EFFECTS OF NAF CUTTINGS DISCHARGE ON MEIOFAUNA COMMUNITIES IN A DEEP SEA SITE OF CAMPOS BASIN (BRAZIL)*

Sérgio A. Netto, Gustavo Fonseca, Fabiane Gallucci

Laboratório de Ciências Marinhas, Universidade do Sul de Santa Catarina, Av. Colombo Sales 84, Laguna, Santa Catarina, 88790-000, Brasil, netto@unisul.br

Resumo – Este trabalho analisa os efeitos do lançamento de cascalhos associados a fluidos não-aquasos (NAF) na estrutura da meiofauna em uma area do oceano profundo da Bacia de Campos, Brasil. Um total de 159 amostras foram tomadas através de um box corer ao longo de 3 cruzeiros oceanográficos: um pré-perfuração (MD1) e dois pós-perfuração (três meses- MD2- e 11 meses após- MD3). Tanto os valores de riqueza (número de taxa) como os de densidade da meiofauna mostraram um significativo decréscimo imediatamente após a perfuração (MD 2). Os resultados das análises multivariadas indicaram que os possíveis impactos na meiofauna ocorreram na porção norte da área, até 500 m do ponto de perfuração. No entanto, os descritores univariados e matrizes multivariadas da meiofauna mostraram uma fraca relação com os parâmetros químicos analisados. Estes resultados sugerem que os efeitos da perfuração sobre a meiofauna foi primariamente relacionado à mudanças físicas no substrato causadas pela presença dos cascalhos. Comparações entre modelos de previsão de descarte e a potencial área afetada determinada através da meiofauna foram coincidentes. Um ano após a perfuração (MD3), a densidade da meiofauna e o número de gêneros mostraram valores similares àqueles observados no período pré-perfuração (MD1). No entanto, a presença de cascalhos no fundo marinho parece ser responsável por alterações na estrutura multivariada da fauna. Provavelmente, as mudanças na comunidade bêntica perdurem até a completa desagregação dos cascalhos na área.

Palavras-Chave: fluido de perfuração não-aquoso; oceano profundo; meiofauna; Bacia de Campos, Brasil

Abstract – This paper discusses the effects of the non-aqueous fluids (NAF) cuttings discharges on the meiofauna in a deep-sea area of Campos Basin, Brazil. A total of 159 samples were undertaken with a box corer on three sampling cruises: one pre-drilling (MD1) and two post drilling (three months – MD2 and 11 months later – MD3). Meiofauna showed a significant decrease in richness and density immediately after drilling. The results of the multivariate statistical analysis indicated that the possible impacts on the meiofauna occurred primarily on the north portion of the area, up to 500 m from the well. All univariate and multivariate measures of meiofauna had a weak correlation with the chemical parameters analyzed. These results suggest that the effects of drilling on the benthic fauna were primarily related to physical changes in the substrate caused by the presence of cuttings. Comparisons between dispersion models and the potentially affect area determined by the meiofauna were coincident. One year after drilling, the meiofauna density and the number of genera showed similar values to the pre-drilling period. However, the presence of cuttings on the bottom was probably responsible for alterations still observed on the multivariate structure of the fauna. Therefore, it is possible that such change on meiobenthic community will last until the complete disaggregation of the cuttings in the area.

Keywords: non-aqueous drilling fluids, deep-sea, meiofauna; Campos Basin; Brazil

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1. Introduction

The response of the organisms to a disturbing agent depends on the nature, frequency and severity of the disturbance (Picket & White, 1985). Thus, a single disturbance may lead to measurable responses in the organisms, associations or communities, followed by compensation or return to a dynamic equilibrium. Under a severe antropic disturbance, benthic communities undergo changes in both biological and trophic structures. When these disturbances lead to changes in chemical and physical proprieties of the sediment, the benthic community is affected, and one community tend to be replaced by another since many morphological and physiological adaptations of the fauna are related to the substrate. When the disturbances lead to organic enrichment, faunal changes lead to a progressive reduction in the complexity of the benthic community structure.

During a petroleum well drilling process, fluids are launched at high pressure in order to remove coarse sediments and cuttings, thus allowing for better movement and penetration of the drill into the ocean floor. Drilling fluids can be classified according to two types, water-based fluids (WBF) and non-aqueous fluids (NAF). NAFs comprehend fluids with a non-aqueous, non-water-dispersible base. They are subdivided in three categories, according to the concentration of aromatics present (I- high; II- medium; III- low; Darley and Gray, 1988). In spite of recycling and selection of NAFs and sediment associated to petroleum platforms, it is estimated that 25% of the NAFs used are dumped into the marine environment along with drill cuttings at a 10-15% weight rate. The extension and thickness of the final cuttings deposits will depend, besides the amount of cuttings dumped, on the oceanographic conditions and the drilling depth (Breuer et al., 2004). Once deposited, the persistence of cuttings and NAFs will depend on a series of factors, such as sediment resuspension and transport, and the biodegradation rate (Neff *et al.*, 2000).

The discharge of NAF cuttings is therefore clearly relevant for benthic systems in general, and for invertebrates associated to the seafloor in particular. The use of benthic organisms as indicators of environmental changes or to monitor areas at potential risk of pollution has advantages over the other components of the marine fauna. First, benthic organisms are relatively sedentary, which makes them susceptible to localized disturbances. Second, there is the strict dependence between the benthic organisms and the sediment, where the contaminants tend to settle (Warwick, 1993). Therefore, benthic organisms are a key parameter in any monitoring plan for areas of potential risk.

Several laboratory studies have been conducted examining the effects of NAFs on benthic organisms, such as toxicity, bioaccumulation, and biochemical changes (Neff *et al.*, 2000). Although such studies might provide an early ground for predicting the effects of NAF-associated cuttings on the marine benthic fauna, field studies are essential for evaluating such predictions or experiments. Neff *et al* (2000) and OGP (2003) summarized different field studies assessing the impacts of cutting discharge associated to NAFs type I, II and III on benthic fauna. Though there exists an apparent consensus that cutting discharge has a small, localized effect, one critical analysis of these studies shows that the effects on fauna are variable both in space and time. Further, all the studies were restricted to the continental shelf and only analyzed the macrobenthos. This paper reports on the effects of non-aqueous fluids (NAFs) discharges on meiofauna structure- composition, abundance and trophic structure – in a deep-sea area of Campos Basin, Southeast Brazil.

2. Methods

2.1. Sampling and Samples Processing

The study was conducted at the northern portion of Campos Basin, SE Brazil. Information on the geology and oceanography of the study site is provided by Correa et al. (2004) and Freitas et al. (2004). Campos Basin is located at the SW margin of South Atlantic (Fig. 1) between 20.5º S (Vitória High) and 24º S (Cabo Frio High). From an area of some 100,000 km^2, more than 70 % of Campos Basin is at water depths greater than 200 m (Viana et al., 1998).

Detailed description of the discharge practices, sampling design and samples processing are found in Toldo Jr. and Ayup-Zouain (2004). Briefly, three sampling cruises were carried out in order to describe the effects of NAF cuttings discharge on meiofauna: one pre-drilling (April 2001) and two post-drilling (one month after drilling -July 2001; one year after drilling- July 2002). In each cruise, 54 samples were taken within a 50, 100, 150, 300, 500 and 2,500 m radius from the well, according to the scheme showed in Figure 1. Samples were collected at a depth of 890 (± 20) m using USNEL style box corer (0.25 m^2). From each box corer one subsample for the meiofauna was undertaken with a 2.0 cm diameter core tube pushed to a depth of 10 cm. The subsample was transferred to a 100 ml glass pot and fixed with 10 % formalin. Samples for meiofauna were sieved through a 63 μm mesh and extracted by flotation with Ludox TM (specific gravity of 1.15). Samples were then evaporated to anhydrous glycerol and permanent slides built (Somerfield and Warwick, 1996). All meiofaunal organisms were grouped into higher taxonomic groups. Nematodes identification to genus level was carried out for all individuals. Sediment samples were collected from each box corer for granulometric (sieving and pipette analyses) and total organic content analysis (combustion at 600°C for 3 hours), and analyzed by the Geoscience Institute/CECO/UFRGS (Corrêa et al., 2004). Samples for total petroleum hydrocarbons (TPH - defined as linear hydrocarbons, unresolved complex mixture and aromatics) and metals (Al, Ba, As, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, V, Cd, Hg and Zn) were also collected, analyzed by the Chemistry Institute/LQAA/UFRGS and reported by Peralba et al. (2004).

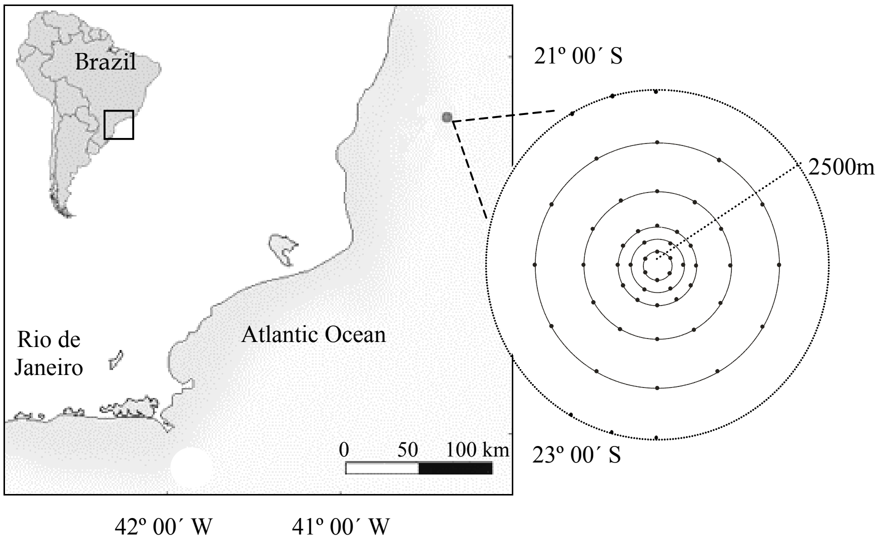

Figure 1. Schematic representation of sampling stations on Campos Basin, SE Brazil.

2.1. Data Processing

Meiofauna density, number of meiofauna taxa, nematodes density and nematodes number of genera were used as univariate descriptors of meiofauna community. One-way analyses of variance (ANOVA) was applied to test for differences in meiofauna descriptors among sampling periods (before, after and one year after drilling). Cochran's C tests were used to test homogeneity of variance and where necessary, data were log (x+1) transformed. Tukey multiple comparison tests were used when significant differences were detected ($p<0.05$; Sokal and Rohlf, 1997).

For multivariate analysis, lower triangular similarity matrices were constructed using the Bray-Curtis similarity measure and ordination was by non-metric multidimensional scaling (MDS, Clarke and Green, 1988). ANOSIM tests (Clarke and Green, 1988) were carried out to detect the significance of the differences in the meiofauna community structure between sampling periods.

Finally, fauna and abiotic data were related. First, Pearson product-moment correlations were carried out between meiofauna descriptors and all abiotic data (granulometry, total organic content, concentration of hydrocarbons and metals). The correlations between the multivariate fauna structure and the similarity matrix derived from the abiotic data were analysed by the RELATE procedure, using the Spearman rank-correlation coefficient (Clarke and Warwick, 1994). Then, the fauna and combinations of environmental variables were linked using BIO-ENV analysis (Clarke and Ainsworth, 1993) to define suites of variables which best explain the faunistic structure.

2. Results

From a total of 8,784 organisms collected, the meiofauna was represented by 10 taxa with densities oscillating between 6 and 461 ind. 10 cm^{-2}. Nematodes numerically dominated all samples, representing almost 80% of the total fauna collected. Copepods were the next abundant group representing around 10% of the fauna. A total of 173 nematode genera, belonging to 50 families, were identified. The Comesomatidae (20% of the total nematodes collected), Xyallidae (17%), Oxystominidae (16%) and Chromadoridae (10%) were the most abundant families on all three sampling cruises. *Sabatieria, Halalaimus, Daptonema, Acantholaimus* and *Sphaerolaimus* were the numerically dominant genera, representing around 50 % of the collected nematodes.

All univariate measure values derived from meiofauna data varied significantly among the three cruises. The number of meiofauna groups was significantly higher on MD3 and lower on MD2. All other univariate measures showed significantly lower values on immediately after drilling cruise (MD2). Meiofauna density and number of genera between Cruises MD1 and MD3 did not differ significantly. Mean values of the meiofauna descriptors along the 3 cruises are shown in Figure 2.

The multidimensional scaling ordination (MDS) of nematode data aggregated at the genus taxonomic level is shown in Figure 3. The analysis show a higher similarity between the cruises conducted prior to drilling and one year after cuttings discharge. Samples from the cruise conducted immediately after drilling showed more scattering, indicating greater differences in fauna structure. One year after drilling, samples on the MDS plot seemed to be more similar to those pre-drill. Analyses of similarity (ANOSIM) applied to the similarity matrixes show that the structure of meiofauna differed significantly among the three cruises. The results also show that, when the cruises are compared, MD1 and MD3 similarity values were higher than other pair-wise comparisons.

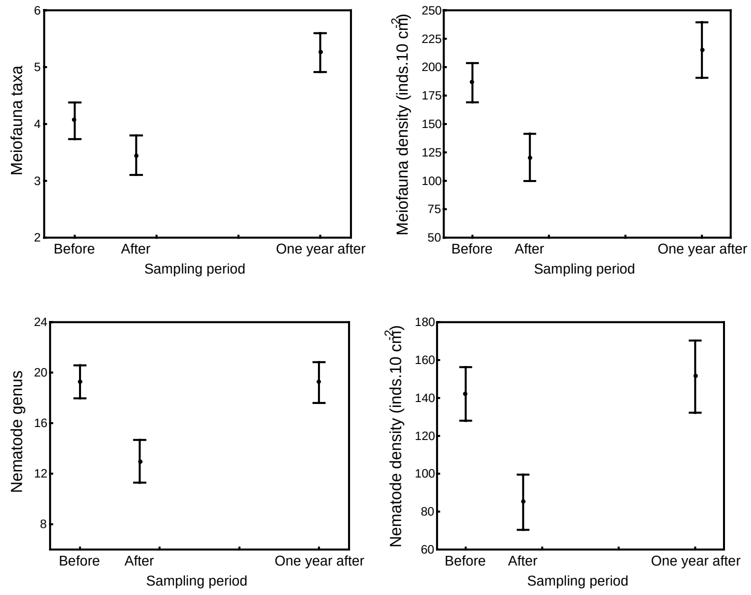

Figure 2. Means and standard error for meiofauna total number of taxa and density and for nematodes total number of genera and density during sampling periods.

Tests for differences in structure of meiofaunal communities (ANOSIM) at each distance sampled showed significant differences between the cruises. At 50 m from the drilling site, only nematodes grouped at the genus level showed significant differences between pre-drilling (MD1) and immediately-after-drilling (MD2) samplings (Table 1). From 100 to 500 meters, the structure of meiofauna grouped into genus level showed significant differences between all cruises. At the reference stations, 2,500 meters from the drilling site, meiofauna structure did not show significant changes among cruises. For trophic groups, differences among all the three cruises were detected only at 300 m from the well (Table 1).

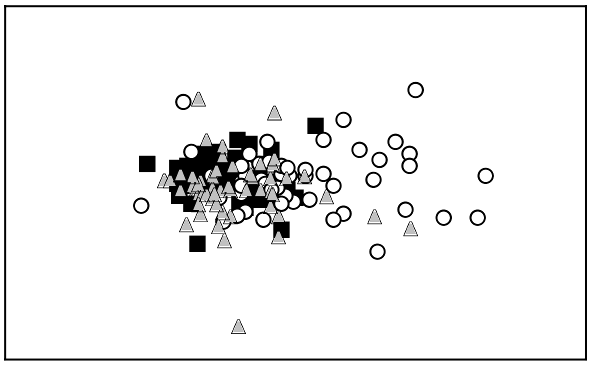

Figure 3. MDS ordination from transformed densities of nematodes at the periods before (■), after (○) and one-year after (▲) the well drilling.

Pearson's correlation analyses were applied for all fauna univariate measures (meiofauna density, nematodes and numerically dominant genera, number of families and genera) and 35 abiotic variables (sediment proprieties, metal and hydrocarbon concentrations). In spite of some correlations having been significant, correlation coefficients were extremely low. Higher values were detected for number of nematode genera and Eh values at subsurface (r^2=0.28). Multiple regression analyses have also been applied for establishing correlations and predictions between meiofauna and other independent variables. As in the Pearson's correlation analyses, it was not possible to determine any significant exploratory variables for meiofauna.

The correlation between similarity matrixes of meiofauna and nematodes and matrixes of abiotic data was determined through the RELATE routine. Correlations were not significant ($p>0.05$). With the aim of defining groups of abiotic variables that best explain the fauna estructure, the Bio-Env analysis was applied. Once again, the correlations between fauna and abiotic variables were extremely weak. The highest scores between the multivariate fauna structure and groups of variables were near 0.1.

Table 1. Significance levels from the analysis of similarity (ANOSIM) comparing the structure of nematodes grouped according to genus and trophic group for each distance on cruises conducted before (MD1), immediately after (MD2) and one year after cuttings discharge (MD3). Bold values indicate significant differences.

	Distance (m)					
	50	100	150	300	500	2500
Cruises compared						
Genus						
MD 1 x MD 2	**0.03**	**0.006**	**0.02**	**0.02**	**0.03**	0.09
MD 2 x MD 3	0.18	**0.01**	**0.01**	**0.02**	**0.03**	0.07
MD 1 x MD 3	0.38	**0.02**	**0.01**	**0.02**	**0.02**	0.07
Trophic group						
MD 1 x MD 2	0.3	0.6	**0.004**	**0.002**	**0.03**	0.6
MD 2 x MD 3	0.9	0.5	0.1	**0.002**	0.1	0.1
MD 1 x MD 3	0.4	0.7	0.3	**0.002**	0.3	0.1

Finally, we estimated a meiofauna potential affected area by selecting the scattered stations from the MDS plot derived from the nematode data immediately after drilling (Fig. 3a) and compared the final result of the cuttings deposition model (Freitas et al., 2004; Fig. 3b). In the figures, the probable impacted areas present similarity and the effects were mainly located to the northern direction and within a 500 m radius from the drilling site.

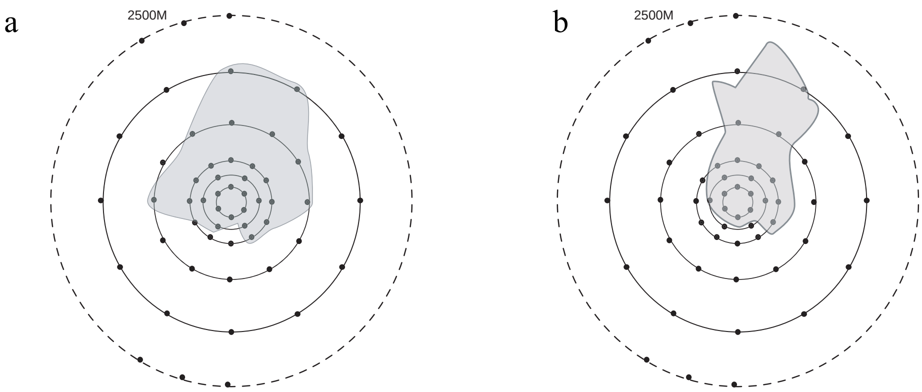

Figure 3. Comparison between probable impacted areas defined by: a – meiofauna, based on multivariate analyses; b – dispersion model (after Freitas et al., 2004).

3. Conclusions

3.1. Effect on the Fauna and the Impacted Area

The results of this work showed that the structure of meiofauna changed over the course of this study. Immediately after drilling, there was a significant decrease in density and genera of nematodes. The univariate analyses showed that the changes verified in MD 2 occurred in several points of study area, including the reference stations, and were independent on the taxonomic level analyzed. Yet the results of the multivariate analysis showed that the possible impacts on meiofauna occurred predominantly at the northern portion of the study area, being limited to a 500 m from the drilling site. Multivariate analyses also showed an increase in the samples variability after drilling and that the determination of the impact area is dependent on the taxonomic level analyzed. For nematodes – the meiofaunal dominant organisms – the genus level has shown to be more sensitive for determining the possible impacted area. Due to the lack of works on temporal variability of the meiofauna on the study area, a possible oscillation caused by natural temporal variability should not be discharged.

3.2. Nature of the Impact on the Fauna

The dynamics of the meiofauna after the drilling activity showed a weak correlation with the chemical parameters analyzed, among them the concentration of hydrocarbons and metals in the sediment. Thus, the drilling fluid used in this study – a paraffin base NAf type III- seemed not to be the responsible for the observed changes in the meiofauna. The results of suggest that the effects on the meiofauna are related to physical changes in the deep-sea caused by the cuttings discharge.

3.3. Fauna Recovery at the Impacted Area

One year after drilling, the density of the meiofauna, as well as the density and number of genera of nematodes exhibited values similar to those at the pre-drilling period. However, the persistence of cuttings on the bottom was probably responsible for the change observed in meiofauna structure on the MD3 Cruise. One year after drilling, a significant increase of copepod densities and epigrowth feeder nematodes was detected, typical of heterogeneous sediments.

5. Acknowledgements

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