SURFACE SEDIMENT SURVEY OF THE SEABED ON THE NORTHWESTERN SLOPE OF CUBA, SOUTHERN STRAITS OF FLORIDA

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SUMMARY

The seabed off the northwestern coast of Cuba was explored to study the sedimentary and biological characteristics of surface sediments in three blocks leased to REPSOL-YPF-Cuba S.A., at depths between 1600 and 2000m. Subcoring of surficial sediments was conducted for stable isotopic analysis, total organic carbon and nitrogen contents, and infauna description. Spatial heterogeneity in moderately laminated sediments was detected among blocks. Surface sediments consist of silty and clay materials, mainly composed by calcite, were impoverished in organic matter and rich in hemipelagic components. From the northeastern end of this area (Block III, 1640m) large limestone blocks stained with hydrocarbons were recovered. Rock fragments had a coarse appearance and were impregnated with a strong oil odor. Their external surface had a blackened tar layer and an irregular iron-oxyhydroxide stain. Bulk sediment isotopic analysis ($\delta^{13}C$: -25.7 to -18.5‰) revealed a non-methanogenic carbon source, suggesting that oil seepage occurs localized. Source of sedimentary organic carbon was mainly oceanic ($\delta^{13}C$: -18.50 to -19.13‰; $\delta^{15}N$: +3.6 to +6.4‰; molar C:N ratios of 2.4 to 5). Bottom water conditions were stable (5ml·l^{-1} O_2, 3-4°C, 35.0psu) and infauna density was low due to reduced organic matter flux to deep sediments. This survey documents one of the deepest oil seeps in the vicinity of the eastern Gulf of Mexico.

An international multidisciplinary research group supported by REPSOL-YPF Cuba S.A. initiated in 2002 a multibeam prospection of the insular slope seabed, off the northwestern coast of Cuba, to describe the main bathymetric features and the prevailing hydrographic conditions in the Southern Straits of Florida. A previous geophysical survey of the area of study (Cesigma, 2002) indicated the presence of sediment mounds, sink holes and a complex of knolls on the slope seafloor associated perhaps to collapsed karstic structures that may potentially encompass oil and gas seeps (see Wilson *et al*., 1974).

Associated to cold seeps are carbonate mounds, coral reefs, pockmarks, mud volcanoes, and seamounts (Mazzini *et al*., 2003). According to these authors, in conventional cold seeps fluids escape to the seafloor through permeable fractures and faults. These systems have been documented with different approaches at numerous

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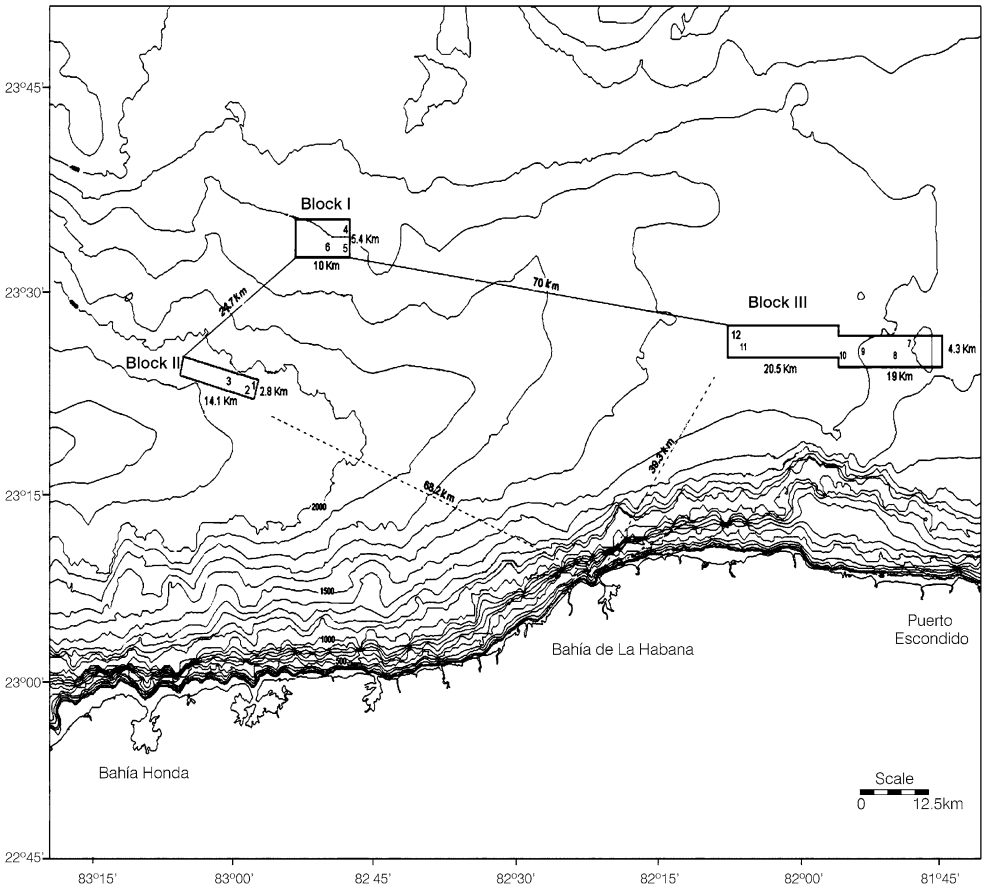

Figure 1. Bathymetry of the Southern Straits of Florida. Explored blocks I, II, and III are indicated from left to right; included in each block are the sites sampled.

sites both at passive and active margins in the Atlantic Ocean, Eastern and Western Pacific Ocean, and in the Mediterranean Sea (Paull *et al*., 1984, 1985; Kennicutt *et al*., 1985; Kulm *et al*., 1986; Sibuet and Olu, 1998; León *et al*., 2007). Hydrocarbon seepage into the seabead also occurs in fore arc basins in the Western Pacific (Schmidt *et al*., 2002) and in the Barbados accretionary wedge (Lance *et al*., 1998). Sibuet and Olu (2003) summarized current knowledge on the benthic communities associated to cold seep environments. In the vicinity of the area of study, cold seeps have been studied off the continental slope of Louisiana, in the northern Gulf of Mexico (Kennicutt *et al*., 1985; Feng *et al*., 2009), and along the Florida Escarpment (Paull *et al*., 1985), and new sites have recently been explored within the Gulf of Mexico (Cordes *et al*., 2007).

The deep seafloor in the studied area remained unexplored for several decades. Echeverría-Rodríguez *et al*. (1991) summarized much of the oil exploration conducted in Cuba both inshore and offshore. Recent initiatives of searching for fossil fuels in the sub-seafloor have renewed interest in studying deep sea processes such as erosion of surficial sediments, new sedimentological depositional models, and organic particle fluxes (Gaumet and Letouzey, 2002; Chambers *et al*., 2003; Magnier *et al*., 2004; Piñón, 2006). This paper documents the presence of oil seeps in the Southern Straits of Florida and provides new data on the sedimentary features, the sources of organic carbon an nitrogen based on stable isotopes, the diversity and density of surficial fauna, and the petrographic characteristics of seep-related authigenic carbonates.

Materials and Methods

The area of study comprises the insular slope seabead of the southwestern channel of the Florida Straits, between 23º23'57''N, 83º06'47''W and 23º27'39''N, 81º44'37''W, approximately 68 and 39km off Bahía Honda and Puerto Escondido, in the Havana Province, Cuba, respectively (Figure 1). A multibeam depth sub-bottom profiler (50kHz) was employed at water depths ranging 1600 to 2000m in the exploration of three blocks out of the 59 leased on the Exclusive Economic Zone of Cuba for oil and gas extraction. The blocks are referred henceforth as Blocks I, II, and III. The thermohaline structure and current velocity profiles were obtained with a CTD coupled with an ADCP deployed from the surface down to 5-7m above the seafloor. A 2kHz echosounder was employed for the recognition of the bottom structure. Near-surface sediments were sampled with a Reineck box-corer (sample area of 0.06m^2). Recovered box cores were subcored with a 6cm diameter and 30cm long fiberglass core-liner. Subcores were freeze-dried and later divided into standard sediment depth intervals; the resulting sediment fractions were lyophilized and ground to a fine powder. Total organic carbon (TOC) determinations were performed using Gaudette and Flight's technique (Gaudette *et al*., 1974). Total nitrogen (TN) was determined following the procedure of Rodríguez-Medina (1989). The concentrations of TOC and TN are expressed in percent dry weight. C:N ratios were stoichiometrically calculated based on the respective molecular weights. Bulk surficial sediment samples were obtained for isotopic analysis ($^{15}N/^{14}N$ and $^{13}C/^{12}C$), and fauna description. Sediment samples for stable isotopic analysis were acidified in a 1N HCl bath for 24h, washed with distilled water and dried at 60ºC to remove carbonates. The dried samples were ground with a mortar and pestle and analyzed in a Finnigan-MAT 252 Stable Isotope Ratio Mass Spectrometer against air nitrogen and PDB standards, for N and C, respectively. About 200g of the top 10cm of sediments were sieved through 0.50 and 0.25µm screens for qualitative infaunal analysis. Quantitative analyses for macroinfauna and meiofauna were based on two replicate samples taken in each box-core with the aid of syringes of 2.5cm diameter and 10cm penetration; sediment replicates were then sieved through 0.50 and 0.37µm screens. All organisms were counted and manually sorted into major taxa after being stained with Rose Bengal. X-ray diffraction (XRD) analyses of rock subsamples were conducted with a Philips 1130/96 diffractometer utilizing

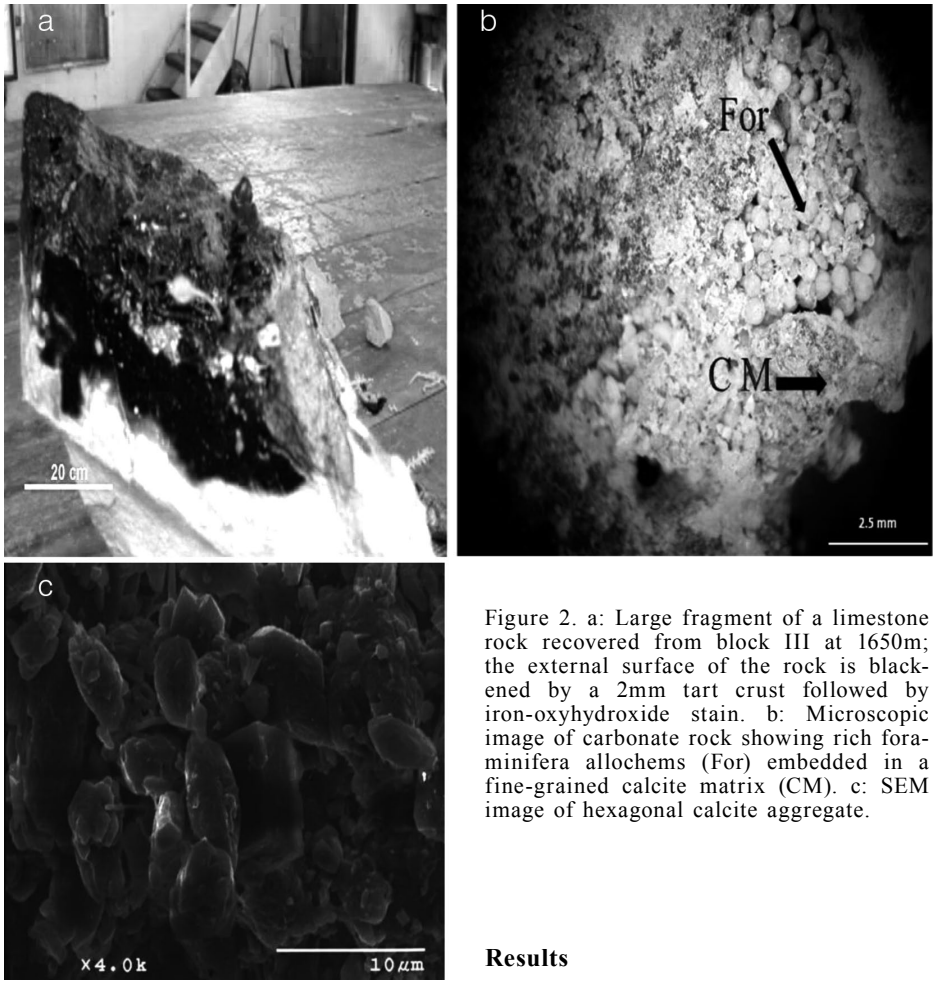

Figure 2. a: Large fragment of a limestone rock recovered from block III at 1650m; the external surface of the rock is blackened by a 2mm tart crust followed by iron-oxyhydroxide stain. b: Microscopic image of carbonate rock showing rich foraminifera allochems (For) embedded in a fine-grained calcite matrix (CM). c: SEM image of hexagonal calcite aggregate.

Cu $K_{\alpha\ 1,\ 2}$ radiation directed toward randomly oriented samples. Standard scans were recorded from 4° to 70° (2θ) at 2°/min. Field descriptions of rock color are given in accordance to the code numbers contained in the Rock-Color Chart of the Geological Society of America (Goddard *et al*., 1948). Non-parametric and parametric ANOVA tests (Friedman's, Kruskal-Wallis with tied ranks) were applied to determine differences in stable C and N isotope ratios, TOC and TN, and infaunal density values among blocks. A multiple regression analysis was used to determine the interrelationship between meio/macrofauna density (dependent variable) and TOC and TN (independent variables). A factorial analysis was employed to generate a correlation matrix of the parameters measured at the 12 sites sampled in the three blocks explored. These sites were later grouped according to the similarity of their biogeochemical attributes with a cluster analysis.

Results

Hydrographic setting

The Southern Straits of Florida lie under the influence of the Florida Current, the Yucatan Current and the southerly-flowing surface Cuban Counter-Current. Four water masses can be recognized: a) the Surface Tropical water mass in the upper 100m, with an average temperature of 29ºC and 35.5psu; b) the Subtropical Subsurface water mass down to 700m depth, with 22-26°C and 36.4-36.7psu; c) the Subantarctic Intermediate water mass near 1000m, with ~7°C and ~34.8psu; and d) the North Atlantic deep-water at depths exceeding 2000m, with ~7°C and 35.0psu. The thermohaline profiles revealed a stratified column with a 70m mixed layer and a permanent thermocline extending to a depth of 700m, a temperature of 10ºC and 35.2psu. In the present study, a strong near-bottom flow had a SE-E direction and an average velocity of 4cm·s^{-1}, 30% higher than the 3cm·s^{-1} known for abyssal basins (Munk *et al*., 1970). In contrast, the thermohaline structure at the bottom of the Southern Straits is stable with 5ml·l-1O_2, 3-4ºC and 35.0psu.

Topographic features

The three studied blocks lie on the slope of the Southern Straits of Florida (Figure 1). The deeper sector (>2100m) consists of a trough-like feature, graded axial slope, with decreasing depths eastwards and northwards, that separates Cuba, the Florida Peninsula and the Bahama Bank (Hurley, 1964; Malloy and Hurley, 1970). The insular margin (~200-1600m) is extremely steep and rugged. Block I, located off Artemisa Province, Cuba, at a maximum depth of 2169m had a surface of 28.49km^2, comprised a v-shaped valley oriented along the main axis of the channel, with faulting structures and small canyon on its western end. Block II (54.11km^2) had a maximum depth of 1640m depth showed a scarped surface faulting NE-SW. The distance between Blocks I and II was of 27.7km. Block III (174.32km^2) at a maximum depth of 1650m included a ridged bottom with prominent knoll-like structures protruding ~100m above the seabed. This area, positioned 70km east from the other two blocks, lies closer to the insular shelf (<28km) just off Puerto Escondido, Mayabeque Province, Cuba. The predominant faunal constituents of the bottom sediments in the biofacie were planktonic foraminifers, pteropod shells, and coccolithophorids that appeared disseminated with a fine-grained carbonate mud. In spite of their relative proximity, the three blocks exhibited certain sediment heterogeneity. In the deepest block (I) surficial sediments were classified as *Globigerina* clay devoid of an oxidized layer, whilst the adjacent block (II) contained an assorted biogenic hemipelagic biota (foraminifera, pteropods, scaphopods, micromolluscs, and echinoid and sponge spicules) and a discrete oxidized layer. Subcores obtained from this area revealed at 5cm sediment depth two dark horizons of organic matter, of 1.3 and 2.0cm. Surficial sediment in Block III was dominated by carbonate, highly cohesive due to the predominance of clay and minor hemipelagic constituents. At this site large fragments of limestone blocks were recovered (Figure 2a). They were coarse with sharp angles, and impregnated by a strong oil odor. Their external surface was blackened by a 2mm tar crust coated by an irregular iron-oxyhydroxides stained.

The XRD analysis of rock fragments revealed a mineral composition predominantly of calcite and aragonite, with a minor proportion of fluoroapatite. Allochems were bioclasts

TABLE I
CARBON AND NITROGEN ISOTOPIC VALUES AND MOLAR C:N RATIO IN SURFICIAL SEDIMENTS AT 12 SITES SAMPLED IN THREE BLOCKS ON THE NORTHWESTERN SLOPE OF CUBA

Site	$\delta^{13}C$‰	$\delta^{15}N$‰	µC:N
	Block I		
1	-18.75	+5.59	2.4
2	-18.5	+5.37	
3	-18.71	+5.74	
	Block II		
4	-18.54	+5.2	3
5	-18.87	+6.4	
6	-18.68	+5.71	
	Block III		
7	-18.71	+3.6	5
8	-19.13	+5.76	
9	-18.68	+5.69	
10	-18.64	+5.72	
11	-18.82	+5.62	
12	-18.63	+5.41	
Average	-18.7± 0.17	+5.4± 0.7	

(foraminifera test and microshell fragments) embedded in a fine-grained calcite matrix (foram biomicrite; Figures 2b, c).

Stable nitrogen and carbon isotope analysis

Stable nitrogen isotope analysis of sediments is employed to elucidate the substrate sources that may sustain heterotrophic activity of bottom-dwelling communities. Surficial sediment samples from the Southern Straits of Florida exhibited mostly enriched $\delta^{15}N$ values, ranging from +3.60 to +6.40‰ (Table I) with an average of +5.48 ±0.66‰. In Blocks I and II $\delta^{15}N$ values were fairly homogeneous, whereas variability in Block III occurred due to a single depleted value (+3.6‰). However, the equality of $\delta^{15}N$ values among blocks was statistically rejected (Friedman's test $p<0.368$). The estimated $\delta^{15}N$ average here recorded suggests a predominant input of pelagic organic matter.

In turn, the $\delta^{13}C$ values of surface bulk sediments varied within a narrow range in all blocks (-18.5 to -19.13‰), with an average value of -18.71 ±0.17‰ (Table I). Regardless of the proximity of the sites from which the core samples were recovered, $\delta^{13}C$ values exhibited small but significant spatial variability with slight enrichment gradient from the westernmost blocks (I and II) towards the slope rise (Block III). Similarly, as in the case of N isotopes, equality of $\delta^{13}C$ values among blocks was rejected (Kruskal-Wallis test with tied ranks $0.05<p<0.010$).

The black crust material on the external surface of the rock corresponded to a kerogen type II composed of an assemblage of organic debris with contrasting $\delta^{13}C$ isotopic signatures. These fluctuated from a depleted value of -25.7‰ to a more enriched value of -18.7‰.

Organic carbon and nitrogen

C_{org} concentrations in the three blocks exhibited an impoverished organic pool with bottom depth. Values ranged from 0.19 to 0.80%, with averages of 0.49, 0.60 and 0.33%, for Blocks I, II and III, respectively. Sites near the island's slope rise had lower C_{org} concentrations (0.19-0.46%) when compared to values close to the channel axis (0.46-0.54%). The concentrations of TN exhibited a heterogeneous trend, particularly at Block III, where values ranged 0.08 to 0.13%. In contrast, at the channel axis, TN concentrations were lower (0.09-0.11%). The mean molar C:N ratio from the three sites ranged from 3.66 (Block I), through 6.17 (Block III), to 9.55 (Block II). The lower ratios near the inner shelf (Block I) are indicative of a relatively greater organic matter input of continental origin, while the higher C:N values in Blocks II and III suggest organic matter deposition of hemipelagic origin (Ruttenberg and Goñi, 1997).

Infaunal community composition

In the three blocks there was a thanatoscenosis overwhelmingly dominated by Foraminifera (*Globigerina* sp.), Pteropoda (*Cavolinia* sp., *Clio* sp.), Coccolithophorida, and micromollusks. The bioscenosis, on the other hand, was composed of 10 taxa: Foraminifera, Turbellaria, Nematoda, Polychaeta, Tardigrada, Ostracoda, Copepoda, Gastropoda and Bivalvia, Amphipoda, and Oligochaeta. All these taxa were represented in Block III, while in Blocks I and II the assemblage included Foraminifera, Nematoda, Tardigrada and Ostracoda, and Foraminifera, Nematoda,Ostracoda and Copepoda, respectively. Meiofauna (0.042-0.5mm) density values at the twelve sampled sites ranged from 32 to 132ind/10cm^2. The average density was higher in Block I (79ind/10 cm^2), followed by Block III (60ind/10cm^2) and Block II (32ind/10cm^2). These density values seem heterogeneously distributed among sites and their apparent patchiness at microscale level creates significant differences (ANOVA $p<0.5000$), mainly due to the high predominance of foraminifera at sites near the channel axis. In fact, foraminifera were abundant at the top 3cm but declined downcore. They accounted for nearly 90% of the total density in all cases examined, and the remaining 10% of the metazoan meiofauna was represented by nematodes, polychaetes, and harpaticoids.

Macroinfaunal components (0.5-4.0mm) appeared reduced to a few taxa (Nematoda, Polychaeta, Oligochaeta, Amphipoda, and Mollusca) with rather low density values. Minor differences in density were noted among the three blocks; density ranged from 0.01 for oligochaets to 0.04ind/10cm^2 for polychaete worms. Total macroinfaunal density in Blocks II and III approached 0.095ind/10cm^2 while that of Block I was only of 0.061ind/cm^2. Marked differences were noted among sites (ANOVA $p<0.0500$), probably caused by the absence of macroinfaunal elements in at least five localities. Nematoda (Chromadorida and Monhysterida) maintained low densities, <12ind/cm^2, which fall within the range reported for deep waters (Rachor, 1975; Coull *et al*., 1977). Polychaete worms were present in all blocks reaching density values of 0.04ind/10cm^2 in Blocks I and II (sites 1 and 3, respectively) and of 0.03ind/10cm^2 in Block III (sites 1 and 5). Ostrocoda and Copepoda were present in the three blocks, attaining densities of 3.7 and 1.7ind/10cm^2, respectively. Harpaticoid copepods were identified in the first 2cm of silty sediments of Block III. In Block II copepods were confined to the uppermost surficial sediments and were absent in Block I. Micromollusk (gastropods and bivalves) appeared only at three sites in Block II (4, 5, and 6).

Correlation analyses to test the relationship between meiofauna density and TOC and TN were negative ($r= -0.27$, $p<0.05$; $r_2= -0.02$, $p<0.05$, respectively). Additionally, the results of a multiple regression analysis between one dependent variable (meiofauna density) and two independent factors (TOC, TN) confirmed the absence of significant relationships, according to the following regression function: $\hat{y}_{12}= 88+(-0.08\ TOC)+(-0.28TN)$; coefficient of multiple correlation $R_1= 0.276$, coefficient of multiple determination $R_2=$

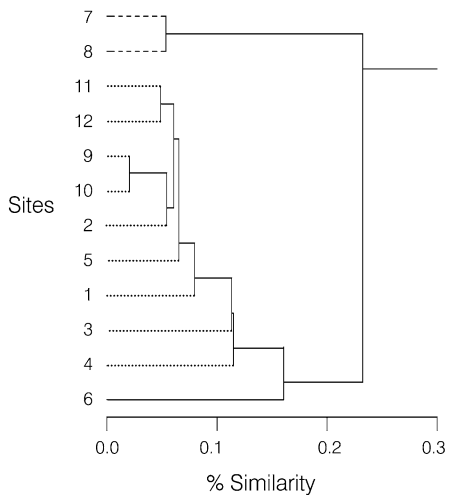

Figure 3. Cluster analysis (single linkage Bray-Curtis similarity values) of $\delta^{13}C$, $\delta^{15}N$, meiofauna and macroinfauna density, depth, TOC, and TN values recorded at 12 sites sampled in three blocks located on the northwestern slope of Cuba.

0.076, F= 0.37, d.f. =2, 9, $p<0.7$. As mentioned above, the insufficient organic matter input to the seabed of the insular slope clearly accounts for the low abundance and density of infaunal organisms. In fact, the TOC in the top 4cm of sediment from the three blocks ranged from 0.19 to 0.80%, with average values of 0.49, 0.60 and 0.34%, respectively. Using the factorial analysis from which the correlation coefficient matrix was generated, the degree of interdependence amongst the six parameters was tested, including the depth at each sampling site. The only cases of positive covariation were the following variables: $\delta^{13}C$, TOC, depth, and macroinfauna density. The remaining computed correlation coefficients revealed moderate covariation, as in the case of TOC, $\delta^{15}N$, and depth, or others had clearly negative covariation and even scores of zero, indicating statistically independent variation. The above parameters represent important attributes for each site, whose interdependence may be the source of the observed heterogeneity among the three blocks. The exploratory cluster analysis of such attributes in the 12 sites (Figure 3) revealed remarkable similarity in three groups encompassing sites 7-8, 9-10 and 11-12, belonging to Block III, located at the slope rise. In contrast, sites included in the other two blocks, near the channel axis, did not follow a defined clustering pattern. This can be mainly attributed to the heterogeneity noted in the meiofauna and macroinfauna density values recorded in these sites.

Discussion

The Straits of Florida is the region where the Florida Current-Gulf Stream system forms. Local water circulation in this area is influenced by frontal eddies originated west of the Loop Current that propagates clockwise anticyclones that impinge the west Florida Continental Slope. In the Southern Straits these anticyclones are called Tortugas eddies (Oey *et al*., 2005). Off western Cuba, southerly flows exist both at the surface and at depth (Sheinbaum *et al*., 2002). Deep flow above the rugged topography had been suggested by various authors (Hansen and Molinari, 1979; Gallegos *et al*., 1998) and was later confirmed by Ochoa *et al*. (2001). These highly hydrodynamic conditions impose severe constrains on the particulate organic carbon (POC) flux to the seabed and may constitute a sediment transporting disturbance for benthic dwellers. In the West Florida slope, the Loop Current outlines the boundary between the shelf and slope, winnows bottom sediments and stimulates pelagic production of calcium carbonate (Mullins *et al*., 1988).

The three explored blocks are part of one of the twelve major biofacies recognized in the Florida-Bahamas area, namely the planktonic-foraminiferal one (Coogan, 1970). The two dark horizons of organic material detected in the sediment subcores possibly account for episodic events of terrigeneous deposition of material exported by surrounding environments suggested by Malloy and Hurley (1970). Echeverría-Rodríguez *et al*. (1991) pointed out that terrigeneous material detected in offshore seismic lines may act as a seal above hydrocarbon-generating Tertiary rocks. Interestingly, in deep-cores obtained in the Straits of Florida (eastern Gulf of Mexico; DSDP-Site 535) Herbin *et al*. (1984) correlated lower cretaceous sediments (sub-bottom depth 582m), well-oxygenated environments, to light carbonate layers, whereas laminated darker sediments indicated oxygen depletion events.

The insular slope has characteristics of an erosional slope without significant sediment deposition. Unfortunately, no sedimentation rate has been estimated in the Straits. According to Denny *et al*. (1994) the Southern Straits of Florida evolved from a shallow-water platform to a deep trough. Due to rapid subsidence in the Late Eocene the depositional regime shifted from a current-dominated to a pelagic/hemipelagic sedimentation.

In reference to the isotopic signature of the sampled sediments, Macko *et al*. (1984) reported $\delta^{15}N$ values of +3.6 ±0.1‰ in the sediments from the continental shelf of South Florida, just north of the studied area. The present values are relatively more enriched by ~1.8‰. Considering a similar N isotope composition for coastal and oceanic particulate matter, this enrichment could reflect organic matter decomposition of material sinking to greater depths. The present $\delta^{15}N$ average falls within the range reported by Macko *et al*. (1984) for zooplankton (+5.9±0.7‰), which emphasizes the incorporation of pelagic POC into the sediments without significant fractionation. The average $\delta^{13}C$ value in surficial sediments from the Southern Straits approaches those from the continental shelf of South Florida (-18.5 ±0.7‰) reported by Macko *et al*. (1984); such value agrees with the autotrophic organic carbon synthesized by phytoplankton (-18.0 to -24.0‰) and has a fairly constant average of -21.0‰ (Fry and Sherr, 1984). The $\delta^{13}C$ values obtained differ significantly from those reported by Beazley (2003) at sites exceeding 2000m in the northern Gulf of Mexico; this author recorded more depleted values (-20.6 to -30.0‰), which suggests both marine and hydrocarbon sources.

In oceanic waters, surface productivity represents the main source of organic matter that fuels benthic life throughout the rapid settling of large particles (>200µm). Suess (1980) postulated an empirical equation that predicts C_{org} flux at any depth in the ocean below the euphotic zone as a function of the primary production rate in surface waters and depth dependent consumption. Since surface waters in the area studied are oligotrophic, attaining values of 50-200mg C $m^{3} \cdot d^{-1}$ in the euphotic zone (Kabanova and López-Baluja, 1973; Okolodkov, 2003), vertical C_{org} flux to the sea floor must be kept to a minimum (<5%) applying Suess'empirical equation. This would explain the depletion in sedimentary organic carbon in our subcore samples (TOC 0.66-0.81%).

The type and source of organic matter may also be inferred from C:N ratios (Ruttenberg and Goñi, 1997). Normally, high (>10) C:N ratios are indicative of refractory or non-degradable organic matter, whereas ratios from 5 to 6 belong to relatively fresh labile organic matter. Export of allochthonous plant material from adjacent continental shelves to the slope and

abyssal plain is a major C_{org} source in the Gulf of Mexico (Pequegnat *et al*., 1983; Soto *et al*., 1998) and off North Carolina (Rowe and Menzies, 1968). According to Rasheed *et al*. (2006) C:N ratios >10 indicate an aged non-degradable organic matter. Our estimated mean molar C:N ratios support this contention and are consistent with the depleted $\delta^{13}C$ value here reported that are similar to the isotopic signature for marine organic matter (-21.0‰) in Southern Florida (Macko *et al*., 1984).

Our estimated meiofauna density values are exceeded by almost two-fold by those reported by Beazley (2003). This author recorded densities of 70.0 to 50.8ind/10cm^2 in the Sigsbee abyssal plain of the Gulf of Mexico at depths of 2050 and 3527m, respectively. Our macroinfauna density values are impoverished nearly threefold when compared to those given by Beazley (2003) from the Sigsbee abyssal plain: 0.354 and 0.143ind/10cm^2. The pressure wave created by the Reineck box-corer has been invoked as a factor for excluding surficial faunal groups (Bett *et al*., 1994) and, therefore, these values should be viewed with caution. Conceding such a sampling bias, the meiofauna and macrofauna total density values estimated in the 12 sites studied herein (32 to 132ind/10cm^2) fall within the range of those reported by Robinson *et al*. (2004) for cold seep habitats in the northern Gulf of Mexico and the Blake Ridge in the Atlantic Ocean. These authors indicated that metazoan meiofauna density seems to be enhanced by the presence of microbial mats. Nonetheless, Shirayama and Otha (1990) and later Levine *et al*. (2003) have acknowledged the lack of significant differences in density between seep and non-seep habitats in Sagami Bay, Japan, and at the continental slope of northern California, respectively. The two average values of TOC recorded in surficial sediments of Blocks I and II were similar to the values reported by Beazley (2003) in the Sigsbee abyssal plain (0.49 and 0.55% OC). In contrast, Block III had low TOC values from a predominantly calcareous sedimentary environment near the base of the Cuban northwestern insular slope. These averages are similar to those from the Nova Scotia continental rise (0.46 and 0.47%; Thistle *et al*., 1985) at 4600m depth, where polychaetes were the most abundant macrofaunal group and nematodes the most abundant meiofaunal group. Although TOC concentrations are similar to those from Nova Scotia rise, polychaete density is around 100-150 times smaller (0.04 *vs* 4-6ind/10cm^2) for the same depth (Thistle *et al*., 1985 and references therein). The data obtained in the present study was deemed insufficient to resolve the factors accountable for the atypical trend described between meio/macrofauna abundance and density and TOC/TN. In addition to the small organic matter input to the deep sediments in the Florida Straits Channel, the exclusion effect upon surficial fauna caused by the box corer employed cannot be overruled.

The petrographic characteristics of the limestone rock recovered from Block III are similar to those described by Canet *et al*. (2006) for carbonate rocks extracted from the Chapopote Knoll in the abyssal plain near the Campeche Bank in the southeastern Gulf of Mexico, described as a wackestone micrite with $\delta^{13}C$ ranging between -23.0 and -23.5‰. The $\delta^{13}C$ values obtained from the recovered limestone fragment in Block III fall within the range of relatively depleted $\delta^{13}C$ range of seep carbonates (-29.4 to -15.1‰) recorded by Feng *et al*. (2009) from porous limestone slabs from Bush Hill (GC 185) in the northern Gulf of Mexico. According to these authors, values above -20.0‰ indicate non-methane hydrocarbons being incorporated during seep carbonate-precipitation. It is feasible that Block III constitutes a fracture zone that allows the migration mature hydrocarbons. The $\delta^{13}C$ value of -25.7‰ approaches the isotopic range (-26 to -28 ‰) known for oils in deep reservoirs of the Gulf of Mexico (Kennicutt *et al*., 1988) which are mainly produced by marine type II kerogen (Andrusevich *et al*., 2000). Possible variations in the make-up of kerogen assemblage can alter the carbon isotopic relationship of oil-labile components (Burwood *et al*., 1988). Such variations may be caused by diagenesis that promotes the incorporation of humic carbon in the kerogen structure. Humic carbon is normally more enriched in the ^{12}C isotope, which could account for the significant enrichment in $\delta^{13}C$ of -18.7‰ herein recorded, relative to the pelagic carbon source of -22.7‰. The specific site in the northeastern corner of Block III at the base of the NW Cuba's slope from which limestone rocks impregnated with hydrocarbons were recovered, conforms to the conventional type of cold seeps in which fluids escape from hydrocarbon reservoirs through permeable fractures and faults (Mazzini *et al*.,2003).

Conclusions

Although the three sampled blocks on the NW insular slope of Cuba were within a 100km radius, topographic features and sediment characteristics revealed significant differences among them. Block I was located within a v-shaped valley with faulting structures and small canyons. Its surficial sediment was dominated by *Globigerina* clay. Block II had a scarped surface and a faulting region and the sediment was constituted by an assortment of biogenic hemipelagic biota; a discrete oxidized horizon suggests that this site receives episodic terrigeneous influence. Block III was characterized by a ridged bottom with prominent knolls. In spite of its proximity to the insular coast, sediment was dominated by carbonate with evidence of intermittent hydrocarbon seepage, producing in authigenic deposits whose isotopic signature approaches that known for oils in deep reservoirs of the Gulf of Mexico. Calcite was predominant in sediments of the three blocks. Stable carbon isotope in bulk sediment samples indicated a dominance of marine organic matter deposition, with no evidence of thermogenic or biogenic isotopic signatures. The low TOC within the cores and terrestrial plant remains in a sample, along with the $\delta^{13}C$ and $\delta^{15}N$ values of sediments, suggests that an important carbon source to benthic fauna is pellet sinking rather than the rainfall from suspended particulate matter generated within the photic zone. In this highly hydrodynamic energy system, surface particulate matter may be trapped above the thermocline and advected out of the region before reaching the bottom, thus precluding benthic community complexity. Future research in this region must seriously consider conducting direct submersible observations to examine local fluid chemistry and seep community composition in one of the deepest seep sites near the Gulf of Mexico.

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ESTUDIO DEL SEDIMENTO SUPERFICIAL DEL LECHO MARINO FRENTE A LA COSTA NOROCCIDENTAL DE CUBA, EN EL ESTRECHO DE LA FLORIDA

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RESUMEN

El lecho marino frente a la costa noroccidental de Cuba fue explorado con el propósito de estudiar las características biogeoquímicas de los sedimentos superficiales en tres Bloques asignados a REPSOL-YPF-Cuba, S.A., entre los 1600 y 2000m de profundidad. Se analizaron isótopos estables y el contenido de carbono y nitrógeno total, así como los componentes infaunales en sedimentos superficiales. Los sedimentos de los tres bloques estudiados son moderadamente laminados y exhiben una cierta heterogeneidad espacial. Estos son de tipo limo-arcilloso con predominancia de calcita, empobrecidos en materia orgánica, pero con depósitos hemipelágicos significativos. En el extremo noreste del área estudiada (Bloque III, 1640m) se recuperó un fragmento grande de roca caliza impregnada de hidrocarburo. La superficie del fragmento era áspera y presentaba un fuerte olor a petróleo. Su superficie externa estaba cubierta por una capa ennegrecida de brea y manchas irregulares de oxihidróxido de hierro. El análisis isotópico de sedimentos totales ($\delta^{13}C$ -25,7 a -18,5‰) reveló una fuente de carbono no-metanogénica, procedente de un sitio de filtración de petróleo puntual. Se estableció que la fuente principal de carbono orgánico sedimentario es de origen oceánico ($\delta^{13}C$: -18,50 a -19,13‰; $\delta^{15}N$: +3,6 a +6,4‰; proporción molar de C:N de 2,4 a 5). Los parámetros fisicoquímicos de las aguas profundas fueron estables (5ml·l^{-1} O_2, 3-4°C, 35,0ups) y la densidad de la infauna fue baja debido al aporte limitado de materiales orgánicos a los sedimentos profundos. Este estudio documenta uno de los sitios de filtración de petróleo de mayor profundidad en el este del Golfo de México.

ESTUDO DO SEDIMENTO SUPERFICIAL DO LEITO MARINHO EM FRENTE DA COSTA NOROESTE DE CUBA, NO ESTREITO DA FLORIDA

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RESUMO

O leito marinho em frente à costa noroeste de Cuba foi explorado com o propósito de estudar as características biogeoquímicas dos sedimentos superficiais em três Blocos designados a REPSOL-YPF-Cuba, S.A., entre os 1600 e 2000m de profundidade. Analisaram-se isótopos estáveis e o conteúdo de carbono e nitrogênio total, assim como os componentes infaunais em sedimentos superficiais. Os sedimentos dos três blocos estudados são moderadamente laminados e exibem certa heterogeneidade espacial. Estes são de tipo limo-argiloso com predominância de calcita, empobrecidos em matéria orgânica, mas com depósitos hemipelágicos significativos. No extremo noreste da área estudada (Bloco III, 1640m) se recuperou um fragmento grande de rocha caliça impregnada de hidrocarboneto. A superfície do fragmento era áspera e apresentava um forte cheiro de petróleo. Sua superfície externa estava coberta por uma camada escura de alcatrão e manchas irregulares de oxi-hidróxido de ferro. A análise isotópica de sedimentos totais ($\delta^{13}C$ -25,7 a -18,5‰) revelou uma fonte de carbono não metanogênica, procedente de um local pontual de filtração de petróleo. Estabeleceu-se que a fonte principal de carbono orgânico sedimentário é de origem oceânica ($\delta^{13}C$: -18,50 a -19,13‰; $\delta^{15}N$: +3,6 a +6,4‰; proporção molar de C:N de 2,4 a 5). Os parâmetros físico-químicos das águas profundas foram estáveis (5ml·l^{-1} O_2, 3-4°C, 35,0ups) e a densidade da infauna foi baixa devido ao aporte limitado de materiais orgânicos aos sedimentos profundos. Este estudo documenta um dos locais de filtração de petróleo de maior profundidade no leste do Golfo do México.