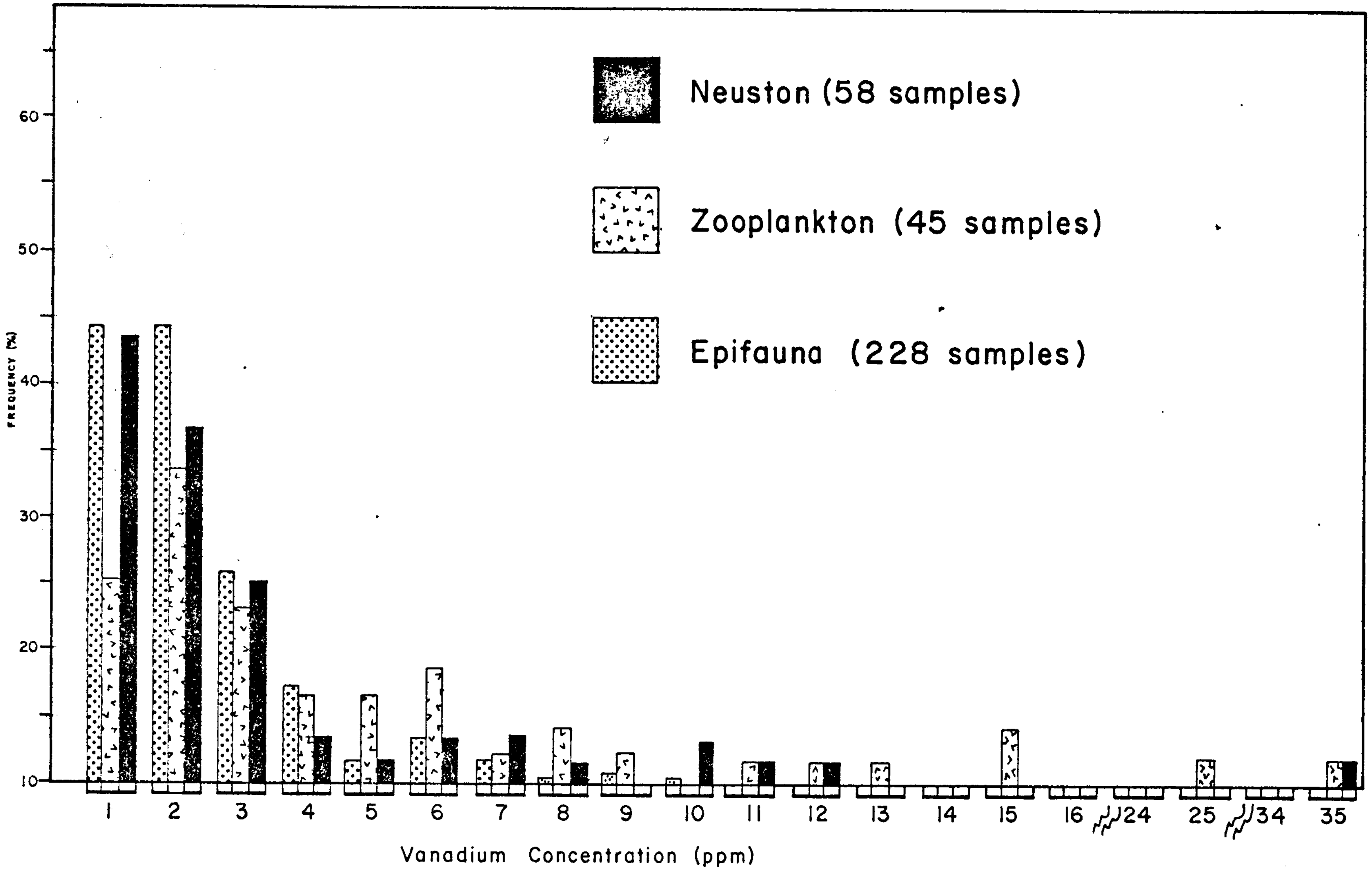


Figure 123. Distribution of vanadium in the neuston, zooplankton, and epifauna of the MAFLA area.

and particulate phases, although there were several exceptions to this trend.

The higher hydrocarbon concentrations near shore may be the result of direct terrestrial input or enhanced in situ production stimulated by terrestrially derived nutrients. The unresolved envelope components seem to have a terrestrial source, either Tampa Bay on Transect I, or the Mississippi River/Sound on Transect IV. These unresolved components may be the remnants of highly weathered crude oil from marine sources or waste oil from terrestrial sources. Both dissolved and particulate hydrocarbons contained a series of n-alkanes from nC_{21} to nC_{32} with an odd/even ratio of near unity. This feature might be the result of weathered petroleum residues, but could also be derived from marine phytoplankton (Clark and Blumer, 1967). This series of alkanes was present when the lower molecular weight biogenic alkanes were absent. If they are of recent biosynthetic origin, their stability in sea water must be greater than that of nC_{15}, nC_{17} and pristane.

The biogenic hydrocarbons nC_{15}, nC_{17} and pristane were dominant in the particulate aliphatic fraction and were probably the result of plankton collected on the filters. These hydrocarbons then should correlate with plankton biomass; however, the remaining aliphatic and unsaturated/aromatic hydrocarbons in both dissolved and particulate phases were apparently not reflective of in situ biomass. Thus total hydrocarbon should not correlate with biomass estimators, such as chlorophyll a and no correlation was noted between chlorophyll a values on samples taken simultaneously with these hydrocarbon samples. This differs from the correlation between chlorophyll a and total non-aromatic hydrocarbons reported by Zsolnay (1972) for waters off the west coast of Africa. However, the upwelling region off Africa was much richer in phytoplankton than the MAFLA region.

The total dissolved hydrocarbons did correlate with dissolved organic carbon analysis of samples collected simultaneously with hydrocarbon samples (Aller, 1976). The ratio of total dissolved hydrocarbons to dissolved organic carbon was 0.4±0.2 μg/mg in summer, 0.2±0.2 μg/mg in fall and 0.3±0.2 μg/mg in winter ($\overline{X}$±1 S.D.). The relative constancy of this ratio during each season indicates that the distributions of dissolved hydrocarbons and dissolved organic carbon were controlled by similar processes. No such relationship existed between particulate hydrocarbons and particulate

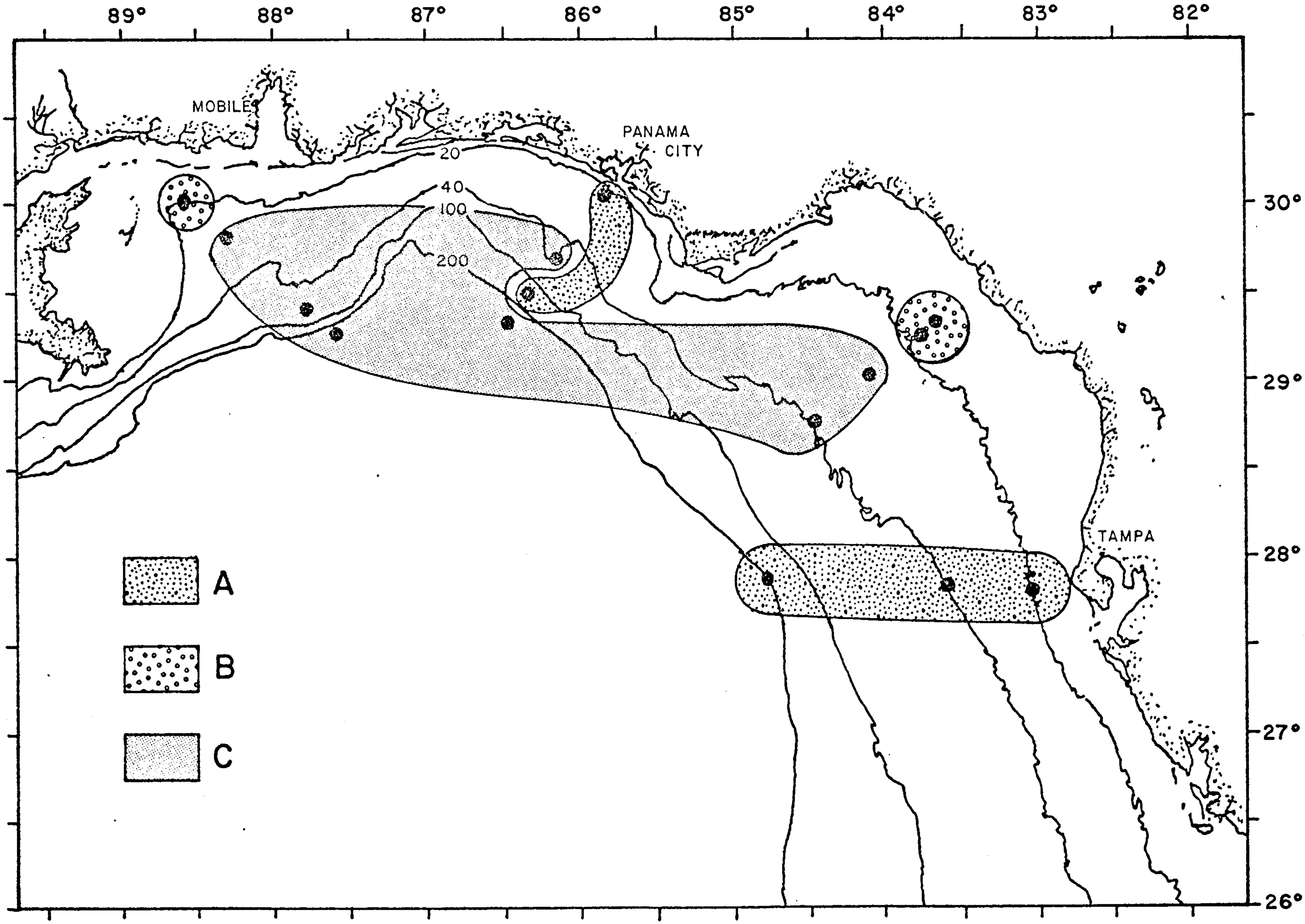


Figure 124a. Zooplankton hydrocarbon group distribution, June-July, 1975.

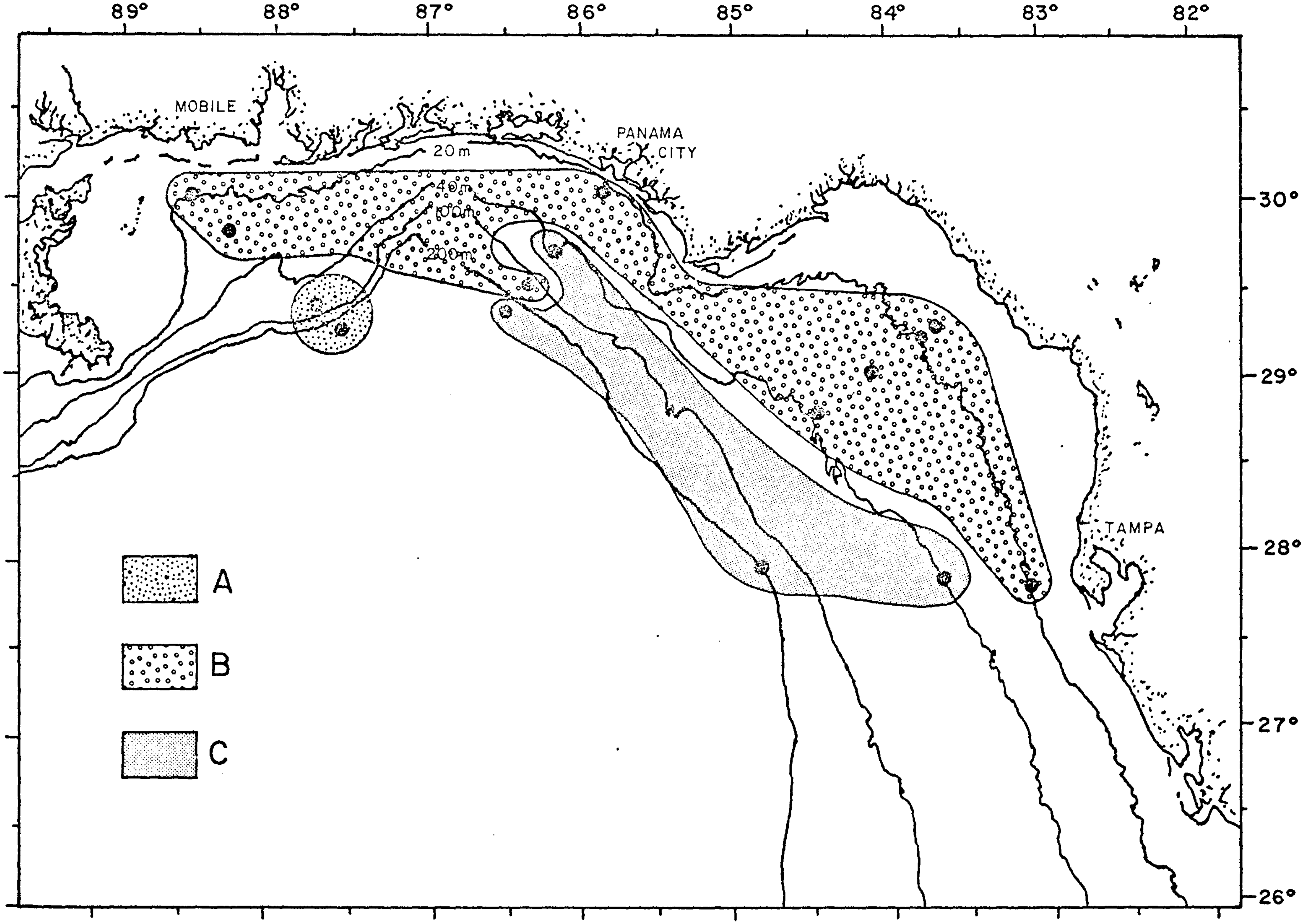


Figure 124b. Zooplankton hydrocarbon group distribution, fall, 1975.

while the A group appeared only at the two outermost stations on Transect IV. In the winter (Figure 124c), the B group was not present and the A group occupied the nearshore stations of Transects I, II and III as well as one offshore station on each of Transects III and IV. The C group occupied the nearshore stations of Transect IV, but was in its usual offshore spot on the other transects.

The three hydrocarbon compositions could be the result of three factors:

a. different biosynthetic hydrocarbons from different zooplankton species

b. different hydrocarbons taken up from different food sources or water masses

c. different biosynthetic hydrocarbons resulting from environmental variation (e.g., temperature).

A first level examination of the zooplankton species composition showed that the major zooplankton groupings occurred in nearly every sample at all seasons. Thus, the hydrocarbons in the A and C group must be due to very lipid rich minor components of the zooplankton if taxonomic variation is responsible for observed hydrocarbon variations. This may be more likely than it first seems because the hydrocarbon extraction was done on a bulk zooplankton sample, while taxonomy was performed on a sample that had been split from seven to eleven times. The splitting could have diluted a minor yet lipid rich component.

Neither dissolved hydrocarbons nor those on suspended particulates bear any relation to the zooplankton hydrocarbons (Calder, 1976) and thus the zooplankton hydrocarbons do not appear to have been taken up from different external sources.

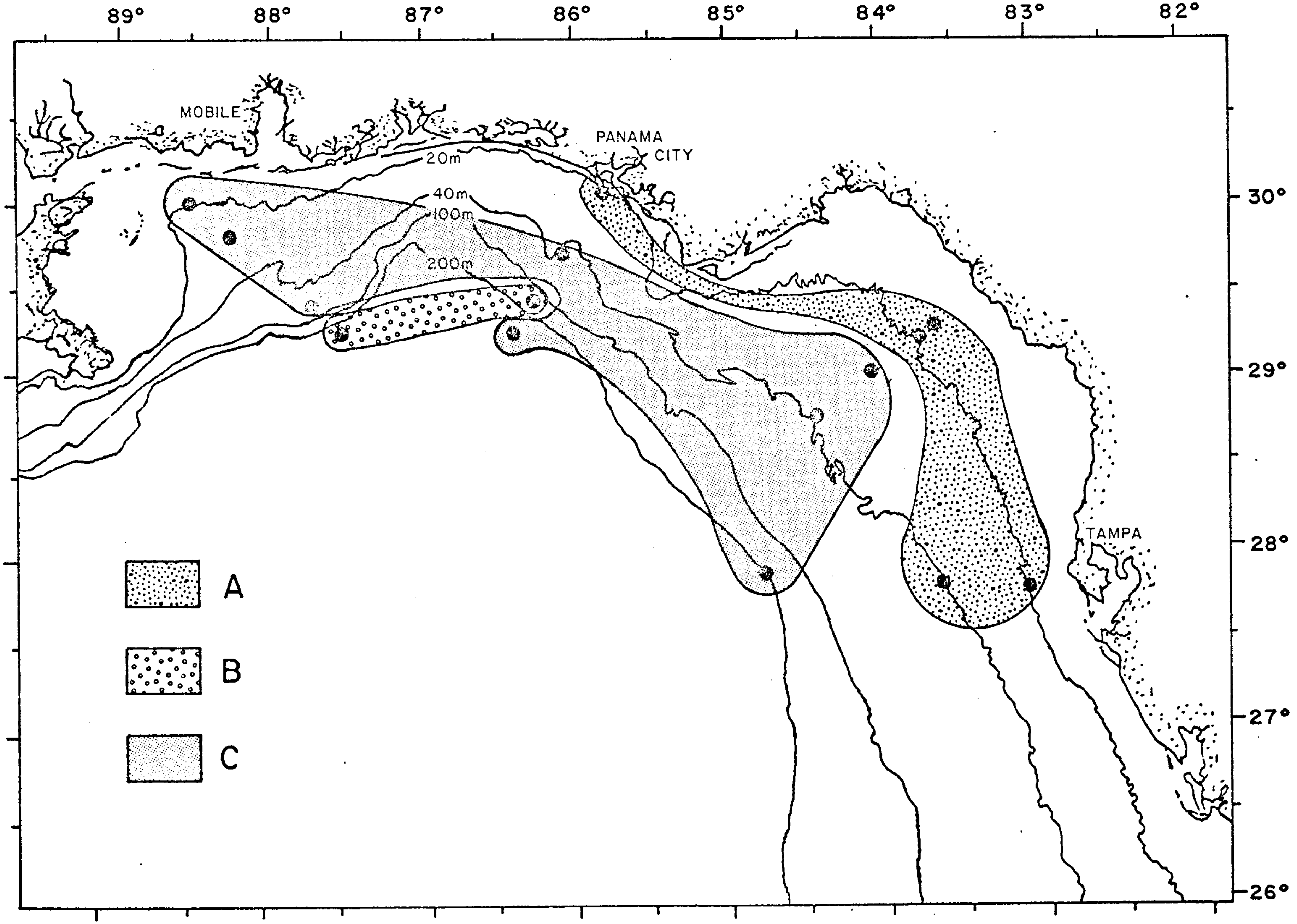


Figure 124c. Zooplankton hydrocarbon group distribution, winter, 1976

Since the C group was generally found offshore it came from waters generally deeper, colder and more saline. Yet the inshore stations in winter were just as cold and saline as the offshore stations in summer and contained the A, not the C group. Temperature and salinity variations do not seem then to cause the zooplankton to alter their biosynthetic hydrocarbon content.

Beacuse the hydrocarbon groups do display spatial patterns, rather than random distribution, they must be the result of general circulation phenomena. Hydrocarbon analysis of the major zooplankton groups (e.g., copepods, jellies, etc.) may be the best way of clarifying these observations.

To assess the effect of location on the variability of organic carbon levels, the data was also considered by depth zones (Table 128).

Table 128. The average seasonal concentration (mg/ℓ) of particulate and dissolved organic carbon by depth zones.

	SUMMER		FALL		WINTER	
Zone	POC	DOC	POC	DOC	POC	DOC
1*	0.21	1.34	0.14	1.36	0.16	2.18
(S)+	(0.15)	(0.74)	(0.05)	(0.34)	(0.06)	(0.39)
2**	0.12	0.98	0.07	1.05	0.12	1.89
(S)	(0.04)	(0.29)	(0.03)	(0.24)	(0.04)	(0.33)
3***	0.13	1.27	0.04	0.94	0.10	1.94
(S)	(0.06)	(0.43)	(0.01)	(0.29)	(0.05)	(0.24)

1* Inshore Zone (Stations 1101, 1204, 1205, 1308, 1412)
2** Intermediate Zone (Stations 1102, 1206, 1207, 1309, 1413)
3*** Offshore Zone (Stations 1103, 1310, 1311, 1414, 1415)
(S)+ Standard deviation

These data show trends that, in all seasons, indicate that the particulate organic carbon (POC) decreases in the transition from inshore to offshore. Only the trends observed in the fall were significant. These data are in general agreement with the findings of Fredericks and Sackett (1970) in their study of organic carbon in western Gulf waters.

The dissolved fraction (DOC), in contrast to the particulate organic carbon, does not appear to exhibit any pronounced pattern in any of the three sampling seasons and this is in contrast to the data of Fredericks, _et al_. (1961) for tropical and semi-tropical waters.

It is generally accepted that living organisms make variable and significant contributions to the particulate fraction by their presence, and to the dissolved fraction by their metabolic products (Riley and Chester, 1971). Thus, in discussing possible interpretations of Figures 125a through 125d,POC has been related to chlorophyll and zooplankton and DOC to primary productivity.

Considering first the total Gulf shelf area under study (Figure 4) it is apparent that the seasonal fluctuations of dissolved organic carbon and primary productivity are similar. Likewise the relative levels of particulate organic carbon and chlorophyll _a_ follow one another closely. Zooplankton varies with particulate organic carbon in the summer-fall but not in the winter. In previous sections it has been shown that the dissolved organic carbon and particulate organic carbon curves do, in fact, indicate statistically significant seasonal differences. Unfortunately, the high variability of the other parameters (Tables 61, 62 and 63), does not allow similar statistical distinctions to be drawn for these variables. Figure 125 does suggest that, over the Northeastern Gulf Shelf, _in situ_

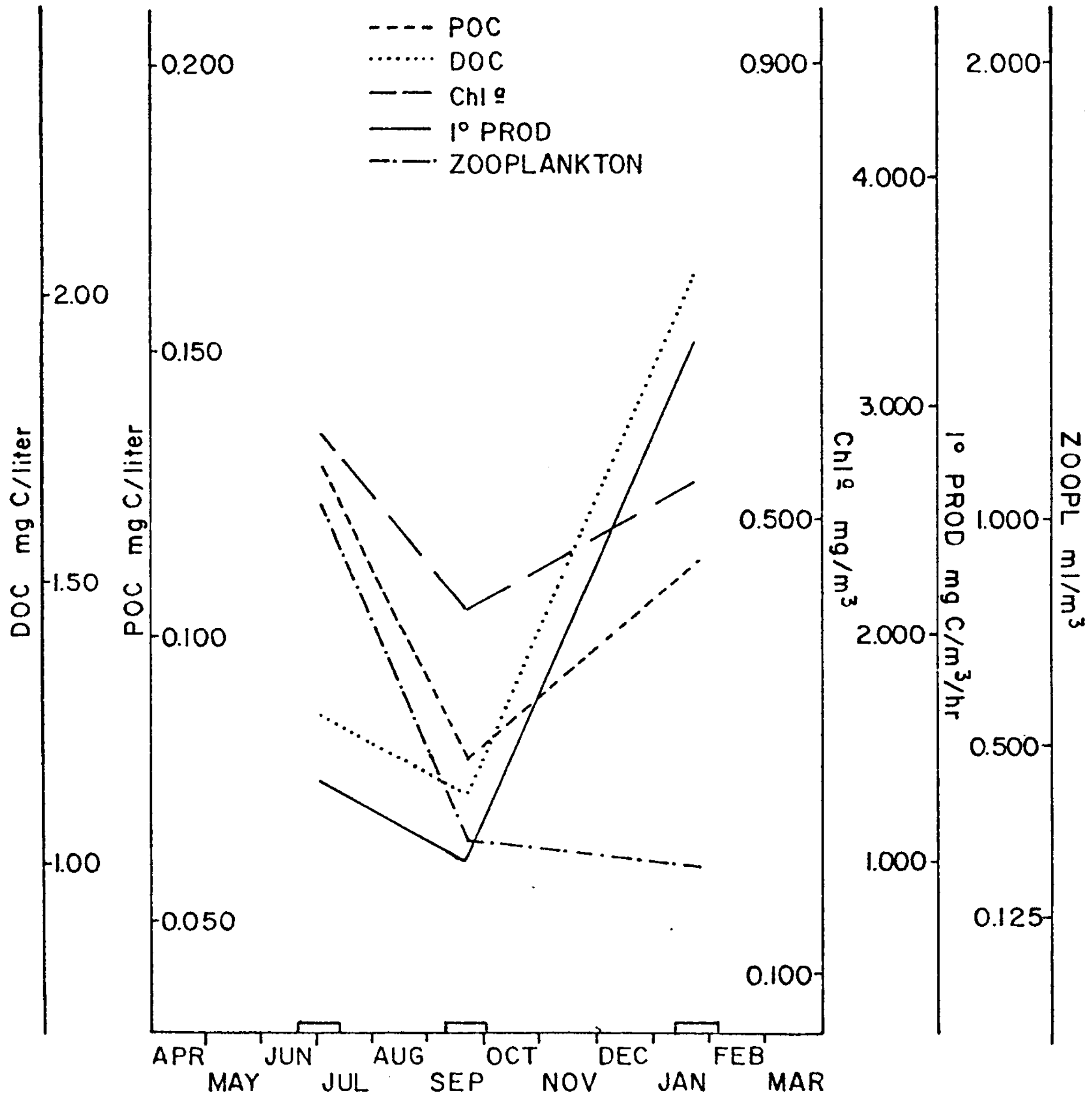


Figure 125a. Temporal Variation of Organic Carbon, Chlorophyll, Primary Productivity, and Zooplankton Over the Continental Shelf of the Northeast Gulf of Mexico.

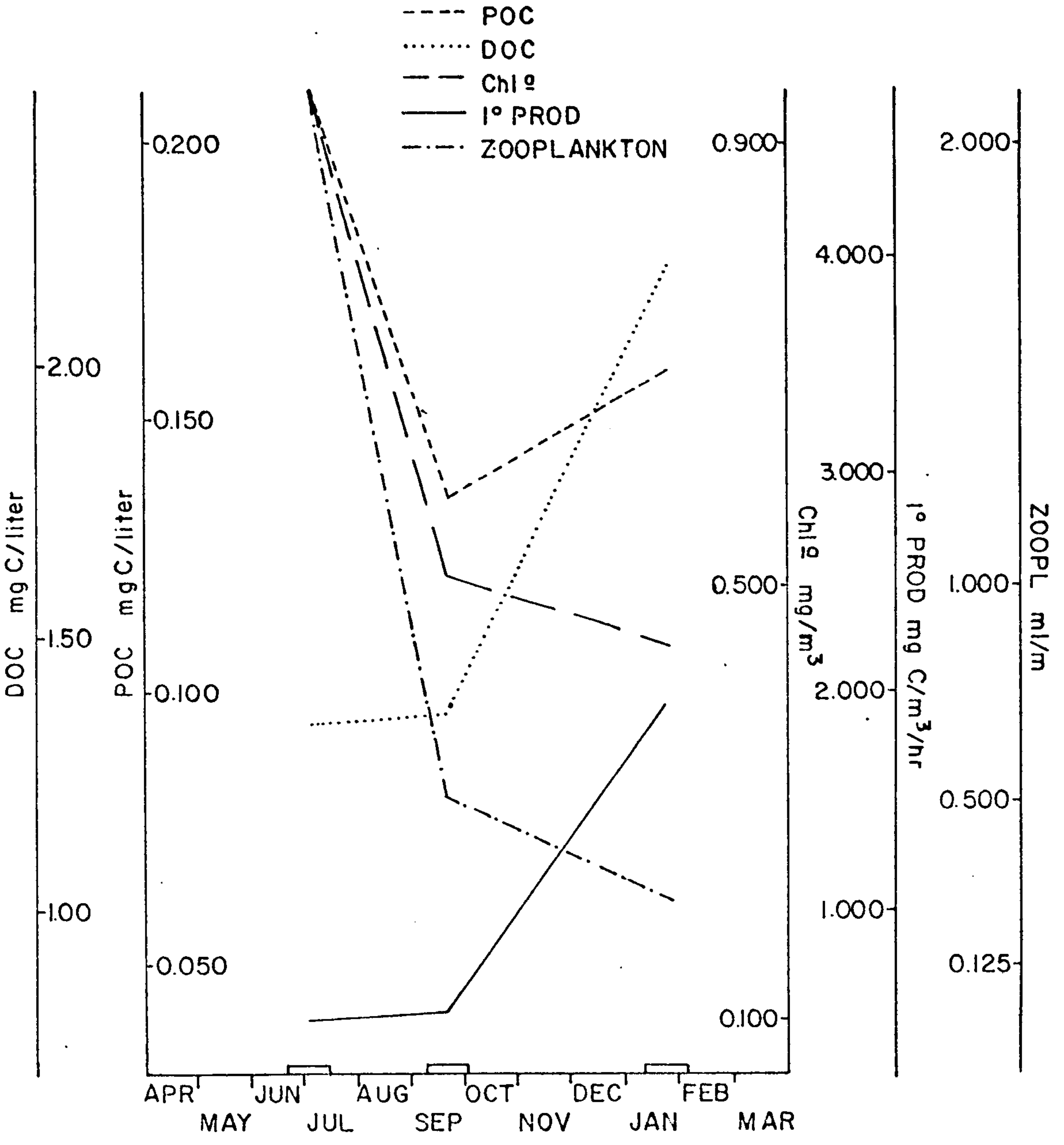


Figure 125b. Temporal Variation of Organic Carbon, Chlorophyll, Primary Productivity, and Zooplankton – Depth Zone I

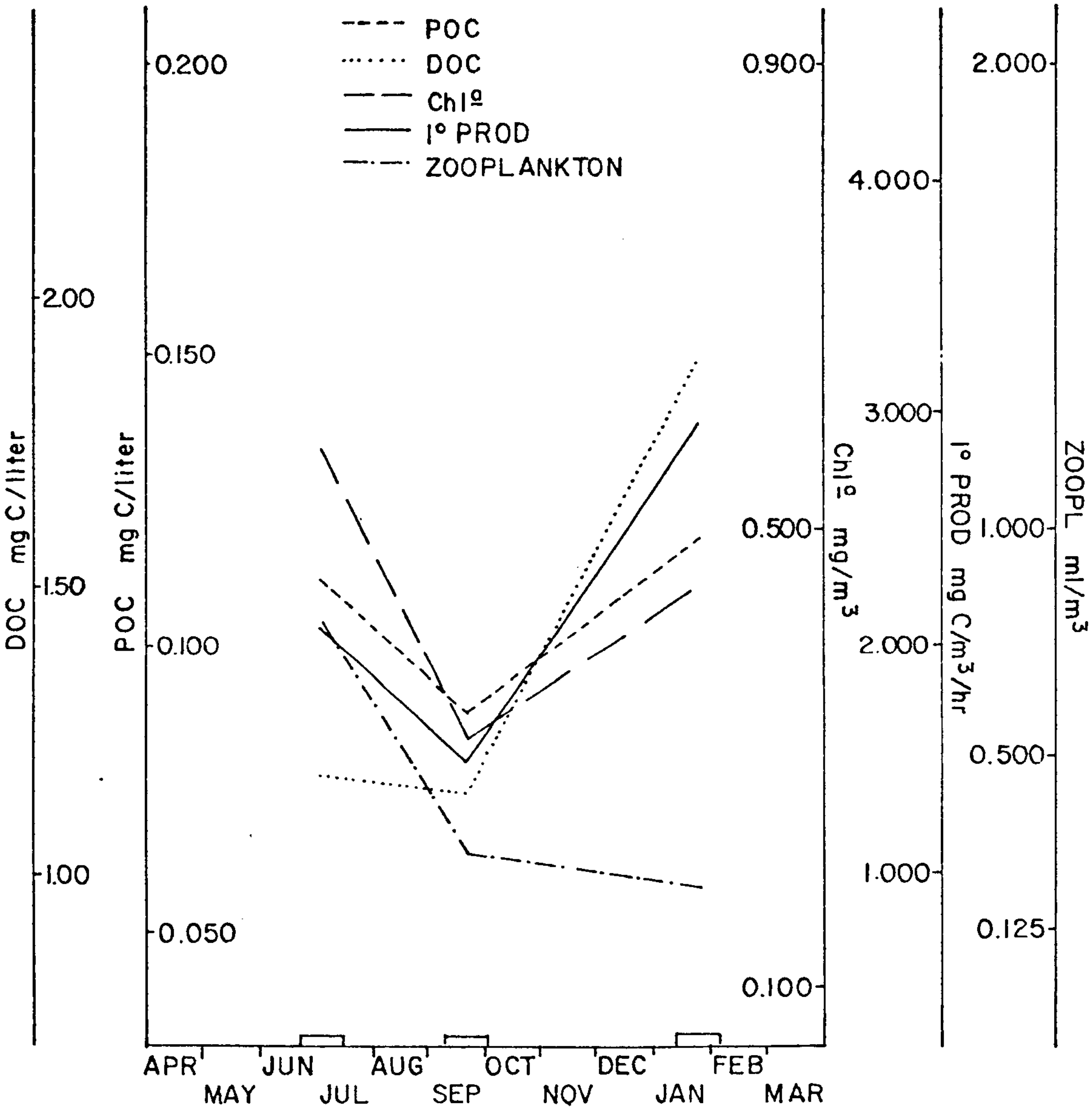


Figure 125c. Temporal Variation of Organic Carbon, Chlorophyll, Primary Productivity, and Zooplankton – Depth Zone 2

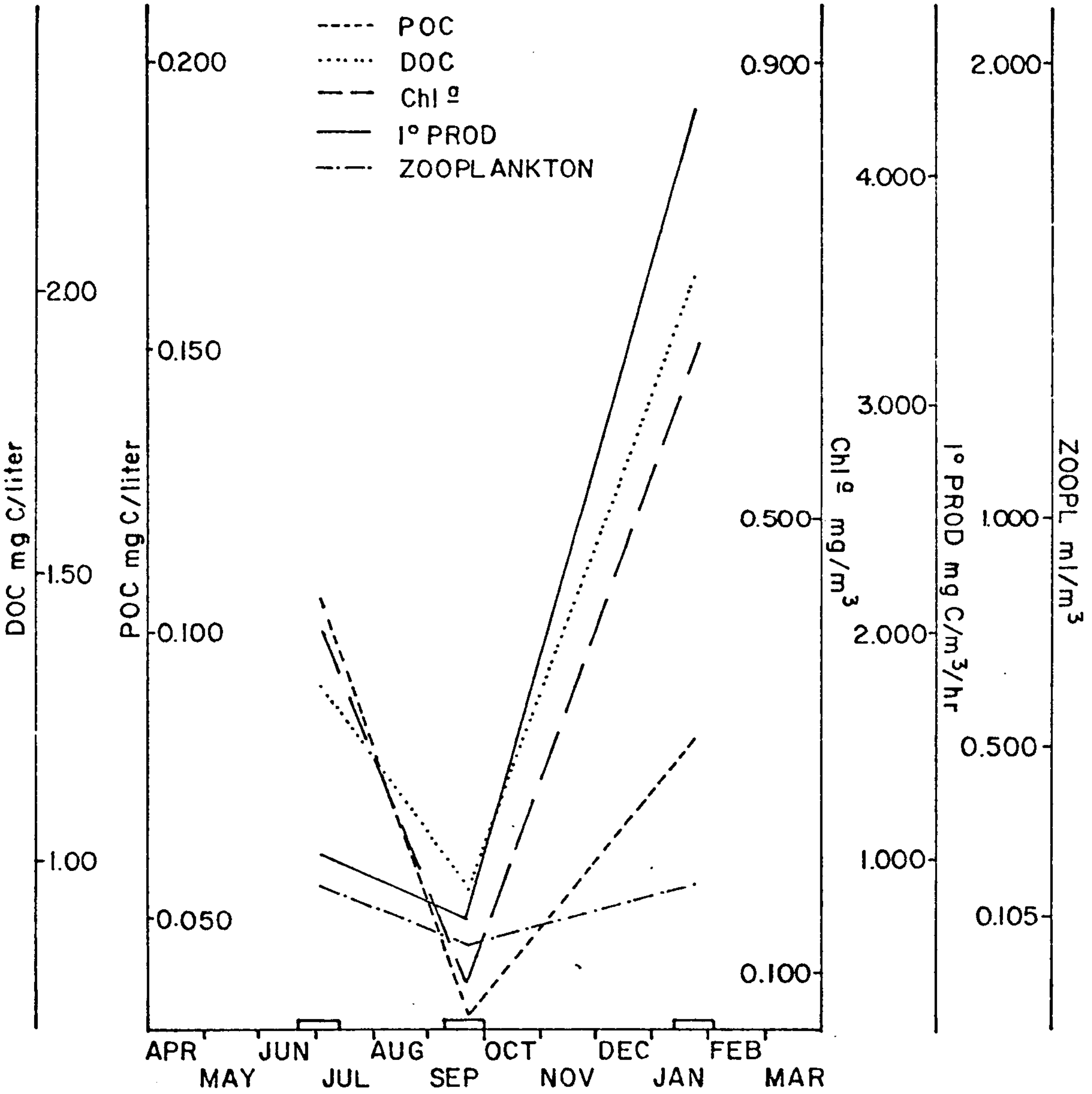


Figure 125d. Temporal Variation of Organic Carbon, Chlorophyll, Primary Productivity, and Zooplankton – Depth Zone 3

biological processes may be exerting an influence on the observed levels of POC and DOC.

Aggregating data for the entire shelf may obscure different processes occurring in other shelf areas. Figures 125a-125d, which present the seasonal fluctuations for all parameters by depth zone groupings, suggest that this is the case. Inshore trends, as with the total shelf trends for primary productivity and dissolved organic carbon, vary in a similar manner. Unlike the total shelf, the chlorophyll trend parallels the zooplankton measurements from the fall to the winter sampling period suggesting that other factors may strongly influence the inshore levels of particulate organic carbon during this time period. These processes may include exchange or mixing with sediments or effects from land run-off. The intermediate and offshore zones follow the general pattern of trends for the total shelf.

Considering the seasonal mean levels of all the parameters under consideration by transects reinforces the concept that each area of the Gulf represents different combinations of processes and interactions between the parameters. Data from Transect III suggest that this region is quite similar to the entire Gulf shelf study area as depicted in Figure 72 and previously discussed. Transect IV follows the general trend pattern established for the total shelf (Figures 72, 73), but is an area of extreme seasonal fluctuation undoubtedly heavily influenced by the Mobile Bay and Mississippi River systems. The lack of clearly identifiable patterns along Transects I and II indicates that processes other than those *in situ* biological ones examined may be largely responsible for the seasonal fluctuations of particulate organic carbon and dissolved organic carbon.

Along Transect I the influence of human activity from heavily populated coastal areas is evident while the relatively shallow Transect II reflects the fluctuating inputs from the extensive coastal marsh and seagrass systems in this region.

Although limited by its high variability, one method of assessing the contribution of phytoplankton to particulate carbon levels has been the determination of carbon to chlorophyll ratios (Steele and Baird, 1961; Steele and Baird, 1962). For this study, over the total northeastern Gulf Shelf, the carbon to chlorophyll ratios varied throughout the year from 95:1 in the summer, 44:1 in the fall, to 69:1 during the winter. This suggests that the phytoplankton make the most significant percentage contribution to particulate organic carbon during the fall.

A means of examining the temporal relationships of these parameters more closely is to focus on each of the sampling periods rather than across the entire year. This has been done through a series of linear regression analyses which employed the following procedures. The ten meter organic carbon determinations were compared with either the surface or the closest to ten meter phytoplankton hydrocast. The one percent light level organic carbon determinations compare exactly with the phytoplankton hydrocast. Separate analyses by depth (ten meters versus one percent light level) supported the validity of this technique; the significance of regressions was not affected by employing this approximation. Salinity and temperature regressions with organic carbon were precise depth matches in almost all instances. Since zooplankton tows fished the entire water column, upper and lower organic carbon determinations were averaged for purposes of regression analysis. Transmissometry and organic carbon matched exactly in depth at ten meters.

Regression analysis was performed using all variables with particulate and dissolved organic carbon as the independent variable. Table 129 summarizes the significant ($\alpha = 0.05$) correlations. Regressions for depth zones are based on few points and should be considered with caution. Figures 126a, b, c through 128a, b, c show scattergrams for chlorophyll a, primary productivity, and zooplankton against particulate organic carbon and dissolved organic carbon respectively.

The data of Table 129 permit a closer examination of the relationships suggested by Figures 126 through 128. Immediately evident is the fact that, over the northeastern Gulf shelf, particulate organic carbon correlates well with chlorophyll a during the summer and fall sampling periods. Further, the supportive correlation coefficients for the depth zones for chlorophyll a in these two time categories suggest that it is the areas closest to shore which exhibit the strongest relationship between phytoplankton and particulate carbon. These associations have been noted by other investigators (Menzel and Goering, 1965; Parsons and Strickland, 1959).

During summer and fall, the zooplankton also show good correlations with particulate organic carbon. The significant inshore correlation coefficients in support of those for the total shelf, probably indicate that the zooplankton are related to the particulate organic material primarily through the necessity to feed on phytoplankton. In fact, since zooplankton will usually contribute only a few percent to the actual particulate

Table 129. Significant r^2 Values of Linear Regression Analysis

Variable	Region	Jun/Jul 1975 POC	Jun/Jul 1975 DOC	Sep/Oct 1975 POC	Sep/Oct 1975 DOC	Jan/Feb 1976 POC	Jan/Feb 1976 DOC
Chl a	Shelf	0.70		0.57	0.18		
	Zone 1	0.98		0.86		0.97	
	Zone 2	0.44		0.46			
	Zone 3					0.72	
Primary Productivity	Shelf						
	Zone 1			0.79		0.86	0.89
	Zone 2						
	Zone 3	0.63		0.49		0.85	
Zooplankton	Shelf	0.87		0.77	0.42		
	Zone 1	0.97		0.77			
	Zone 2						
	Zone 3			0.79			
Temp	Shelf					0.39	
Salinity	Shelf			0.25	0.25	0.52	0.32
Trans	Shelf						

Note: $\alpha \leq 0.05$. All correlations are positive except temperature and salinity. Blank cells indicate no significant correlation with the exception of transmissometry (summer) for which data was absent.

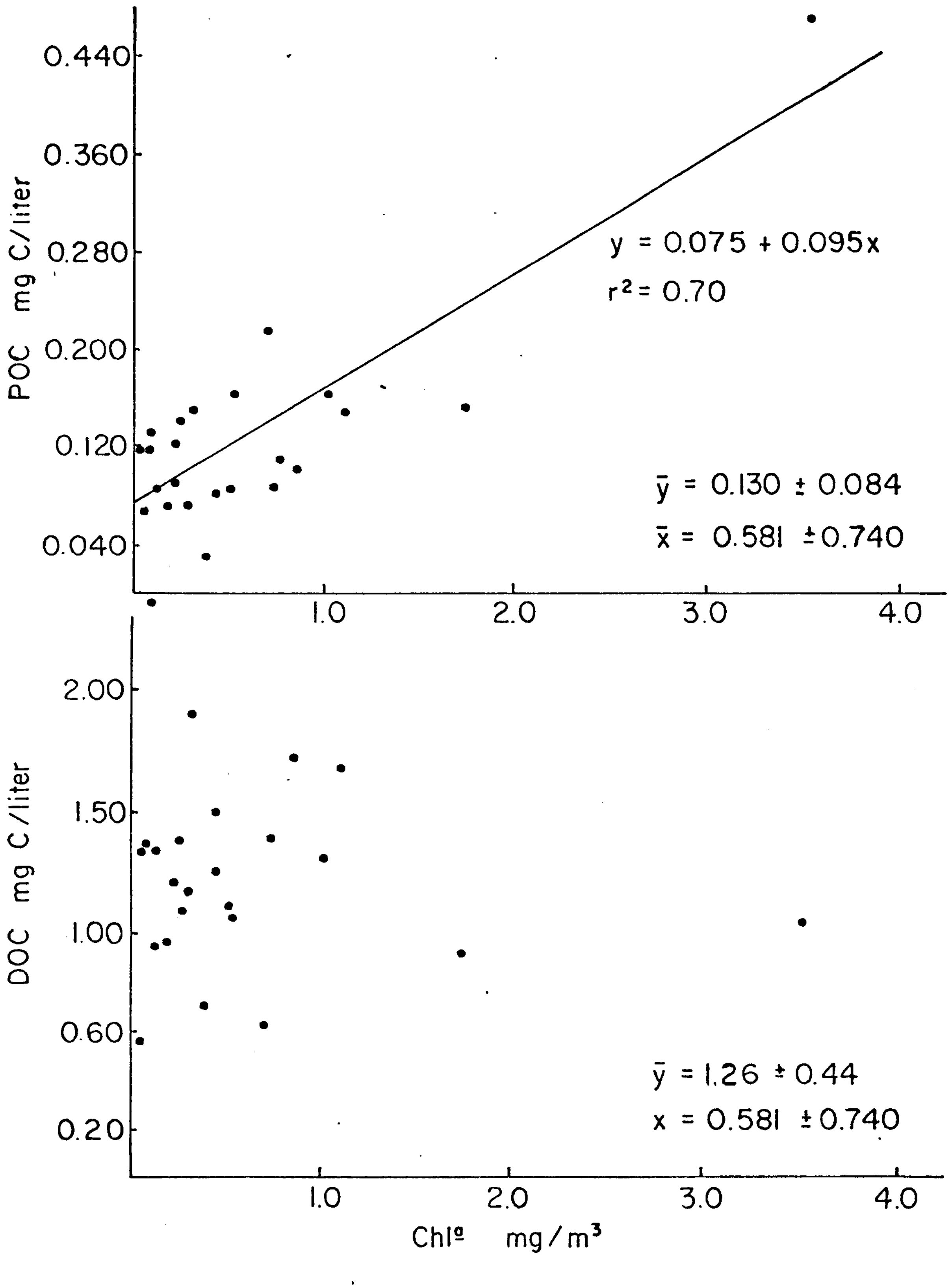


Fig. 126a. Organic carbon vs chlorophyll a, summer, 1975.

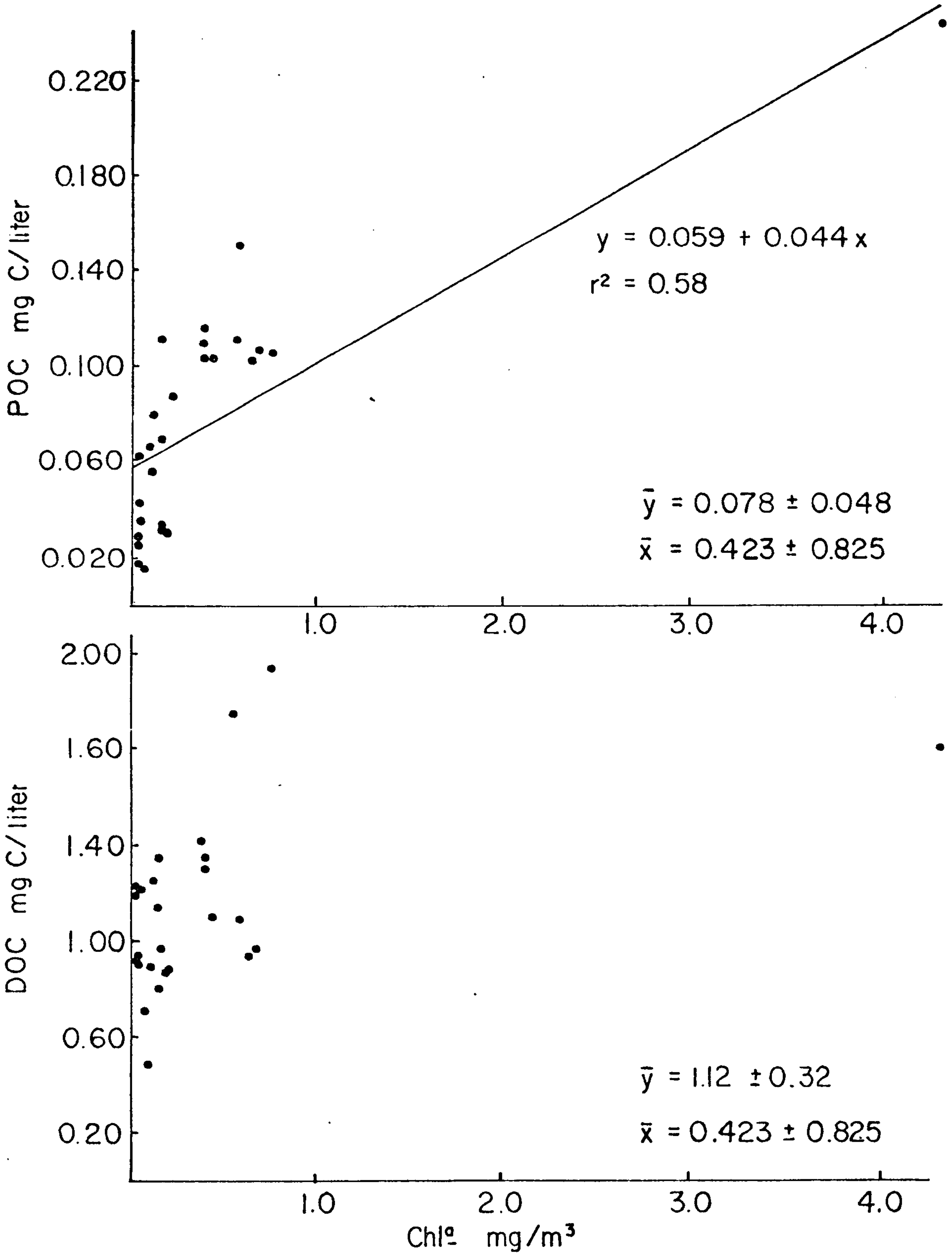


Fig. 126 b. Organic carbon vs chlorophyll a, fall, 1975.

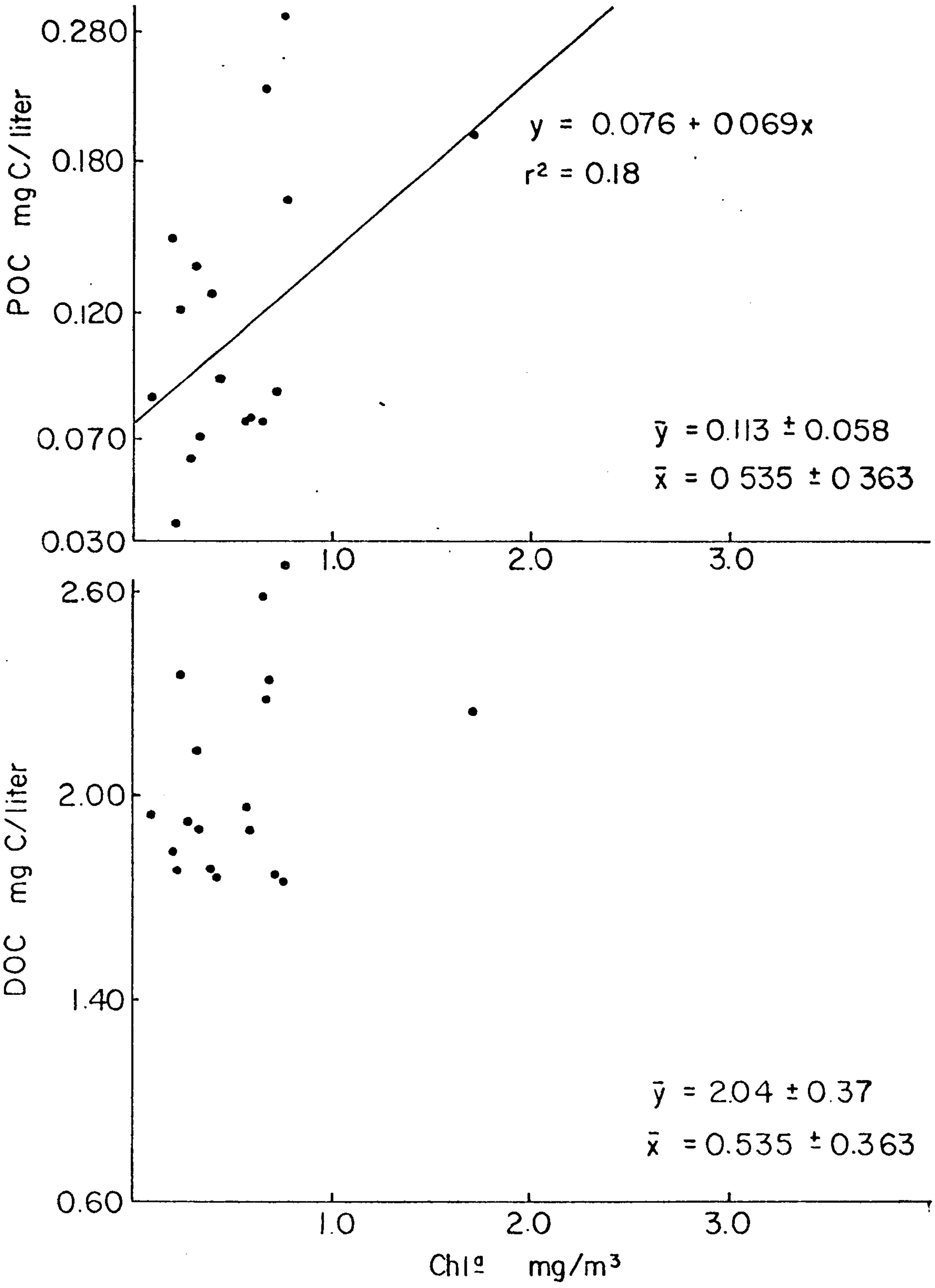


Fig. 126c. Organic carbon vs chlorophyll a, winter, 1976.

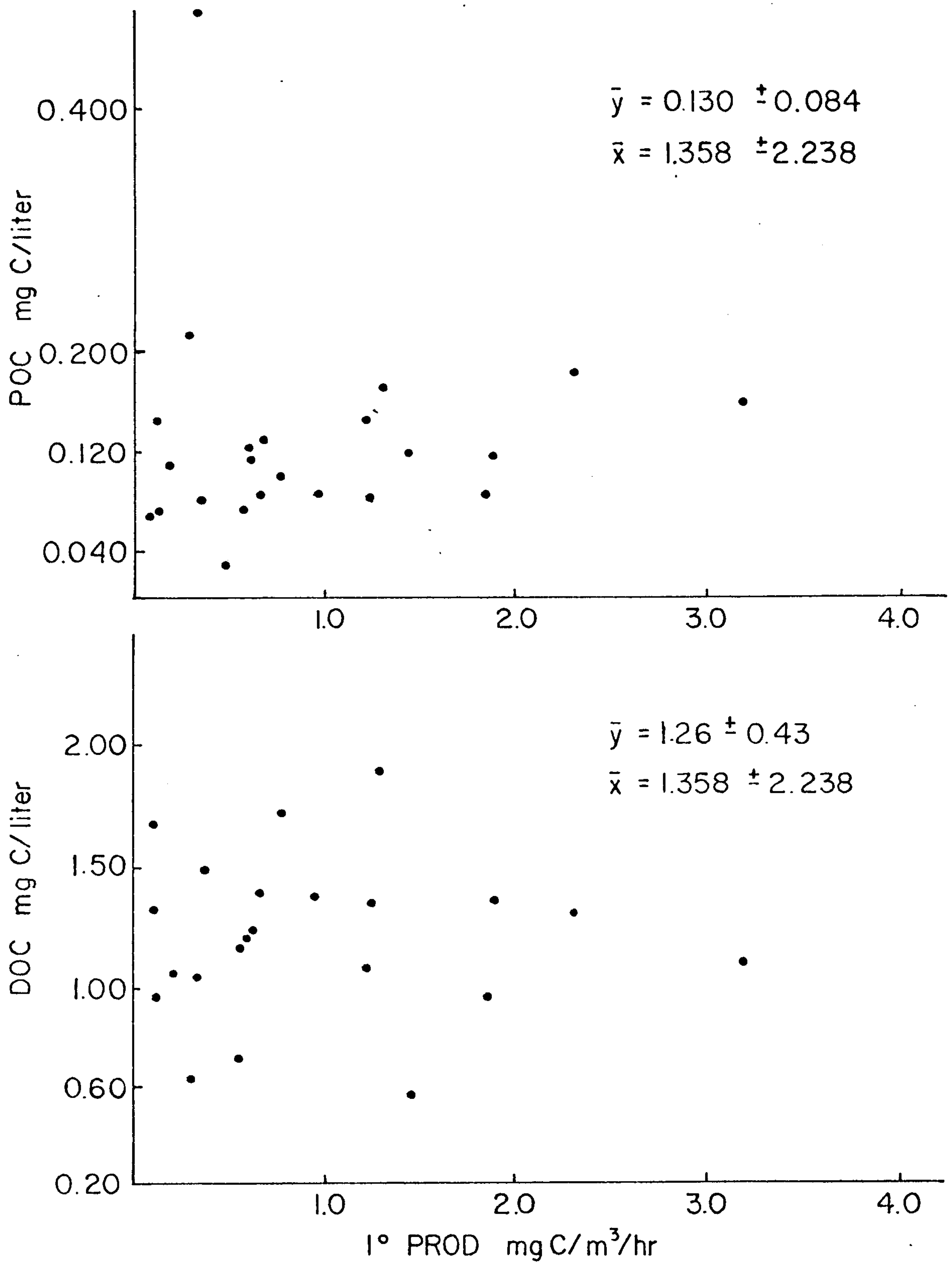


Fig. 127a. Organic carbon vs primary producivity, summer, 1975.

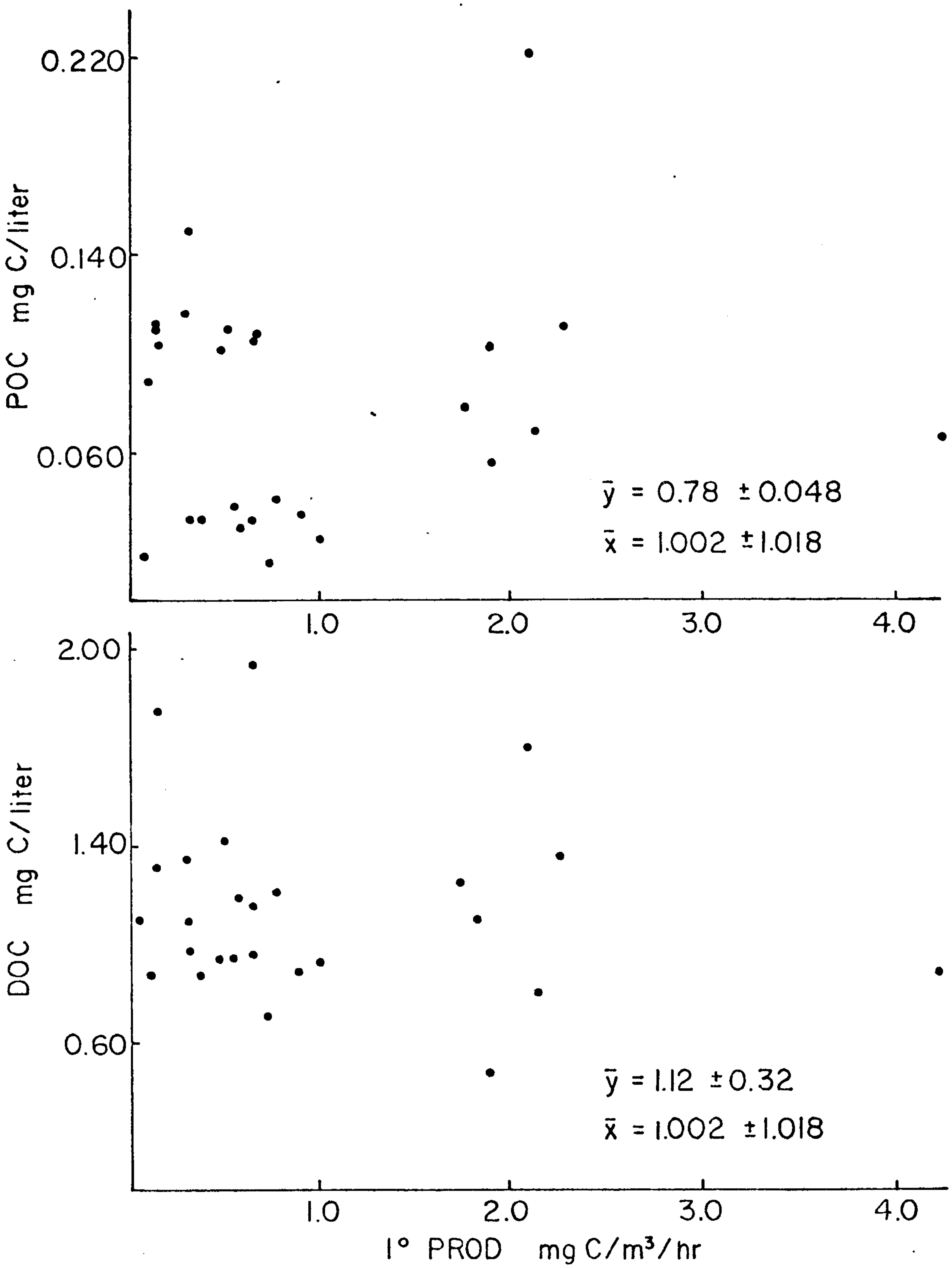


Fig. 127b. Organic carbon vs primary productivity, fall, 1975.

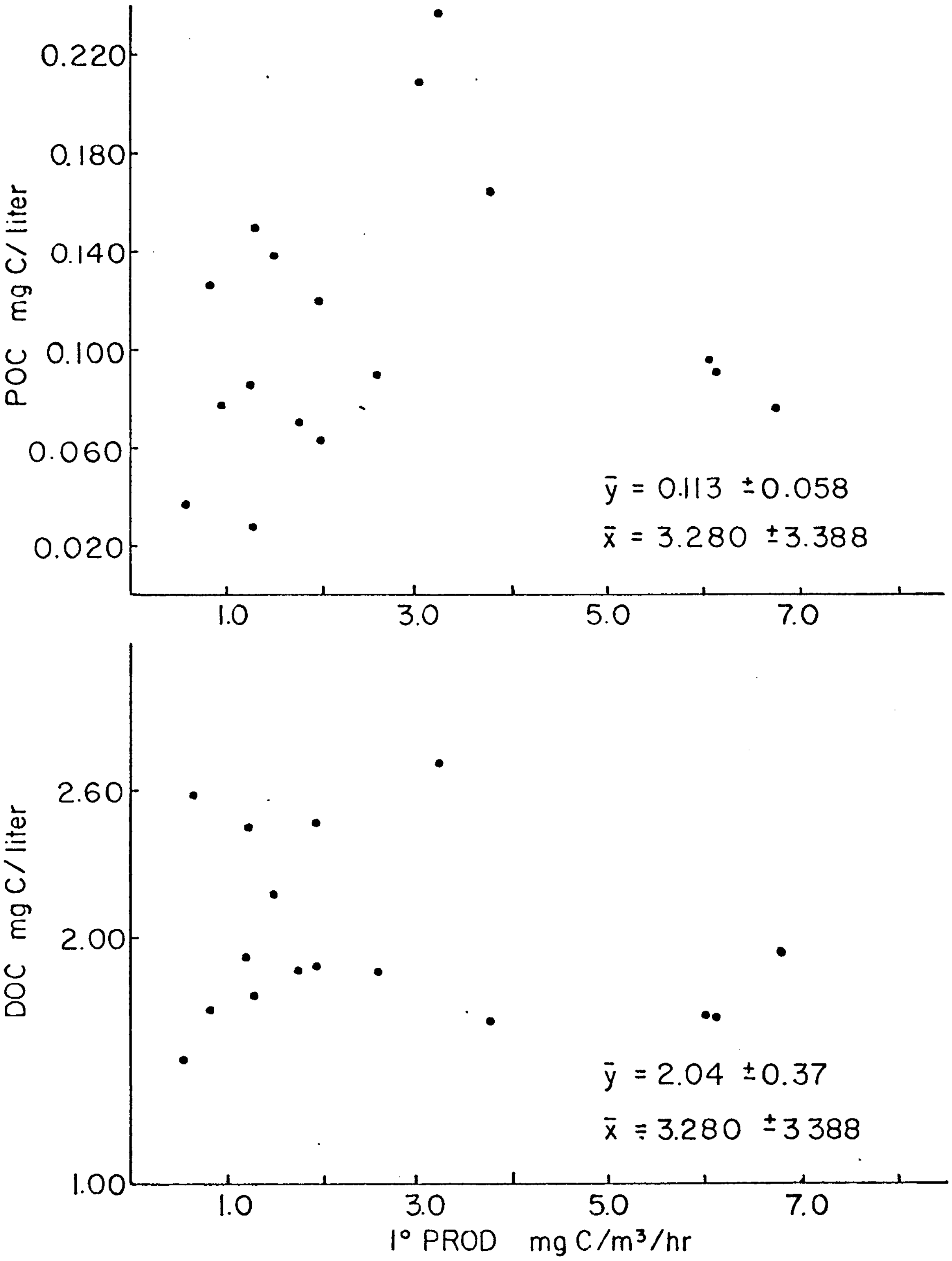


Fig. 127c. Organic carbon vs primary productivity, winter, 1976

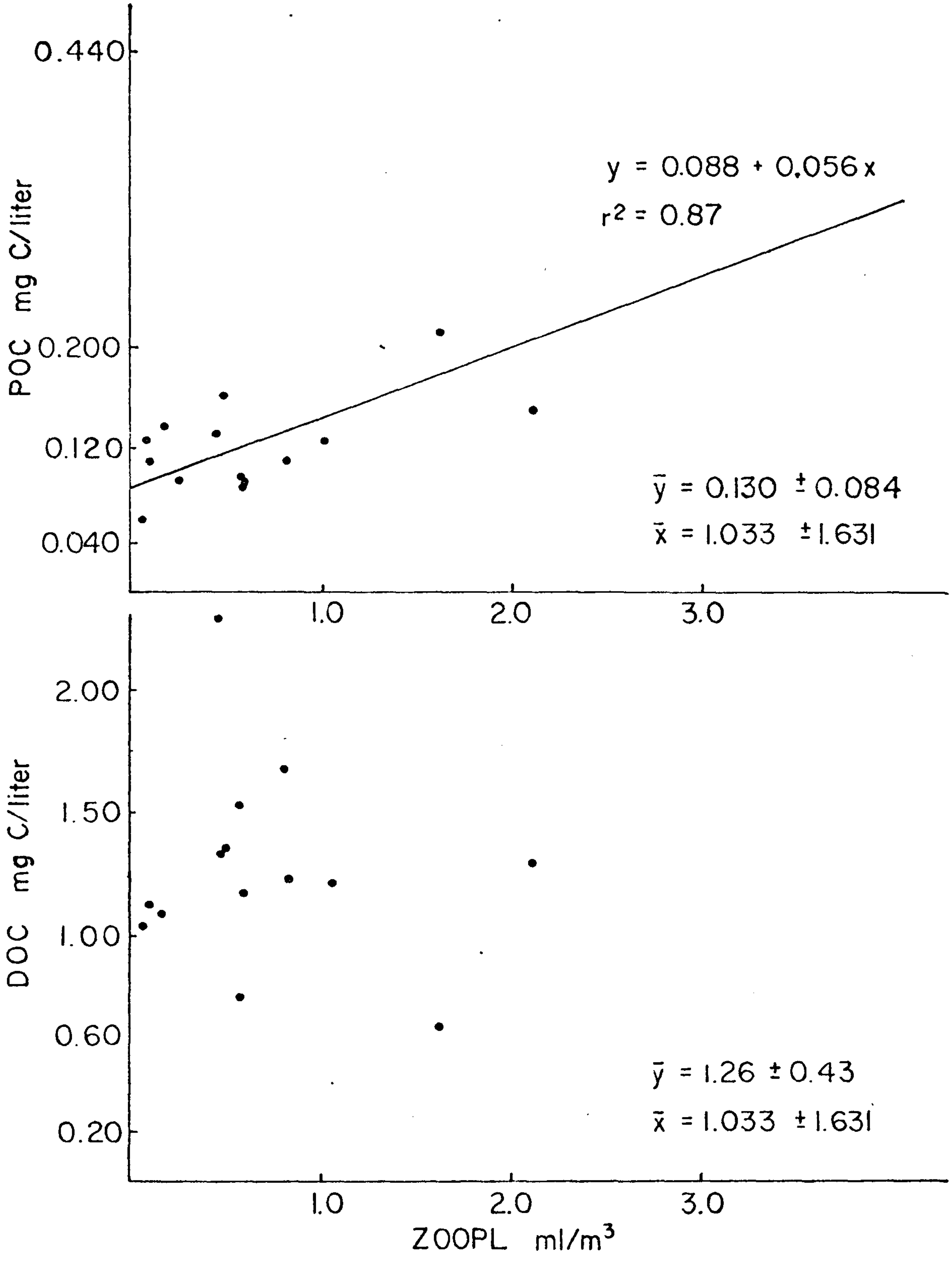


Fig. 128a. Organic carbon vs zooplankton, summer, 1975.

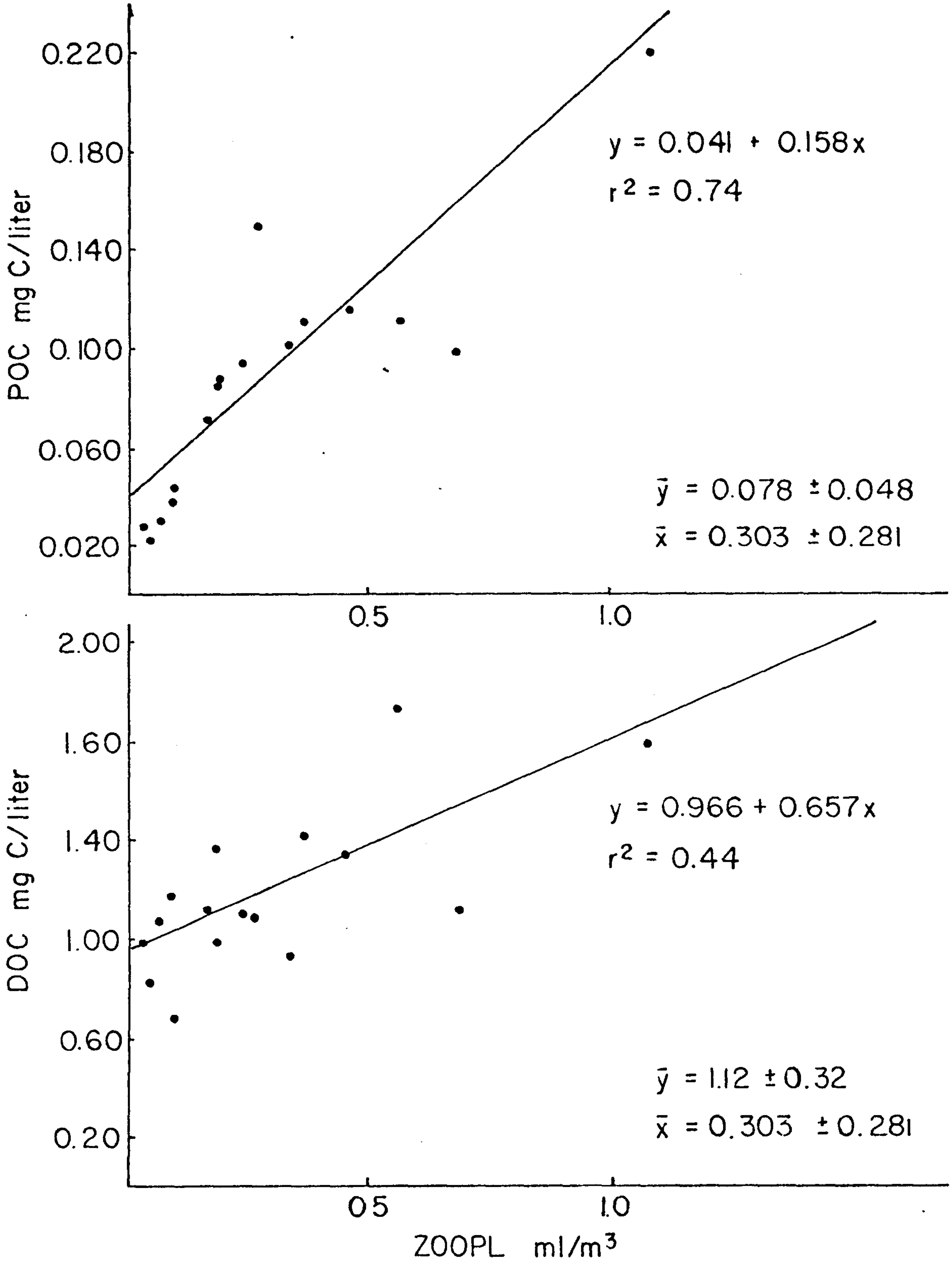


Fig. 128b. Organic carbon vs zooplankton, fall, 1975.

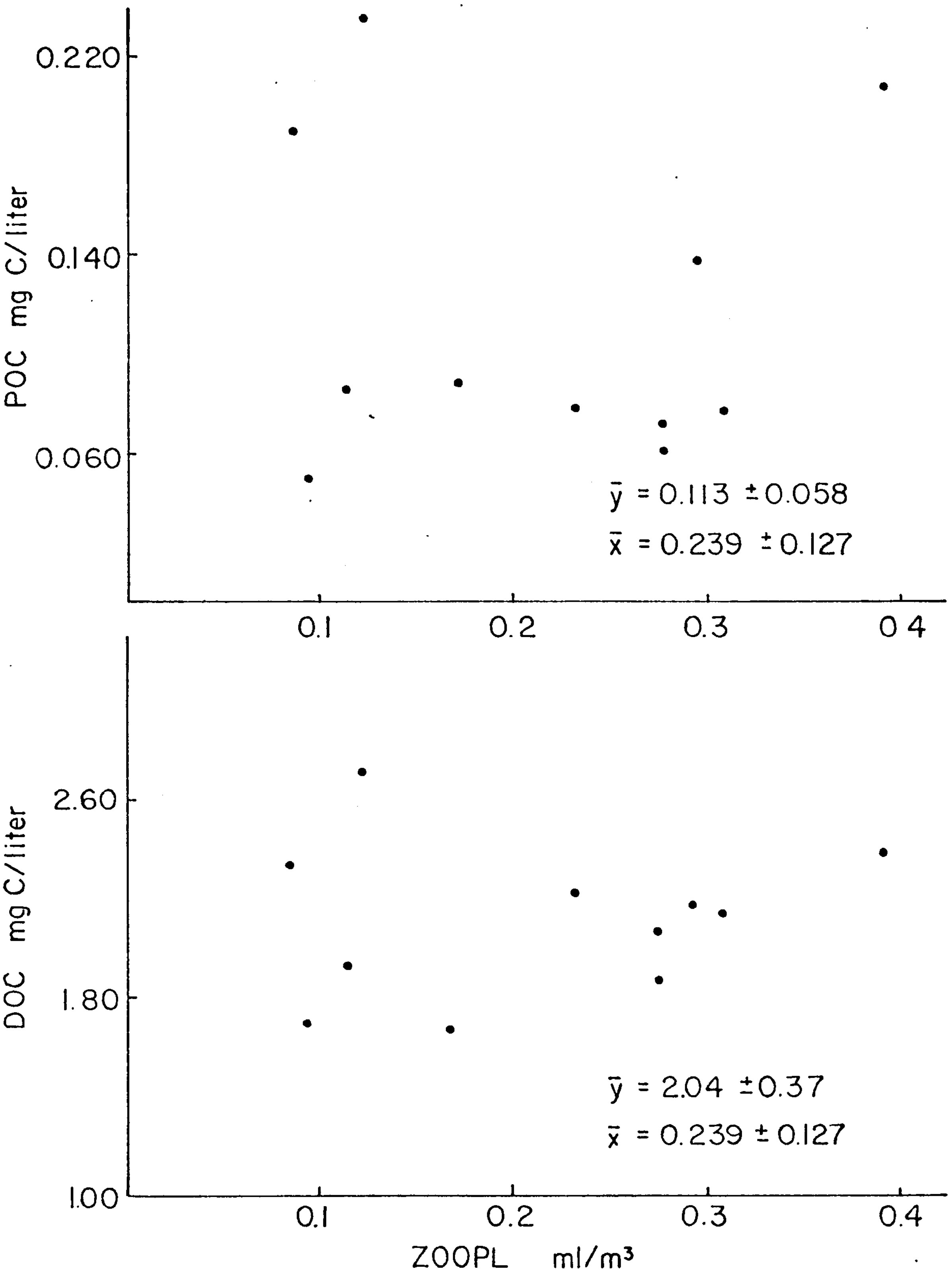


Fig. 128c. Organic carbon vs zooplankton, winter, 1976.

organic carbon present, the correlations between particulate organic carbon and zooplankton may be taken as a further indication of a more direct relationship between the particulate fraction and phytoplankton. The scattered, inconclusive correlations-between particulate organic carbon and primary productivity may be related to zooplankton grazing pressure. The limited winter relationships between particulate organic carbon, chlorophyll *a* and primary productivity in the absence of any zooplankton correlation appears to sustain this contention.

Particulate organic carbon relates weakly to salinity in the fall but this relationship is more pronounced during winter when the offshore salinity increase is most pronounced. This would have the effect of making any consistent decline in POC as the result of dilution offshore appear more evident. Recalling the earlier discussion which noted the immediate offshore winter decline in the levels of particulate organic material, and observing that chlorophyll *a* correlates well with particulate organic carbon during the winter inshore, it would appear that the processes affecting particulate organic carbon were fairly similar throughout the year along the northeast Gulf shelf. Thus the data suggests that the current-salinity structure rather than some change in the source of particulate organic carbon is responsible for the salinity correlations during the fall and winter sampling periods.

Unlike particulate organic carbon, the results of this study cannot link the dissolved fraction to *in situ* biological processes. Correlations for dissolved organic carbon recorded in Table 129 are absent or weak. The apparently strong correlation with primary productivity during the winter is based upon only five data points. The weak salinity correlations during the fall and winter, reflecting simple dilution in the open Gulf, are, as with particulate organic carbon, the result of a more organized inshore to offshore salinity gradient during these seasons. No significant correlations between particulate or dissolved organic carbon and any of the other parameters were found.

The strong and consistent correlations found throughout the year between particulate organic carbon and chlorophyll a and the concurrent fluctuations of these two quantities over the entire shelf study area indicate that the phytoplankton comprise a significant portion of the particulate organic carbon in this region. Considering the entire Gulf of Mexico, Dryer (1973) estimated that phytoplankton contributed 38 times the amount of terrestrially derived particulate organic carbon. When dealing with the shelf this estimate would undoubtedly have to be revised downward because of the proximity to terrestrial inputs. Knauer (1976), working during the summer of 1974 in the same northeastern Gulf shelf area as this study, found by ATP extraction that an average of 50% of the particulate organic carbon was living. Thus, the present finding that phytoplankton strongly influence the levels of particulate organic carbon along the northeast Gulf coast shelf appears to find support in several separate studies.

Dryer (1973) found that terrestrial dissolved organic carbon inputs were the major controlling influence on nearshore Gulf of Mexico dissolved organic carbon concentrations. The decline of this influence was marked by a pronounced dissolved organic carbon gradient related to salinity in estuarine areas. Dryer further calculated that the total contribution to the dissolved organic carbon of the entire Gulf of Mexico from primary production and river inputs were approximately equal.

If the measure of chlorophyll a does in fact provide an indirect measure of approximately 50% of the particulate organic material as Knauer has suggested with ATP extraction, then the relationships established are between quantities on the same order of magnitude. In attempting to link dissolved organic carbon with primary productivity, however, additional considerations are involved. The reservoir of dissolved organic carbon represents a pool of material while the primary productivity is a rate quantity three orders of magnitude smaller (Tables 60 and 63). A reliable estimate is that only about ten percent of the photoassimilated carbon is added to the dissolved pool directly as excretion (Hellebust, 1965). This suggests that the annual relationships depicted in Figures 126a through 128c may exist but are undetectable by the comparisons of Table 129. Certainly the unique station to station variations and the absence of the inshore to offshore gradient noted by Fredericks and Sackett (1970) are indications that in situ processes are important to the observed levels of dissolved organic carbon.

Chlorophyll a measurements are generally used in biologically related studies to indicate the quantity of phytoplankton population in a given volume of water. Spatial and temporal changes in these concentrations are useful in interpreting observed changes in other parameters.

The increased concentration of chlorophyll a in the bottom waters is in part a function of phytoplankton dependence upon light for photosynthetic activity. The presence of higher concentrations of the pigment in the deeper portions of the water column is typical of tropical and subtropical waters and is in agreement with other data (Alexander, _et_ _al_., 1961; Alexander and Corcoran, 1963).

The previously established correlations between chlorophyll _a_ and particulate organic carbon levels were further confirmed by the correlation coefficient between these two parameters of 0.81 in the fall whereas in the summer and winter the coefficient was 0.25 and 0.50 respectively. The above relationships considered all of the data for chlorophyll _a_ and particulate organic carbon. If the shelf is divided into three zones such as Inshore (Master Stations 1101, 1204, 1205, 1308 and 1412), Intermediate (Master Stations 1102, 1206, 1207, 1309 and 1413) and Outer (Master Stations 1103, 1310, 1311, 1414 and 1415), more meaningful relationships can be seen. _Subsequent correlations are based on fewer data points and should be considered accordingly_.

Strong to moderate correlations between chlorophyll _a_ and particulate organic carbon in the summer were present in the Inshore (r = 0.9) and Intermediate (r = 0.7) zones. In the fall a significant correlation was present between these two parameters in the Intermediate zone only (r = 0.8), while in the winter strong relationships were observed in the Inshore and Offshore region (r = 0.9).

No significant relationships existed between chlorophyll _a_ and dissolved organic carbon in the summer. Strong correlations were found between these two parameters in the fall in the Inshore and Intermediate Zone (r = 0.8 and 0.9 respectively) and in the winter in the Inshore and Offshore Zone (r = 0.8 and 0.9 respectively).

No significant relationships were found during any season between salinity and chlorophyll _a_ when the data from the shelf were treated as a whole. When compared on a zonal basis similar to the above, strong correlations were present between these parameters in the Inner and Intermediate Zones (r = 0.9) in the summer, none in the fall and moderate to strong relationships were present in all three zones (r = 0.7-0.9) in the winter.

Chlorophyll a and particulate iron relationships in these same zones also showed evidences of strong relationships (although these must be treated with caution due to few data points involved). For example, weak acid soluble iron correlated strongly with chlorophyll in the Inshore and Intermediate Zone in the summer (r = 0.9) and in all zones in the winter (r = 0.8-0.9). Refractory iron correlated with the pigment in all zones in the summer and winter (r = 0.7-0.9). Copper generally showed no correlation and no consistent trends were evidenced in cadmium and lead chlorophyll relationships. Weak acid soluble chromium was consistently below detection limits and refractory chromium-chlorophyll correlation ranged between 0.7-0.9 in all zones in the summer and winter. Interestingly, in only one out of the 27 data sets (weak acid soluble plus refractory) was a significant correlation found between the metals and chlorophyll in the fall. The exception was an r value of 0.9 between weak acid soluble cadmium and chlorophyll in the Inshore Zone. This single occurrence is considered as random.

The general pattern of decreasing density of zooplankton with increased distance from shore is to be expected since the inshore areas are generally considered to be more productive in terms of supporting a larger standing crop of zooplankton. Population densities were strongly correlated with biomass in both the summer and fall (r = 0.83 and 0.85 respectively). Similar comparisons in the fall showed a correlation value of 0.59.

As shown in Table 130 (Shannon-Weaver diversity index) the diversity of zooplankton generally increased from inshore to offshore in the summer and fall. The exception to this was present in the winter where the opposite trends were noted along Transects II and IV. The generally higher diversity in the fall (as compared to fall and winter) relates to the lower population densities at this time of the year.

Interpretation of the neuston data and associated statistical analyses reported here is difficult because of the great quantitative variability among collections. The tendency of water column populations to exhibit patchiness in distribution also adds to the difficulty of interpreting distributions. At best, one can only say, with any degree of certainty, that the distribution of neuston in the MAFLA study tract appear to exhibit spatial and temporal patterns of heterogeneity but that these are poorly understood at present. The paucity of previous neustonic studies on eastern Gulf of Mexico waters adds to the problem. It is biologically significant that crustaceans, especially copepods, dominated the collections. This is typical of most zooplankton populations sampled in marine waters. Fish are not a major component of the neuston.

The negative relationships between neuston abundance and light intnesity may be indicative of vertical migration patterns. This seems feasible since many of the specimens collected can be classified as bentho-hyponeuston and bathyplankto-hyponeuston. This is of particular importance considering the dominance of copepods, known vertical migrators, in the collections.

Of particular importance is the negative correlation of neuston

Table 130. Shannon-Weaver index of zooplankton species diversity.

Station	Summer, 1975	Fall, 1975	Winter, 1976
1101	2.165	2.085	1.948
1102	2.553	2.526	2.431
1103	2.708	2.830	2.629
1204	0.716	1.613	2.280
1205	1.063	1.692	2.084
1205A	-	2.414	
1206	2.175	2.551	2.077
1207	2.685	2.363	1.975
1308	2.179	2.399	2.316
1309	2.384	2.487	2.530
1310	2.431	2.825	2.490
1311	2.563	2.754	2.965
1412	2.316	2.185	2.868
1413	2.441	2.515	2.779
1414	2.809	2.570	2.154
1415	2.730	2.769	2.062

abundance with tar in the surface waters and air/sea film. It is unknown if this relationship is due to an avoidance mechanism or different wind-rafting characteristics for hydrocarbon substances and neustonic organisms. If the former is the case then oil dispersal within the surface layer may have a detrimental effect on the neustonic community.

Sea Floor

The Mississippi River Delta System forms a continental margin province which dominates the north central portion of the Gulf of Mexico. East of the Delta, off the coast of Mississippi, Alabama, and Florida lies a second province known by the acronym MAFLA (Figure 1). The eastern part of the MAFLA margin is dominated by the Florida platform, an accumulation of over 4,570 m of carbonate sediment ranging in age from Jurassic to Recent. West of Cape San Blas, carbonates become intercalated with increasing amounts of clastics. Across the northern extension of the Florida Escarpment (Figure 82) the sedimentary basement rocks change from dominantly carbonates on the east to Cenozoic clastics on the west. The Florida Escarpment trend therefore represents a major sedimentary boundary between the Gulf Coast Geosyncline and the Florida carbonate platform.

Most of the sediment of the Mississippi River is delivered directly to the shelf edge or is transported west by the Coriolis effect, the long-shore current system, and the prevailing surface currents. As a result, the MAFLA continental margin is covered by a sand sheet which Uchupi and Emery (1968) have called relict, which is dominantly quartz west of Cape San Blas and carbonate east of Cape San Blas.

Excepting mineralogy, the MAFLA sand sheet is much like that of the continental shelf of the southeastern Atlantic margin. Rivers which empty into the MAFLA waters carry very little sediment and virtually none of this is sand sized. Furthermore, most of the fine sediments delivered to the coast are trapped in estuaries, bays and lagoons.

Estuaries, bays, and the coastal zone of the MAFLA area have been thoroughly investigated by Tanner (1960), Goodell and Gorsline (1961), Kofoed and Gorsline (1963), Tanner and others (1963), Kofoed and Jordan (1964), Gorsline (1966), and many more. However, surprisingly few studies of the continental shelf of the MAFLA area have ever been undertaken, and with the exception of the broad overview of Uchupi and Emery (1968) data covering limited sectors of the area have never been integrated. Many of the individual investigations which have been conducted are listed in Brooks (1973). Gould and Stewart (1955), Ludwick (1964), and Grady (1972) have contributed most to the description of the MAFLA continental shelf. Holmes and others (1963) have investigated the innershelf sediments between Cape Romano and Cape Sable and Shepard (1956) the eastern flank of the Mississippi Delta. Gould and Stewart (1955) have depicted the central portion of the West Florida Shelf as covered with predominantly carbonate sediments zoned into quartz sand, quartz-shell sand, shell sand, algal sand, oolite sand, and foram sand and silt bands. Banded character of the sediments was also evident in Stewart and Gould's (1955) description of sediment textures. Ludwick (1964) described the sediments between the Mississippi Delta and Cape San Blas as a number of sand, mud, and transitional facies. Grady (1972) mapped sediment textures based upon a triangular diagram presentation of percent sand, silt, and clay in the northern Gulf of Mexico and his data was used to construct the latest existing sediment texture chart of the area published by BLM (1974). Finally, Van Andel and Poole (1960) and Fairbank (1962) have described the heavy mineral suites of the Eastern Gulf.

Although never before integrated, these studies are of good quality and provide a framework upon which a discussion of the sediments and sedimentary processes of the MAFLA shelf can be built and compared and contrasted with those of the southeastern United States. Geologic data analyzed for this study is small in comparison to those of the aforementioned work, but ties those investigations together and provides a basis for modifying interpretations put forth in them.

In the 1974 benchmark survey of the MAFLA lease tracts the bottom sediments in study areas I, II and III were dominated by carbonate in the sand fractions (>62 μm material). Where non-carbonate material was present in significant amounts, it increased in abundance in the finer sand fractions.

Mollusc and shell fragments were the predominant grain type in all size fractions (>2000, 2000-1000, 1000-500, 500-250, 250-125, and 125-62 μm) in nearly all samples. All other grain types showed large variations in abundances either between areas or within areas.

Skeletal grain types tended to predominate in that size fraction associated with the size of the unbroken grain or the physically stable fragment and decreased in abundance in the finer sand fractions. That is, the mollusc shell grains decreased in abundance from the coarser to finer sand sizes (from whole to fragmental). Bryozoan fragments, Halimeda plates, and echinoid plates and spines showed a similar distribution. Ostracod tests, sponge spicules and alcyonarian spicules occurred only in the finer fractions.

Non-skeletal grain types showed a less predictable size distribution. These were commonly lesser amounts of unidentifiable grains in the finer sand fractions. This was in sharp contrast to the trends of shallow water carbonate sediments in southeastern Florida and the Bahamas. The abundance of unidentifiable grains in the coarser fractions appears to reflect more intense rock-boring organism activity into coarser sand grains.

The distribution of the carbonate sediment attributes in the lease tracts in 1974 showed three important characteristics:

1. In the size fractions greater than 500 µm there was a large variation in grain type abundance between samples that reflected variations in substrate (rock vs sediment), local abundance of skeletal producing organisms, local pellet production or local intraclast formation. Grouping of these attributes commonly cut sharply across bathymetric contours.
2. In the size fractions less than 500 µm, variations between samples commonly either decreased or displayed groupings that trended more parallel to the bathymetric contours. These distributions indicate that bottom wave and current energy was important in redistributing the more transport prone finer sediment fractions.
3. Weathering characteristics of a grain type displayed a different distribution pattern than the abundance of the associated attribute.

In this study the mapped distribution of constituents on the Eastern Gulf of Mexico Shelf generally reflects the maps of Gould and Stewart (1956), the results of Back (1972), and the synthesis map of Ginsburg and James (1974). There were a number of important quantitative differences.

1. Gould and Stewart (1956) defined a broad, elongate zone in which coralline algae was the predominant constituent. This generally correlated both with the >1% coralline algae abundance zone and with the >20% unidentifiable carbonate zone. Thin sections confirm that most of the unidentifiable carbonate was coralline algae in samples with significant identifiable coralline algae. Yet these samples can only contain 20-30% coralline algae at most and were in nearly all cases dominated by molluscan remains. Two possibilities may cause this discrepancy: a) these samples were biased against an adequate reflection of abundance of the >4000 μm fraction (which is dominantly coralline algae) or b) the sampling and recovery methods of Gould and Stewart caused bias towards the coarser for their samples.
2. Gould and Stewart defined a broad zone of oolitic sand seaward of the coralline algae zone along the southern portion of the Eastern Gulf Shelf, narrowing north of 27°30'N and terminating in the vicinity of 28°30'N. Although ovoid grains were recognized in loose grain analysis from Master Stations 2105 and 2533, they were classified as unidentifiable because of moderate surficial biological corrosion. Thin section examination of these samples verified that ooids were an important to dominant constituent at these stations. Most were only a thin oolitic coating on carbonate or non-carbonate nucleus. Master Station 2105 is just seaward of the mapped distribution of oolite suggested by Gould and Stewart while Master Station 2522 was located

at 29°43'N and was well north and west of the previously suggested occurrence of oolitic sands.

Earlier maps suggest an important boundary between carbonate dominated mid-shelf (to the south) and non-carbonate dominated mid-shelf (to northwest)occurs between Transects III and IV of the 1975 box coring study. Carbonate abundance data of Doyle (1976) and this study support this boundary. Associated with this was a sharp change in the abundance of certain carbonate constituents. Especially notable were the benthic foraminifera, increasing dramatically landward along Transect III, but were nearly absent from Transect IV just to the north. Benthic foraminifera were so abundant in the shelf zone represented by Master Stations 2317 and 2318 that this would fall into the category of a molluscan-foraminiferal sediment [such as that defined for Florida Bay by Ginsburg and James (1974)].

The densely sampled shelf area just west of Cape San Blas (Destin Dome area) contains a carbonate constituent distribution that reflects the complexity of the middle to outer shelf. In this area there is a low bathymetric ridge protruding across the shelf and separating two zones of fine sediment accumulation. A scan of the mapped attributes showed an abundance of mollusc, pelagic foraminifera, echinoid, ostracod, sponge spicules, and alcyonarian spicule grains in a broad shelf indentation in the vicinity of 29°45'N and 86°30'W. Just to the east was a narrow zone of abundant benthic foraminifera, coralline algae, bryozoan, blackened carbonate and unidentifiable carbonate (mostle coralline algae). The mapped distribution of each of these firm bottom constituents varied somewhat producing a somewhat broader composite zone than is apparent from examining individual maps. The coralline algae abundance on this promontory is the highest observed. Because constituent composition distribution cuts across bathymetric contours and does not correlate with previous sediment maps, no attempt has been made to correlate beyond sampling area.

Stations to the west of DeSoto Canyon occur along a rather narrow band from the shelf margin to near the Chand$\overset{e}{\text{i}}$leur Islands. Contouring of this complex area has considered Ludwick's facies and grain-size distribution bathymetric contours and MAFLA geophysical data. The reef and inner-reef facies of Ludwick contain no significant coralline algae but rather an abundance of bryozoan, benthic foraminifera, and unidentifiable grains. The complex alternations of bathymetry and substrate landward cause variations in constituent abundance. Benthic foraminifera, echinoid, blackened carbonate and unidentifiable carbonate increased markedly on the inner third of the shelf here. Echinoids in the inner shelf here were very delicate, porous spines, and were in marked contrast to most other areas.

One of the most significant aspects of the MAFLA sediment sheet is the quartz band that is shown as Zone VIII in Figure 80 and the transition between it and the carbonate sand sheet of the West Florida continental shelf. Since virtually no sand sized sediment has been brought into the system during the present high stand of sea level, and since it is bordered on the south and west by carbonate sands, the quartz sand belt provides a natural laboratory in which to test some of the current theories on shelf sediment transport. Since it is cut off from a quartz source, longshore current systems that affect it must balance out essentially to zero net transport or else the band should have disappeared or evinced dilution with carbonates.

Pilkey and others (1972) have suggested that the beaches of the southeastern Atlantic continental margin are fed by sediments from the adjacent continental shelf. If this is indeed the case, the ramifications for the onshore transport of oil related pollutants which may become incorporated in shelf sediments are ominous.

Sediment texture in any sand sheet is subject to considerable variation over short distances. A major factor in controlling textural variation is local bathymetry. Thus while the attributes of a sand sheet as a whole may be accurately described, specific grain size is difficult or impossible to predict at any projected station. Small scale variability is illustrated by Figure 81c which shows a series of stations taken at one mile intervals across the central portion of the West Florida carbonate sand sheet (see Figure 82 for station locations). Table 131 shows variation within the sand sheet on an even smaller scale, i.e. variation among the box cores at each station among the several sampling periods. Distances among the individual box cores are limited by the swing of the vessel and by accuracy and reproducibility of the navigation systems used. Average maximum variation within a station among the sampling periods is 7.9% in sand sized sediment. Maximum variation in percentage of sand at one station is about 28.6. These variations are significant and suggest that grain size analysis should be conducted on each box core sample in order to have complete confidence in biological and chemical data interpretations.

Analysis by settling tube should theoretically result in a hydraulic equivalent grain size since the particles are sized by the time it takes them to settle through a water column of known length. Sieve analysis is a direct measure of particle diameter. Comparison of settling tube and

Table 131. Seasonal deviations in sediment weight among box core stations.

Station	Greatest Deviation Among Box Cores Over Three Cruises Expressed as Weight Percent
2101	8.0
2102	9.9
2103	20.6
2104	14.8
2105	12.0
2106	16.3
2207	2.3
2208	9.7
2209	8.0
2210	9.0
2211	4.8
2212	6.2
2313	9.0
2314	4.0
2315	28.2
2316	7.7
2317	15.5
2318	2.6
2419	7.6
2420	3.1
2421	6.3
2422	7.9
2423	5.1
2424	8.0
2425	5.0
2426	2.7
2427	7.6
2528	8.7
2529	3.6
2530	8.4
2531	9.3
2532	8.1
2533	6.7
2534	9.2
2535	9.9
2636	7.0
2637	7.6
2638	1.0
2639	9.3
2640	1.8
2641	7.4
2642	0.8
2643	5.9
2644	4.6
2645	3.7

sieve analyses shows no interpretable pattern of variation. It is therefore recommended that settling tube analysis of grain size be discontinued. Since organisms respond to the physical size, morphology and composition, of the particles and not to the hydraulic character of grains, sieving should be the preferred method for MAFLA type studies.

Previous research provides a general framework of the carbonate sediment environments of the MAFLA shelf. Ludwick (1964) mapped general surface sediment facies between the Mississippi River Delta and Cape San Blas. This provides little information on carbonate sediment constituents, but recognizes a long carbonate-rich deep reef (sandy) and inter-reef (muds and sands) facies towards the shelf margin south of the Mississippi-Alabama zone. To the west of DeSoto Canyon, he terms the equivalent depth zone as western Florida lime mud facies, in which are dispersed pinnacle and other positive zones considered to be reefal. He concluded that the western Florida lime mud facies was of broader seaward extent than the Mississippi-Alabama reef; the inter-reef facies was of broader seaward extent than the Mississippi-Alabama reef and the inter-reef facies was also muddier, had smaller median grain size and contained significantly less terrigenous material.

Ludwick defines two sand facies on the northeastern shelf section. Mississippi-Alabama sand facies occurs in 12-80 m of water to the west of DeSoto Canyon, and the Cape San Blas sand facies occurs from nearshore to the 50-100 m contour.

The studies indicate slow deposition and (slow) erosion taking place uniformly across the eastern Continental Shelf of the Gulf of Mexico.

The high degree of bioturbation is attributed to infaunal organisms. The few variations in percentage of bioturbation may be due to: 1) Seasonal variations - for example the stations near the Suwannee and Choctawhatchee Rivers show faint primary physical structures, laminations and cross bedding, during the rainy season when there is a corresponding increase in sediment supply, and 100% bioturbation when there is no sediment input from river run-off during the dry months; 2) Differences in ~~in~~station sampling locations. Regardless of location on the shelf, shallow or deep, all stations have shown 100% bioturbation.

The distribution of kaolinite suggests that its abundance is primarily controlled by transportation from West Florida. Chlorite-vermiculite distribution probably reflects the reworking of older shelf deposits or the transformation from smectite transported by the rivers of West Florida (Huang, et al., 1975). The abundance of smectite would appear to be related to the offshore currents of the Gulf as described by Shepard (1973) along the margins of the slope. The distribution of smectite present in this study was consistent with those found by Milne and Earley (1958), Griffin (1962) and Huang, et al. (1975).

Major factors for the clay distribution patterns in the Mississippi-Alabama region relate primarily to the transportation of sediments from the Mississippi and Mobile Rivers.

The only samples indicating detectable amounts of barium were located adjacent to the eastern influence of the Mississippi River and approach values documented for similar clay rich sediments (Holmes, 1973). Additional evidence for this is indicated in the high iron, low carbonate and high percentage of fines at Master Stations 2637 and 2638.

Table 132 shows the inter-element relationships as expressed by the correlation coefficient. Strong relationships ($r > 0.8$) were present between chromium, copper, iron and vanadium; between chromium, copper and nickel and between chromium and vanadium. Moderate correlations ($r = 0.7$) existed between iron, lead and nickel; between copper and vanadium and between chromium and nickel. Only chromium and copper co-varied with the fine sediment fraction.

To examine the interrelationships between possible controlling factors and metal concentrations, Trefry, et al. (1976) and Trefry and Presley (1976) have normalized metal concentrations to iron. Sediment with metal concentrations which deviate from their expected ratio to iron have been cited as having an anthropogenic contribution. This is reasonable because metals, including iron, are well correlated with grain size, organic matter, $CaCO_3$, etc. but iron is unlikely to be added by man in amounts which would increase natural levels.

At the completion of the initial (1974) study of the MAFLA area, it was shown that metal concentrations correlated well with the fundamental sediment characteristics and that there was no indication of metal pollution (Presley, et al., 1975). This observation also holds for the 63 second-year samples. To examine all of the interrelationships between metal concentrations and their controlling factors would require an extensive analytical program and a rigorous statistical treatment of the data. It is more convenient to normalize observed metal concentrations to a single index which encompasses the more important concentration controlling factors. As mentioned, iron provides such an index and in an effort to

Table 132. Sediment inter-element relationships as expressed by the correlation coēfficient.

	Fe	Pb	Cu	Ni	Cr	Cd	V	CO_3	Fines
Fe	--	0.697	0.834	0.701	0.866	0.141	0.871	-0.015	0.600
Pb		--	0.557	0.729	0.640	0.209	0.188	0.262	0.400
Cu			--	0.809	0.895	0.056	0.772	-0.089	0.810
Ni				--	0.728	0.058	0.593	0.298	0.656
Cr					--	0.101	0.869	0.117	0.719
Cd						--	0.062	0.254	0.023
V							--	-0.094	0.564
CO_3								--	0.028
Fines									--

evaluate the distributions found in this study this approach was applied to the data.

Figures 129 through 131 give the metal to iron scatter plots for the 1975-1976 MAFLA sediment data. In each case, there is a significant linear correlation of the metals with iron. This occurs despite the three areas of provenance for MAFLA sediments. The plots provide a prediction interval for evaluating future sediment analyses and show no present-day evidence of pollution. Any input of trace metals from oil-related activities would result in data points which deviate from linearity in the positive y-direction on the scatter plots, assuming that anthropogenic iron input is not high enough to influence the normal sediment iron content and that trace metal concentrations could be more easily and noticeably increased. Such an approach may be subject to difficulty in some of the extremely low iron Florida shelf areas; however, any appreciable metal increase to these areas will be observable due to the very low natural levels.

To gain information relating to seasonal changes in the trace metal content of the surface sediments samples were collected at 18 of the stations previously occupied during the summer sampling. The results of this are shown in Table 133. As stated previously the precision of the analyses for the various metals was: Cd, 35%; Cr, 20%; Cu, 12%; Fe, 9%; Pb, 15%; Ni, 11% and V, 25%. Although evidence for differences between the samples was present in the chromium, lead and nickel data these changes should be considered as apparent for the moment. Further study is needed to determine the variability in the metal content of the surface sediments about a particular station before any conclusions can be drawn.

As indicated previously the metal content of the sponges was variable.

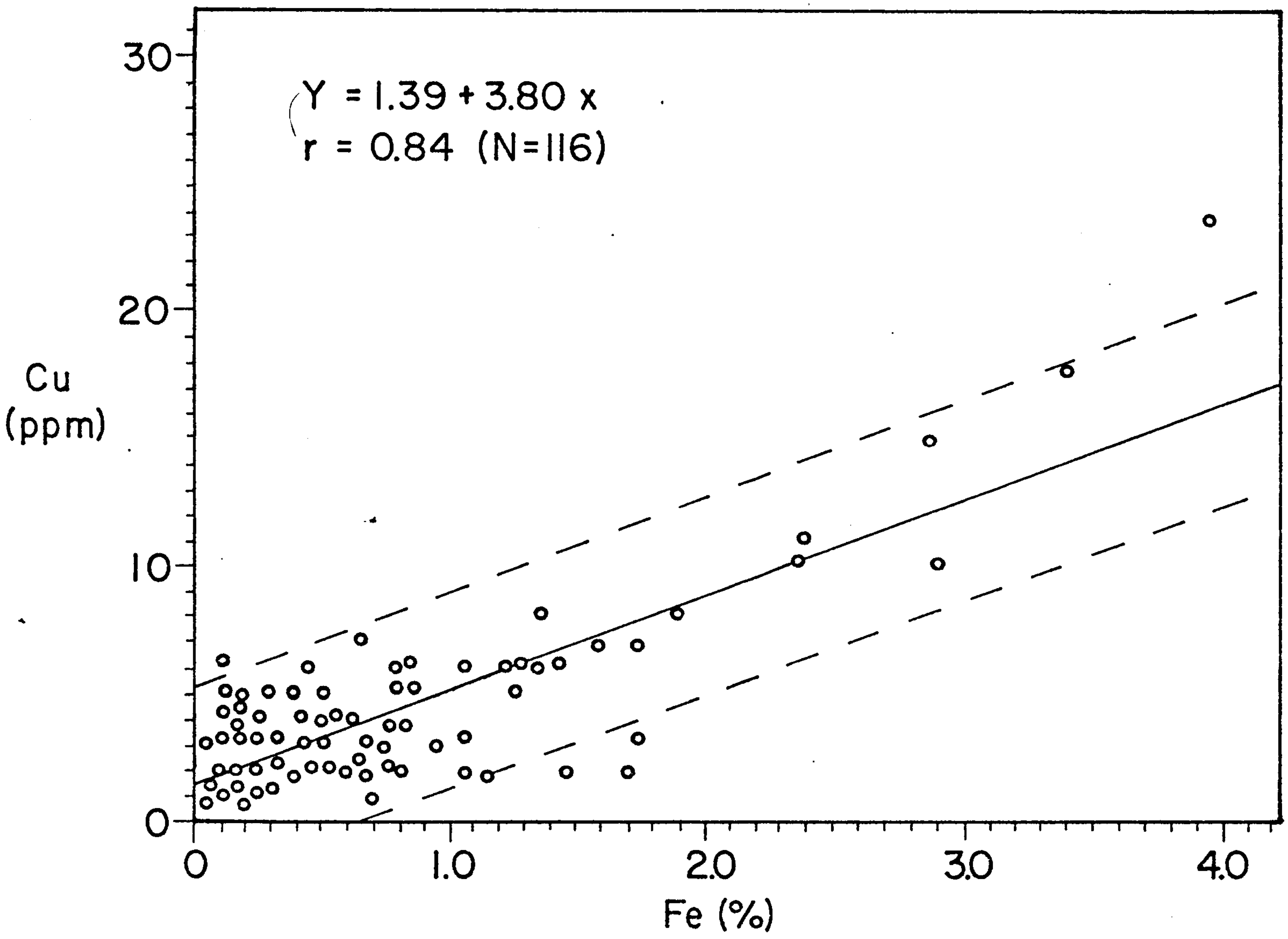


Figure 129. Copper versus iron scatter plot for the MAFLA shelf sediments with 95% prediction interval.

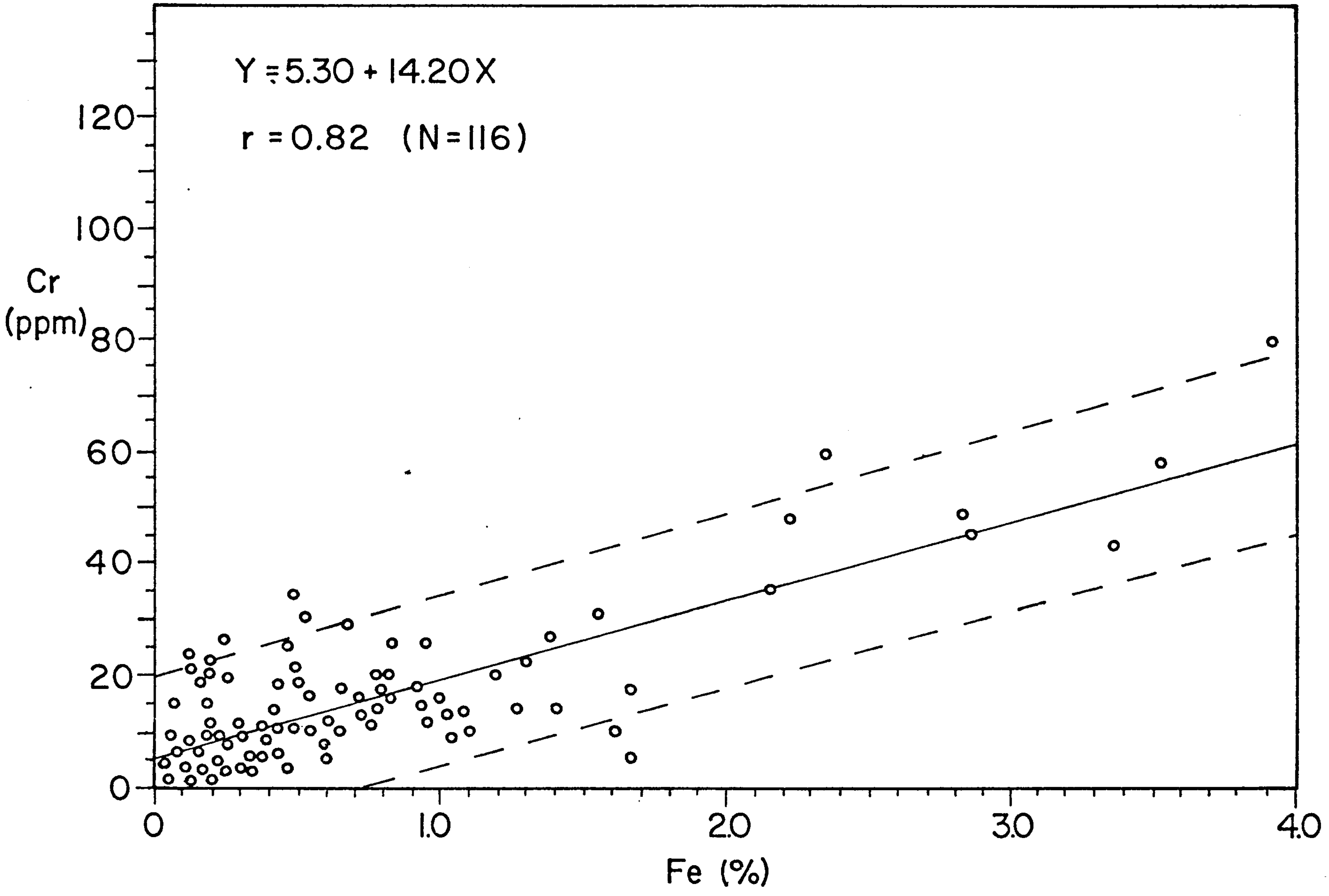


Figure 130. Cromium versus iron scatter plot for the MAFLA shelf sediments with 95% prediction interval

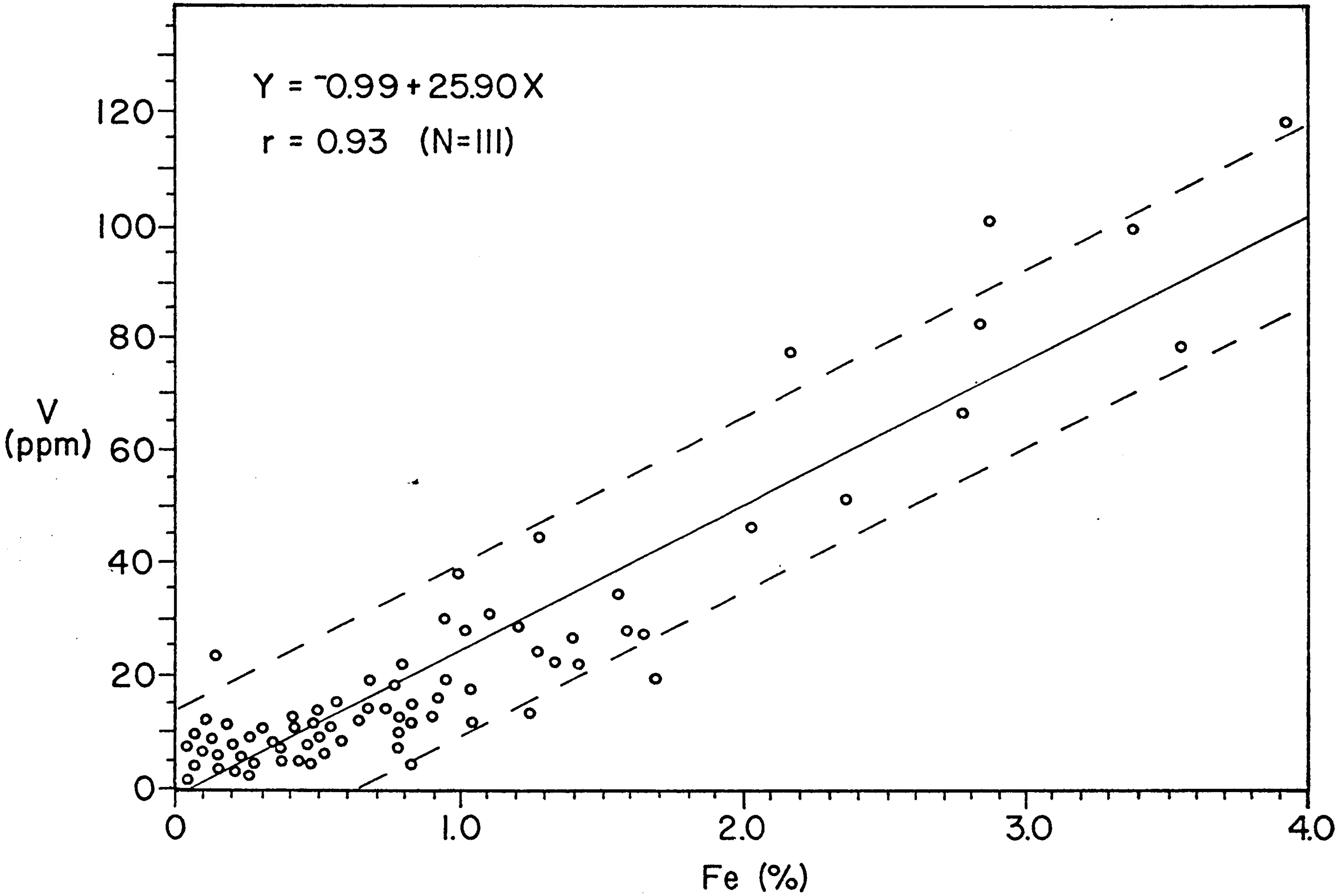


Figure 131. Vanadium versus iron scatter plot for the MAFLA shelf sediments with 95% prediction interval.

Table 133. The trace metal content of the surface sediments (ppm) at 18 stations in the summer and winter.

	Ba		Cd		Cr		Cu		Fe		Pb		Ni		V	
Station	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
2101	53	-	<.05	<.04	2	3.2	1	1.1	.13	.13	6	3.7	5	1.5	9	24
2104	<34	<86	.10	.13	4	5.1	2	1.7	.09	.10	9	5.0	8	1.5	4	3
2106	<44	<41	.10	.20	8	7.8	4	2.9	.39	.33	10	5.8	13	7.0	5	7
2207	<41	-	.10	.11	3	3.9	1	0.6	.08	.08	7	2.0	2	1.1	7	-
2212	<53	<97	.10	.13	14	13.3	5	4.8	.81	.78	11	5.3	14	7.9	13	11
2313	<58	<102	.10	< 04	16	3.8	5	3.6	1.05	.74	12	2.2	18	9.1	13	15
2318	<65	< 47	<.05	<.04	1	2.4	1	0.5	.02	.00	2	0.8	2	<.04	2	7
2424	<24	<59	<.05	<.04	5	4.6	1	0.7	.08	.10	2	2.0	2	1.4	3	7
2425	81±25	<49	<.05	.04	3	3.4	1	.04	.08	.05	3	2.2	3	1.2	-	-
2427	<67	<12.3	.07	.08	17	14.9	7	6.4	1.70	1.29	11	9.5	17	12.4	20	24
2531	<39	<80	.15	.10	13	10.8	2	1.8	.60	.52	9	6.1	11	9.2	8	8
2536	<76	<138	.10	.02	23	13.4	8	5.9	1.34	1.05	15	10.1	20	14.2	45	39
2637	321	-	.08	.07	35	36.7	8	8.3	2.17	1.87	15	16.1	14	15.0	78	-
2638	288	288	.10	.05	45	48.3	10	10.1	2.87	2.34	15	18.0	22	16.7	101	-
2639	<59	<89	<.05	<.04	12	14.1	3	2.3	.94	.78	12	8.2	8	<.04	23	19
2643	<72	<86	.10	.04	10	14.6	2	2.1	1.63	1.43	18	11.0	12	7.5	28	23
2644	<75	<76	.10	.70	10	10.1	2	1.7	1.12	1.05	20	5.4	9	5.1	31	29
2645	<59	<107	.10	.07	13	11.3	3	2.4	1.04	.80	20	9.0	9	4.0	18	21

I Summer concentration
II Winter concentration

Iron concentrations ranged over two orders of magnitude when the sponges are treated as a group and these organisms exhibit greater variation in metal content than most other groups. They were surpassed only by the cadmium and copper variations present in the molluscs and crustaceans. The precise reasons for these variations are not clear although they are undoubtedly related to species variations, geography and composition of the suspended matter.

In general, the sponges contained elevated concentrations of chromium, iron and nickel (although considerable "scatter" was present in the data). A majority of the sponges had nickel concentrations in excess of ten parts per million and although this may, in part, be a result of sediment contamination in some of the sponges it is felt that it is not true for such other sponges as <u>Cinachyra</u> sp. and <u>Pseudoceratina</u> <u>crassa</u>. Bowen and Sutton (1951) attributed the high nickel values found in many sponges to the associated microflora.

The average trace metal concentration (ppm) among the various phyla are listed in Table 134. Within the sponges only two species display any dominance (<u>Cinachyra</u> sp. and <u>Pseudoceratina</u> <u>crassa</u>) (Table 135). The only consistency in metal concentration within each of these species was found in the copper and nickel concentration. This trend was present in each season.

Geological trends in trace metal concentrations were not readily apparent among the sponges. This is probably due to the lack of sufficient numbers of samples, of the same species, at all stations. Therefore, only those stations where samples were collected during at least two of the

Table 134. Comparison of the Average Trace Metal Concentrations among the Various Phyla of Benthic Macrofauna from the MAFLA Lease Areas (concentrations in ppm dry weight).

Group Name	No. of samples* analyzed		Cd	Cr	Cu	Fe	Pb	Ni	V
Sponges	68	Range	0.058-9.670	0.06-29.80	3.0-20.5	30.0-4500	<0.01-8.82	0.4-372	<0.4-8.8
		Mean	2.367	3.11	7.7	516	<1.17	22.7	<1.6
		Std. Dev.	2.540	5.75	3.9	835	1.50	52.0	1.7
Corals	55	Range	0.020-1.610	<0.01-0.59	3.7-10.1	17.0-123	0.07-2.72	<0.2-9.6	<0.4-6.0
		Mean	0.214	<0.23	7.1	39.3	0.29	<1.0	<1.9
		Std. Dev.	0.317	0.43	1.2	19.0	0.41	2.2	1.4
Molluscs	14	Range	0.660-35.0	0.32-9.52	1.5-44.2	19.3-308	0.15-1.66	1.3-70.3	<0.4-6.0
		Mean	13.65	4.38	7.9	89.4	0.94	22.1	<3.1
		Std. Dev.	11.33	3.14	10.8	67.8	0.43	17.6	2.0
Crustaceans	59	Range	0.050-12.120	<0.01-1.46	12.7-110	11.0-773	<0.01-6.94	<0.2-1.9	<0.4-3.9
		Mean	1.807	<0.38	50.7	125	<0.82	<0.7	<1.5
		Std. Dev.	2.141	0.28	24.1	144	1.46	0.4	0.9
Echinoderms	30	Range	0.056-1.190	<0.01-1.53	5.1-21.3	19.3-1832	0.27-7.96	<0.2-6.2	0.4-8.3
		Mean	0.320	<0.73	7.8	267	1.26	<0.9	<1.9
		Std. Dev.	0.274	0.52	3.2	355	1.75	1.2	1.9

* For some metals, the number of samples analyzed is one less than that given.

Table 135. Intraspecies variability of trace metals among the dominant macrofauna (concentrations in ppm dry weight).

Species Name	No. of samples* analyzed		SPONGES						
			Cd	Cr	Cu	Fe	Pb	Ni	V
Cinachyra sp.	8	Range	1.900-5.850	0.43-5.39	4.5-6.9	65.8-935	0.10-1.96	1.1-26.9	0.8-3.8
Summer		Mean	3.080	2.05	6.0	339	0.77	14.7	1.6
		Std. Dev.	1.450	2.00	0.9	370	0.76	9.6	1.0
Cinachyra sp.	2	Range	1.500-5.100	0.58-1.39	3.9-4.7	130-200	0.16-0.45	0.8-16.8	<0.4-1.2
Fall		Mean	3.310	0.98	4.3	165	0.30	8.8	<0.8
		Std. Dev.	2.600	0.57	0.6	49	0.20	11.3	0.6
Cinachyra sp.	9	Range	0.239-1.877	0.32-1.05	5.0-7.1	86.9-863	0.30-0.95	0.8-20.9	<0.4 3.9
Winter		Mean	0.785	0.96	5.9	231	0.58	9.0	<0.8
		Std. Dev.	0.570	1.02	0.7	230	0.20	7.3	1.4
Pseudoceratina crassa	6	Range	1.220-5.800	0.36-3.15	6.4-20.5	79.6-312	0.72 5.39	5.3-23.6	1.0-5.8
Summer		Mean	2.967	1.75	9.4	172	2.27	15.6	2.1
		Std. Dev.	2.357	1.07	5.5	87.0	1.98	6.2	1.8
Pseudoceratina crassa	2	Range	1.000-1.550	0.89-1.66	8.1-19.2	67.0-268	0.07-0.23	31.8-33.1	<0.4-1.7
Fall		Mean	1.275	1.27	13.6	137	0.15	32.4	<1.0
		Std. Dev.	0.389	0.54	7.8	185	0.11	0.9	<0.9
Pseudoceratina crassa	6	Range	0.216-0.790	0.18-1.25	8.3-11.4	79.3-126	0.33-1.20	20.0 39.6	---- ----
Winter		Mean	0.377	0.51	9.6	101	0.64	25.1	<0.4
		Std. Dev.	0.200	0.32	1.2	18.1	0.35	7.5	----

Table 135. Continued.

			ECHINODERMS						
Species Name	No. of samples* analyzed		Cd	Cr	Cu	Fe	Pb	Ni	V
Stylocidaris affinis	2	Range	0.842-0.924	0.28-0.64	5.1-6.7	19.3-196	0.27-0.82	0.8-0.8	1.9-2.2
<u>Summer</u>		Mean	0.883	0.46	5.9	107	0.54	0.8	2.0
		Std. Dev.	0.058	0.25	1.1	125	0.39	0.0	0.2
Stylocidaris affinis	2	Range	0.100-0.239	0.36-0.80	6.8-7.6	369-580	0.55-1.51	0.4-0.6	0.8-2.1
<u>Winter</u>		Mean	0.167	0.58	7.2	474	1.03	0.5	1.5
		Std. Dev.	0.070	0.22	0.4	106	0.48	0.1	0.6
Clypeaster sp.	2	Range	0.162-0.210	0.78-0.79	7.2-7.6	81.4-229	0.35-0.54	0.6-0.8	1.8-1.9
<u>Summer</u>		Mean	0.186	0.78	7.4	155	0.44	0.7	1.8
		Std. Dev.	0.040	0.01	0.3	105	0.13	0.1	0.0
Clypeaster sp.	4	Range	0.107-0.326	0.28-1.53	7.2-10.0	140-704	0.43-1.58	0.3-3.2	<0.4-2.4
<u>Fall</u>		Mean	0.222	0.79	7.8	337	0.80	1.1	<1.3
		Std. Dev.	0.079	0.51	1.2	216	0.46	1.2	0.8
Clypeaster sp.	4	Range	0.056-0.278	0.36-0.91	5.9-7.0	94.2-278	0.39-0.67	<0.2-0.6	1.0-4.6
<u>Winter</u>		Mean	0.191	0.73	6.6	165	0.52	<0.3	2.2
		Std. Dev.	0.090	0.22	0.4	68	0.10	0.2	1.5

Table 135. Continued.

Species Name	No. of samples* analyzed		CORALS Cd	Cr	Cu	Fe	Pb	Ni	V
Madracis decactis	6	Range	0.061-1.330	0.17-0.40	3.7-7.0	17.3-24.8	0.11-0.31	0.3-1.5	1.0-2.8
Summer		Mean	0.479	0.32	5.3	20.0	0.19	0.6	1.5
		Std. Dev.	0.500	0.12	1.1	3.0	0.08	0.5	0.7
Madracis decactis	7	Range	0.041-0.081	---- ----	6.5-7.6	27.0-41.8	0.13-0.35	---- ----	1.9-6.0
Fall		Mean	0.055	<0.01	7.0	35.0	0.21	<0.2	3.4
		Std. Dev.	0.016	----	0.3	5.0	0.09	----	1.5
Madracis decactis	7	Range	0.020-0.072	0.01-0.11	7.6-8.5	36.3-44.9	0.11-0.17	---- ----	<0.4-1.9
Winter		Mean	0.040	0.07	7.8	39.5	0.14	<0.2	<0.7
		Std. Dev.	0.010	0.03	0.3	2.8	0.04	----	0.8
Porites divaricata	5	Range	0.129-1.110	0.26-0.59	5.1-6.9	18.3-21.7	0.13-0.28	<0.2-1.0	0.4-4.9
Summer		Mean	0.478	0.37	6.3	20.0	0.18	<0.4	2.0
		Std. Dev.	0.379	0.14	0.7	2.0	0.07	0.3	1.7
Porites divaricata	6	Range	0.108-0.325	---- ----	6.3-7.0	31.6-36.2	0.07-0.27	---- ----	1.7-3.8
Fall		Mean	0.233	<0.01	6.7	35.0	0.16	<0.2	2.7
		Std. Dev.	0.084	----	0.2	2.0	0.08	----	0.8
Porites divaricata	6	Range	0.068-0.280	<0.01-0.20	6.8-8.5	32.2-42.3	0.11-0.31	---- ----	<0.4-1.7
Winter		Mean	0.154	<0.10	7.6	40.0	0.17	<0.2	<1.2
		Std. Dev.	0.090	0.09	0.5	4.6	0.07	----	0.9

Table 135. Continued.

Species Name	No. of samples* analyzed		Cd	Cr	Cu	Fe	Pb	Ni	V
			MOLLUSCS						
Spondylus americanus	2	Range	20.4-20.8	1.89-2.59	6.9-9.2	71.9-80.8	1.04-1.42	5.4-20.5	5.6-6.0
Summer		Mean	20.6	2.25	8.0	76.0	1.23	13.0	5.8
		Std. Dev.	0.3	0.49	1.6	6.4	0.27	10.6	0.3
Spondylus americanus	6	Range	19.4-35.0	3.31-9.56	2.3-6.1	63.2-79.5	0.51-1.66	25.8-33.7	3.0-5.1
Fall		Mean	22.7	6.92	4.2	72.0	1.03	29.9	4.1
		Std. Dev.	7.8	2.58	1.4	6.0	0.46	3.1	1.0
Spondylus americanus	3	Range	1.525-3.875	1.76-6.31	1.5-3.3	19.3-66.1	0.15-0.71	5.9-17.1	<0.4 3.9
Winter		Mean	2.479	4.14	2.2	39.5	0.51	10.7	<1.8
		Std. Dev.	1.010	1.86	0.8	19.6	0.25	4.5	1.6
			CRUSTACEANS						
Sicyiona brevirostris	2	Range	0.149-0.571	0.44-0.44	12.7-31.0	11.2-106	0.73-0.80	<0.2-1.2	<0.4-1.7
Summer		Mean	0.360	0.44	21.8	58.6	0.76	<0.8	<1.1
		Std. Dev.	0.298	0.00	12.9	67.0	0.05	0.5	0.9
Sicyiona brevirostris	4	Range	0.228-0.474	<0.01-1.07	29.9-92.0	49.9-104	0.15-0.67	0.5-0.8	0.6-2.1
Fall		Mean	0.361	0.29	73.0	79.0	0.41	0.6	1.4
		Std. Dev.	0.110	0.52	29.7	24.0	0.26	0.1	0.6

Table 135. Continued.

Species Name	No. of samples* analyzed		Cd	Cr	Cu	Fe	Pb	Ni	V
			CRUSTACEANS						
Sicyiona brevirostris	4	Range	0.050-0.827	0.20-0.51	37.5-110	51.4-84.2	0.26-0.39	0.4-0.8	---- ----
Winter		Mean	0.282	0.32	69.6	72.3	0.32	0.6	<0.4
		Std. Dev.	0.320	0.12	29.5	13.1	0.05	0.1	----
Acanthocarpus alexandri	3	Range	0.500-1.250	0.65-1.46	38.7-53.7	245-773	0.24-5.88	0.8-1.9	1.2-2.4
Summer		Mean	0.950	0.94	45.8	431	2.20	0.9	1.6
		Std. Dev.	0.397	0.45	7.5	296	3.19	0.8	0.7
Acanthocarpus alexandri	2	Range	0.518-2.68	<0.01-0.49	71.8-80.0	124-245	0.28-0.66	<0.2-0.6	2.3 3.0
Fall		Mean	1.600	<0.19	75.9	184	0.47	<0.4	2.6
		Std. Dev.	1.529	0.26	5.8	85	0.26	0.3	0.5
Acanthocarpus alexandri	1	Range	---- ----	---- ----	---- ----	---- ----	---- ----	---- ----	---- ----
Winter	Mean	Mean	0.445	0.42	39.1	383	0.33	0.7	0.9
		Std. Dev.	----	----	----	----	----	----	----
Portunus spinicarpus	6	Range	0.815-7.120	0.33-1.05	19.1-61.4	26.5 669	0.29-6.94	0.3-1.4	<0.4-1.4
Summer		Mean	3.143	0.54	45.7	190	3.42	0.9	<0.9
		Std. Dev.	2.400	0.27	18.5	245	3.03	0.5	0.5

Table 135. Continued.

Species Name	No. of samples* analyzed		Cd	Cr	Cu	Fe	Pb	Ni	V
Portunus spinicarpus	6	Range	0.358-5.870	<0.01-0.75	36.0-79.8	35.9-326	0.15-0.67	<0.2-0.9	1.1-3.1
Fall		Mean	2.636	0.21	55.9	129	0.30	<0.6	2.1
		Std. Dev.	1.986	0.30	15.7	104	0.14	0.2	0.6
Portunus spinicarpus	3	Range	3.201-5.466	0.19-0.35	39.4-67.8	51.5-172	0.25-0.45	0.3-0.9	<0.4-1.4
Winter		Mean	4.007	0.25	55.9	93.6	0.35	0.6	<0.7
		Std. Dev.	1.030	0.07	12.0	55.4	0.08	0.2	0.6
Stenorhynchus seticornis	6	Range	1.070-1.890	0.25-0.46	19.3-34.3	32.1-61.9	0.17-0.83	0.9-1.7	1.4-2.5
Summer		Mean	1.547	0.36	25.4	41.0	0.48	1.0	2.0
		Std. Dev.	0.349	0.07	5.5	7.0	0.28	0.3	0.4
Stenorhynchus seticornis	6	Range	0.635-1.250	0.28-0.89	28.5-57.8	39.4-71.4	0.34-0.56	<0.2-1.6	1.4-2.5
Fall		Mean	0.959	0.53	39.9	56.9	0.44	<0.9	1.8
		Std. Dev.	0.254	0.22	9.7	14.9	0.08	0.6	0.4
Stenorhynchus seticornis	6	Range	0.397-0.661	0.09-0.28	25.6-39.1	52.4-86.3	0.22-0.73	<0.2-0.7	<0.4-3.0
Winter		Mean	0.466	0.17	31.7	69.5	0.45	<0.2	<0.5
		Std. Dev.	0.090	0.09	4.7	12.0	0.16	0.3	1.1

* For some elements, the number of samples analyzed is one less than that given.

three sampling periods were considered in establishing geographical trends. Also, because of the lack of sufficient data, geographical trends should be viewed only as possible indicators.

Sponges collected at Master Stations I-B, II-A, 062, and 064 were consistently lower in their nickel concentrations than those from other stations (Table 74) while the sponges from Master Stations VI-V and V-A were consistently higher in chromium and iron. They also contained slightly elevated concentrations of vanadium and nickel, respectively. These values may be biased somewhat in the case of Master Station VI-A, since Guitarra sp. was dominant and high chromium and iron values may be characteristic of this sponge. This situation does not exist at Master Station V-A. Due to the location of this station which is proximal to areas where the suspended loads are at times greater than in the areas further to the south, the elevated chromium, iron and nickel values may be due to sediment contamination. Brooks and Rumsby (1965) have demonstrated similar correlations between these elemental concentrations and sediment content of organisms. Within a sampling period, Cinachyra sp. was noticeably higher in cadmium, iron, lead and vanadium at Master Stations II-A, 062, and 064 than at the other stations. The precise reasons for this were not clear, although these stations were located close to the Tampa-St. Petersburg region.

Seasonal trends in metal content were not readily apparent among the sponges. Since Cinachyra sp. and P. crassa were the only sponges collected in sufficient quantities at the same station locations during all three sampling periods, they were the only sponges used for seasonal trends.

Both sponges show a steady decrease in every metal, excluding copper and nickel, from summer to winter.

Although the range of values for metals in sponges appeared quite large, other studies indicate that these values are within the ranges of those found by other investigators (Bowen, 1966; I.D.O.E., 1972; Vinogradov, 1953).

Corals exhibit the greatest consistency in their concentrations of trace metals (Table 135). Although the ranges in the nickel and vanadium data appear to contradict this statement, only seven out of 55 samples showed values greater than the mean for vanadium. What was even more significant was that most of the nickel and vanadium values are below the detection limit. This lack of "scatter" in values may be due to 1) the similar metabolism and feeding habits of the group as a whole, 2) only seven species were collected and 3) restricted distribution (Florida Middle Ground and off Clearwater, Florida). Other authors have noted this same uniformity in trace element concentrations (Livingston and Thompson, 1971). In addition to the consistency in their trace metal concentrations, corals also have the lowest values for the metals when compared to other phyla. They average from five to ten times lower in their values than most of the other groups.

The lack of variation in trace element concentrations within species of corals is more remarkable than the lack of variation between the groups. Since all coral samples were collected in a localized area, it was not possible to discern geographical trends in the metal data although one seasonal trend was observed. Both dominant corals, _Madracis decactis_ and

Porites divaricata, show decreasing values in their cadmium, chromium, and nickel content from summer to winter. It is possible that this trend may not be completely due to environmental conditions since the analytical group was working at or near the detection limit for the above-mentioned metals during the three sampling periods. The analytical techniques were improved with time and thus, the ability to distinguish between slight variations in instrumental results was refined and the detection ability improved. Since the analytical ability was improved slightly during the course of the year, the slight differences in the metal concentrations in corals may not be significant.

Data concerning trace metal concentrations in corals is scarce. The few studies that have been done used neutron activation analysis (Livingston and Thompson, 1971; Forster, et al., 1972). The detection limits for many of the metals by this method is not good and thus these data are significantly lower for many of the metals in corals than those reported in the literature.

The results on the data obtained on molluscs is scarce (only 14 samples were collected and analyzed) and data interpretation is difficult. Essentially only one species was collected, Spondylus americanus.

The metal content of the molluscs showed considerable variation in their concentrations of cadmium, chromium and copper. This is surprising, when one considers that one species, S. americanus, comprised 11 of the 14 samples and that most samples were collected from the Florida Middle Ground. Cadmium, chromium, and nickel values were greater than those of most of the other groups.

S. americanus, with one exception, exhibits no trends in its trace metal concentrations. The exception was cadmium, and the concentration of this metal decreased from summer to winter. Comparative values of the molluscs analyzed in this study are almost non-existent in the literature, except for a few values (I.D.O.E., 1972).

As a whole, crustaceans vary to a lesser degree in their heavy metal concentrations than most other groups. This is somewhat surprising since crustaceans are the most diverse and mobile group of organisms sampled and exhibit many types of feeding habits (filter feeders, detrital feeders, and carnivores). Also, crustaceans were collected from stations covering the entire MAFLA area. Thus, if there were any differences in trace metal concentrations due to geography, the ranges in trace metal concentrations would be influenced accordingly. Other than cadmium and copper the trace metal values were not significantly higher in crustaceans and nickel and vanadium values were near the detection limit in most organisms.

Variations in trace element concentrations among the dominant species are shown in Table 135. In all three sampling periods, Stenorhynchus seticornis shows the least variation for all elements. Since all S. seticornis samples were collected from the Florida Middle Ground this may explain the uniformity of the trace element concentrations.

No geographical trends were encountered and at best, seasonal trends were limited. S. seticornis was the only crustacean collected in sufficient quantities at the same location during the three sampling periods that could be used to show any seasonal trends. Cadmium, nickel, and vanadium decreased slightly in concentration from summer to winter and iron values showed a slight increase.

A number of the crustacean species analyzed in this study are not cited elsewhere in the literature. In order to make any comparisons to the trace element concentrations of other studies, it was necessary to integrate the various crustacean species together and in general, the trace metal values in crustaceans from this study compare favorably with those of other investigators (Bryan, 1968; I.D.O.E., 1972; Martin, 1974; Sims and Presley, 1976).

Except for iron and lead, the echinoderms were second only to corals in their degree of consistency in trace element composition. This also, was surprising, since out of the 29 samples analyzed there were 11 species (Brissopsis elongata, from the winter were not included in this group because the values were so much greater for chromium and iron). Furthermore, the samples were collected from stations encompassing most of the MAFLA lease area. As is the case with most other groups, nickel and vanadium values were low.

Due to the lack of sufficient data, any trends in this phylum were limited. Samples from Transect VI (especially Master Station VI-C) contained higher iron values than the rest of the samples. A possible explanation for this may be the input of terrigenous material in this area. No seasonal trends were observed.

When comparing trace metal values in echinoderms from this study to others, the same problem was encountered as that with the crustaceans: the same species have not been analyzed by others and it was again necessary to group all echinoderms together. These data were similar to those of Riley and Segar (1970) and I.D.O.E. (1972). Vinogradov's (1953) values were similar except that his copper values were greater (>100 ppm).

Some sediment hydrocarbon differences that were not evident in comparing the summer and fall period chromatograms can be seen by observing the data calculated in Table 136. Though there is considerable difference in aliphatic weights at Master Stations 2101, 2312, 2427 and 2637 for the two collections, the n-alkanes/aliphatic ratio remains virtually constant indicating that the difference was more likely due to sampling variability than contamination. This ratio was remarkably similar in all cases regardless of the absolute value of either component. Therefore, this parameter is probably a safer one to use in assessing pollution since it is less subject to natural variability. In general, the ratios show less variability than gravimetric concentrations.

Master Station 2104 was notable in that low molecular weight n-alkanes are ca 75% higher compared to high molecular weight material in the winter period. At Master Station 2638 however, the ratio of low molecular weight (LMW)/high molecular weight (HMW) was four times higher in the winter. This probably resulted from laboratory losses at the low end since neighboring stations in both cases agree more favorably with the winter samples.

The odd/even ratios were fairly constant when comparing results of the summer and fall. The major exceptions occurred at Master Stations 2104 and 2639 where the ratio among HMW n-alkanes was higher in the summer. This being a terrestrial component probably reflects the natural variability in sampling.

Surprisingly the n-alkane/C_{16} ratio did not vary significantly considering the high risk of loss of C_{16} by evaporation. Only at Master

Table 136. Comparison of summer with winter - Chromatographic Parameters 1975-1976.

		ppb dry wt. sed*			%Σn-alk	ΣC<20	Odd/Even			Σn-alk	15+17	Pris/	Pris+Phy
tation	Season	Aliph	n-alk	Arom	Σaliph	ΣC>21	C<20	C>21	All	n-C16	2x16	17	Σn-alk
2101	Summer	736.	64.	119.	8.7	1.43	4.9	3.2	3.6	40.2	6.7	0.10	0.037
	Winter	1021.	87.	110.	8.5	1.64	4.6	2.4	3.4	63.6	13.4	0.05	0.022
2104	Summer	129.	15.	372.	11.4	1.17	1.7	3.1	2.3	22.	2.0	-	0.03
	Winter	111.	12.2	108.	11.0	1.88	1.4	1.9	1.5	30.4	3.8	0.22	0.09
2106	Summer	150.	30.	68.	19.1	0.17	1.5	3.9	3.8	133.	-	0.70	0.027
	Winter	174.	39.1	61.	22.5	0.16	1.2	2.8	2.7	109.	1.5	0.57	0.024
2207	Summer	561.	68.	30.	7.0	0.46	2.5	2.1	2.2	36.7	2.6	0.62	0.168
	Winter	417.	30.7	151.	7.4	0.35	2.5	2.1	2.4	52.3	3.9	0.92	0.169
2210	Winter	297.	24.	73.	8.1	0.28	2.4	1.9	2.2	91.7	6.7	0.24	0.052
2212	Summer	242.	55.	50.	26.	0.19	1.0	4.0	2.5	15.4	0.87	0.75	0.02
	Winter	217.	58.	104.	27.0	0.09	1.4	2.9	3.1	166.	1.1	0.58	0.016
2313	Summer	397.	116.	88.	29.	0.2	0.8	2.3	1.9	42.6	1.1	0.45	0.028
	Winter	197.	54.8	78	27.8	0.17	1.0	3.1	2.6	50.	1.1	0.63	0.032
2314	Winter	518.	36.	171.	6.9	0.21	1.3	2.3	2.5	93.3	2.45	0.50	0.054
2315	Winter	234.	27.7	137.	11.8	0.64	2.1	3.1	2.4	25.	2.2	0.21	0.06
2318	Summer	136.	6.	6.	4.	-	-	-	-	-	-	0.82	-
	Winter	130.	9.	40.	6.8	1.5	3.9	1.7	2.6	40.	8.6	0.55	0.21
2424	Summer	120.	14.	37.	11.2	1.1	1.3	3.0	2.8	15.	1.9	0.29	0.20
	Winter	165.	20.	35.	12.3	0.85	1.5	2.3	2.2	40.	4.0	0.16	0.11

* Measured gas chromatographically

Table 136. Comparison of summer with winter - Chromatographic Parameters 1975-1976 - continued.

Station	Season	ppb dry wt. sed*			%Σn-alk	ΣC<20	Odd/Even			Σn-alk	15+17	Pris/	Pris+Phy
		Aliph	n-alk	Arom	Σaliph	ΣC>21	C<20	C>21	All	n-C16	2x16	17	Σn-alk
2425	Summer	142.	31.	15.	21.6	1.9	1.3	1.9	1.5	11.2	4.1	0.32	0.20
	Winter	73.	11.	27.	15.5	2.2	1.6	1.3	1.4	29.6	4.8	0.13	0.17
2427	Summer	295.	105.	68.	35.6	0.08	1.1	4.8	3.9	46.	0.9	0.59	0.04
	Winter	141.	40.	55.	27.9	0.13	1.4	3.3	3.1	53.	1.1	0.62	0.02
2531	Summer	122.	26.	44.	21.	0.40	1.1	4.1	2.8	55.	3.2	0.21	0.04
	Winter	82.	11.2	36.	14.	0.31	0.9	3.6	2.2	44.8	1.7	0.41	0.06
2536	Summer	663.	199.	144.	30.1	0.07	1.0	3.7	3.3	123.	1.3	0.43	0.01
	Winter	446.	112.	293.	25.0	0.09	1.0	3.0	2.7	108.	1.3	0.58	0.02
2637	Summer	1700.	1160.	1280.	67.	0.02	1.5	4.1	3.3	>100	1.9	0.77	0.01
	Winter	705.	320.	115.	45.	0.19	1.2	3.7	2.9	32.	1.1	0.57	0.04
2638	Summer	700.	481.	313.	68.5	0.06	1.1	3.0	2.8	113.	1.3	0.88	0.02
	Winter	875.	442.	280.	51.0	0.29	1.1	2.9	2.5	27.	1.0	0.76	0.05
2639	Summer	171.	62.	77.	37.	0.16	1.1	5.1	3.9	37.	1.1	0.79	0.05
	Winter	260.	65	145.	25.	0.13	1.4	3.4	2.8	61.	1.3	0.93	0.03
2643	Summer	128.	49.	50.	38.	0.10	1.0	2.9	2.7	~100.	1.5	0.51	0.03
	Winter	197.	40.	40.	20.	0.17	1.2	3.0	2.7	49.	1.2	0.71	0.03
2644	Summer	124.	35.	42.	29.	0.18	1.0	4.0	3.1	53.	1.4	0.62	0.08
	Winter	83.	27.	33.	33.	0.14	1.3	3.3	3.2	95.	1.5	0.74	0.02
2645	Summer	232.	100.	94.	43.	0.09	1.3	2.7	2.5	87.	1.4	0.44	0.03
	Winter	216.	76.	51.	35.	0.16	1.4	2.7	2.7	55.	1.1	0.63	0.02

* Measured gas chromatographically

Station 2212 where the value increased by ten-fold in the winter was evaporation a serious problem.

The ratio of pristane/C_{17} varied more than most parameters. However, strong evidence that pristane does not even occur in most of the samples has become available and very little should be made of these deviations until the compound labelled as pristane has been positively identified.

Most of the 183 epifaunal organisms analyzed in this study gave Carbon Preference Indices (CPI) values between one and three for their n-alkanes hydrocarbons. Although this is generally considered to be low for biological samples, similar low values have been reported for marine samples. Doons, et al. (1965) found numbers ranging from 1.0 to 1.4 for 11 samples of invertebrates, and Clark and Blumer (1967) determined values from 0.4 to 1.5 for algae and total plankton samples. The CPI values of 24 macroepifauna from the MAFLA area, analyzed earlier, ranged from 0.20 to 5.26 and averaged 1.58±1.30 ($\overline{X}$±1 S.D.) (Meyers, 1976).

Plant waxes have been reported to have CPI values greater than ten (Eglinton and Hamilton, 1963). The CPI values of the algae samples analyzed in this study ranged from three to 245 with the majority ranging from ten to 39.

These data suggest that Carbon Preference Indices of marine epifaunal samples may normally be lower than those derived from land organisms or marine algae. Alternatively, these data may indicate a weakness of the CPI concept when applied to biological samples. As pointed out by Scalan and Smith (1970), CPI values of geological samples can become misleading when they are calculated over different ranges of n-alkanes. In the 183 samples of epifaunal organisms in this study, an homologous series of n-alkanes was not commonly encountered. Therefore, the CPI values calculated for these samples were not necessarily based upon the same n-alkanes for all samples, and it is likely these values have less meaning than when this ratio is applied to geological samples.

Almost none of the chromatograms of either the saturated or unsaturated hydrocarbon fractions of the epifaunal organisms analyzed in this study contained a complex, unresolved mixture of hydrocarbons. However, 25% of the algal chromatograms definitely contained this unresolved mixture and an additional 25% may have contained the mixture. The presence of such a mixture is indicative of petroleum contamination (Blumer, et al., 1970; Burns and Teal, 1973). Therefore, few of the epifaunal organisms give evidence of containing petroleum hydrocarbons, and their hydrocarbons' composition were judged to be representative of natural, biological hydrocarbons in these populations.

The algae samples, on the other hand, may be contaminated with petroleum or petroleum residues. There was no correlation of this contamination with the presence of petroleum residues in nearby sediments or the specie of algae. However, the frequency with which the contamination appeared definitely decreases from summer to fall to winter. It is possible that seasonal variation of tar ball occurrence, for example, may have contaminated the algae samples but not the epifaunal samples collected at the same time because of the larger algae surface area (it is also possible that the decreasing frequency of contamination occurrence is due to increased expertise in sampling and analysis).

Inspection of the tabulated ratios in Tables 136 and 137 reveals no discernible changes in either amounts or compositions of hydrocarbons in

Table 137. Summary Tabulation of Hydrocarbon Analyses Benthic Algae.

Sample Number	Organism	A	B	C	D	E	F	G	H
First Sampling Period									
IA A+B - 6	*Halimeda* sp.	11.3	.008	64.3	-	0.11	3.8	1.0	2.5
- 7	*Rhodymenia* sp.	12.0	.002	85.3	-	0.0	34.6	11.3	29.5
- 8	*Cystodictyon pavonium*	-	0.0	52.0	-	0.0	68	8.7	35
IIA A+B - 1	*Laurencia corallopsis*, *Gracilaria cylindrica* - *blodgettii*	10.0	.017	66.0	0.3	0.005	38	12	25
- 2	*G. mammilaris*	-	.012	76.0	0.6	0.005	171	8	129
- 3	*Eucheuma* sp.	23.7	.005	38.2	1.1	0.003	50	7	19
062-A -17	*Caulerpa sertularoides*	15.5	.001	61.7	-	0.003	153	11.5	95
IIIA A+B - 2	*Codium* sp.	6.6	.009	77.5	-	0.010	20.8	1.1	16.1
047-A - 3	*C. repens*	35.8	.002	76.8	-	0.802	50.5	1.1	38.7
- 5	*Halimeda discoidea*	29.9	.004	86.9	0.8	0.003	96.2	6.7	83.5
146-B - 1	*Kallymenia perforata* + *Dictyota dichotoma*	-	0.0	92.7	-	0.002	143	14	133
147-B - 5	*H. discoidea*	5.0	.003	86.2	0.9	0.004	71.6	11.6	61.7
247-A - 2	*C. repens*	44.5	.006	85.9	0.2	0.001	44	5	38
251-B -25	*H. discoidea*	62.0	.001	84.2	-	0.002	31	4.3	26.1
Second Sampling Period									
IIA A -12	*Halymenia* sp.	52.0	.005	94.2	1.4	0.003	42.8	5.7	40.4
062-A - 5	*C. sertularoides*	55.0	0.0	64.4	-	0.0	30.6	11.5	19.7
064-A - 3	*G. blodgettii* + *compressa*	41.0	.006	92.3	1.0	0.003	61.1	13.6	56.4
-B - 3	*G. blodgettii*	62.2	.002	98.1	-	0.002	66.5	0.9	63.8

Table 137. Continued.

Sample Number	Organism	A	B	C	D	E	F	G	H
Second Sampling Period - contirued									
IIIA A -10	*Caulerpa* sp.	3.2	.031	5.1	1.8	0.0110	854	25.5	42
047-A - 5	*Halimeda discoidea*	9.8	.001	61.6	-	.001	79.8	10.4	49.1
146-B -14	*Dictyota dichotoma*	245.0	.002	67.1	-	0.101	327	137	220
147-A - 2	*H. discoidea*	35.7	.004	86.1	-	.004	22	4	19
151-A - 3	*Laurencia intricata*	72.0	0.0	68.1	-	0.0	20	50	15
247-A - 4	*Codium repens*	61.0	.004	83.0	0.45	.002	92.2	10.1	74.9
251-A - 3	*H. discoidea*	10.9	.002	65.0	-	.003	39.2	2.5	25.7
IVA A - 6	*Codium* sp.	21.0	.003	51.8	-	.004	33.0	2.6	16.7
VA A -12	*Pryssonnelia rubra*	14.9	.014	81.8	-	.017	6.5	3.0	5.3
Third Sampling Period									
IIA A -17	*Codium* sp.	11.9	.014	73.7	-	.017	4.2	5.3	3.1
062-A - 1	*C. isthmocladium*	17.4	.020	77.0	1.4	.014	4.4	3.3	3.4
064-A - 9	*Eucheuma isiforme*	-	-	94.0	-	-	35.9	2.7	34.0
047-A -25	*C. caroliniarum*	44.9	.002	60.2	-	.002	30.5	3.5	18.4
146-A - 1	*C. caroliniarum*	-	.002	59.0	-	.002	80.4	10.3	47.4
147-A - 2	*H. discoidea*	23.9	.003	61.2	-	.004	38.8	9.3	23.8
151-A - 1	*C. caroliniarum*	45.4	.001	85.0	-	.001	66.9	6.3	57.0
247-A -27	*C. caroliniarum*	23.7	.007	57.6	1.4	.005	40.9	3.1	23.5
251-A -10	*C. caroliniarum*	50.0	.001	85.0	-	.002	28.5	1.3	24.3

A = odd/even ratio
B = pristane + phytane/n-alkane
C = % n-alkane/aliphatics
D = pristane/phytane
E = pristane/n-heptadecane
F = total aliphatics; µg/gm dry wt.
G = total aromatics; µg/gm dry wt.
H = total n-alkanes; µg/gm dry wt.

these samples over the ten-month interval covered by sampling operations. A similar lack of seasonal trend is obtained from comparison of chromatograms of individuals of a given species collected from the three sampling periods. If seasonal variations do occur in hydrocarbon compositions of benthic macrofauna or flora from the MAFLA area, they must be relatively small and concealed by natural, intraspecific variability. No discernible differences in hydrocarbons could be detected between organisms collected from different MAFLA sampling stations. Although many of the samples contained more than one organism, it is felt that not enough replicates of a species were collected at a given location to allow a meaningful statistical comparison of geographical or seasonal influences on hydrocarbon compositions to be performed.

The analyses do, however, give a good representation of the hydrocarbon content of the benthic population. The broad and general characterization of this content indicates an absence of non-biogenic hydrocarbons. The organisms appear to be basically pristine. Natural hydrocarbon distributions appear to be relatively simple, with a small number of major components dominating. These components are different for different genera and phyla and may be useful in chemical taxonomic studies in the future. At present, however, few of these hydrocarbons have been identified.

In general, the ATP levels for Transects I-IV were lowest during the winter period reflecting the extreme conditions of this season. Transect VI, on the other hand, had high winter ATP levels and only the two outermost stations (2644 and 2645) showed obviously minimal ATP levels in winter. Seasonal influence on ATP levels was inconsistent for Transect V, and no set pattern of seasonality was conspicuous for the majority of the stations. Transects II and III were sampled in July 1975, October 1975 and January 1976. The observed seasonal variations in ATP levels for these two transects are probably indicative of a natural cycle of low summer values, increased fall values and minimal winter values attributable to temperature and nutrient availability patterns. The summer ATP samples for the other four transects were collected in late May and early June and high ATP levels for these transects at this time probably reflect normal late spring conditions. The high winter ATP concentrations for Transect VI are, however, an anomaly and suggest that some aspect of the environment maintained or increased ATP levels during the winter. A major factor may be high nutrient inputs independent of season.

The higher ATP levels measured at Transects IV, V and VI during all sampling periods suggest consistently more optimal conditions compared to Transects I, II and III. It would seem that conditions at Transect VI were most optimal while conditions at Transect II were least optimal. Again, nutrient input is presented as a major factor influencing this geographical variation among transects. Comparison of the transect locations reveals that most of the stations along Transects IV, V and VI are considerably closer to land than are the stations along Transects I, II and III. It seems feasible to assume that substantial nutrient input to Transects IV, V and VI is derived from terrestrial sources via estuarine outflow and land run-off. The proximity of Transect VI to Mobile Bay and the West drainage basin supports this contention. Likewise, Transect V is located in close proximity to St. Andrew Bay and Transect IV parallels the northern land boundary of Apalachee Bay and Apalachicola Bay. The lower ATP levels recorded for the most offshore stations of Transects I-V may be indicative of a decreased nutirent availability away from land and lend further support to the contention of substantial land-derived nutrients to the more inshore stations. Again, Transect VI did not conform, and its highest ATP levels were obtained from offshore stations (2642 and 2643).

Interpretation of the regression results is difficult and tenuous because of the "pre-regression" elimination of stations which deviated greatly from the straight line plots of ATP against sediment grain size or organic carbon of the sediment. The regressions, however, do demonstrate the tendency of ATP levels to co-vary with sediment grain size and organic carbon. Those stations and transects which did not adhere to the plotted and formulated regressions patterns are apparently influenced by additional controlling variables which result in a lack of consistency in ATP-single environmental factor relationships.

The ATP-sediment grain size regressions are more likely indicative of microbial dependence on some factor(s) other than sediment grain size _per se_. As postulated previously, a major controlling influence on microbial populations is nutrient availability. It is conceivable for Transects I-V that the bottom currents bring in required nutrients and remove the fine fraction of the sediment. This could lead to a significant and positive ATP-sediment grain size relationship; the stronger the current the more nutrients carried in and the coarser the remaining sediment. The situation for Transect VI is undoubtedly related to the transport of nutrients and suspended materials from Mobile Bay and the Mississippi River System into the area resulting in a significant and negative ATP sediment grain size relationship. In either case the ATP-sediment grain size relationships were only coincidental and reflect a nutrient replenishment (or other factors) mechanism which affects both variables simultaneously. Seasonal deviations in these mechanisms would tend to mask or obliterate previously apparent ATP-sediment grain size relationships. The negative regressions of ATP on organic carbon of the sediment seem to be opposite to those expected. One would expect microbial biomass to increase as a result of increased organic carbon available as a nutrient source. However, the regression results may be indicative of a rapid exploitation of the organic carbon into microbial biomass leading to depressed organic carbon levels present at any given time. Such a mechanism requires that the carbon source be qualitatively suitable for assimilation into microbial biomass. High organic carbon levels associated with low ATP levels may be suggestive of accumulated, non-utilizable carbon sources. Thus, the ATP-organic carbon regressions imply both a quantitative and qualitative relationship. The relatively high ATP levels obtained from Transect V and the independence of ATP levels from organic carbon present would suggest that either organic nutrients are not a limiting factor in this region or that the utilizable organics are qualitatively different from those present in the sediment. In the same vein it can be postulated that the organic carbon of Transect VI is more readily assimilated into microbial biomass than that of the other transects.

The lack of biologically strong correlations between ATP levels and aliphatic and aromatic hydrocarbons and trace metals in the sediments shows that present levels of these materials are not major factors influencing microbial populations (albeit the metals probably function as trace elements in the biochemistry-physiology of the organisms). These correlation results are not unexpected since the trace metals are present in the sediments at low natural levels and ratios. The hydrocarbon content of the sediments is also well below pollution levels and most of the hydrocarbon fractions are indicative of naturally occurring forms.

In the meiofauna the nematodes and copepods were abundant and exhibited seasonal, geographic and bathymetric variations in density, although these patterns of nematode and copepod distributions were neither completely uniform nor consistent in the MAFLA study tract. Correlations of nematode and copepod densities with sediment grain size, although statistically significant, were not sufficiently strong to warrant a strong biological relationship. If these correlation coefficients (r) are inverted to coefficients of determination (r^2) the density-sediment grain size relationships become biologically meaningless.

Consideration of the seasonal patterns in nematode and copepod densities suggests that winter conditions adversely affect densities at most stations. Those stations which show maximum densities during winter may be influenced by other factors which "offset" or "relax" the normally harsh regime of winter. All of these winter maxima stations are either shallow (<40 m) water stations or are located along Transects V and VI. This may be indicative of high, land-derived nutrient input during the winter. A similar hypothesis was put forth in the previous section.

Factors causing the decreased nematode densities along Transect V and decreased copepod densities along Transect VI are unknown. The decreased copepod densities at Transect VI may be attributable to a high sedimentation rate in this area. The most consistent pattern of density distributions for nematodes and copepods seems to be with depth; densities decreased as depth increased. More than likely these relationships are not directly depth-related but related to some other environmental factor(s) which are influenced by, or coincident with, depth and/or distance offshore. Some of these factors may be nutrient availability, sediment grain size and sedimentation rate.

The depth distribution and ratio relationships of Carcharodorhynchus and Eukalinorhynchia (Table 88) may be indicative of different environmental characteristics (types) in the MAFLA study tract. Alterations in the distributions/relationships of these taxa may be indicative of environmental changes.

Although the correlation coefficients are quite high for several of the meiofauna density-sediment grain size correlations, these r values are suspect. One reason for this skepticism is the low r values for individual taxa and the high r values for these groups combined. Also, for the 27 correlations run, all the correlation coefficients obtained fell into only two ranges; 0.20-0.26 and 0.95-0.99.

Seasonal variations in foraminifera densities suggest two different environmental mechanisms at work; one which elicits minimal densities in Transects I-IV during winter and one which elicits maximal densities in Transects V and VI during winter. This interpretation, however, must be considered in light of Hurricane ELOISE which passed over Transects V and VI only two days before these two transects were sampled in the fall. Storm surge from the hurricane undoubtedly caused the resuspension of bottom sediments at Transects V and VI resulting in a perturbated nutrient turnover which may have triggered a foraminiferal bloom along these transects resulting in the high winter densities. Winter depression of foraminifera abundances for Transects I-IV most probably relate to the lack of Mississippi River and eastern Gulf of Mexico water in the region (the Loop Current moves to the south in the winter).

The northward and westward increase in live/dead ratios may reflect elevated nutrient inputs via the Mississippi River, Mobile Bay, St. Andrew's Bay and other run-off drainage systems in this region.

The apparent influence of the sedimentation rate on live/dead ratios although not completely understood may be attributable to one or several of the following:

1. High sedimentation rates create conditions which produce increased mortality rates.
2. High sedimentation rates create conditions which slow down processes of dead test dissolution.
3. Conditions in areas with low sedimentation rates speed up processes of dead test dissolutions.
4. Conditions in low sedimentation areas are conducive to decreased mortality rates.

The relationship of increased specimen abundance with decreased sediment grain size would lend support to contentions one and/or two. The specimen abundance-grain size relationship possibly reflects a combination of greater nutrient availability and more individual, interstitial habitats in fine sediment as opposed to coarser sediments.

The free living/attached specimens-depth relationship seems indicative of bottom substrate shifting and scouring by localized inshore bottom currents. Free living/attached specimen ratios exceeded unity (usually by a factor of two to four) at stations greater than 100 m in depth. Ratios at the other stations were less than unity with many samples being completely void of free-living foraminifera. These data also indicate that 100 m is the approximate depth of bottom substrate stability (i.e., bottom scouring below 100 m depth is negligible in the MAFLA area). The occurrence of attached specimens of *Asterigerina carinata* and *Rosalina concinna* collected from the Transect I-IV shallow stations is the first known published account of sediment attachment for these species.

The high abundances of *Ammonia beccarii* var. *parkinsoniana* and *Ammonia becarrii* var. *tepida* at the shallow water stations of Transect VI suggest these stations lie in a region of environmental stress. The proximity of these stations to heavily populated, coastal cities and major drainage basin systems (e.g., West and Northwest drainage basins) supports the contention of environmental stress. Changes in distribution of this species and other pollution indicators (*Nonion depressulum matagordanum* and several *Elphidium* spp) in the MAFLA study tract may well be indicative of environmental degradation of the area.

The low species diversity and evenness observed at Master Station 2424 on Transect IV during the fall and winter sampling periods may be due to the coarse sediment encountered at this station during these seasons.

Transects V and VI showed no appreciable seaward increase in diversity. On Transect VI this was due to the number of deeper-water species living further up the shelf along with the normal species for the depths encountered. Upwelling along the DeSoto Canyon is apparently creating conditions favorable for the deeper-water species, while the fauna normal to those depths are probably more dependent on other parameters such as light penetration, the two factors, upwelling and light, together providing favorable conditions for the two faunas to coexist and hence causing higher diversity in shallow water. Transect VI showed a slight increase in diversity at the seawardmost stations, but much less so than the clearly defined trends of Transects I-IV. The smoothing out of the curve may be due to sediment grain size, with the shallowest stations nearest shore being much finer-grained than the deeper offshore stations (a reversal of the trend in the other five transects). The finer-grained sediments support a more diverse fauna inshore even though the habitat may be stressed due to low salinity, highly turbid river run-off water, while the offshore stations are considerably more coarse-grained, and thus support a less diverse fauna even though the habitat is normally marine.

The Sander's affinities obtained indicate that the mid-shelf is a transitional zone (ecotone) between the inshore and outer shelf foraminifera populations. These populations appear to maintain their integrity in that species composition is not significantly altered seasonally. Dominant foraminiferal species associations were also seasonally uniform. This indicates that foraminiferal populations within the MAFLA study region are delineated by bathymetric and geographic factors.

A total of 305 species of molluscs represented by living specimens were collected in this study. Twenty-three of these species were identified only from the micromollusc collections, 259 were identified only from the macromollusc collections while 23 were common to both collections. A total of 106 species of molluscs were represented in the dead micromollusc collection. Of this total of 106 species, 58 occurred in the macromollusc collections and 28 occurred in the live micromollusc collections. It is probable that the species overlap between the dead micromolluscs, live micromolluscs and macromolluscs would have been greater had the sampling techniques, sample size and numbers of samples been the same for all three. The live micromollusc and macromollusc species can be numerically broken down into classes as follows: Gastropods, 154 species; Bivalves, 129 species; Scaphapods, 14 species; Polyplacophorans, 7 species; and Aplacophorans, 1 species.

All three molluscan categories showed similar patterns of distribution within the MAFLA region. These patterns were decreased abundances at the deeper stations of all transects and at the inshore stations of Transects V and VI. Abundances along Transects V and VI were less than those along Transects I-IV.

Live micromolluscs were scarce, and conclusions drawn from such small sample size must be treated with caution. These low levels of live molluscs may be indicative of low food availability and high predation rates. Computations of density, based on the total numbers of live molluscs collected and the total area sampled, yield an average density of 509.06 specimens/m^2. This value is relatively low and densities off the Florida

Peninsula are considerably higher. Separation of stations into shallow (<50 m) and deep (>50 m) yield density figures of 709.7 speciment/m^2 for the shallow stations and 126.3 specimens/m^2 for the deep stations. This depth-density relationship may be indicative of the increased availability of food in the shallower waters. The noticeable decrease in specimen abundance and species occurring on Transects V and VI suggest that these areas are not conducive to the existence of micromolluscs. The low numbers in these transects may be attributable to the amount of fine sediment in this area and the low productivity.

Seasonal considerations indicate that winter is a period of maximal abundance. One reason for this may be a decreased predation rate at this time of year. However, since three station collections accounted for over 50% of the total specimen abundance taken during the winter period, any discussion of apparent seasonality must be considered as speculative at best. Also, the benthic molluscs tend to be gregarious and occur in patches.

The dead micromollusc fauna was more abundant than the live fauna. Much of the dead fauna showed effects of heavy predation; bivalve shells were mostly bored and gastropod shells were usually crushed or broken. Sea stars, crustaceans, demersal fish and predatory gastropods are most likely the primary predators of benthic molluscs. Like the live molluscs, the specimens and species abundances of the dead fauna were noticeably decreased in the collections from Transects V and VI.

Future micromollusc studies in the MAFLA region should, if feasible, investigate the preyed upon/non-preyed upon ratios of the dead fauna. Increases in the proportion of non-preyed upon forms could be useful as an indicator of environmental alteration/degradation.

Dead fauna distributions (depth, sediment type) mostly paralleled those of the live fauna and this is to be expected since the dead fauna represents previously living populations. The live/dead ratios more than likely represent a high exploitation rate of the micromolluscan fauna in the MAFLA study tract. Again, caution must be used since the rate of incorporation of dead shell into the sediment is unknown (i.e., how old or recent is the dead fauna?).

Dead micromollusc fauna associations (community structure), as suggested by the dominant species associations show shifts with both geographical location (transects) and depth (stations). *Parvilucina multilineata* and *Finella dubia* co-occur as dominants in ten of the 12 shallow station collections (<50 m) of Transects I, II and III and do not co-occur as dominants in any deep station collections (>50 m) nor in the shallow water collections of Transects IV, V and VI. With one exception (Master Station 2101), *Natica pusilla* and *Nuculana concentrica* are found as dominants in only the shallow station collections of Transect VI. *Vesicomya pilula* occurs as a dominant in all deep station collections and *Bathyarca* sp. occurs as a dominant in only those collections from depths of 150 m or greater. Thus, dead micromollusc assemblages may be used to characterize biotopes within the MAFLA study tract.

Variations in species composition and abundance by habitat and season contribute to assemblages which appear to be unique entities in space and time. Populations within the MAFLA area are affected by seasonal phenomena such as recruitment based upon innate reproductive cycles or larval settlement induced through larval transport by seasonal currents such as the Loop

Current. Loss within the populations may result either because of natural physiological factors such as age or because of adverse environmental conditions such as a hurricane (a phenomenon which may have affected some populations on Transects V and VI during the fall, 1976).

The stations which generally showed the lowest diversity (<2.00) were found either on the shelf break or on the northern two transects (V and VI). On the northern transects especially, the assemblages are obviously influenced by the Mississippi River. Large amounts of fine sediments are contributed to these stations and turbidity remains high throughout the year (Manheim, 1976). This environment, and to a lesser extent the slope environment, must be inhabited by species tolerant of such conditions and these assemblages are composed of essentially deposit feeders. Relatively few species in small abundances occur at these stations and any environmental perturbation is likely to eliminate the assemblage. Such assemblages are extremely difficult to sample adequately since the number of individuals per unit area is small and measures of diversity and affinity at these stations based upon molluscs are tentative at best. Polychaetes and molluscs should be considered together especially at the northern and deeper stations.

On the southern transects, the assemblages are typified by relatively low numbers of individuals compared to other assemblages in more temperate areas (Popham and Ellis, 1971; Boesch, 1972). The nearshore stations of Transects I, II, III and IV are characterized by species with few individuals although considerably more than appear on the northern Transects V and VI.

Clear definition of these molluscan assemblages is difficult based upon the techniques employed. The Mountford Clustering technique yielded very low similarity values between stations as well as between seasons. The partial definition of a community based upon a dominant mollusc in the Petersen-Thorson fashion (Thorson, 1957) is not readily apparent for the majority of the stations.

A more appropriate definition of the majority of the MAFLA benthic communities was given by Mills (1969) who viewed a community as a continuum in space and time and as "a group of organisms occurring in a particular environment presumably interacting with each other, and separable by means of ecological survey from other groups." At the present time because of the variability, a low predictive capability exists for describing the benthic macromolluscan assemblages over the majority of the MAFLA area.

The dominant foraminiferal species associations presented in Table 91 were integrated to determine the degree of dominant species "commonness" among the transects for the two depth zones (<90 m and >90 m). The results are presented in Table 138. Dominant species commonness among adjacent transects is approximately 0.5 for the shallow water assemblages with the exception of Transects IV and V which have a commonness ratio (CR) value of 0.3. The cumulative data reveals that the CR value for Transects I-IV is almost double that of Transects I-V and the addition of Transect VI to the cumulative data does not greatly alter the commonness value. This same pattern is obvious for the deep water assemblages but was much more pronounced; the degree of commonness for Transects I-IV is 0.2 and that for Transects I-V is 0.0. In both shallow and deep water assemblages there is a large increase in total number of dominant species when Transect V is combined with Transects I-IV. This demonstrates a sharp break in the

Table 138. Numerical measures of commonness of dominant species for shallow (<90 m) and deep (>90 m) water foraminiferal assemblages.

	Shallow Assemblages			Deep Assemblages		
Transects	A Total No. of Species	B No. of Species in Common	B/A	A Total No. of Species	B No. of Species in Common	B/A
I and II	13	7	0.54	7	4	0.57
II and III	11	6	0.54	8	4	0.50
III and IV	12	6	0.50	9	4	0.44
IV and V	17	5	0.29	10	2	0.20
V and VI	19	9	0.47	7	0	0.00
I and III	14	6	0.43	9	3	0.33
I and IV	15	5	0.33	10	2	0.20
I and V	22	4	0.18	13	0	0.00
I and VI	26	4	0.15	13	0	0.00

dominant species associations going from Transect IV to Transect V with the degree of commonness being greater among Transects I-IV than between the adjacent Transects IV and V. Thus, the dominant foraminiferal species associations west of Cape San Blas are considerably different from those east of Cape San Blas. Within the west region there is no dominant species commonness among the Transects V and VI deep water assemblages. The geographic and bathymetric dominant species associations within the MAFLA study area are presented in Table 139. Reference back to Table 138 shows that there is zero commonness of dominant species between the shallow and deep water assemblages of each of the six transects.

Table 139 clearly shows that four of the five dominant species common to Transects I-IV shallow assemblages are ubiquitous within the MAFLA study region. The only dominant species unique to the Transect I-IV shallow assemblages was Rosalina concinna which did not occur as a dominant on either Transect V or VI. Cassidulina curvata and Cassidulina subglobosa display a "tropical submergence" being common dominant species in the deep water assemblages of Transects I-IV and the shallow water assemblages of Transects V and VI. Of the five dominant species common only to Transects V and VI only one, Planulina exorna, occurred as a dominant on another transect; this was on Transect IV. Bathymetric species distributions (shallow vs deep) are more distinct than are the geographic distributions indicating that depth is a primary limiting factor to foraminiferal distributions within the study area.

In an attempt to delineate broad distributional patterns of benthic infauna in the MAFLA study region a "measure of species commonness" ratio was devised for dominant species associations for several benthic phyla

Table 139. Dominant foraminiferal species common within shallow (<90 m) and deep (>90 m) water assemblages.

Shallow Water Assemblages

Transects I-IV	Transects V-VI	Transects I-VI
	Amphistegina gibbosa	
	Cassidulina corvata	
	Cassidulina subglobosa	
Cibicides aff. *C. floridanus*	*Cibicides* aff. *C. floridanus*	*Cibicides* aff. *C. floridanus*
Hanzawaia strottoni	*Hanzawaia strottoni*	*Hanzawaia strottoni*
	Nonionella atlantica	
	Planulina exorna	
Quinqueloculina lamarckiana	*Quinqueloculina larmarckiana*	*Quinqueloculina lamarckiana*
Rosalina columbiensis	*Rosalina columbiensis*	*Rosalina columbiensis*
Rosalina concinna		

Deep Water Assemblages

Transects I-IV	Transects V-VI	Transects I-VI
Cassidulina curvata	none	none
Cassidulina subglobosa		

Shallow and Deep Water Assemblages

Transect	I	II	III	IV	V	VI
	none	none	none	none	none	none

or taxa. This ratio was derived by dividing the total number of dominant species in two or more assemblages into the number of dominant species common to the assemblages. A commonness ratio (CR) of 1.00 would indicate absolute similarity while a CR of 0.00 would indicate no similarity. The assemblages used are the shallow (<90 m) and deep (>90 m) water dominant species for each of the six benthic transects. If the data are split seasonally then 36 assemblages occur (three seasons times two depth zones times six transects equals 36 assemblages). The rationale behind this procedure is that the greater the commonness ratio between assemblages, the more similar are the populations and the total benthic environment. The procedure is limited to consideration of dominant species since these species are usually indicative of community types and also are the more obvious and readily collectable species in an ecosystem.

Tables 140a, b and c list the CR values for the dominant macromollusc species assemblages for each of the three seasons. The CR values show that the degree of similarity between the transects for both the shallow and deep water assemblages is low (CR $\leq$ 0.50) and decreases drastically as the number of assemblages under consideration increases from two up to six. This low similarity is apparent for all three seasons. Intra-transect CR values are considerably less than inter-transect CR values. This demonstrates that depth is a more limiting influence on macromollusc distributions than is geographic location. The same situation was apparent in the foraminiferal distributions discussed previously. In general, the degree of species similarity between adjacent transects was greater for the deep water assemblages than for the shallow water assemblages.

Table 140a. Dominant macromollusc species commonness for shallow (<90 m) and deep (>90 m) water assemblages for the summer sampling period.

	Shallow Water Assemblages			Deep Water Assemblages		
Transects	A Total No. of Species	B No. of Species in Common	B/A	A Total No. of Species	B No. of Species in Common	B/A
I and II	25	5	0.20	10	1	0.10
II and III	15	2	0.13	8	2	0.25
III and IV	28	5	0.18	4	1	0.25
IV and V	44	8	0.18	7	1	0.14
V and VI	35	4	0.11	9	1	0.11
I and III	22	5	0.23	4	1	0.25
I and IV	38	8	0.21	4	1	0.25
I and V	41	5	0.12	7	1	0.14
I and VI	29	4	0.14	7	1	0.14
II and IV	30	6	0.20	9	2	0.22
II and V	34	2	0.06	10	3	0.30
II and VI	22	1	0.04	12	1	0.08
III and V	30	3	0.10	5	2	0.40
III and VI	17	3	0.18	6	1	0.17
IV and VI	34	5	0.15	6	1	0.17
I - III	27	2	0.07	10	1	0.10
I - IV	43	1	0.02	11	1	0.09
I - V	60	1	0.02	13	1	0.08
I - VI	66	1	0.01	17	1	0.06
Shallow vs. deep water assemblages for each transect						
I	22	1	0.04			
II	18	0	0.00			
III	8	1	0.12			
IV	29	2	0.07			
V	29	3	0.10			
VI	17	2	0.12			

Table 140b. Dominant macromollusc species commonness for shallow (<90 m) and deep (>90 m) water assemblages for the fall sampling period.

	Shallow Water Assemblages			Deep Water Assemblages		
Transects	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A
I and II	17	6	0.35	7	1	0.14
II and III	21	5	0.24	5	1	0.20
III and IV	28	8	0.29	2	1	0.50
IV and V	38	9	0.24	5	1	0.20
V and VI	36	5	0.14	9	1	0.11
I and III	18	5	0.28	5	1	0.20
I and IV	28	5	0.18	4	1	0.25
I and V	28	6	0.21	8	1	0.13
I and VI	25	2	0.08	7	2	0.29
II and IV	29	7	0.24	4	1	0.25
II and V	32	5	0.16	7	2	0.29
II and VI	27	3	0.11	8	1	0.13
III and IV	31	6	0.19	6	1	0.17
III and VI	26	4	0.15	6	1	0.17
IV and VI	37	3	0.08	5	1	0.20
I and III	24	4	0.17	8	1	0.13
I and IV	36	3	0.08	8	1	0.13
I and V	49	2	0.04	11	1	0.09
I and VI	60	1	0.02	14	1	0.07
Shallow vs. deep water assemblages						
I	13	1	0.08			
II	16	1	0.06			
III	14	1	0.07			
IV	24	0	0.00			
V	27	2	0.07			
VI	21	1	0.05			

Table 140c. Dominant macromollusc species commonness for shallow (<90 m) and deep (>90 m) water assemblages for the winter sampling period.

	Shallow Water Assemblages			Deep Water Assemblages		
Transects	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A
I and II	17	6	0.35	6	3	0.50
II and III	18	3	0.17	8	2	0.25
III and IV	33	6	0.18	8	3	0.38
IV and V	40	10	0.25	10	1	0.10
V and VI	39	10	0.26	ND*	ND	ND
I and III	25	3	0.12	10	1	0.10
I and IV	35	6	0.17	9	1	0.11
I and V	33	6	0.18	9	2	0.22
I and VI	36	4	0.11	ND	ND	ND
II and IV	29	5	0.17	8	1	0.13
II and V	28	4	0.14	8	2	0.25
II and VI	31	2	0.06	ND	ND	ND
III and V	31	6	0.19	11	1	0.09
III and VI	34	4	0.12	ND	ND	ND
IV and VI	44	7	0.16	ND	ND	ND
I and III	26	2	0.08	10	1	0.10
I and IV	42	2	0.05	12	1	0.08
I and V	53	2	0.04	16	1	0.06
I and VI	64	1	0.02	ND	ND	ND
Shallow vs. deep water assemblages						
I	18	2	0.11			
II	10	2	0.20			
III	18	1	0.06			
IV	29	2	0.07			
V	28	2	0.07			
VI	ND	ND	ND			

*ND Not determined because the Transect VI sample contained no living macromolluscs

Dominant species associations were disjunct in the summer with the CR values generally being greater between separated transects than between adjacent transects. For the shallow water assemblages the degree of similarity between adjacent transects ranged from a CR of 0.18 to 0.11. The highest CR value obtained was for Transects I and III (0.23). The ubiquitous species of the shallow water assemblages was Tellina versicolor, and the ubiquitous species for the deep water assemblages was Abra lioica. A. lioica was also nearly ubiquitous for the shallow water assemblages being absent only from the Transect II shallow water assemblage. The CR values show that the macromollusc populations within the MAFLA region in the summer were relatively dissimilar within, between and among transects. The slightly higher CR values for the deep water assemblages are indicative of more stable and less diverse conditions off the edge of the shelf.

During the fall the macromollusc species associations for the shallow water assemblages were not disjunct and the CR values of adjacent transects were generally greater than those of separated transects. The shallow water assemblages showed a general decrease in adjacent transect similarities going north and west from Transect I; the highest degree of similarity was between adjacent Transects I and II (CR = 0.35) and the lowest was between Transects V and VI (CR = 0.14). The deep water assemblages displayed disjunct similarity patterns and the CR values of adjacent transects were usually less than that of separated transects. The deep water assemblages of Transects I and VI were considerably more similar than those of Transects I and II and Transects V and VI. The degree of similarity between adjacent deep water assemblages was greatest for Transects III and IV (CR = 0.50) and then decreased north and west and south and east.

As in the summer, Tellina versicolor was the ubiquitous species of the shallow water assemblages in the fall. Abra lioica, Crassinella lunulata, and Varicorbula operculata occurred in five of the six transect shallow water assemblages. Abra lioica was the ubiquitous species of the deep water assemblages, and its absence from only the Transect IV shallow water assemblage accounted for the zero similarity between the Transect IV shallow and deep water assemblages.

Winter similarity distributions were not disjunct and both the shallow and deep water assemblages had greater degrees of commonness between adjacent transects than between separated transects. The highest CR values for both shallow and deep water assemblages were between adjacent Transects I and II. These CR values are 0.35 and 0.50 respectively. Again, as in the summer and fall, Tellina versicolor was the ubiquitous species of the shallow water assemblages. Other species occurring in five of the six shallow water assemblages are Varicorbula operculata and Crassinella lunulata. Abra lioica occurred in only four of the shallow water assemblages, and, as in the fall and summer, Abra lioica was the ubiquitous species of the deep water assemblages (with the exception of Transect VI which had no live fauna in the deep water collections).

Inter-seasonal comparisons for the individual transects show that the greatest degree of dominant species similarity was between the fall and summer sampling periods for the deep water assemblages of Transects II-VI (Table 141). The deep water assemblages of Transects V and VI had summer-fall CR values of 1.00 (unity). Transect I did not follow this pattern and

Table 141. Dominant macromollusc species commonness for shallow (<90 m) and deep (>90 m) water assemblages among sampling seasons.

Shallow Water Assemblages

Transect	Summer vs. Fall			Fall vs. Winter			Summer vs. Winter		
	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A
I	25	5	0.20	20	5	0.25	28	7	0.25
II	17	6	0.35	15	6	0.40	13	5	0.38
III	15	5	0.33	22	4	0.18	18	2	0.11
IV	40	9	0.23	41	8	0.20	42	10	0.24
V	39	11	0.28	37	11	0.30	39	11	0.28
VI	24	6	0.25	33	9	0.27	33	5	0.15

Deep Water Assemblages

Transect	Summer vs. Fall			Fall vs. Winter			Summer vs. Winter		
	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A
I	6	1	0.17	7	2	0.29	7	1	0.14
II	8	4	0.50	6	2	0.33	10	2	0.20
III	3	1	0.33	7	1	0.14	7	1	0.14
IV	2	1	0.50	5	1	0.20	6	1	0.17
V	5	5	1.00	9	2	0.22	9	2	0.22
VI	5	5	1.00	ND*	ND	ND	ND	ND	ND

ND* Not determined because the Transect VI sample contained no living macromolluscs had its highest CR value for the fall-winter deep water assemblages. But this value was not particularly high (CR = 0.29). The shallow water assemblages had relatively low CR values for the different seasonal comparisons (maximum CR = 0.38). Deep water assemblages showed little intra-transect similarities for the fall-winter and summer-winter seasons.

The total CR results demonstrate that macromollusc communities are highly variable within the MAFLA study region. This variability extends to bathymetric, geographic, and seasonal considerations. The exceptions to this generalization were the deep water assemblages of Transects V and VI which had a perfect seasonal unity between the summer and fall sampling periods.

Table 142 lists the CR values for the dead micromollusc dominant species assemblages. The shallow water assemblages of adjacent transects were moderately similar. Transects II-VI displayed disjunct similarity patterns. Transects II and IV were more similar than Transects II and III and III and IV. Likewise, Transects IV and VI were more similar than Transects IV and V and V and VI. The highest CR values for the shallow water assemblages occurred between Transects I and II, II and IV and II and V.

Similarities between the deep water assemblages of Transects II and III, III and IV and IV and V were measurably higher than those of the shallow water assemblages. The opposite was true for Transects I and II and V and VI.

Five species ubiquitous to the shallow water assemblages accounted for most or all of the similarity between and among transects. The five species were _Finella dubia_, _Ervillia concentrica_, _Crassinella lunulata_, _Meioceras cubitatum_ and _Gouldia cerina_. Two other species, _Caecum bipartitum_ and _Parvilucina multilineata_, were common to the Transects I-IV assemblages

Table 142. Dominant "dead" micromollusc species commonness for shallow (<90 m) and deep (>90 m) water assemblages.

	Shallow Water Assemblages			Deep Water Assemblages		
Transects	A No. of Total Species	B No. of Species in Common	B/A	A No. of Total Species	B No. of Species in Common	B/A
I and II	17	8	0.47	9	2	0.22
II and III	20	8	0.40	4	2	0.50
III and IV	27	10	0.37	3	2	0.67
IV and V	26	8	0.31	3	1	0.33
V and VI	23	7	0.30	9	1	0.11
I and III	22	8	0.36	9	2	0.22
I and IV	23	10	0.43	8	2	0.25
I and V	21	7	0.33	9	1	0.11
I and VI	21	9	0.43	14	2	0.14
II and IV	21	10	0.48	4	2	0.50
II and V	17	8	0.47	4	1	0.25
II and VI	21	6	0.29	10	1	0.10
III and V	31	6	0.19	4	1	0.25
III and VI	25	8	0.32	10	1	0.10
IV and VI	26	10	0.38	9	1	0.11
I and III	24	7	0.29	10	2	0.20
I and IV	31	7	0.23	10	2	0.20
I and V	35	5	0.14	11	1	0.09
I and VI	39	5	0.13	17	1	0.06
Shallow vs. deep water assemblages for each transect						
I	21	1	0.05			
II	14	0	0.00			
III	20	0	0.00			
IV	21	1	0.00			
V	16	0	0.00			
VI	19	5	0.26			

and their absence from Transects V and VI accounts for the large decrease in the CR value going from the combined species data of Transects I-IV to that of Transects I-V. Vesicomya pilula and Bathyarca sp. were the dominant species common to the Transects I-IV deep water assemblages. Of these two species only Vesicomya pilula extended to Transects V and VI resulting in a sharp drop in the CR value when Transects V and VI were added to the cumulative transect assemblages.

The species and specimen abundance and biomass data indicate that polychaetes are a significant component of the benthos in the MAFLA study tract. The occurrence of more than 30 possible new species in the collection shows that the polychaete systematics of this region are still open to considerable investigation.

The non-random seasonal variations in density, biomass, and species abundance observed for Transects V and VI may not be due to natural (normal) environmental influences but rather may be the result of environmental perturbation stemming from Hurricane ELOISE. This storm crossed this region only two days prior to the sampling of these transects in the fall. Thus, the lower values obtained for these parameters during the fall may be indicative of detrimental effects of the hurricane. The fact that these parameters displayed random seasonal variation for Transects I-IV supports the contention of a hurricane cause-and-effect.

The only significant correlation between polychaete parameters and environmental factors was polychaete density to depth. These two variables displayed an inverse relationship which was significant for all three sampling periods, i.e., density decreases as depth increases for all seasons. However, conversion of the correlation coefficients (r) to coefficients of determination (r^2) shows that a relatively small proportion of density changes are associated with depth changes. Species diversity showed a partial relationship with sediment grain size when substrate was partitioned into "gross" size classes (Table 108). However, no significant correlation existed when diversity was compared against the actual mean sediment grain sizes of the individual stations. This demonstrates that sediment texture and morphology rather than grain size _per se_ is the controlling factor influencing populations. A similar type of relationship was indicated for biomass and substrate and species abundance and depth. In all probability, variations in all of these polychaete parameters are influenced simultaneously (albeit to different degrees) by several environmental factors. In general, these polychaete parameters were higher in silt and fine sand substrates than in coarser substrates at the shallow stations (<70 m) whereas this relationship is reversed for the deeper stations (>70 m). Thus, polychaete distributions seem to be bimodally influenced by interdependent depth-substrate factors. Multivariate analyses (including nutrient levels) would possibly clarify the situation.

The relatively high J' values obtained for most of the stations at all sampling periods demonstrate that polychaete communities (populations) in the MAFLA study tract are evenly distributed with respect to species/specimen representation. Or, put another way, polychaete communities within the MAFLA study tract are quite diverse. Evenness of distribution (a measure of relative diversity within an ecosystem or ecotype) is usually a good indicator of long-term population stability. Significant changes in species diversity indices would reflect environmental alterations.

The polychaete dominant species data, while not indicative of any strong biological trends, are suggestive of possible species distributions and relationships. Seventeen percent of the approximate 616 species collected were dominant at least once in the study area. This relatively high frequency of dominant species coupled with the complete lack of any species comprising more than 60% of the specimens in any collection partially corroborates the high evenness of distribution (J') values and species diversity values (H') obtained.

Some polychaete species, such as Lambrinerio parvipedata, appear to be ubiquitous dominants (dominant in five or more transects) while others, exemplified by Websterinereis tridentata, appear to be isolated dominants (dominant several times but only at one or two adjacent transects). Changes in these well-delineated dominance patterns may also serve as indications of environmental alteration.

The high variability of within-station homogeneity suggests that either the replicate samples were not representative of the polychaete communities at each station or that well-defined, segregated micro-ecosystems exist at the stations. Again, the possible influence of patchiness and non-random clumping cannot be discounted as contributing to the wide variability in homogeneity. In this regard, it should be mentioned that rich, diverse communities usually do not display spatially even distributions within small areas.

The mean polychaete homogeneity values for Transects V and VI show a relationship with sediment grain size. Lowest homogeneities occurred at stations characterized by coarse sands and it may be that coarse sediment substrates represent "patchy" microenvironments where available habitats are non-randomly interspersed among the coarse material. Highest sample homogeneity generally occurred in uniformly-fine sediments suggesting habitat continuity (these observations may be artifacts resulting from the high variability of the within-station homogeneity values).

The Bray-Curtis similarity percentages derived for the epifaunal molluscs, decapod crustaceans, echinoderms, polychaetes and anthozoan corals clearly demonstrates that the distribution of these groups is not substrate-dependent. Molluscs and decapod crustaceans showed similar patterns of depth-dependent distributions with the outer shelf populations being more similar in species composition than the intermediate or shallow shelf populations. This increased similarity with increasing depth most probably is a function of more stable benthic conditions at the deeper stations (∿183 m). The disjunct similarity patterns of the crustaceans along depth lines indicates a cosmopolitan distribution limited by depth rather than latitude. Considering the high mobility of decapods, this latitudinal cosmopolitan aspect of their distribution is not surprising. Molluscs do not show this disjunctness and this reflects their sedentary nature. Disjunct distribution occurrences for molluscs are considered to be indicative of larval transport systems (i.e., water movements).

The echinoderm distributions are opposite those of molluscs and decapods but still remain depth-dependent. The inshore populations show stronger affinities than the intermediate populations and the deep populations show almost no similarity. As in the decapods, distributional similarities are disjunct. Again, this indicates larval transport along depth contours. The general lack of similarity among C stations indicates niche specific clumpings or lack of transport between stations. In this respect it must be mentioned that disjunct similarities between C stations for both decapods and echinoderms showed Transects I and II as being most similar to Transect VI. This strongly suggests the direction of water flow to be from the Transect VI region to the southeast towards Transects II and I since the opposite situation would have resulted in the highest similarities being present between Transects I and II. Additional evidence for this hypothesis is given by the 100% species similarity between Transects I, V and VI for the anthozoan corals with most of the in-between similarities being zero.

The polychaete distribution data are not totally discernible and may be more a function of collection and identification rather than real disjunctiveness. This is especially so since polychaetes are rarely epifaunal and those captured in the dredge/trawl may be accidental collections of infaunal populations. However, the infaunal polychaete data suggest a distributional pattern which is influenced by both depth and substrate.

The anthozoan corals, surprisingly, also display substrate independent but depth dependent similarity distributions. If any of these five epifaunal groups would be expected to show substrate-dependent distribution it would be the corals.

The postulated substrate independent, depth dependent epifaunal distributions with varying degrees of disjunctness (i.e., cosmopolitan along depth contours) is in agreement with the similar hypothesis put forth for the infaunal foraminifera, macromolluscs and micromolluscs. Thus, it is concluded that benthic communities in the MAFLA region are primarily delineated by depth, partially by latitude and least by substrate.

On the basis of the epifaunal collections, four epibenthic community assemblages are proposed for the MAFLA region (Tables 111-112). Not surprisingly, these communities are depth delineated and represent inner, mid and outer shelf ecosystems. The North Middle Ground High Relief Epifaunal Assemblage has a distinct tropical fauna and flora. It is proposed that the Florida Middle Ground is maintained by the Loop Current (Austin and Jones, 1974) which brings in recruitment from the Bahamian and Florida Keys environments.

Interpretation of the demersal fish data is difficult and conclusions drawn are highly tenuous since towing speeds and durations of tows were not uniform throughout the study. Also, demersal fish populations are known to exhibit non-random clumping (patchiness). However, with these limitations in mind, some general statements can be made regarding demersal fish distributions in the MAFLA study tract.

The demersal fish populations in the MAFLA study tract cannot be characterized or differentiated on a geographical basis since differences between transects were inconsistent, variable and limited. Thos differences observed among transects most probably reflect the non-random distribution of demersal fishes.

Seasonal variations were more consistent than geographical variations. The data suggest that fall is a period of increased species diversity, species abundance, numbers of specimens and biomass. One explanation for this is summer recruitment of juvenile fishes into the catchable size ranges and fall offshore-inshore migrations resulting in mixed populations.

Species dominance and occurrence, as exemplified by *Syacium papillosum* and *Citharichthys cornutus*, are perhaps the most valuable indices for characterizing demersal fish populations and distributions within the study area. However, this cannot be done on a geographical or seasonal basis and is only applicable to depth distributions. *Syacium papillosum* was a prominent member of the Station A and B collections and was totally absent from the Station C collections. *Citharichthys cornutus* was a prominent member of the Station C collections, infrequently found in the Station B collections and totally absent from the Station A collections. Thus, under existing aquatic conditions in the MAFLA study tract, *Syacium papillosum* is probably an indicator of the inshore and mid-shelf environments and *Citharichthys cornutus* is an indicator species of the outer shelf environment.

The lack of any histopathologic conditions in all of the organisms examined is indicative of the pristine nature of the MAFLA region. Organisms to be used in future histopathological studies should include the hard corals, bivalve molluscs and crustacea. Indicator tissues should include the gills, digestive diverticula, carapace, cornea, reproductive tract and kidney.

SUMMARY

Factors affecting the total transport of the waters within the MAFLA area are atmospheric disturbances, tides, river run-off, and the Loop Current and each of these factors, except perhaps the tides, can have a large seasonal and annual variation.

In the summer the Loop Current was present at the outer stations on Transects IV and III at a depth of approximately 100 m and on Transect I Loop Current water (present as two detached eddies) appeared as a mid-water intrusion extending inward to approximately 75 m of depth on the shelf. Strong temperature, salinity and sigma t gradients were present on each transect. Except on Transect I the salinity gradient was separated from that of the temperature and sigma t with the gradients increasing with depth to the south. Perhaps the most important phenomenon observed was the short and long-term tempeoral variability of salinity and temperature at the various stations.

In the fall the indications were for a flow of water onto the shelf in the vicinity of Transect III influenced by the presence of Loop Current eddy waters and the exit of this water from the shelf near Transect II. There was no indication of Mississippi River System water moving to the east and south as observed in the summer months. After the passage of

Hurricane ELOISE the time series data from Master Station 1207 and the rest of the data from Transect II indicate the presence of major oscillation patterns along the bottom and in the nepheloid layer.

Hurricane ELOISE probably affected thermocline depths by three to four meters out to depths of 35 m and possibly to as much as 15 m at the edge of the Continental Shelf. The mixed layer extended from the surface to the bottom out to a depth of 15-18 m and to a depth of 30-45 m at the edge of the shelf.

In the winter neither the Loop Current nor eastern Gulf of Mexico waters were present in the study area. The effects of run off could be seen on the inshore portion of each transect and these effects did not appear to extend seaward any further than they had in the summer and fall. There was a difference in their influence as represented by the isothermal and isohaline conditions at the inshore stations rather than the previously present surface pockets. Only on Transect I were any surface pockets detected.

The data also indicated that in January-February, 1976 the Mississippi River System drainage discharges were not moving to the east as was the case during the summer and fall when Loop Current waters and eddies were present. There was an indication that upwelling was occurring in the vicinity of the DeSoto Canyon and the Horseshoe Bend eddy water mass had been reestablished as a ridge of high salinity. Outer Continental Shelf water had also moved onto the Continental Slope.

Historically the water temperatures in the MAFLA area in 1976 were colder or just as cold as the lowest temperatures observed and the effect of this was not uniformly distributed throughout the region. For example, the winter of 1976 was not unique on Transect IV but was colder by one degree on Transect III, two degrees on Transect II, and three degrees on Transect I.

Transmissometry data in the summer and early fall of 1975 indicate that most areas except in the vicinity of the Mississippi Delta contain clear waters having upwards of 80% light transmission in the upper portion of the water column. A few meters from bottom, more turbid layers characterized the inshore waters. In January and February, 1976 the shelf waters were turbid over long periods due to repeated resuspensions of fine fractions of the bottom sediments as a result of storms. Inshore waters were vertically well mixed to a considerable degree.

Turbidity distributions were frequently closely related to water mass structures and movements. A notable example was provided by Hurricane ELOISE on the Florida Middle Ground a few days after the occurrence of the storm. Sharply defined turbid boluses of near-bottom water were related to temperature, salinity and density anomalies and were interpreted as contour currents which were enhanced by the forcing function of the storm.

Suspended loads and chemical compositions of the suspended matter throughout the MAFLA area indicated a bi-seasonal water structure for the northeastern Gulf of Mexico. The chemical composition of the suspended matter also appeared to reflect an environment of resuspended bottom sediments during the winter being transported towards the central Gulf. During the remainder of the year the suspended loads appeared to be dominated by biological particles both carbonate and siliceous in nature.

With the exception of cadmium the average trace metal content of the neuston as compared to that of the zooplankton appeared to be regionally distinguishable. In the area east and south of Cape San Blas the average trace metal content of the neuston is generally higher than that observed in the zooplankton in both the fall and winter. On Transect IV the average trace metal content of the neuston was generally less than that found in the zooplankton in both seasons. On Transect III the average copper, iron and lead content of the neuston was higher than that found in the zooplankton in the fall and less in the winter. The average cadmium content of the neuston was, with one exception, less than that of the zooplankton. On Transect II in the winter the cadmium content of both groups was equal.

Trace metal concentrations in the epifauna reported on in this study were within the range reported by other investigators. Corals, contrary to the other groups, were uniform in their trace metal concentrations and this was true not only among the various groups but between the individuals within a species. Among the other groups the variation in metal content was high and this was true among the species within a phylum. This was most evident in the sponges where the variation was several orders of magnitude. In spite of this large variation, geographical trends in metal content were indicated for the sponges and echinoderms.

Weathered petroleum was found to occur in both the dissolved and particulate phases of the water column. This was especially true near Tampa Bay and near Mississippi Sound where unresolved envelopes and a series of $\underline{n}$-alkanes from $\underline{n}C_{21}$ to $\underline{n}C_{32}$ were found. Hydrocarbons in zooplankton, water and suspended particulate materials fell into geographically coherent patterns and no recent petroleum contamination was evident in any of these samples (although almost every neuston sample was contaminated by tar balls). In all sample types hydrocarbons were lowest during the fall sampling period. It was also noted that in all sample types the aromatic/unsaturated (benzene) fraction contained significant concentration and complexity of hydrocarbons.

Both dissolved and particulate organic carbon were found to fluctuate seasonally over the shelf. The former exhibited low levels during the summer and fall and was at a maximum during the winter. Particulate organic carbon concentrations were highest during the summer and winter. When different regions of the Gulf were considered, particulate organic carbon was found to be more variable and followed localized seasonal patterns while dissolved organic carbon was found to be remarkably uniform throughout the MAFLA region.

Within each season the apparent levels of particulate and dissolved organic carbon were not generally found to differ statistically when distance from shore or transects were considered. An exception to this was the decline in particulate organic carbon immediately offshore during the fall. Levels of particulate carbon were closely related to phytoplankton standing crops, as estimated by chlorophyll a, along the entire northeastern Gulf shelf although the relationship was strongest nearshore. Measured quantities of dissolved organic carbon could not be related to any parameters other than the total dissolved hydrocarbons. The range of the ratio of total dissolved hydrocarbons to dissolved organic carbon (0.2-0.4) indicates that the distribution of both of these parameters is controlled by similar processes.

The pigmented population, as evidenced by chlorophyll a, showed both local and seasonal changes in concentration possibly reflecting the addition of nutrients to the water column either as a result of Hurricane ELOISE or increased river discharge with the entrained nutrients. There was no apparent correlation between either chlorophyll a or primary productivity values and temperature or salinity.

Zooplankton density and biomass was highest during the winter. This was due primarily to the high abundance of the Paracalanus sp. group. The lowest values were found in the fall. An inshore-offshore pattern of decreasing abundance and biomass was shown in the distribution of the zooplankton during all seasons. Shannon-Weaver diversity indices indicated a trend of increasing diversity from inshore to offshore and the diversity appeared to be higher in the fall than in the summer.

Copepods dominated the neuston while non-crustacean adult invertebrates represented minor constituents of the population. During daylight hours significant differences occurred between seasons with respect to "all invertebrate families" and "number of copepod families" categories. At night, significant seasonal differences occurred in the "all adult family." Positive correlations between numbers of organisms captured and degree of darkness, and negative correlations existed between Forel color and the number of invertebrate phyla captured. An interesting observation was the negative correlation between tar weight and the number of invertebrate phyla captured. Whether this is due to (1) wind rafting of pollutants and surface organisms, (2) the avoidance of the tar balls by the neuston or (3) sampling error is not clear.

Demersal fish species diversity was most consistent at the deeper stations. Numbers of species and biomass appeared only slightly higher at shallower depths and there appeared to be little geographical variation in any of these parameters. Species dominance was the most consistent and variable faunal characterization noted. Based on species dominance, faunal variation was more marked between depths than between geographically separate stations of the same depth.

The results of shelf epifaunal assemblage studies lend further support to the establishment of depth related communities. That region of the shelf between 30-60 m in depth is referred to as the Middle Shelf I; between 60-140 m is referred to as Middle Shelf II and the Deep Shelf ranges between 140-200 m in depth. Within each of these zones characteristic epifaunal assemblages were present.

In the Florida Middle Ground there were strong and positive indications for the presence of a unique faunal and floral assemblage. It was proposed that the recruitment for this area was provided by the Loop Current. The effects of Hurricane ELOISE were dramatic in this area and the cumulative effects of later autumn and winter storms were even more severe. Despite the apparent devastation caused by autumn and winter storms it is evident from three seasons of observations (1974, 1975, 1976) that the plant populations recover each year.

The activity of the infaunal population within the sediments indicate relatively high rates of bioturbation regardless of depth sediment type, etc. This is indicative that the bioturbation rate of the organisms is far greater than the rate of sediment accumulation and structure formation.

Infaunal polychaete distribution was inversely related to depth. Indications were also present in the data that sediment texture and morphology rather than grain size *per se* may be the controlling factor influencing the polychaete populations. A similar type of relationship was indicated for biomass and substrate and species abundance and depth. Polychaete communities within the MAFLA region were found to be quite diverse and this was considered to be an indicator of long term population stability.

Tests for "measures of species commonness" among the macromolluscs showed that the degree of similarity between the transects for both the shallow and deep water assemblages was low during all three seasons. This again indicates the significance of depth as a limiting influence on macromollusc distribution (this was also true for the foraminifera). In general, the degree of species similarity between adjacent transects was greater for the deep water assemblages than for the shallow water assemblages and this is indicative of more stable and less diverse conditions off the edge of the shelf.

The total "measures of species commonness" among the macromolluscs indicate that these communities are highly variable within the MAFLA region. This variability extends to bathymetric, geographic and seasonal considerations. The exceptions to this generalization were the deep water assemblages of Transects V and VI which had a perfect seasonal unity between the summer and fall sampling periods.

Shallow water assemblages of micromolluscs in adjacent transects were moderately similar and this,in part, is explained by the presence of five species which were ubiquitous to the shallow water assemblages.

Affinity tests also indicated that the mid-shelf is a transition zone in the distribution of foraminifera and these populations appear to maintain their identity in that species composition and species associations were not significantly altered seasonally. Seasonal variations in foraminifera density suggested two different environmental mechanisms operating in the MAFLA area during the winter. In the area east and south of Cape San Blas minimal foraminiferal densities were present along Transects I-IV while west of Cape San Blas maximal foraminiferal densities were present on Transects V and VI. The role of Hurricane ELOISE in this is not clear. A general trend for a northward and westward increase in the live/dead ratios possibly reflected elevated nutrient inputs via the increased drainage systems present in the region. The high abundance of indicator species at the inshore stations of Transect VI suggest that these stations lie in a region of environmental stress. The proximity of this region to heavily populated areas and to major drainage systems supports this contention.

In the meiofauna, the nematodes and copepods were abundant and exhibited seasonal, geographic and bathymetric variations in density, although these patterns were neither completely uniform nor consistent. Consideration of the seasonal patterns in nematode and copepod densities suggest that the winter conditions adversely affect densities at most stations.

The lack of strong correlations between ATP levels and aliphatic and aromatic hydrocarbons and trace metals in the sediments indicates that present levels of these materials are not major factors adversely affecting the microbial population. The organic carbon content and the grain size at many of the stations did co-vary with ATP. The microbial biomass was also higher along Transects IV, V and VI during all sampling periods. Lower ATP levels were present along Transect II and for most offshore stations of Transects I-V and this may be indicative of decreased nutrient availability in these areas.

No discernible changes in either the amounts or composition of hydrocarbons in the epifaunal samples were detected between stations nor between sampling periods (nor were any non-biogenic hydrocarbons found). All organisms appeared to be basically pristine and the natural hydrocarbon distributions appeared to be relatively simple with a small number of major components dominating. These components are different for different genera and phyla.

In the algae, however, 15 out of the 36 samples analyzed contained hydrocarbons indicative of petroleum contamination. There was no correlation of this contamination with the presence of petroleum residues in nearby sediments or the species of algae. It was noted that the frequency of this contamination decreased steadily from summer through winter.

Terrestrial hydrocarbons were present in all of the sediment samples collected from Transect VI and all of the deep water stations from Transects I-V. Of lesser amounts in these samples were the low molecular weight hydrocarbons which produce a pattern similar to weathered crude oil. The remainder of the sediment samples from Transects I-IV contain neither of these features but have a great abundance of a C_{25} branched-unsaturated moiety and a major n-alkane of $\underline{n}C_{17}$ such as found in marine algae. Transect V sediments were intermediate in nature between Transect VI and Transects I-IV sediments.

Trace metals in the sediments correlated well with the fundamental sediment characteristics and there was no evidence of metal pollution. Significant correlations of the metals with iron occurred throughout the MAFLA area. The data indicate that iron may be used as an index for predicting trace metal concentrations, thus providing a means for assessing future anthropogenic input.

Geologically there were two major divisions of sediments within the MAFLA area. West of Cape San Blas the sediments are dominantly clastic and east of Cape San Blas the carbonates dominate. Within these major subdivisions at least eight separate sediment zones can be defined on the basis of sand/fine ratios, percent carbonate and mineralogy. Mississippi River influence diminishes from west to east and is not detectable in the shelf sediments east of Cape San Blas.

RECOMMENDATIONS

1. The large number of variables investigated and the required interdisciplinary approach to the data interpretation make it imperative that a proper statistical design be established prior to the initiation of any future sampling in this (or any other)area. The specific statistical tests to be conducted on (and between) each of the variables should be determined a priori; a posteriori testing should be limited to those instances where apparent relationships show promise of major significance to the work at hand. The establishment of a pre-sampling statistical design format would help to insure that the various disciplines would be privy to the information necessary for their data manipulation and the statistical analysis group would be continually aware of the statistical demands of the data.
2. The flow of data, dictated by the contract to be through Data Management to the Program Manager, unfortunately posed difficulties in establishing positive control not only over the actual data on hand but also delayed

the appropriate management control that could have been provided earlier. It is recommended that future work contracts be designed to allow for the proper flow of materials thereby allowing for the proper checks and balances. This will then allow for the timely exchange of data for interdisciplinary interpretation.

3. It has long been recognized by the BLM that monitoring studies must be long term in nature with the most intensive efforts being conducted early in these investigations. The duration of these intensive efforts has been accepted as being of at least three continuous years. However, it is also recognized that in the interim the BLM must make management decisions from the existing data base inadequate as it may be. It is strongly recommended therefore that sufficient capability and time be given to the programs to allow for continuing partial data synthesis the results of which can be forwarded to the BLM upon request.

Specifically, this means either more manpower to complete the sample analyses within the specified time periods (90 days) must be provided or a longer time period before submission of the draft final report. In the latter instance an additional 90-120 days for more complete data syntheses is in order before submission of the draft final report. This is especially critical to the benthic biology program. This is based upon our experience throughout the course of the present MAFLA work.

4. Intercalibration should be conducted on a national level among all BLM funded laboratories and one laboratory should be designated to prepare and distribute the intercalibration samples and to receive the data for comparisons, interpretation, etc. Intercalibration samples should be run

after a laboratory is in full operational status and at least before routine analysis of environmental samples begins.

5. It is strongly recommended that future water column studies not be restricted to one level in the water column and that at least the near surface, middle and near bottom waters be sampled. The location of those samples collected between the surface and bottom should be determined in the field and be based on the physical structure of the water column. This is especially necessary for the trace metals, hydrocarbons and the physical parameters. It should also be recognized that long term time studies are essential for the water column parameters if proper interdisciplinary interpretations are to be made. Further evidence of the need for these long term time studies is apparent from an examination of the distribution patterns of temperature, salinity and sigma t which resulted from the reoccupation of certain of these transects during the fall and winter seasons of 1975-1976.

6. The presence of what appears to be wax esters in the benzene fraction of certain of the zooplankton hydrocarbon analyses indicates a fault in the saponification procedures. This fault could have been detected earlier if GC/MS analysis had been a part of this contract. It is recommended that GC/MS analyses be made an integral part of all hydrocarbon programs and each investigator should have access to such instrumentation.

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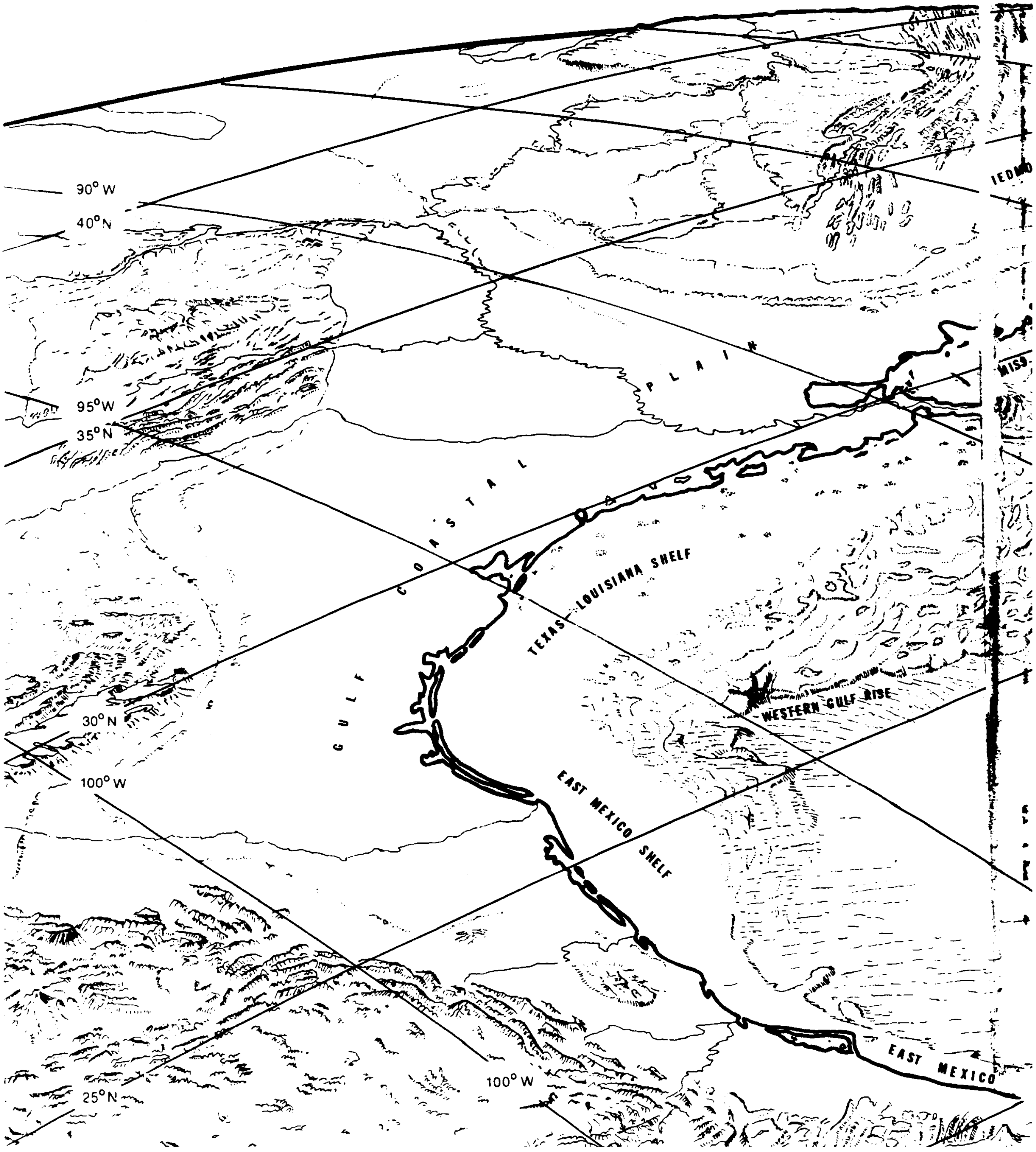

IEDMO
90° W
40° N
MISS
P L A I N
95° W
35° N
G U L F   C O A S T A L
TEXAS-LOUISIANA SHELF
WESTERN GULF RISE
30° N
100° W
EAST MEXICO SHELF
100° W
25° N
EAST MEXICO