THE SIGNIFICANCE OF ORGANIC CARBON AND SEDIMENT SURFACE AREA TO THE BENTHIC BIOGEOCHEMISTRY OF THE SLOPE AND DEEP WATER ENVIRONMENTS OF THE NORTHERN GULF OF MEXICO

A Thesis

by

MELANIE J BEAZLEY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2003

Major Subject: Oceanography

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Approved as to style and content by:

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ABSTRACT

The Significance of Organic Carbon and Sediment Surface Area to the Benthic Biogeochemistry of the Slope and Deep Water Environments of the Northern Gulf of Mexico. (August 2003)

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Chair of Advisory Committee: Dr. John W. Morse

The bioavailability of metabolizable organic matter within marine sediments is one of the more important driving mechanisms controlling benthic pelagic communities. Interactions between organic material and mineral surfaces within the sediment, such as adsorption, can cause organic matter to be unavailable for degradation by organisms; therefore for this study we have used the relationship of organic carbon-to-sediment surface area as an indicator of available organic carbon in northern Gulf of Mexico sediments. We have determined that these sediment interactions demonstrate a significant association with benthic fauna abundances; however they are not the most dominant environmental variables. It may be the combination of biogeochemical parameters, such as organic carbon content, sediment surface area, grain size, water depth and other geophysical variables, that is the ultimate control on the bioavailability of metabolizable organic matter in the northern Gulf of Mexico.

ACKNOWLEDGMENTS

I thank my advisor Dr. John W. Morse for academic support during my time at Texas A&M University and for his encouragement to complete this work in two years. I thank my committee members Dr. Mahlon C. Kennicutt II, Dr. Gilbert T. Rowe and Dr. Ethan Grossman for their advice and constructive comments on this thesis. I thank Dr. Jay Pinckney at Texas A&M University for statistical advice and Dr. Gary Wolff at the Geochemical & Environmental Research Group for map construction. I thank Dr. Andreas Luttge and Dr. Rolf Arvidson at Rice University for use of the surface area analyzer. Dr. Luis Cifuentes and Brian Jones at Texas A&M University provided equipment and assistance with stable carbon isotope analysis. I thank the following for generously providing fauna data: Dr. Gilbert T. Rowe at Texas A&M University for macrofauna data, Dr. Paul A. Montagna at the University of Texas Marine Science Institute for meiofauna data and Dr. Jody W. Deming at the University of Washington for bacteria data. Funding for the Deep Gulf of Mexico Benthic Ecology program was provided by the Minerals Management Service. Graduate financial support was provided by a fellowship from the Sustainable Coastal Margins Program.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

INTRODUCTION

There is great debate in the literature concerning the factors that control the preservation of organic matter in marine sediments. It has been determined that burial of organic matter is directly associated with the global cycles of carbon, oxygen and sulfur (Berner, 1982) and therefore of great significance. Though considerable research has been done on the preservation of organic matter, the mechanisms for its preservation still remain unclear (Keil and Cowie, 1999; Hartnett et al, 1998; Canfield, 1994; Lee, 1994; Hedges et al., 1999).

Organic matter enters the world's oceans from two primary sources: marine primary productivity and terrestrial river runoff. Rivers adjacent to continental margins deposit 0.01 to 1 cm (Berner, 1980) of organic-rich sediment onto deltas and continental shelves and slopes each year. These areas are also rich with primary productivity due to the increased flux of nutrients from rivers and coastal upwelling. It is along these continental margins that over 90% of the organic matter in all of the oceans reside (Berner, 1980; Hedges and Keil, 1995). Therefore, the sediments of deltas, shelves and slopes adjacent to continents provide excellent test sites to study the mechanisms of preservation of organic matter in marine sediments.

Organic material is produced in marine surface waters by the photosynthetic processes of phytoplankton. This primary production is grazed upon by herbivorous zooplankton which release biochemical compounds and excreta to the water column.

This thesis follows the style and format of *Geochimica et Cosmochimica Acta*.

As the detritus sinks through the water it is subject to break down, or remineralization, by bacterial activity releasing dissolved nutrients to the water. The original organic material produced in the surface waters is repeatedly recycled and sinks in the particulate form to the sea bottom. The amount of organic material that reaches the sediment is proportional to the depth of the water column and the amount of primary production in surface waters. The percentage of organic matter that makes it to the sediments is generally <10% depending on the depositional conditions (Mayer, 1993). The chemical composition of this material is complex being composed of carbohydrates, amino acids, carboxylic acids and other organic macromolecules (Keil et al., 1998)). The biochemical structures determine how "labile" it is to degradation. The more labile materials are easier for organisms to digest and therefore these materials are recycled faster than the less labile fractions. The organic material that reaches the sediment becomes the energy source for benthic organisms including bottom-feeding fish and deposit-feeders at or near the sediment-water interface. Once deposited in the sediment, organic material is consumed and recycled by heterotrophic macrofauna, meiofauna, and bacteria.

The organic material that is transported to the oceans by rivers is a complex mixture of humic substances derived from plant and animal detritus. Much of this material consists of non-labile lignin structures which can be deposited on river deltas and fans. Due to high sedimentation rates, deposited organic material may have insufficient time to be completely oxidized under aerobic conditions before being buried by continuing sedimentation.

Once organic matter reaches the sediment, whether from marine or terrestrial sources, it will be exposed to degradation processes and can be completely respired back to CO_2, transformed to by-products, or preserved in the sediment. Several factors affect the preservation of organic material in marine sediments including, but not limited to, bottom-water oxygen levels (Canfield, 1994) organic matter origin (Hedges et al., 1988) water column depth (Suess, 1980), geopolymerization (Berner, 1980), microbial dynamics (Lee, 1992), and adsorption to mineral surfaces (Mayer, 1994a; Mayer, 1994b). The purpose of this study is to examine one of these preservation factors: the adsorption of organic matter on the surfaces of minerals within the marine sediment.

During the past decade there has been increased interest in the study of organic matter associated with the surfaces of marine particles. Marine sediments are composed of a wide assortment of minerals of varying sizes which have been transported from the continents due to weathering or have been formed *in situ* by chemical reactions in sediment pore spaces. The size of the grains is one determination on the amount of mineral surface area. These surfaces exhibit an imbalance in charge which makes them especially effective for adsorption of dissolved organic material (Langmuir, 1997). Reactive sites are the locations for exchanges of ions and molecules between the solid and liquid porewater phases. The ion exchange capacity of a mineral may be negative or positive and either permanent or dependent on porewater conditions, such as pH (Langmuir, 1997). In addition to ionic bonding between organics and mineral surfaces there are other chemical mechanisms such as covalent bonding, hydrogen bonding and weak van der Waals attractions (Mayer, 1993). Due to the heterogeneity of marine

sediments and the organic matter it contains, delineating specific mechanisms of mineral adsorption in marine systems is difficult at best.

One method for examining the extent of organic matter adsorption onto mineral surfaces is to determine the relationship of organic material to the surface area of the sediment (Keil et al., 1994a; Keil et al., 1994b; Mayer 1994a; Mayer, 1994b). Over 90% of the organic matter in sediments has been found to be intimately associated with the mineral phase (Keil et al., 1994a); therefore it is possible to correlate the organic matter content with the surface area and grain size of sediment constituents. Mayer (1994a) examined the organic carbon-to-surface area (OC/SA) relationship of sediments from continental shelves around the world. He found a general linear relationship in which he termed a 'monolayer-equivalent' (ME) level of 0.5-1.0 mg-OC m^{-2} in non-deltaic shelf sediments, which corresponded to a monolayer of organic coating covering the mineral surfaces. Deltaic sediments had values of 0.2 mg-OC m^{-2}, which was lower than ME levels (Mayer, 1994a; Mayer, 1994b). Carbonate sediments had higher than ME levels and deep-sea sediments had lower than ME levels (Mayer, 1994b). He also determined that the organic matter was primarily associated with the mineral surfaces and could not be physically separated, suggesting adsorption. The monolayer-equivalent level was also confirmed by Keil et al. (1994a) for sediments off the shore of Washington state.

Mayer (1994a) examined the topography of the mineral surfaces and found that the roughness of the surface contributed greatly to the surface area. The majority of the surface area was found within mesopores (<10 nm width) on the surfaces of the minerals. He hypothesized that organic matter might be contained within mesopores and

was therefore unavailable for enzymatic attack during the biological oxidation of organic matter.

Ransom's results (Ransom et al., 1997; Ransom et al., 1998) contradicted the monolayer hypothesis. Transmission electron microscopy (TEM) showed that organic matter was present in patchy, discontinuous smears on particle surfaces. Adsorption was associated with clay minerals and did not occur as monolayer coatings or filled mesopores. She found that the organic content was controlled primarily by interaction with clay minerals, and that different clays had variable retention capabilities.

Mayer (1999) countered that visible microscopy lacked the resolution for inspecting monolayers and developed a technique using gas adsorption to determine the extent of mineral surface coverage. His results indicated that organic matter was not adsorbed in a monolayer but in patches thicker than a single layer.

If adsorbed organic material is protected from degradation, it is probable that desorption will make labile material available for oxidation. Laboratory experiments indicate that desorbed organic matter is labile when exposed to bacteria (Keil et al., 1994b). This suggests that the adsorption of organic material to mineral surfaces protects organic matter and slows remineralization reactions within sediments (Keil et al., 1994b; Mayer, 1994a). The stabilization of organic matter by mineral matrices is found in terrestrial soil environments as well. Baldock and Skjemstad (2000) determined that although protection is not permanent, it can slow the rate of decomposition protecting the organic matter from oxidation. The "protective capacity" of the soil depends on the specific chemical and physical structure of the minerals and

organic matter. Different minerals have different organic matter stabilization capabilities. They determined that organic carbon in soils correlated positively with clay content and was protected from biological attack especially in the presence of $CaCO_3$ or Al and Fe oxides. The adsorption of organics on mineral surfaces in soils is not only a function of mineral structure but also of the chemical structure of the organic matter itself (Keiser and Guggenberger, 2000). In marine sediments, carbon-rich fractions of organic material were found in larger grain sizes and nitrogen-rich fractions were found in smaller clay-sizes (Keil et al., 1994a).

Recent studies (Bergamaschi et al., 1997; Volkman et al., 2000) indicate that hydrodynamic controls affecting grain size distributions in marine sediments are a principal factor in determining sediment organic carbon content. Using TEM, energy-filtering TEM (EFTEM) and electron energy loss spectroscopy (EELS), Furukawa (2000) found that organic matter in clay-rich sediments is closely associated with clay aggregates. It occurs in high concentration at the edge of clay plates and in some cases is incorporated into the structural matrix of the mineral. In addition, organic material was found specifically on minerals, such as smectitic clays, which contained calcium edges. He could not distinguish if this was due to chemical bonding, depositional dynamics or smectite mesopores.

Over the past decade the study of organic matter preservation in the presence of mineral matrices has been the subject of intense study. Much progress has been made in understanding how the interaction of organics and minerals affect not only preservation but also bioavailability to organisms. The aim of this research is to determine how

associations of organic material with mineral surface area affect the biogeochemistry of benthic sediments in the continental slope and deep water environments of the northern Gulf of Mexico (GOM).

EXPERIMENTAL

Deep Gulf of Mexico Benthic Ecology Program

Previous studies have demonstrated the importance of mineral surface area and grain size to the preservation of organic carbon in marine sediments. The aim of this study is to continue this investigation in the northern Gulf of Mexico. The Gulf of Mexico is a region with a high diversity of sedimentary environments. It offers an opportunity to study a wide variety of sediments, including those on the continental shelf, the deep abyssal plain and in proximity to the Mississippi River Trough and the Florida Escarpment. The study was conducted in conjunction with the Deep Gulf of Mexico Benthic Ecology (DGoMB) program contracted by the Minerals Management Service.

The objective of the DGoMB program is to "provide a better understanding of: 1) the present condition of biological communities in the study area, 2) the distribution patterns of deep-sea biota, 3) the biological and physical processes that control the environmental setting, and 4) the effects that these processes have on the character of benthic and benthopelagic communities" (Rowe and Kennicutt II, 2001). As part of this investigation specific objectives include the study of the role of organic carbon and sediment surface area in controlling biological processes and availability of organic matter within sediments.

The DGoMB program will span 4.5 years and include data collected from 53 sites throughout the Gulf of Mexico. The sites were chosen based on water depth,

nutrients, productivity, hydrocarbon seeps, temporal changes and the presence or absence of basins, canyons and steep escarpments.

This research is unique in that it includes a full suite of concurrent chemical, physical, geological and biological data, greatly enhancing data synthesis and interpretation.

Hypotheses

The null hypotheses developed for the DGoMB (Rowe and Kennicutt II, 2001) program were revised to reflect the aim of this study to determine if organic matter-to-surface area (OC/SA) is an important biogeochemical factor in describing Gulf of Mexico biological and physical patterns.

H_{01}: There is no variation in OC/SA with water depth.

H_{02}: There is no variation in OC/SA along an east to west gradient.

H_{03}: There is no variation in OC/SA among different sampling dates.

H_{04}: There is no variation in benthic organism abundance with OC/SA.

Study Sites

The sites selected for this study (Table 1; Figure 1) were based on water depth and proximity to the Mississippi River Trough, the Florida Escarpment, hydrocarbon seeps, and high production areas.

Sample Collection

Samples were collected during the summers of 2000, 2001, and 2002 on cruises aboard the *R/V Gyre*. Sediment cores (20 cm in length) were collected at each station using a 0.2 m^2 GOMEX boxcore. The top 2 cm of sediment and porewater was

collected and immediately frozen. A total of 23 sample sites were chosen with five of the sites visited in two different years.

Table 1. Sample sites (D = depth, P = productivity, S = seeps, T = temporal, E = escarpment).

Station	Latitude N	Longitude W	Depth (m)	Year	Characteristic
AC1	26°23.2813'	94°33.2633'	2450	2000	D
B2	26°33.3750'	92°13.4716'	2630	2000	D
Bush Hill	27°47.8935'	91°28.2050'	548	2001	P,S
HiPro	28°33.0955'	88°34.7428'	1574	2001	P
MT1(a)	28°32.4666'	89°49.5011'	481	2000	D,T
MT1(b)	28°32.1101'	89°49.5365'	490	2001	D,T
MT3(a)	28°13.0561'	89°29.6289'	988	2000	D,T
MT3(b)	28°13.4727'	89°30.7579'	980	2001	D,T
MT4	27°49.7018'	89°9.8829'	1401	2000	D
MT5	27°19.5819'	88°40.1733'	2290	2000	D
MT6(a)	27°0.0892'	87°59.2938'	2750	2000	D,T
MT6(b)	26°59.4407'	88°0.8396'	2740	2001	D,T
NB4	26°14.9693'	92°23.4231'	2050	2000	D
RW1	27°29.9333'	96°0.2164'	213	2000	D
RW2	27°15.2852'	95°44.6402'	950	2000	D
RW3	27°0.2956'	95°30.0541'	1325	2000	D
RW4	26°44.9468'	95°14.6826'	1580	2000	D
RW5	26°30.0261'	95°0.1315'	1620	2000	D
RW6	26°0.0142'	94°29.9381'	3015	2000	D
S36(a)	28°55.0080'	87°40.0627'	1832	2000	D,P
S36(b)	28°54.7195'	87°40.7206'	1849	2001	D,P
S42(a)	28°15.0602'	86°25.1562'	772	2000	D,E
S42(b)	28°15.2223'	86°25.7206'	773	2001	D,E
S43	28°30.1434'	86°4.8562'	360	2000	D,E
S44	28°44.9996'	85°44.8622'	212	2000	D,E
S1	24°59.8793'	92°0.7778'	3527	2002	D
S4	24°14.6713'	85°28.2728'	3408	2002	D
W5	26°16.5781'	93°21.7309'	2740	2000	D,S

(a) = year 2000; (b) = year 2001

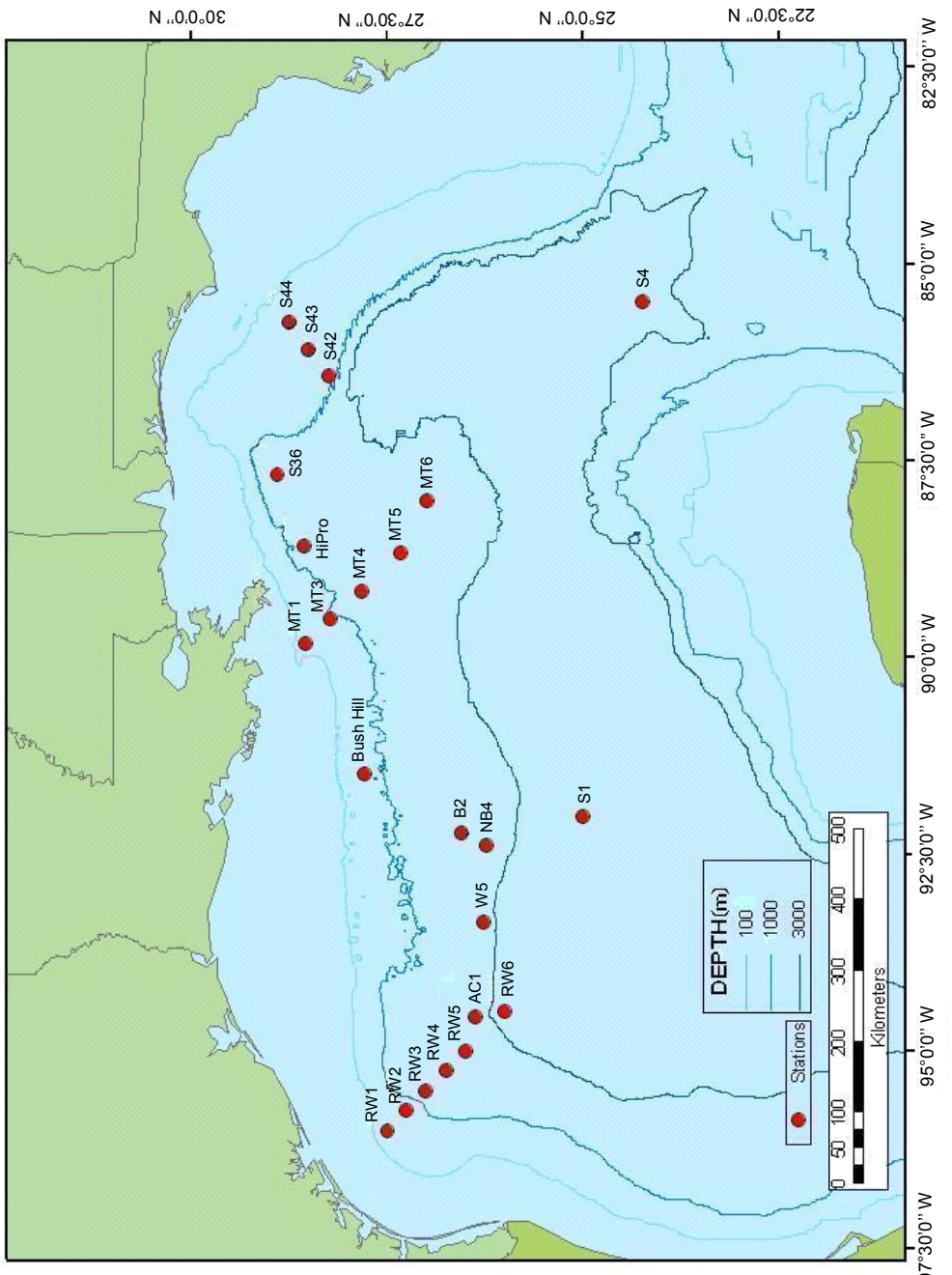

Figure 1. Map of Gulf of Mexico sampling stations.

Experimental Methods

Surface area

Solid sediment was freeze-dried and outgassed at 150°C for several hours prior to analysis. Surface area determinations were made by nitrogen adsorption at 77.35 K on a Micromeritics ASAP 2010 Analyzer using multi-point BET (Brunauer-Emmett-Teller) adsorption isotherms (Brunauer et al., 1938; Mayer, 1994a). Replicate samples of alumina silica standards had a standard deviation of ± 1%.

O*rganic and inorganic carbon*

Solid sediment was prepared for carbon analysis by drying at 100°C and grinding with a mortar and pestle. Total carbon was determined by combusting samples at 950°C for 10 minutes with a carbon furnace (UIC, Inc.) and measuring the released CO_2 with an attached coulometer (UIC, Inc.). Samples were prepared for organic carbon analysis by drying at 100°C, grinding with a mortal and pestle, and acidifying with 1N HCl. Samples were then dried at 100°C prior to combustion. Inorganic carbon and organic carbon was determined by difference adjusting for $CaCl_2$ formation. Replicate samples of soil standards (Leco) had a standard deviation of ± 3%.

Weight percent calcium carbonate (wt % $CaCO_3$) was determined from % inorganic carbon using Equation 1:

$$\text{wt \% } CaCO_3 = (100/12) * \text{ \% inorganic carbon.} \quad (1)$$

Percent organic carbon (wt % OC) on a carbonate-free basis was calculated using Equation 2:

$$\text{wt \% OC (carbonate-free)} = \text{wt \% OC} / (1-(\text{wt \% } CaCO_3 / 100)). \quad (2)$$

Grain size

Grain size analysis was performed according to the method described by Sweet et al. (1998). The sediment sample (~15-20 grams) was treated with ~50-100 mL of 30% hydrogen peroxide for 12 hours prior to analysis to oxidize organic matter. The sample was washed with distilled water to remove soluble salts and 400 mL of sodium hexametaphosphate solution (~5.5 g/L) was added to disperse the sample, followed by shaking for ~24 hours on a shaker table.

The sample was sieved through a 62.5 μm screen to separate the sand fraction and dried for 24 hours. The standard Folk settling method (Folk, 1974) was utilized to determine the silt and clay fractions (8φ and 4φ dry weights).

Stable carbon isotopes

Stable carbon isotope ratios were analyzed using a Finnigan MAT 252 Isotope Ratio Mass Spectrometer on acidified (1N HCl) freeze-dried samples that had been dry combusted to CO_2 under vacuum with CuO using the method described by (Boutton, 1991). The $^{13}C/^{12}C$ ratio of the organic carbon is reported relative to the PDB standard (VPDB) in per mil (‰). Replicate samples of glucose standards had a standard deviation of ± 0.1%.

Microelectrode profiles

Microelectrode profiles of the redox species O^{2-}, Mn^{2+}, Fe^{2+} and ΣH_2S were produced using a reference and counter (Pt wire) electrode in conjunction with a working electrode (Au/Hg) according to the method described by Brendel and Luther (1995). The microelectrodes used in this project were manufactured by encasing a

100µm gold wire in a borosilicate glass tube and filling the tube with an epoxy. The tip of the electrode was then polished and plated with mercury to create the amalgam. To strengthen the amalgam, the tip was placed into a 1.0M solution of NaOH while applying a voltage of -9.0V. The strengthening of the amalgam comes from the polarization which facilitates the diffusion of mercury up the gold wire. Methods of square wave voltammetry (SWV), linear sweep voltammetry (LSV), and cyclic wave voltammetry (CWV) were used to quantify the redox species. Standards used were analytical grade Fe (NH_4) $(SO_4)_2 \cdot 6H_2O$ (Baker), $MnCl_2 \cdot 6H_2O$ (Baker), and a standard solution of 0.001 M $Na_2S \cdot 9H_2O$ (Aldrich). Measurements were made at depth intervals of 2 mm.

Macrofauna abundance

The top 15 cm of sediment from each of five replicate boxcores was sieved through a 300 µm sieve and fixed in 10% formalin with seawater. The macrofauna were sorted under dissecting microscopes into major taxonomic groups. The abundance values used in this study were the average of the five replicate boxcores.

Meiofauna abundance

The top 3 cm of sediment from five replicate boxcores was sampled for meiofauna abundance. The samples were fixed in 7% $MgCl_2$ and preserved in 5% formalin and the Ludox centrifugation technique (deJong and Bouwman, 1977) utilized to extract the meiofauna. Samples were sieved through 300 µm and 63 µm screens and counted into major taxonomic groups. The abundance values used in this study were the average of the five replicate boxcores.

Bacteria abundance

Sediment cores from five replicate boxcores were subsampled and fixed in 2% formaldehyde. Bacteria abundance was determined using a dual staining technique and standard epifluorescence microscopy (Relexans et al., 1996; Schmidt et al., 1998). The bacterial abundance in the top 1 cm of sediment was used in this study.

RESULTS

Surface Area and Grain Size

BET surface areas ranged from 8.92 to 49.7 m^2g^{-1} (Table 2; Figure 2) across the sites in the Gulf of Mexico with a mean of 32.1 ± 9.75 m^2g^{-1}. These surface areas were indicative of sediments with high silt and clay (<63 μm) size fractions. The high relative standard deviation indicated the inhomogeneity of sediments across the Gulf of Mexico. Three stations, S42, S43 and S44, along the Florida Escarpment in shallow (<1000 m) sediments had small surface areas (8.92-17.8 m^2g^{-1}) indicating the dominance of >63 μm size fraction. These samples contained 56 to 72 wt % $CaCO_3$ and 17.7 to 56.7 wt % sand fraction. Highest surface areas (>40.0 m^2g^{-1}) were found at RW2, RW3, MT1(b), MT5 and HiPro, which all contained >90% silt and clay fraction except MT5. The majority of the samples (70%) had surface areas with a mean of 32.9 m^2g^{-1} and a relative standard deviation of 4.4%. Surface areas generally increased with increasing wt % <63 μm (Table 2; Figure 3), with the exceptions at MT5 and MT6. This may be due to extensive patches of iron stone that were observed at these stations, which may have been retained by the 63 μm sieve and counted in the sand fraction. Such large sediment pieces would have been removed prior to surface area analysis in order to maintain a homogenous sample. The grain size analysis is illustrated in Figure 4 by a tertiary diagram. The majority of the samples were composed of a clay-silt mix, with the exceptions of S43, S44, MT5 and MT6(a), which contained higher sand fractions.

Table 2. Surface area and grain size analyses.

Station	Depth (m)	% Sand	% Silt	% Clay	SA (m^2g^{-1})	Wt % $CaCO_3$
AC1	2450	5.0	34.5	60.4	31.4	29
B2	2630	3.6	42.7	53.8	33.5	23
BushHill	548	4.9	37.5	57.6	33.4	15
HiPro	1574	2.5	44.5	52.9	48.1	6.7
MT1(a)	481	2.5	40.3	57.2	33.4	5.3
MT1(b)	490	1.5	25.7	72.8	40.9	5.4
MT3(a)	988	3.0	42.6	54.4	34.2	8.1
MT3(b)	980	3.5	38.0	58.5	39.3	8.4
MT4	1401	9.0	45.5	45.5	34.9	20
MT5	2290	64.3	15.3	20.4	42.6	8.0
MT6(a)	2750	38.1	21.5	40.4	26.4	32
MT6(b)	2740	21.2	32.3	46.5	35.0	19
NB4	2050	17.2	35.0	47.9	30.5	34
RW1	213	7.9	33.1	59.1	34.9	20
RW2	950	6.9	37.6	55.5	49.7	11
RW3	1325	7.8	31.3	60.9	39.5	24
RW4	1580	8.2	31.1	60.7	35.8	30
RW5	1620	8.0	28.0	64.0	34.8	30
RW6	3015	4.5	34.2	61.3	33.1	26
S36(a)	1832	7.6	41.2	51.1	36.9	25
S36(b)	1849	4.7	39.6	55.7	30.1	24
S42(a)	772	20.5	31.4	48.1	17.8	57
S42(b)	773	17.7	33.8	48.5	17.3	56
S43	360	36.3	37.5	26.2	11.7	70
S44	212	56.7	27.0	16.3	8.92	72
S1	3527	21.2	27.7	51.1	25.3	39
S4	3408	14.9	27.0	58.1	39.2	16
W5	2740	6.4	33.6	59.9	21.4	29

(a) = year 2000; (b) = year 2001

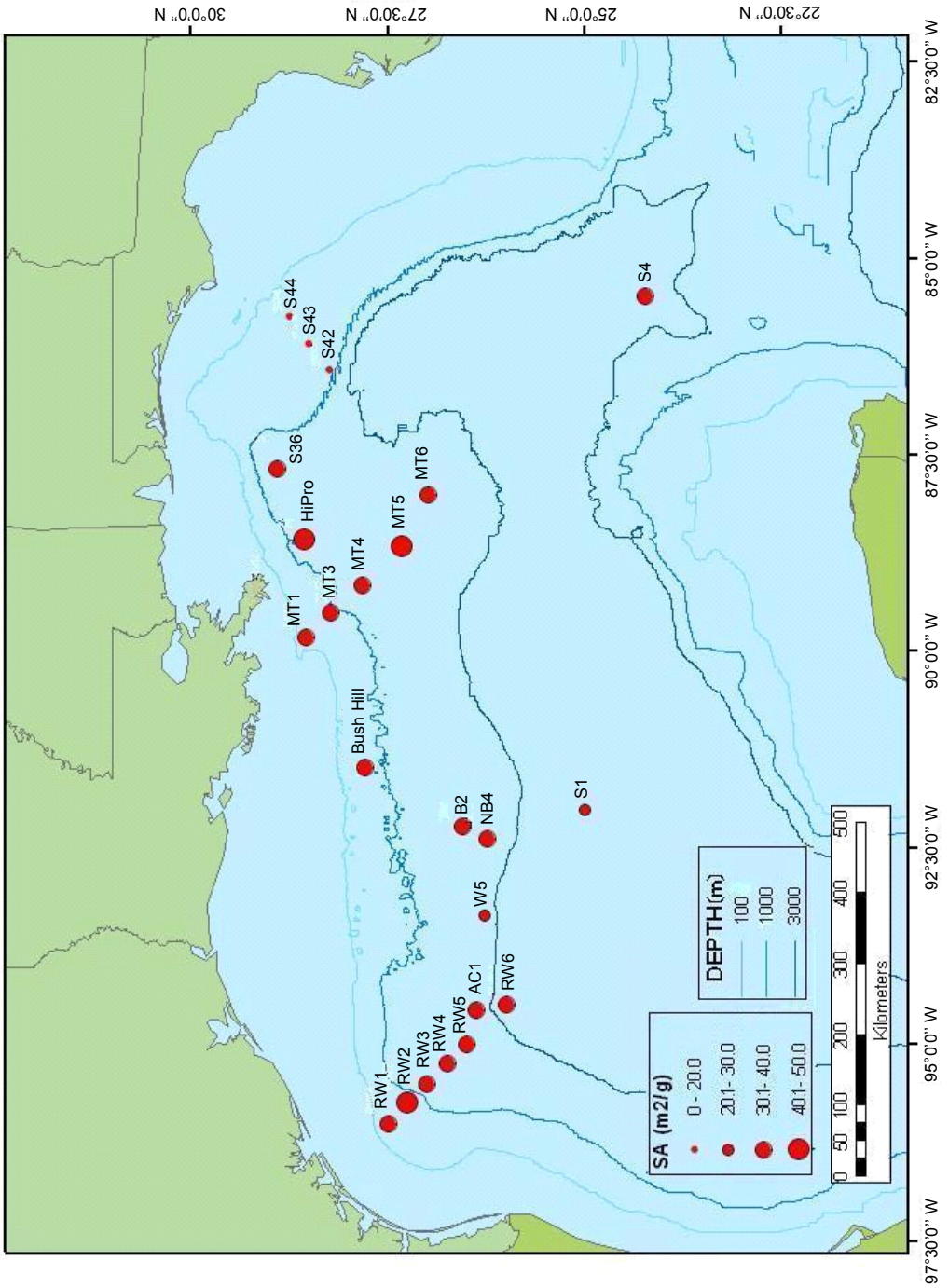

Figure 2. Map of Gulf of Mexico sediment surface area.

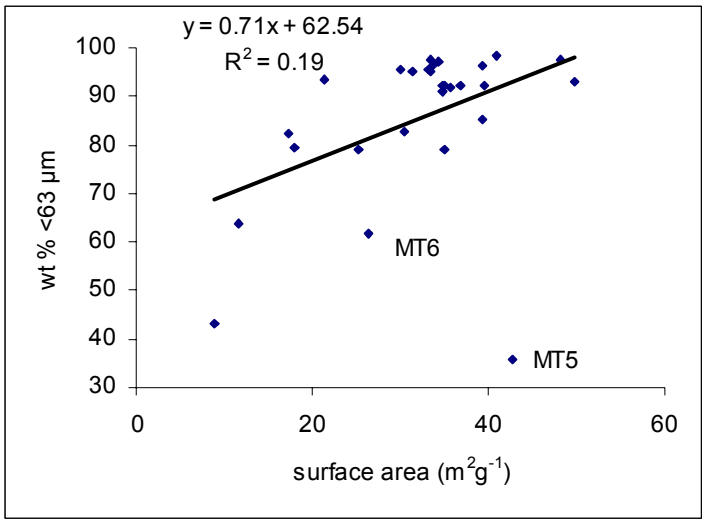

Figure 3. Comparison of sediment wt % <63 µm to surface area. Surface areas generally increased with increasing wt % <63 µm at most stations with the notable exceptions of MT5 and MT6.

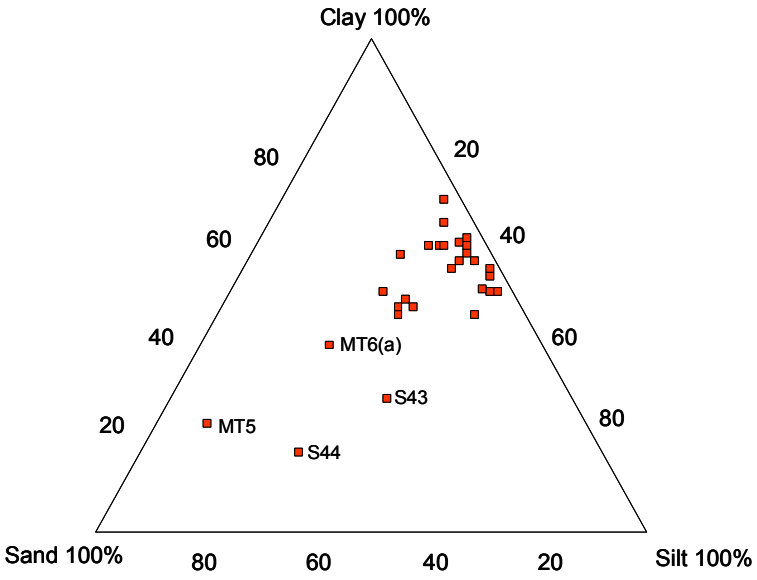

Figure 4. Grain size tertiary diagram.

Organic Carbon

Weight percent organic carbon (wt % OC) in the top 2 cm of sediment ranged from 0.37 to 1.3 wt % (Table 3; Figure 5) with a mean of 0.80 ± 0.27 wt %. The lowest values of organic carbon were found in sediments at depths >2000 m and along the Florida Escarpment at depths of 200 to 750 m. Stations with >1.0 wt % OC include MT1, MT3, HiPro, S36, and Bush Hill.

Mayer (1994a, 1994b) established the dependence of organic carbon on surface area in marine environments across a broad range of sediments throughout the world, including the Mississippi Delta region. Using a linear regression he determined a significant relationship between organic carbon and surface area (OC/SA) of 0.5 to 1.0 mg-OC m^{-2}. Though it has been determined that this does not represent a monolayer of organic coating, it does suggest an adsorptive association of organic carbon with sediment minerals. For Mississippi Delta sediments Mayer determined a lower OC/SA value of 0.26 mg-OC m^{-2} (Mayer, 1994a), which he attributed to high riverine input. OC/SA values determined for this study ranged from 0.11 to 0.52 mg-OC m^{-2} with a mean of 0.27 ± 0.11 mg-OC m^{-2} (Table 3; Figure 6). The OC/SA values near the Mississippi River mouth region (~0.30 mg-OC m^{-2}) were in agreement with those determined by Mayer.

The OC/SA values determined for this study were well below those determined by Mayer and were representative of delta and deep-sea sediments due to low organic carbon content. Of particular note the lowest OC/SA values (0.11 mg-OC m^{-2}) were at MT5 and MT6, which fall off the surface area-grain size trend (Figure 3). There was a

general positive relationship between wt % OC and surface area, but was not significant to $P < 0.05$ for all stations in the northern GOM. When these two stations were omitted from the regression the relationship became significant to $P < 0.05$. This suggests that the relationship between wt % OC and surface area at the sites in the northern GOM is valid for OC/SA values above 0.11 mg-OC m^{-2}.

Table 3. Carbon and surface area data for the Gulf of Mexico sample set.

Station	Depth (m)	wt %Total C	wt % Inorganic Carbon	wt % $CaCO_3$	wt % OC	SA (m^2g^{-1})	OC/SA (mg m^{-2})	$\delta^{13}C_{OC}$(‰)
AC1	2450	4.3	3.4	29	0.88	31.4	0.28	-27.0
B2	2630	3.5	2.7	23	0.74	33.5	0.22	-22.6
Bush Hill	548	2.7	1.8	15	1.0	33.4	0.29	-21.8
HiPro	1574	1.8	0.80	6.7	1.0	48.1	0.21	-23.6
MT1(a)	481	1.9	0.64	5.3	1.3	33.4	0.39	-22.5
MT1(b)	490	1.9	0.65	5.4	1.3	40.9	0.31	-23.5
MT3(a)	988	2.2	1.0	8.1	1.2	34.2	0.35	-21.1
MT3(b)	980	2.2	1.0	8.4	1.2	39.3	0.30	-21.2
MT4	1401	3.3	2.4	20	0.80	34.9	0.23	-25.1
MT5	2290	1.4	1.0	8.0	0.45	42.6	0.11	-26.6
MT6(a)	2750	4.2	3.9	32	0.37	26.4	0.14	-21.5
MT6(b)	2740	2.7	2.3	19	0.40	35.0	0.11	-23.6
NB4	2050	4.8	4.1	34	0.63	30.5	0.21	-30.0
RW1	213	3.4	2.4	20	0.95	34.9	0.27	n.d.
RW2	950	2.0	1.3	11	0.71	49.7	0.14	-20.6
RW3	1325	3.7	2.9	24	0.78	39.5	0.20	-22.5
RW4	1580	4.4	3.6	30	0.80	35.8	0.22	-31.5
RW5	1620	4.3	3.6	30	0.73	34.8	0.21	-33.5
RW6	3015	3.9	3.2	26	0.72	33.1	0.22	-25.0
S36(a)	1832	4.1	3.1	25	1.1	36.9	0.28	n.d.
S36(b)	1849	4.1	2.9	24	1.2	30.1	0.39	-21.8
S42(a)	772	7.5	6.9	57	0.62	17.8	0.35	-24.9
S42(b)	773	7.4	6.7	56	0.66	17.3	0.38	n.d.
S43	360	9.0	8.4	70	0.61	11.7	0.52	-26.6
S44	212	9.1	8.7	72	0.46	8.92	0.52	n.d.
S1	3527	5.2	4.7	39	0.49	25.3	0.20	-20.6
S4	3408	2.5	2.0	16	0.55	39.2	0.14	-24.6
W5	2740	4.5	3.5	29	0.94	21.4	0.44	-26.7

(a) = year 2000; (b) = year 2001

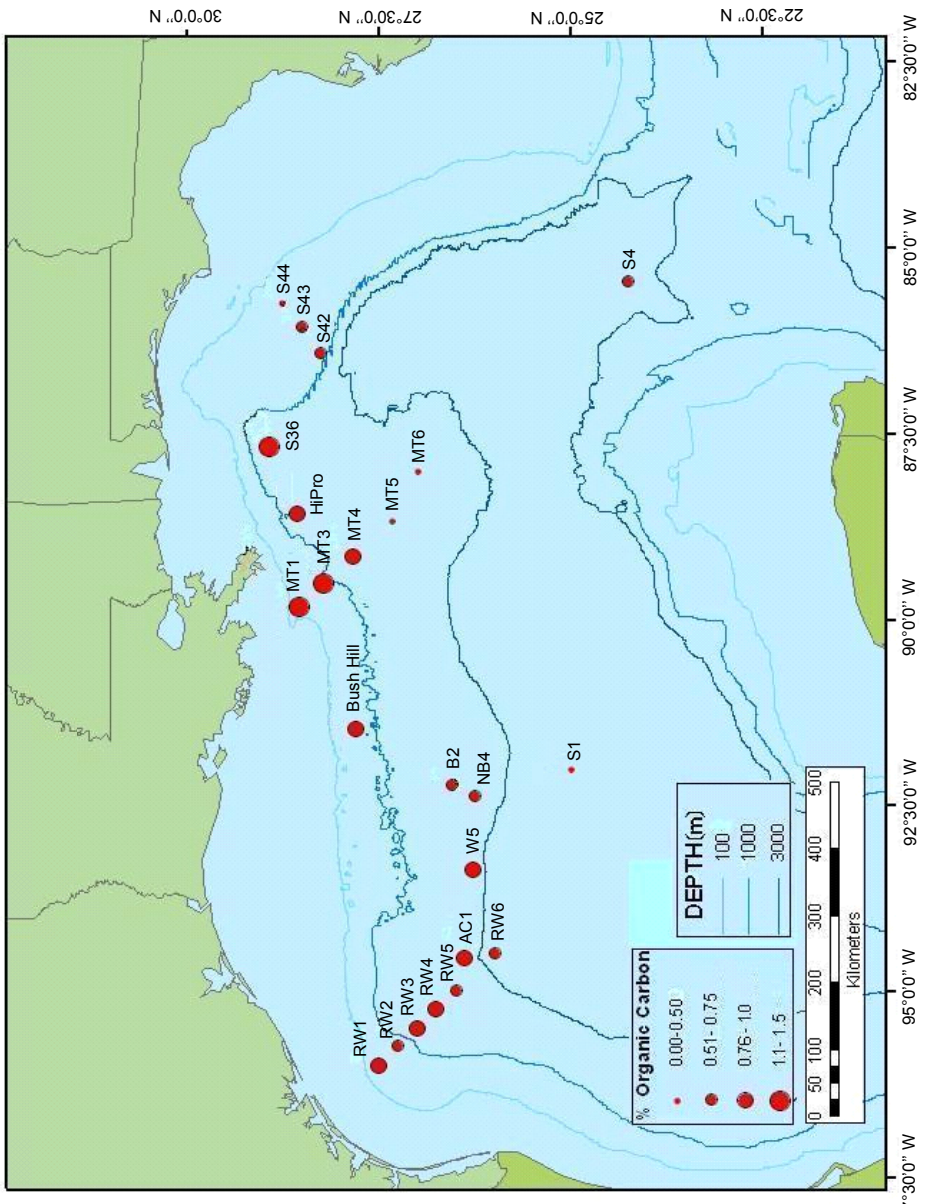

Figure 5. Map of Gulf of Mexico wt % organic carbon.

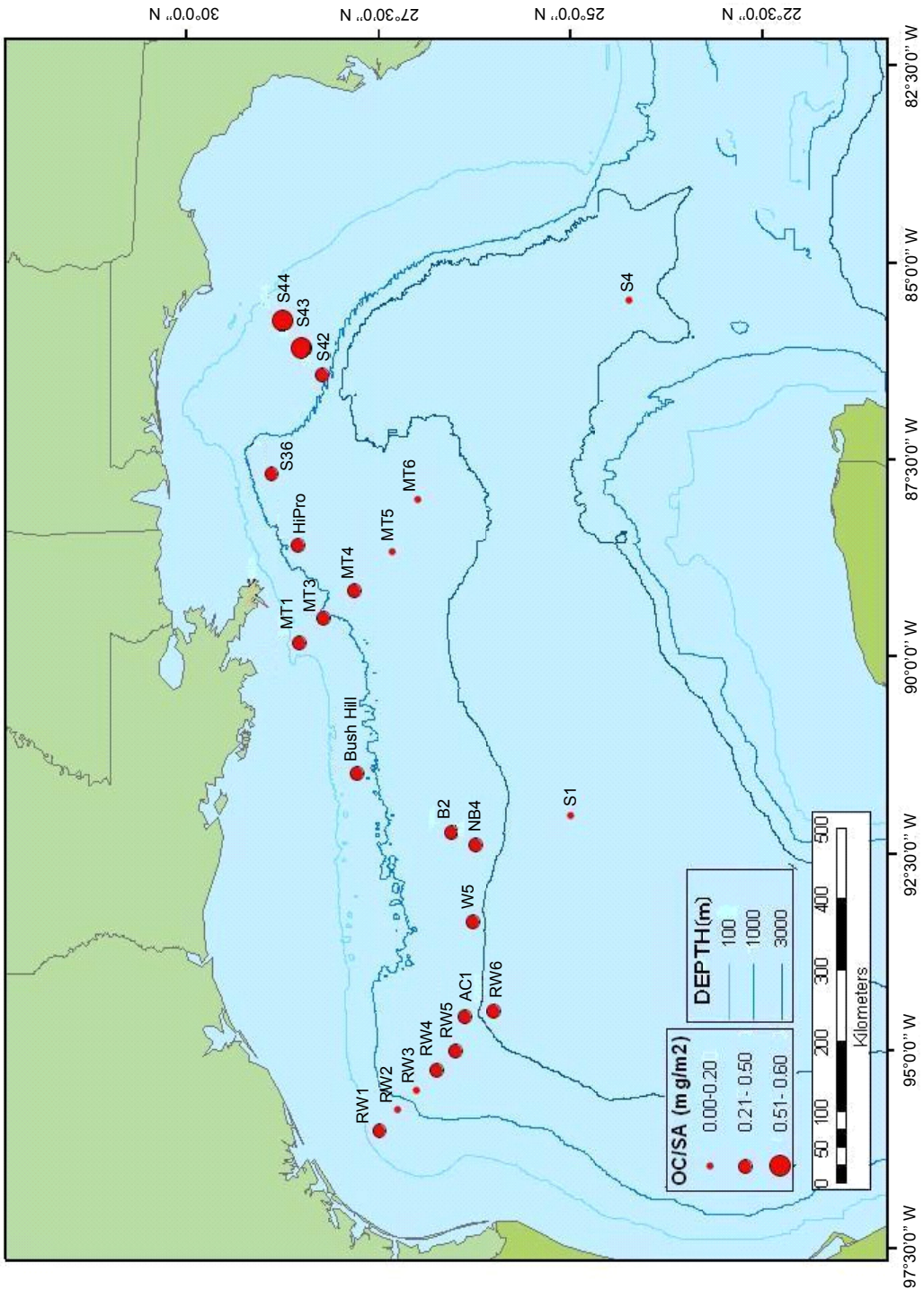

Figure 6. Map of Gulf of Mexico organic carbon-to-surface area (OC/SA).

Calcium Carbonate

Weight percent calcium carbonate (wt % $CaCO_3$) in the Gulf of Mexico sediment samples ranged from 5.3 to 72 wt % (Table 3; Figure 7) with a mean of 27 ± 18 wt %. Stations nearest the Mississippi River (MT1, MT3, MT5, and HiPro) had the least wt % $CaCO_3$ (< 10 wt % $CaCO_3$), which could be due to dilution effects by transported river sediment. Stations along the Florida Escarpment (S42, S43, and S44) had the greatest wt % $CaCO_3$ (>50 wt % $CaCO_3$), due to the carbonate shelf off the western coast of Florida. Calcium carbonate content within GOM sediments could also be attributed to calcareous foraminifera which are ubiquitous in the GOM.

Stable Carbon Isotopes

Stable carbon isotope ratios ($\delta^{13}C_{OC}$) ranged from -20.6 to -33.5‰ (Table 3; Figure 8) with a mean of -24.5 ± 3.45‰. Three stations, RW4, RW5, and NB4, had $\delta^{13}C_{OC}$ values of -30.0 to -33.5‰, indicative of contribution from a hydrocarbon source. MT1, MT3, Bush Hill, HiPro and S36 had $\delta^{13}C_{OC}$ values (~-22‰), which were more typical of marine sources. Similar values have been documented for this area (Sackett and Thompson, 1963; Gearing et al., 1977; Goñi et al., 1998). The waters near the Mississippi River and the Desoto Canyon are characteristically high in nutrients and support high primary production. The $\delta^{13}C_{OC}$ confirmed that primary production at the surface was probably the main source of organic matter to the sediment and not river transport.

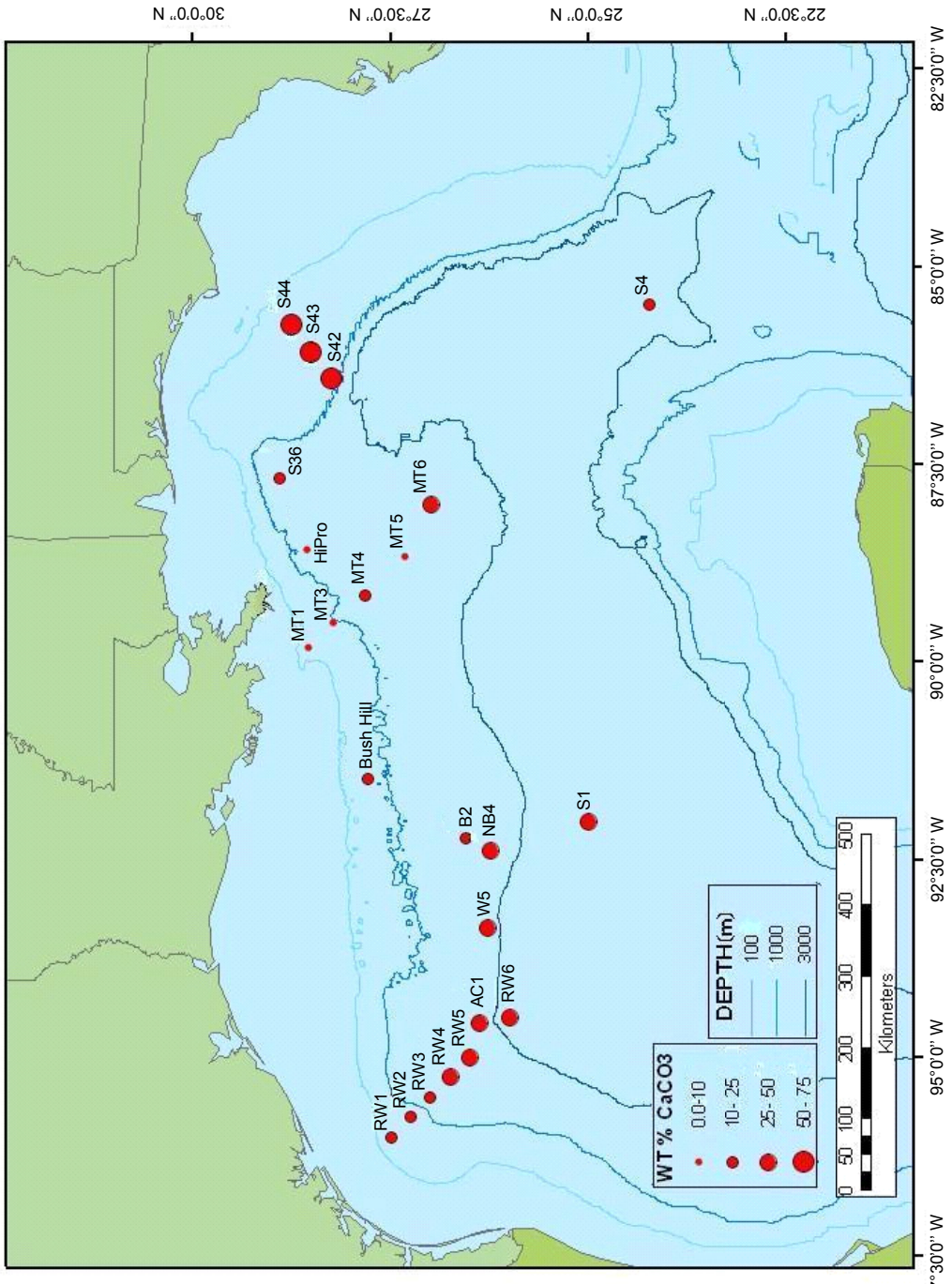

Figure 7. Map of Gulf of Mexico wt % $CaCO_3$.

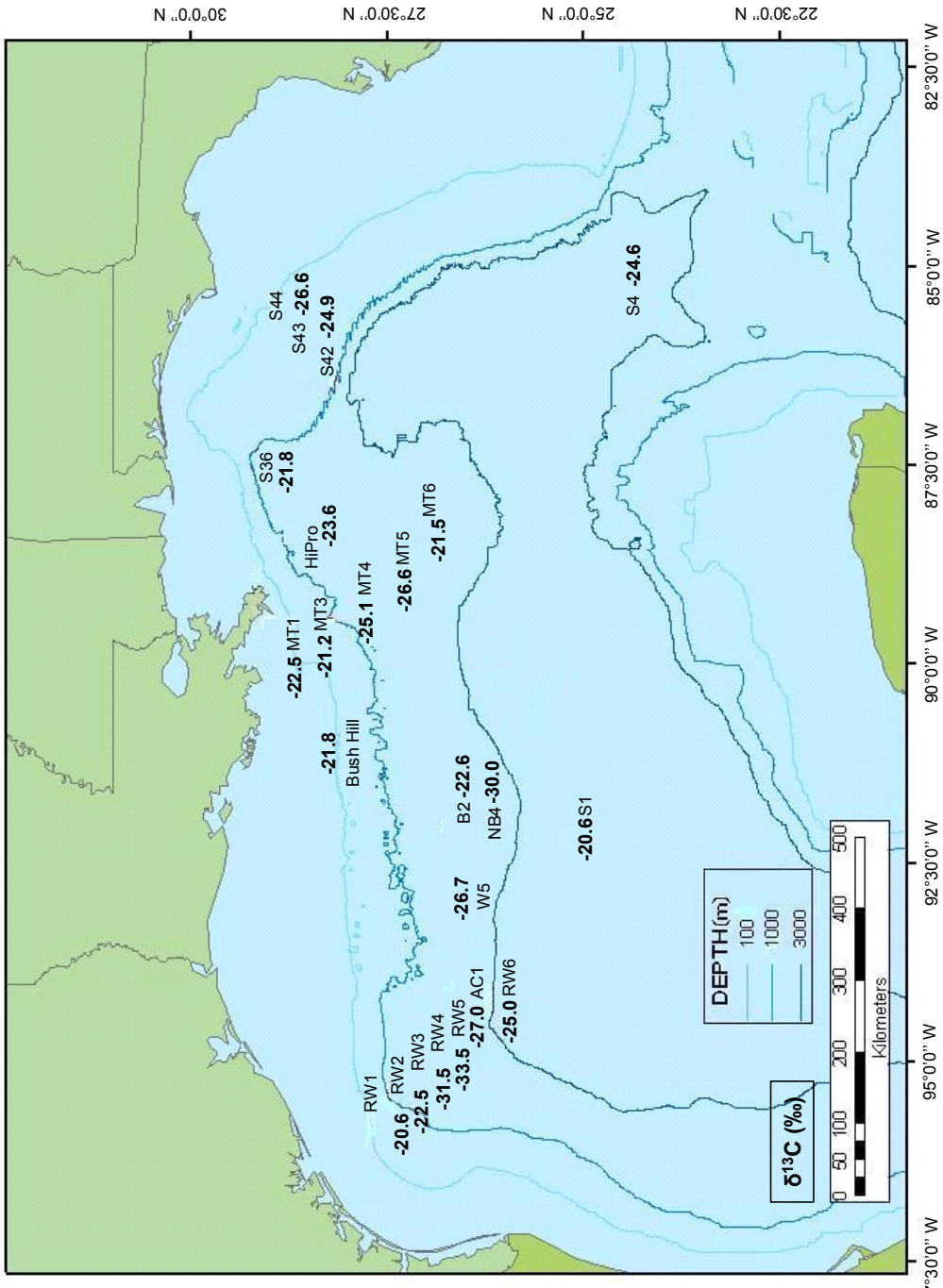

Figure 8. Map of Gulf of Mexico stable carbon isotope compositions (in ‰).

AC1, RW6 and W5 had $\delta^{13}C_{OC}$ values (-27.0, -25.0, and -26.7‰) indicative of terrestrial origin (~ -24 ‰; Gearing et al., 1977); however they were located in deep canyons far away from shore. These sediments may have been deposited from a terrestrial source during glacial periods when sea level was lower. Also the sediments may have slumped from the slope of the canyon or have a mixed hydrocarbon signature. MT4 and MT5 also had lower $\delta^{13}C_{OC}$ values (-25.1 and -26.6‰) and were located in the deep Mississippi Canyon. These sediments could also be a result of transport of ancient terrestrial deposits.

Stations S42 and S43 were in shallow waters and close to shore, thus their terrestrial $\delta^{13}C_{OC}$ values (-24.9 and -26.6‰) were expected.

Microelectrode Profiles

The redox species O^{2-}, Mn^{2+}, Fe^{2+} and ΣH_2S were measured to 10-15 cm depth in sediment cores using microelectrodes at six of the stations: MT3, MT6, S36, S42, S1, and S4 (Figures 9 & 10). At MT3 oxygen concentrations depleted to zero at the sediment-water interface where sulfide and manganese began to increase. Manganese concentrations were elevated between 3 and 8 cm and then began to decline. Iron was not detected at MT3. At station MT6 oxygen concentrations were high at the sediment-water interface and steadily declined to zero at 8 cm depth. Sulfide increased at 2 cm and remained constant downcore. Iron and manganese were not detected. At S36 oxygen concentrations were high at the sediment-water interface (~200 μM) and declined to zero at a depth of 4 cm. Sulfide was first observed at 1 cm and increased slightly and remained constant downcore with low concentrations of around 2 μM. Iron

and manganese were not detected. At S42 oxygen penetrated to 4 cm with low sulfide concentrations beginning at 3 cm and persisting downcore. Iron and manganese were not detected. At site S1 oxygen concentrations were high at the sediment-water interface and steadily declined to near 10 µM and remained constant downcore. Iron, manganese and sulfide were not detected. At site S4 oxygen concentrations began near 45 µM at the sediment-water interface and declined downcore to around 2 µM.

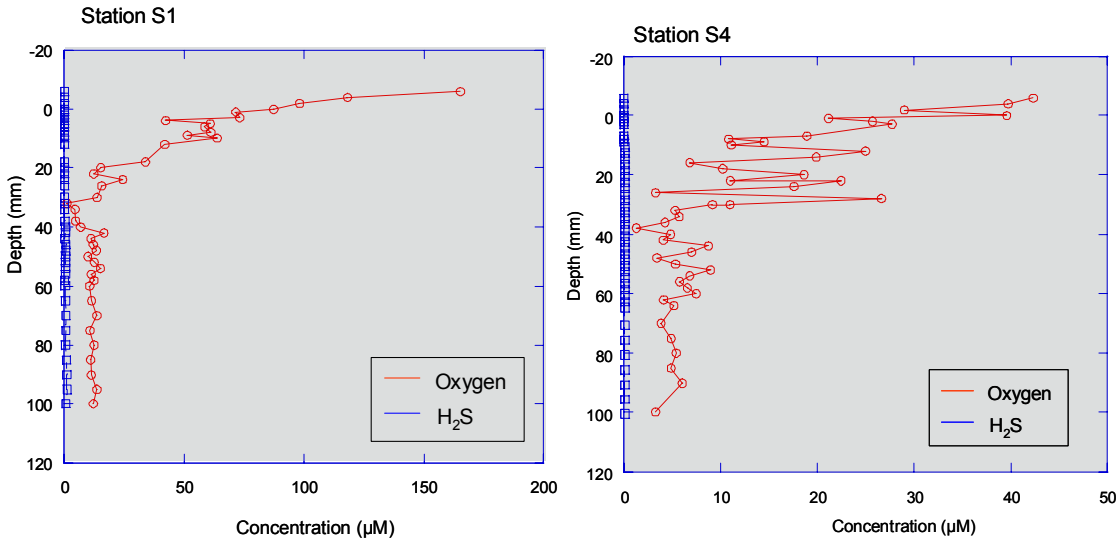

Figure 9. Microelectrode profiles of redox species at Stations S1 and S4 taken in Year 2002.

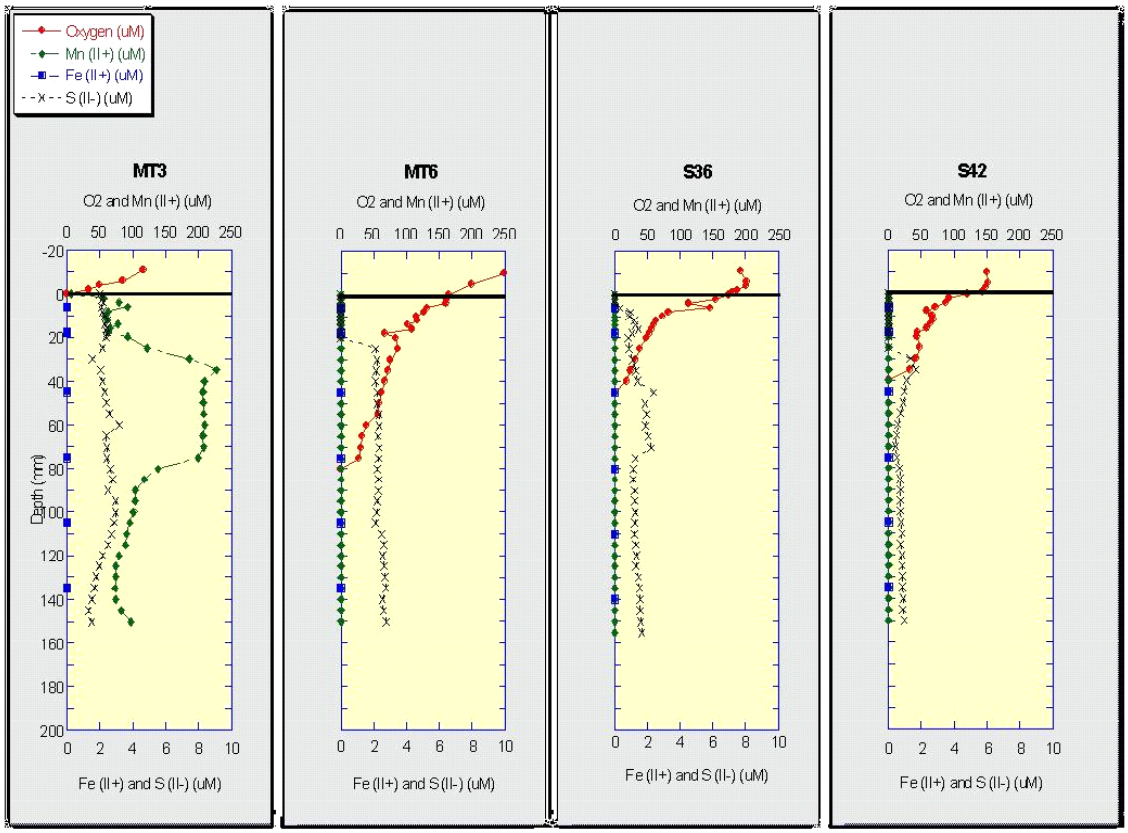

Figure 10. Microelectrode profiles of redox species at Stations MT3, MT6, S36 and S42 taken in Year 2001.

Faunal Abundances

Faunal abundances are summarized in Table 4 for each station.

Table 4. Faunal abundances.

Station	Water Depth (m)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
AC1	2450	286	129974	8.28E+08
B2	2630	276	139907	1.27E+09
Bush Hill	548	691	407852	1.08E+09
HiPro	1574	1220	343118	5.88E+08
MT1(a)	481	3855	430412	6.78E+08
MT1(b)	490	3407	326113	1.13E+09
MT3(a)	988	2419	395478	1.26E+09
MT3(b)	980	875	490517	1.08E+09
MT4	1401	1099	246058	6.47E+08
MT5	2290	448	128964	7.10E+08
MT6(a)	2750	253	72647	6.43E+08
MT6(b)	2740	289	82665	5.88E+08
NB4	2050	453	148409	6.62E+08
RW1	213	1276	411809	1.07E+09
RW2	950	730	219457	8.10E+08
RW3	1325	528	248752	5.88E+08
RW4	1580	526	232842	5.05E+08
RW5	1620	480	170633	8.80E+08
RW6	3015	282	144453	9.83E+08
S36(a)	1832	2173	450026	1.53E+09
S36(b)	1849	1353	349936	1.11E+09
S42(a)	772	688	209608	8.65E+08
S42(b)	773	924	282929	2.03E+08
S43	360	1260	276279	1.01E+09
S44	212	1154	254813	1.45E+09
S1	3527	354	70038	1.16E+09
S4	3408	143	50761	1.05E+09
W5	2740	274	104552	6.79E+08

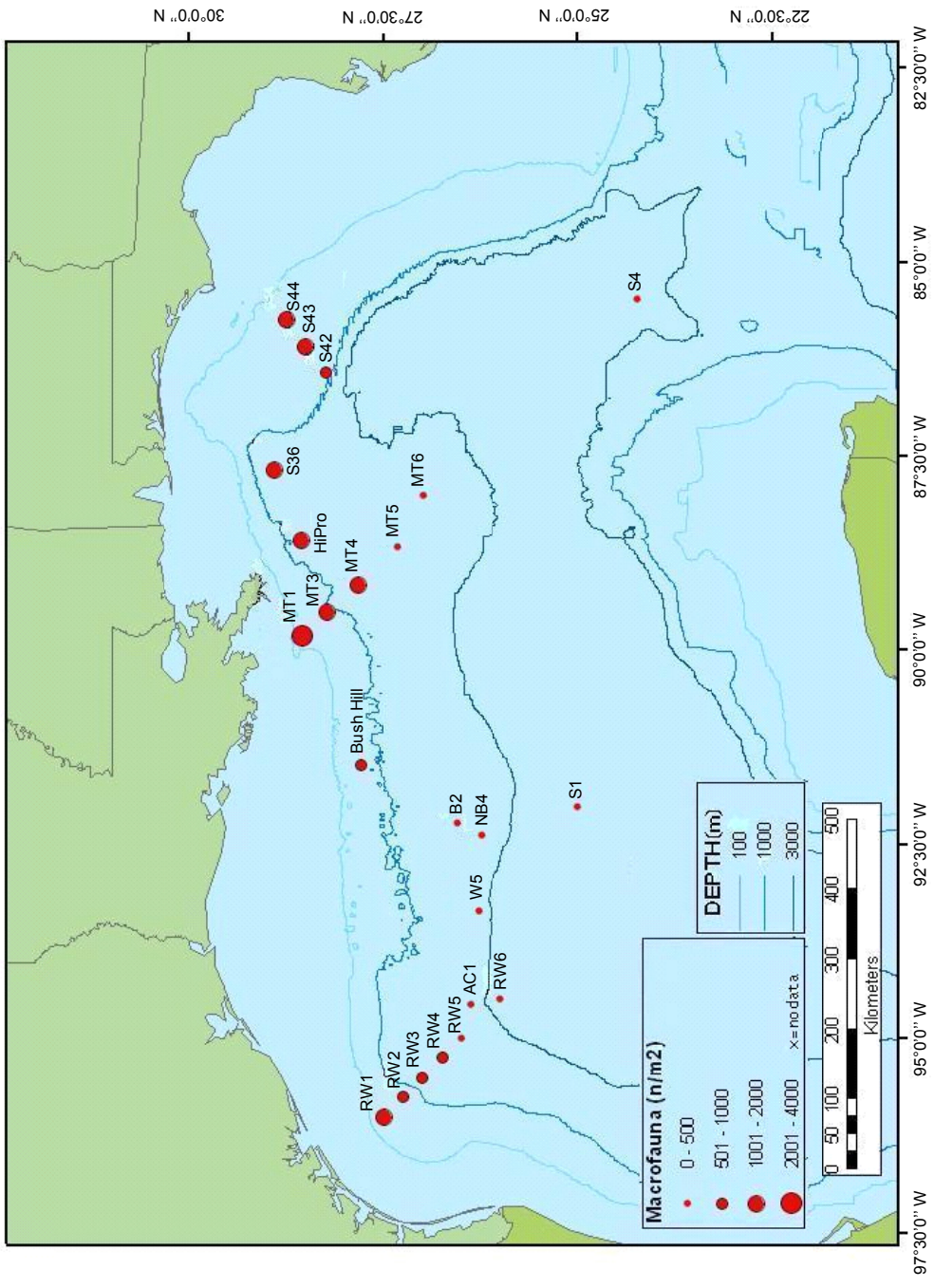

Figure 11. Map of Gulf of Mexico macrofauna abundance.

Macrofauna

Macrofauna abundance (G. Rowe, personal communication) ranged from 143 to 3855 n m^{-2} with a mean of 990 ± 935 n m^{-2} (Figure 11). Highest abundances were at MT1, MT3, S36, HiPro, RW1, S43 and S44. These were all shallow (<1000 m) stations, except S36 and HiPro. Lower abundances occurred at deeper depths (>2000 m) with the lowest abundance in 3400 m of water at site S4. Polychaetes, nematodes and amphipods accounted for 75% of the macrofauna across the Gulf of Mexico.

Meiofauna

Meiofauna abundance (P. Montagna, personal communication) was determined in the top 3 cm of sediment for the Gulf of Mexico stations (Figure 12). Meiofauna abundance ranged from 50,761 to 490,517 n m^{-2} with a mean of 243,536 ± 129,423 n m^{-2}. Highest abundances were at MT1, MT3, S36, HiPro, RW1, and Bush Hill. With the exceptions of S36 and HiPro these were all shallow water (<1000 m) stations. Lower abundances occurred at >2000 m water depth with the lowest at site S4. Meiofauna were primarily nematodes (68%), harpacticoid copepods (12%) and copepod nauplii (11%).

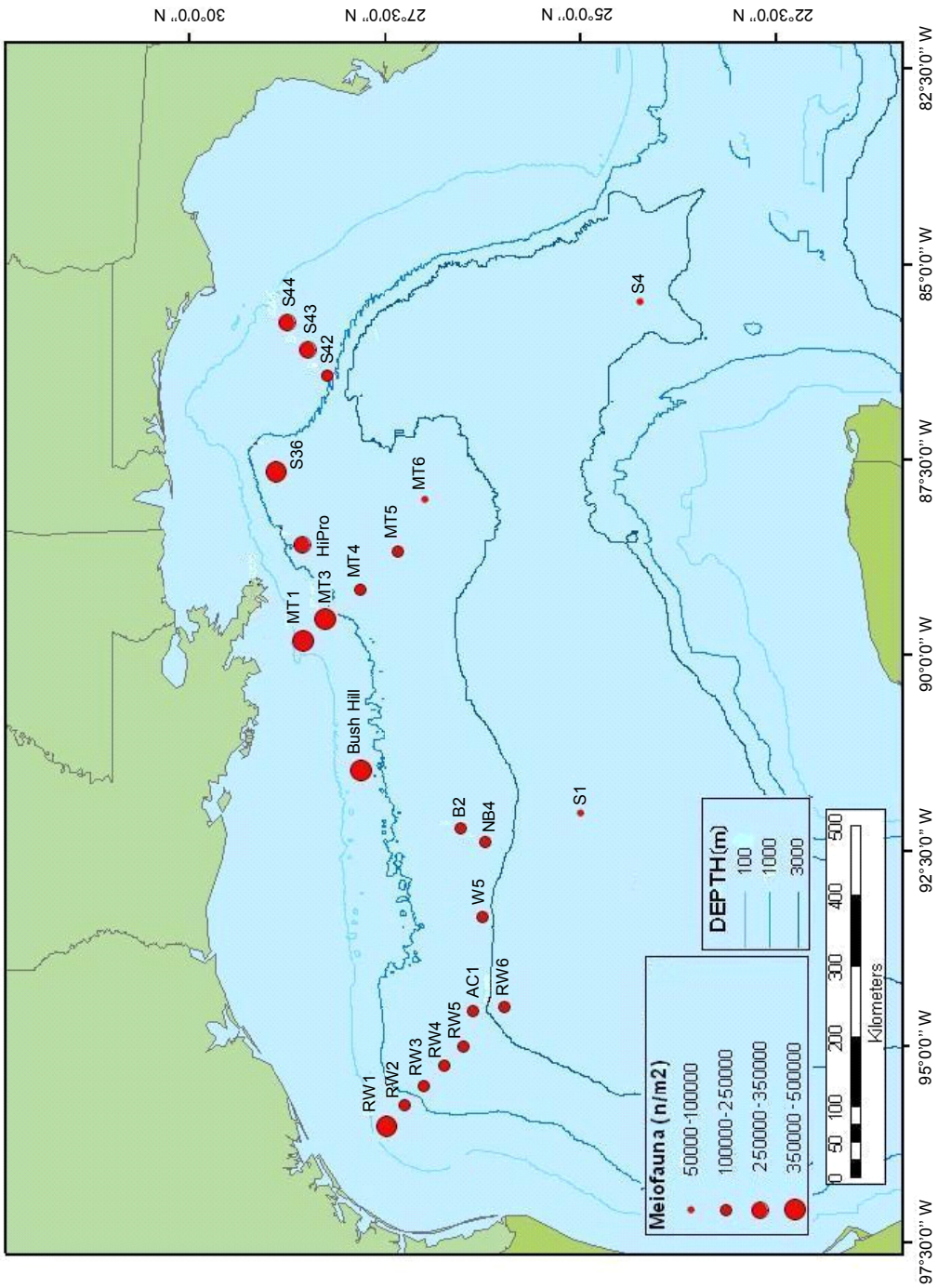

Figure 12. Map of Gulf of Mexico meiofauna abundance.

Bacteria

Bacteria abundance (J. Deming, personal communication) was determined for the top 1 cm of sediment for the Gulf of Mexico stations (Figure 13). Bacteria abundance ranged from 2.03E+08 to 5.32E+09 bacteria per cc sediment with a mean of 8.95E+08 ± 3.06E+08 bacteria per cc sediment. High abundance sites included MT3, S36, B2 and S1, which ranged in depths from 988 to 3500 m. Lowest bacteria abundances were observed at S42, RW4, HiPro and MT6.

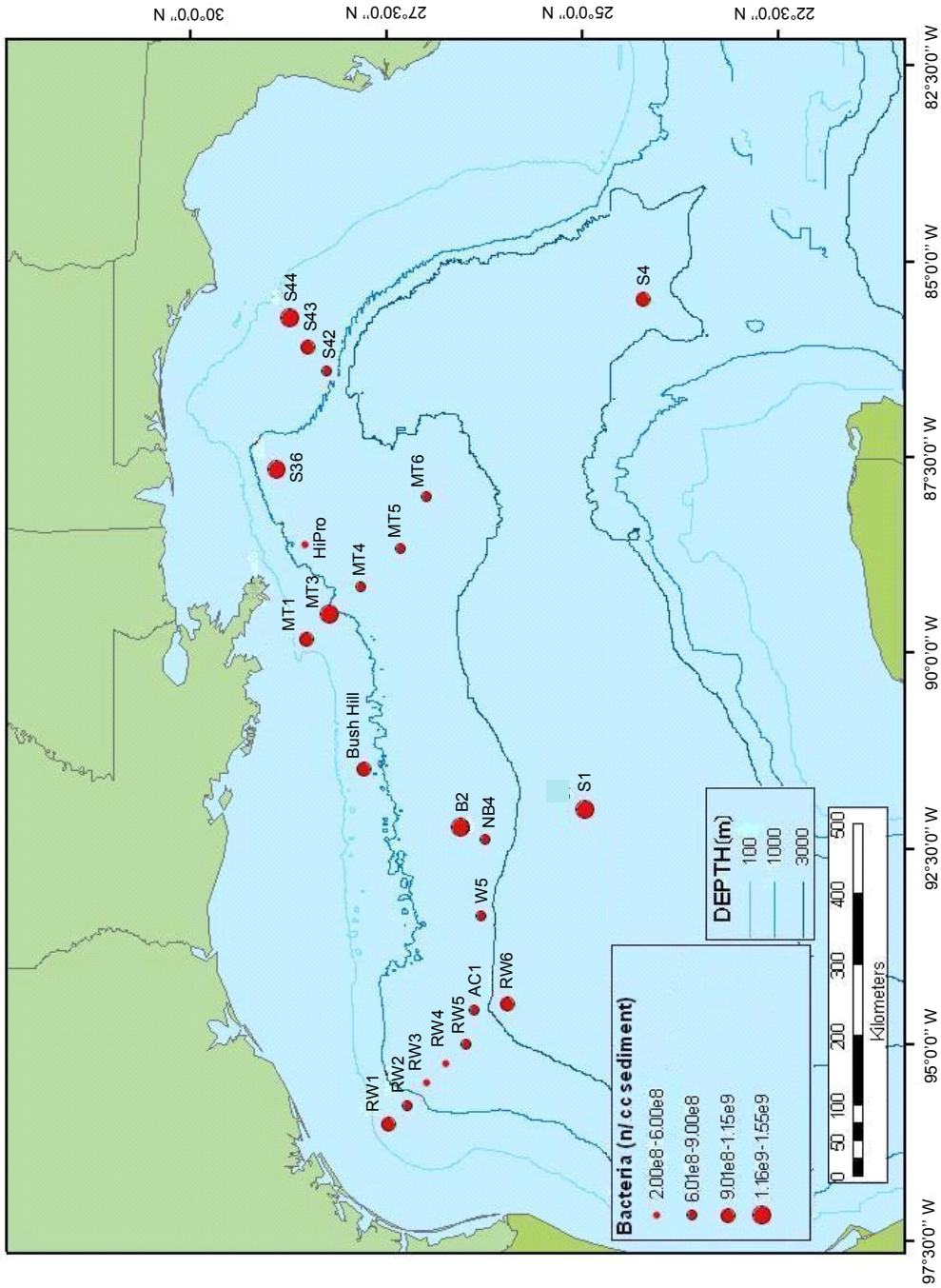

Figure 13. Map of Gulf of Mexico bacteria abundance.

STATISTICAL ANALYSIS

Statistical analysis of the data collected was conducted to test the four null hypotheses for all stations included in this study. The stations were then separated into five subsets based on geographical location, water depth and high primary production. Statistical analysis was again performed to test the null hypotheses (H_{01} and H_{04}) for each of the subsets to determine if there were significant differences between the subsets and all the northern GOM sites. The four null hypotheses are listed below.

H_{01}: There is no variation in OC/SA with water depth.

H_{02}: There is no variation in OC/SA along an east to west gradient.

H_{03}: There is no variation in OC/SA among different sampling dates.

H_{04}: There is no variation in benthic organism abundance with OC/SA.

Standard regression analysis was chosen to test $H_{01,}$ H_{02} and H_{04}. The analysis determined if there was a relationship between OC/SA and water depth and an east/west gradient (using longitude as the independent variable) and if OC/SA was related to the abundance of benthic fauna. The analysis assumed independent residuals with a normal distribution and constant variance. Correlation analysis was also used to determine the degree of association between the fauna abundances and OC/SA. The parametric Pearson's product-moment correlation was utilized and assumed continuous bivariate data and normal distribution. OC/SA, meiofauna and bacteria abundances were normally distributed; however, macrofauna abundance had to be logarithmically transformed to achieve normal distribution. The Wilcoxon's signed ranks test was used to test $H_{03.}$ Due to the small number of data pairs (5) it could not be assumed that the

data was continuous, normally distributed with homogeneous variances. Significance levels were defined by the following P-values: (1) significant, $P<0.05$, (2) moderately significant, $P<0.01$, and (3) highly significant, $P<0.001$.

Gulf of Mexico

Standard linear regression analysis was performed to test the relationship between OC/SA and water depth. The results of the linear regression (Figure 14) indicated a moderately significant relationship between OC/SA and water depth (r^2 = 0.31, P = 0.002, F = 12.0). The best-fit line explained 31% of the variation in OC/SA. The P-value of 0.002 indicated that the null hypothesis had a 0.2% chance of being true. Therefore, the null hypothesis (H_{01}) must be rejected, indicating there was significant variation in OC/SA with water depth in the sample set.

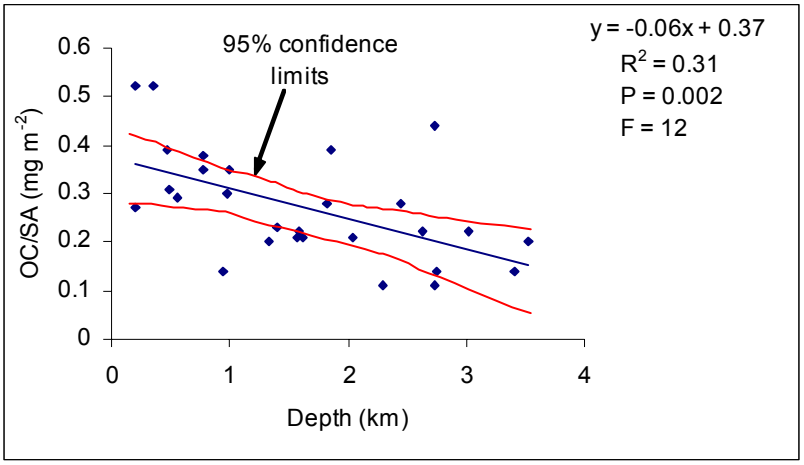

Figure 14. Linear regression analysis of OC/SA and water depth for the GOM sample set.

Standard linear regression analysis was performed to test the relationship between OC/SA and an east to west gradient. Longitude values were used to numerically represent the east to west gradient in the northern GOM. The results of the linear regression analysis (Figure 15) did not indicate a significant relationship between OC/SA and longitude ($r^2 = 0.10$, P = 0.10, F = 2.96). The best-fit line explained only 10% of the variance in OC/SA. The null hypothesis had a 10% chance of being accepted as indicated by the P-value of 0.10. Therefore the null hypothesis (H_{02}) must be accepted, indicating there was no variation in OC/SA along an east to west gradient in the sample set.

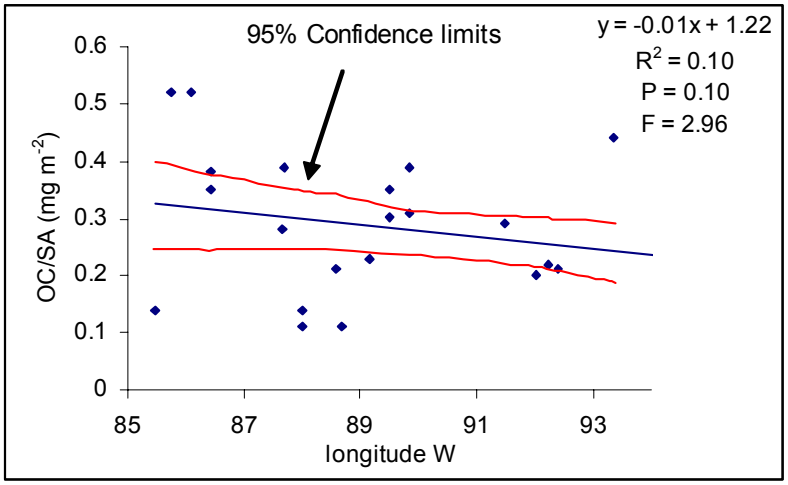

Figure 15. Linear regression analysis of OC/SA with an east/west gradient.

The nonparametric Wilcoxon's signed ranks test was performed to test if OC/SA varied between sampling years. Samples were recovered from five stations (MT1, MT3, MT6, S36 and S42) in two separate years. The results of the Wilcoxon's test indicated that the null hypothesis (H_{03}) must be accepted ($Z = -0.271$, $P = 0.786$). The P-value indicated that the null hypothesis had a 79% chance of being true, therefore there was no significant difference in OC/SA between sampling years.

Correlation analysis and standard regression analysis were performed to test the relationship between fauna abundances and OC/SA. The results of correlation analysis indicated a moderately significant positive correlation between OC/SA and macrofauna abundance ($r = 0.519$, $P = 0.005$, d.f. = 28). The results of the regression analysis (Figure 16) indicated a moderately significant exponential relationship between macrofauna abundance and OC/SA ($r^2 = 0.26$, $P = 0.005$, $F = 9.6$). The best-fit line explained 26% of the variation in macrofauna abundance. The P-value of 0.005 indicated that the null hypothesis had a 0.5% chance of being true. Therefore, the null hypothesis (H_{04}) must be rejected, indicating there was a significant relationship between macrofauna abundance and OC/SA in the sample set.

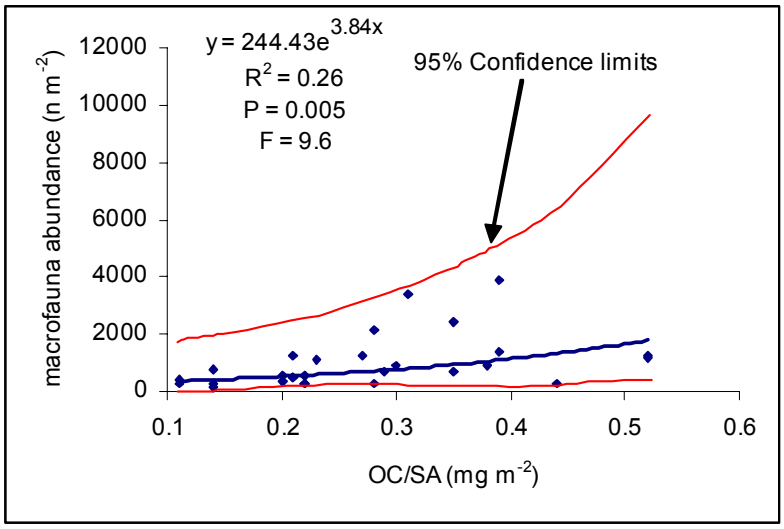

Figure 16. Regression analysis results of macrofauna abundance and OC/SA for the GOM sample set.

Correlation analysis indicated a significant positive correlation between OC/SA and meiofauna abundance ($r = 0.444$, $P = 0.018$, d.f. = 28). The results of regression analysis (Figure 17) indicated a significant logarithmic relationship between meiofauna abundance and OC/SA ($r^2 = 0.28$, $P = 0.004$, $F = 9.99$). The best-fit line explained 28% of the variation in meiofauna abundance. The P-value of 0.004 indicated that the null hypothesis had a 0.4% chance of being true. Therefore, the null hypothesis (H_{04}) must be rejected, indicating there was a significant relationship between meiofauna abundance and OC/SA in the sample set.

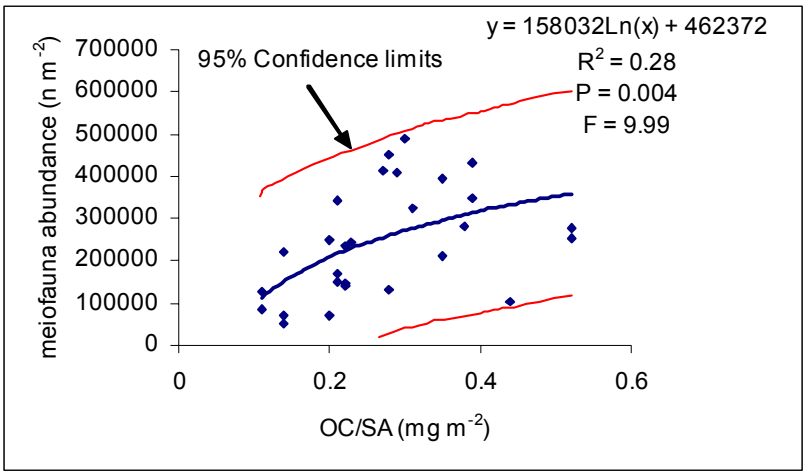

Figure 17. Regression analysis results of meiofauna abundance and OC/SA for the GOM sample set.

The results of correlation analysis indicated no significant correlation between OC/SA and bacteria abundance ($r = 0.269$, $P = 0.167$, d.f. = 28). The results of regression analysis (Figure 18) did not indicate a significant relationship between bacteria abundance and OC/SA ($r^2 = 0.08$, $P = 0.14$, $F = 2.29$). The best-fit line explained only 8% of the variation in bacteria abundance. The P-value of 0.14 indicated that the null hypothesis had a 14% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA in the sample set.

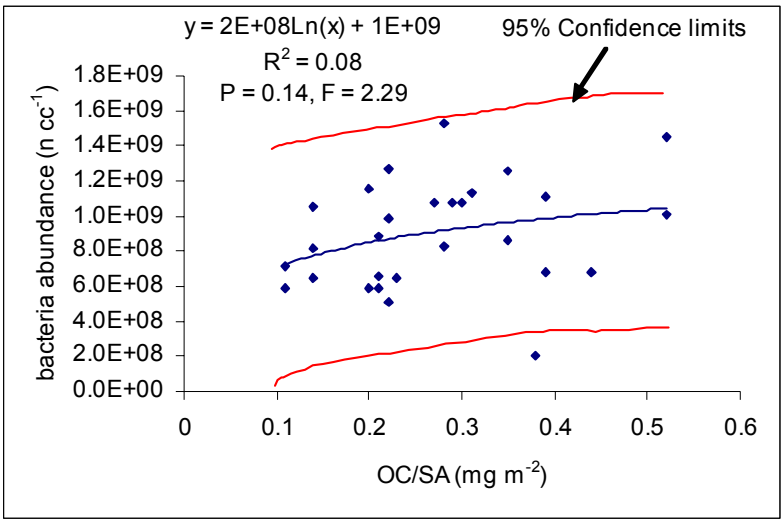

Figure 18. Regression analysis results of bacteria abundance and OC/SA for the GOM sample set.

Stations in this study were located at various geographical locations and water depths throughout the Gulf of Mexico. In addition, various local environments, such as chemosynthetic communities, basins, canyons, and escarpments could affect the biogeochemical parameters at these stations. All the data collected for this study of the northern GOM was analyzed as a whole to determine if relationships existed among the different variables throughout the northern GOM. Regression analysis was chosen as the primary statistical tool because we wanted to determine what variable(s) accounted for the greatest variance among the biogeochemical constituents in the northern GOM. In particular this study was focused on the variable OC/SA and its relationship to the other biogeochemical parameters at these sites. In addition, other variables such as water depth, organic carbon, calcium carbonate and grain size were also tested to determine significant relationships.

The regression analysis performed for all variables is summarized in Table 5. The analysis assumed independent residuals with a normal distribution and a constant variance. All results indicated were significant with a P-value < 0.05.

The regression analysis indicated several significant relationships among the different parameters in the northern GOM sample set. One of the important relationships considered was the association of organic carbon with water depth. It has been generally shown that the amount of organic matter that reaches the sediment is inversely proportional to water depth. This generalization was also observed for northern GOM sediment samples as indicated by the slightly significant linear decrease of wt % OC with increasing water depth (Figure 19). The linear relationship of wt % OC and water depth became more significant when wt % OC was calculated on a carbonate-free basis. The regression analysis demonstrated that wt % OC was positively related to the smaller grain sizes and was inversely proportional to wt % $CaCO_3$.

Table 5. Summary of regression analysis results for the GOM sample set.

Dependent variable	Independent variables: Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm		East/West (longitude)	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC	0.17	5.3	--	--	--	--	0.34**	13	0.75*	76	0.56*	36		
OC/SA	0.32	12	--	--	--	--	0.28	10.0						
wt % $CaCO_3$			0.34*	13	0.28	10	--	--	0.41**	18	0.24	8.2		
wt % > 63 µm			0.75*	76			0.41*	18	--	--	--	--	0.21**	6.7
wt % < 63 µm			0.56**	36			0.24	8.2	--	--	--	--	0.21**	6.7
Macrofauna	0.33	13	0.50	26	0.27*	9.6			0.22**	7.4				
Meiofauna	0.69*	56.8	0.59	38.1	0.28**	9.99	0.15**	4.39	0.25	8.5				
Bacteria														

All results indicated are significant ($P < 0.05$) and linear, except * exponential and ** logarithmic.

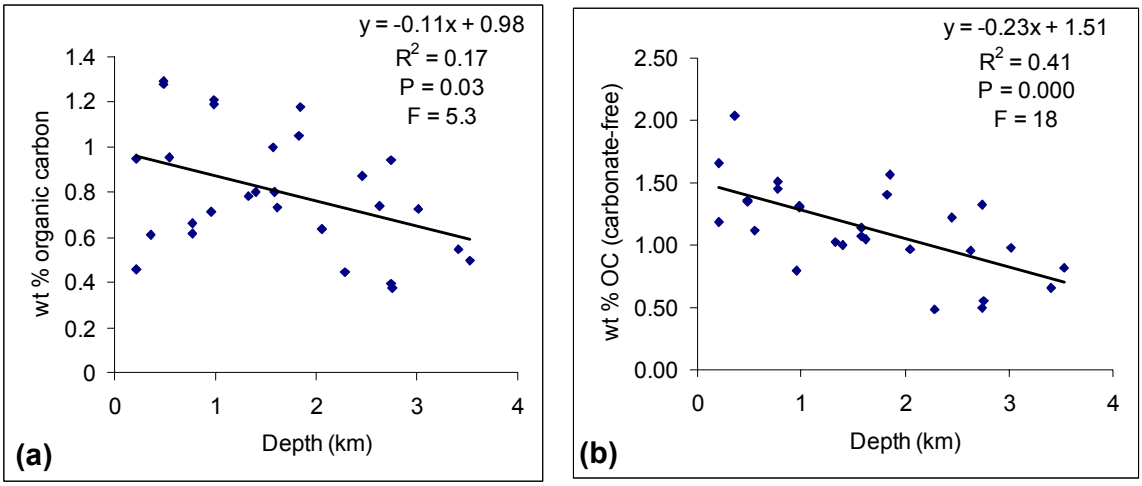

Figure 19. Plots of (a) wt % OC, and (b) wt % OC (carbonate-free) as a function of water depth for the GOM sample set.

It is generally accepted that benthic faunal abundances are closely associated with water depth and organic carbon content in the sediment. As demonstrated in Figures 20-22, macrofauna and meiofauna abundances had significant relationships with both water depth and wt % OC. However, bacteria abundance showed no association with either wt % OC or water depth.

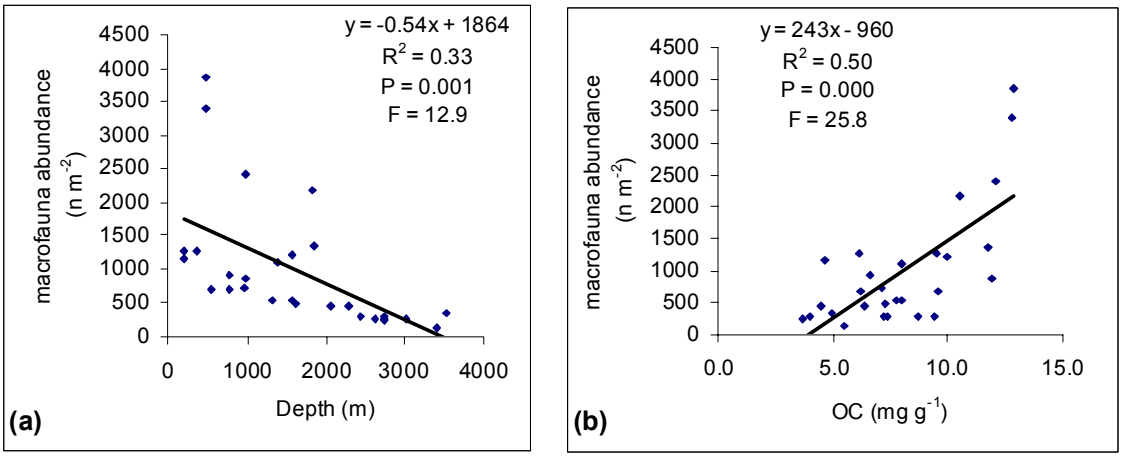

Figure 20. Macrofauna abundance as a function of (a) water depth and (b) organic carbon for the GOM sample set.

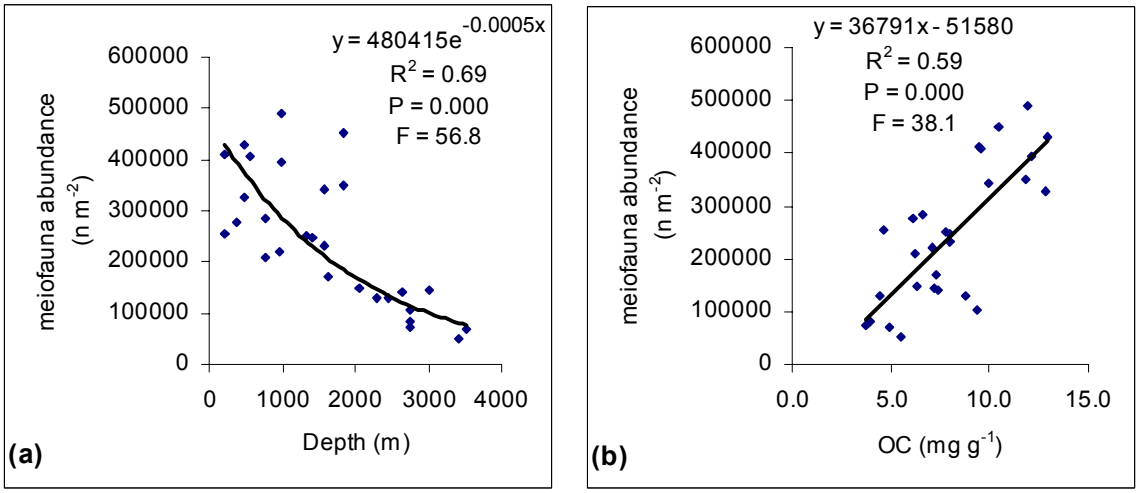

Figure 21. Meiofauna abundance as a function of (a) water depth and (b) organic carbon content for the GOM sample set.

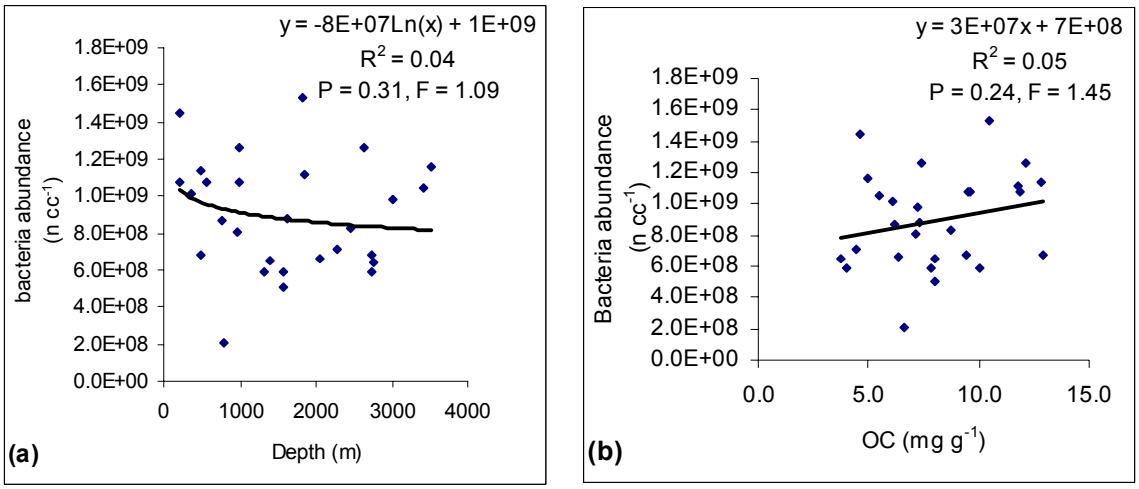

Figure 22. Bacteria abundance as a function of (a) water depth and (b) organic carbon content for the GOM sample set.

As indicated in Table 5 there were several significant relationships observed between the parameters at the northern GOM sample sites and it would be difficult to determine which specific independent variable was the most important. To help statistically determine among the independent variables which was the best predictor of faunal abundance, stepwise multiple linear regression analysis was utilized. The procedure examined all possible combinations of independent variables to produce the better fit and identify the most important independent variable(s). The independent variables included water depth, wt % OC, OC/SA, and wt % $CaCO_3$; the dependent variables were macrofauna, meiofauna and bacteria abundances. The results indicated that for the northern GOM sample set: (1) wt % OC and water depth were the best predictors of both macrofauna and meiofauna abundances (y = -47 + 1943 wt % OC – 321 water depth, DW = 1.3, r^2 = 0.60, F = 19, P = 0.000; y = 138,665 + 266,231 wt %

OC – 66,812 water depth, DW = 1.6, r^2 = 0.82, F = 55.7, P = 0.000); and (2) none of the independent variables were good predictors of bacteria.

Western Stations

A subset of stations located in the far western northern GOM is listed in Table 6. These sites are influenced by westward currents which deposit sediment transported from the Mississippi River. Stations RW1-RW5 represented a depth transect with depths ranging from 213 to 1620 m. Station AC1 was located in the Alaminos Canyon, B2 and NB4 represented basin and non-basin sites, W5 and RW6 were located within submarine canyons, and S1 was located on the abyssal plain at a depth of 3527 m.

Wt % OC at these stations ranged from 0.49 to 0.95 wt % with a mean of 0.76 wt % which was below the sample mean of 0.80 wt %. The stations with the highest wt % OC included RW1 (0.95 wt %, 213 m), AC1 (0.88 wt %, 2450 m), and W5 (0.94 wt %, 2740 m). High organic matter content was expected at the shallow RW1 site; however, it was not expected at stations deeper than 2000 m. Sites AC1 and W5 were both located in deep canyons and the high wt % OC could be due to sediment slumping from the canyon edges to the canyon floor. The lowest wt % OC was observed at S1 (0.49 wt %), which was expected for a deep station (3527 m). Sediment at these sites was composed of >90% silt and clay fractions as indicated by the high surface areas. S1 had a lower surface area (25.3 m^2g^{-1}) and a higher sand fraction (21.2 wt %), probably due to the high concentrations of calcareous foraminifera which are ubiquitous throughout the GOM. This interpretation is supported by a high wt % $CaCO_3$ (39 wt %). W5 also had a lower surface area (21.4 m^2g^{-1}), however this was not associated with a high sand

fraction (6.4 wt %), and the wt % $CaCO_3$ (29 wt %) was comparable to other stations in the western GOM.

Table 6. Western stations.

Station	Depth (m)	wt % OC	SA (m^2g^{-1})	OC/SA (mg m^{-2})	Wt % $CaCO_3$	$\delta^{13}C_{OC}$ (‰)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
RW1	213	0.95	34.9	0.27	20	n.d.	1276	411809	1.07E+09
RW2	950	0.71	49.7	0.14	11	-20.6	730	219457	8.10E+08
RW3	1325	0.78	39.5	0.20	24	-22.5	528	248752	5.88E+08
RW4	1580	0.80	35.8	0.22	30	-31.5	526	232842	5.05E+08
RW5	1620	0.73	34.8	0.21	30	-33.5	480	170633	8.80E+08
NB4	2050	0.63	30.5	0.21	34	-30.0	453	148409	6.62E+08
AC1	2450	0.88	31.4	0.28	29	-27.0	286	129974	8.28E+08
B2	2630	0.74	33.5	0.22	23	-22.6	276	139907	1.27E+09
W5	2740	0.94	21.4	0.44	29	-26.7	274	104552	6.79E+08
RW6	3015	0.72	33.1	0.22	26	-25.0	282	144453	9.83E+08
S1	3527	0.49	25.3	0.20	39	-20.6	354	70038	1.16E+09

OC/SA values ranged from 0.14 to 0.44 mg-OC m^{-2} with a mean of 0.24 mg-OC m^{-2}, which was 12% lower than the sample mean of 0.27 mg-OC m^{-2}. The $\delta^{13}C_{OC}$ values ranged from -20.6 to -33.5‰. RW2, RW3, B2, and S1 had $\delta^{13}C_{OC}$ values which were more enriched in ^{13}C (-20.6 to -22.6‰) and were representative of marine origin. RW4, RW5 and NB4 had $\delta^{13}C_{OC}$ values -30.0 to -33.5 ‰, which possibly indicated a hydrocarbon source. The canyon sites at AC1, RW5 and W5 had more depleted $\delta^{13}C_{OC}$ values (-25.0 to -27‰) possibly indicating ancient terrestrial transport. No significant linear relationship was observed between $\delta^{13}C_{OC}$ and water depth contrary to previous studies.

Macrofauna and meiofauna abundances at the western stations were below the sample means by 66% and 28%, respectively, and declined significantly with water depth. RW1 had abundances that were approximately 25% greater than the mean as expected at a shallow water site. Bacteria abundances showed no trend with water depth and were 4% below the sample mean, except at B2 and S1, which were both approximately 30% greater than the mean. Station S1 (3527 m) had a 22% increase in macrofauna abundance and 16% increase in bacteria abundance compared to the next deepest station, RW6. Sediment oxygen concentrations at S1 penetrated to 10 cm subsurface as indicated by microelectrode redox profiles.

The macrofauna taxonomic groups (N = 38) in the western stations were composed primarily of nematodes (36%) and polychaetes (27%), which were similar to the sample means. Amphipods comprised <1% of the macrofauna, which differed from the sample mean of 22%. Of note was the large abundance of copepods (21%) and harpacticoids (15%) at S1, which compared to ~2% and ~6%, respectively at the other western stations and northern GOM sites. The copepod abundance could be due to contamination from surface phytoplankton introduced during sieving. Meiofauna taxonomic groups (N = 17) were comprised primarily of nematodes (66%), harpacticoids (12%), and copepod nauplii (12%), which reflected the sample means.

Standard linear regression analysis was performed to test the relationship between OC/SA and water depth at the western stations. The results of the linear regression (Figure 23) indicated no significant relationship between OC/SA and water depth ($r^2 = 0.04$, $P > 0.05$, $F = 0.40$). The best-fit line only explained 4% of the variation

in OC/SA and the null hypothesis had a 55% chance of being true. Therefore, the null hypothesis (H_{01}) must be accepted, indicating there was no significant relationship between OC/SA and water depth in the sample subset.

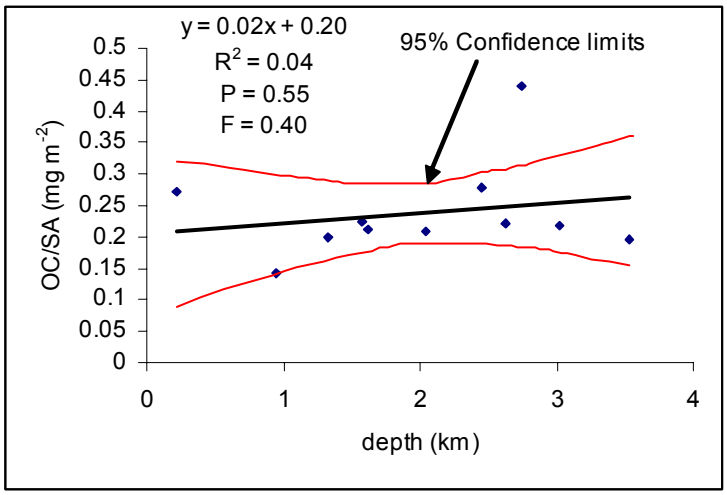

Figure 23. Linear regression analysis of OC/SA and water depth for the western GOM stations.

Correlation analysis and standard regression analysis were performed to test the relationship between faunal abundances and OC/SA. Macrofauna abundance and OC/SA were logarithmically transformed to normally distribute the data and correlation analysis indicated no significant correlation between OC/SA and macrofauna abundance ($r = -0.309$, $P = 0.354$, d.f. =11). The results of the regression analysis (Figure 24) indicated no significant relationship between macrofauna abundance and OC/SA ($r^2 = 0.02$, $P > 0.05$, $F = 0.23$). The best-fit line explained only 2% of the variation in macrofauna abundance and the null hypothesis had a 65% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no

significant relationship between macrofauna abundance and OC/SA in the sample subset.

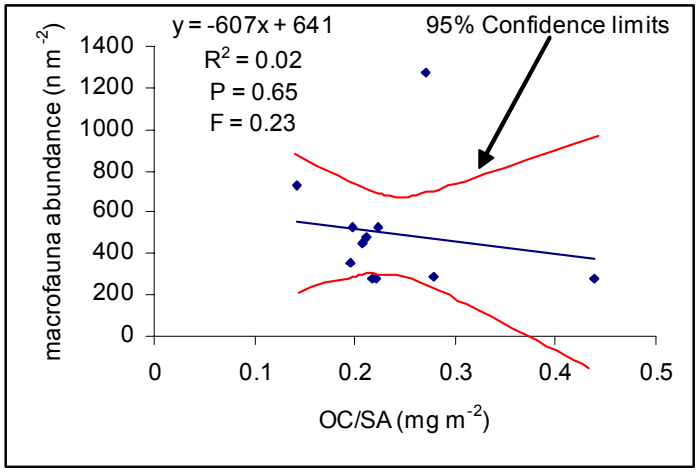

Figure 24. Linear regression analysis of macrofauna abundance and OC/SA for the western GOM stations.

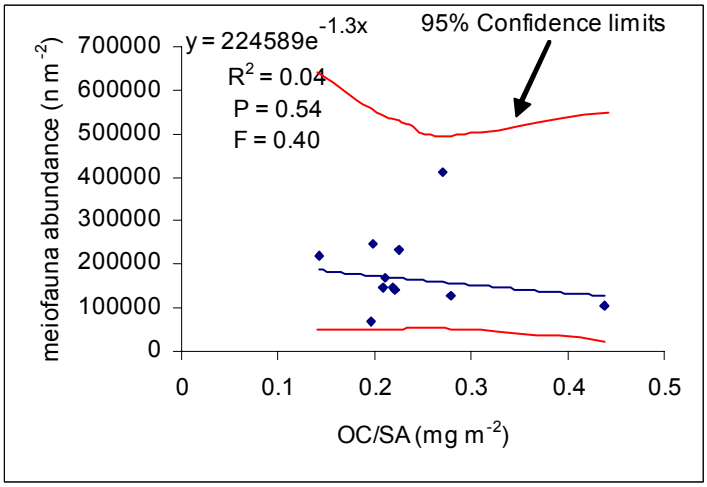

Figure 25. Regression analysis results of meiofauna abundance and OC/SA for the western GOM stations.

No significant correlation was indicated between OC/SA and meiofauna abundance (r = -0.132, P = 0.699, d.f. = 11). The results of regression analysis (Figure 25) did not indicate a significant relationship between meiofauna abundance and OC/SA (r^2 = 0.04, P > 0.05, F = 0.40). The best-fit line explained only 4% of the variation in meiofauna abundance and the null hypothesis had a 54% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between meiofauna abundance and OC/SA in the sample subset.

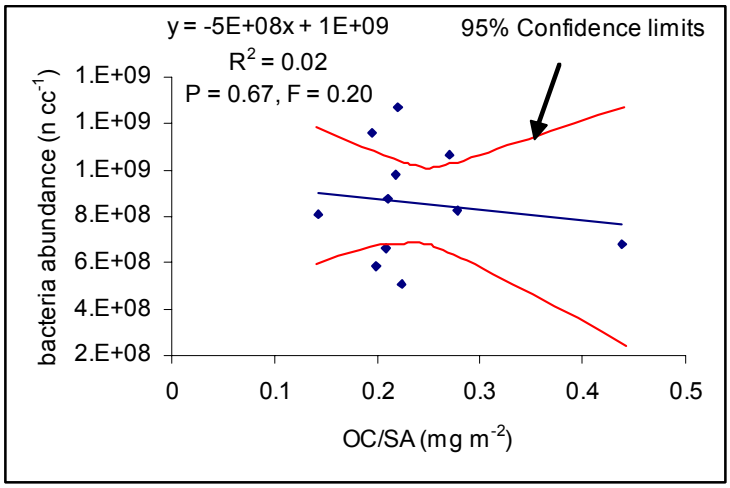

Figure 26. Regression analysis results of bacteria abundance and OC/SA for the western GOM stations.

No significant correlation was indicated between OC/SA and bacteria abundance (r = -0.103, P = 0.764, d.f. = 11). The results of regression analysis (Figure 26) did not indicate a significant relationship between bacteria abundance and OC/SA (r^2 = 0.02, P = 0.67, F = 0.20). The best-fit line explained only 2% of the variation in bacteria

abundance and null hypothesis had a 67% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA in the sample subset.

Table 7 summarizes the regression analysis results for the biogeochemical parameters of the western GOM sample subset. Few significant relationships were observed at these stations. Macrofauna and meiofauna had highly significant logarithmic relationships with water depth (Figure 27); however, bacteria did not demonstrate any significant association with water depth. Wt % OC was observed to be positively associated with the small grain sizes.

Table 7. Summary of regression analysis results for the western GOM stations.

Dependent variable	Independent variable											
	Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC									0.58**	12.2	0.57**	12.1
OC/SA												
Macrofauna	0.96**	233										
Meiofauna	0.92**	105					0.41*	6.1				
Bacteria												

All results indicated are significant ($P < 0.05$) and linear, except * exponential and ** logarithmic.

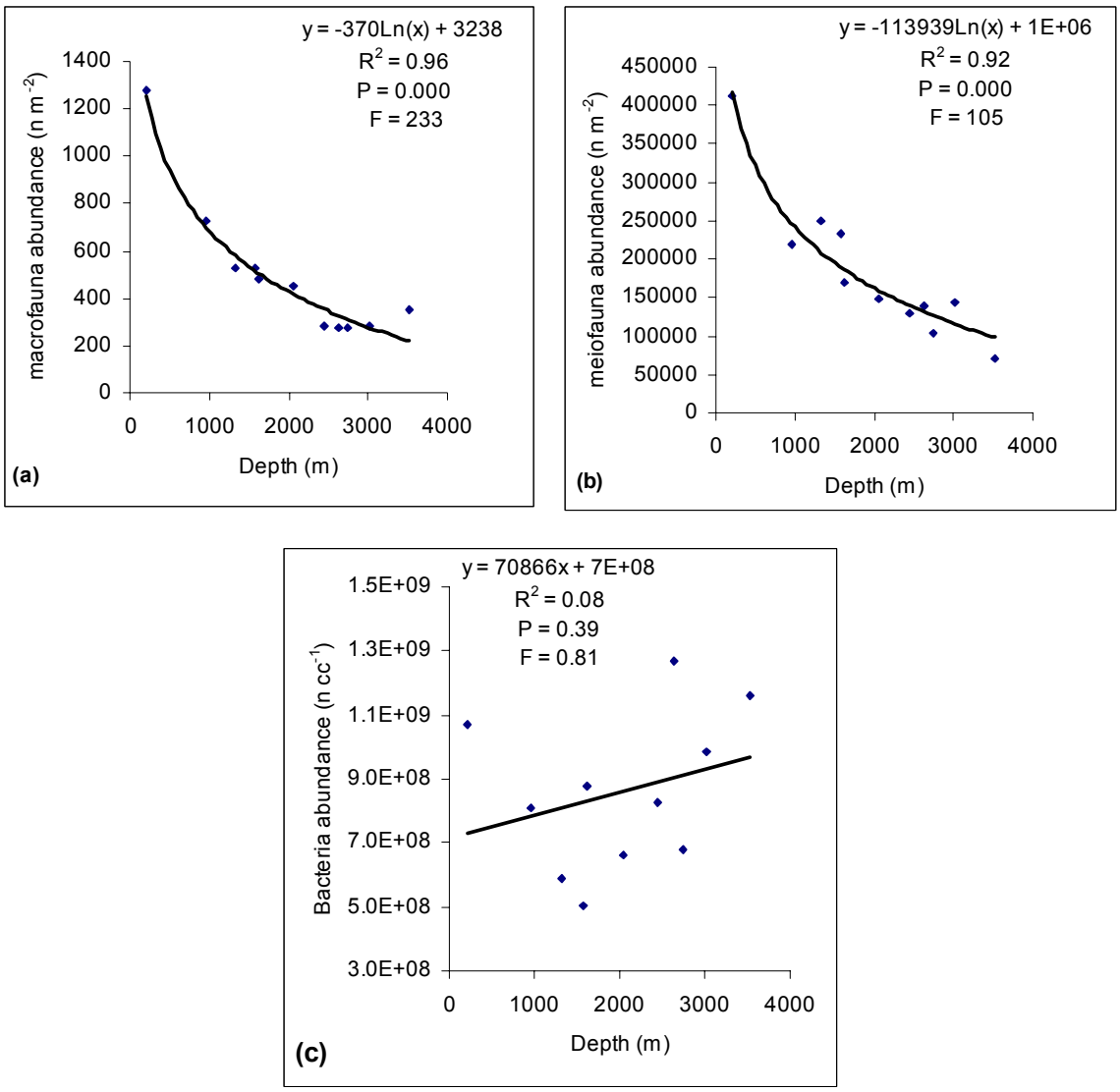

Figure 27. Plots of (a) macrofauna, (b) meiofauna and (c) bacteria abundance as a function of water depth for the western GOM stations.

Mississippi Canyon Stations

The stations included in the Mississippi Canyon sample subset are presented in Table 8. Three of the stations (MT1, MT3, and MT6) were sampled in two separate years as indicated. The Mississippi Canyon subset included stations that were located

within the Mississippi River Trough and were located in proximity to the Mississippi River discharge area. Water depths ranged from 481 m at MT1 to 2750 m at MT6. The mean wt % OC for this area was 0.87 wt %, which was higher than the sample mean of 0.80 wt %. MT1 and MT3 display the greatest wt % OC (1.3 and 1.2 wt %, respectively) in all the northern GOM samples, which was probably due to high primary productivity in the surface waters as indicated by the $\delta^{13}C_{OC}$.

Sediment at sites nearest the Mississippi River mouth (MT1, MT3, and MT4) had high silt and clay fractions (>90 wt %) which was supported by high sediment surface areas (>33 m^2g^{-1}). This was probably due to high silt and clay fractions

Table 8. Mississippi Canyon stations.

Station	Depth (m)	wt % OC	SA (m^2g^{-1})	OC/SA (mg m^{-2})	Wt % $CaCO_3$	$\delta^{13}C_{OC}$ (‰)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
MT1(a)	481	1.3	33.4	0.39	5.3	-22.5	3855	430412	6.78E+08
MT1(b)	490	1.3	40.9	0.31	5.4	-23.5	3407	326113	1.13E+09
MT3(b)	980	1.2	39.3	0.30	8.4	-21.2	875	395478	1.26E+09
MT3(a)	988	1.2	34.2	0.35	8.1	-21.1	2419	490517	1.08E+09
MT4	1401	0.80	34.9	0.23	20	-25.1	1099	246058	6.47E+08
MT5	2290	0.45	42.6	0.11	8.0	-26.6	448	128964	7.10E+08
MT6(b)	2740	0.40	35.0	0.11	19	-23.6	289	72647	6.43E+08
MT6(a)	2750	0.37	26.4	0.14	32	-21.5	253	82665	5.88E+08

(a) = year 2000; (b) = year 2001

transported from the Mississippi River. MT5 displayed a higher sand fraction (64.3 wt %) without a corresponding lower surface area (42.6 m^2g^{-1}), which could possibly be due to the iron stone that was observed in sediments at MT5. MT6 also displayed a higher sand fraction for both years sampled (~30 wt %), with a corresponding slightly lower

surface area (~30 m^2g^{-1}) and higher carbonate content (~25%), possibly due to foraminifera.

OC/SA values ranged from 0.11 to 0.39 mg-OC m^{-2} with a mean of 0.24 mg-OC m^{-2}, which was 12% below the sample mean of 0.27 mg-OC m^{-2}. Mean wt % $CaCO_3$ for this transect was 13 wt %, which was half the sample mean of 26 wt %. The $\delta^{13}C_{OC}$ values for stations closest to the river mouth (MT1 and MT3) had enriched $\delta^{13}C_{OC}$ values of -23.5 to -21.0‰, representative of marine origins. MT4 and MT5 had more depleted $\delta^{13}C_{OC}$ values of -25.1 and -26.6‰, respectively, which became more enriched at MT6 (~-22‰). Macrofauna and meiofauna abundances were 46% and 11% above the sample mean, respectively. Bacteria abundance was 6% above the sample mean. Macrofauna taxonomic groups (N = 40) at the Mississippi Canyon stations were composed primarily of amphipods (44%), polychaetes (21%) and nematodes (14%). Of note, was the large abundance of amphipods (75%) at MT1. Meiofauna taxonomic groups (N = 20) were comprised primarily of nematodes (66%), harpacticoids (11%), and copepod nauplii (9%), which reflected the sample means.

Sediment pore water oxygen concentrations at MT3 were observed to deplete to zero at the sediment-water interface probably due to high sedimentation rates caused by river transport and high biological activity within the sediment. Sulfide and manganese increased within the top 2 cm of sediment as evidence of sulfate and manganese reduction. Sulfide concentrations were low (~2 μM), and obviously not at toxic levels to organisms since fauna abundance was so high in the top 2 cm. In contrast oxygen penetrated to 8 cm at MT6 and sulfide was detected at 4 cm, which was expected for a

deep station. Sedimentation rates were low and oxygen was able to penetrate further into the sediment. Organic matter had more time to be consumed, which was evident by the low organic carbon content (0.37 wt %), which was the lowest of all the GOM sites.

Standard linear regression analysis was performed to test the relationship between OC/SA and water depth at the Mississippi Canyon stations. The results of the linear regression (Figure 28) indicated a highly significant relationship between OC/SA and water depth ($r^2 = 0.89$, P = 0.000, F = 48.3). The best-fit line explained 89% of the variation in OC/SA and the null hypothesis had a 0.0% chance of being true. Therefore, the null hypothesis (H_{01}) must be rejected, indicating there was a significant relationship between OC/SA and water depth in the Mississippi Canyon sample subset.

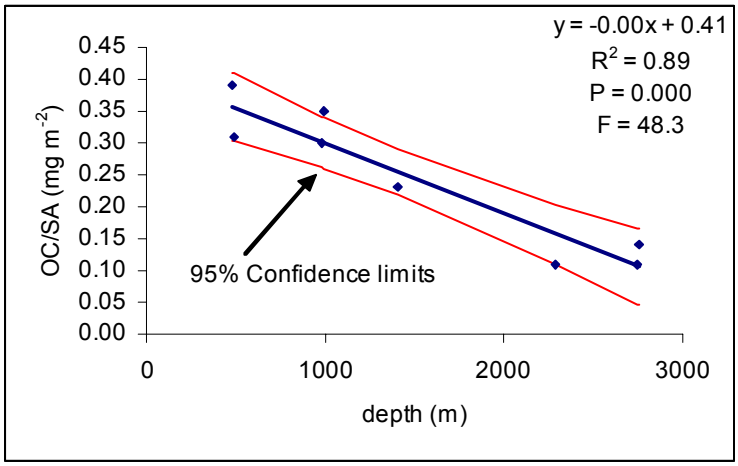

Figure 28. Linear regression analysis of OC/SA and water depth for the Mississippi Canyon stations.

Correlation analysis and standard regression analysis were performed to test the relationship between fauna abundances and OC/SA for the Mississippi Canyon sample subset. Bacteria abundance was logarithmically transformed to achieve normal distribution. A moderately significant positive correlation was indicated between OC/SA and macrofauna abundance ($r = 0.861$, $P = 0.006$, d.f. = 8). The results of the regression analysis (Figure 29) indicated a highly significant exponential relationship between macrofauna abundance and OC/SA ($r^2 = 0.85$, $P = 0.0011$, $F = 34.6$). The best-fit line explained 85% of the variation in macrofauna abundance and the null hypothesis had a 0.11% chance of being true. Therefore, the null hypothesis (H_{04}) must be rejected, indicating there was a significant relationship between macrofauna abundance and OC/SA in the Mississippi Canyon sample subset.

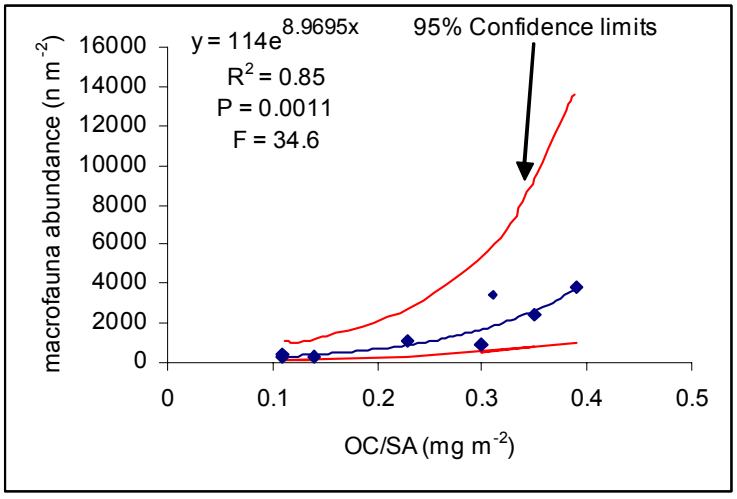

Figure 29. Linear regression analysis of macrofauna abundance and OC/SA for the Mississippi Canyon stations.

A highly significant positive correlation was indicated between OC/SA and meiofauna abundance ($r = 0.960$, $P = 0.000$, d.f. = 8). The results of regression analysis (Figure 30) indicated a highly significant exponential relationship between meiofauna abundance and OC/SA ($r^2 = 0.92$, $P = 0.0002$, $F = 71.3$). The best-fit line explained 92% of the variation in meiofauna abundance and the null hypothesis had a 0.02% chance of being true. Therefore, the null hypothesis (H_{04}) must be rejected, indicating there was a significant relationship between meiofauna abundance and OC/SA in the Mississippi Canyon sample subset.

No significant correlation was indicated between OC/SA and bacteria abundance ($r = 0.576$, $P = 0.135$, d.f. = 8). The results of regression analysis (Figure 31) did not indicate a significant logarithmic relationship between bacteria abundance and OC/SA ($r^2 = 0.35$, $P = 0.12$, $F = 3.23$). The best-fit line explained 35% of the variation in bacteria abundance and the null hypothesis had a 12% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA in the Mississippi Canyon sample subset.

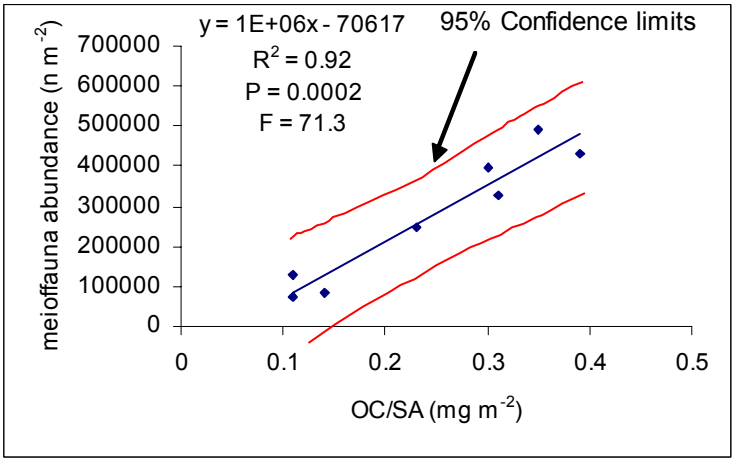

Figure 30. Regression analysis results of meiofauna abundance and OC/SA for the Mississippi Canyon stations.

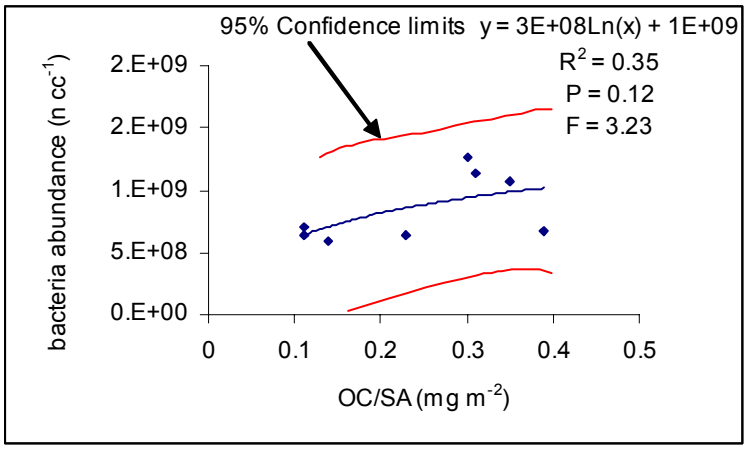

Figure 31. Regression analysis results of bacteria abundance and OC/SA for the Mississippi Canyon stations.

The results of the standard regression analysis for the biogeochemical parameters at the Mississippi Canyon stations are presented in Table 9. There were many significant relationships among the variables at the Mississippi Canyon sites. A strong

linear association was observed between wt % OC and water depth as demonstrated in Figure 32. Highly significant exponential relationships were observed for macrofauna and meiofauna abundances with both water depth (Figure 33) and wt % OC (Figure 34). Bacteria was only moderately significantly associated with wt % OC (Figure 34).

Table 9. Summary of regression analysis results for the Mississippi Canyon stations.

	Independent variable											
Dependent variable	Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC	0.96	147	--	--	--	--	0.58**	8.2	0.92**	71.5		
OC/SA	0.89	48	--	--	--	--			0.86**	35.8		
Macrofauna	0.92*	66.3	0.86*	37.1	0.85*	34.6	0.56**	7.7	0.69**	13.3		
Meiofauna	0.90*	56.5	0.92*	66.8	0.92*	71.3	0.51*	6.3	0.75**	18.1		
Bacteria			0.52*	6.59								

All results indicated are significant ($P < 0.05$) and linear, except * exponential and ** logarithmic.

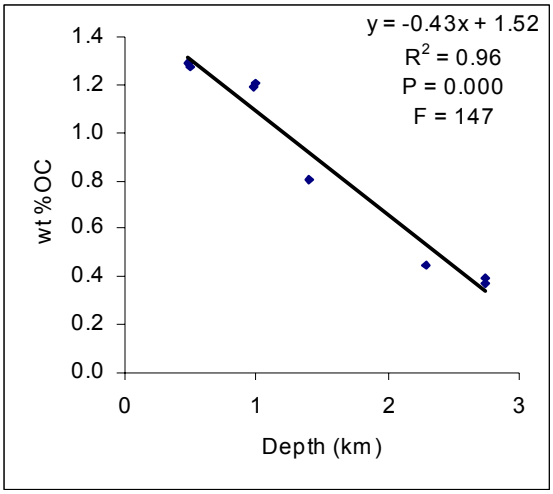

Figure 32. Plot of wt % OC as a function of water depth for the Mississippi Canyon stations.

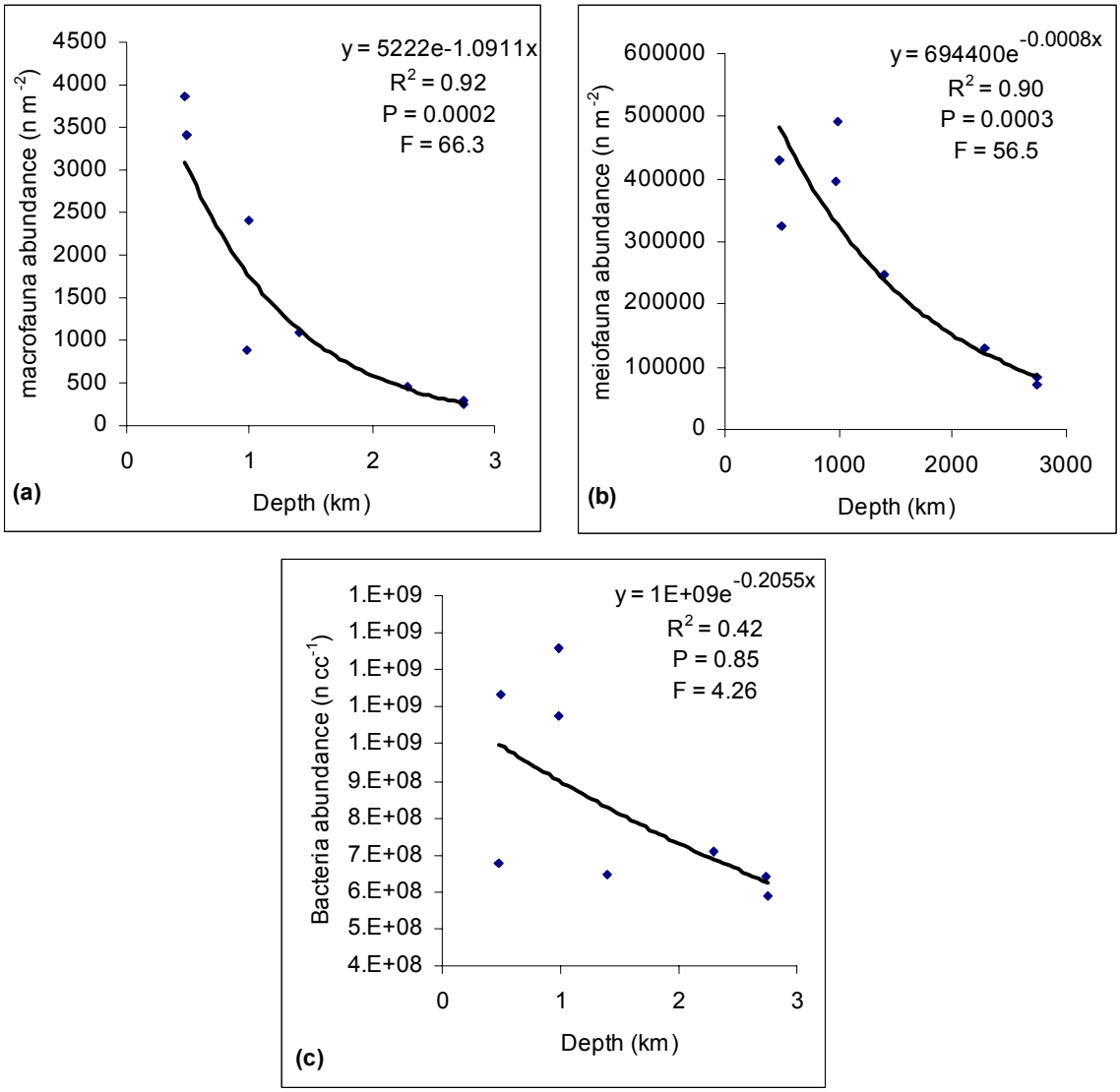

Figure 33. Plots of (a) macrofauna, (b) meiofauna, and (c) bacteria abundances as functions of water depth for the Mississippi Canyon stations.

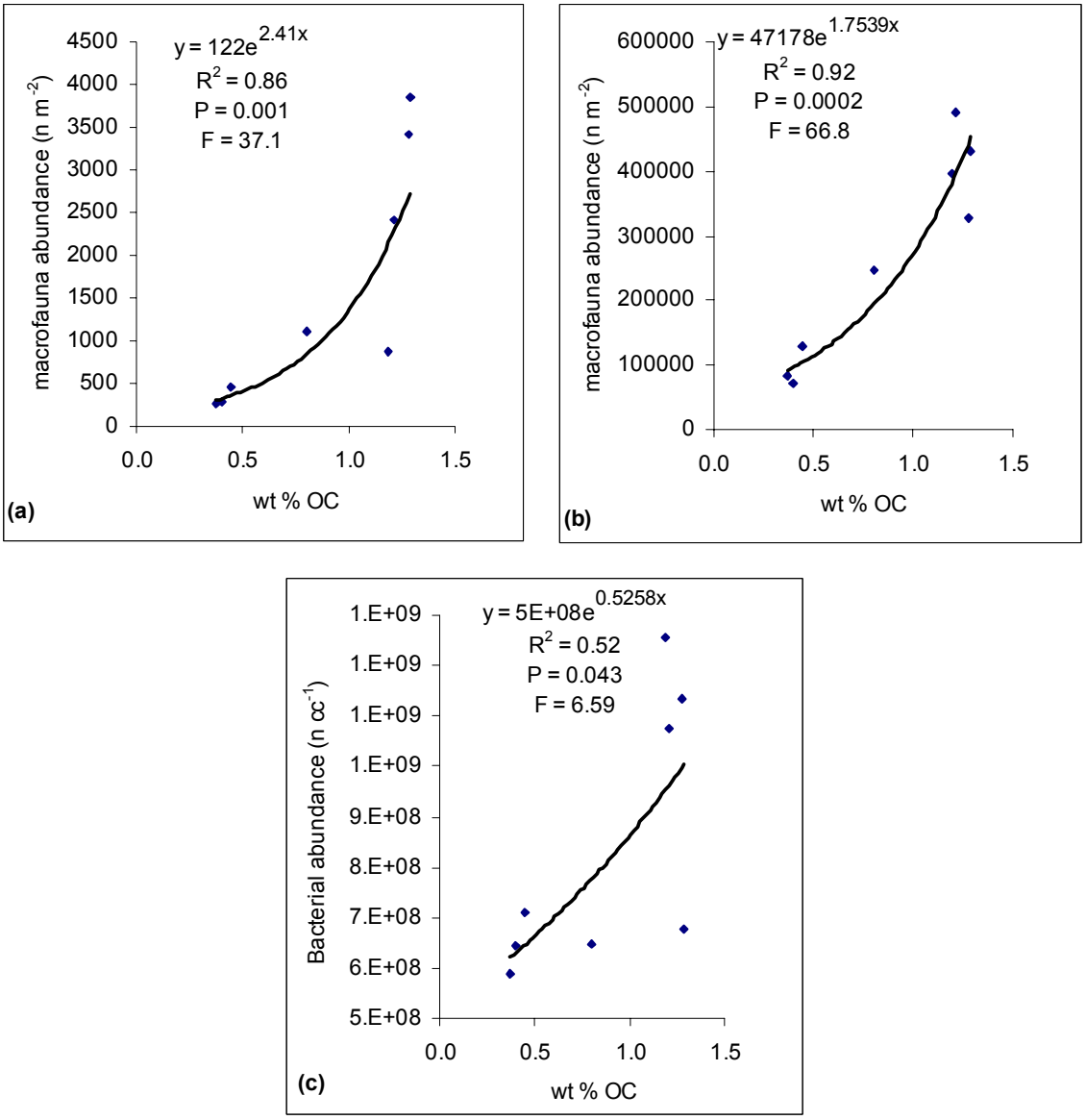

Figure 34. Plots of (a) macrofauna, (b) meiofauna, and (c) bacteria abundances as functions of wt % OC for the Mississippi Canyon stations.

Obviously variables at the Mississippi Canyon were confounded as illustrated by the many correlations making it difficult to determine which independent variable was the most important. To help statistically determine among the independent variables

which was the best predictor of biological abundance, stepwise multiple linear regression analysis was utilized. The independent variables included water depth, wt % OC, OC/SA, wt % $CaCO_3$, wt % >63 μm and wt % <63 μm and the dependent variables were macrofauna, meiofauna and bacteria abundances. The results of the stepwise multiple regression analysis indicated that at the Mississippi Canyon stations: (1) water depth was the best predictor for macrofauna abundance (y = 3577 – 1318 water depth, DW = 1.97, r^2 = 0.75, P = 0.005, F = 18.0); (2) OC/SA was the best predictor for meiofauna abundance (y = -70,617 + 1,411,232 OC/SA, DW = 1.39, r^2 = 0.92, P = 0.000, F = 71.3); and (3) wt % OC was the best predictor for bacteria abundance (y = 4.4E+08 + 4.5E+08 wt %OC, DW = 1.56, r^2 = 0.50, P = 0.049, F = 6.06).

Eastern Stations

Table 10. Eastern stations.

Station	Depth (m)	wt % OC	SA (m^2g^{-1})	OC/SA (mg m^{-2})	Wt % $CaCO_3$	$\delta^{13}C_{OC}$ (‰)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
S44	212	0.46	8.92	0.52	72		1154	254813	1.45E+09
S43	360	0.61	11.7	0.52	70	-26.6	1260	276279	1.01E+09
S42(a)	772	0.62	17.8	0.35	57	-24.9	688	209608	8.65E+08
S42(b)	773	0.66	17.3	0.38	56		924	282929	2.03E+08
HiPro	1574	1.0	48.1	0.21	6.7	-23.6	1220	343118	5.88E+08
S36(a)	1832	1.1	36.9	0.28	25		2173	450026	1.53E+09
S36(b)	1849	1.2	30.1	0.39	24	-21.8	1353	349936	1.11E+09

(a) = year 2000; (b) = year 2001

The eastern stations included sites located in the far eastern region of the northern GOM (Table 10). Stations S36 and S42 were sampled in two separate years as

indicated. Water depths at these stations ranged from 212 to 1849 m with a mean wt % OC of 0.80 wt %, which equaled the sample mean. Stations S42 to S44 were located on the eastern side of the Desoto Canyon along the Florida Escarpment at depths of 212 to 773 m. Sites S36 and HiPro (1574 and 1849 m) were located on the western rim of the Desoto Canyon and were influenced by high primary productive surface waters and possibly by Mississippi River discharge. Wt % OC was greatest at S36 and HiPro (>1.0 wt %) with high surface areas (>30 m^2g^{-1}) and corresponding high silt and clay fractions (>92 wt %). S36 had greater wt % $CaCO_3$ (25 wt %) compared to HiPro (6.7 wt %) possibly due to foraminifera. Stations S42 to S44 had low surface areas (<20 m^2g^{-1}) and corresponding high sand fractions (~20-50 wt %) with high calcium carbonate content (>50 wt %). S44 (212 m) had the greatest wt % $CaCO_3$ of all GOM stations at 72 wt %.

The $\delta^{13}C_{OC}$ values were more depleted (-24.9 to -26.6‰) at stations on the eastern side of the Desoto Canyon indicating a terrestrial source and more enriched (-21.8 to -23.6‰) at stations on the western rim indicating a marine source. The stations on the eastern side were in shallow water and had much lower organic carbon content (<0.66 wt %).

OC/SA values ranged from 0.21 to 0.52 mg-OC m^{-2}, which were the highest in the GOM sample set and were 33% greater than the sample mean of 0.27 mg-OC m^{-2}. The mean calcium carbonate content of 54 wt % was twice the sample mean of 27 wt %.

Macrofauna and meiofauna abundances were both 24% above the sample mean and bacteria abundance was 8% higher. The macrofauna taxonomic groups (N = 38) were comprised primarily of nematodes (35%) and polychaetes (32%). Meiofauna

taxonomic groups (N = 21) were comprised primarily of nematodes (66%), harpacticoids (11%), and copepod nauplii (11%), which reflected the sample means. Sediment oxygen concentrations at stations S36 and S42 were observed to penetrate down past the top 2 cm and sulfide was detected ~0.5 cm at S36 and ~3 cm at S42.

Standard regression analysis was performed to test the relationship between OC/SA and water depth for the eastern GOM sample subset. The results of the regression analysis (Figure 35) indicated a significant logarithmic relationship between OC/SA and water depth ($r^2 = 0.68$, P = 0.022, F = 10.8). The best-fit line explained 68% of the variation in OC/SA and the null hypothesis had a 2.2% chance of being true. Therefore, the null hypothesis (H_{01}) must be rejected, indicating there was a significant relationship between OC/SA and water depth in the eastern GOM sample subset.

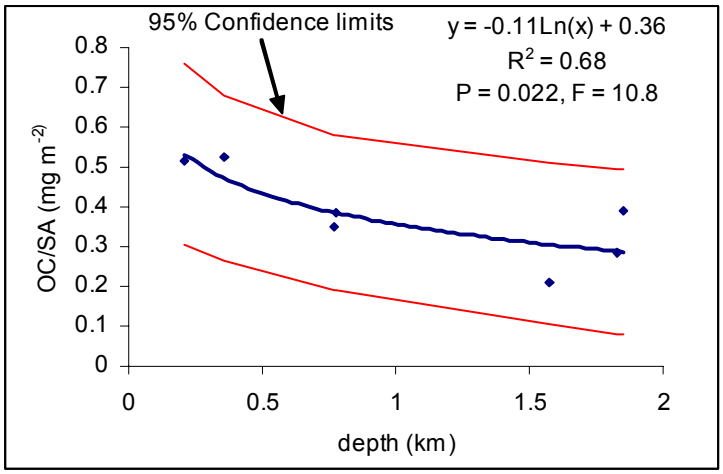

Figure 35. Linear regression analysis of OC/SA and water depth for the eastern GOM stations.

Correlation analysis and standard regression analysis were performed to test the relationships between fauna abundances and OC/SA for the eastern GOM stations. No significant correlation was indicated between OC/SA and macrofauna abundance ($r = -0.238$, $P = 0.607$, d.f. = 7). The results of the linear regression analysis (Figure 36) did not indicate a significant relationship between macrofauna abundance and OC/SA ($r^2 = 0.06$, $P = 0.61$, $F = 0.30$). The best-fit line explained only 6% of the variation in macrofauna abundance and the null hypothesis had a 61% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between macrofauna abundance and OC/SA in the eastern GOM sample subset.

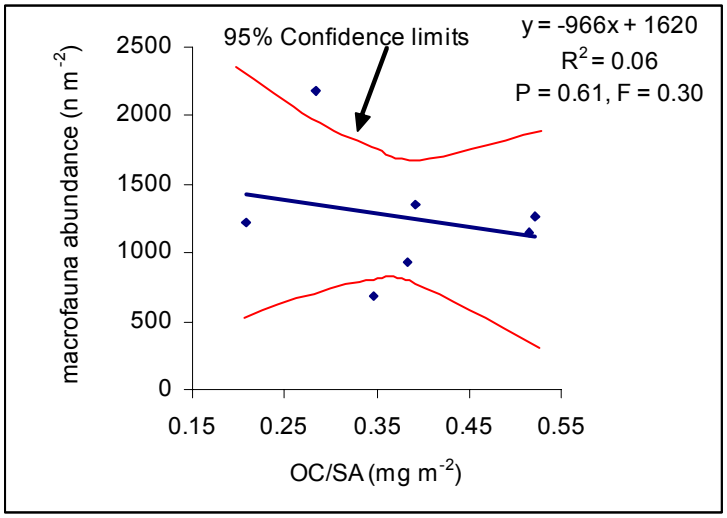

Figure 36. Linear regression analysis of macrofauna abundance and OC/SA for the eastern GOM stations.

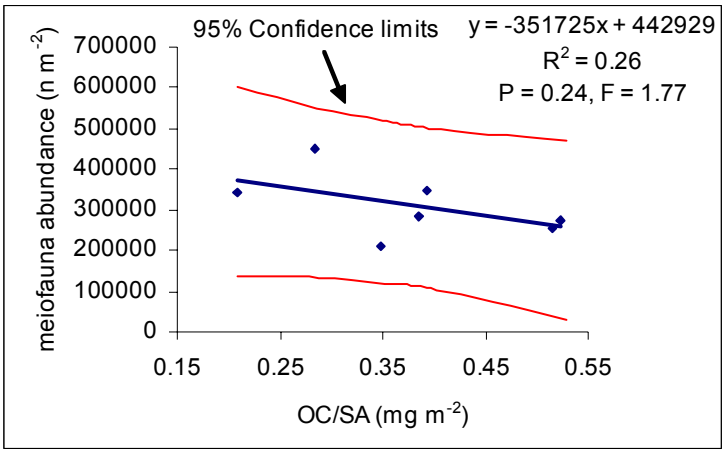

Figure 37. Regression analysis results of meiofauna abundance and OC/SA for the eastern GOM stations.

No significant correlation was indicated between OC/SA and meiofauna abundance ($r = -0.511$, $P = 0.241$, d.f. = 7). The results of regression analysis (Figure 37) did not indicate a significant relationship between meiofauna abundance and OC/SA ($r^2 = 0.26$, $P = 0.24$, $F = 1.77$). The best-fit line explained 26% of the variation in meiofauna abundance and the null hypothesis had a 24% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between meiofauna abundance and OC/SA in the eastern GOM sample subset.

No significant correlation was indicated between OC/SA and bacteria abundance ($r = 0.265$, $P = 0.565$, d.f. = 7). The results of regression analysis (Figure 38) did not indicate a significant exponential relationship between bacteria abundance and OC/SA ($r^2 = 0.07$, $P = 0.57$, $F = 0.38$). The best-fit line explained 7% of the variation in bacteria

abundance and the null hypothesis had a 57% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA in the eastern GOM sample subset.

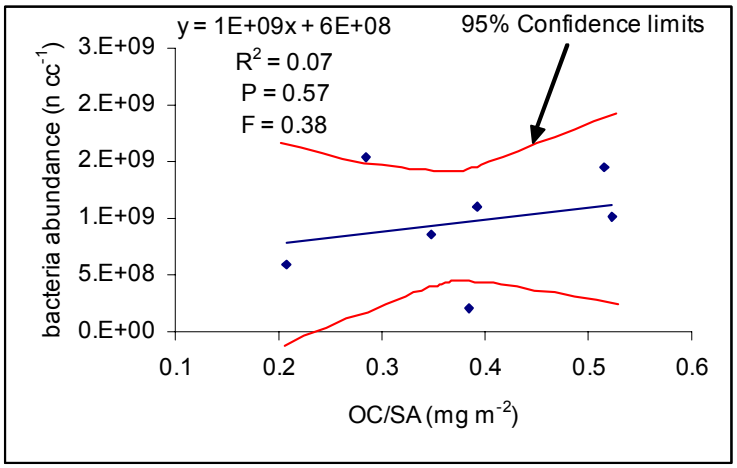

Figure 38. Regression analysis results of bacteria abundance and OC/SA for the eastern GOM stations.

The summary of the regression analysis for the eastern GOM sample subset is presented in Table 11. Wt % OC was directly related to water depth (Figure 39). Meiofauna abundance was significantly associated with both water depth and wt % OC. Macrofauna and meiofauna were positively correlated ($r = 0.922$, $P = 0.003$, d.f. = 7).

Table 11. Summary of regression analysis results for the eastern GOM stations.

Dependent variable	Independent variable: Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC	0.96	107					0.84*	26.0	0.82*	23.2	0.82*	23.2
OC/SA	0.68**	10.9					0.70*	15.2	0.72**	13.0	0.70	11.8
Macrofauna												
Meiofauna	0.65	0.03	0.65	.03								
Bacteria												

All results indicated are significant (P < 0.05) and linear, except * exponential and ** logarithmic.

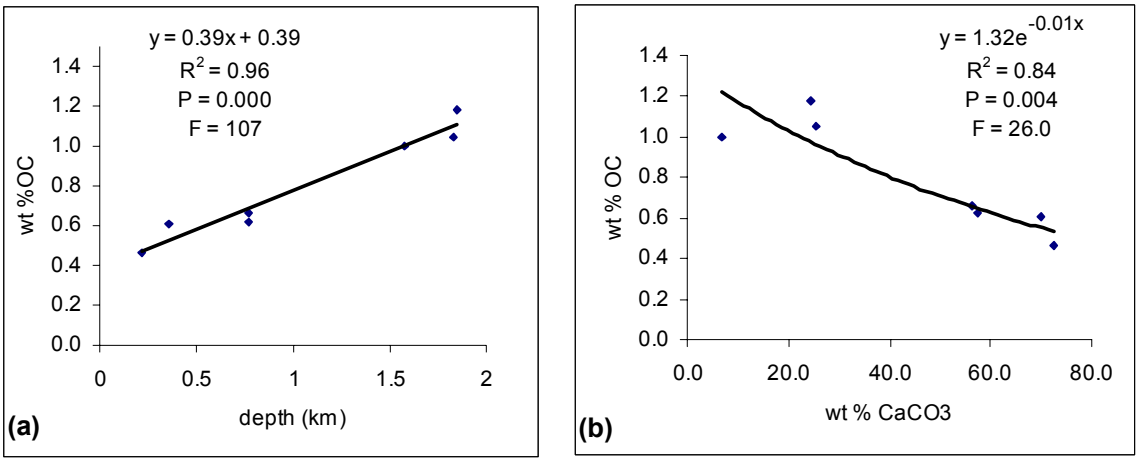

Figure 39. Plots of (a) wt % OC vs. water depth, and (b) wt % OC vs. wt % $CaCO_3$ for the eastern GOM stations.

High Production Stations

Table12. High Production stations.

Station	Depth (m)	wt %OC	SA (m^2g^{-1})	OC/SA (mg m^{-2})	wt % $CaCO_3$	$\delta^{13}C_{OC}$ (‰)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
MT1(a)	481	1.3	33.4	0.39	5.3	-22.5	3855	430412	6.78E+08
MT1(b)	490	1.3	40.9	0.31	5.4	-23.5	3407	326113	1.13E+09
BushHill	548	1.0	33.4	0.29	15	-21.8	691	407852	1.08E+09
MT3(b)	980	1.2	39.3	0.30	8.4	-21.2	875	490517	1.08E+09
MT3(a)	988	1.2	34.2	0.35	8.1	-21.1	2419	395478	1.26E+09
HiPro	1574	1.0	48.1	0.21	6.7	-23.6	1220	343118	5.88E+08
S36(a)	1832	1.1	36.9	0.28	25	n.d.	2173	450026	1.53E+09
S36(b)	1849	1.2	30.1	0.39	24	-21.8	1353	349936	1.11E+09

(a) = year 2000; (b) = year 2001

The High Production sample subset included stations in the GOM located in waters known for high surface primary production (Table 12). Stations MT1, MT3, and S36 were sampled in two separate years as indicated. MT1 and MT3 were located near the Mississippi River mouth; HiPro and S36 were also in proximity to the river and were possibly influenced by its discharge. Bush Hill was located to the west of the Mississippi Canyon stations and was also influenced by sediment transport from the river. In addition, Bush Hill was located near a well-documented chemosynthetic community. Water depths at these stations ranged from 481 to 1849 m with a mean wt % OC of 1.1 wt %, which was 35% greater than the sample mean of 0.80 wt %. Surface areas were high (>30 m^2g^{-1}) with corresponding high silt and clay content (>90 wt %) and low calcium carbonate content (<25 wt %). OC/SA values ranged from 0.21 to 0.39 mg-OC m^{-2} with a mean of 0.32 mg-OC m^{-2}, which was 16% higher than the sample

mean of 0.27 mg-OC m^{-2}. The $\delta^{13}C_{OC}$ values ranged from -21.1 to -23.6‰, representative of marine origin. Macrofauna abundances were 68% greater than the sample mean and the taxonomic groups (N = 38) were comprised primarily of amphipods (36%), polychaetes (25%) and nematodes (18%). Meiofauna abundances were 48% greater than the sample mean, with taxonomic groups (N = 22) comprised primarily of nematodes (64%), harpacticoids (12%), and copepod nauplii (9%). Bacteria abundances were 17% greater than the sample mean.

Standard linear regression analysis was performed to test the relationship between OC/SA and water depth at the High Production stations. The results of the linear regression (Figure 40) indicated no significant relationship between OC/SA and water depth ($r^2 = 0.03$, P = 0.67, F = 0.20). The best-fit line only explained 3% of the variation in OC/SA and the null hypothesis had a 67% chance of being true. Therefore, the null hypothesis (H_{01}) must be accepted, indicating there was no significant relationship between OC/SA and water depth at the High Production sample subset.

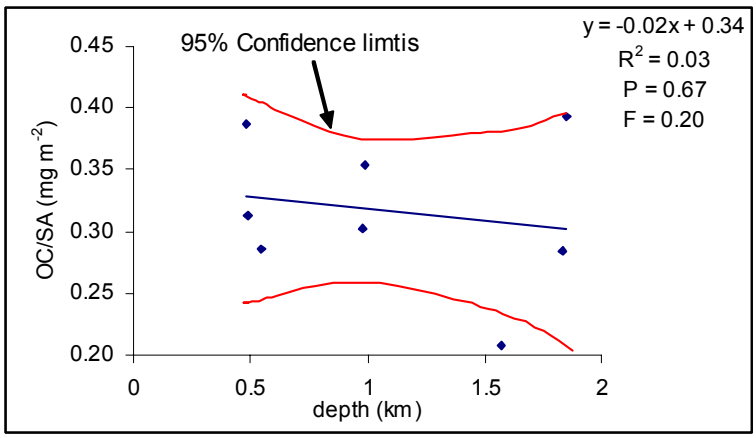

Figure 40. Linear regression analysis of OC/SA and water depth for the High Production stations.

Correlation analysis and standard regression analysis were performed to test the relationships between fauna abundances and OC/SA. No significant correlation was indicated between OC/SA and macrofauna abundance ($r = 0.451$, $P = 0.262$, d.f. = 8). The results of the regression analysis (Figure 41) indicated no significant relationship between macrofauna abundance and OC/SA ($r^2 = 0.20$, $P = 0.26$, $F = 1.53$). The best-fit line explained only 2% of the variation in macrofauna abundance and the null hypothesis had a 26% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between macrofauna abundance and OC/SA at the High Production sample subset.

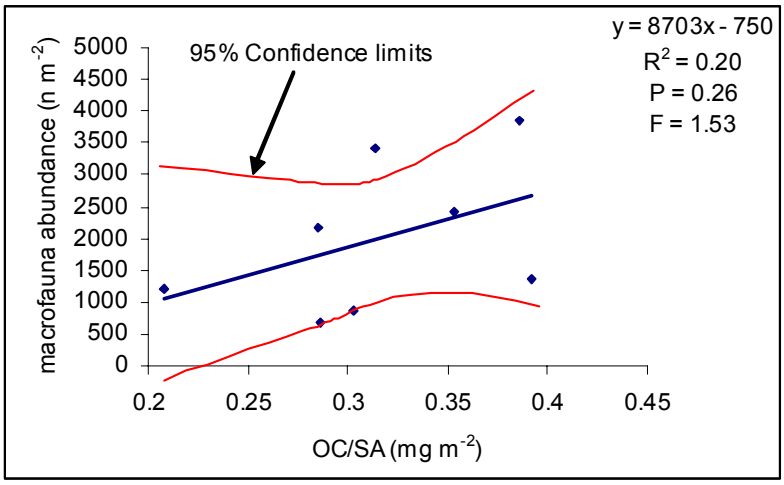

Figure 41. Linear regression analysis of macrofauna abundance and OC/SA for the High Production stations.

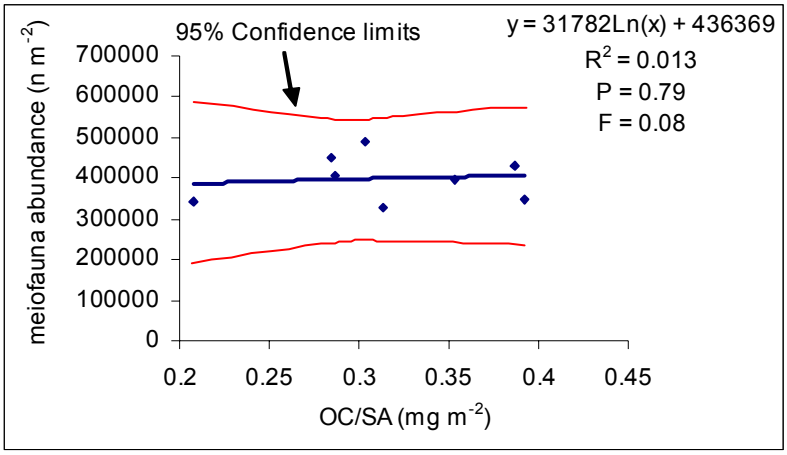

Figure 42. Regression analysis results of meiofauna abundance and OC/SA for the High Production stations.

No significant correlation was indicated between OC/SA and meiofauna abundance ($r = 0.063$, $P = 0.882$, d.f. = 8). The results of regression analysis (Figure 42) did not indicate a significant relationship between meiofauna abundance and OC/SA ($r^2 = 0.013$, $P = 0.79$, $F = 0.08$). The best-fit line explained only 1.3% of the variation in

meiofauna abundance and the null hypothesis had a 79% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between meiofauna abundance and OC/SA at the High Production sample subset.

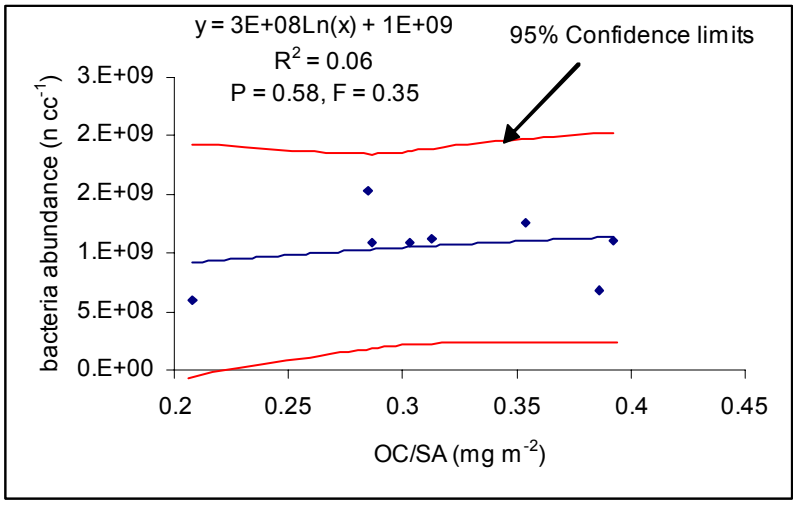

Figure 43. Regression analysis results of bacteria abundance and OC/SA for the High Production stations.

No significant correlation was indicated between OC/SA and bacteria abundance ($r = 0.155$, $P = 0.713$, d.f. = 8). The results of regression analysis (Figure 43) did not indicate a significant relationship between bacteria abundance and OC/SA ($r^2 = 0.06$, $P = 0.58$, $F = 0.35$). The best-fit line explained that only 6% of the variation in bacteria abundance and the null hypothesis had a 58% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA at the High Production sample subset.

The summary of the regression analyses determined for the variables at the High Production sample subset is presented in Table 13. As the results indicate there was only one significant relationship among the different parameters at the High Production stations. There was a significant linear association between macrofauna abundance and wt % OC as observed in Figure 44.

Table 13. Summary of regression analysis results for the High Production stations.

	Independent variable											
Dependent variable	Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC												
OC/SA												
Macrofauna			0.53	6.7								
Meiofauna												
Bacteria												

All results indicated are significant ($P < 0.05$) and linear, except * exponential and ** logarithmic.

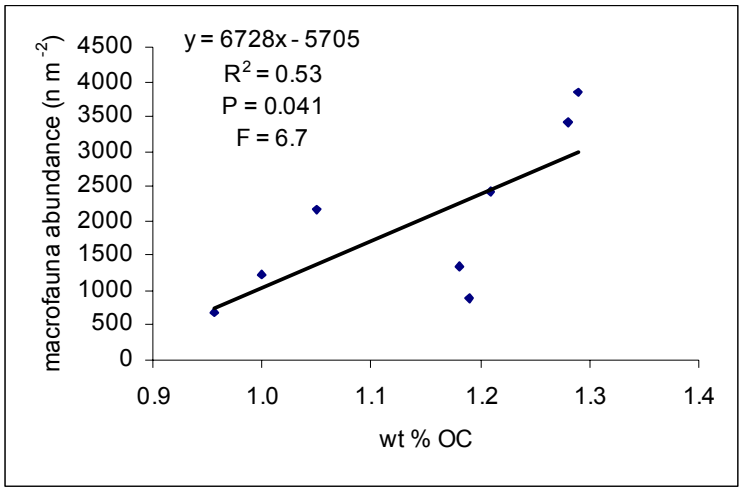

Figure 44. Macrofauna abundance at the High Production stations plotted as a function of wt % OC.

Abyssal Plain Stations

The Abyssal Plain stations are presented in Table 14 and include sites located at >2000 m water depth and along the abyssal plain of the northern GOM. Water depths ranged from 2050 to 3527 m and sediment wt % OC from 0.37 to 0.72 wt % with a mean of 0.52 wt % which was 43% less than the sample mean of 0.80 wt %.

Table 14. Abyssal Plain stations.

Station	Depth (m)	wt % OC	SA ($m^2 g^{-1}$)	OC/SA (mg m^{-2})	Wt % $CaCO_3$	$\delta^{13}C_{OC}$ (‰)	Total Macrofauna Abundance (n m^{-2})	Total Meiofauna Abundance (n m^{-2})	Total Bacteria Abundance (n cc^{-1})
NB4	2050	0.63	30.5	0.21	34	-30.0	453	148409	6.62E+08
MT5	2290	0.45	42.6	0.11	8.0	-26.6	448	128964	7.10E+08
MT6(b)	2740	0.40	35.0	0.11	19	-23.6	289	82665	5.88E+08
MT6(a)	2750	0.37	26.4	0.14	32	-21.5	253	72647	6.43E+08
RW6	3015	0.72	33.1	0.22	26	-25.0	282	144453	9.83E+08
S4	3408	0.55	39.2	0.14	16	-24.6	143	50761	1.05E+09
S1	3527	0.49	25.3	0.20	39	-20.6	354	70038	1.16E+09

OC/SA values ranged from 0.11 to 0.21 mg-OC m^{-2} with a mean of 0.16 mg-OC m^{-2}, which was 51% lower than the sample mean of 0.27 mg-OC m^{-2}. Surface area, wt % $CaCO_3$ and $\delta^{13}C_{OC}$ values for the abyssal stations were all within 7% of the sample means. NB4 had the most depleted $\delta^{13}C_{OC}$ (-30.0‰), which indicated a possible hydrocarbon source. S1 had the most enriched $\delta^{13}C_{OC}$ (-20.6‰), which was representative of marine origin. The other stations ranged from -21.5 to -26.6‰. Microelectrode probes indicated oxygen penetration to 10 cm in the sediments at S1 and S4 and no sulfide concentration.

Macrofauna abundance was 3 times below the sample mean with taxonomic groups (N = 35) comprised primarily of nematodes (36%) and polychaetes (23%). Meiofauna abundance was 84% below the mean with taxonomic groups (N = 14) comprised primarily of nematodes (62%), harpacticoids (13%), and copepod nauplii (13%). Bacteria abundance was 8% below the sample mean.

Standard regression analysis was performed to test the relationship between OC/SA and water depth at the Abyssal Plain stations. The results of the linear regression (Figure 45) indicated no significant relationship between OC/SA and water depth ($r^2 = 0.02$, P = 0.76, F = 0.11). The best-fit line explained only 2% of the variation in OC/SA and the null hypothesis had a 76% chance of being true. Therefore, the null hypothesis (H_{01}) must be accepted, indicating there was no significant relationship between OC/SA and water depth in the Abyssal Plain sample subset.

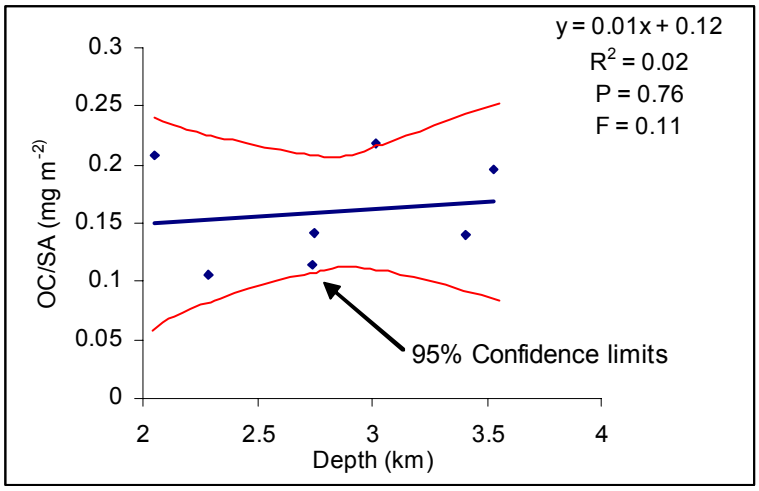

Figure 45. Linear regression analysis of OC/SA and water depth for the Abyssal Plain stations.

Correlation analysis and standard regression analysis were performed to test the relationship between fauna abundances and OC/SA. No significant correlation was indicated between OC/SA and macrofauna abundance ($r = 0.148$, $P = 0.751$, d.f. = 7). The results of the regression analysis (Figure 46) indicated no significant relationship between macrofauna abundance and OC/SA ($r^2 = 0.02$, $P = 0.75$, $F = 0.11$). The best-fit line explained only 2% of the variation in macrofauna abundance and the null hypothesis had a 75% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between macrofauna abundance and OC/SA at the Abyssal Plain sample subset.

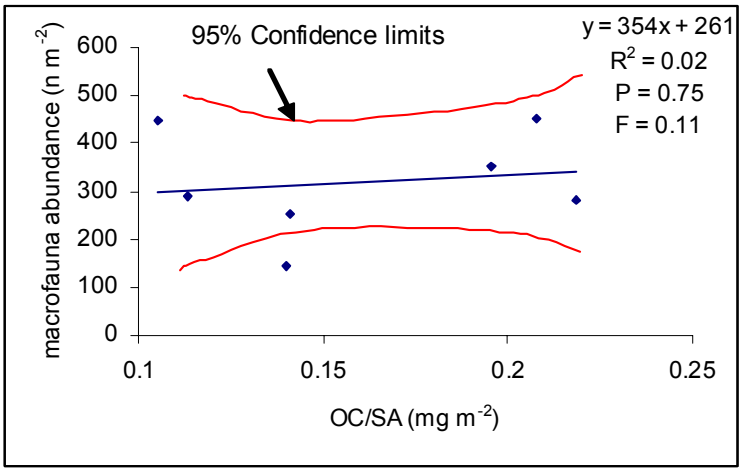

Figure 46. Linear regression analysis of macrofauna abundance and OC/SA for the Abyssal Plain stations.

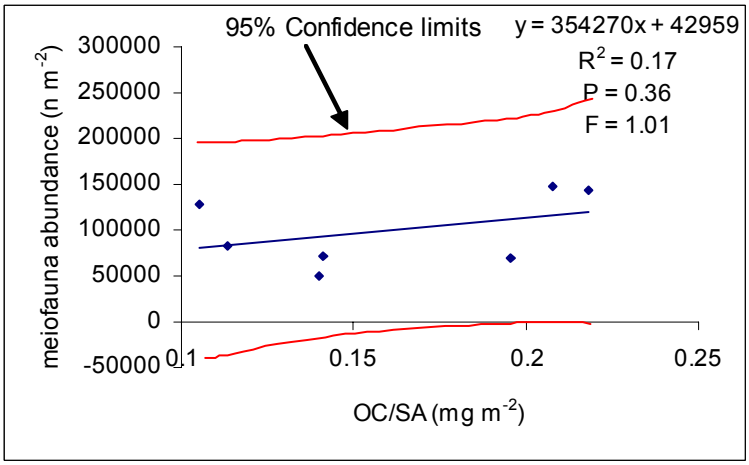

Figure 47. Regression analysis results of meiofauna abundance and OC/SA for the Abyssal Plain stations.

No significant correlation was indicated between OC/SA and meiofauna abundance ($r = 0.411$, $P = 0.359$, d.f. = 7). The results of regression analysis (Figure 47) did not indicate a significant relationship between meiofauna abundance and OC/SA (r^2

= 0.17, P = 0.36, F = 1.01). The best-fit line explained 17% of the variation in meiofauna abundance and the null hypothesis had a 36% chance of being true. Therefore, the null hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between meiofauna abundance and OC/SA in the Abyssal Plain sample subset.

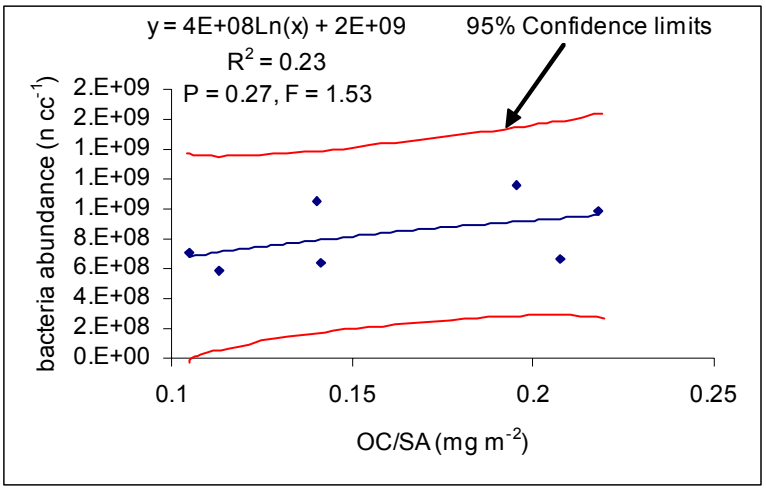

Figure 48. Regression analysis results of bacteria abundance and OC/SA for the Abyssal Plain stations.

No significant correlation was indicated between OC/SA and bacteria abundance (r = 0.463, P = 0.295, d.f. = 7). The results of regression analysis (Figure 48) indicated no significant logarithmic relationship between bacteria abundance and OC/SA (r^2 = 0.23, P = 0.27, F = 1.53). The best-fit line explained 23% of the variation in bacteria abundance and the null hypothesis had a 27% chance of being true. Therefore, the null

hypothesis (H_{04}) must be accepted, indicating there was no significant relationship between bacteria abundance and OC/SA in the Abyssal Plain sample subset.

The regression analysis results for the Abyssal Plain stations are presented in Table 15. As the results indicate very few significant relationships were observed at the Abyssal Plain sites. Bacteria abundance increased significantly with increasing water depth and wt % OC decreased significantly with increasing grain size.

Table 15. Summary of regression analysis results for the Abyssal Plain stations.

	Independent variable											
Dependent variable	Water Depth		wt % OC		OC/SA		wt % $CaCO_3$		wt % > 63µm		wt % < 63 µm	
	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F	r^2	F
wt % OC									0.66**	9.8		
OC/SA							0.59*	7.3				
Macrofauna												
Meiofauna												
Bacteria	0.68	10.7										

All results indicated are significant (P < 0.05) and linear, except * exponential and ** logarithmic.

Summary of Statistical Results

A summary of the statistical analysis results used for testing the null hypotheses is presented in Table 16. As a reminder the null hypotheses are listed below.

H_{01}: There is no variation in OC/SA with water depth.

H_{02}: There is no variation in OC/SA along an east to west gradient.

H_{03}: There is no variation in OC/SA among different sampling dates.

H_{04}: There is no variation in benthic organism abundance with OC/SA.

Table 16. Summary of statistical analyses of the null hypotheses.

	H_{01}	H_{02}	H_{03}	H_{04} (macrofauna)	H_{04} (meiofauna)	H_{04} (bacteria)
GOM	R	A	A	R	R	A
Western GOM	A	--	--	A	A	A
Mississippi Canyon	R	--	--	R	R	A
Eastern GOM	R	--	--	A	A	A
High Production	A	--	--	A	A	A
Abyssal Plain	A	--	--	A	A	A

A = null hypothesis accepted; R = null hypothesis rejected

OC/SA varied significantly with water depth across the northern GOM sample set, as well as at the Mississippi Canyon sites and the eastern GOM subset. No significant variations in OC/SA with water depth were observed at the western GOM, High Production, or the Abyssal Plain sample subsets. OC/SA did not significantly vary in an east-to-west gradient across the northern GOM sites and among different sampling years.

OC/SA was significantly related to macrofauna and meiofauna abundance for the northern GOM sample set and the Mississippi Canyon sample subset. No associations were observed for the other subsets. In contrast, OC/SA was not significantly related to bacteria abundance for any areas of the northern GOM sample set.

DISCUSSION

Past research has indicated that organic matter within marine sediments may be correlated with sediment surface area to determine the degree of association between organic matter and mineral surfaces. A strong positive correlation between organic carbon and surface area has been attributed to the adsorption of organics to the surfaces of mineral grains (Mayer, 1994a; Mayer, 1994b). This relationship of OC/SA was examined for deep-sea sediments in the northern GOM and the values were determined to range from 0.37 to 0.52 mg-OC m^{-2}, which was well below the typical continental margin levels of 0.5-1.0 mg-OC m^{-2} determined by Mayer (1994a, 1994b). However, they were consistent with values determined by Mayer (1994b) for Pacific Ocean and Atlantic Ocean deep sea sediments, which had values of 0.1 to 0.4 mg-OC m^{-2}. OC/SA values at the eastern GOM sites were highest (~0.50 mg-OC m^{-2}) due to the low surface area of carbonates and were lowest at the Abyssal Plain sites due to low loadings of organic carbon.

The linear relationship between organic carbon and surface area at the northern GOM sites was statistically insignificant ($r^2 = 0.11$, $P = 0.085$), which was consistent with deep sea sediments (Mayer, 1994b). However, the weak OC/SA relationship was in sharp contrast with sediments from other geographical areas where organic matter is more plentiful, such as the Peru Margin. A strong positive correlation of organic carbon and sediment surface area has been observed in sediments of the Peru Margin (Hedges and Keil, 1995; Bergamaschi et al., 1997), which contain in excess of 6 wt % OC, indicating that surface area was an important variable to organic carbon in these

sediments. These findings suggest that in areas where organic matter is low (<1 wt %OC), surface area is not a dominant factor to organic carbon content. In sediments with <3 wt % OC, <15% of the mineral surfaces are coated in organic material (Mayer, 1999). Moreover, the organics are found in localized patches, specifically along the edges of clay plates (Furukawa, 2000). This suggests that in areas of low organic loadings organic carbon would have a stronger correlation with clay content than with surface area. This was seen at the northern GOM study sites where a strong positive exponential relationship was observed between organic carbon and clay content (r^2 = 0.39, P = 0.0003, F = 16.9), suggesting that sediment mineralogy has a more dominant influence on organic matter than surface area at the northern GOM sites.

The low OC/SA values determined for this study indicated that organic carbon is very limiting for stations in the northern GOM. Previous studies have considered the OC/SA association in relation to adsorption (Keil et al., 1994a; Keil et al., 1994b; Mayer 1994a; Mayer, 1994b); however, none have examined the relationship between OC/SA and benthic faunal abundance. Since the availability of organic matter in the sediment is one of the more important factors to the organisms, this study addressed the relationship between OC/SA and faunal abundance. There was a significant relationship observed between OC/SA and macrofaunal and meiofaunal abundances, however the associations were not strong (r^2 = 0.27 and 0.29, respectively). This suggests that OC/SA was a factor affecting faunal abundance, though not the most dominant. Water depth and wt % OC were observed to have stronger correlations with faunal abundance than OC/SA.

Statistical analysis indicated that wt % OC was the most significant variable associated with faunal abundance across the northern GOM stations.

The strong correlation between macrofauna and meiofauna ($r = 0.839$, $P = 0.000$) at these stations suggested a trophic coupling between the two fauna. The only location this correlation was not observed was at the High Production stations where organic carbon content was high. At these stations macrofauna were positively correlated with organic carbon, indicating possibly that macrofauna were using the organic material in the sediment as a main food source and not grazing on the meiofauna. The $\delta^{13}C_{OC}$ values at these stations indicated that the organic matter was predominantly from a marine source (~ - 22‰), which would be more labile to marine organisms than terrestrial material. The $\delta^{13}C_{OC}$ values were consistent with those determined from previous studies for this area (Sackett and Thompson, 1963; Gearing et al., 1977; Goñi et al., 1998). There were no correlations observed between the larger fauna and bacteria. This could indicate that the macrofauna and meiofauna were not grazing on the bacteria or that the bacteria were not limiting and in plentiful supply.

The stations near the Mississippi River were observed to have higher wt % OC, OC/SA and faunal abundances, demonstrating the influence of the river on organic matter in the northern GOM. Stations at similar water depths in other areas of the northern GOM did not exhibit the same high values. This was in sharp contrast to the western GOM and Abyssal Plain stations where wt % OC, OC/SA and faunal abundances were much lower.

CONCLUSION

The availability of metabolizable organic matter is one of the more important factors that control benthic communities. The results of this study confirmed that wt % OC was the most significant variable associated with macrofauna and meiofauna abundances at stations sampled across the northern GOM. The relationship of OC/SA was also determined to be an important factor to the faunal abundances, particularly in the Mississippi Canyon sample subset. Macrofauna and meiofauna abundances tended to vary together with OC/SA, possibly indicating a trophic relationship. Bacteria did not correlate with the other fauna or with OC/SA.

The results also illustrated the complexity of the northern GOM with variable relationships at different locations. This demonstrated the necessity of considering not only the whole northern GOM as one system, but also of recognizing its individual environments as important to benthic biological patterns.

In conclusion, the interactions of organic matter with mineral surfaces in deep-sea sediments within this study of the northern GOM demonstrated a significant association with benthic communities; however, wt % OC was the more important environmental variable.

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